FIVE ESTUARIES OFFSHORE WIND FARM

PRELIMINARY ENVIRONMENTAL INFORMATION REPORT

VOLUME 2, CHAPTER 2: MARINE GEOLOGY, OCEANOGRAPHY AND PHYSICAL PROCESSES

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GLOSSARY OF TERMS

Term	**Definition**
Beach	A deposit of non-cohesive material (e.g. sand, gravel) situated on the interface between dry land and the sea (or other large expanse of water) and actively "worked" by present-day hydrodynamic processes (i.e. waves, tides and currents) and sometimes by winds.
Bedforms	Features on the seabed (e.g. sandwaves, ripples) resulting from the movement of sediment over it.
Bedload	Sediment particles that travel near or on the bed.
Benthic	A description for animals, plants and habitats associated with the seabed. All plants and animals that live in, on or near the seabed are benthos.
[Wave] breaking	Reduction in wave energy and height in the surf zone due to limited water depth.
Clay	A fine-grained sediment with a typical grain size of less than 0.004 mm. Possesses electromagnetic properties which bind the grains together to give a bulk strength or cohesion.
Climate change	A long-term trend in the variation of the climate resulting from changes in the global atmospheric and ocean temperatures and affecting mean sea level, wave height, period and direction, wind speed and storm occurrence.
Coast	A strip of land of indefinite length and width that extends from the seashore inland to the first major change in terrain features.
Coastal processes	Collective term covering the action of natural forces on the coastline and adjoining seabed.
Cohesive	Sediment containing a significant proportion of clays, the electromagnetic properties of which cause the particles to bind together.
Erosion	Movement of material by such agents as running water, waves, wind, moving ice and gravitational creep.

Term	Definition
Geophysical survey	Activities to obtain data on the distribution and nature of geophysical properties of the seabed (e.g. bathymetry, surficial sediment type and bedforms, sub-surface geology). Geophysical survey outputs typically include multibeam bathymetry, side-scan sonar and sub-bottom profiler data.
Habitat	The place in which a plant or animal lives. It is defined for the marine environment according to geographical location, physiographic features and the physical and chemical environment (including salinity, wave exposure, strength of tidal streams, geology, biological zone, substratum, 'features' (e.g. crevices, overhangs, rockpools) and 'modifiers' (e.g. sand-scour, wave-surge, substratum mobility).
Hydrodynamic	Of or relating to the motion of fluids and the forces acting on solid bodies immersed in fluids and in motion relative to them.
Intertidal	The zone between the highest and lowest tides. May also be referred to as the littoral zone.
Light Detecting and Ranging (LiDAR)	A surveying method that measures distance to a target by illuminating that target with a laser light.
Littoral drift, littoral transport	The movement of beach material in the littoral zone by waves and currents. Includes movement parallel (longshore transport) and perpendicular (onshore- offshore transport) to the shore.
Longshore drift	Or alongshore or littoral drift. Movement of sand and shingle along the shore. It takes place in two zones, at the upper limit of wave activity and in the breaker zone. Movement of beach (sediments) approximately parallel to the coastline.
Mean High-Water Springs	The average throughout the year of two successive high waters during those periods of 24 hours when the range of the tide is at its greatest
Morphological	Of or relating to the form, shape and structure of landforms

Term	**Definition**
Neap tides	Tides with the smallest range between high and low water, occurring at the first and third quarters of the moon.
Regime	The behaviour, statistical properties and trends characterising the variability of hydrodynamic, meteorological, sedimentological and morphological parameters.
Return period	In statistical analysis an event with a return period of N years is likely, on average, to be exceeded only once every N years.
Salinity	Measure of all the salts dissolved in water.
Scour	Local erosion of sediments caused by local flow acceleration around an obstacle and associated turbulence enhancement.
Sediment	Particulate matter derived from rock, minerals or bioclastic debris.
Sediment transport	The movement of a mass of sedimentary material by the forces of currents and waves. The sediment in motion can comprise fine material (silts and muds), sands and gravels. Potential sediment transport is the full amount of sediment that could be expected to move under a given combination of waves and currents, i.e. not supply limited.
Sediment transport pathway	The routes along which net sediment movements occur.
Significant wave height	The average height of the highest of one third of the waves in a given sea state.
Spring tides	Tides with the greatest range which occur at or just after the new and full moon.
Seastate	The state of the sea as described using the Douglas sea scale, based on wave height and swell, ranging from 1 to 10, with accompanying descriptions.
Shoreline Management Plan (SMP)	A large-scale assessment of the risks associated with coastal processes. It aims to lessen these risks to people and the developed, historic and natural environments.

Term	Definition
Surficial sediments	Sediments located at the seabed surface (not necessarily of the same character as underlying sediments).
Surge	In water level as a result of meteorological forcing (wind, high or low barometric pressure) causing a difference between the recorded water level and that predicted using harmonic analysis, may be positive or negative.
Suspended sediment concentration	Mass of sediment in suspension per unit volume of water.
Swell (waves)	Wind-generated waves that have travelled out of their generating area. Swell characteristically exhibits a more regular and longer period and has flatter crests than waves within their fetch.
Tidal current asymmetry	1) Relative difference in peak current speed or duration of adjacent flood and ebb half tidal cycles. 2) Relative difference in high or low water levels or duration of adjacent flood and ebb half tidal cycles.
Tidal excursion	The Lagrangian movement (the physics of fluid motion as an individual fluid parcel moves through space and time) of a water particle during a tidal cycle.
Tidal excursion ellipse	The path followed by a water particle in one complete tidal cycle.
Tidal harmonics	Component parts of the tidal (water level) signal at a location. A discrete timeseries of tides can be separated into a variable number of sinusoidal signals of known frequency, phase and amplitude. These can be used to predict values for the same location, outside of the original period of data.
Tide	The periodic rise and fall in the level of the water in oceans and seas; the result of gravitational attraction of the sun and moon.
Topographic	The form of the features of the actual surface of the earth in a particular region considered collectively
United Kingdom Climate Projections (UKCP)	UKCP18 is the name given to the latest UK Climate Projections. UKCP18 provides information on plausible changes in 21st

Term	**Definition**
	century climate for land and marine regions in the United Kingdom.
Wave propagation	The spread of waves across the sea which in deep water will usually be in the direction of the wind causing them. In shallow water the direction will vary due to the influence of the seabed and tidal currents.
Wave refraction	When waves approach the shoreline obliquely, the wave crests tend to conform to the bottom (bed) contours; due to the inshore portion of the wave travelling at a lower velocity than the portion in deeper water. The extent of wave refraction depends on the relative magnitudes of water depth to wavelength.

DEFINITION OF ACRONYMS

Term	**Definition**
BSI	British Standards Institution
CBRA	Cable Burial Risk Assessment
Cefas	Centre for Environment, Fisheries and Aquaculture Science
COWRIE	Collaborative Offshore Wind Research into the Environment
CPA	Coast Protection Act 1949
CSIP	Cable Specification and Installation Plan
cSAC	candidate Special Area of Conservation
Defra	Department for Environment, Food and Rural Affairs
ECC	Export Cable Corridor
EIA	Environmental Impact Assessment
ES	Environmental Statement
ETG	Expert Topic Group
FEPA	Food and Environment Protection Act 1985
GBF	Gravity Base Foundation
GOWF	Galloper Offshore Wind Farm
GGOWF	Greater Gabbard Offshore Wind Farm
HDD	Horizontal Directional Drilling
LAT	Lowest Astronomical Tide
MCZ	Marine Conservation Zone
MDS	Maximum Design Scenario
MFE	Mass Flow Excavator
MHWS	Mean High Water Springs
MMO	Marine Management Organisation
MW	Megawatt
NPS	National Policy Statement
O&M	Operation & Maintenance
OSP	Offshore Substation Platform
PEIR	Preliminary Environmental Information Report

Term	**Definition**
PINS	Planning Inspectorate
RCP	Representative Concentration Pathway
RIAA	Report to Inform Appropriate Assessment
SAC	Special Area of Conservation
SCI	Site of Community Importance
SMP	Shoreline Management Plan
SPA	Special Protection Area
SSC	Suspended Sediment Concentration
SSSI	Sites of Special Scientific Interest
TSHD	Trailing Suction Hopper Dredger
SoS	Secretary of State
VE	Five Estuaries
WTG	Wind Turbine Generator

2 MARINE GEOLOGY, OCEANOGRAPHY AND PHYSICAL PROCESSES

2.1 INTRODUCTION

2.1.1 This chapter of the Preliminary Environmental Information Report (PEIR) presents the results of the Environmental Impact Assessment (EIA) for the potential impacts of the Five Estuaries Offshore Wind Farm (VE) on marine geology, oceanography and physical processes (hereafter referred to as physical processes). It builds upon the earlier work undertaken for the Scoping chapter, taking into account feedback from statutory consultation. Specifically, this chapter considers the potential impact of VE seaward of Mean High-Water Springs (MHWS) during its construction, operation and maintenance (O&M), and decommissioning phases.

2.1.2 Marine physical processes is a collective term for the following:

> Water levels;
> Currents;
> Waves (and winds);
> Sediments and geology (including seabed sediment distribution and sediment transport);
> Seabed geomorphology; and
> Coastal geomorphology.

2.1.3 The assessment results presented in this chapter are supported by the following technical annexes

> Volume 4, Annex 2.1: Physical Processes Baseline Technical Report
> Volume 4, Annex 2.2: Physical Processes Model Design and Validation
> Volume 4, Annex 2.3: Physical Processes Technical Assessment

2.1.4 The results of the assessment have been used to inform the impact assessments for other environmental receptors, considered within the following chapters:

> Volume 2, Chapter 3: Marine Water and Sediment Quality;
> Volume 2, Chapter 4: Offshore Ornithology;
> Volume 2, Chapter 5: Benthic and Intertidal Ecology;
> Volume 2, Chapter 6: Fish and Shellfish Ecology;
> Volume 2, Chapter 7: Marine Mammal Ecology; and
> Volume 2, Chapter 10: Shipping and Navigation.

2.2 STATUTORY AND POLICY CONTEXT

2.2.1 The assessment of potential impacts upon physical processes has been made with specific reference to the relevant legislation, plans and policies. Details of legislation and policy are provided in Volume 1: Chapter 2 Policy and Legislation. Those specifically relevant to this Chapter are:

> Conservation of Habitats and Species Regulations 2017
> Conservation of Offshore Marine Habitats and Species Regulations 2017
> Overarching NPS for Energy (EN-1) (July 2011; draft review September 2021); and

> NPS for Renewable Energy Infrastructure (EN-3) (July 2011; draft review September 2021).
> NPS for Electricity Networks Infrastructure (EN-5) (draft September 2021)
> Marine policy Statement (March 2011)
> East Inshore and East Offshore Marine Plans (April 2014)
> South East Marine Plan (June 2021)

2.2.2 Relevant legislation and policy are outlined in Table 2.1.

Table 2.1: Legislation and policy context.

LEGISLATION/ POLICY	KEY PROVISIONS	SECTION WHERE COMMENT ADDRESSED
Conservation of Habitats and Species Regulations 2017	Maintain or, where appropriate, restore habitats and species listed in Annexes I and II of the Habitats Directive to a favourable conservation status.	The study area overlaps with a number of nationally and internationally designated nature conservation sites, some of which are designated on the basis of the geological and geomorphological features contained within them. The locations of these sites are shown in Figure 2.1 with potential impacts considered in Paragraph 2.10.1 *et seq.* (for the construction phase), Paragraph 2.11.1 *et seq.* (for the O&M phase) and Paragraph 2.12.1 *et seq.* (for the decommissioning phase).
Overarching National Policy Statement for Energy (NPS EN-1) (DECC, 2011a)	Paragraph 5.5.6 states: *"Where relevant, applicants should undertake coastal geomorphological and sediment transfer modelling to predict and understand impacts and help identify relevant mitigating or compensatory measures."*	Predictions of change to physical processes that could arise from construction, O&M and decommissioning of VE are presented in Paragraph 2.10.1 *et seq.* (for the construction phase), Paragraph 2.11.1 *et seq.* (for the O&M phase) and Paragraph 2.12.1 *et seq.* (for the decommissioning phase).
Overarching National Policy Statement for Energy (NPS EN-1) (DECC, 2011a)	Paragraph 5.5.7 states: *"The Environmental Statement should include an assessment of the effects on the coast. In particular, applicants should assess:* > *The impact of the proposed project on coastal processes and*	The impact of VE on coastal processes and geomorphology is considered in Paragraph 2.10.1 *et seq.* (for the construction phase), Paragraph 2.11.1 *et seq.* (for the O&M phase) and Paragraph 2.12.1 *et seq.* (for the decommissioning phase).The implications of the proposed project on strategies for

LEGISLATION/ POLICY	KEY PROVISIONS	SECTION WHERE COMMENT ADDRESSED
	geomorphology, including by taking account of potential impacts from climate change. If the development will have an impact on coastal processes the applicant must demonstrate how the impacts will be managed to minimise adverse impacts on other parts of the coast; > *The implications of the proposed project on strategies for managing the coast as set out in Shoreline Management Plans (SMPs), any relevant Marine Plans…and capital programmes for maintaining flood and coastal defences;* > *The effects of the proposed project on marine ecology, biodiversity and protected sites;* > *The effects of the proposed project on maintaining coastal recreation sites and features; and* > *The vulnerability of the proposed development to coastal change, taking account of climate change, during the project's operational life and any decommissioning period."*	managing the coast are considered within the landfall assessment, presented in Paragraph 0 *et seq. and* Paragraph 2.11.71 *et seq*. The effects of the proposed project on marine ecology, biodiversity and protected sites are set out elsewhere in the PEIR, in particular in Volume 2, Chapter 5: Benthic and Intertidal Ecology; The effects of the proposed project on maintaining coastal recreation sites and features are set out in Volume 2, Chapter 12: Infrastructure and Other Marine Users The vulnerability of the proposed development to coastal change is not assessed because any such vulnerability would be inherently mitigated to a suitable degree by the engineering design process and standards.
Overarching National Policy Statement for Energy (NPS EN-1) (DECC, 2011a)	Paragraph 5.5.9 states: *"The applicant should be particularly careful to identify any effects of physical changes on the integrity and*	The predicted changes to physical processes have been considered in relation to indirect effects on other receptors elsewhere in the PEIR, in particular in Volume 2, Chapter 5: Benthic and Intertidal Ecology and in

LEGISLATION/ POLICY	KEY PROVISIONS	SECTION WHERE COMMENT ADDRESSED
	special features of Marine Conservation Zones (MCZs), candidate marine Special Areas of Conservation (cSACs), coastal SACs and candidate coastal SACs, coastal Special Protection Areas (SPAs) and potential Sites of Community Importance (SCIs) and Sites of Special Scientific Interest (SSSI).”	the Report to Inform Appropriate Assessment (RIAA).
Overarching National Policy Statement for Energy (NPS EN-1) (DECC, 2011a)	Paragraph 5.5.11 states: *“The Secretary of State (SoS) should not normally consent new development in areas of dynamic shorelines where the proposal could inhibit sediment flow or have an adverse impact on coastal processes at other locations. Impacts on coastal processes must be managed to minimise adverse impacts on other parts of the coast. Where such proposals are brought forward consent should only be granted where the SoS is satisfied that the benefits (including need) of the development outweigh the adverse impacts.”*	A cable landfall assessment is presented in Paragraph 0 *et seq. and* Paragraph 2.11.71 *et seq*. This assessment considers the nature of ongoing shoreline change at the landfall and the potential for cables and other project infrastructure to impact coastal processes. A full description of coastal processes understanding at the landfall is set out in Volume 4, Annex 2.1: Physical Processes Baseline Technical Report.
Overarching National Policy Statement for Energy (NPS EN-1) (DECC, 2011a)	Section 4.8 states: *“The resilience of the project to climate change (such as increased storminess) should be assessed in the Environmental Statement accompanying an application.”*	Potential changes in climate are described in Volume 4, Annex 2.1: Physical Processes Baseline Technical Report and are considered alongside predicted changes described in the assessment sections (Paragraph 2.10.1 *et seq.*).
National Policy Statement for Renewable	Paragraph 2.6.81 states: *“An assessment of the effects of installing cable across the*	Predictions of change to physical processes that could arise from the construction, and O&M of VE are

LEGISLATION/ POLICY	KEY PROVISIONS	SECTION WHERE COMMENT ADDRESSED
Energy Infrastructure (NPS EN-3) (DECC, 2011b)	*intertidal zone should include information, where relevant, about:* > *Any alternative landfall sites that have been considered by the applicant during the design phase and an explanation for the final choice;* > *Any alternative cable installation methods that have been considered by the applicant during the design phase and an explanation for the final choice;* > *Potential loss of habitat;* > *Disturbance during cable installation and removal (decommissioning);* > *Increased suspended sediment loads in the intertidal zone during installation; and* > *Predicted rates at which the intertidal zone might recover from temporary effects.*	presented in Paragraph 2.10.1 to 2.11.80. A cable landfall assessment is presented in Paragraph 0 *et seq. and* Paragraph 2.11.71. This assessment considers the effects of installation, operation and decommissioning activities on coastal processes as well considering recovery and ongoing shoreline change at the landfall. Details regarding alternative landfall sites and installation methods that have been considered during the design phase and an explanation for the final choice are provided in Volume 1, Chapter 4: Site Selection and Alternatives. The assessment of the potential loss of habitat in the intertidal zone is documented in Volume 2, Chapter 5: Benthic and Intertidal Ecology.
National Policy Statement for Renewable Energy Infrastructure (NPS EN-3) (DECC, 2011b)	Paragraph 2.6.113 states: *"Where necessary, assessment of the effects on the subtidal environment should include:* > *Environmental appraisal of array and cable routes and installation methods;* > *Habitat disturbance from construction vessels' extendible legs and anchors;*	Predictions of change to physical processes that could arise from construction, O&M and decommissioning of VE are presented in Paragraphs 2.10.1 to 2.12.13.

LEGISLATION/ POLICY	KEY PROVISIONS	SECTION WHERE COMMENT ADDRESSED
	> *Increased suspended sediment loads during construction; and* > *Predicted rates at which the subtidal zone might recover from temporary effects.*	
National Policy Statement for Renewable Energy Infrastructure (NPS EN-3) (DECC, 2011b)	Paragraph 2.6.190 states: *"Assessment should be undertaken for all stages of the lifespan of the proposed wind farm in accordance with the appropriate policy for offshore wind farm EIAs."*	The impact of the proposed project on coastal processes and geomorphology is considered in Paragraph 2.10.1 *et seq.* (for the construction phase), Paragraph 2.11.1 *et seq.* (for the O&M phase) and Paragraph 2.12.1 *et seq.* (for the decommissioning phase).
National Policy Statement for Renewable Energy Infrastructure (NPS EN-3) (DECC, 2011b)	Paragraphs 2.6.191 and 2.6.192 state: *"The Applicant should consult the Environment Agency, Marine Management Organisation (MMO) and Centre for Environment, Fisheries and Aquaculture Science (Cefas) on methods for assessment of impacts on physical processes."*	Consultation on the approach to assessment for physical processes has been carried out with MMO as the relevant marine licencing body. Details of the approach to consultation are provided in Table 2.2.
National Policy Statement for Renewable Energy Infrastructure (NPS EN-3) (DECC, 2011b)	Paragraph 2.6.192 states: *"Mitigation measures which the Infrastructure Planning. Commission (IPC) (now the Planning Inspectorate (PINS)) should expect the applicants to have considered include the burying of cables to a necessary depth and using scour protection techniques around offshore structures to prevent scour effects around them. Applicants should consult the statutory consultees on appropriate mitigation."*	The embedded mitigation relating to cable burial and scour protection are set out in Table 2.9. Consultation is ongoing with statutory consultees and other interested parties.

LEGISLATION/ POLICY	KEY PROVISIONS	SECTION WHERE COMMENT ADDRESSED
National Policy Statement for Renewable Energy Infrastructure (NPS EN-3) (DECC, 2011b)	Paragraph 2.6.193 states: *"Geotechnical investigations should form part of the assessment as this will enable the design of appropriate construction techniques to minimise any adverse effects."*	Geotechnical data was collected to inform the (adjacent) Galloper and Greater Gabbard OWF assessments. This has been used alongside the project specific geophysical survey (Fugro, 2022a; b) to inform the sediment and morphological assessments and project design of VE.
National Policy Statement for Renewable Energy Infrastructure (NPS EN-3) (DECC, 2011b)	Paragraph 2.6.194 states: "*The assessment should include predictions of the physical effect that will result from the construction and operation of the required infrastructure and include effects such as the scouring that may result from the proposed development.*"	Predictions of change to physical processes that could arise from the construction, and O&M of VE are presented in Paragraphs 2.10.1 to 2.11.80.
National Policy Statement for Renewable Energy Infrastructure (NPS EN-3) (DECC, 2011b)	Paragraph 2.6.195 states: "*The direct effects on the physical environment can have indirect effects on a number of other receptors. Where indirect effects are predicted, the IPC (now the Planning Inspectorate (PINS) should refer to relevant Sections of this NPS and EN 1.*"	The predicted changes to the physical environment have been considered in relation to indirect effects on other receptors elsewhere in the PEIR, in particular within Volume 2, Chapter 5: Benthic and Intertidal Ecology and in Volume 2, Chapter 3: Marine Water and Sediment Quality.
National Policy Statement for Renewable Energy Infrastructure (NPS EN-3) (DECC, 2011b)	Paragraph 2.6.196 states: "*The methods of construction, including use of materials should be such as to reasonably minimise the potential for impact on the physical environment.*"	The Project has proposed designs and installation methods that seek to minimise significant adverse effects on the physical environment where possible. Where necessary, the assessment has set out mitigation to avoid or reduce significant adverse effects.
National Policy Statement for Renewable Energy Infrastructure	Paragraph 2.6.197 states: *"Mitigation measures which the SoS should expect the applicant to have considered include the burying of cables*	The embedded mitigation measures relating to cable burial and scour are set out in Table 2.9.

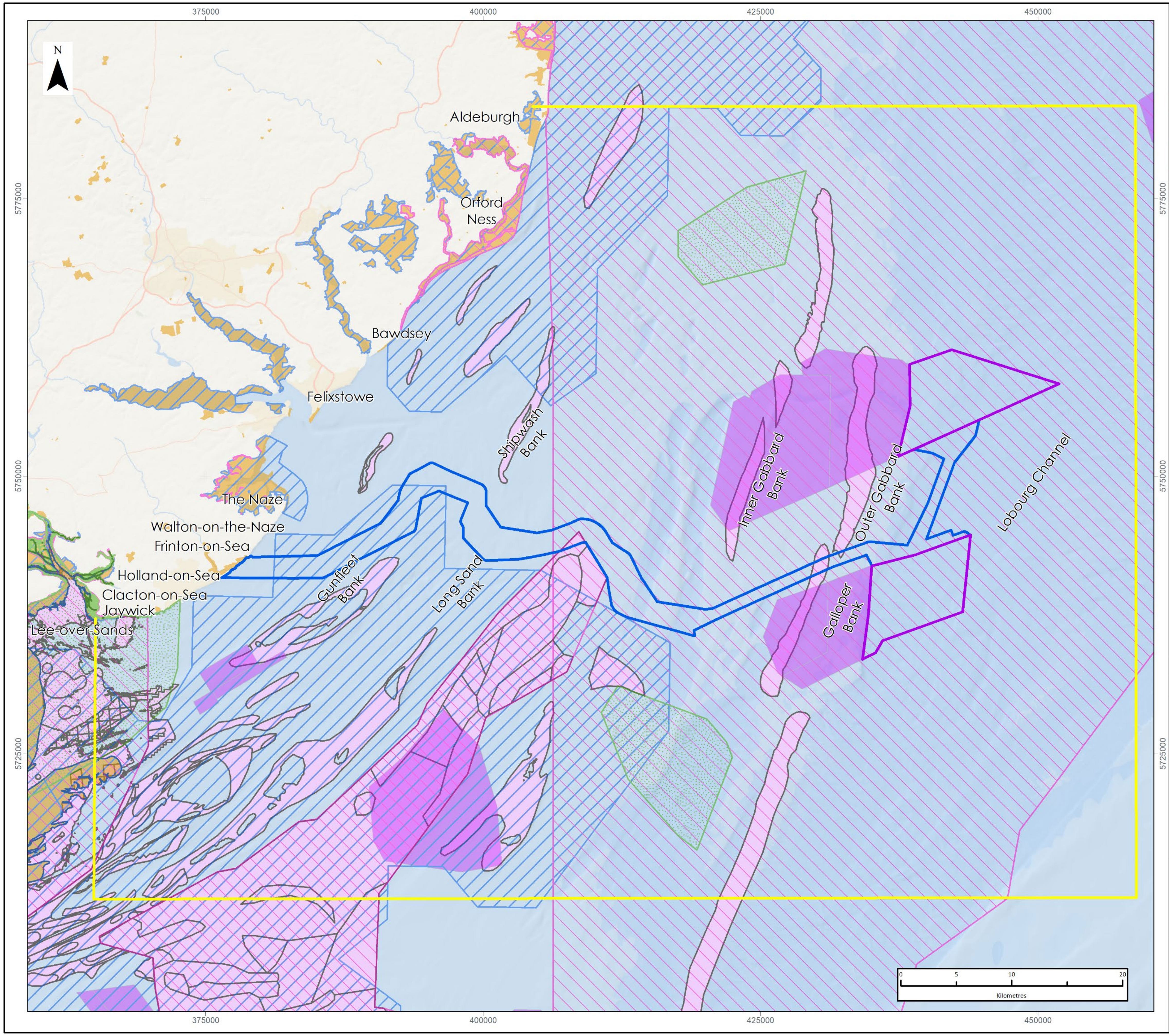
LEGISLATION/ POLICY	KEY PROVISIONS	SECTION WHERE COMMENT ADDRESSED
(NPS EN-3) (DECC, 2011b)	*to a necessary depth and using scour protection techniques around offshore structures to prevent scour effects around them. Applicants should consult the statutory consultees on appropriate mitigation."*	
Draft National Policy Statement for Renewable Energy Infrastructure (EN-3) (BEIS, 2021b)	Paragraph 2.25.1 states: *"The construction, operation and decommissioning of offshore energy infrastructure can affect the following elements of the physical offshore environment, which can have knock on impacts on other biodiversity receptors:* > *water quality* > *waves and tides* > *scour effect* > *sediment transport* > *suspended solids"*	Predictions of change to physical processes (including all of those listed in Paragraph 2.25.1 of Draft NPS EN-3) which could arise from construction, O&M and decommissioning of VE are presented in Paragraph 2.10.1 *et seq.* (for the construction phase), Paragraph 2.11.1 *et seq.* (for the O&M phase) and Paragraph 2.12.1 *et seq.* (for the decommissioning phase).
Draft National Policy Statement for Renewable Energy Infrastructure (EN-3) (BEIS, 2021b)	Paragraph 2.25.3: *"Geotechnical investigations should form part of the assessment as this will enable design of appropriate construction techniques to minimise any adverse effects."*	Geotechnical data was collected to inform the (adjacent) Galloper and Greater Gabbard OWF assessments. This has been used alongside the project specific geophysical survey (Fugro, 2022a; b) to inform the assessment and project design of VE.
Draft National Policy Statement for Renewable Energy Infrastructure (EN-3) (BEIS, 2021b)	Paragraph 2.25.5: *"The SoS should expect applicants to have considered the best ecological outcomes in terms of potential mitigation. These might include the burying of cables to a necessary depth, using scour protection techniques around offshore structures to prevent scour effects or designing turbines to*	The embedded mitigation measures relating to cable burial and scour are set out in Table 2.9.

