Pentland floating offshore wind farm

Volume 2: Offshore EIAR

Chapter 7: Marine Physical Processes

PENTLAND FLOATING OFFSHORE WIND FARM

OFFSHORE EIAR (VOLUME 2): MAIN REPORT

CHAPTER 7: MARINE PHYSICAL PROCESSES

Document Title:	Pentland Floating Offshore Wind Farm Offshore EIAR
Document no.	GBPNTD-ENV-XOD-RP-00003
Project:	Pentland Floating Offshore Wind Farm
Originator Company	Cooper Marine Advisors & Xodus Group Ltd
Revision	01
Originator	Bill Cooper / Anna Chaffey
Date	14.07.2022

Revision History:

Revision	Date	Status	Originator	Reviewed	Approved
01	14.07.2022	Final	BC/AC	TW/PM	PM

CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY OF PROJECT TERMS

Key Terms	Definition
Dounreay Trì Floating Wind Demonstration Project (the 'Dounreay Trì Project')	The 2017 consented project that was previously owned by Dounreay Trì Limited (in administration) and acquired by Highland Wind Limited (HWL) in 2020. The Dounreay Trì Project consent was for two demonstrator floating Wind Turbine Generators (WTGs) with a marine licence that overlaps with the Offshore Development, as defined. The offshore components of the Dounreay Trì Project consent are no longer being implemented.
Highland Wind Limited	The Developer of the Project (defined below) and the Applicant for the associated consents and licences.
Landfall	The point where the Offshore Export Cable(s) from the PFOWF Array Area, as defined, will be brought ashore.
Offshore Export Cable(s)	The cable(s) that transmits electricity produced by the WTGs to landfall.
Offshore Export Cable Corridor (OECC)	The area within which the Offshore Export Cable(s) will be located.
Offshore Site	The area encompassing the PFOWF Array Area and OECC, as defined.
Onshore Site	The area encompassing the PFOWF Onshore Transmission Infrastructure, as defined.
Pentland Floating Offshore Wind Farm (PFOWF) Array and Offshore Export Cable(s) (the 'Offshore Development')	All offshore components of the Project (WTGs, inter-array and Offshore Export Cable(s), floating substructures, and all other associated offshore infrastructure) required during operation of the Project, for which HWL are seeking consent. The Offshore Development is the focus of this Environmental Impact Assessment Report.
PFOWF Array	All WTGs, inter-array cables, mooring lines, floating sub-structures and supporting subsea infrastructure within the PFOWF Array Area, as defined, excluding the Offshore Export Cable(s).
PFOWF Array Area	The area where the WTGs will be located within the Offshore Site, as defined.
PFOWF Onshore Transmission Infrastructure (the 'Onshore Development')	All onshore components of the Project, including horizontal directional drilling, onshore cables (i.e. those above mean low water springs), transition joint bay, cable joint bays, substation, construction compound, and access (and all other associated infrastructure) across all project phases from development to decommissioning, for which HWL are seeking consent from The Highland Council.
PFOWF Project (the 'Project')	The combined Offshore Development and Onshore Development, as defined.

ACRONYMS AND ABBREVIATIONS

ADCP	Acoustic Current Doppler Profiler
BGS	British Geological Survey
BODC	British Oceanographic Data Centre
CBRA	Cable Burial Risk Assessment
CD	Chart Datum
CEMP	Construction Environmental Management Plan
CIRIA	Construction Industry Research and Information Association
CMS	Construction Method Statement
CPT	Cone Penetration Tests
CTD	Conductivity Temperature Depth
COWRIE	Collaborative Offshore Wind Research into the Environment
DECC	The Department of Energy and Climate Change
DHI	Danish Hydraulic Institute
EEA	European Economic Area
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EIAR	Environmental Impact Assessment Report
HAT	Highest Astronomical Tide
HDD	Horizontal Directional Drilling
IAC	Inter-Array Cables
INNS	Invasive Non Native Species
LAT	Lowest Astronomical Tide
MBES	Multi-Beam Echo Sounder
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLD	Mixed Layer Depth
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
MNR	Mean Neap Range
MPA	Marine Protected Area
MS-LOT	Marine Scotland - Licensing Operations Team
MSL	Mean Sea Level
MSR	Mean Spring Range
MSS	Marine Scotland Science
NTSLF	National Tidal and Sea Level Facility

NRW	Natural Resources Wales
OEMP	Operational Environmental Management Plan
OWF	Offshore Wind Farm
PFOWF	Pentland Floating Offshore Wind Farm
PO	Plan Option
RCP	Representative Concentration Pathways
SAC	Special Area of Conservation
SBP	Sub-Bottom Profiler
SHE	Scottish Hydro Electric
SNH	Scottish Natural Heritage
SPA	Special Protection Area
SPM	Suspended Particulate Matter
SSC	Suspended Sediment Concentrations
SSSI	Site of Special Scientific interest
THC	The Highland Council
TSHD	Trailer Suction Hopper Dredger
UHRS	Ultra High Resolution Seismic
UK	United Kingdom
UKCP	United Kingdom Climate Projections
UKHO	United Kingdom Hydrographic Office
WTG	Wind Turbine Generator

7 MARINE PHYSICAL PROCESSES

7.1 Introduction

The potential effects of the Pentland Floating Offshore Wind Farm (PFOWF) Array and the Offshore Export Cable(s), hereafter referred to as the 'Offshore Development', during the construction, operation and maintenance, and decommissioning phases on Marine Physical Processes (including coastal processes) are assessed in this chapter. This chapter also includes an assessment of the potential cumulative impacts with other relevant projects.

Cooper Marine Advisors and Xodus Ltd have drafted and carried out the impact assessment. Further competency details of the Project Team including lead authors for each chapter are provided in Volume 3: Appendix 1.1: Details of the Project Team of this Offshore Environmental Impact Assessment Report (Offshore EIAR).

Table 7.1 below provides a list of the appended supporting studies which relate to the Marine Physical Processes impact assessment. Other site-specific surveys and supporting studies that have been used to inform this Marine Physical Processes impact assessment are described in Section 7.4.3.

Table 7.1 Supporting studies

Details of study	Locations of supporting studies
Environmental Baseline Report – MMT Pentland Floating Offshore Wind Farm, Geophysical & Environmental Survey 2021- 103760-HWL-MMT-SUR-REP-ENVEBSRE.	Offshore EIAR (Volume 3): Appendix 9.1: Environmental Baseline Report

7.2 Legislation, Policy, and Guidance

The preparation of the Marine Physical Processes chapter has been informed by the following legislation, policy and guidance documents.

7.2.1 Legislation

There are no specific legislative controls relevant to the scope of the marine physical environment impact assessment.

7.2.2 Policy

The relevant plans and policies which have been considered include:

- Scotland's National Marine Plan. General Policy 8. The Scottish Government, 2015; and
- Pilot Pentland Firth and Orkney Water Marine Spatial Plan. General Policy 5B. The Scottish Government, 2016.

7.2.3 Guidance

The most up-to-date technical guidance for offshore wind related marine physical processes assessments includes:

- Offshore Wind Energy in Scottish Waters. Regional Locational Guidance. Marine Scotland. October 2020;
- Advice to Inform Development of Guidance on Marine, Coastal and Estuarine Physical Processes Numerical Modelling Assessments. Report No 208. NRW, 2017;

- Guidance Note. Marine Physical Processes Guidance to inform Environmental Impact Assessment (EIA). GN041. NRW, 2020; and
- Coastal Process Modelling for Offshore Wind Farm Environmental Impact Assessment: Best Practice Guidance. COWRIE, 2009[i].

7.3 Scoping and Consultation

Scoping and consultation has been ongoing throughout the Environmental Impact Assessment (EIA) process and has played an important part in ensuring the scope of the baseline characterisation and impact assessment is appropriate with respect to the Offshore Development and the requirements of the regulators and their advisors.

The Scoping Report was submitted to Marine Scotland on 16th December 2020 (Highland Wind Limited (HWL), 2020). A Scoping Opinion was then received from Marine Scotland - Licensing Operations Team (MS-LOT) on 28th September 2021 (MS-LOT, 2021). A Scoping Report Addendum was then submitted to MS-LOT on 17th December 2021, covering changes to the proposed Wind Turbine Generator (WTG) parameters, increased mooring spread and lines, as well as introducing driven piles as a potential anchoring solution. A Scoping Opinion Addendum was then received from MS-LOT on 16th May 2022 (MS-LOT, 2022).

A method statement clarifying the proposed analytical approaches to inform the assessment was submitted on 10th January 2022 to MS-LOT (Highland Wind Limited, 2021). Agreement to the points and approaches discussed within the method statement was received from Marine Scotland Science (MSS) and NatureScot on 7th April 2022.

Relevant comments from the EIA Scoping Opinion, Scoping Opinion Addendum and comments in response to the Physical Processes Method Statement, alongside other relevant consultations to Marine Physical Processes provided by MS-LOT, MSS and NatureScot are summarised in Table 7.2, which includes a high-level response on how these comments have been addressed within this Offshore EIAR.

Table 7.2 Summary of consultation responses specific to Marine Physical Processes

Consultee	Comment / Issue Raised	Offshore Development Approach and Section ID
Scoping Opinion		
MS-LOT	*The Scottish Ministers broadly agree with the receptors and potential impacts for physical processes detailed in Table 7-1 of the Scoping Report however, advise that impacts on the Sandside Bay site of special scientific interest ("SSSI") must be scoped in if the option of pinning the cable to the disused water intake is within the extended landfall corridor. If the extended landfall corridor area is proposed to only be used for the horizontal directional drilling landfall option then the Scottish Ministers are content that this can be scoped out. This view is supported by both NatureScot and MSS representations.*	In the method statement (Highland Wind Limited, 2021) submitted to MS-LOT, it was confirmed that pinning the export cable to the disused water intake was no longer a viable option and was subsequently removed from the Project Description. On this basis, assessment of direct impacts to Sandside Bay SSSI was scoped out. The approach was agreed by MSS and NatureScot in response provided on 7th April 2022, so no further assessment is required.
	The Scottish Ministers agree with NatureScot and MSS that for the increase in suspended sediments impacts, the assessment methodology must include the potential use of specific analysis, for example modelling, in order to adequately assess the impacts. In addition, the Scottish Ministers advise that for impacts on local sediment transport, scour	The assessment for potential scour around the seabed infrastructure and the requirements for and extents of scour protection are considered in Section 7.6.2.3.

[i] Despite the age of this guidance, it is continually applied in the impact assessment for a range of OWF developments across the UK and is a recognised industry best practice.

Consultee	Comment / Issue Raised	Offshore Development Approach and Section ID
	protection must be included in the project elements to be considered and these impacts should also be scoped in during the construction phase.	
	The Scottish Ministers direct the Developer to the additional sources of information provided by MSS in its representation and advise that these sources are considered within the assessment for bathymetry, water level and currents in the EIA Report.	Section 7.4.2 identifies primary datasets used to inform the Baseline Characterisation, including data for bathymetry, water level and currents. This includes the data identified by MSS.
MSS	*Reviewing NatureScot's comment I can add to the following statement: Sandside Bay SSSI: It appears that the landfall could, if HDD is not chosen, involve some form of hard protection such as rock armour in the nearshore (5.2.6). Although the potential for disruption to hydrodynamics and sediment transport seems relatively low, there is a clear impact pathway, and we advise that these impacts should be scoped in.*	The latest revision of the Project Description uses horizontal directional drilling (HDD) as the landfall installation option which negates the need for rock armour within the SSSI. Instead, the HDD exit point will be between 400 and 700 m offshore, beyond the extent of the SSSI. Consideration of impacts to sediment transport pathways from any remedial protection is provided in Section 7.6.2.2.
	The scoping report states: "The sheltered nature of the beach limits sediment transport within the bay, although there is some disturbance during storm events and some wind driven movement of sediments that have led to formation of the extensive dune system present behind the beach." Therefore we agree with the statement that if the developer can confirm that the extended landfall corridor would only be used for the HDD option, then the above impacts can be scoped out.	As above, HDD is confirmed as the landfall installation methodology to be employed, therefore, this impact has been scoped out from further assessment.
	In Table 7-1 the 'impacts on SSSI' need to then potentially get scoped in, depending on the above comment.	As above, HDD is confirmed as the landfall installation methodology to be employed, therefore, this impact has been scoped out from further assessment.
	In Table 7-1 we agree with NatureScot that the impact 'increase in suspended sediments' needs additional specific analysis, for example modelling, in the assessment methodology to adequately assess the impacts.	'Increase in suspended sediments' is assessed in Section 7.6.1.1 based on analytical methods drawing on baseline information and relevant details from the Project Description.
	We agree with NatureScot's comment on including scour protection for 'impacts on local sediment transport.	The assessment for potential scour around the seabed infrastructure and the requirements for and extents of scour protection are considered in Section 7.6.2.3.
	Section 7.2.3 on Additional Information for bathymetry, water level, currents: the applicant could consider the Scottish Shelf Model sub-model of the Pentland Firth and Orkney Waters as a source of extra information (and to be used in section 7.2.10): > *The Scottish Shelf Model. Part 2: Pentland Firth and Orkney Waters Sub-Domain | Marine Scotland Data Publications The*	Section 7.4.2 identifies primary datasets used to inform the Baseline Characterisation, including data for bathymetry, water level and currents. This includes the data identified by MSS. 'Impacts on the local sediment transport regime' during the construction phase are considered in Section 7.6.2.2 in terms of potential changes to suspended sediment concentrations. As described in the agreed method statement (Highland Wind Limited, 2021), consideration of impacts to sediment transport pathways from

Consultee	Comment / Issue Raised	Offshore Development Approach and Section ID
	Pentland Firth and Orkney Waters Model | Marine Scotland Information. > *In Table 7-1 'impacts on local sediment transport regime' we would suggest to also scope those in during the construction phase.*	any remedial protection is completed with respect to operational and maintenance impacts which is considered in Section 7.6.2.2.
NatureScot	*Sandside Bay SSSI: The report scopes out impacts on the 'SSSI seabed and morphology' because construction activities would not overlap the SSSI (Table 7-1). However, as the sand dunes SSSI feature is conditioned by marine energy and sediment supply, it can be affected by activities outwith the SSSI.*	Potential changes in waves, tides and sediment transport are considered and assessed in terms of operational impacts in Section 7.6.2.1 and Section 7.6.2.2. This includes consideration of the sediment transport pathways to the coast and supported designated sites such as the Sandside Bay SSSI.
	The boundary of the potential landfall corridor has been extended westward (relative to Dounreay Tri) right up to the SSSI's north-east boundary (Figure 5-13). It appears that the landfall could, if HDD is not chosen, involve some form of hard protection such as rock armour in the nearshore (5.2.6). Although the potential for disruption to hydrodynamics and sediment transport seems relatively low, there is a clear impact pathway, and we advise that these impacts should be scoped in.	HDD is confirmed as the landfall installation methodology, so the potential impact of rock armour in the nearshore is no longer a consideration and has been scoped out from further assessment.
	The non-HDD landfall option (5.3.1.1) is "pinning the cable to the disused cooling water intake at Dounreay" – no location given. If the developer can confirm that the extended landfall corridor would only be used for the HDD option, then we agree with the above impacts being scoped out.	Pinning the export cable to the disused water intake is no longer a viable option and HDD is confirmed as the landfall installation methodology.
	We are content with the remainder of the scoping for Offshore Physical Environment (Table 7-1) and Onshore Physical Environment (Table 10-2), with two comments: *- for the impact 'increase in suspended sediments', the assessment methodology needs to include the potential use of specific analysis, such as modelling, and*	The assessment methodology uses analytical approaches which are considered proportionate to the issues and quantify the anticipated spread of suspended sediments, as described in Section 7.6.1.1.
	For 'impacts on local sediment transport', the project elements needing to be considered should include scour protection.	The assessment for potential scour around the seabed infrastructure and the requirements for and extents of scour protection is considered in Section 7.6.2.3.
Scoping Opinion Addendum		
MSS	*We have no comments to add on the proposed changes to the Pentland Floating Offshore Wind Farm project reported in the scoping report addendum, since the proposed changes are unlikely to impact physical processes. Comments were previously provided in response to the original scoping report, and these are still valid.*	Noted

<table>
<tr><th>Consultee</th><th>Comment / Issue Raised</th><th>Offshore Development Approach and Section ID</th></tr>
<tr><td colspan="3">Comments received on 7th April 2022, in response to PFOWF EIA - Method Statement to Inform The Marine Physical Process Impact Statement.</td></tr>
<tr><td rowspan="4">MSS</td><td>MSS has reviewed the applicant's response to consultee's comments, the method statement, as well as NatureScot's comments, and are broadly content with the proposed way forward. Namely, the proposal to use analytical techniques previously applied to other wind farms is pragmatic for a wind farm of this size.</td><td>The acceptance of the analytical approach to inform assessments is noted.</td></tr>
<tr><td>The concern associated with this wind farm, when compared to other projects in the past, is that it is a floating development and there is uncertainly around how floating structures interact with the physical processes, namely mixing and stratification. This is briefly mentioned in sections 3.1 and 4.6. The region is likely to undergo intermittent or seasonal stratification (van Leeuwen et al. 2015). The baseline water column conditions should be described in the EIA.</td><td>Consideration of the potential for seasonal fronts and stratification is discussed in the Baseline Characterisation, in Section 7.4.4.9, whilst an assessment of the potential effects on fronts and stratification, due to the presence of the Offshore Development is assessed in Section 7.6.2.4.</td></tr>
<tr><td>Whether the wind farm is likely to change the extent and timing of stratification should be scoped into the EIA. The wind farm could change water column mixing, through the presence of the floating structures generating turbulent wakes, and/or by altering the near sea surface wind speeds (Christiansen et al. 2022, Durrell et al. 2022). The applicant should provide details of the baseline water column conditions, including the extent and timing of stratification.</td><td>Consideration of the potential for seasonal fronts and stratification across the Offshore Site is discussed in the Baseline Characterisation, in Section 7.4.4.9.</td></tr>
<tr><td>Given the limited scale of the proposed development (6 – 10 floating structures) qualitatively considering how the wind farm could alter these processes would be sufficient. Changes to mixing has the potential to impact other receptors, such as primary productivity, with potential consequences for higher trophic levels, and this should also be qualitatively considered in the EIA.</td><td>Assessment of the potential effects on fronts and stratification due to the presence of the Offshore Development is assessed in Section 7.6.2.4.

As set out in the latest revision of the Project Description (Chapter 5), the maximum number of WTGs to be installed at the PFOWF Array is now seven.</td></tr>
<tr><td>NatureScot</td><td>NatureScot has reviewed the Method Statement to Inform the Marine Physical Processes Impact Assessment (Highland Wind, Jan 2022), and have no major concerns to raise. The Method Statement states that the landfall installation will be by HDD only.

We agree that potential impacts on the SSSI, via changes to nearshore hydrodynamics, can therefore be scoped out. The report proposes that effects on physical impact pathways will be assessed using analysis based on empirical formulae informed by the various site data (including data from ongoing wave & tide monitoring).

We are content with the decision to not undertake numerical modelling - which we had suggested only</td><td>The agreements from NatureScot are welcomed. The assessment for potential scour around the seabed infrastructure and the requirements for and extents of scour protection is considered in Section 7.6.2.3.1.</td></tr>
</table>

Consultee	Comment / Issue Raised	Offshore Development Approach and Section ID
	for assessing construction-phase increase in suspended sediment. We welcome the fact that the methodology for assessing operational phase effects on local sediment transport regime explicitly mentions potential effects of installed scour protection.	
Cumulative Projects List		
The Highland Council (THC)	*Having reviewed the submitted document, I would suggest the following projects are also included in the cumulative assessment:* *Space Hub Sutherland (in all chapters of the EIAR not just the SLVIA section).*	As described in Chapter 18: Other Users of the Marine Environment, the launch vehicles for the Space Hub Sutherland Project (approximately 38 km south-west of the Offshore Site) will be between 7 degrees east of due North and 8 degrees west of due North. An overflight launch exclusion zone will be activated prior to and during launches that will be active for approximately six hours per launch, and there are expected to be approximately 12 launches per year. Whilst the launch exclusion zone is in operation, restrictions will be placed on marine users. Considering the properties of the Space Hub Sutherland Project, the intervening distance between the Offshore Site and the Project, as well as the very short duration of the launch exclusion zones, there is limited potential for a cumulative impact with the Marine Physical Process properties or receptors.

7.4 Baseline Characterisation

The baseline characterisation provides a description of physical features in the marine environment which are expected to become influenced by offshore development activities. These features include the local seabed, adjacent coastline, and properties of the water column (in particular; waves, tides and turbidity). This description helps to establish the reference condition against which the potential physical effects of the development are assessed.

In addition, the baseline represents the Marine Physical Process conditions that are expected to prevail without any development taking place and with consideration of an equivalent duration as the seabed lease, to cover construction, operation and maintenance, and decommissioning phases. Given the project development timescales span several decades (e.g. two to three years for construction and an anticipated 30 years for operation) then baseline variability over this period is also a consideration, including the likely effects of climate change.

7.4.1 Study Area

The Offshore Development is located off the north coast of Caithness, Scotland, and west of the Pentland Firth. The PFOWF Array Area is around 7.5 km offshore at the closest point to the adjacent coastline, extending around 2.5 km east to west and 4 km north to south, covering an area of 10 km^2.

The Marine Physical Processes Study Area (the 'Study Area') has been established using a 10 km buffer around the Offshore Site boundary (Figure 7.1). Based on available flow evidence, the maximum excursion to the west on the ebb phase of a spring tide is around 6 km, whereas the equivalent distance to the east on the flood phase is around 9 km (see Section 7.4.4.7). These excursion distances reduce towards the coast due to weaker flows. The relevant directions for waves passing across the PFOWF Array Area towards the adjacent coastline is from west to northerly sectors. The applied 10 km buffer, based on flow evidence from the Offshore

Site, is considered to be appropriate to capture effects that extend beyond the Offshore Site. This includes effects associated with pathways for tidal advection of sediment plumes (lagrangian effects) from seabed disturbance activities (e.g. anchor installation, cable trenching, etc.) and the extent of local wakes (eularian effects) due to flows and waves passing individual floating foundation units across the PFOWF Array Area.

All measurable effects on Marine Physical Processes are expected to be contained within the 10 km buffer area, noting that very fine sediments may still be advected further by subsequent tides, but the associated concentrations at this time are expected to have become negligible (undetectable above background), due to wider dispersion and/or settling of material. Any wave effects along the adjacent coastline are expected to be bounded between the two main headlands; Strathy Point and Ushat Head.

The following areas are therefore referred to in this impact assessment:

- Offshore Site: the area encompassing the PFOWF Array Area and Offshore Export Cable Corridor (OECC), as defined;
- PFOWF Array Area: The area where the WTGs will be located within the Offshore Site, as defined;
- OECC: The area within which the Offshore Export Cable(s) will be located. This extends from the PFOWF Array Area in a south-easterly direction to a cliffed landfall area west of the former Dounreay Nuclear Facility and east of Sandside Bay; and
- Study Area: The 10 km buffer area around the Offshore Site, which is considered to be the region which encapsulates all potential effects on marine processes due to all phases of project development activities planned for the Offshore Site, as well as potential overlapping cumulative effects with adjacent projects or activities.

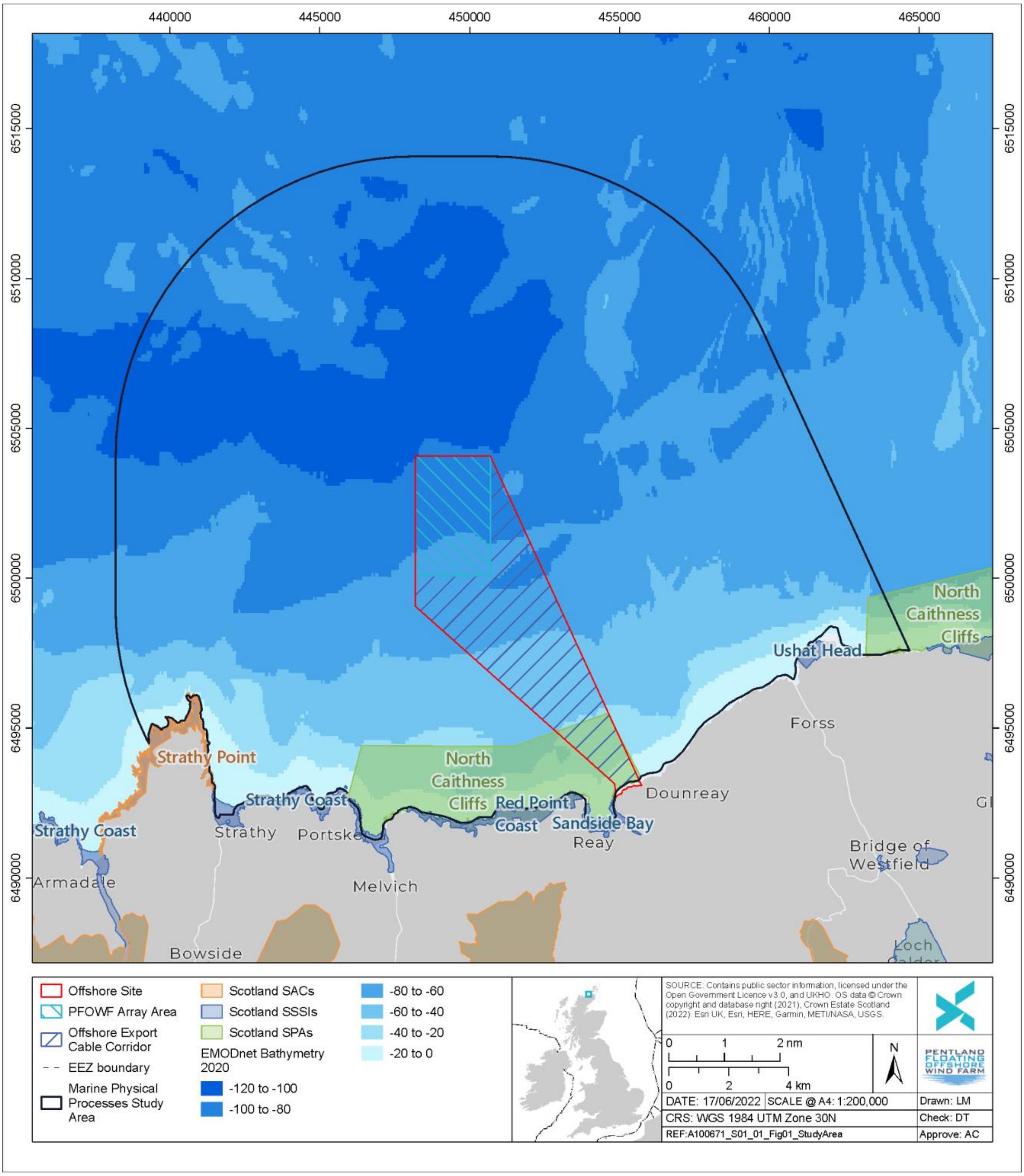

Figure 7.1 Study area for Marine Physical Processes

7.4.1.1 Receptors

In most cases, Marine Physical Processes are not in themselves receptors but are instead pathways with the potential to indirectly impact other environmental receptors. The exceptions to this are physical features associated with designated areas adjacent to the Offshore Site and falling within the Study Area. Identified Marine Physical Process receptors relevant to the Offshore Site and the applicable interest features are summarised in Table 7.3 below.