LEGISLATION/ POLICY	KEY PROVISIONS	SECTION WHERE COMMENT ADDRESSED
	withstand scour, so scour protection is not required or is minimised."	
Draft National Policy Statement for Electricity Networks Infrastructure (EN-5) (BEIS, 2021)	Paragraph 2.6.1 states: *"Applicants should in particular set out to what extent the proposed development is expected to be vulnerable, and, as appropriate, how it has been designed to be resilient to… coastal erosion – for the landfall of offshore transmission cables and their associated substations in the inshore and coastal locations respectively."*	The vulnerability of the Proposed Development to coastal change is considered in the context of the project design, in Volume 2, Chapter 1: Offshore Project Description. A cable landfall assessment is presented in Paragraph 0 *et seq. and* Paragraph 2.11.71 *et seq*. This assessment considers the nature of ongoing and potential future shoreline change at the landfall. A full description of coastal processes understanding at the landfall is set out in Volume 4, Annex 2.1: Physical Processes Baseline Technical Report.
Marine Policy Statement (2011)	Paragraph 2.6.8.5 states: *"Marine plan authorities should consider existing terrestrial planning and management policies for coastal development under which inappropriate development should be avoided in areas of highest vulnerability to coastal change and flooding. Development will need to be safe over its planned lifetime and not cause or exacerbate flood and coastal erosion risk elsewhere."*	The suitability of the Proposed Development to coastal change is considered in the context of the project design, in Volume 2, Chapter 1: Offshore Project Description. A cable landfall assessment is presented in Paragraph 0 *et seq. and* Paragraph 2.11.71 *et seq*. This assessment considers the nature of ongoing and potential future shoreline change at the landfall. A full description of coastal processes understanding at the landfall is set out in Volume 4, Annex 2.1: Physical Processes Baseline Technical Report.
East Inshore and East Offshore Marine Plans (April 2014)	Policy BIO2 states: *"Where appropriate, proposals for development should incorporate features that*	BNG is not currently a statutory or policy requirement within the marine environment, however VE are committed to following the outcome of recent Defra consultation,

LEGISLATION/ POLICY	KEY PROVISIONS	SECTION WHERE COMMENT ADDRESSED
	enhance biodiversity and geological interests."	industry discussions and therefore the evolution of this topic.
East Inshore and East Offshore Marine Plans (April 2014)	Policy CC1 states: *"Proposals should take account of:* > *how they may be impacted upon by, and respond to, climate change over their lifetime; and* > *how they may impact upon any climate change adaptation measures elsewhere during their lifetime* *Where detrimental impacts on climate change adaptation measures are identified, evidence should be provided as to how the proposal will reduce such impacts."*	Volume 3, Chapter 11: Human Health and Climate change provides further information and signposts to the relevant chapters which consider the likely significant effects associated with VE on climate change. This includes: > Volume 3, Chapter 10: Air Quality, which considers the effects of air quality impacts upon climate change. > Volume 3, Chapter 6: Hydrology and Flood Risk, which considers the effects of climate change on tidal, fluvial and surface water flood risk in relation to VE. A cable landfall assessment is presented in Paragraph 0 *et seq. and* Paragraph 2.11.71 *et seq*. This assessment considers the nature of ongoing and potential future shoreline change at the landfall. A full description of coastal processes understanding at the landfall is set out in Volume 4, Annex 2.1: Physical Processes Baseline Technical Report.
East Inshore and East Offshore Marine Plans (April 2014)	Policy CAB1 states: *"Preference should be given to proposals for cable installation where the method of installation is burial. Where burial is not achievable, decisions should take account of protection measures for the cable that may be proposed by the applicant."*	Cables will be buried where possible and cable protection will be applied as and where appropriate according to the cable burial design plan. Indicative design options for cable burial and protection are set out in Volume 2, Chapter 1: Offshore Project Description.

LEGISLATION/ POLICY	KEY PROVISIONS	SECTION WHERE COMMENT ADDRESSED
South East Inshore Marine Plan (June 2021)	Policy SE-CC-2 states: *"Proposals in the south east marine plan area should demonstrate for the lifetime of the project that they are resilient to the impacts of climate change and coastal change."*	The vulnerability of the proposed development to coastal change is considered in the context of the project design, in Volume 2, Chapter 1: Offshore Project Description. A cable landfall assessment is presented in Paragraph 0 *et seq. and* Paragraph 2.11.71 *et seq*. This assessment considers the nature of ongoing and potential future shoreline change at the landfall. A full description of coastal processes understanding at the landfall is set out in Volume 4, Annex 2.1: Physical Processes Baseline Technical Report.
South East Inshore Marine Plan (June 2021)	Policy SE-CC-3 states: *"Proposals in the south east marine plan area, and adjacent marine plan areas, that are likely to have significant adverse impacts on coastal change, or on climate change adaptation measures inside and outside of the proposed project areas, should only be supported if they can demonstrate that they will, in order of preference: a) avoid b) minimise c) mitigate - adverse impacts so they are no longer significant."*	The impact of the proposed project on coastal change is considered in Paragraph 0 *et seq*. (for the construction phase), Paragraph 2.11.71 *et seq.* (for the O&M phase) and Paragraph 2.12.8 *et seq.* (for the decommissioning phase).
South East Inshore Marine Plan (June 2021)	Policy SE-MPA-2 states: "*Proposals that may have adverse impacts on an individual marine protected area's ability to adapt to the effects of climate change, and so reduce the resilience of the marine protected area network, must demonstrate that they will, in order of*	The study area overlaps with a number of nationally and internationally designated nature conservation sites (Figure 2.1). The potential for VE to impact the seabed in these designated areas is considered in Paragraph 2.10.12 *et seq*. (for the construction phase) and Paragraph 2.11.52 *et seq.* (for the O&M phase).

LEGISLATION/ POLICY	KEY PROVISIONS	SECTION WHERE COMMENT ADDRESSED
	preference: a) avoid b) minimise c) mitigate - adverse impacts."	The assessment of potential effects on marine ecology and the marine protected area network is documented in Volume 2, Chapter 5: Benthic and Intertidal Ecology.



LEGEND

- Array Areas
- Offshore Export Cable Corridor
- Wind Farm (Active/In Operation)
- Marine Conservation Zone
- Special Area of Conservation
- Special Protection Area
- Site of Special Scientific Interest
- Annex I Sandbanks
- Physical Processes Study Area

Data Source: VE OWFL (2022); JNCC,2020.

PROJECT TITLE:

FIVE ESTUARIES OFFSHORE WINDFARM

DRAWING TITLE:

Physical Processes Study Area

VER	DATE	REMARKS	Drawn	Checked
1	28/02/2023	For Issue	CRO	NKD

DRAWING NUMBER:

2.1

SCALE: 1:350,000 | PLOT SIZE: A3 | DATUM: WGS84 | PROJECTION: UTM31N

FIVE ESTUARIES OFFSHORE WIND FARM

N:\5031_Five_Estuaries\GIS\MXDs\02 PEIR\PEIRch_Fig_Study_Area_A3.mxd

2.2.3 The following guidance documents have been used to inform the assessment methodologies used in this chapter:

- 'Evidence Report No: 243 Guidance on Best Practice for Marine and Coastal Physical Processes Baseline Survey and Monitoring Requirements to inform EIA of Major Development Projects.' For Natural Resources Wales. (Brooks et al. 2018);
- 'Environmental impact assessment for offshore renewable energy projects.' (BSI, 2015).
- 'Guidelines for Data Acquisition to Support Marine Environmental Assessments of Offshore Renewable Energy Projects'. (Cefas, 2011);
- 'General advice on assessing potential impacts of and mitigation for human activities on Marine Conservation Zone features, using existing regulation and legislation' (JNCC and Natural England, 2011);
- 'Coastal Process Modelling for Offshore Wind farm Environmental Impact Assessment: Best Practice Guide'. ABPmer & HR Wallingford for COWRIE, 2009, [http://www.offshorewindfarms.co.uk];
- 'Guidelines in the use of metocean data through the lifecycle of a marine renewables development'. (ABPmer et al., 2008); and
- 'Offshore Windfarms: Guidance note for Environmental Impact Assessment in Respect of FEPA and CPA requirements'. (Cefas, 2004).

2.2.4 The following studies have also been considered:

- 'Review of environmental data associated with post-consent monitoring of licence conditions of offshore wind farms'. MMO Project No: 1031. (Fugro-Emu, 2014);
- 'Further review of sediment monitoring data'. (COWRIE ScourSed-09).' (ABPmer et al., 2010);
- 'Review of Cabling Techniques and Environmental Effects applicable to the Offshore Wind farm Industry'. Department for Business Enterprise and Regulatory Reform in association with Defra. (BERR, 2008);
- 'Review of Round 1 Sediment process monitoring data - lessons learnt. (Sed01)' (ABPmer et al., 2007);
- 'Dynamics of scour pits and scour protection - Synthesis report and recommendations. (Sed02)' (HR Wallingford et al., 2007); and
- 'Potential effects of offshore wind developments on coastal processes'. (ABPmer and METOC, 2002).

2.3 CONSULTATION

2.3.1 As part of the EIA process for VE, a formal Scoping Opinion (PINS, 2021) was sought from PINS following submission of the Scoping Report (RWE, 2021).

2.3.2 Ongoing consultation has taken place through the Marine Ecology and Marine Mammals Expert Topic Group (ETG) of which covers (amongst other topics) marine physical processes. This process supports the development of the VE Evidence Plan (the Evidence Plan) within which agreement has been sought as to the suitability of available evidence, assessment methodologies, and forthcoming guidance where appropriate.

2.3.3 Consultation responses and responses received through the development of the Evidence Plan have been important in informing this PEIR chapter and in the development of the technical supporting annexes.

2.3.4 Responses relating to physical processes are addressed throughout this chapter. Table 2.2 provides a summary of key points raised and describes how they have been addressed.

Table 2.2: Summary of consultation relating to physical processes.

Date and consultation phase/ type	Consultation and key issues raised	Section where comment addressed
November 2021 Scoping	Clear justification needs to be given in the PEIR/ ES as to how the extent of the Zone of Influence around the Project has been determined	The rationale used to determine the spatial extent of the study area is set out in Paragraph 2.4.4 *et seq*.
November 2021 Scoping	Detailed understanding of the baseline environment across the Study Area must be set out in the PEIR/ ES, also demonstrating the adequacy of available survey data.	A full description of physical processes across the study area is set out in Volume 4, Annex 2.1: Physical Processes Baseline Technical Report. Details of all of the Project specific and existing datasets used to inform this assessment are also provided. This report provides a detailed conceptual understanding of sediment transport pathways and associated morphological change.
November 2021 Scoping	The coverage and scope of the project specific geophysical survey data should be clearly set out in the PEIR/ ES.	Multibeam bathymetry, side-scan sonar and sub-bottom profiler data has been collected, providing full coverage of the array areas and partial coverage of the ECC. This data has been used to inform baseline understanding, as set out in Volume 4, Annex 2.1: Physical Processes Baseline Technical Report.

Date and consultation phase/ type	Consultation and key issues raised	Section where comment addressed
		Full details of the geophysical surveys undertaken for VE (including survey extent) are set out in the Five Estuaries Geophysical Survey: WPM1 Main Array Seafloor and Shallow Geological Results Report (2022a) – for the array areas and Five Estuaries Geophysical Survey: WPM2 & WPM3 ECR Seafloor and Shallow Geological Results Report (2022b) – for the ECC.
November 2021 Scoping	The Scoping report does not provide sufficient justification for new numerical modelling to be ruled out	This issue has been progressed through the Evidence Plan process and new numerical modelling has been undertaken to inform the VE assessment of changes to the wave and tidal regime. Details of the model set up are provided in Volume 4, Annex 2.2: Physical Processes Model Design and Validation.
November 2021 Scoping	The assessments in the PEIR/ ES should also take account of the of the dual policy in the Shoreline Management Plan (both “hold the line” and managed realignment) which applies to the landfall area.	Shoreline management strategies have been considered within the landfall assessment, presented in Paragraph 0 *et seq. and* Paragraph 2.11.71 *et seq*.
November 2021 Scoping	The combined influence of the proposed development, existing adjacent offshore windfarms (i.e. GGOW and GWF) and the planned North Falls OWF, on the hydrodynamics and sediment transport regime will need to be sufficiently	An assessment of the potential for cumulative effects with other projects in the study area is considered in Paragraph 2.13 *et seq*.

Date and consultation phase/ type	Consultation and key issues raised	Section where comment addressed
	investigated and characterised. In turn, this investigation will need to consider cumulative impacts on the integrity of coastal and offshore receptors.	
December 2021 Evidence Plan consultation	The PEIR/ ES should state whether a geotechnical survey will be undertaken for VE in time to inform the EIA	Offshore geotechnical surveys will not be undertaken in advance of the Project EIA. However, geotechnical data available from the adjacent GOWF has been used to validate the VE geophysical survey. A cable burial risk assessment (CBRA) is also being undertaken for the Project, informed by the geophysical data, sub-bottom profiler (SBP) data, and the existing Galloper geotechnical data.
December 2021 Evidence Plan consultation	The PEIR/ ES should consider nearby receptors at the coast, along with sandbanks and designated sites.	The coast, sand banks and the seabed within designated nature conservation sites are all included as marine physical processes receptors, as set out in Paragraph 2.5.2 *et seq*.
December 2021 Evidence Plan consultation	The anticipated maximum sediment plume spatial extent, concentration, persistence and related bed level changes should be shown visually for the export cable route particularly in relation to Margate and Long Sands SAC, nearshore, the Hamford Water SPA and in the array areas. Where applicable, concurrent activities should be assessed.	A full assessment of potential changes in SSC and associated changes in bed level are set out in Paragraph 2.10.1 *et seq* with further details of the assessment approach provided in Volume 4, Annex 2.3: Physical Processes Technical Assessment. This includes visual representations of the realistic maximum spatial

Date and consultation phase/ type	Consultation and key issues raised	Section where comment addressed
		footprint of sediment plumes.
December 2021 Evidence Plan consultation	A clear explanation of physical processes pathways should be provided in the PEIR chapter.	Physical processes pathways are assessed in detail in Paragraph 2.10.1 *et seq*. (for the construction phase), Paragraph 2.11.1 *et seq*. (for the O&M phase) and Paragraph 2.12.1 *et seq*. (for the decommissioning phase). Further details regarding changes to the hydrodynamic and wave regimes (which have been assessed using numerical modelling) are set out in Volume 4, Annex 2.3: Physical Processes Technical Assessment.
December 2021 Evidence Plan consultation	An assessment of the ancillary infrastructure at the landfall is required and assessed for the lifetime of the project. Similarly, potential impacts associated with the presence of cable crossings on hydrodynamics and sediment transport processes should also be considered in the PEIR.	A cable landfall assessment is presented in Paragraph 0 *et seq. and* Paragraph 2.11.71 *et seq*. An assessment of the potential impact of cable crossings on hydrodynamics and sediment transport processes (with associated potential impacts to sandbank morphology and designated areas of seabed) is presented in Paragraph 2.11.17 *et seq*. and Paragraph 2.11.52 *et seq*.
October 2022 Evidence Plan consultation	Requests to: include results from (then ongoing) sediment mobility modelling to inform baseline understanding; account for potential impact of cable crossing protection in the ECC in assessment of	Results from the sediment mobility modelling are included in the baseline description, summarised in Paragraph 2.7.1 *et seq* and in Volume 4, Annex 2.1: Physical Processes Baseline Technical Report.

Date and consultation phase/ type	Consultation and key issues raised	Section where comment addressed
	impact on currents/waves/ sediment transport; include an indicative map of potential sediment deposition footprints in relation to the extent of designated areas.	An assessment of the potential impact of cable crossings on hydrodynamics and sediment transport processes (with associated potential impacts to sandbank morphology and designated areas of seabed) is presented in Paragraph 2.11.52 *et seq.* Indicative footprints of sediment deposition are provided with the assessments presented in Paragraph 2.10.1 *et seq.*

2.4 SCOPE AND METHODOLOGY

SCOPE OF THE ASSESSMENT

IMPACTS SCOPED IN FOR ASSESSMENT

2.4.1 The following impacts have been scoped into this assessment:

- Construction:
  - Impact 1: Potential changes to suspended sediment concentrations (SSC), bed levels and sediment type.
  - Impact 2: Potential morphological impacts to sandbanks and designated areas of seabed.
  - Impact 3: Potential impacts to landfall morphology.
- Operation and maintenance:
  - Impact 4: Potential changes to the tidal regime.
  - Impact 5: Potential changes to the wave regime.
  - Impact 6: Potential changes to the sediment transport regime.
  - Impact 7: Potential for scour of seabed sediments, including that around scour protection structures
  - Impact 8: Potential morphological impacts to sandbanks and designated areas of seabed.
  - Impact 9: Potential impacts to coastal morphology.
- Decommissioning:

- Impact 11: Potential changes to SSC, bed levels and sediment type.
- Impact 12: Potential impacts to landfall morphology.

IMPACTS SCOPED OUT OF ASSESSMENT

2.4.2 Based on the baseline environment information currently available and the project description (outlined in Volume 2, Chapter 1: Offshore Project Description), no impacts have been scoped out at this stage, principally due to the potential for indirect impacts on other topic receptors.

STUDY AREA

2.4.3 The study area is located within the Outer Thames Estuary and includes the VE array areas and offshore ECC (Figure 2.1). The landfall for the offshore ECC is located at Holland Haven, between Frinton-on-Sea and Clacton-on-Sea on the Essex coast. The array areas, offshore ECC and landfall have all been determined following a process of detailed physical and environmental constraints mapping, also taking into consideration other seabed uses including the proposed North Falls OWF development.

2.4.4 The wider physical processes study area surrounding the array areas and offshore ECC is also shown on Figure 2.1 and encompasses the Outer Thames Estuary as well as adjacent seabed areas up to MHWS. The spatial extent of the wider study area has been informed through combined consideration of the potential extent of physical processes impact pathways:

- The distance away from VE which suspended sediment plumes may be advected (and meaningfully interact with potentially sensitive receptors) has been defined by a spring tidal excursion ellipse buffer around the array areas and offshore ECC;
- The distance up/down drift from the landfall that littoral processes could theoretically be impacted by Project infrastructure has been defined through consideration of coastal sub-cell information set out in Shoreline Management Plans; and
- The distance from the array areas that wave blockage impacts could theoretically be detected has been informed by expert judgment, drawing upon (amongst other things), the evidence base from analogous projects including GGOWF and GOWF and consideration of the prevailing wave directions.

2.4.5 The study area overlaps with a number of nationally and internationally designated nature conservation sites, some of which are designated on the basis of the geological and geomorphological features contained within them (Figure 2.1).

DATA SOURCES

2.4.6 Baseline understanding of physical processes within the study area has been developed through consideration of a range of project-specific and existing data sources. These are summarised in Table 2.2, Table 2.3, and Figure 2 of Volume 4, Annex 2.1: Physical Processes Technical Baseline and include:

- VE project specific geophysical survey data collected in 2021 (Fugro, 2022a; b);
- Geophysical, geotechnical, benthic and oceanographic data collected to inform the GOWF and GGOWF EIAs;

- UKHO Marine Data Portal for multibeam and singlebeam bathymetry and Environment Agency LiDAR and multibeam bathymetry data;
- Seabed sediment maps and borehole records from the British Geological Survey;
- Tide data from the National Tide and Sea Level Facility;
- Hydrodynamic data from the British Oceanographic Data Centre;
- Wave data from Cefas WaveNet, ABPmer SEASTATES and ABPmer's Marine Renewables Atlas;
- Topographic survey data, aerial imagery and oceanographic data from the Anglian Coastal Monitoring programme;
- Environmental Statements and supporting studies for the GOWF and GGOWFs;
- Work undertaken for the aggregate industry including The Outer Thames Estuary Regional Environmental Characterisation and Thames Marine Aggregate Regional Environmental Assessment;
- Relevant academic literature and other key studies such as the Southern North Sea Sediment Transport Study and Shoreline Management Plans; and
- Numerical modelling of hydrodynamic, wave and sediment transport processes developed to inform the assessment (Volume 4, Annex 2.2: Physical Processes Model Design and Validation).

ASSESSMENT METHODOLOGY

2.4.7 In order to assess the potential effects upon the marine physical environment relative to the existing (baseline) coastal environment, a combination of analytical methods has been used. These include:

- VE project specific numerical modelling;
- The 'evidence base' containing monitoring data collected during the construction and O&M of other OWF developments;
- Analytical assessments of project-specific data; and
- Standard empirical equations describing (for example) the potential for scour development around structures (e.g. Whitehouse, 1998).

2.4.8 The assessment has been undertaken in accordance with industry best practice and guidance, as previously described (Paragraph 2.2.3). Full details of the methodological approach to the assessment of sediment disturbance related effects and scour are set out in Volume 4, Annex 2.3: Physical Processes Technical Assessment.

2.4.9 The assessment also considers likely naturally occurring variability in, or long-term changes to, physical processes within the project lifetime due to natural cycles and/or climate change (e.g. sea level rise). This is important as it enables a reference baseline level to be established against which the potentially modified physical processes can be compared, throughout the project lifecycle. Baseline conditions are described in detail within Volume 4, Annex 2.1: Physical Processes Baseline Technical Report and include for the potential effects of climate change.

2.4.10 The assessment of impacts on the marine physical environment has been considered over two spatial scales. These are:

- Far-field. Defined as the area surrounding the VE array areas and offshore ECC over which indirect changes may occur (i.e. the study area); and
- Near-field. Defined as the footprint of the array areas and offshore ECC.

2.5 ASSESSMENT CRITERIA AND ASSIGNMENT OF SIGNIFICANCE

2.5.1 For the most part, physical processes are not in themselves receptors but are instead 'pathways'. However, changes to physical processes have the potential to indirectly impact other environmental receptors (Lambkin et al., 2009). For instance, the creation of sediment plumes (the potential for which is considered in the physical processes assessment) may lead to settling of material onto benthic habitats. The potential significance of this particular change is assessed in Volume 2, Chapter 5: Benthic and Intertidal Ecology. This distinction between assessments of pathways and receptors is summarised in Table 2.3, for each of the potential impacts/ changes considered within the assessment section.

Table 2.3: Summary of potential impacts/ changes considered in the physical processes assessment.

POTENTIAL IMPACTS/ PATHWAY EFFECTS	PATHWAY/ RECEPTOR
CONSTRUCTION	
Impact 1: Potential changes to suspended sediment concentrations (SSC), bed levels and sediment type arising from construction related activities including dredging, drilling and cable installation	Pathway
Impact 2: Potential morphological impacts to sandbanks and designated areas of seabed	Pathway/ receptor
Impact 3: Potential impacts to landfall morphology	Pathway/ receptor
OPERATION	
Impact 4: Potential changes to the tidal regime	Pathway

POTENTIAL IMPACTS/ PATHWAY EFFECTS	PATHWAY/ RECEPTOR
Impact 5: Potential changes to the wave regime	Pathway
Impact 6: Potential changes to the sediment transport regime	Pathway
Impact 7: Potential for scour of seabed sediments, including that around scour protection structures	Pathway/ receptor
Impact 8: Potential morphological impacts to sandbanks and designated areas of seabed	Pathway/ receptor
Impact 9: Potential impacts to coastal morphology	Receptor
DECOMMISSIONING	
Impact 10: Potential changes to SSC, bed levels and sediment type	Pathway
Impact 11: Potential impacts to landfall morphology	Pathway/ receptor
CUMULATIVE	
Impact 12: Potential for cumulative temporary increases in SSC and seabed levels as a result of VE foundation installation, inter-array/ export cable laying and aggregate dredging.	Pathway

POTENTIAL IMPACTS/ PATHWAY EFFECTS	PATHWAY/ RECEPTOR
Impact 13: Potential for cumulative temporary increases in SSC and seabed levels as a result of export cable laying and dredge spoil disposal at licensed disposal grounds.	Pathway
Impact 14: Potential for cumulative temporary increases in SSC and seabed levels as a result of VE foundation installation, inter-array/ export cable laying and interconnector cable installation.	Pathway
Impact 15: Potential for cumulative changes to the wave regime, with associated impacts to sandbanks and the coast, arising from interaction with other proposed OWF projects.	Pathway/ receptor

2.5.2 Whilst physical processes can largely be considered as pathways, a small number of features have been identified as potentially sensitive physical processes receptors. These are:

- The coast;
- Nearby Annex I offshore sand banks (including Galloper Bank, Long Sand Bank and Gunfleet Bank); and
- Seabed areas contained within nationally or internationally important sites. (The locations of these sites are shown in Figure 2.1).

2.5.3 These receptors have been identified on the basis of:

- Professional judgement, local and regional specialist experience;
- The Scoping Opinion (PINS, 2021);
- Outcomes from the consultation process; and
- Reference to best practice guidance.

2.5.4 Where these receptors have the potential to be affected by changes to physical processes, a full impact assessment (i.e. assigning sensitivity, magnitude and significance) has been carried out.

2.5.5 The assessment of effects upon physical processes receptors is a systematic process that is determined by taking into account the 'magnitude of the impact' and 'sensitivity and importance' of the receptor. These assessment criteria are described in more detail within this Section.

2.5.6 The magnitude of impact describes the extent or degree of change that is predicted to occur to a receptor. It has been assessed using expert judgement and described qualitatively with a standard semantic scale. Definitions for each term are provided in Table 2.4. These expert judgements regarding the magnitude of effect relative to baseline conditions have been made by experienced marine physical process specialists and formed following consideration of the information sources previously set out in Paragraph 2.4.6.

Table 2.4: Impact magnitude definitions.

Magnitude	Description/ reason
High	Permanent changes across the near- and large parts of the far-field to key characteristics or features of the particular environmental aspect's character or distinctiveness.
Medium	Permanent changes, over the near- and parts of the far-field, to key characteristics or features of the particular environmental aspect's character or distinctiveness
Low	Noticeable, temporary (for part of the project duration) change, or barely discernible change for any length of time, restricted to the near-field and immediately adjacent far-field areas, to key characteristics or features of the particular environmental aspect's character or distinctiveness.
Negligible	Changes which are not discernible from background conditions.

2.5.7 The importance and sensitivity of each receptor has been assessed using expert judgement and described with a standard semantic scale using the terms negligible, low, medium and high. Definitions for each term are provided in Table 2.5. The characterisation of receptor sensitivity/importance is closely guided by the conceptual understanding of regional-scale physical processes, developed during the baseline characterisation process (Volume 4, Annex 2.1: Physical Processes Baseline Technical Report).

Table 2.5: Sensitivity/importance of the environment.

Receptor sensitivity/ importance	Definition
High	Very low or no capacity to accommodate the proposed form of change; and/ or receptor designated and/ or of international level importance. Likely to be rare with minimal potential for substitution. May also be of very high socioeconomic importance.
Medium	Moderate to low capacity to accommodate the proposed form of change; and/ or receptor designated and/ or of regional level importance. Likely to be relatively rare. May also be of moderate socioeconomic importance.
Low	Moderate to high capacity to accommodate the proposed form of change; and/ or receptor not designated but of district level importance.
Negligible	High capacity to accommodate the proposed form of change; and/ or receptor not designated and only of local level importance.

2.5.8 Assessment of the significance of potential effects is described in Table 2.6. This has been determined by taking into account the magnitude of the impact and the sensitivity and importance of the receptor and applying to construction, O&M and decommissioning stages of the Project.

Table 2.6: Matrix to determine effect significance.

Magnitude		Sensitivity: High	Sensitivity: Medium	Sensitivity: Low	Sensitivity: Negligible
Negative	High	Major	Major	Moderate	Minor
Negative	Medium	Major	Moderate	Minor	Negligible
Negative	Low	Moderate	Minor	Minor	Negligible
Neutral	Negligible	Minor	Minor	Negligible	Negligible
Beneficial	Low	Moderate	Minor	Minor	Negligible
Beneficial	Medium	Major	Moderate	Minor	Negligible
Beneficial	High	Major	Major	Moderate	Minor

Note: shaded cells are defined as significant with regards to the EIA Regulations 2017[1].

2.5.9 It is noted here that a distinction is made throughout the assessment between the magnitude, extent and duration of 'impacts' and the resulting significance of the 'effects' upon physical processes receptors. Various actions may result in impacts: for instance, the installation of the export cable at the landfall, causing a localised and short-term change to intertidal morphology (which is defined as a physical process receptor). The significance of effect associated with the impact will be dependent upon the sensitivity/ importance of the receptor, with particular consideration given to the receptor's ability to tolerate and recover from the impact, as well as status.

2.6 UNCERTAINTY AND TECHNICAL DIFFICULTIES ENCOUNTERED

2.6.1 Uncertainty exists with regard to characterisation of the future baseline with respect to global climate change. Key areas of uncertainty include actual future rates of sea level rise and the extent to which future changes in the wave regime may occur. There is also related uncertainty with regard to how the coastline may respond to a future wave climate acting in combination with higher than present sea levels. More detail on the future baseline is provided in Volume 4, Annex 2.1: Physical Processes Baseline Technical Report.

[1] The Infrastructure Planning (Environmental Impact Assessment) Regulations 2017

2.6.2 It is recognised that all data (including survey data) is subject to varying levels of uncertainty. The datasets have been reviewed and levels of accuracy considered in the assessment process along with the application of appropriate assessment methods and the use of multiple datasets where available. More detail on the assessment methodologies is provided in Volume 4, Annex 2.3: Physical Processes Technical Assessment:

2.6.3 There is uncertainty associated with the specific construction methodology and timing of construction works. Our methodology accounts for this by assessing a realistic worst case scenario.

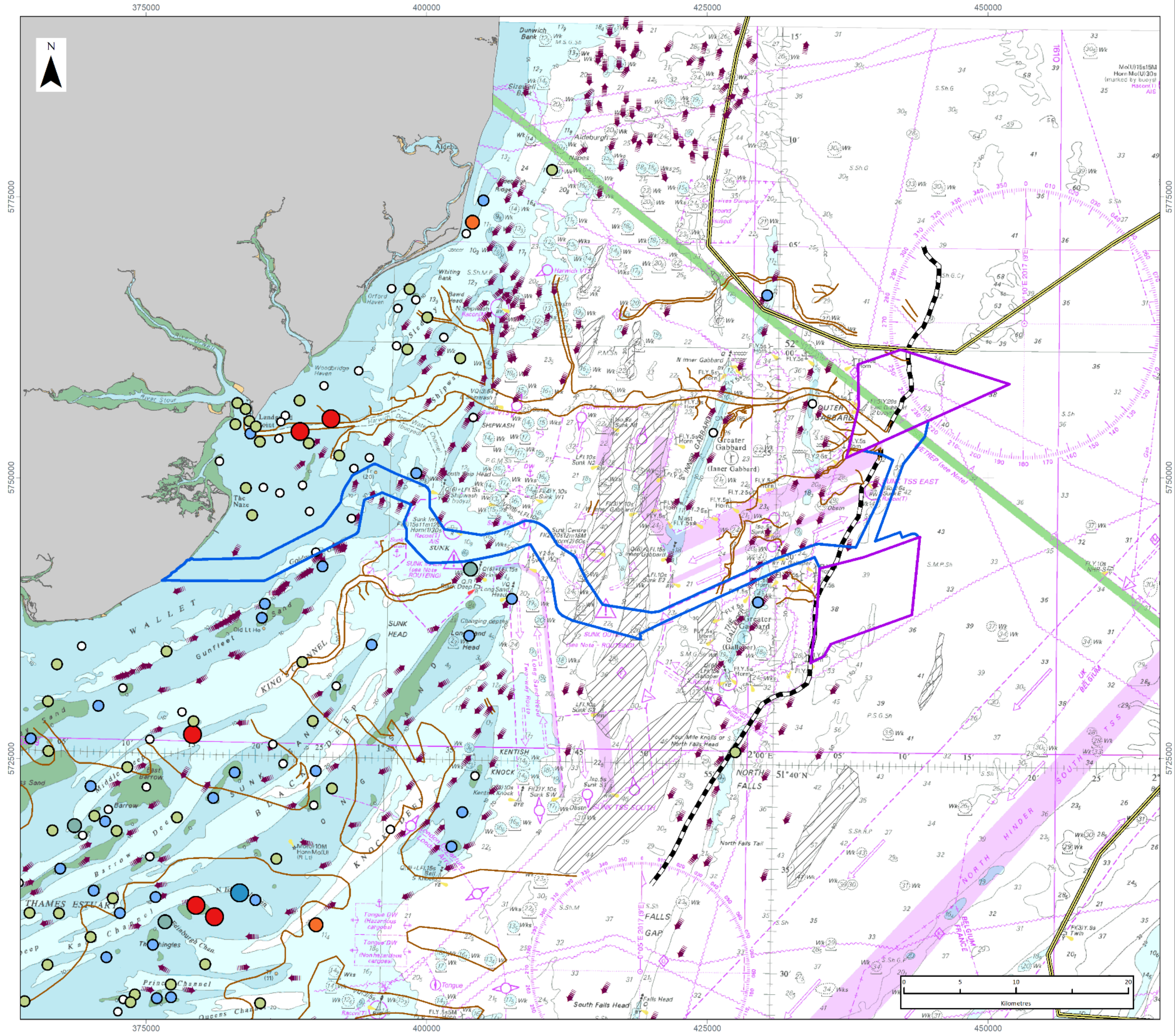
2.6.4 The assessments have included the development and use of numerical wave, hydrodynamic and sediment models. These models are robust tools but are subject to a number of assumptions. These include the input parameters (using a representative sediment grain size for sediment transport for example), scenario assumptions (for example, the volume and location of drilling spoil released under different release scenarios) as well as uncertainty in the underpinning datasets (e.g. wave data and bathymetry data). Such uncertainty is managed in the design of the modelling study and the interpretation of the model results in the context of the baseline and using expert judgement. Discussion relating to the performance of the models developed to support the assessment is also set out in Volume 4, Annex 2.2: Physical Process Model Design and Validation.

2.7 EXISTING ENVIRONMENT

2.7.1 The existing environment across the study area is described in detail within Volume 4, Annex 2.1: Physical Processes Baseline Technical Report. This has been achieved through the combined analysis of project specific survey data, information previously collected to inform the construction and operation of the adjacent GOWF and GGOWF, as well as data collected as part of regional coastal and seabed monitoring programmes.

2.7.2 The baseline includes GOWF and GGOWF and it is noted that many of the datasets used to inform the baseline post-date the construction of GOWF and GGOWF, any localised changes associated with these operational projects are, therefore, sufficiently captured within the baseline for VE.

2.7.3 A summary of key findings is set out below and an overarching conceptual understanding of marine physical processes within the study area is shown in Figure 2.2.



LEGEND

- Array Areas
- Offshore Export Cable Corridor
- Historic Trend in Seabed Elevation (m/yr) (Burningham & French, 2009)
  - -0.005 to 0.005
  - -0.05 to -0.005
  - -0.1 to -0.05
  - -0.3 to -0.1
  - 0.005 to 0.05
  - 0.05 to 0.1
  - 0.1 to 0.3
- Net Bedload Transport (SNSSTS, 2002)
- Bedload Parting Zone
- Interpreted Channel Systems (MALSF, 2009)
- Plateau Margin (MALSF, 2009)
- Enclosed Deeps (MALSF, 2009)

Data Source:VE OWFL (2022); Fugro (2022).

PROJECT TITLE:

FIVE ESTUARIES OFFSHORE WINDFARM

DRAWING TITLE:

Concept Understanding

VER	DATE	REMARKS	Drawn	Checked
1	28/02/2023	For Issue	CRO	NKD

DRAWING NUMBER:

2.2

SCALE:	PLOT SIZE:	DATUM:	PROJECTION:
1:350,000	A3	WGS84	UTM31N

FIVE ESTUARIES OFFSHORE WIND FARM

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THE ARRAY AREAS

HYDRODYNAMICS AND WAVES

2.7.4 The array areas are located in a meso-tidal setting, with the mean spring tidal range increasing from circa 2.0 m in the north to 3.0 m in the south. Peak current speeds are approximately 1.2 to 1.3 m/s across the array areas with little difference between the northern array area and southern array area.

2.7.5 The array areas are exposed to longer wave fetches (distances of open water over which waves can develop) from the north to northeast. Smaller but more frequently occurring wave conditions generated by local winds predominantly come from southerly and southwesterly directions.

SEDIMENTS AND GEOLOGY

2.7.6 Seafloor sediments in the array areas have been determined on the basis of the project specific geophysical survey, from acoustic variations in the low frequency side scan sonar acoustic reflectivity, local sediment grab samples, and changes in morphology derived from the bathymetry by Fugro (2022a). The seabed is found to be dominated by coarse grained sediments, with sands and gravelly sands accounting for circa 75% of the footprint of the array areas. The remaining areas are characterised by the presence of muddy sand, which is found in the west of the northern array area and in localised northeast- to southwest-trending bands in the southern array area.

2.7.7 Where present, sand is expected to be highly mobile. Rates of sediment transport are expected to generally be higher in the southern array area in comparison to the northern array area, consistent with increased distance from the bedload parting zone to the north of the array areas.

2.7.8 On the basis of the sub-bottom profile data collected during the VE geophysical survey, three main units have been interpreted in the array areas, all deposited within the past 56 Ma:

- Holocene: present day surficial sediments (largely sands and gravels) which reach a maximum thickness of 19 m below the seafloor in the northern array area;
- Pleistocene: variety of channel complexes of varying sizes, incising through London Clay Formation and Harwich Formation. They reach a maximum thickness of 7 m below the seafloor in the array areas;
- London Clay Formation: dominated by fine-grained deep-water marine clayey silts, silty clays and clays, found at or close to the surface in much of the array areas.

SEABED GEOMORPHOLOGY

2.7.9 Consideration of the project specific geophysical survey data shows that water depths within the northern array area range between 25 m and 55 m below LAT (Fugro 2022a). Depths shallow abruptly in the west, in relation to the presence of a notable plateau feature, with the seafloor being relatively flat and featureless on this plateau, with limited sediment cover. Sandwaves with superimposed megaripples are visible in the centre of the northern array area. The largest sandwaves measured approximately 12 m in height with wavelengths of approximately 300 m (Fugro, 2022a).

2.7.10 Water depths within the southern array area range between 22 m and 60 m below LAT (Fugro 2022a). As in the northern array area, depths shallow abruptly in the west. Sandwaves with superimposed megaripples, are visible in the east and centre of the southern array area. The largest sandwaves measured approximately 12 m in height and exhibited wavelengths of approximately 250 m (Fugro, 2022a).

2.7.11 During VE survey operations it was observed that some of the megaripples and sandwaves mapped within the array areas were actively mobile and were migrating in the time between adjacent survey lines (Fugro, 2022a). This assertion is supported by a comparison between the 2021 project specific bathymetric data and the earlier (2009) multibeam bathymetric survey data collected for Galloper OWF (Volume 4, Annex 2.1: Physical Processes Baseline Technical Report). This analysis suggests that these sandwaves are migrating in a southerly direction but at a relatively slow rate of around 1 m/yr on average. This observation is consistent with the findings of regional scale sediment transport studies in this region (e.g. SNSSTS, 2002; Kenyon & Cooper, 2005).

THE OFFSHORE EXPORT CABLE CORRIDOR

HYDRODYNAMICS AND WAVES

2.7.12 The mean spring tidal range increases from circa 2.6 m offshore to 3.6 m at the landfall. Tidal currents generally reduce with proximity to the coast, from around 1.3 m/s offshore, to less than 1 m/s at the landfall. However, currents can become considerably faster and more complex locally around the major offshore sandbank features.

2.7.13 Wave heights will tend to reduce with distance into the Outer Thames Estuary and with increased proximity to the coast. This is due to decreasing water depth, decreasing fetch length in the predominant wind direction, and generally greater protection from waves generated elsewhere in the North Sea. The associated local predominant wave direction will also vary accordingly. Just offshore from the landfall, waves predominantly approach from the northeast and southwest although these waves will be refracted as they approach the coast.

SEDIMENTS AND GEOLOGY

2.7.14 The distribution of seabed sediments along the offshore ECC is highly complex, with coarse grained (sands and gravels) and fine grained (muddy) sediments widespread (Fugro, 2022b). In many nearshore areas (<20 km from the coast), rock is found at or very near to the surface, alongside extensive areas of gravelly mud. This unit likely reflects winnowing of the underlying London Clay formation.

2.7.15 Where present, sand is expected to be highly mobile along the offshore ECC. This is particularly the case on and around the active bank systems and throughout much of the nearshore area. At the regional scale, sediment transport is broadly in a southerly direction along the offshore ECC although superimposed on this are highly complex localised patterns of sediment circulation around banks and other topographic features.

2.7.16 On the basis of the sub-bottom profile data collected during the VE geophysical survey, four main units have been interpreted in the offshore ECC:

- Holocene: present day surficial sediments which reach a maximum thickness of 16 m below the seafloor in the offshore ECC;
- Pleistocene: variety of channel complexes of varying sizes, reaching a maximum thickness of >12 m below the seafloor in the offshore ECC;
- London Clay Formation: dominated by fine-grained deep-water marine clayey silts, silty clays and clays, found within 2 m of the seafloor along most of the offshore ECC; and
- Harwich Formation: consists of sands and silts. Only observed within nearshore areas (<20 km from the coast) of the offshore ECC. The top of the unit was identified between 0 and 19.8 m below the sea floor, with sub-crop or outcrop also interpreted (Fugro, 2022b).

SEABED GEOMORPHOLOGY

2.7.17 Along the offshore ECC, water depths ranged from 0.3 m below LAT to circa 57 m below LAT. Towards the west, the seafloor is relatively flat with some rocky outcrop and sections of flat, featureless seafloor between these. Progressing further east, toward the middle and eastern part of the offshore ECC, there are large sandwaves and megaripples visible. Bedforms are predominantly located in areas where sand was interpreted as the primary sediment type (Fugro, 2022b).

2.7.18 Within the offshore ECC, megaripples are typically found to be between 0.1 and 0.8 m in height, with average wavelengths between 2 and 20 m. Most of the megaripples are present within the areas of interpreted sand, although some isolated patches were present in areas of interpreted gravelly mud, gravelly sand, and even as thin veneers within the outcrop/subcrop areas. Sandwaves are typically found to be between 0.7 and 7.5 m in height along the offshore ECC, with average wavelengths between 25 and 50 m, up to a maximum of approximately 260 m for the largest sandwaves (Fugro, 2022b).

2.7.19 During survey operations it was observed that the megaripples and sandwaves were actively mobile and were migrating in the time between adjacent survey lines. This was investigated further through consideration of the differences in seabed elevation observed between the project specific (2021) bathymetric survey and earlier seabed surveys by the UKHO (since 2012) (Volume 4, Annex 2.1: Physical Processes Baseline Technical Report). It was found that:

- The northern tip of the Galloper bank shows evidence of a number of associated sandwave features migrating over (and possible around) the underlying bank. The orientation of the associated bedforms and the asymmetry of the crests indicates migration of features from south to north along the western edge of the Galloper Bank, consistent with the regional conceptual understanding.

- Further inshore at Sunk Sand, there is clear evidence of sandwave migration to the north. Rates vary both spatially and temporally but appear to reach ~7 m/yr.
- UKHO regularly survey the waters approaching Harwich Deep Water Channel, likely in response to the potential navigational hazards posed by migrating sandwaves. Bathymetric comparison clearly shows that the bed is mobile in this region although it is difficult to discern the rate and/or direction of bedform displacement.

2.7.20 Long-term morphological evolution of the seabed and larger sandbank features has been assessed in a number of previous studies, over varying temporal and spatial scales. Relevant to nearshore areas of the offshore ECC, Burningham & French (2009) analysed the variation of sandbanks in the Outer Thames between 1824 and 2003. Over the approximately 180-year span of the study data, the assessment identified broad-scale changes to bed elevation as the major bank features migrated laterally, mostly in a general west to east direction.

THE LANDFALL

2.7.21 The proposed Landfall (Essex coastline at Holland Haven, between Frinton-on-Sea and Holland-on-Sea) is located within the SMP2 Management Unit C (Tendring Peninsula), in SMP2 Policy Development Zone C2 (Holland Haven) (Figure 2.1). The future management policy is listed as 'Hold the Line' for the next 50-years (Environment Agency, 2010). For epoch 3 (out to 2105) there is a dual policy of either Managed Realignment or Hold the Line. In either case, flood defence to the dwellings, roads and sewerage treatment works will be continued. The standard of protection will be maintained or upgraded.

2.7.22 The coastline within the landfall area is heavily managed with an almost continuous concrete sea wall at the back of the beach, fronted by a mixture of sloped smooth and/or rock revetment. Wooden groynes between Clacton and Holland-on-Sea to the southwest (downdrift) of the landfall area were replaced with numerous fishtail rock breakwaters in approximately 2014 to 2015, which has increased the volume of sediment on the beach foreshore, and so the foreshore width. The new groynes extend both physically and in terms of influence into the western edge of the landfall area. Wooden groynes have been historically present on the coastline to the northeast (updrift) of the landfall area, as far as The Naze headland. The character of the beach and coastline in the landfall area is therefore presently stable due to the coastal defences present; however, the future stability of the coastline will remain dependent on the future management policies and activities for both the local area and for coastal regions up drift (to the northeast).

2.7.23 The SMP2 (Environment Agency, 2010) describes the alongshore transport between Jaywick (southwest of the landfall) and Walton (northeast of the landfall) as 'variable, but generally towards the south-southwest'. The supply of material from the north is limited by the presence of erosion protection coastal defences described above.

DESIGNATED SITES

2.7.24 The study area overlaps with several nationally and internationally designated nature conservation sites, which contain qualifying geological and geomorphological features. The locations of these sites are also included in Figure 2.1. The study area has been informed by expert judgement, based on (amongst other things) physical process understanding developed from work undertaken for the nearby (operational) Galloper and Greater Gabbard OWFs and analysis of prevailing wave direction and tidal excursion distance. The sites are primarily designated for the habitats they contain rather than for the presence of geological and geomorphological features. However, changes to the physical characteristics of these sites have the potential to impact the habitats they support and, therefore, consideration will be given in the physical processes assessment. The designated sites that are coincident with (or very close to) the array areas and offshore ECC are listed in Table 2.7.

Table 2.7: Marine nature conservation designations with relevance to physical processes.

Site	Closest distance to VE	Feature or description
UK'S NATIONAL SITE NETWORK		
Alde, Ore and Butley Estuaries SAC	15.2 km	Network of three estuaries flanked by salt marsh and mudflats, with shingle bar at the mouth.
Essex Estuaries SAC	7.5 km	Large estuarine site typical of an undeveloped, coastal plain estuarine system with associated open coast mudflats and sandbanks
Hamford Water SAC/ SPA	3.2 km	Large, shallow estuarine basin comprising tidal creeks, islands, intertidal mud, sand flats and saltmarshes
Margate and Long Sands SAC	[Coincident with ECC]	Contains a number of Annex I Sandbanks composed of well-sorted sandy sediments, with muddier and more gravelly sediments in the troughs between banks
Orfordness - Shingle Street SAC	12.3 km	Extensive shingle spit containing series of undisturbed ridges with vegetated shingle, accompanied by coastal lagoons
Southern North SAC	[Coincident with Array Areas and ECC]	Site covers a very large area (36,951 km^2) and includes a mix of habitats, such as sandbanks and gravel beds
Alde-Ore Estuary SPA	12.3 km	Wide variety of habitats including intertidal mud-flats, saltmarsh, vegetated shingle and saline lagoons

Site	Closest distance to VE	Feature or description
Deben Estuary SPA	11.4 km	Estuarine setting characterised by saltmarsh and intertidal mud flats in most areas, along with reedswamp, unimproved neutral grassland and scrub
Foulness (Mid-Essex Coast Phase 5) SPA	18.8 km	Site characterised by the presence of extensive saltmarsh habitats
Outer Thames Estuary SPA	[Coincident with ECC]	Comprises areas of sand banks and inter-tidal sand/ mud flats. It also includes shallow and deeper water, high tidal current streams and a range of mobile mud, sand, silt and gravely sediments
Stour and Orwell Estuaries SPA	12.8 km	The estuaries include extensive mud-flats, low cliffs, saltmarsh and small areas of vegetated shingle on the lower reaches.
Blackwater, Crouch, Roach and Colne Estuaries MCZ	4.2 km	Extensive areas of mudflats and saltmarsh, which support a wide range of species including internationally and nationally important numbers of waterfowl
Kentish Knock East MCZ	6.2 km	Sandbank setting, with the site characterized by predominantly mixed sediments with areas of sandy sediment and coarse gravel and pebbles
Orford Inshore MCZ	14.4 km	Habitats composed of subtidal mixed sediments which are important nursery and spawning grounds.
SITES OF SPECIAL SCIENTIFIC INTEREST		
Alde-Ore Estuary SSSI	12.3 km	Major shingle landforms with accompanying cliffs which are of scientific importance
Bawdsey Cliffs SSSI	11.1 km	The cliffs provide over 2km of section in the Butleyan division of the Early Pleistocene Red Crag
Clacton Cliffs & Foreshore SSSI	4.2 km	Site designated for its geological importance, with sediment filled channels containing rare fossils
Colne Estuary SSSI	9.4 km	A short branching estuary whose shingle spit is of geomorphological importance
Deben Estuary SSSI	11.4 km	Estuarine setting characterised by saltmarsh and intertidal mud flats in most areas, along with reedswamp, unimproved neutral grassland and scrub

Site	Closest distance to VE	Feature or description
Foulness SSSI	18.8 km	Site characterised by the presence of extensive saltmarsh and mudflat habitats
Hamford Water SSSI	3.7 km	Large, shallow estuarine basin comprising tidal creeks, islands, intertidal mud, sand flats and saltmarshes
Harwich Foreshore SSSI	11.9 km	Site contains designated exposures of Harwich Stone Bands
Holland on Sea Cliff SSSI	0.1 km	Site contains designated cliffs containing geologically important gravel sequences
Landguard Common SSSI	10.0 km	Sand and shingle spit consisting of a loose shingle foreshore backed by vegetated beach
Leiston-Aldeburgh SSSI	29.6 km	Contains a range of habitats including vegetated shingle
The Naze SSSI	4.0 km	Geologically important site containing designated Pleistocene cliff exposures
Orwell Estuary SSSI	13.7 km	Long and relatively narrow estuary with extensive mudflats and some saltmarsh.
Stour Estuary SSSI	12.8 km	Estuarine site containing mud and saltmarsh habitats, along with geologically important exposures of early Eocene sediments

EVOLUTION OF THE BASELINE

2.7.25 The Infrastructure Planning (Environmental Impact Assessment) Regulations 2017 require that "*A description of the relevant aspects of the current state of the environment (baseline scenario) and an outline of the likely evolution thereof without implementation of the development as far as natural changes from the baseline scenario can be assessed with reasonable effort on the basis of the availability of environmental information and scientific knowledge*." is included within the ES (EIA Regulations, Schedule 4, Paragraph 3).

2.7.26 The baseline is expected to evolve in response to natural variation (e.g. lunar nodal cycle, North Atlantic Oscillation etc), wider changes in climate expected over the lifetime of the project, and anthropogenic management of the coast. These are discussed below.

2.7.27 By 2060, relative sea level may have risen by approximately 0.4 m above present day (2021) levels (Representative Concentration Pathway 8.5, 95%ile)) (Palmer et al., 2018). A rise in sea level may allow larger waves, and therefore more wave energy, to reach the coast in certain conditions and consequently result in an increase in local rates or patterns of erosion and the equilibrium position of coastal features.

2.7.28 The UK Climate Impacts Programme dataset 'UKCP18' also provides projections of changes in wave climate over the 21st Century. The findings indicate that within the study area, mean annual maxima significant wave heights may decrease but by less than 0.2 m by 2100 (Palmer et al., 2018). However, natural variability is noted to be high in this area, and there is substantial uncertainty in projecting future change (e.g. Palmer et al. 2018; Bonaduce et al. 2019; Wolf et al. 2020).

2.7.29 Much of the shoreline adjacent to the project is defended. This includes the coastline within the landfall area which is heavily managed with an almost continuous concrete sea wall at the back of the beach, fronted by a mixture of sloped smooth and/or rock revetment. The future evolution of the coastline in these areas will depend to some extent on any changes to the existing management strategies.

2.8 KEY PARAMETERS FOR ASSESSMENT

2.8.1 This section identifies the Maximum Design Scenario (MDS) for physical processes. This is provided in Table 2.8 for each of the potential effects identified during Scoping and from subsequent discussions with stakeholders as part of the Evidence Plan process.

2.8.2 The MDS is defined by the project design envelope (Volume 2, Chapter 1: Offshore Project Description) and includes embedded mitigation. The method adopted is in accordance with the requirements of the Rochdale Envelope approach to environmental assessment as set out in the PINS Advice note nine: 'Using the Rochdale Envelope' (The Planning Inspectorate, 2018).

2.8.3 Defining the MDS for sediment disturbance activities is highly complex as the actual disturbance will be temporally and spatially variable (depending upon the metocean conditions at the time). For sediment plumes, the MDS is intended to be representative in terms of peak concentration, plume extent and plume duration but will not correspond to a single sediment disturbance activity.

2.8.4 The same holds true for sediment deposition at the bed, where the MDS is a representation of maximum deposit thickness, maximum footprint extent or likely duration.

2.8.5 The justification for the MDS is set out in Volume 4, Annex 2.3: Physical Processes Technical Assessment.

Table 2.8: Maximum design scenario for the project alone.

Potential effect	Maximum adverse scenario assessed	Justification
Construction		
Impact 1: Potential changes to suspended sediment concentrations (SSC), bed levels and sediment type arising from construction related activities including dredging, drilling and cable installation	**Greatest volume of sediment disturbed and released by dredging for seabed preparation prior to foundation installation at a single foundation location** OSP gravity base foundation, associated bed preparation > length/width 70 x 100 m > associated bed preparation area 7,000 m^2 per foundation > average dredge depth 4 m > OSP spoil volume per foundation 28,000 m^3 Dredging carried out using a representative trailer suction hopper dredger > Indicative 11,000 m^3 hopper capacity > Split bottom for spoil disposal > Disposal locations within the array area **Greatest volume of sediment disturbed and released by dredging for seabed preparation prior to foundation installation over the entire array area** 79 WTG gravity base jacket foundations, associated bed preparation > Length/width 60 x 60 m, area 3,600 m^2 per foundation, average dredge depth 4 m, WTG spoil volume for entire array area 1,137,600 m^3; 2 OSP gravity base foundations, associated bed preparation > Length/width 70 x 100 m, associated bed preparation area 7,000 m^2 per foundation, average dredge depth 4 m,	Dredging for seabed preparation prior to foundation installation Seabed preparation works would only be required prior to installation of suction caisson or gravity base foundations (if at all). Two maximum adverse scenarios are identified, corresponding to the greatest volume of sediment disturbance locally (from a single foundation) and across the entire array (from all foundations).