Table 7.3 Summary of physical features of Designated Sites

Site Name	Description of Site	Relevant Designated Feature	Distance to Offshore Site (km)
Strathy Point Special Area of Conservation (SAC)	Strathy Point SAC is a terrestrial designated site along the headland of Strath Point. The SAC is an important example of northern, hard acidic rock cliffs, subject to extreme wind and wave exposure, which contribute the diverse vegetation communities. As a result, the vegetated sea cliffs are considered to be one of the best representative areas of vegetated sea cliffs of the Atlantic and Baltic coasts in the UK.	> Vegetated sea cliff	PFOWF Array Area: 8.3 Offshore Export Corridor: 7.8
North Caithness Cliffs Special Protection Area (SPA)	North Caithness Cliffs SPA designated for supporting very large populations of breeding seabirds. The site overlaps either partly or wholly with a number of SSSIs. The seaward extension extends approximately 2 km into the marine environment to include the seabed, water column and surface. Although, it is noted that these do not constitute designated interest features and the site is only designated for marine seabirds.	> Breeding seabird assemblages	PFOWF Array Area: 5.6 Offshore Export Corridor: 0
Red Point Coast Special Site of Scientific Interest (SSSI)	Red Point Coast SSSI is a 6 km stretch of coast between Sandside Bay in Caithness and Melvich Bay in Sutherland. The site is located to the west of Sandside Bay and is nationally important for geology, coastal vegetation and colonies of breeding seabirds.	> Maritime cliff; > Non-marine Devonian (geology); and > Quaternary of Scotland.	PFOWF Array Area: 7.7 Offshore Export Corridor: 1.2
Sandside Bay Site SSSI	Sandside Bay SSSI lies just north of Reay, on the north coast of Caithness. The site is located immediately adjacent to the western boundary of the export cable corridor and covers the entire area of Sandside Bay. The site is in two parts. The main part of the site includes the foreshore, dunes, dune slacks and the banks of the Burn of Isauld. The second part of the site, known locally as the Sahara, is an area of herb-rich grassland within Reay Golf Course.	> Sand dunes.	PFOWF Array Area: 9.4 Offshore Export Corridor: 1.2
Strathy Coast SSSI	Strathy Coast SSSI covers a section of the north Sutherland coast centred around Strathy Point, 7 km to the east of Bettyhill. It comprises north, east and west facing cliffs, interrupted by beach systems at Armadale, Strathy and Melvich. The site is notified for the nationally important maritime cliff, sand dune, machair	> Machair; > Maritime cliff; > Moine;	PFOWF Array Area: 8.2 Offshore Export Corridor: 7.0

Site Name	Description of Site	Relevant Designated Feature	Distance to Offshore Site (km)
	and salt marsh habitats found along the coast and for the assemblage of rare plants. It is also notified for the Moine rocks around Portskerra.	> Saltmarsh; and > Sand dunes.	
Ushat Head SSSI	Ushat Head SSSI is a low exposed headland, approximately 9 km north-west of Thurso on the north coast of Caithness. It is of particular botanical importance for its maritime heath, which is a northern, species rich type of heathland that is found only in Caithness, Sutherland and Orkney. There is a good representation of species-rich maritime heath communities in a mosaic with maritime grassland.	> Maritime cliff.	PFOWF Array Area: 10.7 Offshore Export Corridor: 6.5

7.4.2 Sources of Information

A number of publicly available, regional and local information sources, including scientific papers, have been considered to support the baseline characterisation. The primary data sources used in the preparation of this chapter are listed below in Table 7.4.

Table 7.4 Summary of key sources of information pertaining to Marine Physical Processes

Topic	Title	Source	Year	Author
Sediments, Geology and Geomorphology	British Geological Survey (BGS) Offshore GeoIndex Map	http://mapapps2.bgs.ac.uk/geoindex_offshore/home.html	2020	BGS
	Cefas Suspended Sediment Climatologies around the UK	https://assets.publishing.service.gov.uk/	2016	Cefas
	Scottish Government Dynamic Coast: Scotland's National Coastal Change Assessment Map	https://snh.maps.arcgis.com/apps/webappviewer/index.html	2020	NatureScot
	EMODnet Geology	https://www.emodnet-geology.eu/	2021	EMODnet
Bathymetry	EMODnet Bathymetry	https://www.emodnet-bathymetry.eu/	2021	EMODnet
	Farr Point Bathymetry Survey (Figure 7.2)	http://marine.gov.scot/information/farr-point-bathymetry-2014	2014	Marine Scotland Science
Waves, Flows and Water Levels	WaveNet	https://wavenet.cefas.co.uk/map	2021	Cefas
	Atlas of UK Marine Renewable Energy. Interactive Map	https://www.renewables-atlas.info/explore-the-atlas/	2002	ABPmer
	SEASTATES Metocean Data and Statistics Interactive Map	https://www.seastates.net/explore-data/	2020	ABPmer

Topic	Title	Source	Year	Author
	United Kingdom Hydrographic Office (UKHO) Admiralty Tide Tables	n/a	2017	UKHO
	National Tidal and Sea Level Facility- Observational Water Level Records	https://www.ntslf.org/	2020	NTSLF
	Pentland Floating Offshore Wind Farm (PFOWF) Metocean Hindcast Data and Analysis	Analysis and report completed by DHI for HWL	2021	DHI
	The Scottish Shelf Model. Part 2: Pentland Firth and Orkney Waters Model	https://marine.gov.scot/information/pentland-firth-and-orkney-waters-model#:~:text=The%20Pentland%20Firth%20and%20Orkney%20Waters%20(PFOW)%20is%20an%20important,total%20Scottish%20tidal%20stream%20resource.	2016	Marine Scotland
	Pentland Firth and Orkney Waters Climatology 1.02	https://data.marine.gov.scot/dataset/pentland-firth-and-orkney-waters-climatology-102	2021	Marine Scotland, O'Hara Murray, R. & Campbell, L.
Stratification and Frontal Systems	British Oceanographic Data Centre Observational Conductivity Temperature Depth (CTD) Records	https://www.bodc.ac.uk/data/bodc_database/ctd/search/	2019	BODC
	UK Offshore Energy Strategic Environmental Assessment 3 (OESEA3). Appendix 1D – Water Environment (Regional Sea 8)	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/504541/OESEA3_A1d_Water_environment.pdf	2016	DECC
	Frequent locations of oceanic fronts as an indicator of pelagic diversity: Application to marine protected areas and renewables. Marine Policy, 45, 318-329.	n/a	2014	Miller, P. I., & Christodoulou, S
Coastal properties	Coastal Cells in Scotland: Cell 4 - Duncansby Head to Cape Wrath	n/a	2000	Ramsay & Brampton
	Dynamic Coast - National Coastal Change Assessment: Cell 4 - Duncansby Head to Cape Wrath	n/a	2017	Fitton, *et al*

7.4.3 Site-specific Surveys and Studies

Site-specific surveys provide more detailed and up-to-date information across the Offshore Site to complement the publicly available data referred to in Section 7.4.2. These surveys support both the enhanced baseline characterisation and preliminary engineering design. The following site-specific surveys have been completed:

- Geophysical survey in 2016;
- Geophysical and benthic survey in 2021;
- Geotechnical investigations in 2021;
- Metocean hindcast analysis of winds, waves, water levels and flows for the period between 1979 and 2020; and
- An ongoing metocean survey, which commenced in August 2021.

A brief overview of the purpose and scope of these surveys is provided in the following sections.

7.4.3.1 Geophysical and benthic surveys and environmental sampling and analysis

In 2016, a geophysical survey was completed for the Hexicon array development to map seabed bathymetry, sediment and shallow geology across the previous Dounreay Trì Project for Hexicon (Horizon Geosciences, 2016), as detailed further in Chapter 4: Site Selection and Alternatives of this Offshore EIAR. The 2016 geophysical survey is now largely superseded by the more recent MMT (2021) geophysical survey which provides 100% coverage across the Offshore Site with the following scope relevant to Marine Physical Processes:

- Multi-Beam Echo Sounder (MBES);
- Side-Scan Sonar (SSS);
- Parametric Sub-Bottom Profiler (SBP);
- Offshore: 2D Multi-Channel Sparker (2D-UHRS); and
- Nearshore: Single Channel Boomer.

In addition, MMT also completed a benthic survey over the same period collecting 19 grab samples using Dual Van Veen and Hamon Grab (see Offshore EIAR [Volume 3]: Appendix 9.1). The grab samples were analysed for sediment particle size which has been used to inform this baseline characterisation and impact assessment. The locations of the grab samples are illustrated in Figure 7.2.

7.4.3.2 Geotechnical

Fugro Limited completed a geotechnical site investigation across the offshore site consisting of seabed *in situ* testing and borehole drilling (Fugro, 2021). A total of 17 boreholes were obtained from 13 locations and 23 seabed *in situ* tests from 17 locations involving cone penetration tests (CPTs). Field investigations were completed between September and October 2021 with further laboratory testing and reporting up to December 2021. Borehole depths ranged between 1 to 30 m below the seabed, whilst CPTs ranged between 2.2 and 12.7 m below seabed. Locations of the boreholes and CPT samples within and around the Offshore Site are illustrated in Figure 7.2.

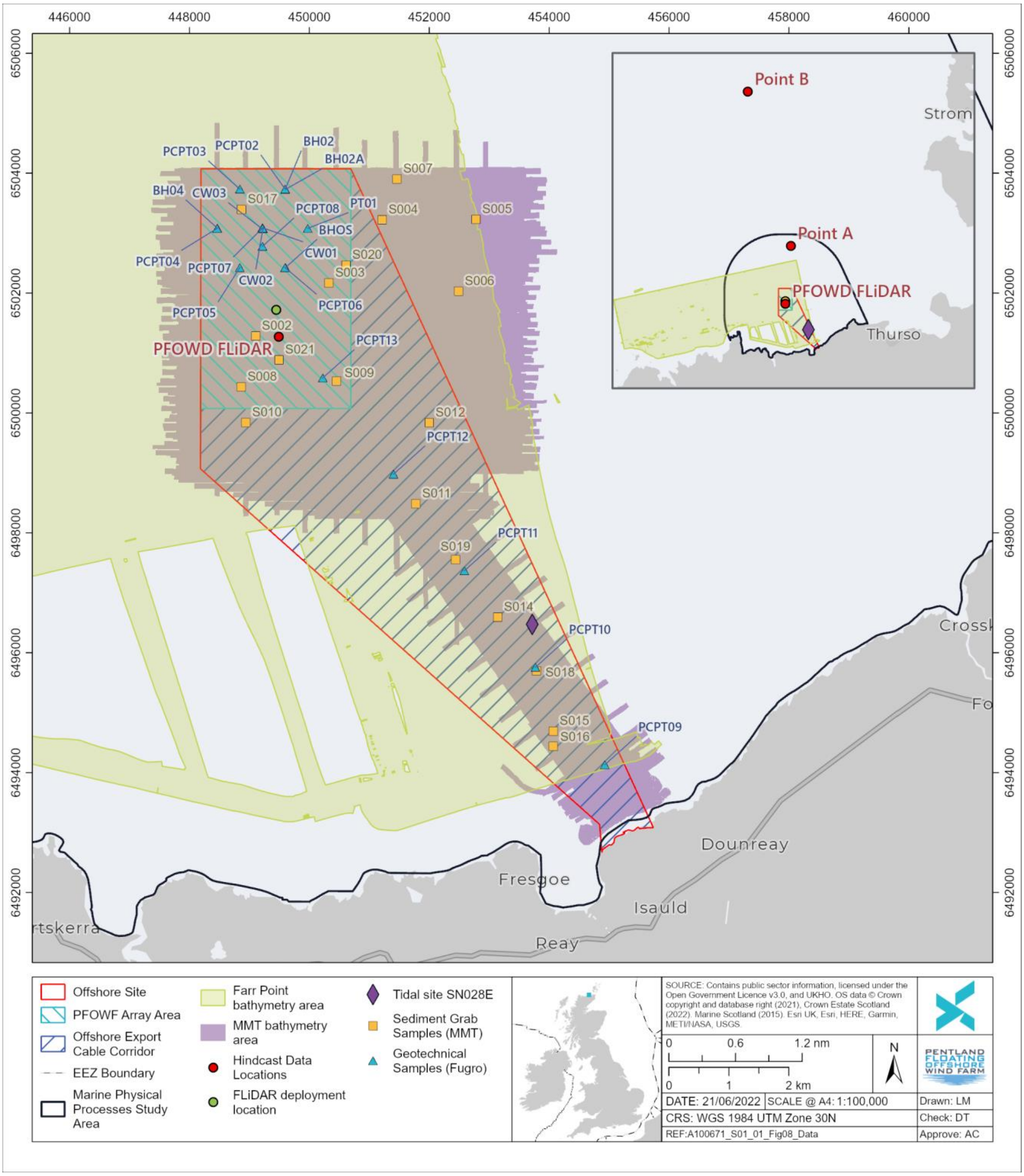

Figure 7.2 Datasets used to inform the marine processes impact assessment

7.4.3.3 Metocean hindcast analysis

Hindcast metocean data for wind, water level, current speed, and wave conditions has been obtained from DHI to support ongoing design and optimisation studies. The hindcast covers a 41-year period from 1979 to 2020 with timeseries information provided by the DHI North Europe Metocean Database (DHI, 2021). The hindcast metocean data was obtained for three locations, two of which were within the Offshore Site and one was slightly to the north. Figure 7.2 illustrates the locations for which the hindcast data was obtained.

This hindcast model is considered comparable to The Scottish Shelf Model. Part 2: Pentland Firth and Orkney Waters Sub-Domain model. This is based on a comparison between hindcast metocean data and information from the Pentland Firth and Orkney Waters climatology 1.02 model (O'Hara Murray and Campbell, 2021), for a coincident location within the Offshore Site, discussed further in Section 7.4.4.7.

7.4.3.4 Metocean survey

Metocean data has been acquired from an ongoing floating light detection and radar (FLiDAR) survey. Deployment commenced in August 2021 at a central location within the PFOWF Array Area. The FLiDAR is deployed in a water depth of around 85 m below Chart Datum (CD) (Figure 7.2.). The data available from the FLiDAR deployment includes waves (from a Wavesense 3 unit) and vertical current profiles (speed and direction from a Nortek Signature 100 and Nortek Aquadopp 600 Acoustic Doppler Current Profiler). Data is collected continuously but averaged and reported at 10 minute intervals. Other environmental data being collected as part of this deployment includes wind and meteorological conditions.

7.4.4 Baseline Description

7.4.4.1 Seabed bathymetry

7.4.4.1.1 Present seabed bathymetry

The geophysical survey (MMT, 2021) provides the most up-to-date description of the seabed bathymetry across the footprint of the Offshore Site based on high-resolution multi-beam echo sounder (MBES) survey, with a 0.5 m grid cell resolution. This information along with the "The bathymetry of the north coast of Scotland off Farr Point" (Marine Scotland, 2014) is used to inform the seabed bathymetry across the Offshore Site.

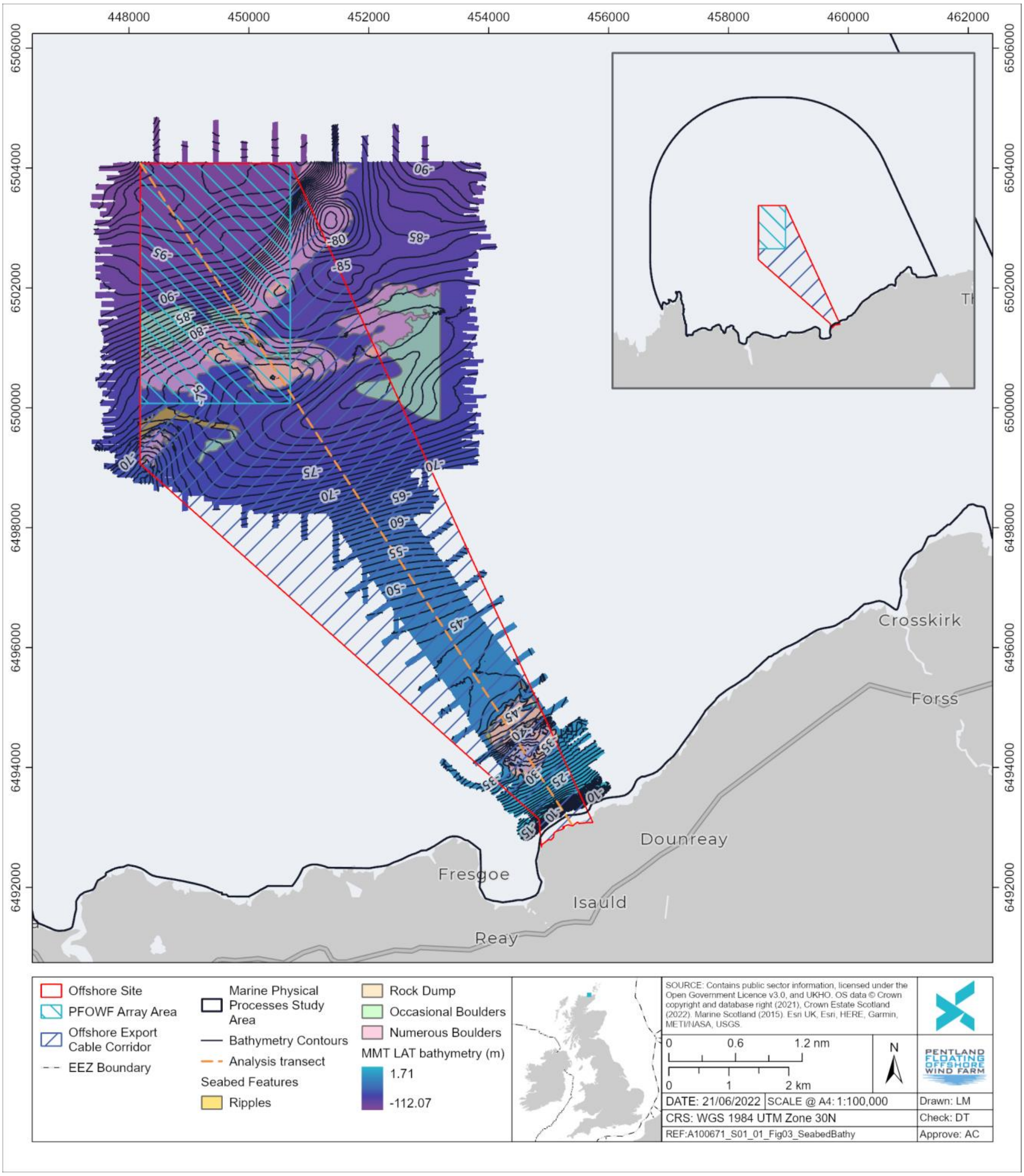

Figure 7.3 Seabed bathymetry and features in the Study Area

The seabed within the Offshore Site has a relatively smooth profile (i.e. no large bedforms, such as sandwaves), however, there are occasional areas with ripples (defined as a sequence of small bedform features with a wavelength < 5 m and a wave height < 0.2 m) identified from the side-scan sonar images (Figure 7.3).

An analysis transect of the seabed profile, that approximately dissects the Offshore Site (Figure 7.3), is illustrated in Figure 7.4. The transect shows that the PFOWF Array Area shallows from north to south from around 100 to 80 m below lowest astronomical tide (LAT), respectively, with a local rise to around 75 m. This shallow gradient extends along the OECC reaching 45 m below LAT at around 1.8 km from the cliffed coastline. From this location, the seabed gradient shoals more steeply up to the coastline (Figure 7.4).

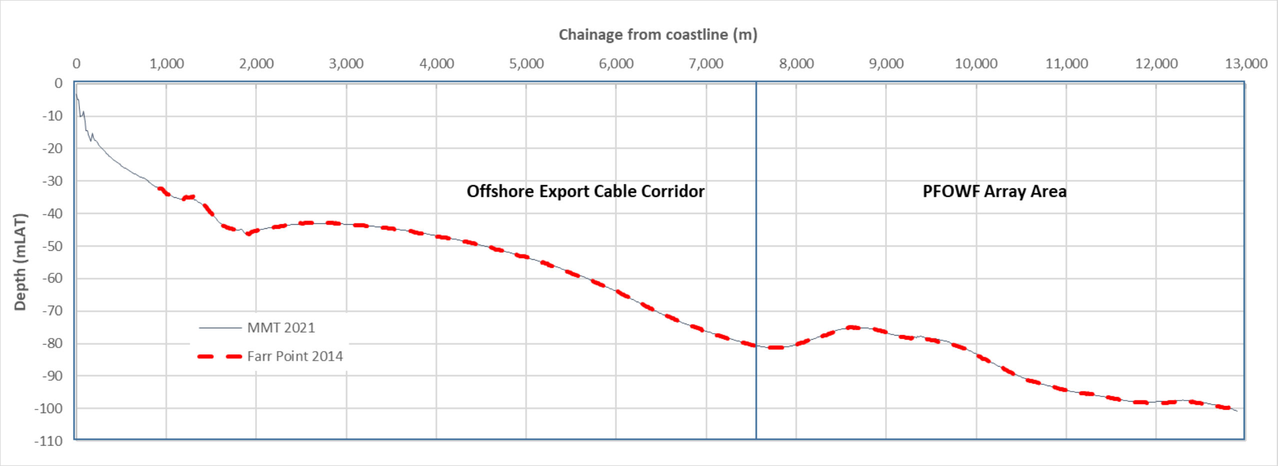

Figure 7.4 Transect of seabed profile through the Offshore Site

Notably, the Farr Point bathymetry (Marine Scotland, 2014) overlaps with the MMT 2021 survey coverage, apart from the very nearshore region. A comparison between these two surveys along the seabed transect in Figure 7.4 Transect of seabed profile through the Offshore Site, shows that seabed levels for the common area remain unchanged, indicating that this area of seabed has been locally stable over the seven year period between surveys.

7.4.4.1.2 Future seabed bathymetry

There is not anticipated to be any change to the seabed bathymetry in the long term. The absence of large mobile bedforms and the consistency in seabed depths between 2014 and 2021 supports this conclusion.

7.4.4.2 Seabed sediments

7.4.4.2.1 Present seabed sediments

The interpretation of the geophysical survey provides a description of seabed sediments derived from acoustic reflectivity of the side-scan sonar and multi-beam backscatter data. Sediment type is classified as either;

> Bedrock: High acoustic reflectivity, no sediment;

> DIAMICTON[ii]: Medium to high acoustic reflectivity; heterogeneous mix of sand, gravel and boulders, may have minor fractions of silt and clay;

> Gravelly SAND to sandy GRAVEL: Medium to high acoustic reflectivity; predominantly sand and gravel, may have minor fractions of silt and/or clay; and

> SAND: Low to medium acoustic reflectivity; predominantly sand, may have minor fractions of silt, clay and/or gravel.

[ii] Under the BGS classification system, capital letters of the unit / sediment are used to denote the dominant sediment type.

In addition, the acoustic data also offers a determination of seabed features, with the following types identified from the survey:

> Ripples: Wave length < 5 m, height < 0.2 m;

> Boulder field (occasional): Concentration of 5 to 20 boulders within a maximum area of 100 m^2; and

> Boulder field (numerous): Concentration of ≥ 20 boulders within a maximum area of 100 m^2.

Boulders are classified as individual contacts resolved by side-scan sonar with a length scale greater than 0.5 m.

Figure 7.5 shows the interpretation of the seabed sediments and features based on these classifications, informed by MMT (Offshore EIAR [Volume 3]: Appendix 9.1) surveys and a reinterpretation of sediment typology based on Folk (1954).