Potential effect	Maximum adverse scenario assessed	Justification
	> OSP spoil volume for entire array area 56,000 m^3; Total spoil volume for entire array area 1,193,600 m^3; Dredging carried out using a representative trailer suction hopper dredger > Disposal locations within the array area	
	Greatest volume of sediment disturbed and released by drilling as part of foundation installation at a single foundation location WTG monopile foundation > Associated drill diameter 16 m, drilling to an average of 68 m penetration depth, spoil volume per foundation 13,672 m^3; > Drilling rate of up to 2 m/hour (34 hours per foundation); and > Release of drill arisings at or above water surface within the array.	Although the volumes of material released via drilling are less than for seabed preparation via dredging, drilling has the potential to release larger volumes of relatively finer sediment. Two maximum adverse scenarios are identified, corresponding to the greatest volume of sediment disturbance locally (from a single foundation) and across the entire array (from all foundations). The greatest volume of drill arisings from a single foundation location is associated with the monopile foundation and the greatest volume of drill arisings for the entire array area is associated with a layout comprising the larger number of WTG foundations.
	Greatest volume of sediment disturbed and released by drilling as part of foundation installation over the entire array area 79 WTG + 2 OSP monopile foundations > Associated drill diameter 16 m, drilling to an average of 68 m penetration depth, 50 % of WTG foundations require drilling, spoil volume for entire array area 567,430 m^3; > Drilling rate of up to 2 m/hour (38 hours per foundation); and > Disposal of drill arisings at or above water surface.	
	Installation of inter-array cables > Total length 200 km;	Cable installation may require some

Potential effect	Maximum adverse scenario assessed	Justification
	> V-shape trench; width = 18 m; depth = 3.5 m; > Assume up to 50% of material is actually ejected from the trench. The rest is fluidised, but retained as sediment cover within the trench; > Total volume of disturbance= (200 km x 18 m x 3.5 m x 0.5 x 50% = 3,150,000 m^3); > Installation method: mass flow excavator (MFE); > Assumed installation rate of up to approximately 400 m/hr.	combination of (e.g.) jetting, ploughing, trenching and/or cutting type installation techniques. Of these, jetting type tools will most energetically disturb the greatest volume of sediment in the trench profile and as such is considered to be the maximum adverse scenario for sediment dispersion. Where required, sandwave clearance or levelling would be undertaken via dredging (separately described below)
	Installation of export cables > Total length 370 km: including four export cable trenches; each up to 80.4 km in length from array area boundary to landfall, plus 15% contingency; > V-shape trench; width = 18 m; depth = 3.5 m; > Assume up to 50% of material is actually ejected from the trench. The rest is fluidised, but retained as sediment cover within the trench; > Total volume of disturbance= 2,156,175 m^3; > Minimum spacing between cables 50 m; > Installation method: MFE; > Assumed installation rate of up to approximately 400 m/hr.	Cable installation may require some combination of (e.g.) jetting, ploughing, trenching and/or cutting type installation techniques. Of these, jetting type tools will most energetically disturb the greatest volume of sediment in the trench profile and as such is considered to be the maximum adverse scenario for sediment dispersion. Where required, sandwave clearance or levelling would be undertaken via dredging (separately described below)
Impact 2: Potential	**Sandwave clearance via dredging (array cables)**	During the construction phase the primary

Potential effect	Maximum adverse scenario assessed	Justification
morphological impacts to sandbanks and designated areas of seabed	> Total length inter-array cables 200 km; up to 50% (100 km) requiring sandwave clearance; > Dredged corridor up to 5 m deep 20 m wide in centre, sloped sides 1:5 gradient, total width 70 m; > Sandwave clearance area (to be confirmed) up to 7.0 km^2; > Sandwave clearance volume (to be confirmed) up to 35,000,000 m^3; > Sandwave clearance via dredging, potentially including TSHD, backhoe or hydraulic (MFE) techniques; and > Material disposed of within the VE array area and ECC. **Sandwave clearance via dredging (export cables)** > Total length of export cables 370 km; up to 50% (185 km) requiring sandwave clearance; > Dredged corridor up to 5 m deep 20 m wide in centre, sloped sides 1:5 gradient, total width 70 m; > Sandwave clearance area (to be confirmed) up to 13.0 km^2; > Sandwave clearance volume up to 64,750,000 m^3; > Sandwave clearance via dredging, potentially including TSHD, backhoe or hydraulic (MFE) techniques; and > Material disposed of within the VE array area and ECC.	means by which sand banks could be impacted is through interruption of sediment transport patterns via sandwave clearance activities.
Impact 3: Potential impacts to landfall morphology	**Trenching at landfall** > Burial technique: plough > Maximum burial depth: 3.5 m > Indicative width of (post-lay) ploughing: 6 m	Sets out construction activities that give rise to the greatest (direct) disturbance to the beach and provide the greatest potential to interact with coastal processes

Potential effect	Maximum adverse scenario assessed	Justification
	> Minimum trench separation distance: 50 m **HDD (or alternative trenching techniques)** > Punch-out location for HDD: intertidal or below LAT. > Up to five HDD exit pits > Size of HDD exit pits: 75 m long x 10 m wide x (up to) 2.5 m deep > Total volume of HDD exit pits: 1,875 m^3 (each) 9,375 m^3 (total) > Exit pits may remain open for several months **Cable protection** > Cable protection will be buried in the intertidal section and out to 1,600 m seaward of MHWS and will consist of erosion resistant units. > Cable protection seaward of 1,600 m from MHWS: rock berm protection with crest height 1.4 m, crest width 4.5 m, side slopes 1:3.9 gradient (each 5.36 m) and total width: up to 16 m	responsible for maintaining the baseline form and function of the beach. The seabed may require preparation in the areas where the export cable installation vessel is likely to rest on the seabed. This would include flattening of any seafloor features (i.e. bedforms), removal of boulders and potential UXOs.
Operation		
Impact 4: Potential changes to the tidal regime Impact 5: Potential changes to the wave regime Impact 6: Potential changes to the sediment	**Foundations** 79 WTG gravity base foundations > Base diameter 55 m, base height up to 8 m, tapering to 15 m diameter monopile around MSL > Minimum WTG foundation spacing of 830 m OSP jacket suction bucket foundations > 6 legs, primary member diameter 3.5 m, suction bucket	The greatest total in-water column blockage to currents, waves and sediment transport processes is presented by an array comprising gravity base foundations. This combination was determined via calculations that quantitatively compare

Potential effect	Maximum adverse scenario assessed	Justification
transport regime	diameter 20 m, height of suction bucket 5 m; > Minimum OSP foundation spacing of 450 m; and > O&M phase lasting approximately 40 years (may increase by the time the project nears decommissioning as technology/maintenance improves). **Cable protection measures (all)** > Standard options include rock placement, concrete mattresses, flow dissipation devices, protective aprons, bagged protection, etc; > Rock berm protection with crest height 1.4 m, crest width 4.5 m, side slopes 1:3.9 gradient (each 5.36 m) and total width: up to 16 m > Total length of cables which may potentially require seabed protection anticipated to be up to approximately 20% of array cable length and 20% of export cable length. **Cable crossings** > Number of export cable crossings: 21 per cable (84 total for all cables); > Number of inter-array cable crossings: 26; > Rock berm protection with crest height 1.4 m, crest width 4.5 m, side slopes 1:3.9 gradient (each 5.36 m) and total width: 15.22 m, 300m length per crossing.	the blockage presented by a range of minimum and maximum sizes of varying foundation types and numbers (see Volume 4, Annex 2.1: Physical Processes Baseline Technical Report).
Impact 7: Potential for scour of seabed sediments,	(Maximum adverse scenario is defined on the basis of the outputs of the scour assessment (see Volume 4, Annex 2.3: Physical Processes Technical Assessment) for results)	Each foundation type may produce different scour patterns therefore monopiles, gravity base and jacket foundations

Potential effect	Maximum adverse scenario assessed	Justification
including that around scour protection structures		have been considered. The foundation type, size and number producing the greatest area and/ or volume of influence cannot be identified in advance of the assessment.
Impact 8: Potential morphological impacts to sandbanks and designated areas of seabed	**Foundations** 79 WTG gravity base foundations > base diameter 55 m, base height up to 8 m, tapering to 15 m diameter monopile around MSL > Minimum WTG foundation spacing of 830 m; OSP jacket suction bucket foundations > 6 legs, primary member diameter 3.5 m, suction bucket diameter 20 m, height of suction bucket 5 m; > Minimum OSP foundation spacing of 450 m; > O&M phase lasting approximately 40 years.	The greatest total in-water column blockage to currents, waves and sediment transport processes is presented by an array comprising the largest number (79 of gravity base Wind Turbine Generator (WTG) foundations. This combination was determined via calculations that quantitatively compare the blockage presented by a range of minimum and maximum sizes of varying foundation types and numbers.
Impact 9: Potential impacts to coastal morphology		
Decommissioning		
Impact 10: Potential changes to SSC, bed levels and sediment type	**Decommissioned Infrastructure** > Array comprising the largest number of foundations (79 WTG, 2 OSP); > Buried cables to be cut and left in situ (but to be determined in consultation with key stakeholders as part of the decommissioning plan and following best practice at the time); > Scour and cable protection left in situ; and	When removing foundations, the greatest disturbance will be associated with the layout containing the greatest number of structures.

Potential effect	Maximum adverse scenario assessed	Justification
	> Decommissioning activities lasting approximately three years.	
Impact 11: Potential morphological impacts to sandbanks and designated areas of seabed Impact 12: Potential impacts to landfall morphology	**Decommissioning Activities** > Removal of export cables from trenches within intertidal/ shallow subtidal; > Filling of HDD ducts; > Decommissioning activities lasting approximately three years.	Maximum disturbance of seabed/ inter-tidal and change in blockage resulting from removal of infrastructure.

2.9 EMBEDDED MITIGATION

2.9.1 Mitigation measures that were identified and adopted as part of the evolution of the project design (embedded into the project design) and that are relevant to physical processes are listed in Table 2.9. General mitigation measures, which would apply to all parts of the project, are set out first. Thereafter mitigation measures that would apply specifically to physical processes issues associated with the array, export cable corridor, landfall, onshore cable corridor and substation, are described separately.

2.9.2 The subsequent assessment stage of the EIA for physical processes (Section 2.10 onwards) is based on the 'mitigated' design.

2.9.3 The embedded mitigation contained in Table 2.9 are mitigation measures or commitments that have been identified and adopted as part of the evolution of the project design of relevance to the topic, these include project design measures, compliance with elements of good practice and use of standard protocols.

Table 2.9: Embedded mitigation relating to physical processes.

Project phase	Mitigation measures embedded into the project design
General	
Project design	The development boundary selection was made following a series of constraints analyses, with the array area and offshore ECC route selected to ensure the impacts on the environment and other marine users are minimised as far as reasonably practicable.
Construction	
Project design	Where practicable, cable burial will be the preferred means of cable protection. This will minimise the requirement for surface laid protection.
Cable Specification and Installation Plan (CSIP)	Development of, and adherence to, a Cable Specification and Installation Plan (CSIP) post consent. The CSIP will set out appropriate cable burial depth in accordance with industry good practice, minimising the risk of cable exposure. The CSIP will also ensure that cable crossings are appropriately designed to mitigate environmental effects, these crossings will be agreed with relevant parties in advance of CSIP submission. The CSIP will include a detailed Cable Burial Risk Assessment (CBRA) to enable informed judgements regarding burial depth to maximise the chance of cables remaining buried whilst limiting the amount of sediment disturbance to that which is necessary. The CSIP will be conditioned in the deemed Marine Licence.
Project design	In the nearshore (out to 1,600 m seaward of MHWS), cable remedial protection measures will not include loose rock or gravel. This will greatly limit the blockage of longshore sediment transport and minimise any modification to nearshore waves and tidal currents.
Project design	The project array areas and offshore ECC will be licensed as disposal sites for the deposition of dredgings and drill arisings. All material that is dredged from the seabed will be disposed of within these sites to ensure material is retained within the local sediment transport system.
Operation	
Project design	Scour protection will be used in areas where the seabed has a significant depth of erodible deposits. This will limit the volume of material that may be eroded and released into the water column.
Scour Protection Management Plan	Development of a Scour Protection Plan (SPP) which will consider the need for scour protection where there is the potential for scour to develop around wind farm infrastructure, including turbine and

Project phase	Mitigation measures embedded into the project design
	substation/ platform foundations and cables. The plan will be secured via a condition in the deemed Marine Licence.
Decommissioning	
Decommissioning Programme	A Decommissioning Programme will be developed to cover the decommissioning phase as required under Chapter 3 of the Energy Act 2004. As the decommissioning phase will be a similar process to the construction phase but in reverse (i.e., increased project vessels on-site, partially deconstructed structures) the embedded mitigation measure will be similar to those for the construction phase. The Decommissioning Plan will be secured as a condition in the dML.
Decommissioning	For the purposes of the MDS for EIA, at the end of the operational lifetime of VE, it is assumed that all infrastructure above the seabed will be completely removed Closer to the time of decommissioning, it may be decided that removal would lead to a greater environmental impact than leaving some components in situ, in which case certain components may be cut off at or below seabed level (e.g. in the case of piled foundations) or left in situ (e.g. in the case of subsea cables and rock protection). As part of the decommissioning works, cables will be removed and HDD ducts will be left in situ and capped appropriately.

2.10 ENVIRONMENTAL ASSESSMENT: CONSTRUCTION PHASE

2.10.1 The changes to physical processes in response to construction of VE have been described in this section. The MDS against which each construction phase change has been assessed is set out in Table 2.8.

2.10.2 Within this section, an assessment of change to pathways is presented first followed by the assessments of potential impacts to physical process receptors. The assessments of potential change to pathways are not at this stage accompanied by a conclusion regarding the significance of effect.

2.10.3 Where the potential for effects on physical process receptors are identified, the assessment of the magnitude of the impact on the receptor is presented along with a judgement on receptor sensitivity/ value. This is followed by a conclusion of significant effect.

IMPACT 1: POTENTIAL CHANGES TO SUSPENDED SEDIMENT CONCENTRATIONS (SSC), BED LEVELS AND SEDIMENT TYPE ARISING FROM CONSTRUCTION RELATED ACTIVITIES INCLUDING DREDGING, DRILLING AND CABLE INSTALLATION

OVERVIEW

2.10.4 This section provides a description of the realistically possible combinations of magnitude and extent of impact for local increases in suspended sediment concentration (SSC) and seabed deposition, due to sediment disturbance potentially caused by:

- Drilling of monopile foundations and pin piles for jacket foundations;
- Seabed preparation by dredging prior to jacket suction bucket foundation installation;
- Sandwave clearance (prior to cable burial);
- Cable burial; and
- Drilling fluid release during HDD at the landfall.

2.10.5 A full assessment of the above, including the methodological approach used to assess the characteristics of sediment plumes and associated changes in bed level arising from settling of material is set out in Volume 4, Annex 2.1: Physical Processes Baseline Technical Report. Summary findings are set out below.

CONCEPTUAL UNDERSTANDING OF CHANGE

2.10.6 The actual magnitude and extent of change in SSC and bed levels will depend in practice on a range of factors, such as the actual total volumes and rates of sediment disturbance, the local water depth and current speed at the time of the activity, the local sediment type and grain size distribution, the local seabed topography and slopes, etc. There will be a wide range of possible combinations of these factors and so it is not possible to predict specific dimensions with complete certainty. To provide a robust assessment, a range of realistic combinations have been considered, based on conservatively representative location (environmental) and project (MDS) specific information, including a range of water depths, heights of sediment ejection/initial resuspension, and sediment types.

2.10.7 This wider range of results can be summarised broadly in terms of four main zones of effect, based on the distance from the activity causing sediment disturbance. These zones are entirely consistent with the results of observational (monitoring) evidence and numerical modelling of analogous activities (e.g. BERR, 2008; TEDA, 2010; Navitus Bay Development Ltd, 2014; Awel y Môr Offshore Wind Farm Ltd, 2022):

- 0 to 50 m - zone of highest SSC increase and greatest likely thickness of deposition. All gravel sized sediment likely deposited in this zone, also a large proportion of sands that are not resuspended high into the water column, and also most or all dredge spoil in the active phase. Plume dimensions and SSC, and deposit extent and thickness, are primarily controlled by the volume of sediment released and the manner in which the deposit settles.
    - At the time of active disturbance - very high SSC increase (tens to hundreds of thousands of mg/l) lasting for the duration of active disturbance plus up to 30 minutes following end of disturbance; sands

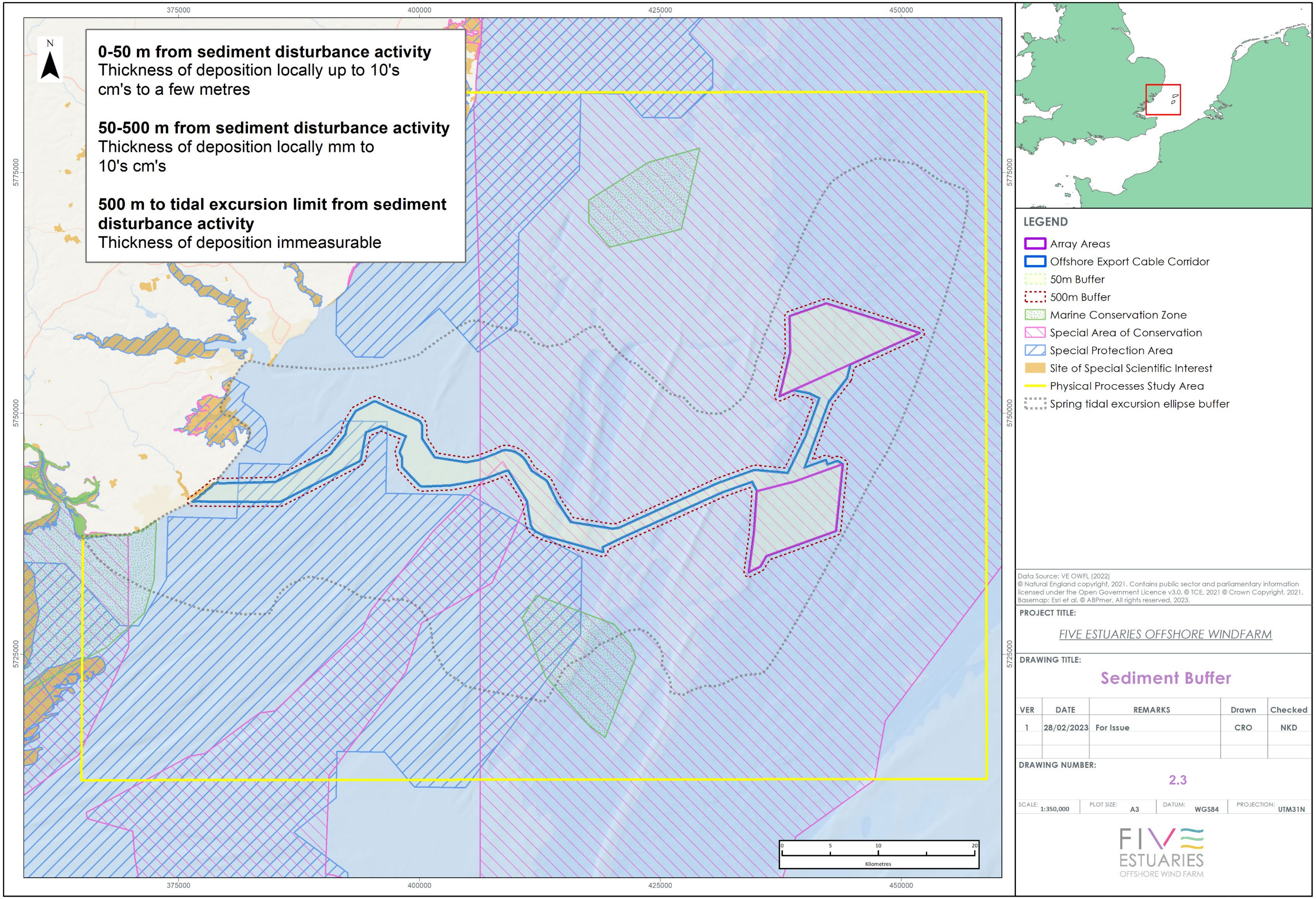
and gravels may deposit in local thicknesses of tens of centimetres to several metres; fine sediment is unlikely to deposit in measurable thickness.

  - More than one hour after the end of active disturbance - no change to SSC; no measurable ongoing deposition.

- 50 to 500 m - zone of measurable SSC increase and measurable but lesser thickness of deposition. Mainly sands that are released or resuspended higher in the water column and resettling to the seabed whilst being advected by ambient tidal currents. Plume dimensions and SSC, and deposit extent and thickness, are primarily controlled by the volume of sediment released, the height of resuspension or release above the seabed, and the ambient current speed and direction at the time.
  - at the time of active disturbance - high SSC increase (hundreds to low thousands of mg/l) lasting for the duration of active disturbance plus up to 30 minutes following end of disturbance; sands and gravels may deposit in local thicknesses of up to tens of centimetres; fine sediment is unlikely to deposit in measurable thickness.
  - more than one hour after end of active disturbance - no change to SSC; no measurable ongoing deposition.
- 500 m to the tidal excursion buffer distance - zone of lesser but measurable SSC increase and no measurable thickness of deposition. Mainly fines that are maintained in suspension for more than one tidal cycle and are advected by ambient tidal currents. Plume dimensions and SSC are primarily controlled by the volume of sediment released, the patterns of current speed and direction at the place and time of release and where the plume moves to over the following 24 hours.
  - at the time of active disturbance - low to intermediate SSC increase (tens to low hundreds of mg/l) as a result of any remaining fines in suspension, only within a narrow plume (tens to a few hundreds of metres wide, SSC decreasing rapidly by dispersion to ambient values within one day after the end of active disturbance; fine sediment is unlikely to deposit in measurable thickness.
  - one to six hours after end of active disturbance - decreasing to low SSC increase (tens of mg/l); fine sediment is unlikely to deposit in measurable thickness.
  - six to 24 hours after end of active disturbance - decreasing gradually through dispersion to background SSC (no measurable local increase); fine sediment is unlikely to deposit in measurable thickness. No measurable change from baseline SSC after 24 to 48 hours following cessation of activities.
- Beyond the tidal excursion buffer distance or anywhere not tidally aligned to the active sediment disturbance activity - there is no expected impact or change to SSC nor a measurable sediment deposition.

2.10.8 It is noted here that the study area is characterised by naturally high levels of suspended sediment concentration which result from ongoing coastal erosion and regular stirring of the bed by the action of tidal currents and wave driven orbital currents. In shallower waters (< circa 30 m) during storm events, these wave driven currents can result in very high SSC (thousands of mg/l or more) close to the bed in areas where mobile sediment is present. Accordingly, even when SSC increases occur in response to windfarm construction activities, they are expected to be comparable to (or less than) the increases which occur naturally under baseline conditions.

2.10.9 Figure 2.3 provides a summary of the spatial extent of these zones in relation to VE. Designated nature conservation sites within the study area are also shown. Figure 2.4 illustrates sediment deposition footprints associated with installation of a single foundation at an indicative location in the northern array area.



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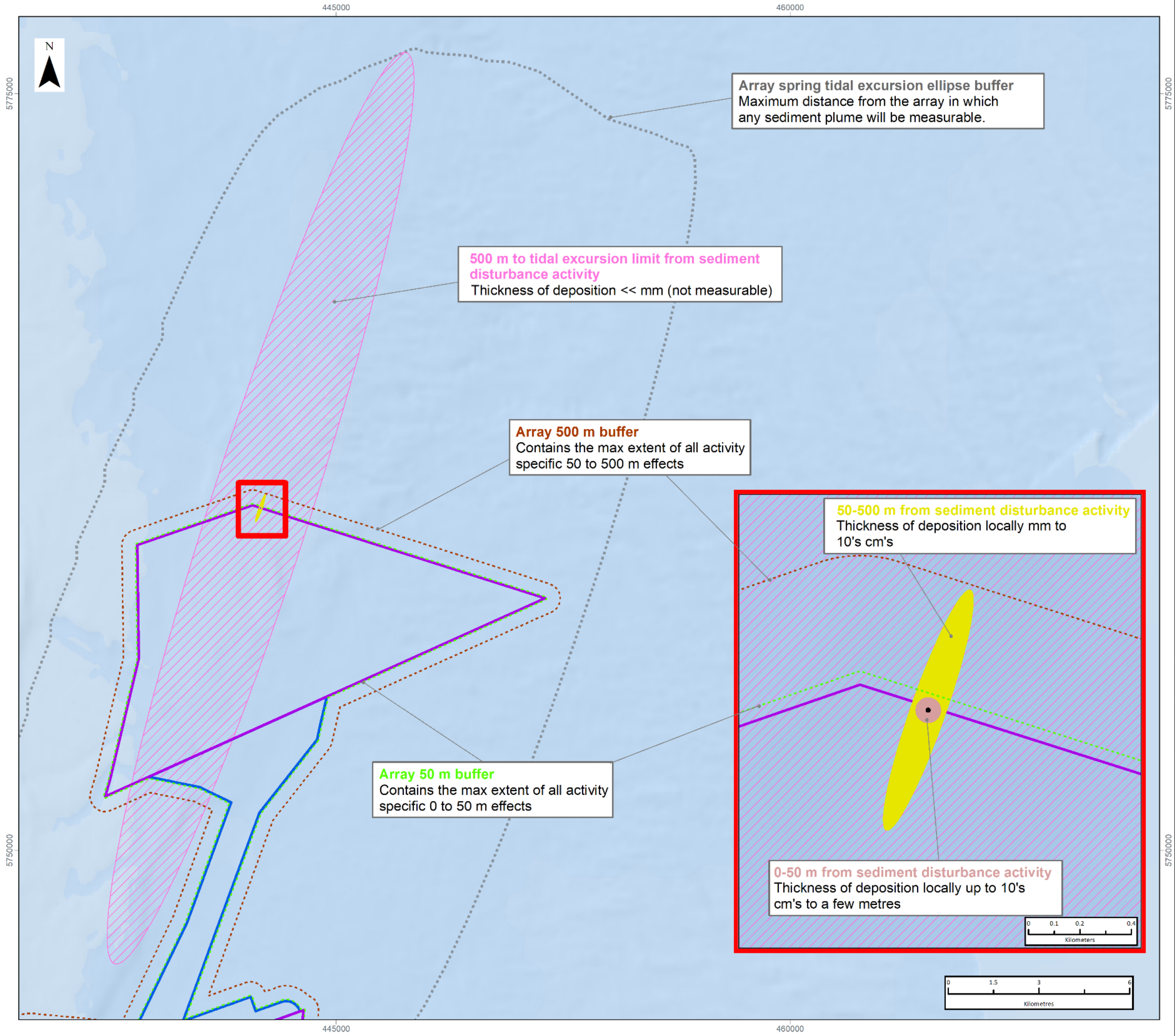

LEGEND

- Array Areas
- Offshore Export Cable Corridor
- Array 50 m Buffer
- Array 500 m Buffer
- Array spring tidal excursion ellipse buffer
- Activity sediment release location
- Activity 50 m buffer
- Activity 500 m buffer
- Activity tidal excursion ellipse maximum zone of influence

Data Source: VE OWFL (2022)

PROJECT TITLE:

FIVE ESTUARIES OFFSHORE WINDFARM

DRAWING TITLE:

Sediment Deposition

VER	DATE	REMARKS	Drawn	Checked
1	28/02/2023	For Issue	AJB	CRO

DRAWING NUMBER:

2.4

SCALE: 1:130,000 | PLOT SIZE: A3 | DATUM: WGS84 | PROJECTION: UTM31N

FIVE ESTUARIES OFFSHORE WIND FARM

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2.10.10 If multiple activities causing sediment disturbance (such as dredging, drilling or cable installation) are undertaken simultaneously at two or more locations that are aligned in relation to the ambient tidal streams, then there is potential for overlap between the areas of change in SSC and sediment deposition. The change in SSC in areas of overlap will be additive if the downstream activity occurs within the area of effect from upstream (i.e. sediment is disturbed within the sediment plume from the upstream location). The change in SSC will not be additive (i.e. the effects will be as described for single occurrences only) if the areas of effect only meet or overlap downstream following advection or dispersion of the effects. Effects on sediment deposition will be additive if and where the footprints of the deposits overlap.

ASSESSMENT OF SIGNIFICANCE

2.10.11 The assessment set out in this section has considered potential changes to pathways, rather than impacts on receptors. Accordingly no assessment of significance is provided. However, the potential for these changes to impact other EIA receptor groups are considered elsewhere within the ES, in particular:

- Volume 2, Chapter 3: Marine Water and Sediment Quality;
- Volume 2, Chapter 4: Offshore Ornithology;
- Volume 2, Chapter 5: Benthic and Intertidal Ecology;
- Volume 2, Chapter 6: Fish and Shellfish Ecology; and
- Volume 2, Chapter 7: Marine Mammal Ecology.

IMPACT 2: POTENTIAL MORPHOLOGICAL IMPACTS TO SANDBANKS AND DESIGNATED AREAS OF SEABED

OVERVIEW

2.10.12 Whilst much of the array areas and offshore ECC are characterised by a paucity of surficial sediments, mobile sandwaves are present in several locations (see Figure 2.5 and Volume 4, Annex 2.1: Physical Processes Baseline Technical report):

- Within the array areas, sandwaves are up to 12 m in height with wavelengths of approximately 300 m (Fugro, 2022a).
- In the offshore ECC, these features are typically found to be between 0.7 and 7.5 m in height, with average wavelengths between 25 and 50 m, up to a maximum wavelength of approximately 260 m for the largest sandwaves (Fugro, 2022b).