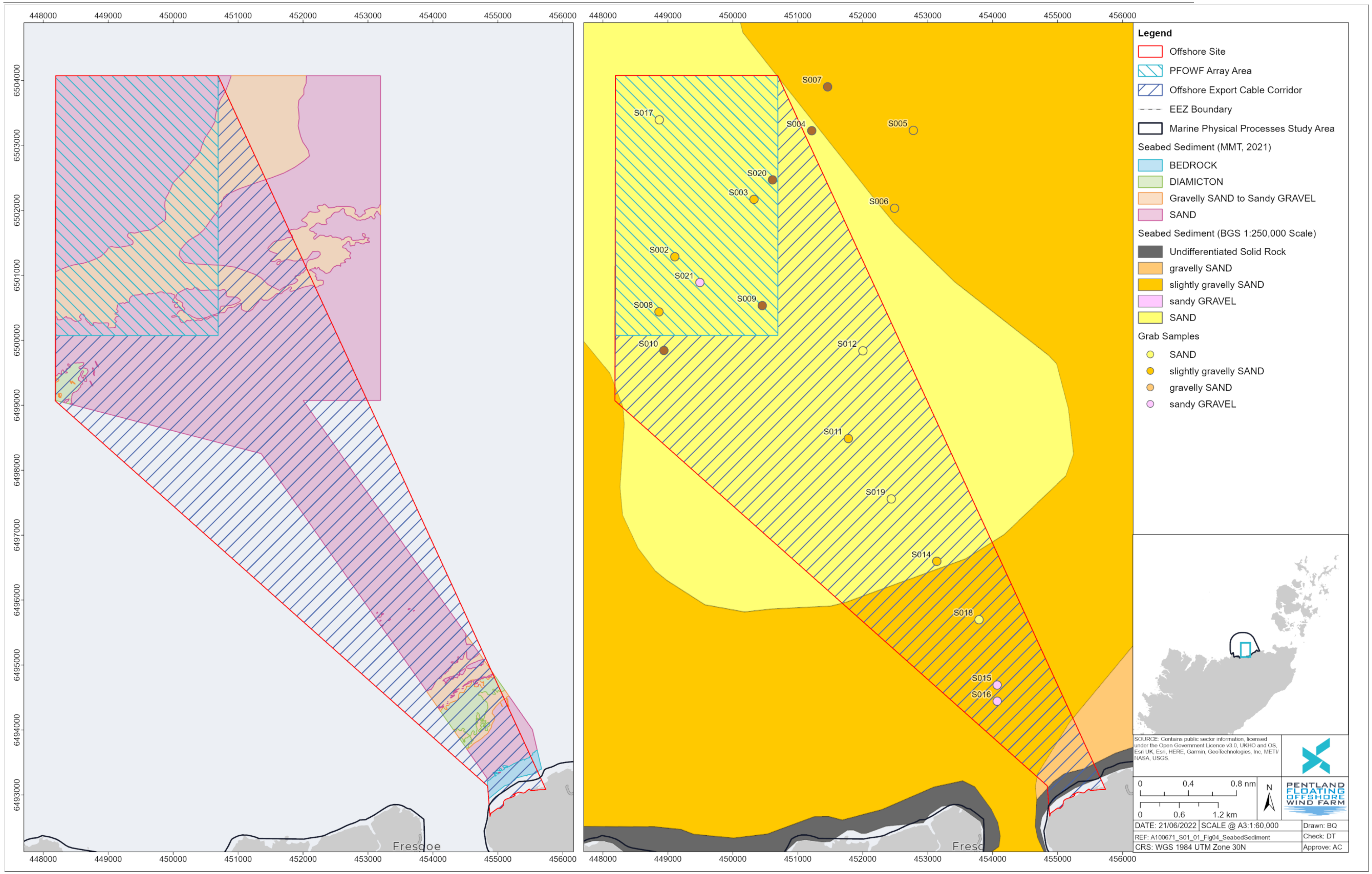

Figure 7.5 Seabed classification across the Offshore Site (Offshore EIAR [Volume 3]: Appendix 9.1)

The majority of the surveyed area is classified as SAND with coarser gravelly SAND to sandy GRAVEL present in the southern and eastern part of the PFOWF Array Area. The shallower region of the OECC from 45 m below LAT up to the coast is crossed by coarser sediments (gravelly SAND and DIAMICTON) onto sand then subtidal bedrock against the cliffed coastline. Boulder fields (numerous) are mainly associated with the areas of sandy gravel. Occasional areas with ripples are present in the PFOWF Array Area as well as closer to the coast.

Separate to the acoustic interpretation, 19 grab samples were collected across the Offshore Site, and surroundings, and represent near-surface sediments (minimum expected sub-surface penetration of the grab in sands is 0.05 cm) (Offshore EIAR [Volume 3]: Appendix 9.1). The samples have been subject to particle size analysis which provides quantification of the relative contributions of sand, gravels and muds (silts and clays). These contributions enable classification of sediment type according to Folk (1954), which is equivalent to the classification scheme provided by regional (1:250,000 scale) mapping of seabed sediments published by BGS (Figure 7.5).

Regional mapping suggests the dominance of coarse sediments (sands and gravels) across the Study Area. Local grab samples confirm slightly gravelly SANDS are the most common sediment type (seven samples), with gravelly SAND (five samples), SAND (four samples) and sandy GRAVEL (three samples).

The contribution of fine sediments (clay and silt fraction) in all samples is low (up to 5% and typically less than 3%) with sand sediments being the most common particle size (mean contribution of 85% for all samples). Gravel sized sediments had a mean content of 12% in all samples (Offshore EIAR [Volume 3]: Appendix 9.1). All sediment samples are described as poorly sorted. Of the dominant sand fraction across the sampled sites, the grain sizes ranged between 0.06 mm (very fine sand) and 2 mm (very coarse sand). Based on the particle distribution curves presented in Offshore EIAR (Volume 3): Appendix 9.1, a representative mean diameter (d50) grain size of 0.63 mm was determined, which is equivalent to coarse sand.

7.4.4.2.2 Future seabed sediments

Seabed sediments are expected to remain the same into the future as there is limited sediment transport across the Offshore Site, as discussed in Section 7.4.4.8..

7.4.4.3 Sub-surface sediments

7.4.4.3.1 Present sub-surface sediments

The composition of sub-surface sediments are interpreted from the sub-bottom profilers (MMT, 2021) and the geotechnical survey vibrocores (Fugro, 2021). In general, four sedimentological units have been identified:

- Unit 1: Holocene surface SAND;
- Unit 1A: Gravelly SAND;
- Unit 2: DIAMICTON – stiff clay with gravel, pebbles and boulders; and
- Unit 3: BEDROCK – Permian Triassic Sandstone.

All units are present on the sea surface at different locations across the PFOWF Array Area and OECC. The BGS offshore bedrock 250k lithostratigraphical map (BGS, 2022) indicates the bedrock across the Offshore Site mainly comprises Permian and Triassic rocks of sandstone, siltstone and mudstone (Figure 7.6). Closer to the coast the bedrock comprises Devonian rocks of mudstone and siltstone (Figure 7.6).

From the acquired borehole information, the PFOWF Array Area primarily comprises Holocene SAND (Unit 1) and Gravelly SAND (Unit 1A), with a less frequent occurrence of DIAMICTON (Unit 2) clay sediment. The sand units across the PFOWF Array Area varied in thickness ranging from around 1 m to about 10 m (Fugro, 2021). The occurrence of BEDROCK (Unit 3) sandstone is largely evident at over 10 m below seabed (Fugro, 2021). Interpretation of penetration and resistance from CPTs across the PFOWF Array Area also suggests a limited occurrence of organic soils (peat deposits). The peat deposits occur as relatively thin units of around 2 m thick, at depths of between 4 to 8 m below the seabed. The peat deposits are not widely distributed across the PFOWF Array Area, but are observed at CPT02, CPT03, CPT08 and CPT09, which are mainly in the south of the PFOWF Array Area (Figure 7.6).

In the nearshore section of the OECC the interpreted shallow geology shows a transition from BEDROCK (Unit 3) dipping below seabed and becoming overlain by DIAMICTON (Unit 2) and softer Holocene SAND sediments (Unit 1). For the remainder of the OECC, the surface layer is mainly Unit 1 but occasionally Unit 1A (Gravelly SAND), overlaying Unit 2 (east of PFOWF Array Area). Vibrocore evidence along the OECC (VC01 to VC05, Figure 7.6) determines the thickness of surface sands to be between 1.25 to > 6.85 m. Where the sands are shallowest (VC04) then these are overlain by sandy GRAVEL. For the purposes of cable trenching, the major sediment type expected to be encountered is Unit 1 – Holocene SAND and this is expected to be generally uniform over the depth of the trench.

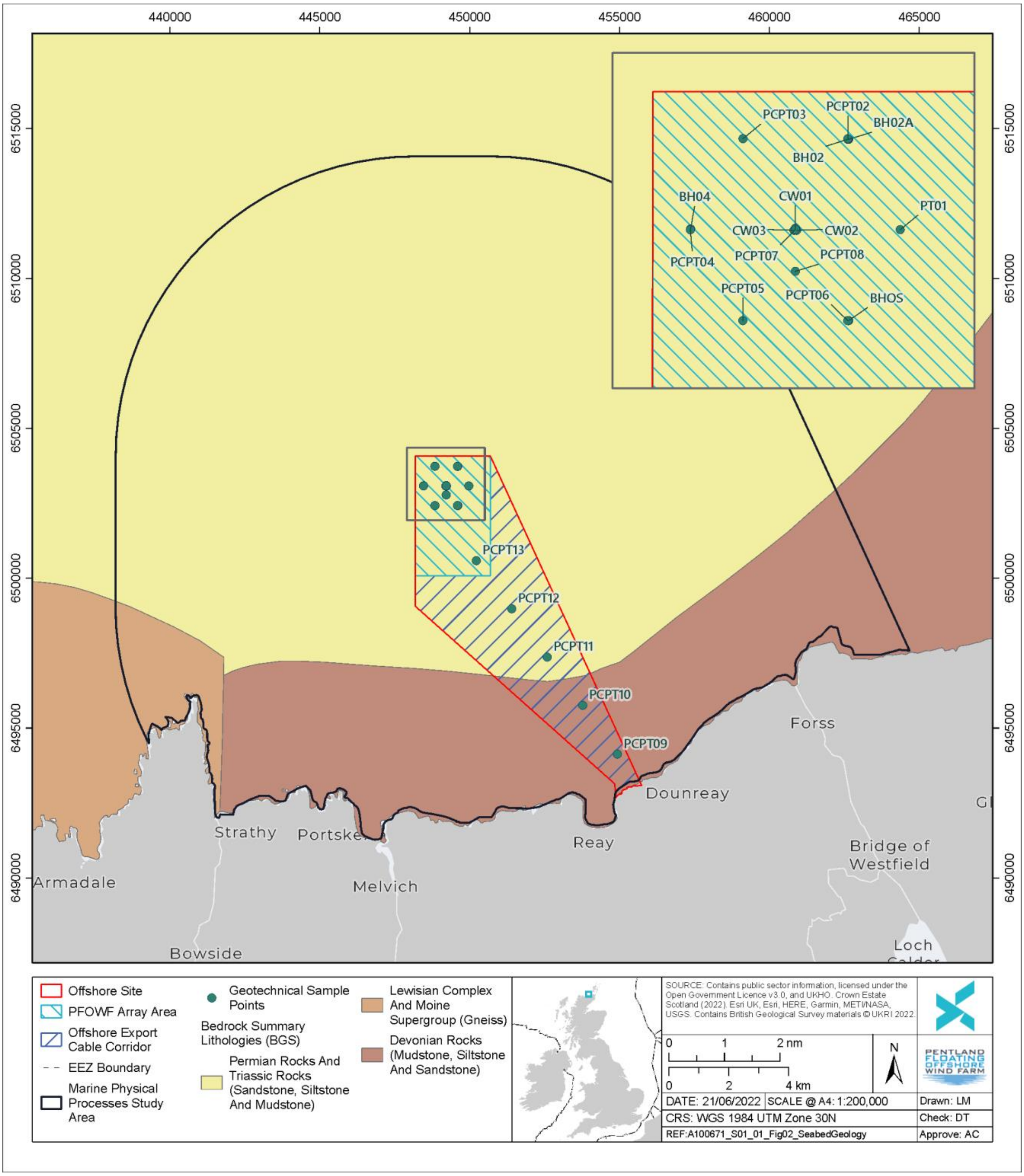

Figure 7.6 BGS bedrock geology and sampled geotechnical locations from Fugro (2021)

7.4.4.3.2 Future sub-surface sediment

There will be no change to the sub-surface sediment and geology across the Offshore Site into the future as climate change effects are unable to alter sub-surface geological units. The underlying sub-surface sediment and geology cover the Pentland Firth region and wider Scottish Continental Shelf, which has been the case for millennia and will continue to be so.

7.4.4.4 Coastline morphology

7.4.4.4.1 Present coastal morphology

According to the results of the Dynamic Coast project, which provides an evidence base for the extent of coastal erosion in Scotland, 24% of the area between Duncansby Head and Cape Wrath has experienced accretion and 22% has experienced erosion between the 1970's and 2017 (Fitton *et al*., 2017). However, the adjacent shoreline in the lee of the offshore wind farm is characterised by rocky cliffs, formed of Devonian Flagstones which are considered to be erosion resistant (EMODnet CoastType: Erosion-resistant rock and/or cliff, without loose eroded material in the fronting sea (Figure 7.7).

In discrete places along the mainly irregular cliffed coastline there are small sandy pocket beaches, such as Sandside Bay to the west of the OECC. The sheltered nature of the beach and the wider bay, limits sediment transport to within the bay, although there is the potential for further disturbance and sediment movement beyond the bay during storm events. Notably, Sandside Bay is backed by extensive mature dune systems present behind the beach, which would have been formed by wind-driven movement of sediments off the fronting beach which was supplied by onshore sediment transport pathways (although the dune forming process is now largely expired, as evidenced by their mature state). Additionally, deposits of fluvial material occur from the Sandside Burn, Reay Burn and Burn of Isauld which flow into the bay (Ramsay and Brampton, 2000). Sandside Bay is a SSSI notified for sand dune habitat and associated plant species. Further along the coast are similar pocket beaches; Melvich Bay and Strathy Bay.

To the west of Sandside Bay SSSI is Red Point Coast SSSI, part of the North Caithness Cliffs SPA designated for the birds. Red Point Coast is designated for nationally important geology, coastal vegetation and breeding seabirds.

The cliffs are considered to be erosion resistant (EMODnet CoastType: Erosion-resistant rock and/or cliff, without loose eroded material in the fronting sea).

7.4.4.4.2 Future coastal morphology

The coastal morphology indicates the presence of erosion resistant rock and a stable coastline along the landfall of the OECC, interspersed with bays and beach systems. Although the wider coastline between Duncansby Head and Cape Wrath has experienced relative variability between the 1970's and 2017 (Fitton *et al*., 2017), with the predictions of relative sea level rise (discussed in Section 7.4.4.6.2) and the landward movement of high water associated with relative sea level rise, there is the potential that this would result in coastal erosion in locations along the Study Area with softer and more erodible frontage (Horsburgh *et al*., 2020). However, this is considered to be less likely along the adjacent shoreline in the lee of the offshore wind farm, primarily due to the presence of erosion resistant rock.

Figure 7.7 Coastline morphology

7.4.4.5 Waves

7.4.4.5.1 Wave climate

The longest uninterrupted fetches for wave exposure around the Offshore Site are from the west to northerly sectors, with reduced fetches to the east due to the Orkney Islands.

The local wave climate is formed by a combination of longer period swell waves, propagating from the long open fetches, and shorter period locally generated wind-waves. The PFOWF Array Area is not sheltered by any offshore sandbanks and can be regarded as 'deep water' for waves (i.e. wave energy transmission is not affected by the seabed).

Available data to characterise the local wave climate (sites shown in Figure 7.2, and Figure 7.11 Mean spring tidal range) includes:

- Long-term hindcast from 1979 to 2020 (42-years) at Point A, a location around 7.7 km north of the Offshore Site in around 100 m depth, a site which is considered to have comparable wave exposure to the PFOWF Array Area. This data includes wind-sea, swell-sea and the total (resultant) waves. Since this is a long-term dataset this enables a more complete description of the wave climate, compared to a short-term dataset which is incomplete in regards to seasonal variations, etc.;
- Short-term (non-directional) wave observations obtained from WaveNet for a near-shore site along the OECC referred to as "Dounreay". Observations in 1997 covered a 41 day period and in 2001 a 47 day period. Despite the age of the dataset, its proximity to the Offshore Site and length of the wave record is still useful to inform the characteristics waves that are representative along this section of coast. The local water depth at the deployment location was around 24 m. The validity of the long-term hindcast predictions of wave height has been demonstrated against the coincident period of these wave observations; and
- Short-term wave observations from the FLiDAR deployment located centrally to the PFOWF Array Area in a depth of around 85 m. Available observations presently extend from August 2021 through to February 2022 (169 days). This period does not overlap with the hindcast so alternative forms of comparison are offered.

Figure 7.8 Wave roses for Point A, north of PFOWF Array Areaprovides a summary of the directional wave distribution for the total seastate (based on the long-term hindcast) as a wave rose, as well as for the swell and wind-sea components. The contribution of waves from the swell component appears to be dominant, notably from the west-north-west directional sector which is open to the long Atlantic fetch. The most common direction for the total seastate is waves arriving from the west-north-west directional sector (281.25 to 303.75 °N) which accounts for close to 30% of all waves. This sector also contains the largest waves in the hindcast record, reaching a significant wave height (Hs) of 13.75 m, with an associated mean wave period (T_{m01}) of 13.5 seconds. Other notable wave directions are west (15.5%), north-west (12.3%), north-north-west (11.7%) and north (13.8%). The most common wave height in the 42-year hindcast period is Hs in the range 1 to 2 m, representing 42% of all waves.

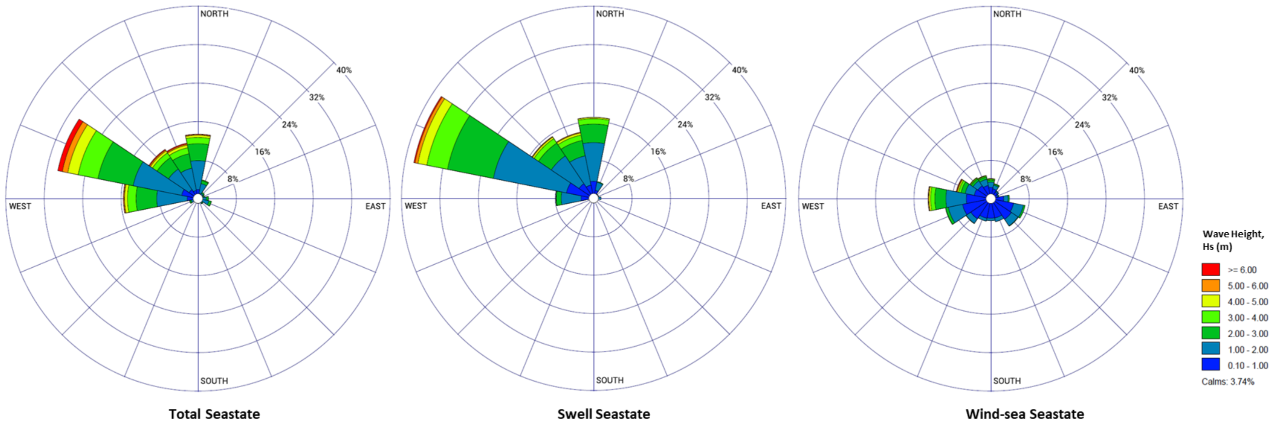

Figure 7.8 Wave roses for Point A, north of PFOWF Array Area

Figure 7.9 presents omni-directional scatter diagrams of significant wave height, Hs versus mean wave period, T_{01} for the 42-year hindcast record, along with the short-term observations from the FLiDAR buoy. This presentation helps to identify the most common wave conditions as well as the marginal events. Both locations indicate that the most common wave heights are for Hs < 5 m and period, T_{01} < 10 s.

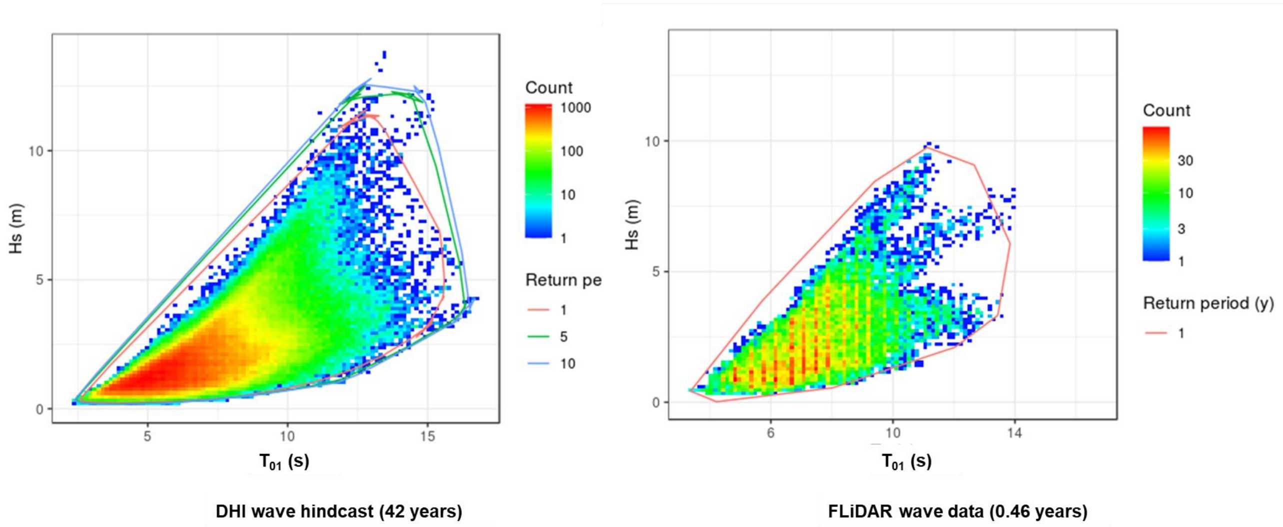

Figure 7.9 Wave scatter diagrams for Point A (DHI hindcast) and the FLiDAR buoy

A directional extreme value analysis of significant wave height, developed from the 42-year hindcast record, is summarised in Table 7.5. This analysis demonstrates that the largest waves under extreme conditions approach from west to northerly sectors.

Table 7.5 Directional extreme wave heights (m)

Directional Sector (°N), +/- 15°	Return Period (years)			
	1	10	50	100
0	6.2	8.6	10.1	10.8
30	3.1	5.0	6.7	7.5
60	2.8	4.1	5.0	5.4
90	2.9	3.8	4.3	4.5
120	2.7	3.5	3.9	4.1
150	2.5	3.4	3.9	4.1
180	2.4	3.2	3.7	3.9
210	2.5	3.5	4.1	4.4
240	2.9	4.2	5.1	5.5
270	7.6	9.5	10.6	11.1
300	9.1	11.9	13.6	14.2
330	7.1	10.3	12.5	13.4

The relevance of waves to marine processes is their capacity to stir local seabed sediments and contribute to sediment transport, as well as the influence of wave energy dissipation at the coast.

Based on the 42-year hindcast record, the majority of waves passing over 100 m depths will be “deep water” (i.e. the ratio of water depth to wave length is greater than 0.5) and will not have the capacity to stir the seabed, apart from the top 2% of waves represented by longer periods (T_{01} > 11.4 s). For these infrequent waves, the associated orbital velocity at the seabed would be between 0.05 and 0.80 m/s (the largest wave of Hs = 13.5 m, T_{01} = 13.75 s has a maximum orbital velocity of 0.68 m/s).

For the short-term data from the FLiDAR buoy in 85 m, all waves remain “deep water” apart from the top 5% of waves represented by wave periods greater than 10.6 s. For these longer period waves the orbital velocity at the seabed would be between 0.04 to 0.60 m/s.

As waves move across slightly shallower water (down to 66 m) in parts of the PFOWF Array Area then the top 8% of longer period waves (T_{01} > 9.8 s) would feel the seabed leading to orbital velocities of between 0.08 and 1.21 m/s.

For the short-term nearshore measurements (from WaveNet) in a water depth of 24 m (and including observed tidal influences), then all waves can be considered as “intermediate waves” where shoaling on the seabed is constantly occurring. The associated maximum wave orbital velocity for the measurement period is between 0.02 to 0.88 m/s, with a 50 percentile value of 0.18 m/s. The largest value of orbital velocity is associated with a measured significant wave height, Hs of 3.5 m and a zero crossing period, Tz of 12.8 s, when water depths were 24.6 m.

In summary, wave stirring influences across the PFOWF Array Area are only associated with the longer period swell waves from the west-north-westerly directions. The shallower parts of PFOWF Array Area (down to 66 m) would experience proportionally more wave influences than the deeper parts (down to 100 m). As these waves move closer inshore into shallower water (around 24 m depth) then they will exert an almost constant influence on the seabed.

7.4.4.5.2 Future wave climate

Due to naturally high inter-annual variability in the wave climate and low confidence in future climate change projections, there is presently no clear consensus on future wave climates affecting the north coast of Scotland (Wolf *et al.*, 2020). Although it is expected that natural variability will continue to contribute to the trends observed in the frequency and intensity of waves and storms within the Pentland Firth and North Atlantic. The Marine Climate Change Impacts report card suggests that there is likely to be an overall reduction in mean significant wave height, although there is also likely to be an increase in the mean annual maximum wave height by 0.5 m, which means the wave heights of extreme waves is increasing (Wolf *et al.*, 2020).

7.4.4.6 Water levels

7.4.4.6.1 Present water level variations

The main variation in local water levels is due to tidal influences. Local observations were obtained by Cefas at a nearshore location just offshore of Dounreay in 1997 and also 2001 (same location as the wave measurements). The period of observations in 2001 covers a 47-day period, 7 April to 25 May, which spans several sequences of spring and neap tides (Figure 7.10).

The metocean hindcast (DHI, 2021) also includes the predicted variation of water levels covering the same period at a site within the PFOWF Array Area (FLiDAR deployment). The two datasets appear highly comparable with the nearshore location exhibiting a slightly larger amplitude (Figure 7.10).