2.10.13 To ensure effective burial below the level of the stable bed, it may (in places) be necessary to first remove sections of sandwaves using standard dredging techniques or through the use of a MFE, before trenching into the underlying bed. In addition to short term (minutes to a small number of days) elevations in SSC (Paragraph 2.10.1 *et seq*.), this sandwave clearance activity will necessarily result in localised and temporary changes to seabed topography. This section assesses the potential for seabed recovery and for longer term changes to sediment transport. The MDS for the assessment is set out in Table 2.8. Finally, it is noted that the potential for cable crossings to impact sandbanks and wider seabed morphology is considered within Paragraph 2.11.17 *et seq*. and Paragraph 2.11.52 for the operational phase (when all of the cable crossings will be in place.)

CONCEPTUAL UNDERSTANDING OF CHANGE

2.10.14 A detailed analysis and discussion of sandwave clearance and recovery, including numerous examples of pre-dredge, post-dredge and partial recovery surveys of the Race Bank Offshore Wind Farm was produced as part of the Habitats Regulation Appraisal for the Hornsea Project Three Offshore Wind Farm (ABPmer, 2018a). Similar analysis was also undertaken for the Norfolk Vanguard and Norfolk Boreas Export Cable Route (ABPmer, 2018b).

2.10.15 The assessment below draws on, and is consistent with, the evidence and conclusions presented in the above references with regards to the observed underlying mechanisms for sandwave recovery, whilst acknowledging and accounting for differences in the environmental setting that might affect the rate of recovery. The observations of sandwave levelling and recovery in the above references are from another location, mainly in the export cable corridor for Race Bank offshore wind farm, outer Wash, east coast UK:

- Similarities include the sediment type (predominantly sandy), general mobility (sediments are regularly mobilised), peak current speeds (1 to 1.25 m/s on a mean spring tide for Race Bank, compared to circa 0.8 to 1.3 m/s for VE.
- Differences mainly relate to water depth (circa 10 m to 25 m LAT for Race Bank but up to circa 60 m LAT for the Project). The greater depths associated within the Proposed Development will mainly act to reduce the contribution of any wave action, and the effectiveness of currents, to cause sediment mobility and bedform evolution in the array areas and offshore ECC.

2.10.16 A summary of the available evidence is as follows:

- Where bedforms are present and mobile, this is the natural state of that environment; the processes that are active are conducive to the development and dynamic evolution of such features. Local perturbations to existing sandwaves that do not change the fundamental conditions of the setting (tidal and wave regime, volume of mobile sediment present) will not prevent continued evolution of the features through the same naturally occurring processes and the features will therefore recover towards a new equilibrium state over time;
- Bedform recovery occurs as a result of the ongoing sediment transport processes (local transport of sediment volume into and retained within the levelled area) and general bedform migration through the system. Observed recovery of sandwaves at Race Bank was mainly the result of local sediment accretion; recovery was projected to occur at these sites in the order of several years under similar tidal forcing conditions but based on a smaller dredged volume and in shallower water depths; and
- The proposed bed levelling is not likely to pose a barrier to sediment transport within, or to locations beyond, the wider sandwave/sandbank system.

2.10.17 The volume of material to be displaced from individual sandwaves will vary according to the local dimensions of the sandwave (height, length and shape) and the level to which the sandwave must be reduced (also accounting for stable sediment slope angles and the capabilities and requirements of the cable burial tool being used). Based on the available geophysical data (Fugro, 2022a,b), it is anticipated that the bedforms requiring localised levelling (or crest lowering) are likely to be up to 12 m in height. The total volume that could be affected by sandwave clearance is presently estimated to be up to 35,000,000 m^3 within the array areas and 64,750,000 m^3 within the offshore ECC. Exact locations requiring sandwave clearance are presently unknown.

2.10.18 The sediments comprising the sandwave features will be predominantly sand, although a small proportion of fines and gravel may also be present. Individual sandwaves will require removal via MFE or by multiple dredging cycles to complete the required corridor. If dredging is undertaken, the preference is for the dredge spoil to be returned to the seabed in the vicinity of the dredged area.

2.10.19 The tidal current regime - (peak current speeds on a mean spring tide of circa 0.8 to 1.3 m/s) - is sufficiently strong to cause mobility of sand on a regular basis. The tidal current regime will not measurably change as a result of the localised levelling, or as a result of any other aspect of the Project. The volume of sediment available in each local system will be locally redistributed by the levelling (via MFE and/or dredging and disposal of removed material back into the water column nearby) but will not change in an overall net sense. As the controlling factors will also not change, the levelled areas and sandwave features will have the potential to recover in time to a new (dynamically evolving) natural state.

2.10.20 The levelled area is considered to be 'recovered' in terms of form and function once the local crest level has re-established to a form that is within the range of natural variability observed in the other similarly sized surrounding bedforms, which may be of different dimensions than the original feature.

2.10.21 The rate and timescale of recovery will vary in proportion to the rate of sediment transport and accumulation. Faster infill and recovery rates will be associated with periods of higher local flow speeds and more frequent wave influence at the seabed. The following factors will all influence the rate of recovery:

- Rates of bedform migration (<1 m/ yr in the array areas to >5 m/yr in places along the offshore ECC – see Volume 4, Annex 2.1: Physical Processes Baseline Technical Report);
- The width of the dredged corridor (70 m);
- The wavelength of the features (up to approximately 250 m); and
- The relatively large volume of sediment being displaced due to the large height of some sandwave features.

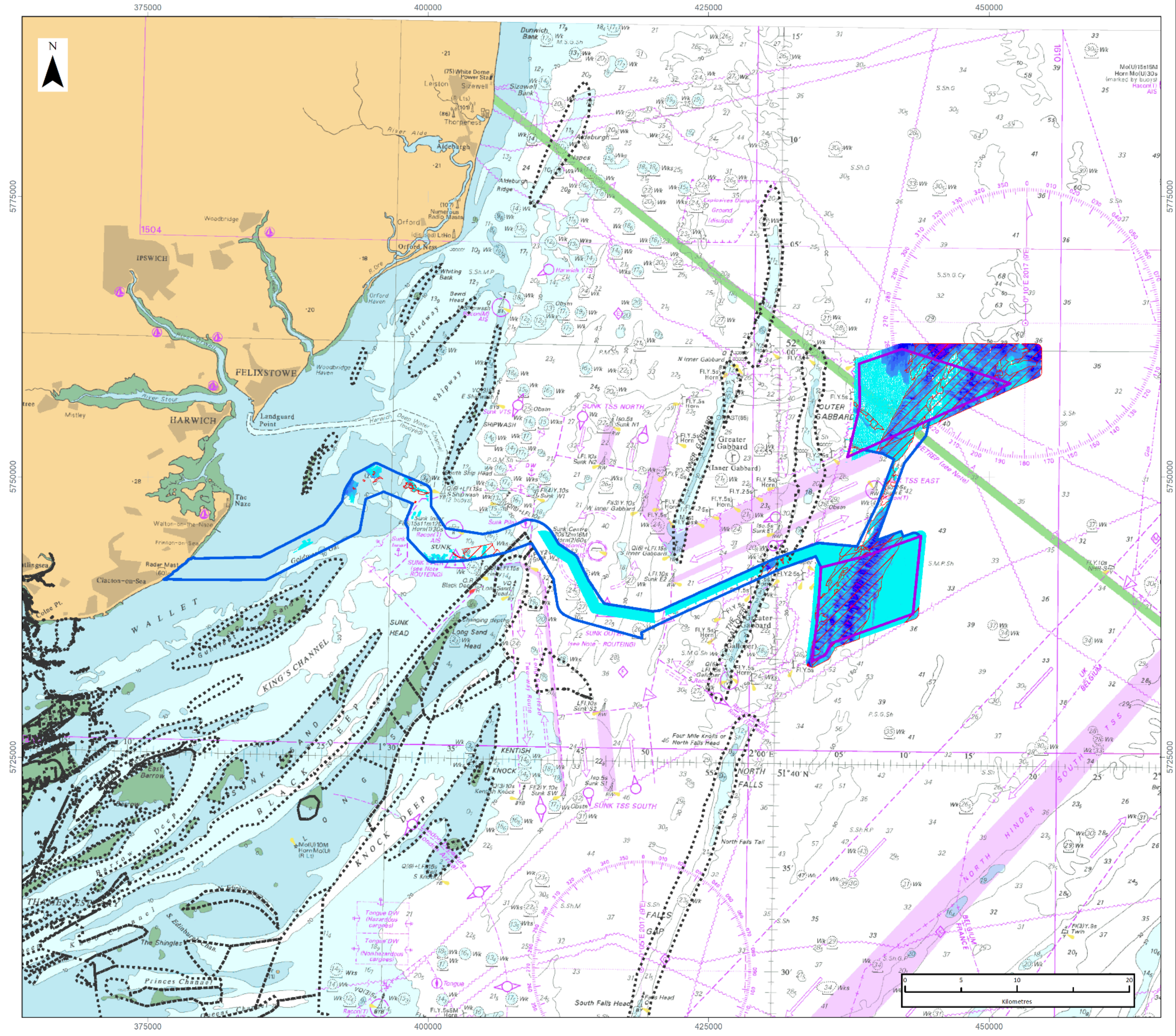
2.10.22 The exact timescale for recovery cannot be calculated with certainty. Based only on the overall rate of observed bedform migration (which is not the main or only mechanism for recovery and is proportional to the long-term net sediment transport rate), the timescale for recovery in the more energetic parts of the offshore ECC is estimated to be in the order of 5 to 10 years; longer timescales of 'at least' 10 years can be inferred for the array areas, based on the relatively low observed rate of bedform migration. However, short-term sediment mobility will also contribute to local sandwave recovery (Volume 4, Annex 2.1: Physical Processes Baseline Technical Report).

2.10.23 A shorter estimated timescale is obtained when considering the instantaneous rate of transport during higher flow periods. As shown by the detailed sand transport modelling (Volume 4, Annex 2.1: Physical Processes Baseline Technical Report), instantaneous transport rates of 0.36 to 3.6 m^3/m/hr may be active up to four times per day (peak flood and ebb) for a few days either side of the peak of spring tides. At a representative mid-level rate of 1 m^3/m/hr, and assuming a representative 70 m wide corridor and a representative volume of 75,000 m^3 sediment displaced per sandwave, it could take in the order of (75,000 m^3/[1 m^3/m/hr x 70 m x 4 hr/day x 4 days]) 70 spring tidal cycles (~2.7 years) as a minimum to move the displaced volume of sediment back into the levelled area. The actual rate of recovery will be slightly longer as not all sediment transported into the area will be retained in the longer term. The rate of transport and so the rate of recovery could be around three times faster or slower than this, depending upon location along the offshore ECC or within the array areas. The overall rate of recovery would also vary in proportion to the volume displaced (relative to the representative value of 75,000 m^3).

2.10.24 The recovery may be gradual or episodic and can be expected to vary spatially. As the recovery is due to natural processes of sediment transport, the nature of the seabed surface sediments in the recovering area will not be measurably different to that on the surrounding seabed and adjacent sections of undisturbed sandwave. In all locations, surficial sediments will continue to be mobilised at the natural ambient rate and direction under sufficiently energetic current and wave conditions, with the associated development and migration of smaller (e.g. ripple and mega-ripple) bedforms. Where the dredge spoil is returned to the seabed in the vicinity of the dredged area, the volume and supply of sediment in the local system is not changed.

2.10.25 The final shape of the bedform following recovery may be similar to its original condition (e.g. rebuilding a single crest feature, although likely displaced in the direction of natural migration) or it might change (e.g. a single crest feature might bifurcate or merge with another nearby bedform). All such possible outcomes are consistent with the natural processes and bedform configurations that are already present in the Study Area and would not adversely affect the onward form and function of the individual bedform features.

2.10.26 The levelled areas are not considered likely to create a barrier to onward sediment transport. Evidence from aggregate dredging activities indicates that if any changes occur to the flow conditions or wave regime, these are localised in close proximity to the dredge pocket (with widths and lengths of several kilometres) (e.g. AODA, 2011). The proposed works will be at a much smaller scale and footprint, with trench widths expected to be in the order of up to 50 m, in water depths of at least 30 m. This means there is likely to be little to no influence on the flow or wave regime, which in turn means little to no change to the regional scale sediment transport processes across the array areas and offshore ECC.



LEGEND

- Array Areas
- Offshore Export Cable Corridor
- Annex I Sandbanks

VE Geophysical Survey (Fugro, 2022a,b)

- Sand waves

Thickness of Holocene (m)

- 0 to 1.0
- 1.01 to 2.0
- 2.01 to 4.0
- 4.01 to 6.0
- 6.01 to 8.0
- 8.01 to 10.0
- 10.01 to 12.0
- 12.01 to 14.0
- 14.01 to 16.0
- 16.01 to 18.0
- >18

PROJECT TITLE:

FIVE ESTUARIES OFFSHORE WINDFARM

DRAWING TITLE:

Sand waves

VER	DATE	REMARKS	Drawn	Checked
1	28/02/2023	For Issue	CRO	NKD

DRAWING NUMBER:

2.5

SCALE: 1:350,000 | PLOT SIZE: A3 | DATUM: WGS84 | PROJECTION: UTM31N

FIVE ESTUARIES OFFSHORE WIND FARM

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ASSESSMENT OF SIGNIFICANCE

SANDBANKS

2.10.27 The Annex I sandbanks within the study area are all internationally important. However, they are understood to be highly dynamic features and assessed to have some capacity to recover from disturbance. Accordingly, they are considered of **medium** sensitivity/ importance.

2.10.28 The magnitude of impact to the Annex I sandbanks resulting from levelling is considered **low** (adverse). This is because although direct impacts to the seabed will occur, the seabed is expected to recover in response to the occurrence of short-term seabed mobility (occurring during peak flood and ebb currents on spring tides in all locations) and observed natural migration of bedforms - (lower rates of migration in the array area, higher in the offshore ECC) - dependant on local patterns of net sediment transport).

2.10.29 The overall level of effect on sandbanks has been assessed as being of **minor** adverse significance which is not significant in EIA terms.

DESIGNATED AREAS OF SEABED

2.10.30 The Project overlaps with Margate and Long Sands SAC, the Outer Thames Estuary SPA and the Southern North Sea SAC all of which are internationally important sites. However, the seabed in these areas has been shown to be dynamic and is assessed to have some capacity to recover from disturbance. Accordingly, they are assessed as having **medium** sensitivity/ importance.

2.10.31 The magnitude of impact to the seabed is predicted to be **negligible** (neutral). This assessment of magnitude is based on the fact that no sediment is being removed from the local sediment transport system, only redistributed. Accordingly, net rates of sediment transport to/ from designated areas of seabed will remain unaltered from the baseline.

2.10.32 The overall level of effect of morphological change has therefore been assessed as being of **minor adverse** significance which is not significant in EIA terms (Table 2.6).

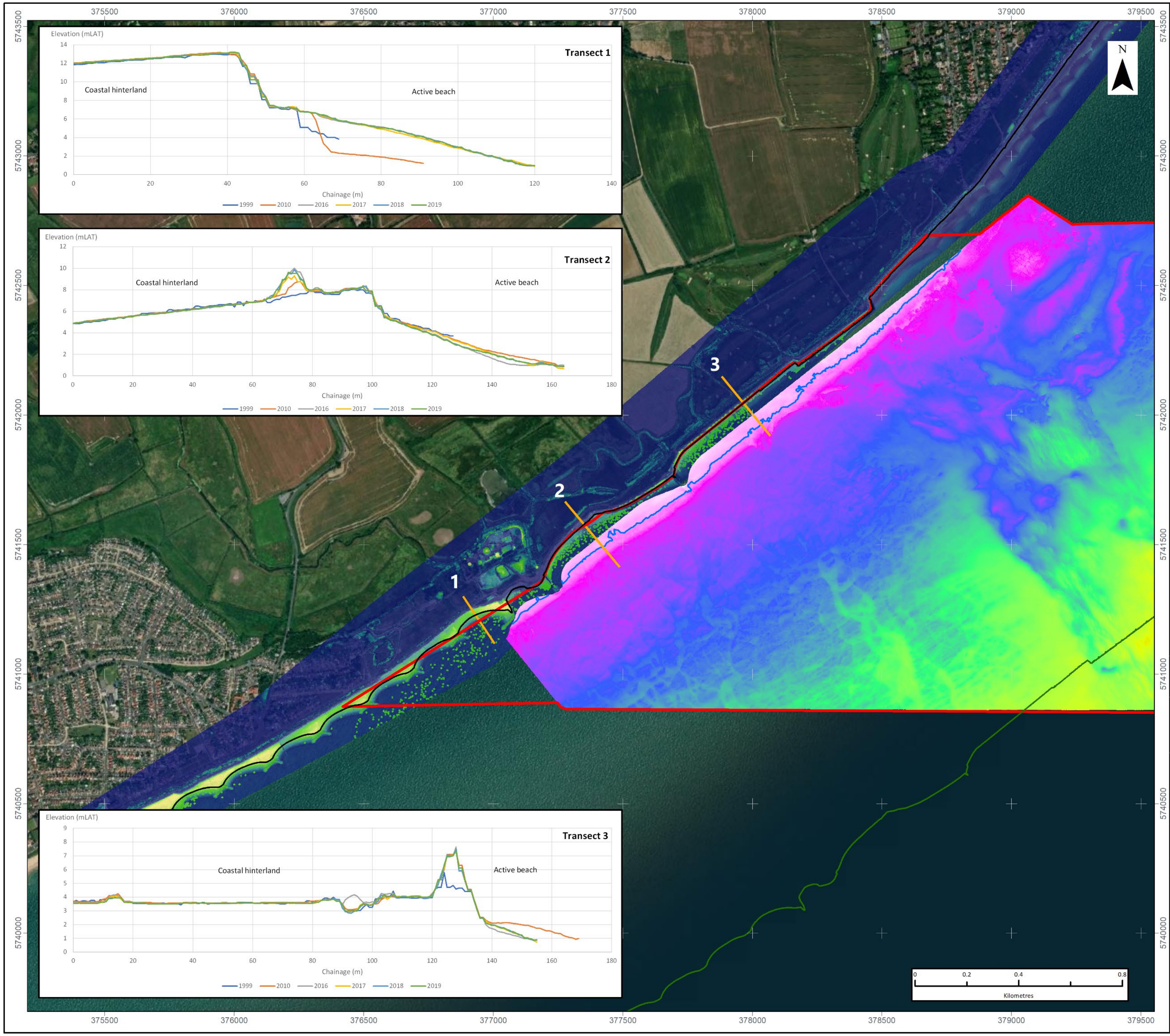
IMPACT 3: POTENTIAL IMPACTS TO LANDFALL MORPHOLOGY

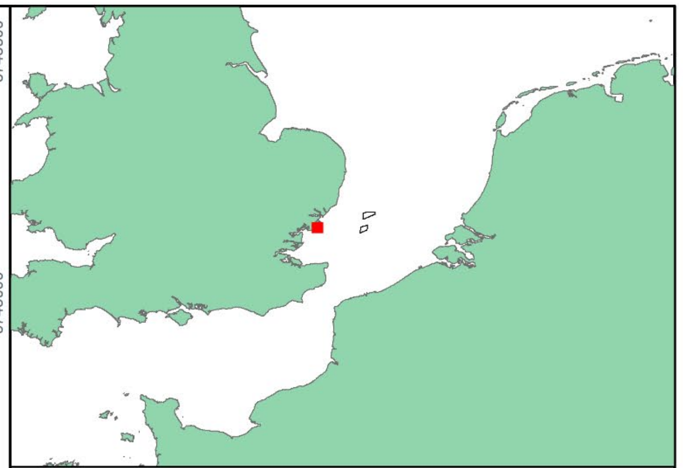
OVERVIEW

The offshore export cables will make landfall between Holland-on-Sea and Frinton-on-Sea on the Essex coast (

2.10.33 Figure 2.6). Full details of the MDS are provided in Table 2.8, whilst a full description of coastal characteristics (including observed historic change and existing/ future management policies) are set out in Volume 4, Annex 2.1: Physical Processes Baseline Technical Report. The assessment below separately considers the potential for impacts associated with:

- Trenchless installation techniques;
- Construction of HDD exit pits;
- Trenching across the intertidal; and
- Use of cable protection measures.





LEGEND

Offshore Export Cable Corridor

LiDAR transects

0m LAT contour

MHWS contour

Contour 1600 m seaward of MHWS contour

Max difference in LiDAR elevation (1999 to 2019) (m)

13

0

Bathymetry 2021 (m LAT)

1.354

-1

-3

-5

-7

-9

-11.145

Data Sources: VE OWFL (2022); RWE, 2020; ABPmer, 2020. Basemap: Esri et al.

PROJECT TITLE:

FIVE ESTUARIES OFFSHORE WINDFARM

DRAWING TITLE:

Landfall LiDAR

VER	DATE	REMARKS	Drawn	Checked
1	28/02/2023	For Issue	CRO	NKD

DRAWING NUMBER:

2.6

SCALE: 1:15,000 | PLOT SIZE: A3 | DATUM: WGS84 | PROJECTION: UTM31N

FIVE ESTUARIES OFFSHORE WIND FARM

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CONCEPTUAL UNDERSTANDING OF CHANGE

TRENCHLESS INSTALLATION TECHNIQUES

2.10.34 The coastline within the landfall area is heavily managed with an almost continuous concrete sea wall at the back of the beach, fronted by a mixture of sloped smooth and/or rock revetment. The character of the beach and coastline in the landfall area is presently stable due to the coastal defences present; however, the future stability of the coastline will remain dependent on the future management policies and activities for both the local area and for coastal regions up drift (to the northeast).

2.10.35 HDD is the established solution for trenchless installation, however it should be noted that other technologies exist, such as micro-boring. HDD involves drilling a long borehole underground using a drilling rig located within the landfall compound. This technique avoids interaction with surface features and is used to install ducts through which cables can be pulled. HDDs can vary in length depending on the ground conditions the maximum length proposed for VE is 1,100 m.

2.10.36 HDD will cause minimal direct disturbance to the existing coastline because it will not interact directly with, or leave any infrastructure exposed in, the active parts of the beach (between the entry and exit points of the drill) and so will not impact upon littoral processes in these areas. Provided that the cable remains buried beyond the exit of the HDD, there is no possibility for it to interact with, or have any effect on nearshore beach processes or morphology. The design of the HDD operation will take this into account.

2.10.37 The presence of the seawall coastal defences means that the choice of location for the onshore HDD works and jointing bay is unaffected by the possibility of coastal retreat due to either natural erosion or sea level rise due to climate change, for as long as the seawall remains in place. However, after 2055 a dual policy for the Management Unit in which the landfall is located means that the existing frontline defences may be held where they are now or some form of Managed Realignment may be implemented. The operational lifetime of the project could extend beyond 2055 and therefore any landfall infrastructure may potentially be impacted either directly or indirectly by possible future changes in coastal management. No details of these potential future managed realignment options are available and therefore an assessment of long-term future change is not possible. However, in as far as is practicably possible, the Project will take into consideration the potential for future managed realignment of the coast in this area, factoring conservatism into the design to 72ocalize the risk of infrastructure exposure in future.

CONSTRUCTION OF HDD EXIT PITS

2.10.38 As the HDD is carried out between a start and end point, entry and exit pits must be excavated at either end of the borehole: one in the landfall compound and one on the offshore side. The HDD exit pits (up to 5 no.) may be located within the intertidal zone or the shallow subtidal. The dimensions of the HDD exit pits will be up to 10 m wide, 75 m long and 2.5 m deep. This corresponds to a total volume of excavated material of approximately 1,875 m^3 for each HDD exit pit, and approximately 9,375 m^3 in total.

2.10.39 Exit pits will be excavated or dredged to the required depth, and side-cast material for backfilling will be stored adjacent to the exit pit. Once the drilling operation has taken place, the ducts will be pulled through the drilled holes. The ducts are either constructed off-site, then sealed and floated to site by tugs, or will be constructed at the landfall compound and pulled over the beach on rollers. The ducts are then pulled back through the boreholes either by the HDD rig itself, or by separate winches.

2.10.40 Once the ducts are in place, the exit pits will likely be temporarily backfilled until ready for cable pull-through. The ducts will then need to be re-exposed to pull in the cable. Between the installation of the ducts and cable pulling operations may be several months. Once installation is complete, the exit pits will either be backfilled using side-cast material or left to naturally backfill.

2.10.41 Although the HDD exit pits may be present for a number of months, the potential for these temporary features to modify the wave regime will be limited as the HDD exit pits will be temporarily infilled with rock bags or concrete mattressing. Accordingly, water depths within their footprint of all nearshore affected areas will remain similar to baseline levels. Depending upon the position of the spoil mounds in the intertidal and the rate and pattern of any redistribution of the material (controlling the change of water depth in their footprint), there may be potential for these to locally modify the nearshore wave regime through the differently distributed transmission of wave energy across the beach. This could theoretically result in a morphological response although this would be highly 73ocalized to the area around the mounds. The potential for local changes to become more widespread would also be limited by the presence of the groynes.

2.10.42 If the HDD exit pits remain open during winter months, there will be a high likelihood that the material comprising the spoil mounds will be at least partially redistributed offshore and across the beach during storm events.

TRENCHING OPERATIONS

2.10.43 Open-cut installation in the intertidal zone could be carried out using one or more methods described for the offshore export cables in Table 2.8 (if and where suitable for use in the intertidal zone). However, ploughing is expected to displace the greatest volume of material out of the trench and therefore is considered to represent the MDS. Excavation of the trench with a plough would result in the formation of berms either side of the trench. The size of these berms will be dependent upon the trench width, cable burial depth and nature of the disturbed sediments.

2.10.44 The disturbed sediments are anticipated to primarily comprise coarse grained material and the trench dimensions are likely to be similar to those described for offshore export and array cable installation (i.e. up to 18m wide; up to 4m deep; ‘V’ shape profile). Actual trench dimensions will be established once more knowledge of the site has been gathered and processed and a detailed Cable Burial Assessment and cable landfall study has been performed.

2.10.45 It is possible that whilst the trenches are open (assumed to be a period of days to a few weeks), the material in the berms could be mobilised by the action of tidal currents and waves and locally redistributed. Accordingly, the potential extent of change to beach/ intertidal morphology could extend across a wider area than the immediate footprint of the trench and berms. However, it is anticipated that the full volume of the berms adjacent to the trench would only be present on the seabed/ beach for a relatively short period of time (order of days to a few weeks, depending on the pattern of tidal inundation and wave action in that time) and therefore the extent to which this redistribution of material could occur is anticipated to be limited. Furthermore, given that the berms would only be present for a very short period of time, any changes to hydrodynamics and sediment transport would also be highly localized and there would be no potential for longer term change to coastal morphology.

2.10.46 Within the lower intertidal/ shallow subtidal, it is anticipated that reworking by currents and/ or waves will quickly (in the order of days to several weeks) redistribute and smooth any remaining local disturbances after the trench has been backfilled, returning the area of the trench (and associated works) to a natural state (e.g. elevation and sediment type) that will be in equilibrium with the baseline environment.

CABLE PROTECTION

2.10.47 Cable protection will be buried in the intertidal section and out to 1,600 m seaward of MHWS and will not consist of loose rock or gravel. If the cable protection is installed below the (winter) beach level it will present no barrier to the passage of waves and so cause no change to long-term patterns of sediment transport.

2.10.48 At a distance of greater than 1,600 m from the MHWS mark, rock berms (with a height of up to 1.4 m) could potentially be used to protect the export cables. The exact location of the rock berms and orientation relative to the beach is presently unknown. However, given the route of the offshore ECC, it is probable that the long axis of the rock berms will be orientated generally across the main tidal current axis but broadly aligned with the direction of waves as they approach the coast.

2.10.49 Cable protection in shallow areas could theoretically work in a similar way to a submerged offshore breakwater, affecting wave transformation processes closer to shore. This in turn could potentially alter the wave approach to the shore leading to wave focusing on areas of the beach not presently eroding, resulting in long-term lowering. The structures themselves could also locally intercept sediment being transported by wave and tidal driven currents. However, whilst it can reasonably be expected to be the case that there will be some 74ocalized change to waves and hydrodynamics immediately within the vicinity of the rock berms, the potential for wider morphological change to the beach at the landfall is considered to be very limited. This is primarily due to the fact that:

- Any rock berms would be distant from the beach (over 1 km away)
- Water depths at a distance of 1600 m seaward of the MHWS mark are circa 5 to 6 m below LAT. Accordingly, for the majority of time waves wouldn’t interact with the berm and might only be expected to do so when larger waves coincided with lower water of spring tides.