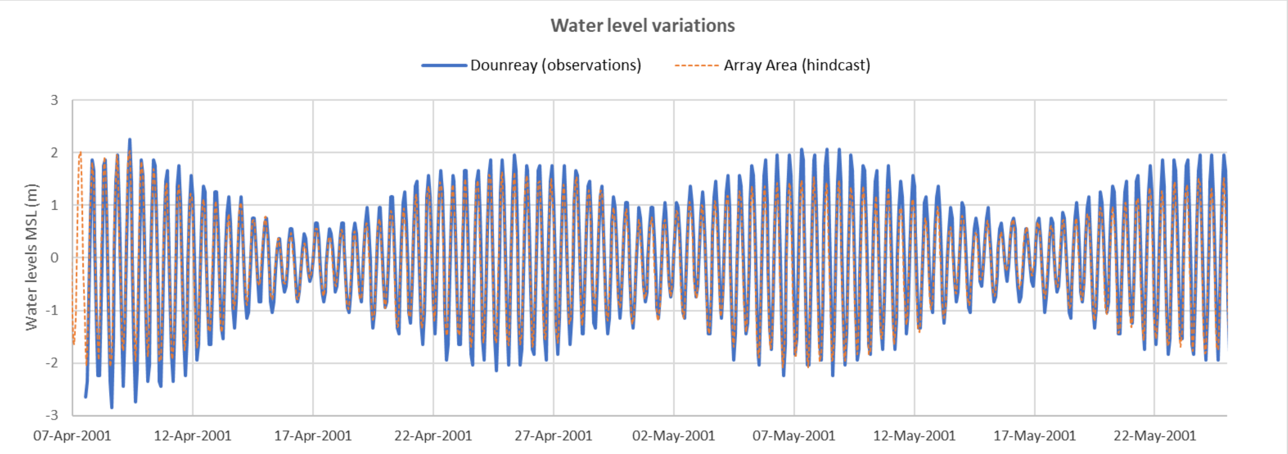

Figure 7.10 Water level variations

Standard tidal levels have been deduced from the hindcast data (DHI, 2021) which are summarised in Table 7.6. Equivalent values in the nearshore are expected to be slightly larger.

Table 7.6 Standard tidal levels for the PFOWF Array Area

Water level	Acronym	[m MSL]
Highest Astronomical Tide	HAT	2.51
Mean High Water Springs	MHWS	1.87
Mean High Water Neaps	MHWN	0.87
Mean Sea Level	MSL	0.00
Mean Low Water Neaps	MLWN	-0.87
Mean Low Water Springs	MLWS	-1.96
Lowest Astronomical Tide	LAT	-2.62
Mean Spring Range	MSR	3.83
Mean Neap Range	MNR	1.74

The mean spring tidal range is 3.83 m and mean neap range 1.74 m (DHI, 2021), noting tidal ranges between 2 and 4 m are considered to be meso-tidal. The mean spring range informed by the hindcast data is in agreement with the information available from the Pentland Firth Orkney Waters model and illustrated in Figure 7.11. Non-tidal influences on water levels (i.e. surges) are random and typically +/- 0.5 m on the tidal level, but can occasionally increase during storm events (positive or negative surges) up to +/- 1.6 m (DHI, 2021).

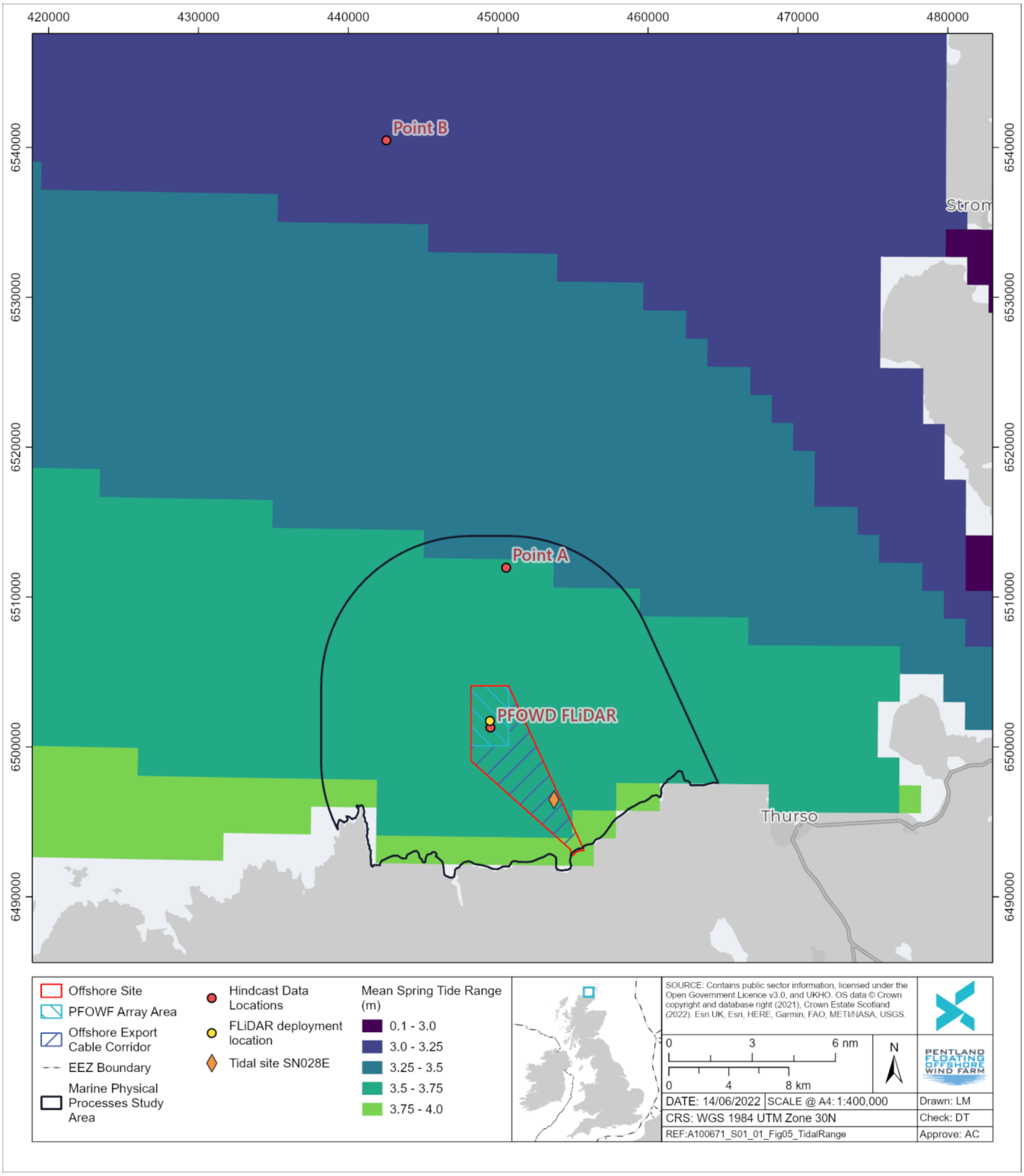

Figure 7.11 Mean spring tidal range

7.4.4.6.2 Future sea levels

UK Climate Projections (UKCP) provides details of climate change projections for mean sea level at sites around the UK coastline. The projections extend to 2100 for various scenarios (representative concentration pathways, RCP). A mean sea level rise of 0.1 m is projected by commencement of operations in 2026 and of 0.27 m by cessation of operations in 2056. Confidence range estimates from UKCP18 (Lowe *et al.*, 2018) project that there is 95% likelihood that a mean sea level rise of more than 0.07 m will occur by 2026 and 5% likelihood that a sea level rise of more than 0.27 m will occur by 2026, similarly models project that there is 95% likelihood that a sea level rise of more than 0.18 m will occur by 2056 and 5% likelihood that a sea level rise of more than 0.40 m will occur by 2056. With the rise in relative sea-level, albeit at relatively low level within the Study Area, this is likely to result in a landward advance of high water and may lead to coastal erosion (Horsburgh *et al.,* 2020) along more erodible shoreline.

7.4.4.7 Tidal flows

7.4.4.7.1 Present tidal flows

Tides are the dominant influence on local flows, although non-tidal influences (i.e. winds and surges) can also make a contribution, albeit on an episodic basis.

The spatial pattern of peak (depth-average) flows on a mean spring tide can be assessed with reference to existing regional models, such as the Pentland Firth and Orkney Waters Model (Figure 7.12). Peak (depth-average) flows on a mean spring tide generally fall in the range 0.01 to 0.50 m/s with the eastern margin of PFOWF Array Area showing slightly higher flows in the range 0.51 to 1.00 m/s. Equivalent peak neap flows would typically be expected to be around 50% less than those on springs. Higher flows would be possible for tidal ranges that exceed mean springs. Overall, the majority of the Study Area can be regarded as an area of relatively weak tidal flows.

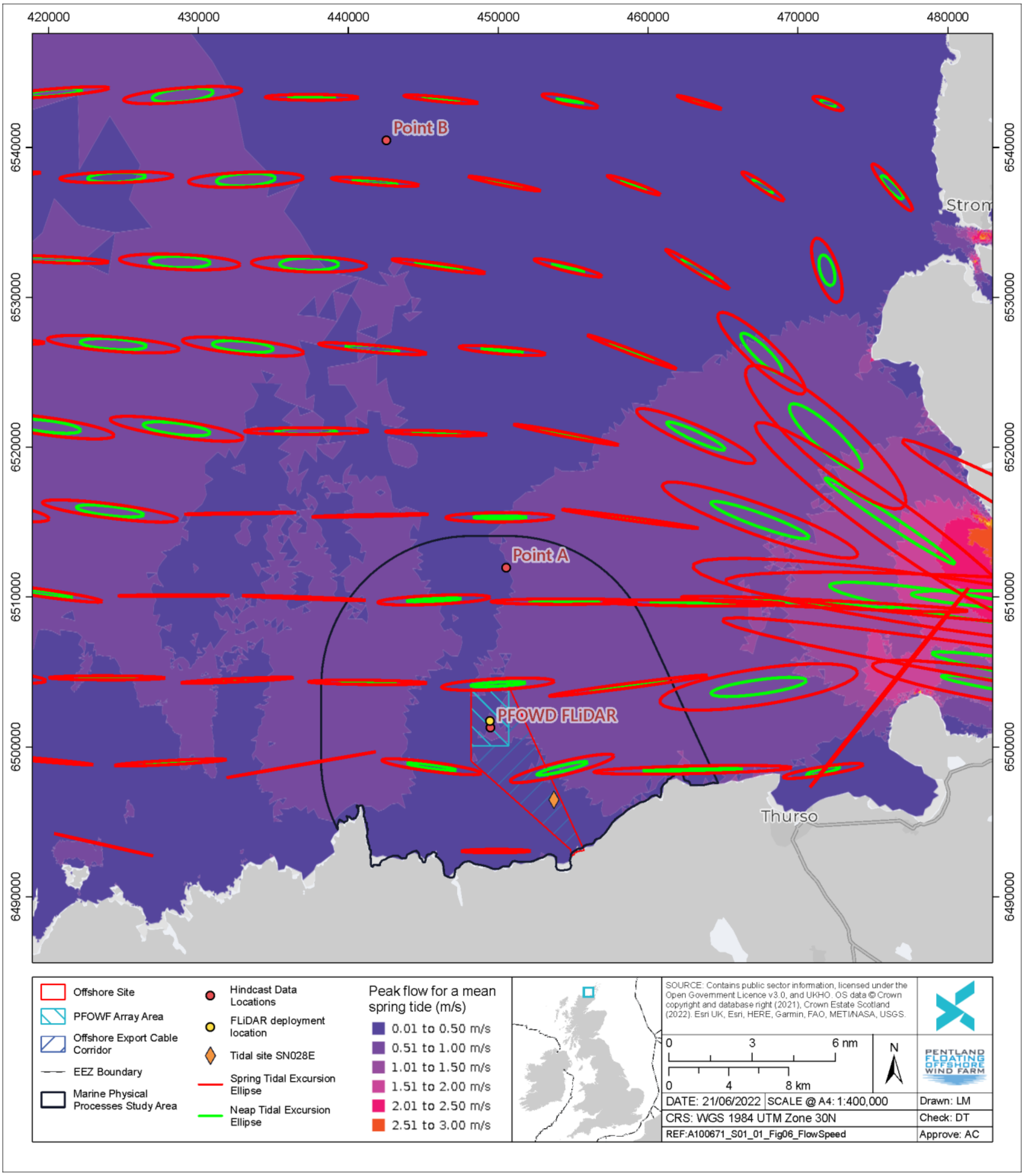

Figure 7.12 Peak (depth-average) flows on a mean spring tide

Figure 7.12 also includes an indication of the orientation of tidal flows across the Study Area based on the mean spring and neap tidal ellipses (sourced from the Atlas of Marine Renewable Energy [ABPmer, 2002]). For the PFOWF Array Area, the general orientation of the tidal ellipse is east to west, with an equivalent excursion distance of around 7.4 km for a mean spring tide, reducing to around 3.6 km on mean neaps. These extents decrease slightly towards the coast (distances of 7.1 and 3.5 km, respectively, midway along the OECC), in line with a marginal reduction in flow speeds. The axis of the ellipse midway along the OECC also slightly changes to be close to shore parallel.

Additional quantification of tidal flows is made with reference to modelled and observed data from a central location within the PFOWF Array Area, with this data considered to be indicative to the whole array area:

- Long-term hindcast of depth-average flows (tidal and non-tidal components) from 1979 to 2020 (42-years), resolved into tidal and non-tidal components.
- Vertical profiles of flows from the FLiDAR deployment in a depth of around 85 m, with available observations from August 2021 through to February 2022 (169 days). N.B. This period does not overlap with the 42-year hindcast period.

For the OECC:

- A one-year period of climatological data from Marine Scotland's Pentland Firth and Orkney Waters Model (Pentland Firth and Orkney Waters Climatology 1.02) is considered.

Figure 7.13 presents a 47-day period of depth-average flow speeds and direction from the hindcast, which is coincident to the period of water level observations shown in Figure 7.9 Wave scatter diagrams for Point A (DHI hindcast) and the FLiDAR buoytides flows reach around 0.54 m/s and during neap tides around 0.2 to 0.3 m/s. The ebb tide is centred on flows toward 260 °N and the flood towards 80 °N, demonstrating a rectilinear reversing flow comparable to the tidal ellipses shown in Figure 7.10 Water level variations. The typical influence of non-tidal flows is around 0.04 m/s (50 percentile), up to 0.20 m/s (99 percentile).

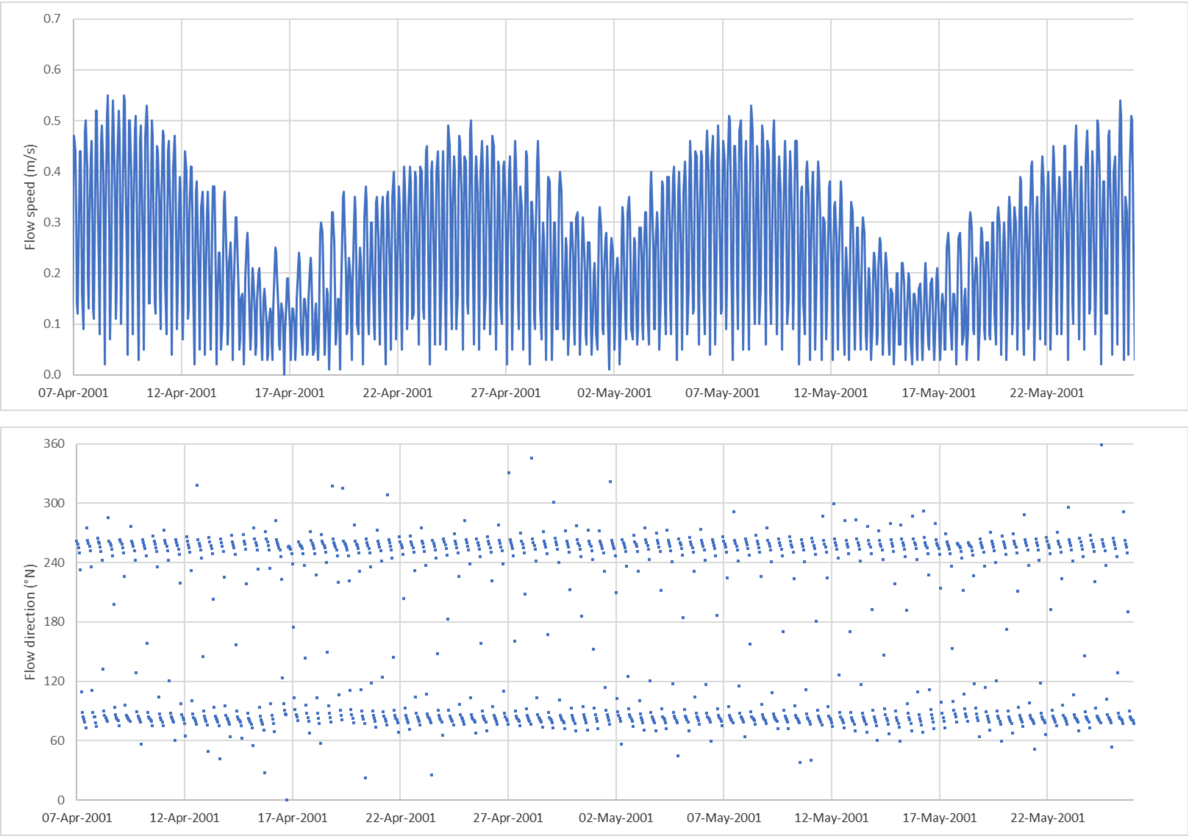

Figure 7.13 Timeseries of depth-average flow speed and direction developed from the hindcast

The whole 42-year period of hindcast data can also be represented as a current rose (Figure 7.14). This presentation reveals strong tidal asymmetry, with the strongest flows occurring during the flood tide to the east (up to 0.7 m/s during a period of high spring tides), in contrast to the ebb which flows to the west (reaching 0.6 m/s). The period of time spent on the flood phase is also longer. These asymmetric properties between flood and ebb phases of the tide are important for determining the direction of net sediment transport, with the available data demonstrating flood dominance.

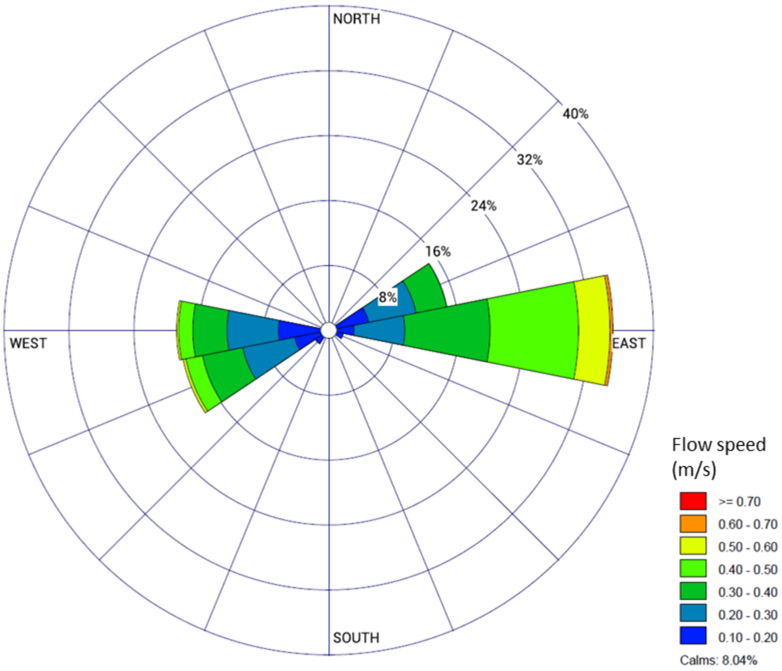

Figure 7.14 Current rose developed from the depth-average hindcast data

The largest tidal excursion within the 42-year hindcast period is associated with a large autumnal equinox spring tide (4.9 m range, larger than a mean spring tide) which produces a maximum excursion to the east on the flood phase around 9 km, and 6 km on the ebb phase to the west. The main relevance of the depth-average tidal excursion is for any surface release of sediments that fall through the entire water column and form sediment plumes.

The vertical profiling of flows obtained from the FLiDAR buoy allows for a consideration of flow structure through the water column from near-surface to near-bed. In particular, near-bed flows will exert a direct influence on any near-bed sediment releases. The Nortek Signature 100 resolves the full water column in 5 m depth increments (bins) with the bin closest to the seabed considered for establishing near-bed flows. Figure 7.15 presents a current rose for the near-bed observations for a period in September 2021. Notably, flows close to the seabed are much reduced compared to depth-average values (Figure 7.12 Peak (depth-average) flows on a mean spring tide), since they are slowed by the influence of seabed drag forming a boundary layer. Notably, the flood tide dominance remains a key feature of near-bed flows.

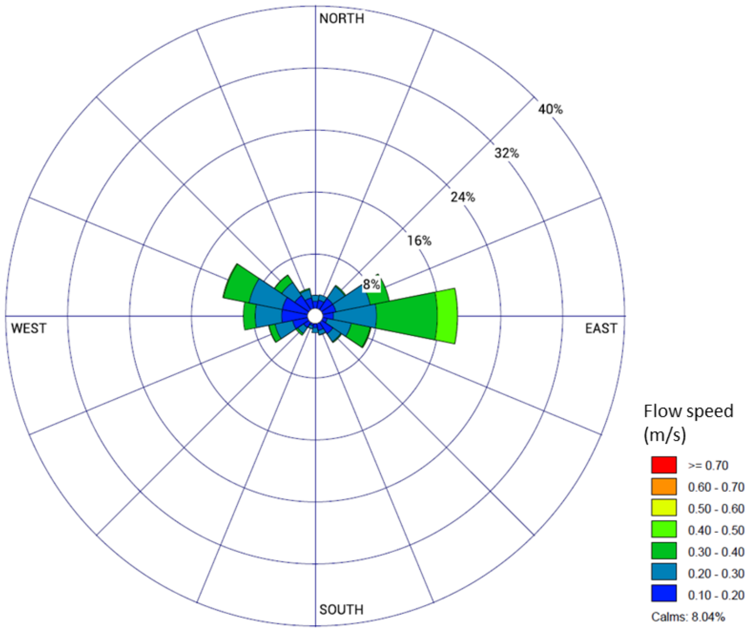

Figure 7.15 Current rose developed from the near-bed flow observations

For the OECC, there is tidal stream data at tidal diamond SN028E (depth of approximately 45 m LAT) on Admiralty Chart 1954 (Scotland – North Coast, Cape Wrath to Pentland Firth, including Orkney Islands). Peak flows on a spring tide are estimated to be 0.31 m/s with the flood tide flowing to the east and the ebb flowing to the west. The peak flow on a neap tide is estimated to be 0.10 m/s.

In addition, flow data has also been obtained from Marine Scotland's Pentland Firth and Orkney Waters Model (Pentland Firth and Orkney Waters Climatology 1.02) for a location mid-way along the OECC. Figure 7.16 presents a current rose for a representative 12-month period of data (from 1993) which characterises near-bed flows. These flows are representative of conditions close to cable trenching at this location.

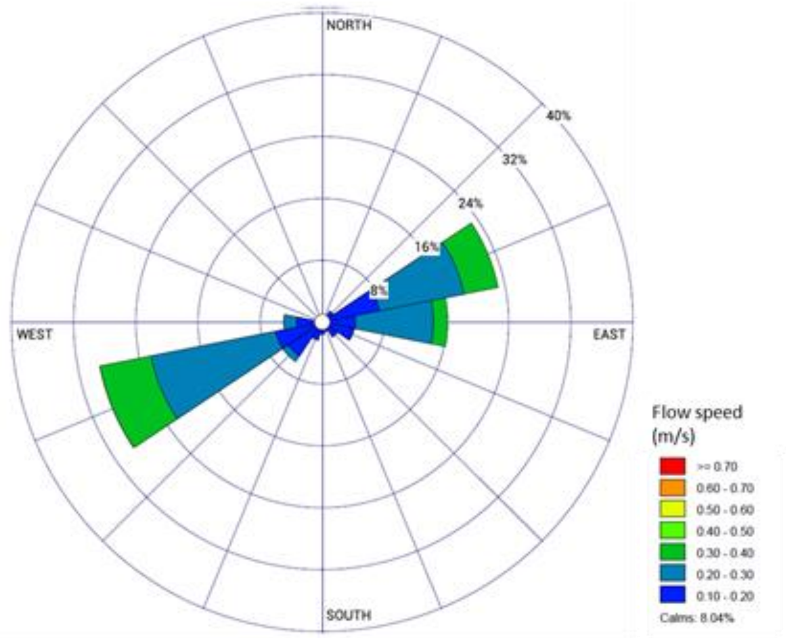

Figure 7.16 Near-bed flows midway along the OECC (data source: Pentland Firth and Orkney Waters Climatology 1.02)

The axis of flood and ebb tides (Figure 7.16) is comparable with a tidal ellipse for this location (Figure 7.12) showing some alignment with the adjacent coastline. The flood tide is towards the east and east-north-east which collectively represent 39% of all flows. The ebb tide is to the west-south-west and represents 29% of all flows. The peak near-bed flows on a spring tide tend to be slightly higher than 0.3 m/s.

7.4.4.7.2 Future tidal flows

There is not expected to be any change to tidal flows into the future. The tidal properties through the Pentland Firth are associated with much larger regional scale tidal movement.

7.4.4.8 Sediment transport

The interaction of the seabed with wave and tidal processes determines how often unconsolidated surficial sediments become mobilised and the way they are transported (i.e. bed load transport and/or suspended load transport).

Section 7.4.4.2 provides an overview of the seabed sediment distribution across the Study Area which are generally sands and gravels, with the dominant sand fraction having grain sizes ranging between 0.06 mm and 2 mm, and a d50 grain size of 0.63 mm (i.e. coarse sand).

7.4.4.8.1 Coarse sediments

Coarser sediments (i.e. sands and gravels) typically move as bedload transport in response to waves and tides, noting that the PFOWF Array Area is generally too deep for wave stirring of sediments and tidal flows are typically too weak.

Table 7.7 considers the current thresholds (after Soulsby, 1997) for sediment mobility for the range of water depths observed across the PFOWF Array Area (75 to 100 m depths).

Table 7.7Current thresholds for sediment mobility

Sediment type	Grain size (micron)	Current threshold (m/s) at 75 m depth	Current threshold (m/s) at 100 m depth
Very fine sand	63 to 125	0.51 to 0.57	0.58 to 0.60
Fine sand	125 to 250	0.57 to 0.58	0.60 to 0.60
Medium sand	250 to 500	0.58 to 0.61	0.60 to 0.64
Coarse sand	500 to 1,000	0.61 to 0.75	0.64 to 0.78
Very coarse sand	1,000 to 2,000	0.75 to 1.06	0.78 to 1.11

In general, the ebb tide flows within the PFOWF Array Area do not reach these thresholds for sediment mobility (99 percentile flow speed of 0.47 m/s), whereas the flood tide flows are marginally stronger (99 percentile flow speed of 0.57 m/s) but would still only very occasionally affect the very fine sand in the shallower parts of the site (75 m depth). All other particle sizes would be immobile to the majority of tidal flows. Coarser sediments, such as gravels, must therefore represent part of a lag deposit.

For tidal diamond SN028E along the OECC (Figure 7.12), the equivalent current threshold for seabed mobility of very fine sand would be 0.52 m/s, noting that the peak flow on spring tides at this location only reach 0.31 m/s. For the d50 0.63 mm (coarse sand) that characterises the study area, flow speeds would again be too low to initiate sediment mobility.

Where there is tidal asymmetry between the flood and ebb phases of the tide, this can develop net sediment transport in the direction of dominant flow, which presently available evidence indicates is to the east on the flood tide. This suggests any very fine sand mobilised on the seabed would preferably move in this direction, albeit with a very low transport rate.

The majority of wave conditions would not be able to stir local seabed sediments due to the deep water across the PFOWF Array Area. The exception to this is the top 1% of waves (i.e. largest waves associated with longer wave periods). These infrequent storm events could produce a wave-induced orbital velocity on the seabed that exceeds any tidal influence, but this infrequent influence would only last for a relatively short period (i.e. duration of storm event). As water depths become shallower along the OECC and towards the coast then wave influences on sediment transport would be expected to increase (i.e. more waves interact with the seabed more often and with stronger near-bed orbital velocities). Waves eventually dissipate their energy through wave breaking along a rocky coastline (rather than drive longshore transport along a sandy beach).

The comparison between bathymetry surveys from 2014 and 2021 indicates the high relative stability of the local seabed, as well as the absence of macro bedforms, confirming that the PFOWF Array Area is relatively immobile to sediment transport for the majority of the time.

7.4.4.8.2 Fine sediments

When finer sediments (i.e. silts and muds) are mobilised they are typically carried in suspension, contributing to higher concentrations of suspended particulate matter (SPM) and increasing the turbidity of water column until they are able to settle out and deposit. Rivers, estuaries and coastal erosion can also provide local sources of increased turbidity.

Long-term (1998 to 2015) monthly average concentration of sea surface SPM have been deduced from satellite data (Cefas, 2016). In general, SPM concentrations across the Study Area are considered to be very low (1 to 2 mg/l) (Figure 7.17). This is attributed to a lack of seabed sediment mobility, no coastal erosion (rocky coastline) and remoteness to any large river or estuary source of fine sediment. The data shows slight seasonal variation in SPM with highest levels occurring in February (as shown in Figure 7.17) and lowest levels in August.

7.4.4.8.3 Future sediment transport

Given that there is not expected to be any changes to the regional scale tidal properties, and only natural variation to the wave climate in response to climate change is likely to occur, there is not anticipated to be any variation to the sediment transport characteristics into the future.

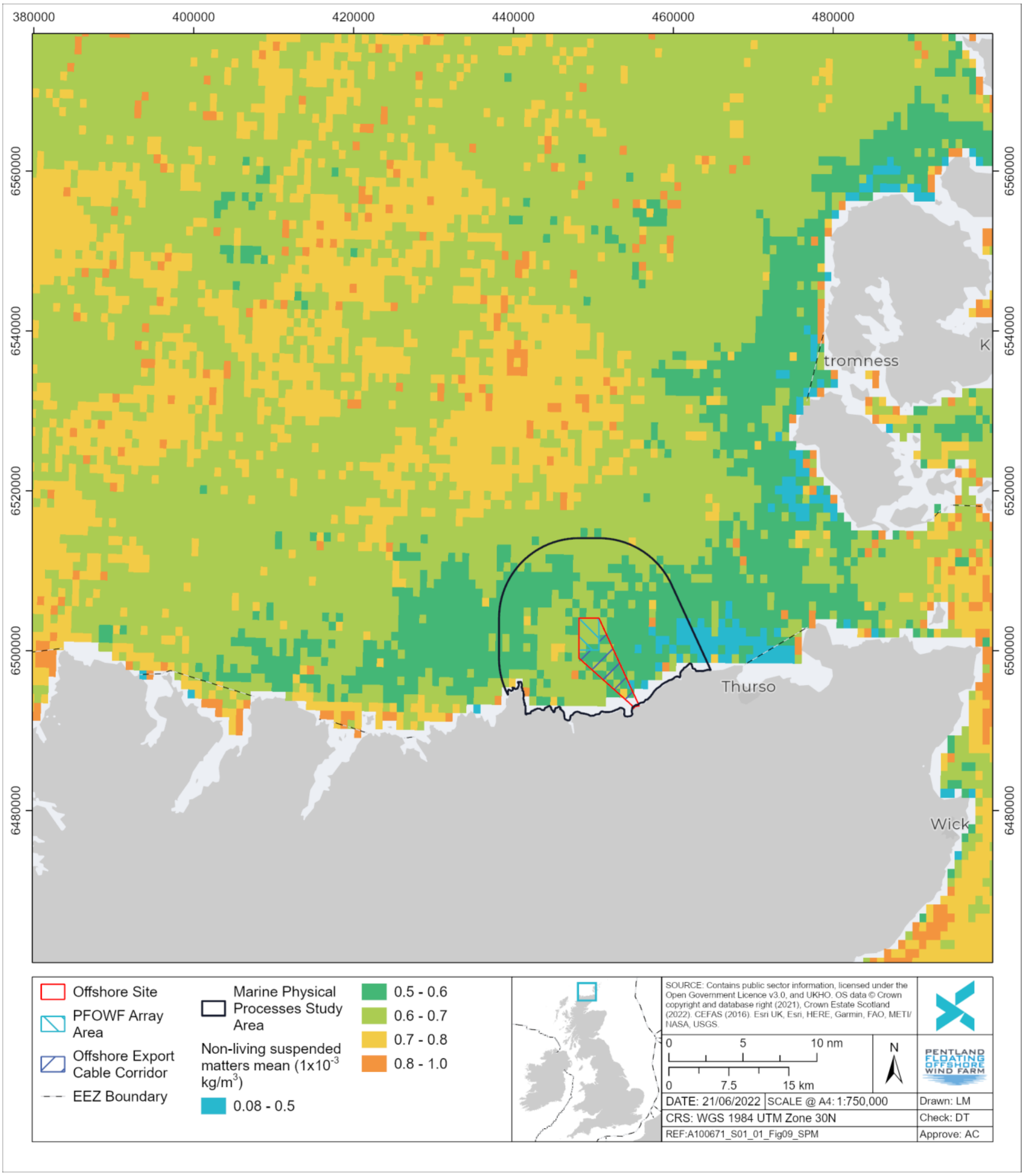

Figure 7.17 Monthly average sea surface SPM concentrations for February (after Cefas, 2016)

7.4.4.9 Stratification and fronts

7.4.4.9.1 Present stratification and fronts

Relatively weak tidal flows combined with deep water provide the possibility for the Study Area to be prone to thermal stratification from spring through to summer, due to periods of increased solar irradiance and lower wind and wave stirring influences. This stratification would expect to dissipate when wind and wave stirring effects increase from autumn through to winter along with reduced lower irradiance (including shorter daylight hours).

The occurrence of stratification across the Study Area has been examined with reference to data from a 3-D baroclinic model sourced from Copernicus Marine (Tonani, *et al*, 2021) which provides details of water temperature through the water column and the development of the mixed layer depth (MLD, the partition between surface water and the rest of the water column, based on the presence of a thermocline).

Figure 7.18 shows the latest full year period of 2021 for a site representing the PFOWF Array Area, to illustrate how water temperature varies seasonally and between near-surface and near-bed water depths, as well as the development of the mixed layer depth.

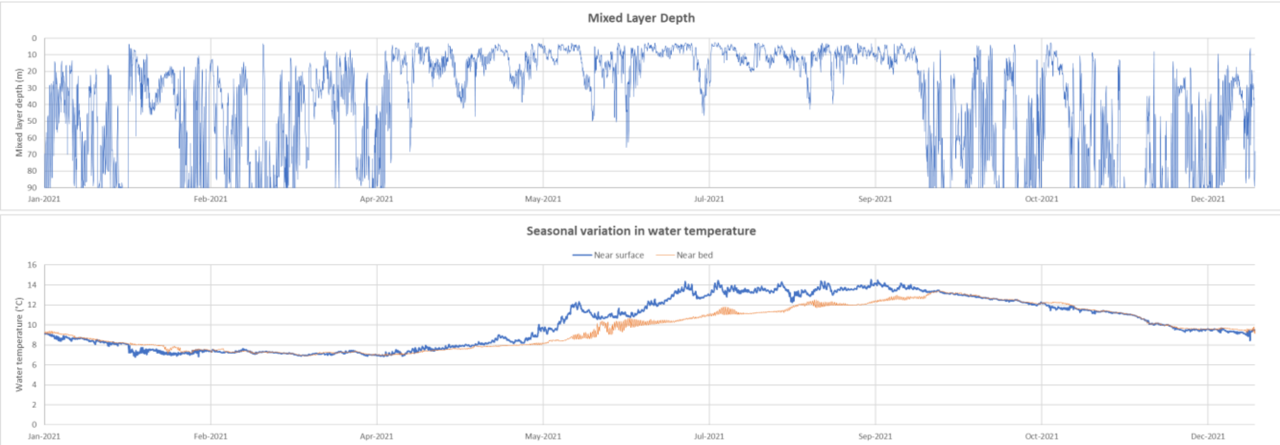

Figure 7.18. Seasonal variation in water temperature and stratification

From April, the near-surface water temperature begins to increase faster than the near-bed with a mixed layer developing at depths of 10 to 20 m below the sea surface as a thermocline is established. Density differences above and below the thermocline lead to a positively buoyant surface layer where water remains well-mixed. The depth of this layer is referred to as the "mixed layer depth" and lasts until early September, after which water temperatures begin to drop due to reduced solar irradiance (and reducing daylight hours). Increased wind speeds and wave activity from this period also contribute to increased mixing in the water column and the eventual breakdown of seasonal stratification.

Where a well-mixed and stratified water body meet, they can develop a distinct density feature known as a front. Fronts can also be associated with higher concentrations of nutrients leading to higher rates of primary productivity.

Figure 7.19 provides a seasonally averaged front frequency map for summer based on an interpretation of ten years of satellite data (1998 to 2008), based on Miller & Christodoulou (2014). The Offshore Site does not coincide with any area of strong frontal activity, such as those identified in SNH (2014), indicated by the low frequency levels that coincide with the Offshore Site in Figure 7.19.

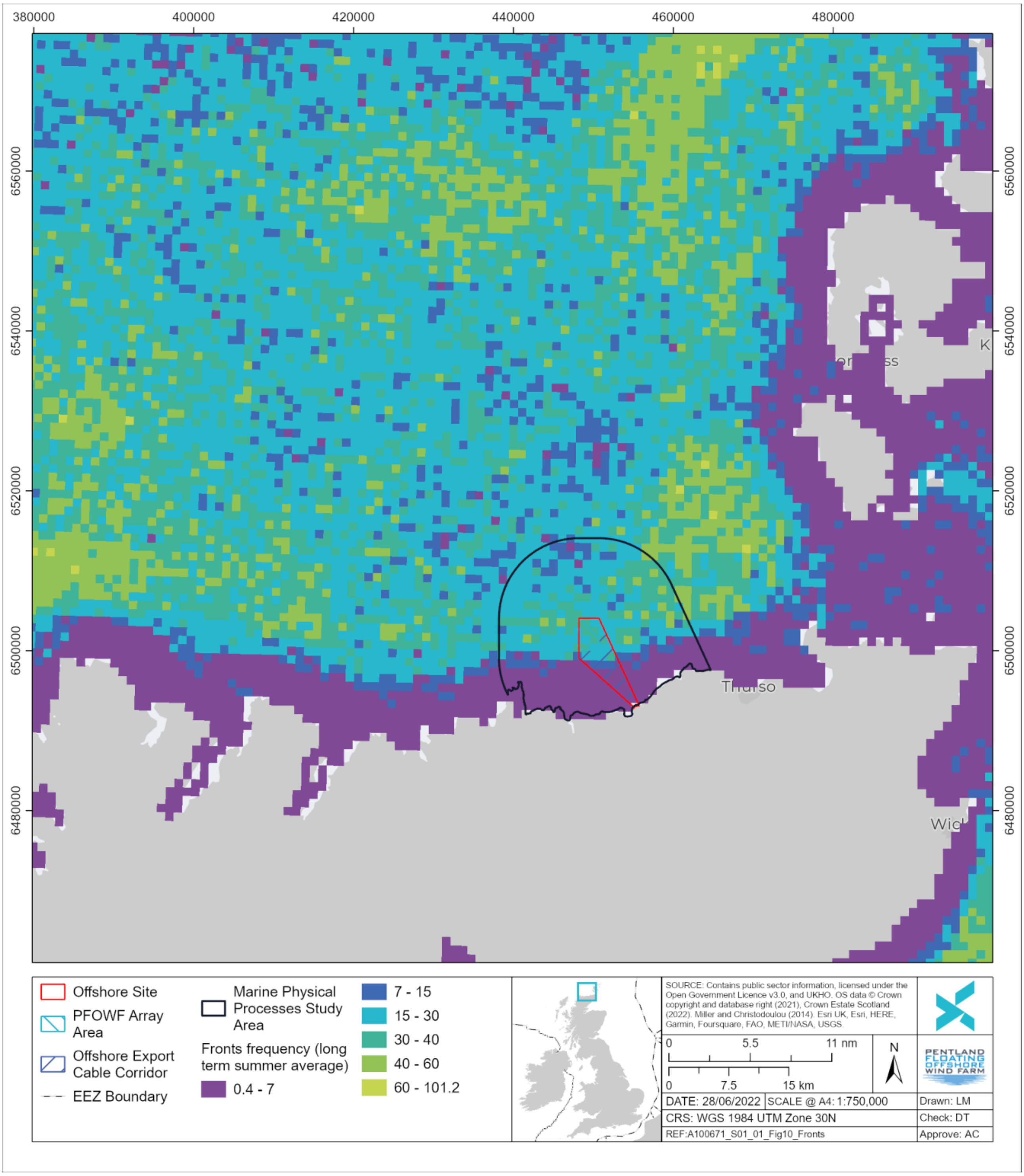

Figure 7.19 Long-term averaged summer frequency of occurrence of fronts (after Miller & Christodoulou, 2014)

7.4.4.9.2 Future stratification and fronts

As further information on the frequency and properties of fronts and stratification becomes available across the north-west coast of Scotland and the Scottish Continental Shelf, so will the understanding of the natural variability and controlling mechanisms for these features within the Pentland Firth. There is little evidence to suggest that fronts and stratification are consistently (even seasonally) present within the region and it is the present understanding of this Offshore EIAR that this is likely to be the case into the future. Any changes to the frequency of occurrence or properties of fronts and stratification within the Pentland Firth, will be dictated by regional changes to the water column, which would also be influenced by climate change.

7.4.5 Summary of Baseline Environment

The Study Area can be characterised as a relatively deep water, weak flow environment with a largely immobile seabed comprised mainly of sands and gravels, and a low content of finer sediment (clays and silts). The Offshore Site is exposed to Atlantic storms and long-period swell-waves, but due to the deep water (with depths greater than 66 mLAT within the PFOWF Array Area), these waves have minimal influence on the seabed until they reach shallower water, at depths of around 24 mLAT. The coastline is formed of erosion resilient, rocky intertidal areas and cliffs which are intersected by occasional small pocket beaches where wind and wave driven sand has developed into a mature dune system. These are now heavily vegetated and largely stable.

7.4.6 Data Gaps and Uncertainties

Complementary evidence has been collated from various sources to support the development of the baseline characterisation. Whilst good overall understanding is achieved for a qualitative description there remains some data gaps (e.g. along the OECC) in local quantification of measured flows, waves and suspended sediments which places reliance on existing models to provide these details. Validated models, such as that of the Pentland Firth and Orkney Waters climatology 1.02 model that has been used within this Offshore EIAR, are an accepted basis of describing the marine environment.

7.5 Impact Assessment Methodology

7.5.1 Source-pathway-receptor

The impact assessment methodology for Marine Physical Processes is undertaken using the well established source-pathway-receptor approach.

The sources of effects are Project activities acting locally within the Offshore Site. The type of effect can be categorised as either:

> **Seabed loss** – long-term effects from the layout of anchor systems;

> **Seabed disturbance** – short-term effects during the construction and decommissioning phases which can lead to increased turbidity and subsequent deposition; or

> **Blockage** – medium to long-term effects from a layout of floating platforms, seabed mountings or remedial protection, during the operational phase which can locally modify wave energy transmission, and develop flow wakes which can locally increase mixing or introduce barriers to sediment transport pathways.

The capacity for these effects to translate over a wider area (in this case defined by the extent of the Study Area) relates to the marine physical processes which can develop a pathway, e.g. tidal advection or wave energy transmission. Methods of assessment have applied a variety of bespoke analytical spreadsheet tools which are supported by available survey and model data.

Where other physical features may be impacted by these effects they are then considered by this topic as physical process receptors (see Table 7.2 Summary of consultation responses specific to Marine Physical Processes). Some effects may also be relevant to receptors from other EIA chapters, and where this is the case, the impacts are considered by the associated chapter. For example, smothering effects of sediment plumes on marine benthos are considered in Chapter 9: Benthic Ecology and the influence of sediment plumes on fish ecology or marine mammals, considered in Chapter 10: Fish and Shellfish Ecology and Chapter 11: Marine Mammals.

Potential receptors and impacts scoped into the assessment of Marine Physical Processes and impacts scoped out are provided in Section 7.5.2 and 7.5.3, along with justification.

7.5.2 Impact Pathways Requiring Assessment

The Marine Physical Processes assessment covers all impact pathways identified through the scoping process, as well as any further potential impacts that have been highlighted as the EIA has progressed.

Table 7.8 summarises Marine Physical Process impact pathways for associated phases of project development. Cumulative impacts are discussed in Section 7.7. Potential inter-relationships from marine and physical processes impacts on other EIA topic receptors addressed within this Offshore EIAR are discussed in Section 7.11.

Table 7.8 Impact pathways

Impact	Source of impact	Impact pathway	Description
Construction			
Increase in suspended sediment	Seabed preparation (OECC and PFOWF Area Area) Cable trenching (Inter-array and OECC) Drilling for fixing seabed anchors (PFOWF Array Area)	Local sediment disturbance leading to short-term increase of suspended sediments	This impact relates to short-term and localised increases in suspended sediment concentrations (SSC) associated with the Offshore Development construction and decommissioning activities, including anchor and mooring installation, seabed and boulder clearance, trenching and cable laying. Increases in SSC lead to changes and increases in water column turbidity, which could result in onward impacts to receptors, potentially sensitive to water turbidity levels, such as the Red Point Coast and Strathy Coast SSSIs or North Caithness Cliffs SPA designated for breeding seabirds. Assessment of this impact is assessed in Section 7.6.1.1.
Loss/ alteration of physical seabed characteristics (bathymetry and sediment type)	Cable protection (Inter-array and OECC) Seabed anchor system and associated moorings (PFOWF Array Area)	Direct loss of seabed characteristics	Offshore Development construction activities, including anchor and mooring installation, trenching and cable laying would lead to the loss of seabed. Construction activities such as drilling for pile anchors and installation of remedial protection could lead to the introduction of a different or new seabed substrate, which could lead to onward changes to marine physical process properties. This impact is assessed in Section 7.6.1.2.
Operation and maintenance			
Changes to wave and tide regime	Floating platforms and seabed anchor system (PFOWF Array Area)	Changes to wave and tides, with onward impacts to sediment transport and fronts and stratification.	The presence of floating substructures at the sea surface, moorings within the water column and structures on the seabed, will interact with the tidal and wave movement across the Offshore Site. This has the potential to bring about changes in the wave and tidal processes

Impact	Source of impact	Impact pathway	Description
			and a reduction in the available energy. Any changes in the wave and tidal energy and distribution could lead to onward impacts on other marine physical processes (including sediment transport, fronts and stratification) and other receptors. This impact is assessed in Section 7.6.2.1.
Changes to sediment transport regime	Cable protection (Inter-array and OECC)	Sediment transport blockage from remedial protection	Changes in the wave and tide regime at the sea surface and on the seabed can lead to changes in sediment transport patterns and behaviour, with onward impacts to other receptors, such as the coast. This impact is assessed in Section 7.6.2.2.
Introduction of scour	Seabed anchor system (PFOWF Array Area)	Local scouring around base of anchor	The presence of structures on or near the seabed has the potential to bring about localised changes to flows resulting in the introduction of scour. This impact is assessed in Section 7.6.2.3.
Impacts on fronts and stratification	Floating platforms and moorings (PFOWF Array Area)	Turbulent wakes with increased mixing of the water column	Changes in the wave and tide regime at the sea surface or through the water column can lead to increased water column mixing with changes to the occurrence of fronts, or seasonal stratification. This impact is only in relation to infrastructure within the PFOWF Array Area, with the potential for onward impacts to the primary productivity across the Pentland Firth. This impact is assessed in Section 7.6.2.4.
Decommissioning			
Increase in suspended sediment	Removal of infrastructure (OECC and PFOWF Array Area)	Local sediment disturbance leading to short-term increase of suspended sediments	Potential impacts arising during the decommissioning phase are expected to be similar to, but not exceeding, those considered during the construction phase.

7.5.3 Impacts Scoped Out

The following impacts were scoped out of the assessment during EIA Scoping or during Consultation, as described in Table 7.2.

7.5.3.1 Construction and decommissioning impacts

7.5.3.1.1 Impacts on geology

No impacts on geology are anticipated due to the use of floating wind structures with small-scale anchoring options that will for the worst case pile option have a pile diameter of up to 3 m and a drill depth of 49.5 m. The small surface area associated with the anchors and the persistence of the underlying sub-surface sediments and geology within the Pentland Firth, means that there will be no impacts to the geological properties across the Offshore Site.

7.5.3.1.2 Impacts on SSSI features

The construction activities within the Offshore Site do not overlap protected geological or coastal morphology features within the Red Point Coast or Sandside Bay SSSI. Therefore, loss, alteration or disturbance to these features, due to construction activities, are not anticipated. Furthermore, in the method statement (Highland Wind Limited, 2021) submitted to MS-LOT, it was confirmed that pinning the export cable to the disused water intake was no longer a viable option and this was subsequently removed from the Project Description. On this basis, assessment of direct impacts to Sandside Bay SSSI was scoped out. This approach was agreed by MSS and NatureScot in their response provided on 7th April 2022, accordingly no further assessment is required.

7.5.3.1.3 Changes to landfall morphology

It was noted within the Scoping Report (Highland Wind Ltd, 2020) that cable installation in nearshore environments may disrupt the coastal morphology by varying degrees depending on the method applied. However, as presented in Highland Wind Ltd, (2021) Method Statement, described in Chapter 6: Project Description and discussed in the consultation summary (Table 7.2), cable installation through HDD is the selected method. The HDD exit point will be between 400 and 700 m from the coastline (subject to further engineering studies). Based on the selected cable landfall methodology it is considered that there would be no impacts to the nearshore morphology during the construction phase and this impact could be scoped out from further assessment. This approach was presented in Highland Wind Ltd, (2021). A formal agreement to the points and approaches discussed within the method statement was received from MSS and NatureScot on 7th April 2022, agreeing that changes to landfall methodology could be scoped out from further assessment.

7.5.3.2 Operation and Maintenance impacts

No impacts were scoped out for this stage of the Offshore Development.

7.5.4 Assessment Methodology

The EIA process and methodology are described in detail in Chapter 6: EIA Methodology.

Project specific criteria have been developed for the sensitivity and vulnerability of the receptor, and the likelihood and magnitude of impact as detailed below.

7.5.4.1 Defining impact magnitude

Defining impact magnitude requires consideration of how the following factors will impact on the baseline conditions:

- Spatial Extent: The area over which the impact will occur;
- Duration: The period of time over which the impact will occur;
- Frequency: The number of times the impact will occur over the project life-cycle;
- Intensity: The severity of the impact;
- Likelihood: The probability that the impact will occur and also the probability that the receptor will be present; and
- Reversibility: The ability for the receiving environment / exposed receptor to return to baseline conditions.

Based on these parameters, and expert judgement, a summarised description on the assignment of magnitude criteria is provided in Table 7.9.

Table 7.9 Impact magnitude criteria

Magnitude	Criteria
High	Impact occurs over a large spatial extent resulting in widespread, long term or permanent changes in baseline conditions or affecting a large proportion of receptor population. The impact is very likely to occur and /or will occur at a high frequency or intensity.
Moderate	Impact occurs over a local to medium extent, with short to medium term change to baseline conditions or affecting a moderate proportion of receptor population. The impact is likely to occur and/ or will occur at a moderate frequency or intensity.

Magnitude	Criteria
Low	Impact is localised and temporary or short term, leading to detectable change in baseline conditions or noticeable effect on small proportion of receptor population. The impact is unlikely to occur or may occur but at low frequency or intensity.
Negligible	Impact is highly localised and short term with full rapid recovery expected to result in very slight or imperceptible changes to baseline conditions or receptor population. The impact is very unlikely to occur and if it does will occur at very low frequency or intensity.
No Change	No change from baseline conditions.

7.5.4.2 Receptor sensitivity

As part of the assessment of significance of effects it is necessary to determine the receptor sensitivity. The sensitivity of a receptor is defined as 'the degree to which a receptor is affected by an impact'.

The overall receptor sensitivity is determined by considering a combination of value, adaptability, tolerance and recoverability. This is achieved through applying known research and information on the status and sensitivity of the feature under consideration coupled with professional judgement and past experience.