ASSESSMENT OF SIGNIFICANCE

2.10.50 Using the criteria presented in Table 2.5, the coastline is of **medium** sensitivity/importance. Although designated in places (for saltmarsh and freshwater marsh), the shoreline is typically a dynamic environment which is subject to natural change under baseline conditions. Accordingly, it is assessed to have some capacity to recover from disturbance.

2.10.51 Based on the criteria set out in Table 2.4, the magnitude of change to the beach at the landfall is assessed to be **low** (adverse). Although some highly localised (i.e. order of 10s of metres) morphological change can reasonably be expected to occur immediately adjacent to the HDD exit pits and trench, the spatial extent is expected to be limited.

2.10.52 Using the sensitivity matrix (Table 2.6), a low magnitude of change to the coastline receptor of medium importance results in an effect of **minor adverse** significance which is not significant in EIA terms.

2.11 ENVIRONMENTAL ASSESSMENT: OPERATIONAL PHASE

IMPACT 4: POTENTIAL CHANGES TO THE TIDAL REGIME

OVERVIEW

2.11.1 The interaction between the tidal regime and the foundations of the wind farm infrastructure will result in a slight reduction in current speed and an increase in levels of turbulence in a narrow, localised wake due to frictional drag and the shape of the structure. Changes to the tidal regime may indirectly impact seabed morphology (including bedforms) in several ways. There exists a close relationship between flow speed and bedform type (e.g. Belderson et al., 1982) and thus any changes to flows have the potential to alter seabed morphology over the lifetime of the Project.

2.11.2 Within the extent of the array areas, the effect on tidal currents will be evident as a series of narrow and discrete wake features extending downstream along the tidal axis from each foundation. For smaller structures such as the wind farm foundations, the wake signature is expected to naturally dissipate within a distance in the order of ten to twenty obstacle diameters downstream (e.g. Li et al., 2014; Cazaneve et al., 2016; Rogan et al., 2016). This wake length distance will be much less than the corresponding c.14 to 17 km spring tidal excursion distance in the array area – the distance over which water is displaced during each flood or ebb tide.

2.11.3 The MDS identified for the assessment is set out in Table 2.8 and corresponds to an array comprising of 79 WTGs on 55 m diameter gravity base foundations and two OSPs. The absolute minimum turbine spacing (centre to centre) is 830 m.

CONCEPTUAL UNDERSTANDING OF CHANGE

2.11.4 Hydrodynamic flow modelling has been undertaken to assess the potential extent of change to tidal currents associated with the MDS. Full details of the model used to inform the assessment are presented in Volume 4, Annex 2.2: Physical Processes Model Design and Validation.

2.11.5 On the basis of the modelling undertaken, it is found that:

- The potential for localised changes in current speed is spatially limited to narrow wakes of (slightly) reduced current speed and proportionally increased turbulence, extending downstream of individual foundations;
- Changes to current speed at the resolution of the model (at length scales greater than 200 m) will be less than 0.05 m/s, which is very small in both absolute and relative terms, within the range of natural variability, and not measurable in practice; and
- Corresponding changes to current direction are less than 1 deg.
- Consistent with the very limited scale of change in instantaneous current speed and direction described above as a result of the MDS, no measurable change in residual current speed or direction is predicted either within the array areas, or elsewhere.
- There is limited potential for interaction between VE and GOWF, not least because measurable wakes associated with the GOWF WTG monopile foundations will be very narrow and of limited length (75 to 150 m) due to their narrow (7.5 m) diameter, but also because the tidal axis is north-northeast to south-southwest whilst GOWF is located to the west of VE (Figure 2.1).

2.11.6 The model also shows that local and regional water level variation will not be measurably affected by the presence of the array areas (<0.01m), including both tidal and non-tidal (surge) contributions.

2.11.7 These conclusions are consistent with other numerical modelling studies previously undertaken to inform a wide range of UK OWF developments of comparable or larger scale (e.g. East Anglia Offshore Wind, 2012; Moray Offshore Renewables Ltd, 2012, Navitus Bay Development Ltd, 2014; Awel y Môr Offshore Wind Farm Ltd, 2022).

ASSESSMENT OF SIGNIFICANCE

2.11.8 The assessment set out in this section has considered potential changes to a pathway, rather than impacts on receptors. Accordingly no assessment of significance is provided.. However, the potential for these changes to impact other EIA receptor groups are considered elsewhere within the ES, in particular:

- Volume 2, Chapter 3: Marine Water and Sediment Quality;
- Volume 2, Chapter 4: Offshore Ornithology;
- Volume 2, Chapter 5: Benthic and Intertidal Ecology;
- Volume 2, Chapter 6: Fish and Shellfish Ecology; and
- Volume 2, Chapter 7: Marine Mammal Ecology.

IMPACT 5: POTENTIAL CHANGES TO THE WAVE REGIME

OVERVIEW

2.11.9 The interaction between waves and the foundations of the wind farm infrastructure may result in a reduction in wave energy locally around foundations. The combined changes arising from all foundations may give rise to an array-scale change that could extend outside of the array areas and into the wider study area. Where the wave climate is important to local processes and is persistently modified, these changes may potentially alter the frequency or pattern of sediment transport and therefore seabed morphology in affected offshore areas, and/or the rate and direction of longshore sediment transport and therefore coastal morphology on affected coastlines.

2.11.10 An array comprising 79 gravity base turbine foundations (base diameter of 55 m, minimum spacing 830 m) and 2 OSPs (minimum spacing 450 m) represents the MDS for the blockage of waves through the array areas. Further details regarding the MDS are provided in Table 2.8. Cumulative blockage to the wave regime arising from operation of VE with other planned and operational wind farms in the study area (including GOWF and GGOWF) are considered separately, in Section 2.13.

CONCEPTUAL UNDERSTANDING OF CHANGE

2.11.11 The wind farm has the potential to impact on the wave regime as individual waves interact with the foundation structures. The blockage caused by the foundation structures has the potential to impact on the following wave characteristics:

- Wave height;
- Wave period; and
- Wave direction.

2.11.12 To quantify the likely magnitude and extent of interaction between the operational scheme and the wave regime, a numerical wave model has been developed (Volume 4, Annex 2.2: Physical Processes Model Design and Validation).

2.11.13 The assessment of potential changes to the wave regime has been undertaken for a series of frequently occurring and extreme return period conditions with and without the turbine foundations in place, in order to obtain a generic measure of the extent and magnitude of any change likely to occur during the lifetime of the Project. These are presented in terms of the difference between the baseline wave environment and that predicted to occur with the operational VE project. The full set of results is presented in Volume 4, Annex 2.2: Physical Processes Model Design and Validation, with a subset of results (associated with a range of frequently occurring and extreme return period conditions for easterly waves – the direction which aligns with the shortest distance to the coast) shown in Figure 2.6.

2.11.14 From the outset, it is noted that changes of less than 5% of the baseline wave height would be indistinguishable from natural variability both within the seastate (difference between individual waves) and compared to normal rates of change (over timescales of one hour or less); such small differences would not be measurable in practice. Changes less than 2.5% are also less than the reasonably expected accuracy of the model and so are excluded from the colour scale.

2.11.15 On the basis of the modelling results shown in Figure 2.7 and in Volume 4, Annex 2.1: Physical Processes Baseline Technical Report, it is found that:

- Wave height is progressively decreased with distance through the array areas in the direction from which the waves are coming. As a result, the maximum reduction in wave height is found downwind of individual WTGs in the central downwind part of the southern array area (5 to 7.5%);
- The maximum reduction in a very localised and limited extent outside of the array areas is only 2.5 to 5% for the full range of wave directions and return periods considered. The scale of the change is dependent on the particular wave height/period/direction condition, and the main direction of the wave energy with respect to the shape/thickness of the array and the alignment of the foundations;
- The maximum corresponding changes to wave period and wave direction (not shown) are less than 0.1 s and 3 deg respectively, at all locations, in all cases; and
- Wave height begins to recover immediately downwind of the array area. Recovery occurs mainly due to a wave energy spreading from areas to the side less or unaffected by interaction with the wind farm. For smaller sea states, recovery of the dominant wave condition can also occur as a result of ongoing wind energy input.

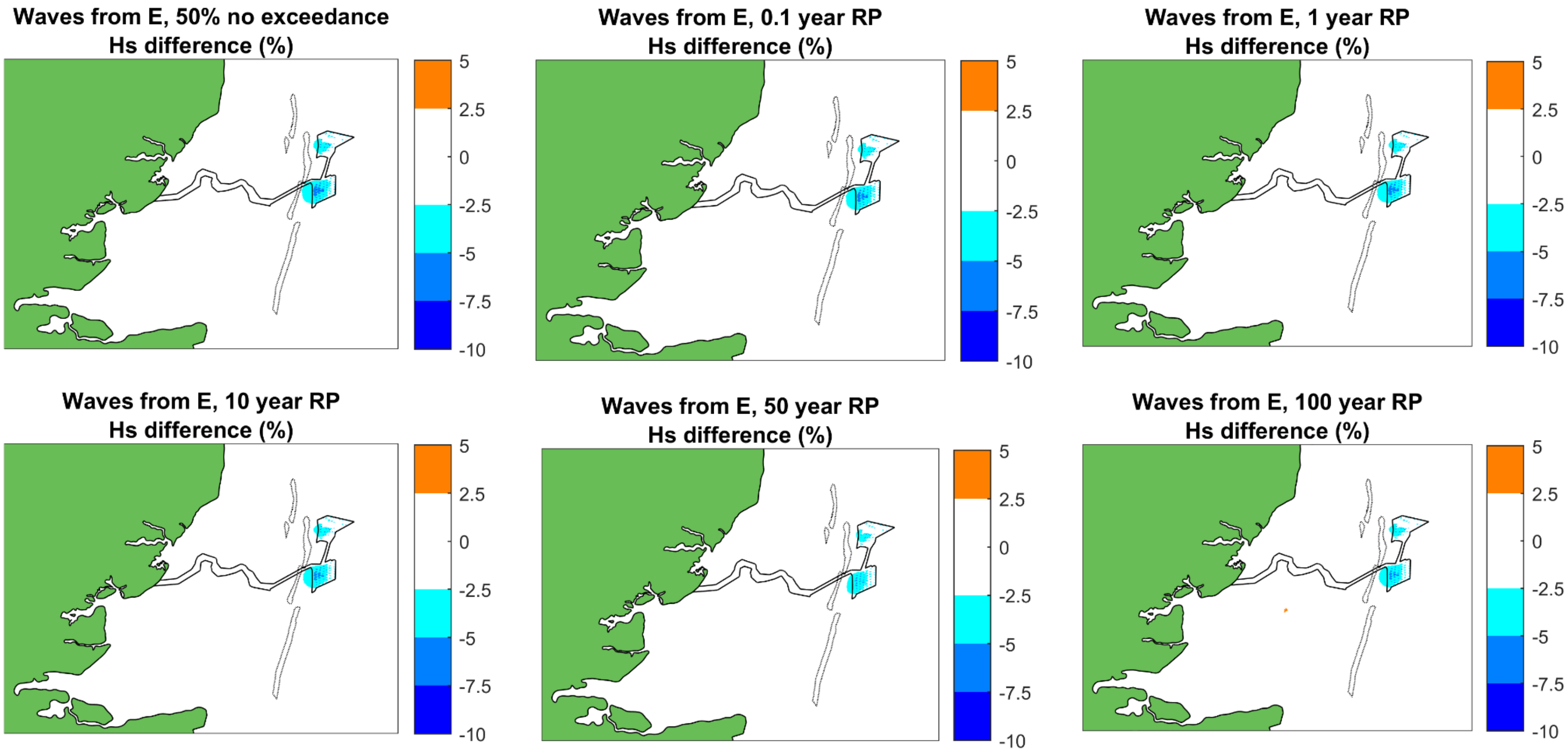


Figure 2.7: Percentage difference in significant wave height (VE minus baseline as a proportion of baseline values) associated with waves from the east for a range of return periods. (Outline of Annex I sand banks also shown).

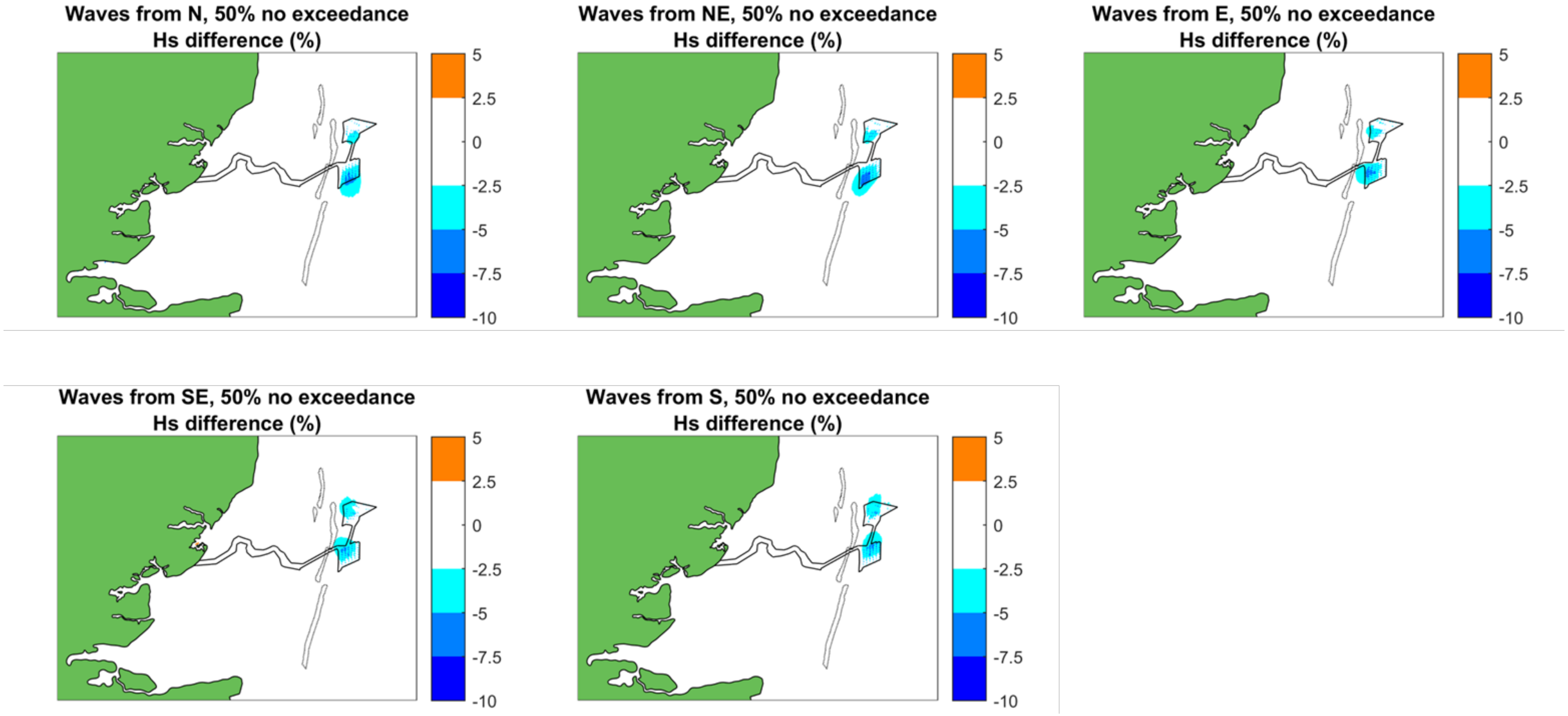


Figure 2.8: Percentage difference in significant wave height (VE minus baseline as a proportion of baseline values) associated with waves from a range of different directions, 50% on exceedance. (Outline of Annex I sand banks also shown).

ASSESSMENT OF SIGNIFICANCE

2.11.16 The assessment set out in this section has considered potential changes to a pathway, rather than impacts on receptors. However, the potential for these changes to impact other EIA receptor groups are considered elsewhere within the ES, in particular:

- Volume 2, Chapter 3: Marine Water and Sediment Quality;
- Volume 2, Chapter 4: Offshore Ornithology;
- Volume 2, Chapter 5: Benthic and Intertidal Ecology;
- Volume 2, Chapter 6: Fish and Shellfish Ecology; and
- Volume 2, Chapter 7: Marine Mammal Ecology.

IMPACT 6: POTENTIAL CHANGES TO THE SEDIMENT TRANSPORT REGIME

OVERVIEW

2.11.17 Modification of existing sediment transport pathways could occur in response to changes in the wave and tidal regimes resulting from the presence of

- Turbine and substation foundations; and/or
- The presence of cable protection measures.

2.11.18 The presence of cable protection measures may also have the potential to cause a direct (albeit very localised and limited volume) blockage to sediment transport. The above changes could potentially occur over a range of timescales, depending on location and the specific project infrastructure that is interacting with the sediment transport regime.

2.11.19 The MDS with respect to the potential for changes to the sediment transport regime is set out in Table 2.8.

CONCEPTUAL UNDERSTANDING OF CHANGE

TURBINE AND SUBSTATION FOUNDATIONS

2.11.20 Additional numerical modelling of sediment transport (driven by tidal currents) was carried out in order to consider the changes associated with the MDS for blockage due to foundations within the VE array area (described in Table 2.8). These are described in full in Volume 4, Annex 2.1: Physical Processes Baseline Technical Report.

2.11.21 Consistent with the very limited scale of change in instantaneous current speed and direction described in Paragraph 2.11.1 *et seq.*, no measurable change in residual sand transport rate or direction is predicted either within the VE array areas, or elsewhere, at the resolution of the model (approximately 200 m). Localised narrow wake features not resolved by the model may have a similarly localised effect on the texture (but not the morphology) of the seabed within their footprint; the wake is only likely to result in changes to seabed morphology immediately around the foundation base in the form of scour (described in Paragraph 2.11.34 *et seq.*).

2.11.22 The differences in wave height, period and direction described in Paragraph 2.11.11 *et seq*. and Figure 2.7 are small in absolute and relative terms and (as a small additional contribution to the tidally dominated transport) could only cause an even smaller change to overall instantaneous sediment transport rates or directions. The differences would not be measurable in practice and are easily within the range of natural variability in wave height from wave to wave, from hour to hour during the passage of a storm, and in the context of seasonal and interannual variation of wave climate:

2.11.23 In the area where changes to wave height are greatest (typically within and immediately to the west or southwest of the array areas), water depths are also relatively large (30 to 35 mLAT, with an additional 1.3 to 2.6 m depth depending on the tidal state). In such water depths, a minimum wave period (approximately 6 s and larger in 30 m depth) is required to penetrate deeply enough to cause any water movement at the seabed. Even longer waves in conjunction with a sufficient wave height are needed to cause sufficient motion at the seabed to contribute to sediment transport.

2.11.24 As the wave period will not be affected (by more than 0.1 s), the ability of individual waves to reach the seabed will be unaffected. Where an individual wave is large enough to reach the seabed, the predicted change in wave height (proportional to the resulting amplitude of water movement) is locally only up to 5 to 10 %. The difference is therefore unlikely to result in a measurably different motion of water.

2.11.25 Finally, it is noted that on the basis of the numerical wave modelling, measurable changes to wave height (as well as period and direction) will not extend to adjacent coastlines. Accordingly, there will be no associated change in wave driven longshore sediment transport.

CABLE PROTECTION MEASURES

2.11.26 Cable protection measures: installation of cable protection could result in a local increase in the elevation of the seabed by up to 1.4 m (Table 2.8), with a sloped side profile. Cable protection would be placed onto the seabed surface above the cable and therefore could directly trap sediment, locally impacting down-drift locations. The height of rock protection at cable crossings (up to 21 no. per export cable; 84 no. in total for four export cables) would also be no greater than 1.4 m above the surrounding seabed, with the length of cable protection at each crossing being up to 300 m.

2.11.27 Following installation and under favourable conditions, an initial period of sediment accumulation would be expected to occur, creating a smooth slope against the cable protection. The process of wedge formation may take place over a period of a few weeks to months, depending on rates of sediment transport.

2.11.28 Sandy sediments are transported in two modes: bedload and saltation. Saltation is the process by which sands are moved up into the water column. These suspended sands would be expected to move relatively freely over the top of the armour although to begin with would regularly be deposited upon it, filling void spaces. Once any void spaces have been infilled, saltation is expected to be largely unaffected by the presence of the cable protection such that existing transport process (including bed form migration) will remain unaffected.

2.11.29 The process of void infilling is expected to occur relatively quickly (in the order of a few months). This is due to saltation as well as the anticipated high rates of transport in areas of mobile seabed (which is where much of the cable protection is anticipated).

2.11.30 Bedload is the process by which sands move while still in contact with the seabed. Bedload will be temporarily affected up until such time that the armour is covered by sand and the slope gradient either side has been reduced in response to the accumulation of a sediment wedge with stable slope angles (approximately 30 degrees). Following this, bedload will continue because the slope angle presented by sections of protected cable would be within the natural range of bed slope angles associated with bed forms mapped within the offshore ECC.

2.11.31 Accordingly, for all areas in which cable protection is used (including where sandwaves are present), it is not expected that the presence of the cable protection devices will continuously affect patterns of sediment transport following the initial period of accumulation. It follows that any changes on seabed morphology away from the cable protection will also be very small. The extent of the cable protection measures does not constitute a continuous blockage along the cable route corridor.

2.11.32 In the nearshore (out to 1,600 m seaward of MHWS), cable remedial protection measures will not include loose rock or gravel. Additionally, in the intertidal, any cable remedial protection methods will be buried. Accordingly, the potential for project infrastructure to interrupt longshore sediment transport (either directly via blockage, or indirectly through modification of the hydrodynamic/ wave regime) will be extremely limited.

ASSESSMENT OF SIGNIFICANCE

2.11.33 The assessment set out in this section has considered potential changes to pathways, rather than impacts on receptors. However, the potential for these changes to impact other EIA receptor groups are considered elsewhere within the ES, in particular:

- Volume 2, Chapter 3: Marine Water and Sediment Quality;
- Volume 2, Chapter 4: Offshore Ornithology;
- Volume 2, Chapter 5: Benthic and Intertidal Ecology;
- Volume 2, Chapter 6: Fish and Shellfish Ecology; and
- Volume 2, Chapter 7: Marine Mammal Ecology.

IMPACT 7: POTENTIAL FOR SCOUR OF SEABED SEDIMENTS, INCLUDING THAT AROUND SCOUR PROTECTION STRUCTURES

OVERVIEW

2.11.34 The term scour refers here to the development of pits, troughs or other depressions in the seabed sediments around the base of WTG and OSP foundations. Minor scour might also occur at the edges of scour protection for foundations and cables, including cable crossings. Scour is the result of net sediment removal over time due to the complex three-dimensional interaction between the foundation and ambient flows (currents and/or waves). Such interactions result in locally accelerated mean flow and locally elevated turbulence levels that also locally enhance sediment transport potential. The resulting dimensions of the scour features and their rate of development are, generally, dependent upon the characteristics of the:

- Obstacle (dimensions, shape and orientation);
- Ambient flow (depth, magnitude, orientation and variation including tidal currents, waves, or combined conditions); and
- Seabed sediment (geotextural and geotechnical properties).

2.11.35 Scour assessment for EIA purposes is considered here for monopile, multi-leg jacket and gravity base foundations. The potential concerns include the seabed area that may be modified from its natural state (potentially impacting sensitive receptors through habitat alteration) and the volume and rate of additional sediment re-suspension, as a result of scour.

2.11.36 The seabed area directly affected by scour may be modified from the baseline or ambient state in several ways, including:

- A different (coarser) surface sediment grain size distribution could develop due to winnowing of finer material by the more energetic flow within the scour pit;
- Seabed slopes could be locally steeper in the scour pit; and
- Flow speed and/or turbulence would be locally elevated, on average.

2.11.37 The scale of change would vary depending upon the foundation type, the local baseline oceanographic and sedimentary environments and the type of scour protection implemented (if needed). In some cases, the modified sediment character within a scour pit may not be so different from the surrounding seabed. However, changes relating to bed slope and elevated flow speed and (near-field) turbulence are still likely to apply. As such, depending upon the sensitivities of the particular ecological receptor, not all scouring necessarily correspond to a loss of habitat. This is discussed further in Volume 2, Chapter 5: Benthic and Intertidal Ecology.

2.11.38 Suction bucket foundations (along with suction bucket & gravity base jacket foundations) have not been considered separately in the assessment below because these will fall within the envelope of change associated with the other three foundation types.

CONCEPTUAL UNDERSTANDING OF CHANGE

2.11.39 In order to quantify the area of seabed that might be affected by scour (either the footprint of scour or scour protection), the following provides an estimate of the theoretical maximum depth and extent of scour. This assessment is based upon empirical relationships described in Whitehouse (1998) and is a summary of a more detailed assessment presented in Volume 4, Annex 2.3: Physical Processes Technical Assessment. Importantly, these estimates are highly conservative as they assume an unlimited depth of erodible sediment at all final foundation locations. In practice, the more erosion resistant London Clay is at or close to the surface in many areas, which will naturally limit the maximum potential scour depth and volume for foundations located in these areas.

2.11.40 Results conservatively assume that the maximum likely ('equilibrium') scour dimensions are present around the perimeter of the structures. Derivative calculations of scour extent, footprint and volume assume an angle of internal friction is 32º. Scour extent is measured from the structure's edge. Scour footprint excludes the footprint of the structure. Scour pit volumes for gravity base foundation structures are calculated as the volume of an inverted truncated cone, minus the structure volume; scour pit volumes for the jacket foundations are similarly calculated but as the sum of that predicted for each the corner piles.

2.11.41 The term 'local scour' refers to the local response to individual structure members. 'Global scour' refers to a region of shallower but potentially more extensive scour associated with a multi-member foundation resulting from the change in flow velocity through the gaps between members of the structure and turbulence shed by the entire structure. Global scour does not imply scour at the scale of the wind farm array.

2.11.42 Key findings are summarised below and in Table 2.10 and Table 2.11:

- Overall, scour development within the array areas is expected to be dominated by the action of tidal currents;
- In practice, the thickness of unconsolidated (and more easily erodible) surficial Holocene sediment is spatially variable across the array arrays, with the greatest thicknesses found in central and central eastern parts of the array areas (Fugro, 2022a). Pre-Holocene (London Clay) material is at or close to the surface in many areas and is expected to limit the extent to which scour can occur;
- Of all of the turbine foundation options under consideration, a 15 m diameter monopile foundation has the potential to cause the greatest equilibrium local scour depth (19.5 m), footprint (4,530 m^2) and volume (up to 34,224 m^3), but only in areas where the seabed is potentially erodible by the action of scour to that depth;
- The greatest individual turbine foundation global scour footprint is associated with the larger (45 m base length) piled jacket foundation (6,323 m^2), although with a relatively small average depth (1.4 m);
- For the array areas as a whole, the greatest total turbine foundation local scour footprint is associated with an array of 79 (15 m diameter) WTG monopile foundations and two OSP monopile foundations (15 m diameter) (366,930 m^2, equivalent to only approximately 0.3% of the array areas); and
- For the array areas as a whole, the greatest total turbine foundation global scour footprint is associated with an array of 79 (45 m base length) piled jacket foundations and two OSP piled jacket foundations (100 m x 60m base length; 6x 3.5 m legs) (515,129 m^2), equivalent to only approximately 0.4% of the array area.

2.11.43 Scour protection may be used to protect the stability of foundations if necessary. Where scour protection is used, primary scour is unlikely to occur, although a small amount of secondary scour may develop at the edges of the scour protection in response to the interaction between the scour protection materials and foundation, and the hydrodynamic and sediment transport regimes. However, the extent and volume of secondary scour will be considerably less than that described for monopile, multileg and gravity base foundations.

2.11.44 For all foundations, the footprint area of scour protection is larger than the predicted footprint of local scour. However, at most, the maximum footprint of scour protection for the MDS (which is an array comprising 79 gravity base foundations with 55 m diameter) is equivalent to only approximately 0.9% of the array areas (1.05% including the footprint of the foundations also).