The ability of a receptor to adapt to change, tolerate, and/or recover and the timing for recovery from potential impacts is key in assessing its vulnerability to the impact under consideration. Table 7.10 details the criteria used to define sensitivity in terms of adaptability and recoverability.

Table 7.10 Sensitivity of receptor (in the context of ability to recover and adaptability)

Receptor sensitivity	Definition
Very high	Receptor with no capacity to accommodate a particular effect and no ability to recover or adapt.
High	Receptor with very low capacity to accommodate a particular effect with low ability to recover or adapt.
Moderate	Receptor with low capacity to accommodate a particular effect with moderate ability to recover or adapt.
Low	Receptor has some tolerance to accommodate a particular effect and a high ability to recover or adapt.
Negligible	Receptor is generally tolerant and can accommodate a particular effect without the need to recover or adapt.

Receptor value considers whether, for example, the receptor is rare, has protected or threatened status, importance at local, regional, national or international scale and in the case of biological receptors whether the receptor has a key role in the ecosystem function. Based on this, receptor value has been defined for Marine Physical Process receptors in Table 7.11 to aid the overall assessment of receptor sensitivity.

Table 7.11 Criteria for value of Marine Physical Process receptors

Value of receptor	Definition
Very high	Receptor comprises a designated interest feature of national and / or international designations and is protected under associated legislation (e.g. biological and geomorphological features designated under SACs, SPAs and MPAs). Receptor is also of high importance and rarity and has no capacity to avoid or adapt to an effect, tolerate or absorb an effect, or recover to baseline conditions.
High	Receptor comprises a designated interest feature of national and / or international designations and is protected under associated legislation (e.g. biological and geomorphological features designated under SACs, SPAs and MPAs). Receptor is a common example of the designated interest feature and has moderate capacity to avoid or adapt to an effect, tolerate or absorb an effect, or recover to baseline conditions.
Medium	Receptor does not comprise a designated interest feature under any national or international legislation, it however, forms a pathway which supports designated interest features that are considered to be of high importance and rarity. Receptor also has a medium to high capacity to avoid or adapt to an effect, tolerate or absorb an effect, or recover to baseline conditions.
Low	Receptor does not comprise a designated interest feature under any national or international legislation, it however, forms a pathway which supports designated interest features that are considered to be a common example of the feature. Receptor also has a high to very high capacity to avoid or adapt to an effect, tolerate or absorb an effect, or recover to baseline conditions.
Negligible	Receptor does not comprise a designated interest feature under any national or international legislation and does not support a pathway to designated features. Receptor of very low importance, such as those which are generally abundant around the UK with no specific value or conservation concern. Receptor has capacity to avoid or adapt to an effect, tolerate or absorb an effect, or recover to baseline conditions.

The overall sensitivity for Marine Physical Process receptors is therefore defined based on professional judgement in line with the above criteria.

7.5.4.3 Evaluation to Determine Significance of Effect

Significance of an effect is determined by correlating the magnitude of the impact and the sensitivity of receptor in conjunction with professional judgement, using industry best practice guidance, science and accepted approaches.

To ensure a transparent and consistent approach throughout this Offshore EIA Report, a matrix approach has been adopted to guide the assessment of significance of effects (Table 7.12). There is however latitude for professional assessment where deemed appropriate in the application of this matrix.

Table 7.12 Significance of effects matrix

Significance of Effects Matrix					
Sensitivity of Receptor	Magnitude of Impact				
	No Change	Negligible	Low	Moderate	High
Negligible	Negligible	Negligible	Negligible	Negligible	Minor
Low	Negligible	Negligible	Minor	Minor	Moderate
Moderate	Negligible	Minor	Minor	Moderate	Major
High	Negligible	Minor	Moderate	Major	Major
Very High	Negligible	Minor	Major	Major	Major

Definitions of significance of effect are described in Table 7.13. For the purposes of this Offshore EIAR, any effect with a significance of moderate or greater is generally considered 'significant' in EIA terms and additional mitigations may be required. Whilst effects identified as minor or negligible are generally considered to be 'not significant' in EIA terms.

Table 7.13 Assessment of consequence

Assessment consequence	Description (consideration of receptor sensitivity and value and impact magnitude)	Significance of Effect
Major Effects	Effects (beneficial or adverse) are likely to be highly noticeable and long term, or permanently alter the character of the baseline and are likely to disrupt the function and/or status / value of the receptor. They may have broader systemic consequences. These effects are a priority for mitigation to avoid or reduce the anticipated significance of the effect.	Significant
Moderate Effects	Effects (beneficial or adverse) are likely to be noticeable and result in lasting changes to the character of the baseline and may cause hardship to, or degradation of, the receptor, although the overall function and value of the baseline / receptor is not disrupted. Such effects are a priority for mitigation to avoid or reduce the anticipated significance of the effects.	Significant
Minor Effects	Effects (beneficial or adverse) are expected to comprise noticeable changes to baseline conditions, beyond natural variation, but are not expected to cause long term degradation, hardship, or impair the function and value of the receptor. Such effects are not typically contentious and will not generally require additional mitigation, but may be of interest to stakeholders.	Not Significant
Negligible	Effects are expected to be either indistinguishable from the baseline or within the natural level of variation. These effects do not require mitigation and are not anticipated to be a stakeholder concern and/or a potentially contentious issue in the decision-making process.	Not Significant

7.5.5 Design Envelope Parameters

As detailed in Chapter 5: Project Description, this assessment considers the Offshore Development parameters which are predicted to result in the greatest environmental impact, known as the 'realistic worst case scenario'. The realistic worst case scenario represents, for any given receptor and potential impact on that receptor, various options in the Design Envelope that would result in the greatest potential for change to the receptor in question.

Given that the realistic worst case scenario is based on the design option (or combination of options) that represents the greatest potential for change, confidence can be held that development of any alternative options within the design parameters will give rise to no effects greater or worse than those assessed in this impact assessment.

Table 7.14 presents the realistic worst case scenario for potential impact pathways related to Marine Physical Processes during the construction, operation and maintenance, and decommissioning phases of the Offshore Development. The realistic worst case scenario has been derived by ensuring that the maximum parameters of components for the Offshore Development with potential to interact with Marine Physical Process receptors and pathways are considered to enable assessment of the identified impacts.

Where there are a number of options for the various Offshore Development components e.g. the range of anchor options being considered, the option(s) which has the largest potential impact on Marine Physical Process receptors and pathways, based on the relevant impact, has been assessed, at the maximum parameters identified. Due to the varying pathways between construction activities in the PFOWF Array Area, compared with the OECC, the worst case parameters relating to each aspect of the Offshore Development were considered.

Therefore, the worst case seabed loss / alteration in the PFOWF Array Area, was determined to be in relation to gravity anchors, due to the anchor footprint and associated scour protection. Whilst for the OECC, it was the presence of remedial cable protection. In terms of the impact of increases in suspended sediment concentrations, which is a pathway, the potential sediment dispersion associated with the varying anchor installation methods (seabed levelling and drilling) both need to be quantitatively investigated to accurately determine the worst case, with respect to the PFOWF Array Area. For the OECC, jetting was considered to be the worst case due to the fluidisation of seabed sediment.

For operational impacts, including potential changes to wave, tide, fronts and stratification, it is the floating substructure that has the potential to provide the largest blockage that is assessed, which is the semi-submersible platform, which is assumed to be a "solid" structure. In terms of the introduction of scour, again the potential scour associated with the range of anchor options was quantitively assessed to determine the worst case.

Table 7.14 Design parameters specific to Marine Physical Processes impact pathway assessment

Potential Impact Pathway	Design Envelope Scenario Assessed
Construction Phase	
Loss/ alteration of physical seabed characteristics (bathymetry and sediment type) Increase in suspended sediments and onward impacts	**Export Cable(s)** > A maximum of two export cables which will run from the PFOWF Array Area to landfall; > Maximum total combined length of cables is approximately 25 km; > Maximum width of cable corridor 15 m (seabed disturbance, not trench width). Seabed preparation including boulder removal, seabed levelling etc. will take place within this corridor; > Seabed preparation to be completed along 100% of cable corridor; > Maximum seabed preparation footprint = 375,000 m^2 (15 m by 25 km); > Maximum trench width 3 m and maximum trench depth 1.5 m; > Cable installation (lay and burial) operations using a jetting tool; > Trenching rate 120 m/hr; > Up to 50% of the offshore export cables may not reach target burial depth of 0.6 m and may require remedial cable protection, therefore maximum length of remedial cable protection will be 6.25 km cable, 12.5 km in total. Remedial cable protection height and width of 1 m and 7 m respectively. Total area of 87,500 m^2 / 0.0875 km^2; > Maximum volume of 50,000 m^3 cable protection for export cables; > Export cable installation (to HDD exit hole) – anticipated to be approximately 7 days (excluding weather downtime) per export cable; > Total duration of offshore ops = approximately 4 months during Stage 1 or Stage 2. **Inter-array Cables** > Maximum of 7 inter-array cables (IAC); > Maximum combined length of IAC is 25 km (all cables combined); > Maximum length of IAC on the seabed is 20 km (all cables combined); > Maximum width of cable corridor 15 m (seabed disturbance, not trench width). Seabed preparation including boulder removal, seabed levelling etc. will take place within this corridor;

Potential Impact Pathway	Design Envelope Scenario Assessed
	> Seabed preparation to be completed along 100% of cable corridor; > Maximum trench width 3 m and maximum trench depth 1.5 m; > Worst case disturbance associated with jetting lay and burial of cables; > Up to 50% of the IAC may need remedial cable protection, therefore 10,000 m in total. Remedial cable protection height and width of 1 m and 7 m respectively. Total area of 70,000 m^2 (0.07 km^2); > IAC installation – anticipated to be approximately 14 days (excluding weather downtime); > Total duration of offshore ops = approximately 3 months Stage 2. **Moorings: catenary** > Maximum number of moorings is 9 per substructure / WTG; > Maximum length of each mooring line 1,650 m; > Maximum length of mooring that may come into contact with the seabed = 1,485 m per line (90% of total length); > Maximum area of seabed where lateral movement of mooring line can occur – 0.035 km^2 per line; and > Total duration of offshore ops = approximately 6 months Stage 2. **Anchors** > Worst case seabed loss: Gravity; > Worst case for alteration of seabed type (sediment): Drilled piles; > Up to 9 anchors per substructure / WTG; and > Maximum scour protection height is 1 m. **Gravity (footprint and scour protection)** > Maximum permanent seabed footprint 625 m^2 per anchor (gravity), 25 m length, 25 m width and 1.5 m height; > Maximum seabed preparation area 900 m^2 (30 m by 30 m) per anchor (gravity); > Maximum scour protection per anchor 260 m^3); and > Maximum scour protection volume for OWF 55,755 m^3 (gravity). **Hammer Piles (footprint and scour protection)** > Maximum pile diameter is 5 m; > Pile burial depth is 20 m; > Maximum scour protection is per pile: 760 m^3; > Maximum scour protection diameter + pile, per pile: 17.5 m (5 m diameter pile plus 12.5 m diameter scour protection); and > Maximum scour protection volume for OWF: 47,880 m^3.

Potential Impact Pathway	Design Envelope Scenario Assessed
	Drilled Piles (volume) - Maximum pile diameter of 3 m and associated burial depth of 49.5 m; - Drilling rate: 4 m/hr; - Maximum drilling duration for OWF is 49 days; - Volume of drill arisings per pile: 350 m^3; and - Volume of drill arisings for OWF is 31,500 m^3.
Operational Phase	

Changes to tidal regime
Changes to wave regime
	Substructures
	- Worst case blockage and wake effects: Semi-submersible (worst case taken as square solid structure);
	- Dimensions relate to overall size: 125 m by 125 m by 50 m;
	- Maximum depth of substructure below sea surface: 20 m; and
	- Minimum separation distance: 800 m.
	Anchors (surface area and scour protection)
	- Maximum scour protection height is 1 m;
	- Up to 9 anchors per substructure / WTG, so 63 anchors for PFOWF Array;
	- Gravity:
	  o Maximum permanent seabed footprint 625 m^2 per anchor (gravity), 25 m length, 25 m width and 1.5 m height;
	  o Maximum scour protection per anchor 260 m^3); and
	  o Maximum scour protection volume for OWF 55,755 m^3 (gravity).
	- Hammer piles:
	  o Maximum scour protection is per pile: 760 m^3;
	  o Maximum scour protection diameter + pile, per pile: 17.5 m (5 m diameter pile plus 12.5 m diameter scour);
	  o Maximum scour protection volume for OWF: 47,880 m^3.
	Export Cable
	- Up to 50% of the offshore export cables may not reach target burial depth of 0.6 m and may require remedial cable protection, therefore maximum length of remedial cable protection will be 6.25 km cable, so 12.5 km in total. Remedial cable protection height and width of 1 m and 7 m respectively. Total area of 87,500 m^2 / 0.0875 km^2;
	- Total volume of 50,000 m^3 protection for export cables.
	Inter-array Cables;
	- Up to of the IAC may need remedial cable protection, therefore 10,000 m in total. Remedial cable protection height and width of 1 m and 7 m respectively. Total area of 70,000 m^2 / 0.07 km^2;
	- Total volume of 40,000 m^3 cable protection for inter-array cables.

Potential Impact Pathway	Design Envelope Scenario Assessed
Changes to sediment transport regime	**Anchors (surface area and scour protection)** > Maximum scour protection height is 1 m; > Up to 9 anchors per substructure / WTG, so 63 anchors for OWF; > Gravity: o Maximum permanent seabed footprint 625 m^2 per anchor (gravity), 25 m length, 25 m width and 1.5 m height; o Maximum scour protection per anchor 260 m^3); and o Maximum scour protection volume for OWF 55,755 m^3 (gravity). > Hammer piles: o Maximum scour protection is per pile: 760 m^3; o Maximum scour protection diameter + pile, per pile: 17.5 m (5 m diameter pile plus 12.5 m diameter scour); o Maximum scour protection volume for OWF: 47,880 m^3. **Moorings: catenary** > Maximum number of moorings is 9 per substructure / WTG; > Maximum length of each mooring line 1,650 m; > Maximum length of mooring that may come into contact with the seabed = 1,485 m per line (90% of total length); and > Maximum area of seabed where lateral movement of mooring line can occur – 0.035 km^2 per line. **Export Cable (scour protection)** > Up to 50% of the offshore export cables may not reach target burial depth of 0.6 m and may require remedial cable protection, therefore maximum length of remedial cable protection will be 6.25 km cable, so 12.5 km in total. Remedial cable protection height and width of 1 m and 7 m respectively. Total area of 87,500 m^2 / 0.0875 km^2; and > Total volume of 50,000 m^3 cable protection for export cables. **Inter-array Cables;** > Up to of the IAC may need remedial cable protection, therefore 10,000 m in total. Remedial cable protection height and width of 1 m and 7 m respectively. Total area of 70,000 m^2 / 0.07 km^2; and > Total volume of 40,000 m^3 cable protection for inter-array cables.
Introduction of scour	**Anchors (surface area and scour protection)** > Maximum scour protection height is 1 m; > Up to 9 anchors per substructure / WTG, so 63 anchors for OWF; > Gravity: o Maximum permanent seabed footprint 625 m^2 per anchor (gravity), 25 m length, 25 m width and 1.5 m height; o Maximum scour protection per anchor 260 m^3); and o Maximum scour protection volume for OWF 55,755 m^3 (gravity).

Potential Impact Pathway	Design Envelope Scenario Assessed
	> Hammer piles: o Maximum scour protection is per pile: 760 m^3; o Maximum scour protection diameter + pile, per pile: 17.5 m (5 m diameter pile plus 12.5 m diameter scour); and o Maximum scour protection volume for OWF: 47,880 m^3.
Impacts on fronts and stratification	**Substructures** > Worst case blockage and wake effects: Semi-submersible (worst case taken as square solid structure) > Dimensions relate to overall size: 125 m by 125 m by 50 m; > Maximum depth of substructure below sea surface: 20 m. **Moorings: catenary** > Maximum number of moorings is 9 per substructure / WTG; > Maximum length of each mooring line 1,650 m; > Maximum length of mooring that may come into contact with the seabed = 1,485 m per line (90% of total length); > Maximum area of seabed where lateral movement of mooring line can occur – 0.035 km^2 per line; and > Total duration of offshore ops = approximately 6 months Stage 2.
Decommissioning	
Potential impacts arising during the decommissioning phase are expected to be similar to, but not exceeding, those arising during the construction phase.	In the absence of detailed information regarding decommissioning works, the implications for Marine Physical Processes are considered analogous with or likely less than those of the construction phase. Therefore, the worst case parameters defined for the construction phase also apply to decommissioning. The decommissioning approach is set out in Chapter 5: Project Description. It is now expected that all offshore components will be removed to shore for re-use, recycling and disposal during decommissioning, unless there is compelling evidence to leave *in situ*. The removal of the WTGs, floating substructures and anchoring systems will largely be a reversal of the construction/installation process, subject to constraints. The only exceptions to the complete removal of infrastructure, is in relation to scour or remedial protection, which may be preferable to leave *in situ* to preserve the marine habitat that may have developed over the life of the Offshore Development. This is particularly the case for rock placement / boulders as these are generally quite small in grade size and thousands in quantity so not practical to recover. Piled anchor options, which are driven or screwed into the seabed to significant depths, may also be cut to below seabed level and recovered to shore. A Decommissioning Programme will be developed pre-construction to address the principal decommissioning measures for the Offshore Development, this will be written in accordance with applicable guidance and detail the management, environmental management and schedule for decommissioning. The Decommissioning Programme will be reviewed and updated throughout the life-cycle of the Offshore Development to account for changing best practice. Relevant stakeholders and regulators will be consulted to establish the approach. The seabed will be restored, as far as reasonably practicable, to the condition it was prior to the construction of the Offshore Development.

7.5.6 Embedded Mitigation and Management Plans

As part of the Offshore Development design process, a number of designed-in measures and management plans have been proposed to reduce the potential for impacts on Marine Physical Processes receptors (Table 7.15). As there is a commitment to implementing these measures which will likely be secured through Section 36 consent and Marine Licence conditions, they are considered inherently part of the design of the Offshore Development and have therefore been considered in the assessment presented below (i.e. the determination of magnitude of impact and therefore significance of effects assumes implementation of these measures). These measures are considered standard industry practice for this type of development.

Further to proposed management plans, embedded mitigation measures, such as the use of HDD for cable installation at landfall and scour protection around anchors are incorporated into the Project Design and are therefore also considered in the assessment presented below.

Table 7.15 Embedded Mitigation Measures specific to Marine Physical Processes for the Offshore Development

Embedded Mitigation Measures and Management Plans	Justification
Management Plans	
Construction Environmental Management Plan (CEMP)	The CEMP will set out procedures to ensure all activities with potential to affect the environment are appropriately managed and will include: a description of works and construction processes, roles and responsibilities, description of vessel routes and safety procedures, pollution control and spillage response plans, incident reporting, chemical usage requirements, waste management plans, plant service procedures, communication and reporting structures and timeline of work. It will detail the final design selected and take into account Marine License Conditions and commitments within the CEMP. The CEMP will include a Marine Pollution Contingency Plan and INNS Management Plan. Adopting these protocols will reduce risk in relation to spread of INNS across all phases of the Offshore Development.
Offshore Construction Method Statement (CMS)	A Construction Method Statement (CMS) will be developed in accordance with the CEMP detailing how the Offshore Development activities and plans identified within the CEMP will be carried out, and also highlighting any possible dangers/risks associated with particular Offshore Development activities.
Operational Environmental Management Plan (OEMP)	The developer will collate an OEMP to guide on-going operations and maintenance activities during the life-cycle of the Offshore Development. The OEMP will also set out the procedures for managing and delivering the specific environmental commitments including a Marine Pollution Contingency Plan and INNS Management Plan. Adopting these protocols will reduce risk in relation to spread of contaminants and radioactive particles across all phases of the Offshore Development.
Cable Plan (CaP)	A Cable Plan will be prepared for the Offshore Development and will detail the location/ route and cable laying techniques of the inter-array and Offshore Export Cable(s) and detail the methods for cable surveys during the operational life of the cables for the Offshore Development. This will be supported by survey results from the geotechnical, geophysical and benthic surveys. The cable plan will also detail electromagnetic fields of the cables deployed. A Cable Burial Risk Assessment (CBRA) will also be undertaken and included within the Cable Plan which will detail cable specifications, cable installation, cable protection, target burial depths / depth of lowering and any hazards the cable will present during the life-cycle of the cable.

Embedded Mitigation Measures and Management Plans	Justification
Embedded Mitigation	
Use of HDD as the landfall cable installation option	HDD negates the need to pin the export cable to the disused water intake which raised concerns about potential effects on coastal morphology and impacts on Sandside Bay SSSI
Application of scour protection	The Project Design Envelope includes the installation of scour protection around the anchor installations within the PFOWF Array Area. This will therefore negate the introduction of scour during the Offshore Development operation stage. The potential scale and requirement for scour protection will be informed by scour studies and the selected anchor solution.
Micrositing of WTGs and associated offshore infrastructure including cable routes	The final Project layout will be presented within the Design Specification and Layout Plan and Cable Plan, which will form conditions of the Section 36 and/or Marine Licence consent. As part of the pre-construction survey (which will be agreed upon with Marine Scotland) data will be analysed to ascertain the locations of the WTGs and cable routes, with the potential for micro-siting of the Project infrastructure.

7.6 Assessment of Environmental Effects

7.6.1 Effects during Construction

7.6.1.1 Increase in suspended sediment

Based on the project design envelope detailed in Chapter 6: Project Description of this Offshore EIAR, with relevant parameters to Marine Physical Processes summarised in Table 7.14, it is clear that there are multiple mechanisms for seabed disturbance leading to increase suspended sediment concentrations. Therefore, the following sub-sections describe and analyse the varying pathways for increased suspended sediment from the different construction activities, to determine the worst case for impact assessment. The construction activities that are considered to lead to sediment disturbance and increases in suspended sediment concentrations are as follows:

- Seabed preparation (which includes boulder clearance and seabed levelling);
- Cable installation; and
- Anchor installation.

Each of the above construction activities are individually quantitatively assessed, based on the Project Design Envelope parameters summarised in Table 7.14 above. The analysis of sediment disturbance and plume development uses developed spreadsheet tools that account for the water depth, sediment properties and tidal flow conditions (informed by the hindcast data, site observations and Pentland Firth and Orkney Waters climatology 1.02 model data). Based on the settling velocity of the sediment present, the tools estimate the sediment plume propagation, in relation to the time series of flow properties for a representative flood and ebb tidal cycle under spring tide conditions.

Results of the suspended sediment plume propagation, direction, duration and concentration are presented for each of the sediment disturbance mechanisms.

7.6.1.1.1 Sediment disturbance from seabed preparation

The initial offshore activity during the construction phase is seabed preparation. This is required to remove obstacles that might interfere with efficient cable burial and / or to provide a level seabed for a particular anchor solution such as the gravity anchors. The construction activities with the potential to cause sediment disturbance and increases is suspended sediment concentration are boulder clearance and seabed levelling. These are quantified below, using the approach introduced in Section 7.6.1.1 above.

7.6.1.1.1.1 Boulder clearance

The geophysical survey does not identify any macro-bedforms (e.g. sandwaves), but does identify boulders (classified as individual contacts resolved by side-scan sonar with a length scale greater than 0.5 m) mainly within the southern part of the PFOWF Array Area, with a further area of boulders towards the coastline from around 35 to 45 m below LAT as illustrated in Figure 7.3.

Boulders would be cleared from areas requiring cable laying and anchor installation. Either a boulder clearance plough or a grab unit lowered from a construction vessel would be used, with the boulders being moved on to seabed adjacent to the cable routes (export cables and inter-array cables). In the case of clearance within the PFOWF Array Area with respect to anchor locations, the cleared boulders would be moved to a suitable nearby location. The expectation is these adjacent areas already have a similar density of boulders. The consequence on Marine Physical Processes is a low level of mechanical disturbance during this short-term operation to the surface of the seabed and an increased density of boulders to the adjacent seabed which could lead to a slight increase in bed roughness. It is also the case that micro-siting could be employed to avoid areas with a lot of boulders.

7.6.1.1.1.2 Seabed levelling for cable trenches

Seabed levelling is a provision for inter-array cable and export cable trenches. The worst case disturbance from seabed levelling for cable installation is a sum of the total footprint associated with the inter-array and export cables. The width of the seabed disturbance footprint (which could involve boulder clearance and levelling) is 15 m for each cable with up to 20 km of inter-array cables on the seabed and 25 km of export cables (assuming a maximum of two export cables). The total areas involved are up to 210,000 + 375,000 m^2, respectively. The method of levelling is not expected to remove material from the seabed, also noting that macro-bedforms (e.g. sandwaves) are not present in the geophysical survey observations.

7.6.1.1.1.3 Seabed levelling for gravity anchors

The worst case seabed disturbance from seabed levelling is considered to be in relation to gravity anchors, as it has the largest footprint, with the worst case envelope summarised in Table 7.14. For gravity anchors, seabed levelling is required to produce a level surface and to remove the top 1 m of sediments, noting the anchors require placement onto a medium to hard seabed. There are up to nine anchors per WTG, and for seven WTG (63 anchors in total). Each gravity anchor is a square unit with a width of 25 m and a height of 5 m, buried to 1 m. The area required for seabed levelling is slightly larger at 30 by 30 m to develop a volume of 900 m^3 to be removed per anchor location (Table 7.14). The geotechnical report (Fugro, 2021) provides details of the dry density of the surface sediment as generally between 1.45 and 1.55 Mg/m3 which gives a mass equivalent value of up to 1,359 tonnes of sediment per anchor.

A trailer suction hopper dredger (TSHD), or similar, would remove the surface layer of soft sediment into a hopper to develop a level seabed. After levelling there is an option to install a gravel bed and a levelling layer via a fall-pipe discharging material close to the seabed. The gravity anchor would then be placed onto the levelled seabed with the temporarily removed seabed sediment in the hopper used as backfill around the anchors, again using a fall-pipe to ensure accurate placement of sediment around the anchor. This backfilling process is likely to lead to some localised short-term disturbance of sediment near to the seabed.

Calculation of sediment plume

The particle size distribution of seabed grab samples across the Offshore Site (Offshore EIAR [Volume 3]: Appendix 9.1) and described in Section 7.4.4.2, identifies that the majority of sediments likely to be dredged from the seabed will be sands and gravels, with a small percentage of fines (silts). Table 7.16 summaries the proportions of sediment type found within the footprint of the offshore development area and provides an associated settling velocity (based on Soulsby, 1997, valid to grain sizes up to 10 mm) for a representative grain size established at the central point between sieve sizes.

Table 7.16 Contributing grain sizes in seabed sediments across the Offshore Site (Offshore EIAR [Volume 3] with associated settling velocities

Sediment type	Grain size (mm)	Range of content in grab samples	Settling velocity (m/s)
Cobble	50.250	0 to 17%	> 0.41
Coarse gravel	28.750	0 to 6%	
Medium gravel	15.000	0 to 10%	
Medium gravel	8.150	0 to 7%	0.41
Fine gravel	4.150	0 to 44%	0.29
Coarse sand	1.315	1 to 62%	0.14
Medium sand	0.415	2 to 59%	0.05
Fine sand	0.132	7 to 74%	0.01
Coarse silt	0.042	0 to 4%	0.001
Medium silt	0.013	0 to 1%	0.0001

The conservative assumption is the same distribution of grain sizes and the same amount of sediment will be returned to the seabed for backfilling around each gravity anchor via a fall-pipe. The distance from the end of the fall-pipe to the seabed is expected to be minimal to ensure accurate backfilling. From the end of the fall-pipe sediments will be carried downward as a density flow with a proportion of fine sediments (silts) expected to remain in suspension (coarser sediments will backfill around the base of the gravity anchor). Since these finer sediments have the slowest settling velocity they also have the potential to be transported away by near-bed flows (a process called advection) and settle elsewhere. Analysis of the potential sediment dispersion demonstrated that during this period, the affected area with increased levels of suspended sediment is expected to be up to 3 m off the seabed, with the time taken for material to settle out estimated to be up to 9 hours for medium silts and less than 1 hour for the coarse silts (accounting for settling and vertical diffusion due to turbulent mixing). For reference, fine sands would settle out within a period of 0.1 hours and have very limited capacity to advect with near-bed flows (less than 100 m during periods of peak flows).

Near-bed flows within the PFOWF Array Area, described in Section 7.4.4.7, are established from outputs of the Nortek Signature 100 ADCP, acquired from the ongoing metocean survey (Section 7.4.3.4), which provides a vertical profile of currents at 5 m increments down to the seabed. Near-bed flows are affected by seabed friction to form a boundary layer and are eventually reduced to nil at the seabed. At 5 m off the seabed the near-bed flows are much reduced compared to mid-depth or near-surface flows. Observed data for near-bed peak flows during spring tides achieve up to 0.34 m/s on the flood phase of the tide which is mainly to the east and 0.21 m/s on the ebb mainly to the south-west (for a representative period in September 2021) (Section 7.4.4.7). Peak flows on the spring tide establish the maximum possible excursion distances for a near-bed release.

Applying the near-bed flow observations for the time required for 100% settling of medium silts provides an indication of the likely spread of fine sediments around a single anchor. Figure 7.20 illustrates the centre line along with the spreading width of the plume for separate flood and ebb releases (accounting for horizontal dispersion) associated with backfilling process using the TSHD fall-pipe. The completed analysis assumes sediment release approximately 3 m off the seabed. The illustrated dispersion is indicative of sediment advection between the release height and the seabed, in the horizontal plane. The potential for mixing at depths shallower than the release (i.e. upward vertical mixing) is assumed to be limited.

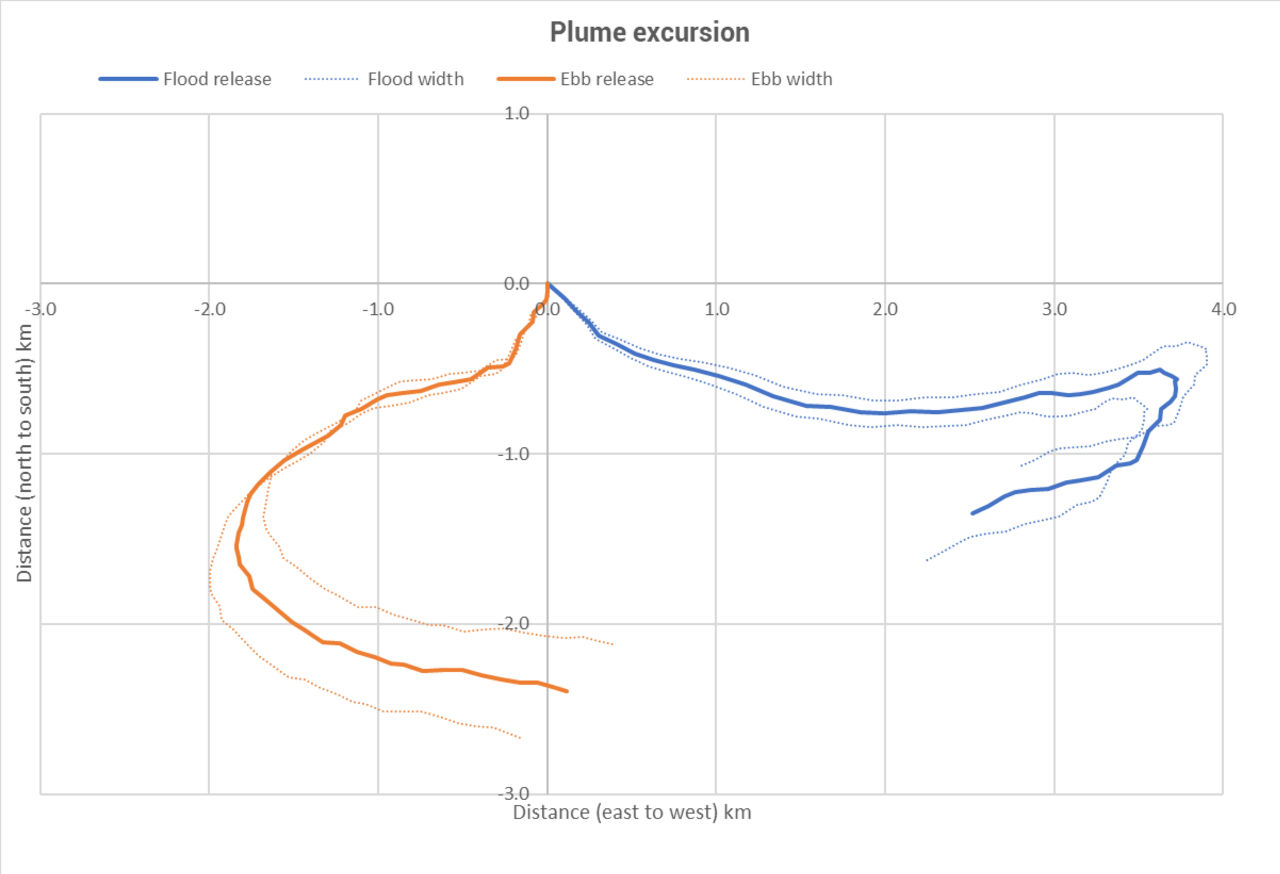

Figure 7.20 Pathway of near-bed sediment plume for flood and ebb releases on a spring tide (backfilling anchor pit)

A flood tide release achieves a distance of around 3.7 km to the east after around 6 hours before the tide turns with the ebb tide to the south-west. The total distance travelled is around 5.5 km for a flood release.

The ebb tide release achieves a distance of around 2.62 km to the south-west after around 5.3 hours before the tide turns with the flood tide to the east. The total distance travelled is around 4.9 km for an ebb release.

Much shorter distances are achieved for the coarse silts, which settle out faster, as well as for any releases during periods of neap tides.

Figure 7.21 presents the near-bed concentration of suspended sediment within the sediment plume which is expected to remain close to seabed. The remainder of the water column is not expected to be affected. The completed analyses uses medium and coarse silts combined, which represent a small proportion of the sediment composition (up to 5% of the total), as evident across the Offshore Site. The instantaneous near-bed sediment concentrations are relatively high, at around 10,000 mg/l until the coarse silts settle out within the first 500 m (or less for the ebb release). Medium silts remain in suspension for slightly longer (around 9 hours) and are transported further but result in a much reduced near-bed concentration of suspended sediments and develop a lower depth of deposition over distance. Figure 7.21 again illustrates the maximum distance that sediment could be advected is around 5.5 km, associated with a flood release and for medium silt. However, as demonstrated in Figure 7.20, the overall distance is not linear and rotates with the tide.

This process is expected to be sequential from a single hopper such that each sediment plume (of silts) and deposition event is separate with no overlapping plumes. Coarser sediments are expected to remain on the seabed as backfill material around the anchor base.

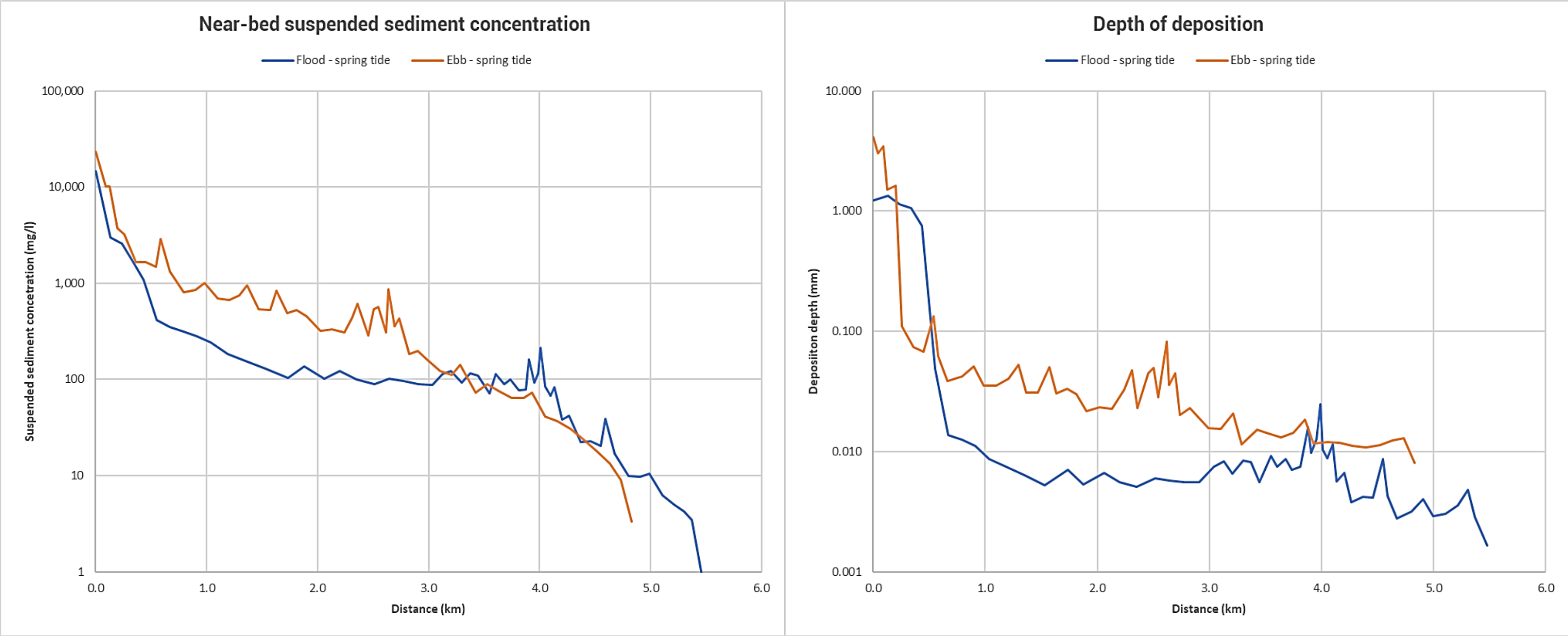

Figure 7.21 Near-bed suspended sediment concentrations and depth of deposition (backfilling anchor pit)

7.6.1.1.2 Sediment disturbance from cable trenching

Cable trenching is likely to lead to the largest amount of sediment disturbance over the OECC, with the exception of the landfall area where the cable will be installed by HDD. The worst case cable trenching method is considered to be associated with jet trenching, where the seabed is temporarily fluidised and the cable is lowered to the required depth. Displaced material is suspended in the water column and then resettles over the cable. The jetting process is controlled, to ensure that sediment is not displaced too far from the cable.

The width, depth and shape of the inter-array and export cable trenches provides a basis to determine the quantities of sediment being disturbed. The installation method and rate of trenching establish how this material may be brought into the water column. Of the various trenching options, jetting is considered the worst case in terms of enabling fine sediments to be put into suspension in the water column (by fluidising the seabed), albeit close to the seabed (conservatively estimated to be up to 3 m off the bed of the trench, i.e. trench depth plus 1.5 m or up to 1.5 m above surrounding seabed).

The amount of sediment involved in trenching, per metre of trench, is based on a trench width of 3 m and a depth of 1.5 m (Table 7.14) for a 'U'-shaped cross-section, providing 4.5 m^3 of sediment per metre of trench.

The amount of sediment disturbed at a trenching rate of 120 m/hr would be 540 m^3 per hour or 0.15 m^3 per second.

Calculation of sediment plume

The geotechnical report (Fugro, 2021) provides details of the dry density of the surface sediment which is generally between 1.45 and 1.55 Mg/m^3. The associated total mass of disturbed sediment is therefore up to 6.98 tonnes per metre of trench.

The representative sediment grain sizes to be trenched, and their associated (unhindered) settling velocities, are summarised in Table 7.16 (applying the mid-point of the sieve sizes used for grain size analysis).

The vibrocore logs (Fugro, 2021) and sub-surface sediment described in Section 7.4.4.3, indicate that seabed composition remains broadly similar in the surface layer where trenching is planned.

Given these sediment properties, the coarser sediments (gravels to medium sand) would all fall out of the water column and back into the trench very quickly (i.e. within 60 s) and without the ability to be transported away by the near-bed spring flows (of around 0.34 m/s on the flood and 0.21 m/s on the ebb, Section 7.4.4.7). The initial high concentration of fluidised particles would create a downwards density flow which would draw down the majority of the disturbed sediment back to the trench.

Any fine sands remaining in suspension would take slightly longer to settle back to the seabed, at around 3 minutes based on the setline velocity of the grain sizes present, which provides limited opportunity to be spread far by any near-bed flows. The majority of this material would likely settle out on or close to the trench.

Any silts remaining in suspension have the potential to be advected away from the trench by near-bed flows in the form of a near-bed-plume, similar to the processes descried above for back-filling the levelled seabed (Section 7.6.1.1.1.1).

Coarse and medium silts represent only a small part of the disturbed sediment (up to 5% of the total), meaning their mass per metre of trench would be limited to no more than 0.35 tonnes. The equivalent release rate of the silt fraction would be 0.01 tonnes/s (11.6 kg/s).

Applying the same representative near-bed flows measured on site (Section 7.4.4.7) allows a consideration of the spread of fine sediments and their deposition away from the trench (for the PFOWF Array Area). The plume excursion distances for flood and ebb releases on a representative spring tide are provided in Figure 7.22 for observed metocean conditions within the PFOWF Array Area (Section 7.4.3.4), as applied for seabed preparation above (Section 7.6.1.1.1.1).

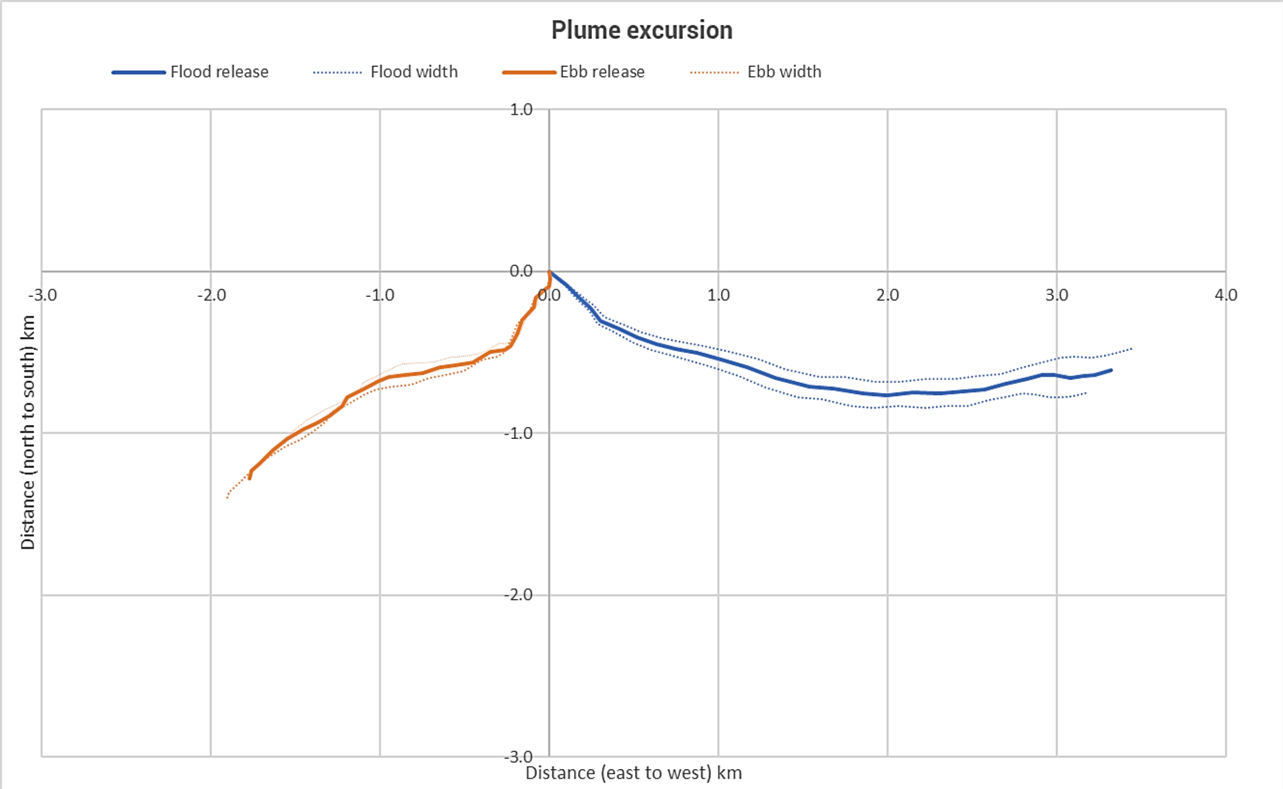

Figure 7.22 Pathway of near-bed sediment plume for flood and ebb releases on a spring tide (trenching)

A flood tide release achieves a distance of around 3.3 km to the east after around 4.7 hours, whereas the ebb tide release achieves a distance of around 2.4 km to the south-west over the same period due to weaker flows. Much shorter distances are achieved for the coarse silts, which settle out faster, as well as for any releases during periods of neap tides.

Figure 7.23 presents the near-bed concentration of suspended sediment (for medium and coarse silts combined) within the sediment plume which is expected to remain close to seabed. The remainder of the water column is not expected to be affected, as little to no upward vertical mixing is anticipated. Instantaneous near-bed sediment concentrations are again relatively high, at just under 10,000 mg/l, until the coarse silts settle out within the first 500 m (or less for the ebb release). Medium silts remain in suspension for longer and are transported further but result in a much reduced near-bed concentration of suspended sediments and develop a lower depth of deposition over distance.

For the OECC, the flows are weaker which will lead to proportionally reduced plume excursion distances, less dispersion, slightly higher near-bed concentrations and increased depths of silt deposition.

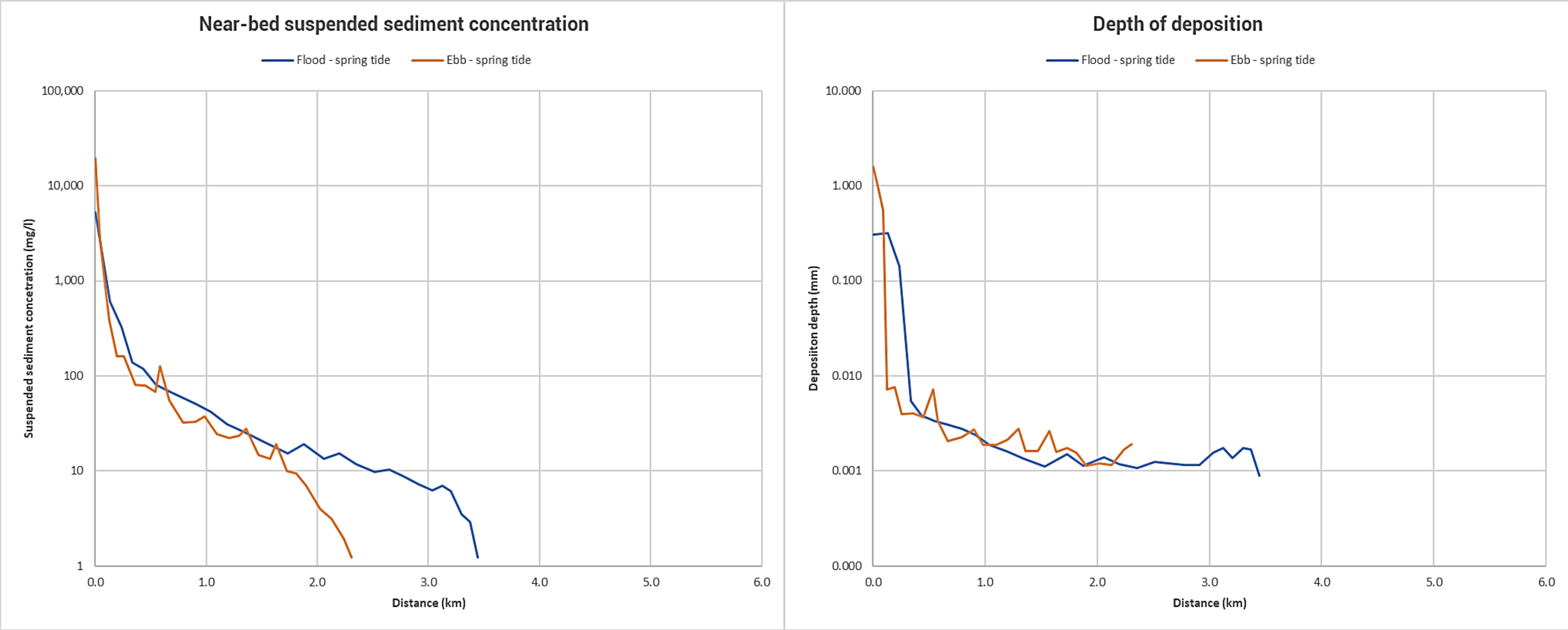

Figure 7.23 Predicted near-bed concentration of suspended sediment during trenching

For the OECC an assessment of the maximum spread of a plume is made using the near-bed flow information from the Pentland Firth and Orkney Waters Climatology 1.02 model. The plume excursion distances for flood and ebb releases on a representative spring tide are provided in Figure 7.24.

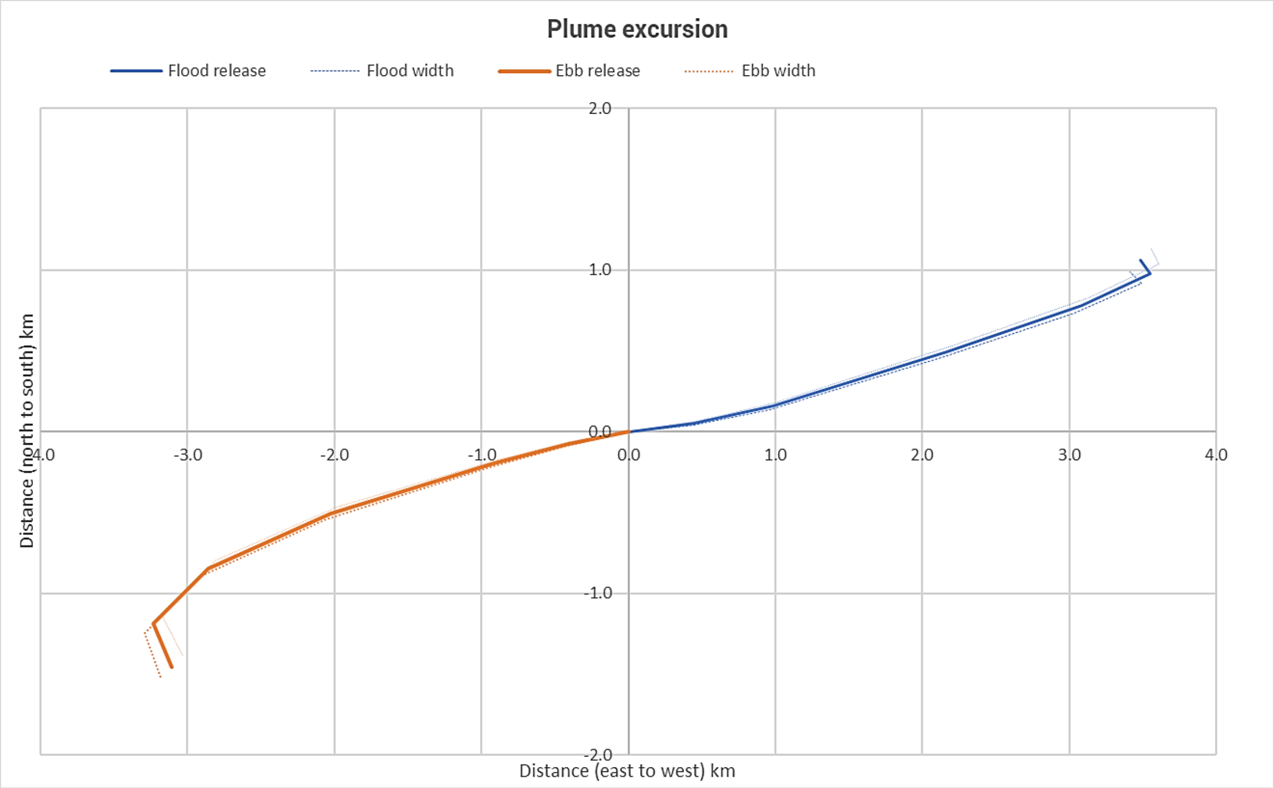

Figure 7.24 Pathway of near-bed sediment plume for flood and ebb releases on a spring tide (along the OECC)

A flood tide release achieves a distance of around 3.7 km to the east-north-east after around 4 hours, whereas the ebb tide release achieves a distance of around 3.6 km to the west-south-west over the same period. Much shorter distances are achieved for the coarse silts, which settle out faster, as well as for any releases during periods of neap tides.