2.11.45 Scour depth can vary significantly under combined current and wave conditions through time (Harris et al., 2010). Monitoring of scour development around monopile foundations in UK offshore wind farm sites suggest that the timescale to achieve equilibrium conditions can be of the order of 60 days in environments where the seabed is mobile (Harris et al., 2011). These values account for tidal variations as well as the influence of waves. (Near) symmetrical scour will only develop following exposure to both flood and ebb tidal directions.

2.11.46 Under waves or combined waves and currents an equilibrium scour depth for the conditions existing at that time may be achieved over a period of minutes, whilst typically under tidal flows alone equilibrium scour conditions may take several months to develop.

2.11.47 Any elevations in SSC because of scour will be short lived and localised and within the range of natural variability.

2.11.48 Finally, highly localised scour may also occur in areas where rock placement is used to protect cables. The raised profile of the protection may cause a limited amount of localised secondary scouring at the edges of the protection in line with the dominant flow or wave direction. The depth and extent of scour will be limited in proportion to the diameter of the individual rocks used (typically graded between 0.05 m to 0.5 m) which may be reduced by embedment or settling over time.

Table 2.10: Summary of predicted maximum scour dimensions for largest individual turbine foundation structures.

Parameter		Foundation type		
		Monopile (15 m diameter)	Multi-leg Jacket (WTG 45 m base, 4 x 3.5 m legs; OSP 100 x 60 m base, 6 x 3.5 m legs)	Gravity Base (55 m diameter)
Equilibrium Scour Depth (m)^	Steady current	19.5	4.6	2.1
	Waves	Insufficient for scour	Insufficient for scour	2.2
	Waves & current	19.5	4.6	3.5
	Global scour	NA	1.4	
Extent from foundation * (m)	Local scour	31.2	7.3	3.3
	Global scour	N/A	45.0	N/A
Footprint* (m^2)	Structure alone	177	38	2,376
	Local scour (exc. Structure)	4,530	987	606
	Global scour (exc. Structure)	N/A	6,323	N/A
Volume* (m^3)	Local scour (exc. Structure)	34,224	1,739	615
	Global scour (exc. local scour and structure)	N/A	8,853	N/A

^ Results assume erodible bed and absence of geological controls

* Based upon the scour depth for steady currents. Footprint and volume values are per foundation.

Table 2.11: Total seabed footprint of the different foundation types with and without Scour.

Parameter	Foundation type		
	Monopile (15 m diameter)	Multi-leg Jacket (WTG 45 m base, 4 x 3.5 m legs; OSP 100 x 60 m base, 6 x 3.5 m legs)	Gravity Base (55 m diameter)
Maximum number of foundations	79 WTG + 2 OSP	79 WTG + 2 OSP	79 WTG + 2 OSP
Seabed footprint of all foundations (m²)	14,314	3,156	192,442
Proportion of array area* (%)	0.01	0.00	0.15
Seabed footprint of all local scour (m²)	366,930	80,896	49,126
Proportion of array area* (%)	0.29	0.06	0.04
Seabed footprint of all foundations + local scour (m²)	381,244	84,052	241,568
Proportion of array area* (%)	0.30	0.07	0.19
Seabed footprint of all global scour (m²)	NA	515,129	NA
Proportion of array area* (%)	NA	0.40	NA
Seabed footprint of all scour protection (m²)	423,945	121,528	1,202,826
Proportion of array area* (%)	0.33	0.09	0.94
Seabed footprint of all foundations + scour protection (m²)	438,259	124,684	1,395,268
Proportion of array area* (%)	0.34	0.10	1.09

Parameter	Foundation type
All scour dimensions are based upon the scour depth for steady currents. Results assume erodible bed and absence of geological controls * Corresponding proportion of the VE array areas (128.03 km^2).	

ASSESSMENT OF SIGNIFICANCE

2.11.49 The array areas overlap with the Southern North Sea SAC which is an internationally important site. However, the seabed in this area is dynamic and is assessed to have capacity to recover from disturbance. Accordingly, it is assessed as **medium** sensitivity/ importance.

2.11.50 The magnitude of impact to the seabed is predicted to be **low** (adverse). This assessment of magnitude is based on the fact that although permanent, any changes would be spatially very limited.

2.11.51 The overall level of effect of scour has therefore been assessed as being of **minor adverse** significance which is not significant in EIA terms (Table 2.6).

IMPACT 8: POTENTIAL MORPHOLOGICAL IMPACTS TO SANDBANKS AND DESIGNATED AREAS OF SEABED

OVERVIEW

2.11.52 Sandbanks and designated areas of seabed could potentially be impacted by:

- Modification of the wave regime arising due to blockage from WTG foundations; and/or
- Blockage/ alteration of sediment transport pathways arising from the use of cable protection.

2.11.53 The interaction between the waves and the foundations of the wind farm infrastructure may result in a reduction in wave energy locally around foundations. The combined changes arising from all foundations may give rise to an array-scale change that could extend out of the array areas and into the far-field. Where the wave climate is persistently modified, these changes may potentially alter the frequency of sediment mobilisation and therefore seabed morphology in offshore areas.

2.11.54 An array comprising 79 x 55 m diameter gravity base foundations (and 2 OSPs) represents the MDS for the blockage of waves through the array areas. The MDS for cable protection is associated with:

- Installation of (up to) 53.6 km of rock protection (max height 1.4 m) as well as rock protection at up to 26 cable crossings within the array areas; and
- Installation of (up to) 47.5 km of rock protection (max height 1.4 m) as well as rock protection at 84 cable crossings along the offshore ECC.

2.11.55 Further details regarding the MDS are provided in Table 2.8.

2.11.56 This section only considers change associated with VE. Cumulative changes associated with other planned and operational wind farms within the study area are considered in Paragraph 2.13.25 onwards

CONCEPTUAL UNDERSTANDING OF CHANGE

IMPACTS ARISING FROM THE PRESENCE OF WTG FOUNDATIONS

2.11.57 In order to undertake the assessment of potential changes to the wave regime, a numerical model was used to simulate the patterns of reduction of wave height through the area areas and the subsequent recovery of wave height downwind. The model setup is described in Volume 4, Annex 2.2: Physical Processes Model Design and Validation, whilst results from the model are summarized in Figure 2.8, focusing in the potential for change at nearby Annex I sand banks.

2.11.58 The operational presence of the array areas could indirectly affect sandbanks by modifying the wave regime. A number of sandbanks are present within the general vicinity of the array areas (Figure 2.1), namely:

- Outer Gabbard (2.5 km);
- The Galloper (4.5 km);
- North Falls (8 km); and
- Inner Gabbard (12 km).

2.11.59 Sandbanks are tidally induced bedforms, with sandbank formation principally governed by sediment availability and the prevailing tidal current regime. The banks within the study area (including those listed above) are known to be active under present day hydrodynamic conditions (e.g. Kenyon and Cooper, 2005; Defra et al., 2009).

2.11.60 Waves primarily influence sandbanks by determining the maximum height (minimum depth) to which they can accumulate (Kenyon and Cooper, 2005). A reduction in wave energy across the banks could therefore theoretically result in shoaling of the bank (i.e. shallowing of crest elevation). The quantitative assessment of potential changes to the wave regime suggests that the greatest instantaneous wave reductions which might be experienced at any bank are < c.2.5%. Impacts to sandbanks could theoretically occur throughout the operational lifetime of the Project (i.e. be of long term duration), although any impacts would be intermittent in nature.

2.11.61 However, for the following reasons it is considered extremely unlikely that these changes to wave conditions would result in a corresponding morphological change to the sandbanks in the form of a small increase in crest elevation:

- The sandbanks are understood to be highly dynamic bedforms subject to natural changes under baseline conditions. Even if very small reductions in the height of waves from those directions aligned to the array area were to occur across these sandbanks, it is extremely unlikely these would manifest in changes to sandbank crest elevation. This is because these sandbanks are also influenced by large waves from other directions which will also contribute to flattening of the crests, thereby maintaining their existing (baseline) elevation.
- The wave events that are likely to cause the greatest effects on offshore sandbanks (including Galloper and Gabbard) occur during low-frequency high-intensity storm conditions (e.g. Kenyon, 2005; Kenyon & Cooper, 2005). However, these wave events will be associated with long period waves whose wavelength becomes 'long' relative to the diameter of the foundation structure. Waves that are long compared to the size of the structure will more simply pass around it, losing little or no energy. (It is the waves with relatively shorter wavelengths which are more likely to impact with the structure and are more likely to be affected by reflection, diffraction or wave breaking).

IMPACTS ARISING FROM THE PRESENCE OF CABLE PROTECTION MEASURES

2.11.62 The locations at which rock protection may be actually required and installed (both for cables and cable crossings) will be subject to the findings of the CBRA. Regardless, it has been demonstrated in Paragraph 2.11.26 *et seq*. that the presence of rock protection will have very limited potential to modify patterns of sediment transport: a very small volume of sediment could be trapped within the rock voids, whilst a similarly small volume of material could also accumulate on the updrift side of the berms, before the slope reaches an equilibrium position defined by the angle of repose of the accumulated material. Thereafter, sediment can reasonably be expected to be transported at the same rate (and in the same direction) as under baseline conditions. Any indirect changes to sediment transport arising from modification of tidal currents and waves as they interact with the berms will be highly spatially restricted – order of 10's of metres (maximum) from the feature. Given that only very minor changes are expected to the sediment transport regime, any associated morphological impacts are also expected to be very limited.

2.11.63 It is further noted that in many places within the array areas and along the offshore ECC, surficial sediment cover is either very limited or absent (Figure 2.5). This will further limit the potential for rock berms to interrupt sediment transport.

2.11.64 Rock protection may be used at cable crossings along the offshore ECC. The maximum height of the rock protection at these locations will also be no greater than 1.4 m and therefore for the same reasons set out above, the potential for modification of the sediment transport regime will be similarly limited.

ASSESSMENT OF SIGNIFICANCE

SANDBANKS

2.11.65 The Annex I sandbanks within the study area are all internationally important. However, they are understood to be highly dynamic features and assessed to have some capacity to recover from disturbance. Accordingly, they are considered of **medium** sensitivity/ importance.

2.11.66 The magnitude of impact to sandbanks is predicted to be **low** (adverse), both as a consequence of any blockage of waves as they pass through the array areas and/or due to blockage of sediment arising from the presence of cable protection measures. This assessment of magnitude is based on the fact that:

- Sandbanks are tidally induced bedforms, with sand bank formation principally governed by sediment availability and the prevailing tidal current regime rather than the action of waves.
- Any blockage of sediment associated with the presence of cable protection measures (including cable crossings) will be extremely small in absolute terms, relative to the sediment volume of the banks.

2.11.67 The overall level of effect on sandbanks has been assessed as being of **minor adverse** significance which is not significant in EIA terms (Table 2.6).

DESIGNATED AREAS OF SEABED

2.11.68 The Project overlaps with Margate and Long Sands SAC, the Outer Thames Estuary SPA and the Southern North Sea SAC all of which are internationally important sites. However, the seabed in these areas has been shown to be dynamic and is assessed to have some capacity to recover from disturbance. Accordingly, they are assessed as having **medium** sensitivity/ importance.

2.11.69 The magnitude of impact to the seabed is predicted to be **low** (adverse), both as a consequence of any blockage of waves as they pass through the array areas and/or due to blockage of sediment arising from the presence of cable protection measures. This assessment of magnitude is based on the fact that although permanent, any changes would be spatially very limited.

2.11.70 The overall level of effect of scour has therefore been assessed as being of **minor** adverse significance which is not significant in EIA terms.

IMPACT 9: POTENTIAL IMPACTS TO COASTAL MORPHOLOGY

OVERVIEW

2.11.71 The primary means by which the coast could be impacted by the operational presence of VE are:

- Modification of the wave regime due to WTG foundations within the array areas, causing associated changes in longshore transport;
- Exposure of buried export cables and associated infrastructure, locally modifying nearshore hydrodynamic, wave and sediment transport processes; and
- The presence of cable protection measures in shallow nearshore areas, locally modifying hydrodynamic, wave and sediment transport processes.

2.11.72 The potential for the above to impact the shoreline is assessed within this section, through consideration of the MDS presented in Table 2.8.

CONCEPTUAL UNDERSTANDING OF CHANGE

WTG FOUNDATIONS

2.11.73 On the basis of the discussion of potential changes to waves (set out in Paragraph 2.11.9 *et seq.;* Figure 2.7) and within Volume 4, Annex 2.1: Physical Processes Baseline Technical Report, there are not expected to be any detectable changes to the wave regime at the coast. Accordingly, the rate (and direction) of net longshore sediment transport at the coast will remain unaltered from baseline conditions and therefore there will be no associated morphological change to the coast.

EXPOSURE OF CABLES

2.11.74 Once buried, the only way in which the cables could influence intertidal morphology during operation would be if they became exposed as a consequence of natural change. Detailed understanding of the likely temporal variability in intertidal topography throughout the lifetime of the Project is therefore critical for informing appropriate target burial depths.

2.11.75 Arguably the most robust means by which to understand the potential for future variability at the landfall is through detailed consideration of the observed longer term morphological behaviour which has taken place alongside consideration of the existing and planned future management measures. This assessment approach is followed here, with a full analysis presented in within Volume 4, Annex 2.1: Physical Processes Baseline Technical report based on:

- Google Earth aerial imagery (period 2000 to 2022) (Figure 2.20),
- Environment Agency LiDAR topographic surveys (period 1999 to 2019); and
- Bathymetric analyses of changes in the nearshore seabed.

2.11.76 In summary, the character of the beach and coastline in the landfall area is presently stable due to the coastal defences present; however, the future stability of the coastline will remain dependent on the future management policies and activities for both the local area and for coastal regions up drift (to the northeast). As previously discussed in Paragraph 2.10.37, after 2055 a dual policy for the Management Unit in which the landfall is located means that the existing frontline defences may be held where they are now or some form of Managed Realignment may be implemented. No details of these potential future managed realignment options are available and therefore an assessment of long-term future change in the context of coastal management is not possible. However, in as far as is practicably possible, the Project will take into consideration the potential for future managed realignment of the coast in this area, factoring conservatism into the design to minimise the risk of infrastructure exposure in future.

2.11.77 Provided a thorough cable burial risk assessment is undertaken, it is considered unlikely that cables within inter-tidal/ nearshore will become exposed throughout the lifetime of the project. However, even if a section of cable were to become exposed, it might locally influence intertidal processes and morphology at a scale proportional to the diameter of the cable (order of a few tens of centimetres) and the length of the exposed section. The cable may become naturally reburied although could require reburial using similar techniques to that set out in the assessment of SSC and bed level changes associated with cable installation activities (Paragraph 2.10.1 *et seq.*).

CABLE PROTECTION MEASURES

2.11.78 Cable protection measures could be installed in shallow subtidal locations near to the landfall potentially influencing nearshore wave conditions and patterns of sediment transport in the immediate vicinity of the cable. However, the Project has committed to not using loose rock or gravel protection within sub-tidal areas of seabed closer than 1,600 m seaward of the MHWS tide mark(although other forms of protection may be used such a mattresses or rock bags). It is assumed that if and where cable protection measures are used in shallow subtidal areas near to the landfall, they would be installed with a sufficiently low profile relative to the surrounding bed to present minimal blockage of sediment or barrier to the passage of waves. Accordingly, there would be no change to patterns of longshore sediment transport and therefore no impacts to coastal morphology.

ASSESSMENT OF SIGNIFICANCE

2.11.79 The coast at the landfall is considered of **medium** sensitivity/ importance and the magnitude of impact to the coast is predicted to be **negligible** (neutral). This assessment of magnitude is based on the fact that any changes would be spatially limited and very hard to discern form natural variability.

2.11.80 The overall level of effect of the removal of cables at the landfall during decommissioning has been assessed as being of **minor adverse** significance which is not significant in EIA terms (Table 2.6).

2.12 ENVIRONMENTAL ASSESSMENT: DECOMMISSIONING PHASE

IMPACT 10: POTENTIAL CHANGES TO SSC, BED LEVELS AND SEDIMENT TYPE

OVERVIEW

2.12.1 The following decommissioning activities could potentially give rise to increases in SSC and associated deposition of material within the array areas and the offshore ECC:

- Removal of foundation structures;
- Cutting off of monopiles and jacket foundation legs; and
- (Possible) removal of cables from the intertidal zone.

2.12.2 Further details regarding the MDS are provided in Table 2.8.

CONCEPTUAL UNDERSTANDING OF CHANGE

2.12.3 The removal of WTG foundations is expected to result in some localised seabed disturbance accompanied by temporary increases in SSC. Foundations involving piled solutions would be cut off at or just below, potentially causing a localised disturbance of the bed and a temporary increase in SSC.

2.12.4 For the purposes of the EIA it has been assumed that all cables will be removed from the intertidal zone during decommissioning. It is probable that equipment similar to that which is used to install the cables could be used to reverse the burial process and expose the cables. Accordingly, the area of seabed impacted during the removal of the cables would be similar as the area impacted during the installation of the cables.

2.12.5 For all of the above, the changes in SSC and accompanying changes to bed levels than those associated with decommissioning activities are expected to be lesser than that associated with construction. Further information is provided in the construction phase assessment (Section 2.10).

2.12.6 It is expected that offshore cables would be left *in situ* where buried and removed where cables are exposed. However, the Project will consider the best environmental option at the time of decommissioning.

ASSESSMENT OF SIGNIFICANCE

2.12.7 The assessment set out in this section has considered potential changes to pathways, rather than impacts on receptors. However, the potential for these changes to impact other EIA receptor groups are considered elsewhere within the ES, in particular:

- Volume 2, Chapter 3: Marine Water and Sediment Quality;
- Volume 2, Chapter 4: Offshore Ornithology;
- Volume 2, Chapter 5: Benthic and Intertidal Ecology;
- Volume 2, Chapter 6: Fish and Shellfish Ecology; and
- Volume 2, Chapter 7: Marine Mammal Ecology.

IMPACT 11: POTENTIAL IMPACTS TO COASTAL MORPHOLOGY

OVERVIEW

2.12.8 The MDS in terms of the potential for impacts to coastal feature receptors would be the total removal of all infrastructure (including foundations, scour protection, cables, and any rock protection) within the array, along the offshore ECC and at the landfall. Details regarding the MDS are provided in Table 2.8.

CONCEPTUAL UNDERSTANDING OF CHANGE

2.12.9 The removal of structures (especially rock protection) which have been in place for a long time could in theory, lead to much longer-term effects on morphodynamics. This is because the coastal and seabed morphology could have evolved to a new equilibrium state including the influence and presence of that structure. However as noted in Paragraph 2.11.32, in the intertidal any cable remedial protection methods will be buried and therefore the potential for the structures to interact with and inhibit the movement of sediment would be greatly diminished.

2.12.10 It is not expected that the removal of any cable protection from shallow sub-tidal areas would lead to substantive morphological change. This is because the presence of any cable protection measures is not expected to result in widespread change to the beach at the landfall in the first instance, for the reasons set out in Paragraph 2.10.47 *et seq*.

2.12.11 Should the cable system require removal at the end of its operational life, it will be removed through the same sediments and sub-strata disturbed during installation. This process could result in short-term elevations in SSC and localised changes in bed level. It is anticipated that the working areas for removal will also be restricted to the area used for installation; accordingly, any change would be no greater in magnitude than for the construction phase. If the cables are left in the seabed at the end of the Project lifespan, impacts will be the same as those described previously for the operational phase.

ASSESSMENT OF SIGNIFICANCE

2.12.12 The coast at the landfall is considered of **medium** sensitivity/ importance and the magnitude of impact to the coast is predicted to be **low** (adverse). This assessment of magnitude is based on the fact that any changes would be temporary and spatially limited.

2.12.13 The overall level of effect of the removal of cables at the landfall during decommissioning has been assessed as being of **minor adverse** significance which is not significant in EIA terms (Table 2.6).

2.13 ENVIRONMENTAL ASSESSMENT: CUMULATIVE EFFECTS

2.13.1 This cumulative impact assessment for physical processes has been undertaken in accordance with the methodology provided in Volume 1, Annex 3.1: Cumulative Effects Assessment Methodology.

2.13.2 The projects and plans selected as relevant to the assessment of impacts to physical processes are based upon an initial screening exercise undertaken on a long list. The longlist of projects and plans is then broken down further into three different tiers (Tier 1, 2 and 3) depending on at what stage the project is at. A full description of the tiers can be found in Volume 1, Annex 3.1: Cumulative Effects Assessment Methodology and is highlighted below in Table 2.12. Each project, plan or activity has been considered and scoped in or out on the basis of effect–receptor pathway, data confidence and the temporal and spatial scales involved. For the purposes of assessing the impact of the VE on physical processes in the region, the cumulative effect assessment technical note submitted through the EIA Evidence Plan provided as Volume 1, Annex 3.1: Cumulative Effects Assessment Methodology, screened in a number of projects and plans as presented in Table 2.13 and shown in Figure 2.9.

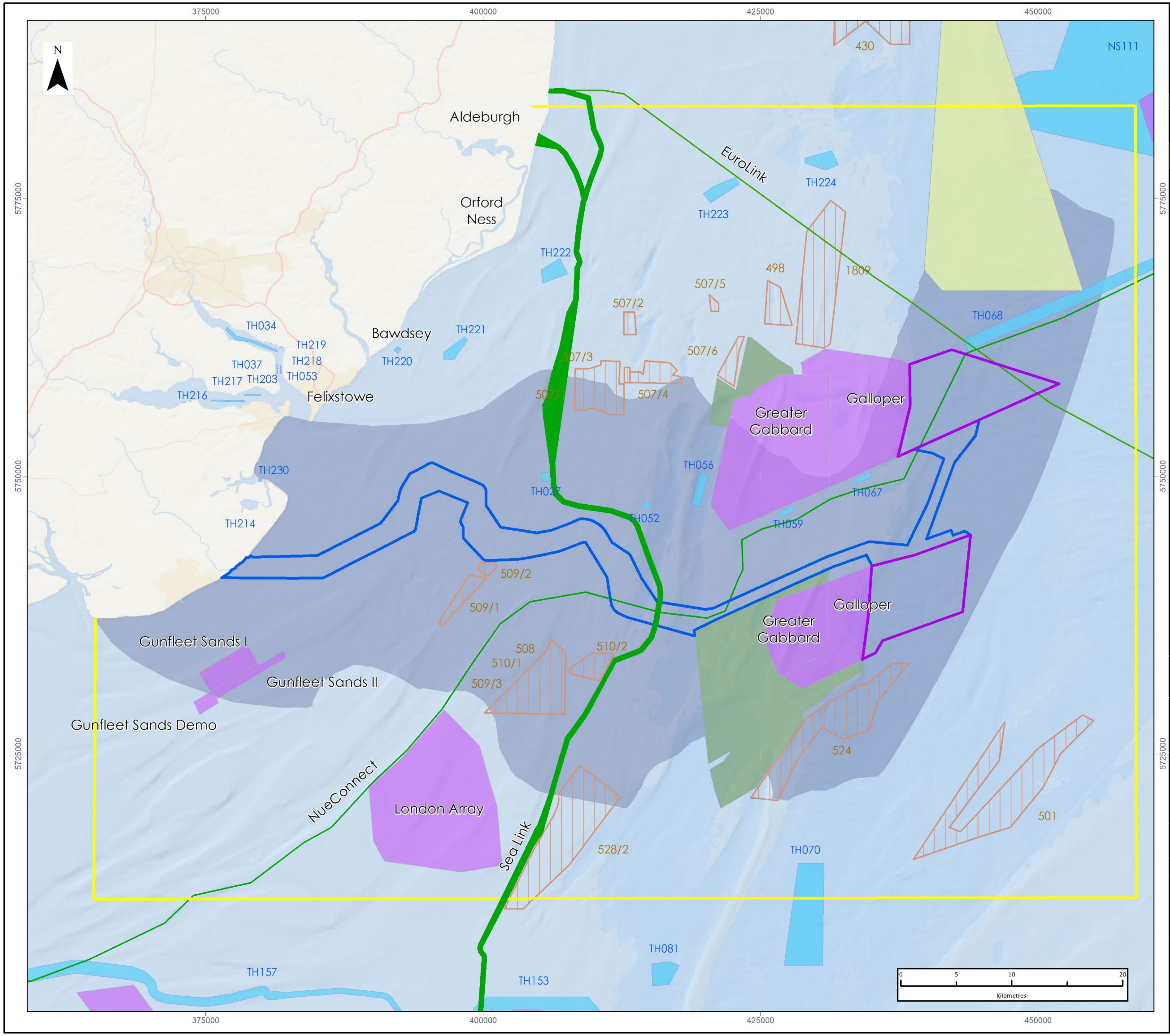
Table 2.12: Description of Tiers of other developments considered for CEA

Tiers	Development Stage
Tier 1	Projects under construction.
	Permitted applications, whether under the Planning Act 2008 or other regimes, but not yet implemented.
	Submitted applications, whether under the Planning Act 2008 or other regimes, but not yet determined.
Tier 2	Projects on the Planning Inspectorate's Programme of Projects where a Scoping Report has been submitted.
	Projects under the Planning Act 2008 where a PEIR has been submitted for consultation.
Tier 3	Projects on the Planning Inspectorate's Programme of Projects where a Scoping Report has not been submitted.
	Identified in the relevant Development Plan (and emerging Development Plans with appropriate weight being given as they move closer to adoption) recognising that much information on any relevant proposals will be limited.
	Identified in other plans and programmes (as appropriate) which set the framework for future development consents/ approvals, where such development is reasonably likely to come forward.

Table 2.13: Projects considered within the physical processes cumulative effect assessment.

Development type	Project	Status	Data confidence assessment/ phase	Tier
Offshore Wind Farm	Galloper	Round 2 Constructed	High	Tier 1
Offshore Wind Farm	Greater Gabbard	Round 2 Constructed	High	Tier 1
Offshore Wind Farm	Gunfleet Sands I	Round 1 Constructed	High	Tier 1
Offshore Wind Farm	Gunfleet Sands II	Round 1 Constructed	High	Tier 1
Offshore Wind Farm	Gunfleet Sands Demo	Constructed	High	Tier 1
Offshore Wind Farm	London Array	Round 2 Constructed	High	Tier 1
Offshore Wind Farm	East Anglia TWO	Consented	High	Tier 1
Offshore Wind Farm	North Falls	Pre-planning application	Medium	Tier 2
Aggregate production area	Area 524	Active	High	Tier 1
Aggregate production area	Area 507/1/4	Active	High	Tier 1
Aggregate production area	Area 508	Active	High	Tier 1
Aggregate production area	Area 509/1/2/3	Active	High	Tier 1
Aggregate production area	Area 510/1/2	Active	High	Tier 1
Aggregate production area	Area 528/2	Active	High	Tier 1
Dredge Spoil Disposal Site	Harwich Haven (TH027)	Active	High	Tier 1
Dredge Spoil Disposal Site	Inner Gabbard (TH052)	Active	High	Tier 1

Development type	Project	Status	Data confidence assessment/ phase	Tier
Dredge Spoil Disposal Site	Inner Gabbard East (TH056)	Active	High	Tier 1
Interconnector cable	NeuConnect Interconnector	Proposed	Medium	Tier 1
Interconnector cable	Sea Link Interconnector	Proposed	Medium	Tier 1
Interconnector cable	Nautilus Multti-Purpose Interconnector	Proposed	Medium	Tier 3
Interconnector cable	EuroLink interconnector	Proposed	Low	Tier 3



LEGEND

- Array Areas
- Offshore Export Cable Corridor
- Physical Processes Study Area
- Wind Farm (Active/In Operation)
- East Anglia TWO (Consented)
- North Falls Wind Farm (Pre-planning)
- Spring Tidal Excursion Buffer
- Cefas Open Disposal Site
- Aggregate Licence Area
- Interconnectors

PROJECT TITLE:

FIVE ESTUARIES OFFSHORE WINDFARM

DRAWING TITLE:

Cumulative Effect Assessment

VER	DATE	REMARKS	Drawn	Checked
1	28/02/2023	For Issue	CRO	NKD

DRAWING NUMBER:

2.9

SCALE:	PLOT SIZE:	DATUM:	PROJECTION:
1:350,000	A3	WGS84	UTM31N

FIVE ESTUARIES OFFSHORE WIND FARM

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2.13.3 The cumulative Rochdale Envelope is described in Table 2.14.

Table 2.14: Cumulative MDS.

Impact	Scenario	Justification
Impact 12: Potential for cumulative temporary increases in SSC and seabed levels as a result of VE foundation installation, inter-array/ export cable laying and aggregate dredging.	MDS as described for construction phase of VE assessed cumulatively with aggregate extraction operations at Area 507/1/4, Area 508, Area 509/1/2/3, Area 510/1/2, Area 524 and Area 528/2.	Identified sites are within a spring tidal excursion ellipse from the array areas and offshore ECC. Meaningful sediment plume interaction generally only has the potential to occur if the activities generating the sediment plumes are located within one spring tidal excursion ellipse from one another and occur at the same time.
Impact 13: Potential for cumulative temporary increases in SSC and seabed levels as a result of export cable laying and dredge spoil disposal at licensed disposal grounds.	MDS as described for construction phase of VE assessed cumulatively with dredge disposal operations at Disposal Sites TH027, TH052 and TH056.	
Impact 14: Potential for cumulative temporary increases in SSC and seabed levels as a result of VE foundation installation, inter-array/ export cable laying and interconnector cable installation	MDS as described for construction phase of VE assessed cumulatively with cable installation operations for the Nautilus, Sea Link, EuroLink and NeuConnect Interconnectors.	
Impact 15: Potential for cumulative changes to the wave regime, with associated impacts to sandbanks and the coast, arising	MDS as described for operation phase of VE (for blockage of waves, currents and sediment transport) assessed cumulatively with operation of the following OWFs:	Maximum potential for cumulative changes to hydrodynamics, waves and sediment transport.

Impact	Scenario	Justification
from interaction with other proposed OWF projects.	> Galloper > Greater Gabbard > Gunfleet Sands I > Gunfleet Sands II > Gunfleet Sands Demo > London Array > East Anglia TWO > North Falls	

IMPACT 12: POTENTIAL FOR CUMULATIVE TEMPORARY INCREASES IN SSC AND SEABED LEVELS AS A RESULT OF VE FOUNDATION INSTALLATION, INTER-ARRAY/ EXPORT CABLE LAYING AND AGGREGATE DREDGING.

OVERVIEW

2.13.4 Aggregate Area 524 is within a distance of one spring tidal excursion ellipse from the southern array area and offshore ECC. Aggregate Areas 507/1/4, Area 508, Area 509/1/2/3, Area 510/1/2, Area 524 and Area 528/2 are also within one spring tidal excursion ellipse from the offshore ECC (Figure 2.9). Accordingly, it is necessary to consider the potential for cumulative changes in SSC and bed levels.

2.13.5 It is understood that the target material at the sites is both sands and gravels, principally for use in the construction industry. The permitted annual licensed tonnage from aggregate sites in the Outer Thames region is 3.8 million tonnes although typical annual dredging amounts are usually around half of this figure (TCE, 2022).

CONCEPTUAL UNDERSTANDING OF CHANGE

2.13.6 The interaction between sediment plumes generated by VE construction activities and those from nearby aggregate dredging could theoretically occur in two ways:

- Where plumes generated from the two different activities meet and coalesce to form one larger plume; or
- Where aggregate extraction occurs within the plume generated by VE construction activities (or vice versa).

2.13.7 For two or more separately formed plumes that meet and coalesce, the physical laws of dispersion theory mean concentrations within the plumes are not additive but instead a larger plume is created with regions of potentially differing concentration representative of the separate respective plumes. In contrast, in the case of plumes formed by a dredging vessel operating within the plume created by foundation installation or bed preparation activities (or vice versa), the two plumes would be additive, creating a plume with higher SSC.

2.13.8 On the basis of the assessment considering potential changes in SSC associated with export cable installation (Paragraph 2.10.1 *et seq*.), it is found that any fine grained sediment plume will be subject to rapid dispersion, both laterally and vertically, to near-background levels (tens of mg/l) within hundreds to a few thousands of metres at the point of release. Similarly, on the basis of the numerical plume modelling presented in TEDA (2010) - considering the characteristics of fine sediment plumes associated with aggregate dredging in the Outer Thames Estuary region - it is found that:

"The predicted increases in suspended sediment concentration that will be experienced outside each of the proposed Licence Areas will be less than 20 mg/l above background levels except when dredging occurs close to the boundary of a Licence Area. Even when this does occur suspended sediment concentrations more than 50 mg/l above background levels are only likely to be experienced within 200 m of the Licence Area boundary and concentrations more than 20 mg/l above background levels are only likely to be experienced within 1 km of the Licence Area boundary.

These concentration increases will be experienced only while dredging occurs and only in the streamline of the dredger. As a result, for the vast majority of the time over the licensing period at any given point in the study region there will be no increases in suspended sediment concentration above background levels. Even when concentration increases, which can be characterised as a few tens of mg/l above background levels, occur, these concentrations are less than the increases which occur naturally as a result of variation in tidal conditions and waves."

2.13.9 With the exception of Area 509/1, all aggregate areas are located over 1 km away. Any cumulative increase in either the spatial footprint or peak concentration of sediment plumes are therefore expected to be indistinguishable. Any associated changes in bed level will also be immeasurable.

2.13.10 The only aggregate licence area within 1 km of the Project is Area 509/1 (Longsand) which is located circa 100 m to the south of the offshore ECC and dredged by Tarmac Marine Ltd. Given the very close proximity of the two activities, it is considered that both types of plume interaction described above could theoretically occur. However, it is noted that in line with UNCLOS (The United Nations Convention on the Law of the Sea) a safety zone is expected to be in place around the cable installation vessel to minimize collision risk. Accordingly, whilst plume interaction may still occur, the potential for much higher concentration and more persistent plumes than that previously described in the project-alone assessments of SSC is considered to be small. Cumulative increases in bed level could still theoretically occur. However, it is noted that this location is characterised by high current speeds which regularly re-work mobile material at the bed, resulting in a general north-easterly direction in net bedload transport in the vicinity of Area 509/1 (Volume 4, Annex 2.1: Physical Processes Baseline Technical Report).

2.13.11 It is also worth noting that spring tidal excursion ellipses are quite strongly rectilinear within the vicinity of the aggregate extraction areas nearby to VE. This means that although at times during the construction phase some plume interaction may occur, the number of occurrences is expected to be less than for an equivalent setting with more rotary tidal excursion characteristics.

ASSESSMENT OF SIGNIFICANCE

2.13.12 The assessment set out in this section has considered potential changes to pathways, rather than impacts on receptors. However, the potential for these changes to impact other EIA receptor groups are considered elsewhere within the ES, in particular:

- Volume 2, Chapter 3: Marine Water and Sediment Quality;
- Volume 2, Chapter 4: Offshore Ornithology;
- Volume 2, Chapter 5: Benthic and Intertidal Ecology;
- Volume 2, Chapter 6: Fish and Shellfish Ecology; and
- Volume 2, Chapter 7: Marine Mammal Ecology.

IMPACT 13: POTENTIAL FOR CUMULATIVE TEMPORARY INCREASES IN SSC AND SEABED LEVELS AS A RESULT OF EXPORT CABLE LAYING AND DREDGE SPOIL DISPOSAL AT LICENSED DISPOSAL GROUNDS.

OVERVIEW

2.13.13 The offshore ECC is located within a spring tidal excursion ellipse of dredge disposal sites TH027 (Harwich Haven), TH052 (Inner Gabbard) and TH056 (Inner Gabbard East). Should export cable installation be occurring at the same time as dredge disposal activities at these sites, there could theoretically be the potential for cumulative changes in SSC and bed levels.

2.13.14 Harwich Haven (TH027) is a relatively new disposal site, characterised by the Harwich Haven Authority (HHA). The site lies off the entrance to the main navigation channel to the ports of Harwich and Felixstowe, 9 km further inshore than the existing Inner Gabbard disposal site (TH052) (Bolam et al. (2018). As part of the licence condition, HHA was required to conduct monitoring during and after these disposal campaigns for turbidity/suspended sediment concentrations, seabed sediment deposition using bathymetry and sediment traps, and benthic sampling for benthic community impacts (HRW, 2017). The main findings were summarised as:

- there was no evidence of any large-scale increase in SSC as a result of the disposal activity;
- analysis of bathymetry showed very little evidence of seabed level changes; and
- there was no evidence of an increase in fine material resulting from the two trial disposal events.

2.13.15 These findings were broadly supported by the independent monitoring analysis undertaken by Cefas at the site during 2017 (Bolam et al. 2018).

2.13.16 The Inner Gabbard East disposal ground is considered to be a non-dispersive site; therefore, apart from the occurrence of natural erosion and deposition, it is likely that once the material has been placed there it will remain in place (HHA, 2019).

2.13.17 The Inner Gabbard East disposal ground (TH056) was originally characterised by Harwich Haven Authority in 2003 for the disposal of consolidated capital dredge material arising from the Bathside Bay approach channel deepening and widening project. A subsequent application to expand the size (and therefore disposal capacity) of the site was made in 2019 to allow disposal of capital dredged material from the deepening of Harwich Harbour and approach channel to the Haven Ports. In future, there is likely to be the potential for further dredging requirements in the various Haven Ports (Felixstowe, Harwich International, Ipswich, Harwich Navyard and Mistley) which may require use of the site. Further dredging requirements may also be required to ensure that the Haven Ports are able to accommodate the changing needs of the global shipping industry and remain competitive (HHA, 2019).

CONCEPTUAL UNDERSTANDING OF CHANGE

2.13.18 Dredge disposal site TH027 and TH052 are located at a distance of circa 5.5 km and 4 km from the offshore ECC, respectively, in relation to the orientation of the tidal axis. At this distance apart, any cumulative increase in either the spatial footprint or peak concentration of sediment plumes is expected to be indistinguishable from that previously reported for the export cable installation on its (Paragraph 2.10.1 *et seq.*). Any associated cumulative changes in bed level will also be immeasurable.

2.13.19 As for the assessment of potential cumulative interaction with aggregate dredging operations, it is also worth noting that spring tidal excursion ellipses are strongly rectilinear within the vicinity of the dredge disposal sites nearby to the offshore ECC. This means that although at times during the construction phase some plume interaction may occur, the number of occurrences is expected to be less than for an equivalent setting with more rotary tidal excursion characteristics.

ASSESSMENT OF SIGNIFICANCE

2.13.20 The assessment set out in this section has considered potential changes to pathways, rather than impacts on receptors. However, the potential for these changes to impact other EIA receptor groups are considered elsewhere within the ES, in particular:

- Volume 2, Chapter 3: Marine Water and Sediment Quality;
- Volume 2, Chapter 4: Offshore Ornithology;
- Volume 2, Chapter 5: Benthic and Intertidal Ecology;
- Volume 2, Chapter 6: Fish and Shellfish Ecology; and
- Volume 2, Chapter 7: Marine Mammal Ecology.

IMPACT 14: POTENTIAL FOR CUMULATIVE TEMPORARY INCREASES IN SSC AND SEABED LEVELS AS A RESULT OF VE FOUNDATION INSTALLATION, INTER-ARRAY/ EXPORT CABLE LAYING AND INTERCONNECTOR CABLE INSTALLATION

OVERVIEW

2.13.21 The EuroLink and NeuConnect interconnectors are all on routes which pass through the northern array area and both the Sea Link and NeuConnect interconnectors cross the offshore ECC. The route for the Nautilus interconnector has not yet been confirmed but is expected to overlap with or be in close proximity to the northern array area. Construction for Nautilus is planned for 2027; NeuConnect is planned for 2027, with construction completed in 2028 and Sea Link planned for 2028/29. It is understood that EuroLink will be constructed by 2030. Since construction of these interconnectors falls within the proposed VE construction period, the potential for cumulative temporary increases in SSC and seabed levels has been assessed here.

CONCEPTUAL UNDERSTANDING OF CHANGE

2.13.22 Given that the interconnectors overlap with the VE offshore boundary, there is some potential for sediment plume interaction during construction/ installation operations. However, as noted earlier in this section for aggregate extraction operations (Paragraph 2.13.4 et seq.), cable installation vessels typically request a vessel safety zone when installing or handling cables. The exact distances within which other such vessels can pass typically varies, depending on location. However, it is reasonable to assume that this zone could be around 500 m. As set out in paragraph 2.10.7, at a distance of greater than 500 m from the source of bed disturbance any increases in SSC are expected to be modest (tens to low hundreds of mg/l) and fine sediment is unlikely to deposit in measurable thickness. In addition to direct communications between the ships, this process will likely be managed via vessel management plans and official bulletins, such as notice to mariners. Accordingly, whilst plume interaction may still theoretically occur, the potential for much higher concentration and/or more persistent plumes than that previously described in the VE-alone assessments of SSC is small.

2.13.23 Cumulative increases in bed level could also theoretically occur although the potential for this to occur is expected to be very low, given the expected separation distance of the vessels and the fact that seabed sediments are regularly re-worked and transported by tidal currents in this region.

ASSESSMENT OF SIGNIFICANCE

2.13.24 The assessment set out in this section has considered potential changes to pathways, rather than impacts on receptors. However, the potential for these changes to impact other EIA receptor groups are considered elsewhere within the ES, in particular:

- Volume 2, Chapter 3: Marine Water and Sediment Quality;
- Volume 2, Chapter 4: Offshore Ornithology;
- Volume 2, Chapter 5: Benthic and Intertidal Ecology;
- Volume 2, Chapter 6: Fish and Shellfish Ecology; and
- Volume 2, Chapter 7: Marine Mammal Ecology.

IMPACT 15: POTENTIAL FOR CUMULATIVE CHANGES TO THE WAVE REGIME, WITH ASSOCIATED IMPACTS TO SANDBANKS AND THE COAST, ARISING FROM INTERACTION WITH OTHER PROPOSED OWF PROJECTS.

OVERVIEW

2.13.25 There are eight offshore wind farms (either operational, under construction or consented) within the marine processes study area. These are:

- Galloper;
- Greater Gabbard;
- East Anglia TWO;
- North Falls;
- Gunfleet Sands I;
- Gunfleet Sands II;
- Gunfleet Sands Demo; and
- London Array.

2.13.26 In the following section, potential changes to the wave regime arising from the operational presence of VE are initially considered, followed by a wider discussion of potential impacts to sandbanks and coastal morphology across the marine processes study area.

CONCEPTUAL UNDERSTANDING OF CHANGE

2.13.27 The same numerical wave model used to assess wave blockage effects arising from the Project alone assessment was also used to consider the potential for cumulative interaction with other wind farms located in the study area. Results are reported in Volume 4, Annex 2.2: Physical Processes Model Design and Validation. The most common prevailing wave directions within the array areas are from the north (16% of the time), northeast (also 16%) and southwest (27%): potential changes to waves from these directions are therefore shown in Figure 2.10. The MDS for East Anglia Two and North Falls are based on the known maximum number of WTGs in conjunction with the largest known foundation design options for these sites. The layout of each array has been assumed with a distribution that achieves maximum cumulative interaction with the Project.

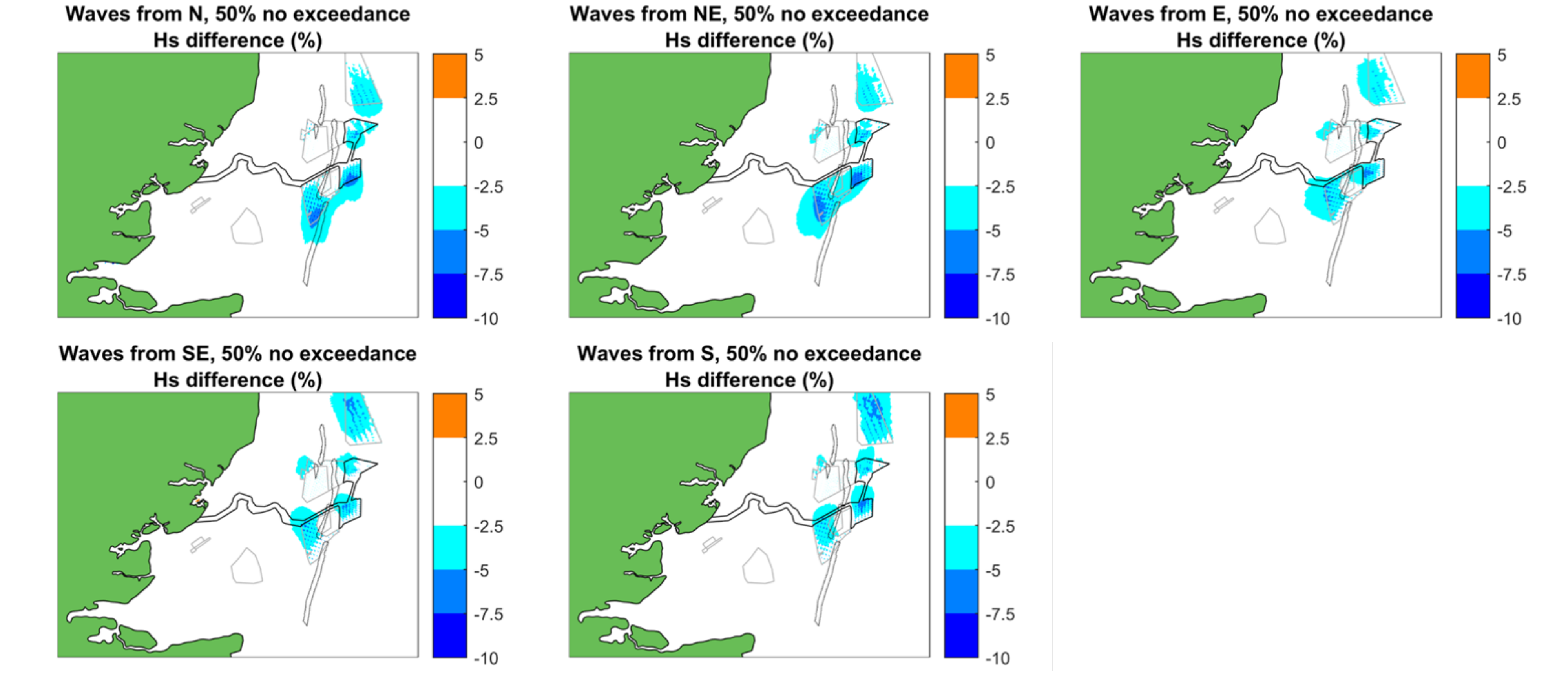

Figure 2.10: Cumulative changes to the wave regime arising from operation of VE along with other planned and operational wind farms within the study area. (Outline of Annex I sand banks also shown)

2.13.28 It is found that:

- GOWF, GGOWF and North Falls are the closest projects to the array areas. However, both GOWF and GGOW were constructed using monopile foundations which cause minimal wave blockage and therefore have very limited potential to cause cumulative change to wave height;
- North Falls could potentially be constructed using gravity base foundations which result in far greater wave blockage than monopiles. The presence of turbine foundations in the southern array area and southern half of the North Falls site do have the potential to cause a cumulative reduction in wave height across a wider area than is the case for the project alone assessment when the projects are aligned with respect to the wave coming directions; and
- Waves from a northerly direction will pass through both East Anglia TWO and VE array areas. However, even if East Anglia TWO is constructed using gravity base foundations, there is minimal potential for a cumulative reduction in wave heights associated with waves from this direction.

2.13.29 Although the numerical wave modelling demonstrates the potential for cumulative changes in waves, the potential for associated changes in morphology at the coast or seabed is considered very low:

- Measurable changes in wave height do not extend to any coastal location within the study area, regardless of prevailing wave direction. Accordingly, there is no potential for change in either the rate or direction of longshore sediment transport.
- Whilst it is possible that intermittent reductions in wave height of (up to) circa 5% may occur for short periods of time over sandbanks inshore of the array areas, it is considered extremely unlikely that such modest changes would manifest in morphological change to the crest elevations of the banks. This is because all of these banks will, at various times, be influenced by storm waves which haven't travelled through the wind farm arrays. These waves would be unaltered from their baseline condition and would redistribute material from the crests, maintaining the existing elevation of the banks.

2.13.30 These small theoretical changes in wave characteristics should be set in the wider context of climate change and natural variability. Predicted changes in wave height, as well as alterations to the directional wave climate driven by changes in large scale climate variability are likely to result in spatial modifications (erosion and accretion) to coastlines and seabed morphology due to deviations in sediment transport and supply (e.g. Palmer et al. 2018; Splinter et al., 2012). Such future changes are expected to far exceed those which theoretically could occur as a result of the presence of the operational wind farms.

ASSESSMENT OF SIGNIFICANCE

SANDBANKS

2.13.31 The Annex I sandbanks within the study area are all internationally important. However, they are understood to be highly dynamic features and assessed to have some capacity to recover from disturbance. Accordingly, they are considered of **medium** sensitivity/ importance.

2.13.32 The magnitude of impact to sandbanks arising from localised (and sporadic) changes to the wave regime is predicted to be **low** (adverse). This assessment of magnitude is based on the fact that sandbanks are tidally induced bedforms, with sand bank formation principally governed by sediment availability and the prevailing tidal current regime rather than the action of waves.

2.13.33 The overall level of effect on sandbanks has been assessed as being of **minor** adverse significance which is not significant in EIA terms.

THE COAST

2.13.34 The coast at the landfall is considered of **medium** sensitivity/ importance and the magnitude of impact to the coast is predicted to be **negligible** (neutral). This assessment of magnitude is based on the fact that changes to the wave regime will not extend to the coast and therefore there is no potential for morphological change.

2.13.35 The overall level of effect of the removal of cables at the landfall during decommissioning has been assessed as being of **minor adverse** significance which is not significant in EIA terms (Table 2.6).

2.14 INTER-RELATIONSHIPS

2.14.1 The term 'Inter-relationship' takes into account the environmental interactions ('inter-relationships') with other receptors within the Project. These are referred to in the Infrastructure Planning (Environmental Impact Assessment) Regulations 2009.

2.14.2 The different physical processes studied are already inter-related; in particular, sediment transport is dependent on currents and waves and therefore these linked processes have already been considered within the assessment. In turn, this information on changes to physical processes has been used to inform other PEIR topics such as Volume 2, Chapter 4: Offshore Ornithology and Volume 2, Chapter 5: Benthic and Intertidal Ecology. Assessments have been undertaken separately within these individual topic Chapters and are not reported here as additional inter-relationships. A full assessment of inter-relationships between topics is presented in Volume 2, Chapter 14: Inter-Relationships.

2.15 TRANSBOUNDARY EFFECTS

2.15.1 No transboundary effects have been identified. This is because the predicted changes to the key physical process pathways (i.e. tides, waves, and sediment transport) are not anticipated to be sufficient to influence any of the identified receptors at this distance from the Project.

2.16 SUMMARY OF EFFECTS

2.16.1 This chapter has investigated potential changes to marine physical processes arising from the Project. The range of potential impacts and associated effects considered has been informed by Scoping responses and from subsequent discussions with stakeholders as part of the ETG process Table 2.2. It has also drawn upon reference to existing policy and guidance.

2.16.2 The assessment has been undertaken in three stages. These are:

- The determination of the MDS from Volume 2, Chapter 1: Offshore Project Description;

- The determination of the baseline physical environment (including potential changes over the Project lifetime due to natural variation) (Volume 4, Annex 2.1: Physical Processes Baseline Technical Report); and
- Assessment of changes to physical processes arising from the MDS both for VE on its own and in conjunction with other built and consented projects.

2.16.3 In order to assess the potential changes relative to the baseline (existing) coastal and marine environment, a combination of complementary approaches have been adopted for the VE physical processes assessment. These include:

- Numerical modelling of hydrodynamic, wave and sediment transport processes;
- The 'evidence base' containing monitoring data collected during the construction and O&M of other OWF developments (especially the adjacent GOWF and GGOWF developments);
- Analytical assessments of project-specific data; and
- Standard empirical equations describing (for example) the potential for scour development around structures (e.g. Whitehouse, 1998).

2.16.4 A wide range of potential changes to physical processes have been considered, including short-term sediment disturbance due to construction activities, scour around foundations and the potential for changes to the coast and nearby bank systems, arising from the blockage of waves and tides.

2.16.5 Even using a worst case MDS approach for the EIA, it has been found that for all receptor groups, the level of effect significance is either Negligible or Low for all phases of development (Table 2.15). Accordingly, all of the potential effects to physical processes receptors are therefore Not Significant in terms of the EIA Regulations (Volume 1, Chapter 3: EIA Methodology).

Table 2.15: Summary of effects for physical processes.

Description of effect	Change/ Effect	Additional mitigation measures	Residual effect
Construction			
Impact 1: Potential changes to suspended sediment concentrations (SSC), bed levels and sediment type arising from construction related activities including dredging, drilling and cable installation	This assessment considers changes to a 'pathway', rather than an impact on a receptor. Accordingly no assessment of effect significance is provided.	Not Applicable – no additional mitigation identified	This assessment considers changes to a 'pathway', rather than an impact on a receptor. Accordingly no assessment of effect significance is provided.
Impact 2: Potential morphological impacts to sandbanks and designated areas of seabed	Minor (adverse)	Not Applicable – no additional mitigation identified	No significant adverse residual effects
Impact 3: Potential impacts to landfall morphology	Minor (adverse)	Not Applicable – no additional mitigation identified	No significant adverse residual effects
Operation			
Impact 4: Potential changes to the tidal regime	(Pathway)	Not Applicable – no additional mitigation identified	(Pathway)
Impact 5: Potential changes to the wave regime	(Pathway)	Not Applicable – no additional mitigation identified	(Pathway)
Impact 6: Potential changes to the sediment transport regime	(Pathway)	Not Applicable – no additional mitigation identified	(Pathway)

Description of effect	Change/ Effect	Additional mitigation measures	Residual effect
Impact 7: Potential for scour of seabed sediments, including that around scour protection structures	Minor (adverse)	Not Applicable – no additional mitigation identified	No significant adverse residual effects
Impact 8: Potential morphological impacts to sandbanks and designated areas of seabed	Minor (adverse)	Not Applicable – no additional mitigation identified	No significant adverse residual effects
Impact 9: Potential impacts to coastal morphology	Minor (adverse)	Not Applicable – no additional mitigation identified	No significant adverse residual effects
Decommissioning			
Impact 10: Potential changes to SSC, bed levels and sediment type	(Pathway)	Not Applicable – no additional mitigation identified	(Pathway)
Impact 11: Potential impacts to landfall morphology	Minor (adverse)	Not Applicable – no additional mitigation identified	No significant adverse residual effects
Cumulative effects			
Impact 12: Potential for cumulative temporary increases in SSC and seabed levels as a result of VE foundation installation, inter-array/ export cable laying and aggregate dredging.	(Pathway)	Not Applicable – no additional mitigation identified	(Pathway)

Description of effect	Change/ Effect	Additional mitigation measures	Residual effect
Impact 13: Potential for cumulative temporary increases in SSC and seabed levels as a result of export cable laying and dredge spoil disposal at licensed disposal grounds.	(Pathway)	Not Applicable – no additional mitigation identified	(Pathway)
Impact 14: Potential for cumulative temporary increases in SSC and seabed levels as a result of VE foundation installation, inter-array/ export cable laying and interconnector cable installation.	(Pathway)	Not Applicable – no additional mitigation identified	(Pathway)
Impact 15: Potential for cumulative changes to the wave regime, with associated impacts to sandbanks and the coast, arising from interaction with other proposed OWF projects.	Minor (adverse)	Not Applicable – no additional mitigation identified	No significant adverse residual effects

2.17 NEXT STEPS

2.17.1 The following steps will be undertaken in order to progress the Marine Geology, Oceanography and Physical Processes assessment from PEIR stage to DCO Application stage.

> Further details about the most realistic MDS foundation design and layout for the nearby proposed North Falls Offshore Wind Farm will be sought, in order to assess the most realistic worst case cumulative impacts with respect to this other development.

> Additional analysis will be undertaken by, or in conjunction with the engineering team, in order to refine the most realistic expectations for the dimensions of trenching and associated sandwave clearance in the array areas and ECC.

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