Figure 7.25 presents the near-bed concentration of suspended sediment (for medium and coarse silts combined) within the sediment plume which is expected to remain close to seabed. The remainder of the water column is not expected to be affected, as little to no upward vertical mixing is anticipated. Instantaneous near-bed sediment concentrations are again relatively high, at just under 10,000 mg/l, until the coarse silts settle out within the first 500 m. Medium silts remain in suspension for longer and are transported further but result in a much reduced near-bed concentration of suspended sediments and develop a lower depth of deposition over distance

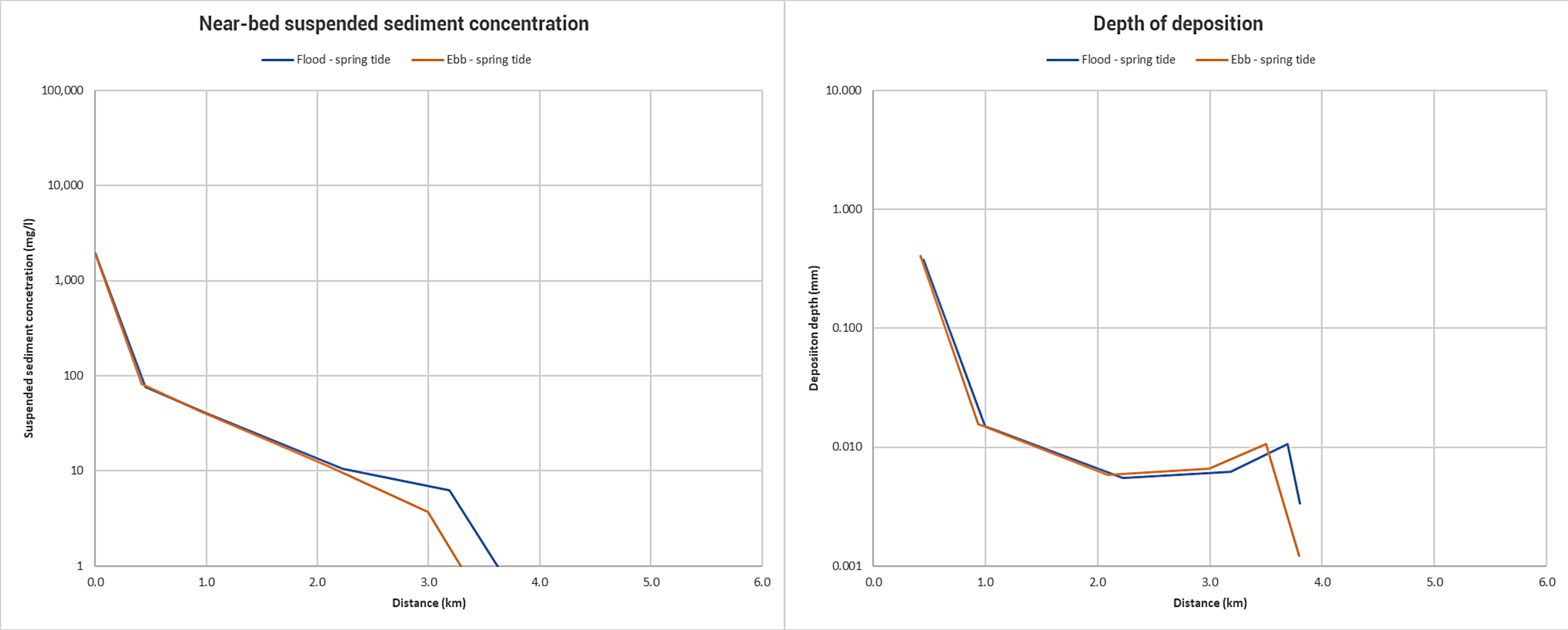

Figure 7.25 Predicted near-bed concentration of suspended sediment during trenching (along the OECC)

7.6.1.1.3 Sediment disturbance from anchor installation

Anchor installation includes the option for drilled piles which have the potential to release drill cuttings on to the seabed. There will be up to nine drilled piles per WTG for seven WTG, a total of 63 drilled piles.

As summarised in Table 7.14, the maximum drill depth is of 49.5 m associated with the largest pile diameter (and drill hole) of 3 m, creating a drill cuttings volume of around 350 m^3 discharged onto the seabed.

The expected drilling rate would be 4 m/hr, depending on the material to be drilled out, as well as the type and pressure of the drill. This rate would release an estimated 21 kg/s of drill cuttings which are expected to comprise of granular material in a range of particle sizes (fine to coarse material).

Drill cuttings would be flushed from the drilled pile hole onto the seabed where finer material has the potential to disperse more widely, and coarser material would quickly settle out to form a cuttings mound.

Calculation of sediment plume

The conservative assumption for widespread dispersion is this material is 100% fine grains (silts), whereas the associated conservative assumption for highest levels of deposition is this material is 100% coarse grains (i.e. sands and gravels) which settle out around the drilled pile to form a cuttings mound. The most likely outcome is some combination of these two extreme situations. The description of the sub-surface sediment across the PFOWF Array Area identified the potential for organic / peat deposits occurring at depths between 4 and 8 m below the seabed. It is assumed that the organic material will behave similar to the fine grains (silts) analysed and assessed within this section.

If the discharge of fine grained (silt sized) drill cuttings achieved a height above the seabed of around 1 m from being flushed out from the drilled pile hole, then this material has the possibility of being advected by near-bed flows with wider dispersion due to turbulent mixing. The completed analyses indicated that at 1 m off the seabed the silts would take around 3 hours to settle out, based on the calculated dispersion associated with the near-bed flows within the PFOWF Array Area (Section 7.4.4.7) and obtained from the ongoing metocean survey (Section 7.4.3.4). The maximum dispersion would occur at times of peak flows on flood and ebb phases of a spring tide.

Applying a representative period of spring tide near-bed flows from observed metocean conditions within the PFOWF Array Area (Section 7.4.4.7), allows a consideration of the maximum spread of fine sediments and their deposition away from the drilled pile. The plume excursion distances for flood and ebb releases are provided in Figure 7.26.

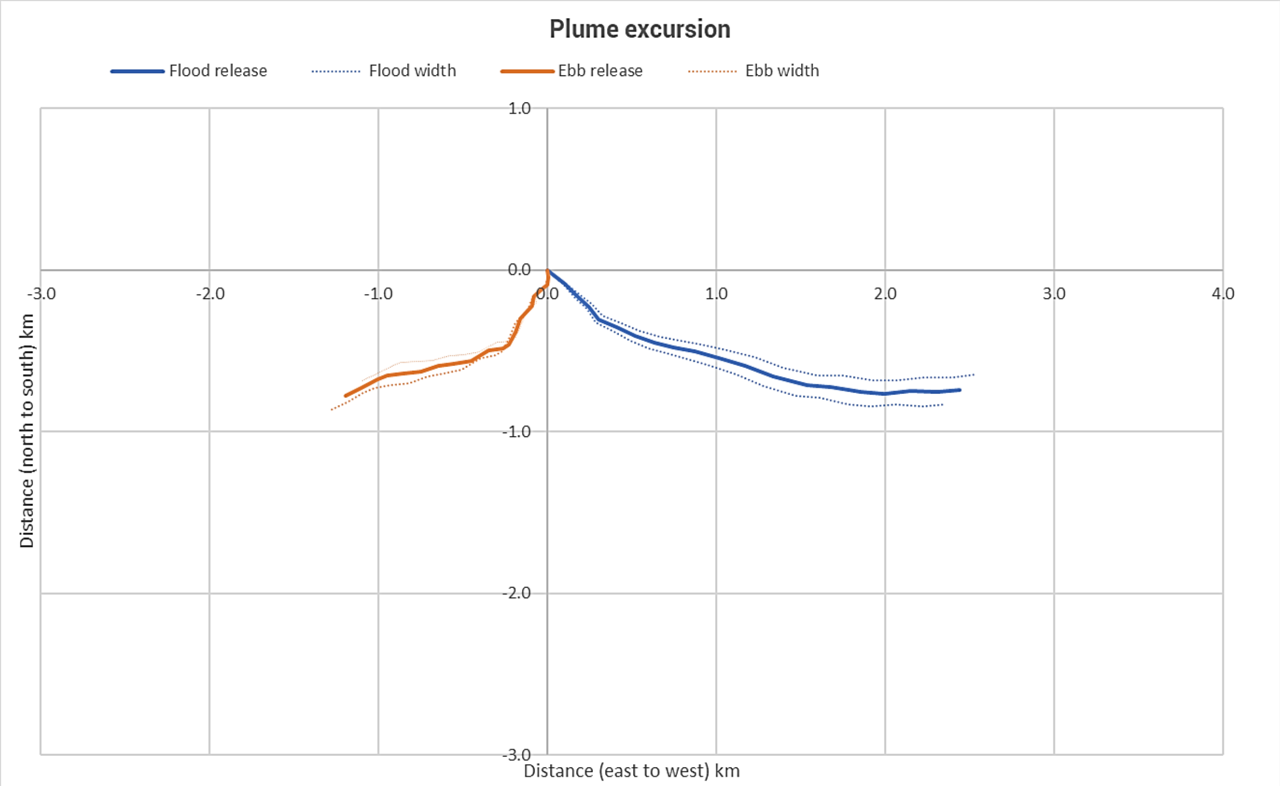

Figure 7.26 Pathway of near-bed sediment plume for flood and ebb releases on a spring tide (drilling)

A flood tide release achieves a distance of around 2.4 km to the east after around 3.2 hours, whereas the ebb tide release achieves a distance of around 1.6 km to the south-west in the same period. With an assumed near seabed release height of 1 m above the seabed for drilling operations, the distance travelled by suspended sediment is much smaller compared with the dispersion described for seabed levelling operations, which applied a release height of 3 m above the seabed (Section 7.6.1.1.1).

Figure 7.27 presents the near-bed concentration of suspended sediment for medium silts within the sediment plume which is expected to remain close to seabed. The remainder of the water column is not expected to be affected. Suspended sediment concentrations rapidly reduce over distance with the associated deposition being relatively low.

The alternative assumption to all drill cuttings being medium silt sized grains is all drill cuttings are coarse grains that immediately form a cuttings mound at the base of the drilled pile without any wider dispersion. The height of the mound would be limited to the capacity of the material flushed out of the drill hole to rise above the seabed as well as the angle of repose for a stable side slope. Based on the estimated drill volume of 350 m^3, and maximum height of 1 m for the cuttings mound around the drill hole, the calculated radius of the cuttings mound would be about 21 m and cover an area of approximately 1,400 m^2 associated with the drill volume. Over time, the mounds may settle slightly in height due to de-watering and compaction of sediment, but are likely to remain relatively long-lasting, due to the limited capacity of near-bed tidal flows to lead to sediment mobility of coarse grained sediments.

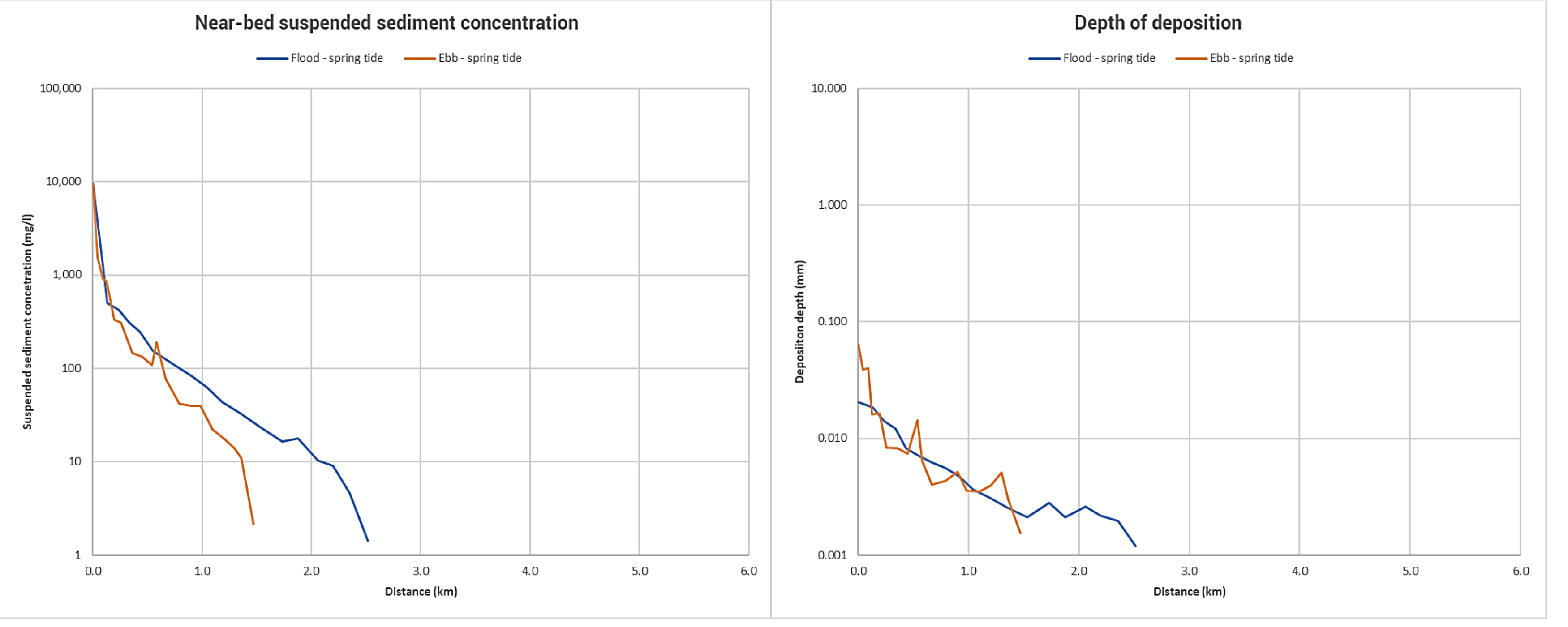

Figure 7.27 Predicted near-bed concentration of suspended sediment during drilling

7.6.1.1.4 Impact Assessment

Based on the completed analyses discussed above, the worst case increase to suspended sediment concentrations, resulting in the development of a plume for the PFOWF Array Area is associated with the seabed levelling operations for gravity anchors. The receiving environment (i.e. the water column) within the PFOWF Array Area is considered to be of **negligible** value due to the absence of designated sites. The sensitivity to increases in sediment concentration is considered to be **negligible**, as the region does experience increased sediment concentrations during periods of storms and the deep water environment means short-term increases at the seabed would be indiscernible elsewhere in the water column. The results of the completed analyses presented in Section 7.6.1.1.1.1 demonstrate that, although the instantaneous increases in concentration are very high at several orders of magnitude above representative background concentrations of 1 to 2 mg/l, this high concentration is only in the immediate vicinity of the fall pipe and gravity anchor, sediment concentrations quickly reduce (by an order of magnitude) within 500 m of the release. The maximum sediment advection occurs with medium silts associated with a release on flood spring tides. In this release scenario, silt sediment can remain in suspension for around 6 hours, with a maximum advection distance of 5.5 km, which would largely remain within 3 m of the seabed. Therefore, the magnitude of impact from the seabed preparation construction activity is considered to be **low**.

Based on the above, the overall effect for the PFOWF Array area is therefore considered to be **negligible** and **not significant**.

For the OECC, the worst case increase to suspended sediment concentrations is associated with jetting. The receiving environment (i.e. the water column) along the OECC is considered to be of **medium value** due to the overlap with North Caithness Cliffs SPA, which is designated for breeding seabird assemblages, but also includes the seabed, water column and sea surface, although the water column is not a designated interest feature. Despite the value, the water column covering the OECC is considered to have a **low sensitivity** to short-term increases in sediment concentration, as it is able to recover quickly from changes. As is the case for the PFOWF Array Area, instantaneous increases in concentration associated with jetting are high, with concentrations largely reducing several orders of magnitude less than 500 m from the release. The increases in concentration would remain near-bed and disperse a maximum distance of around 3.3 km, remaining in suspension for around 4.7 hours. As jet trenching would be transient in the offshore direction, the sediment release and increases in concentration would also be the same. However, levels would again quickly return to background levels within one tidal cycle, so any increase are temporary. As the flow axis are approximately east to west, even in the nearshore environment in the shallowest location along the export cable route, the concentration increases would not interact with the coast. Therefore, the magnitude of impact from the cable installation through jetting is considered to be **low**.
Based on the above, the overall effect for the OECC is considered to be **minor** and **not significant**.

Based on the assessment for both the PFOWF Array Area and OECC, the overall effect of the Offshore Development is considered at worst to be **minor** and **not significant**.

7.6.1.2 Loss / alteration of physical seabed characteristics

Seabed loss is considered here as the direct loss of the natural seabed with remedial cable protection, scour protection, or burial under a drill cuttings mound. Any effects due to seabed loss would be initiated during the Offshore Development construction stage and continue throughout the operational period until decommissioning removes the feature. Alteration of physical seabed characteristics is considered here as the introduction of new sediment or substrate type, which across the PFOWF Array Area could be the installation of remedial cable protection or the deposition of sandstone, bedrock geology or peat deposits associated with drill cuttings.

7.6.1.2.1 Loss / alteration from cable installation

Cable burial is planned for all cables but where this is not achievable remedial cable protection will be used. Of the various remedial cable protection options, rock armour is considered to be the realistic worst case option.

As set out in the Project Envelope in Table 7.14, a provision is made for up to 50% of the inter-array cables and export cables requiring protection with a width of 7 m and height of 1 m. The maximum seabed footprint of export cable protection would be 87,500 m^2, equivalent to approximately 0.35% of the OECC. The maximum seabed footprint of inter-array cable protection would be 70,000 m^2, equivalent to approximately 0.70% of the PFOWF Array Area.

7.6.1.2.2 Loss / alteration of seabed characteristics from anchor installation

Table 7.17 provides a summary of the seabed footprint for each anchor option considering the structure, scour protection and any associated cuttings mound. The target drill depth for the 3 m diameter drilled / screw pile anchor option is 49.5 m. With this target depth, the cuttings pile associated with drilled anchors could lead to the introduction of bedrock sandstone geology or peat deposits that are understood to occur across the PFOWF Array Area. With the introduction of sandstone bedrock, this would be of varying clast sizes, with some material being pulverised and distributed as fines as described and analysed in Section 7.6.1.1.3. The presence of bedrock geology is not uncommon across the Offshore Site, with outcrops known to occur along the OECC and more widely across the Pentland Firth. Therefore, the introduction of sandstone to the seabed substrate will not ultimately alter the sediment type and seabed character.

Differences can, however, be expected with the potential introduction of peat, which is estimated to occur at depths between 4 to 8 m below the seabed. The presence of peat is based on penetration and resistance CPT tests, which were identified as organic matter in sampled boreholes (Fugro, 2021). Information on the nature of the potential peat deposit is unavailable, so for this assessment, it is assumed the deposit behaves similarly to the described sediment within the Offshore Site, in that deposition of the peat deposit would be as large clasts in the immediate vicinity of the pile or disperse in suspension as part of a plume. The maximum drill volume is on the order of 350 m^3 per pile and approximately 22,000 m^3 for all 63 piles (for a 3 m wide pile at target depth of 49.5 m). As the peat deposits are interpreted as relative thin deposits (with a maximum thickness of less than 2 m) within a depth of 4 to 8 m below the seabed, the volume of peat released into a cuttings pile or disaggregated and dispersed in a plume would be approximately 4% of the total sediment released. In time, the cuttings pile on the seabed would be incorporated into the sediment transport regime across the Pentland Firth. The small volume of peat and the eventual integration into the sediment transport regime means that its presence is unlikely to alter the seabed character in the long term.

Table 7.17 Summary of seabed loss for anchor options

Anchor Type	Anchor footprint (m^2)	Scour protection (m^2)	Cuttings Pile (m^2)	Total (m^2), all anchors	% of PFOWF Array Area
Gravity	625	260	-	55,755	0.56%
Drag embedment	200	70	-	17,010	0.17%
Suction bucket	78.5	760 [c]	-	52,826	0.53%
Vertical load	200	70	-	17,010	0.17%
Drilled / screw piles	7.1	280	1,424 [a]	90,153 [b]	0.90%
Hammer / drive piles	19.6	760	-	49,115	0.49%

a. Assumes the conservative assumption that the drill cuttings pile is 1 m high and formed of coarse sediments;

b. Total area is based on anchor footprint and cuttings pile, as the scour protection would be coincident with the cutting pile; and

c. Assumes same scour protection as hammer / driven piles.

If the cuttings pile fully disperses for the drilled pile option, then the largest direct seabed loss / alteration would be for the gravity anchor option.

7.6.1.2.3 Impact Assessment

The worst case seabed loss within the PFOWF Array Area is associated with installation of the anchor options with scour protection and remedial protection for inter-array cables. The seabed within the PFOWF Array Area is considered to be of **negligible** value, due to the absence of designated features. The sensitivity to seabed loss or change in sediment type is considered to be **negligible**, due to the diverse nature of the seabed across the Offshore Site. Less than 1% of the seabed within the PFOWF Array Area would be semi-permanently buried (or removed in the case of piles) by the anchor option and (or) scour protection. With the use of remedial protection for the inter-array cables, the total area buried would equate to about 1.78% of the PFOWF Array Area for the drilled pile anchor (or 1.64% for the gravity anchor). As described in the Section 7.6.1.2.2 above, the potential occurrence of peat deposit in the cuttings pile associated with the drill option is unlikely to alter the seabed character in the long-term, due to the low volumes of material. Therefore, only due to the long-term nature of the anchor option and associated protection is the magnitude of impact considered to be **moderate**.

Therefore, based on the above, the overall effect for the PFOWF Array Area is considered to be **negligible** and **not significant**.

The seabed within the OECC is considered to be of **medium** value due to the overlap with the designated site covering the seabed, although it is noted that the seabed is not a designated interest feature. The sensitivity to seabed loss or change in sediment type is considered to be **low**, although the seabed is diverse, the shallower environment along the OECC mean changes could be discernible. Less than 0.3% of the seabed within the OECC would be semi-permanently buried with the use of remedial protection for the export cables. Despite the long-term nature of the anchor option and associated protection, the small footprint means that the magnitude of impact is considered to be **low**.

Therefore, based on the above, the overall effect OECC is considered to be **minor** and **not significant**.

Based on the assessment for both the PFOWF Array Area and OECC, the overall effect of the Offshore Development is considered at worst to be **minor** and **not significant**.

7.6.1.3 Summary of construction related effects relevant to other EIA topics

- During construction there are various activities which will lead to short-term and localised sediment disturbance, in particular; seabed levelling, cable trenching and anchor installation (in particular pile drilling). In part, the final combination of activities depends on the anchor type to be deployed, with the assessment presented here considering both gravity anchors and drilled pile anchors as worst case scenarios;
- The composition of the seabed is mainly gravels and sands, along with an occasional small percentage of silts. The average ratio of gravel:sand:silt is 13:84:3. The maximum amount of silts in any sample is 5%
- There is the potential for peat material within the PFOWF Array Area, but the dispersion and associated deposition will be similar to that of fine sediment;
- The silt fraction has the slowest settling velocity and therefore the greatest opportunity to be carried away by tidal advection from the source of disturbance. All coarser grains would rapidly fall to the seabed at the location where they are disturbed / discharged;
- All construction activities operate close to the seabed with the ceiling height of any disturbance from the seabed being a controlling influence on the time required for silts to settle out and the opportunity to be carried away by flows in the form of a sediment plume. The assessment has considered representative ceiling heights between 1 to 3 m and assessed the associated spread of any sediment plume based on near-bed flow measurements;

- The maximum excursion on a spring flood tide (to the west) is around 3.7 km before the tide turns and around 2.6 km to the south-west during the ebb. All silt material is expected to settle out within a few hours, depending on the ceiling height of any disturbance. The time limited effects of any single plume are therefore short-term;
- The spread of silts is expected to remain near-seabed with elevated concentrations of suspended sediment not influencing the water column above. Concentrations would rapidly reduce from source due to horizontal spreading of the plume and material settling out. The theoretical depth of deposition onto the seabed is minimal from <10 mm close to the point of disturbance to <0.1 mm within a kilometre travelled;
- Flows closer to the coast, and along the OECC, are expected to be weaker than those across the PFOWF Array Area with consequential reductions in the spread of silts;
- There is the potential for relatively thin (approximately 2 m thick) peat deposits at depths of 4 to 8 m below the seabed across the PFOWF Array Area. The presence of this unit means that there is potential for it to be released to the seabed, should the drilled pile option be applied. Expected volumes released into a cuttings pile are expected to be less than 5% of the overall drilled volume, due to the thin deposit thickness. Released peat, along with the drilled volume, could either be deposited as a cuttings pile, or completed disaggregated into a plume, The actual result is more likely to be between the two deposition scenarios;
- The largest seabed loss / alteration is considered to relate to the drilled pile option, due to the cuttings pile. Should the cuttings pile fully disperse for the drilled pile option then the largest direct seabed loss / alteration would be for the gravity anchor option; and
- Impacts relating to the increase in suspended sediment and loss / alteration of seabed type were assessed to have **negligible** to **minor** overall effect across both the PFOWF Array Area and OECC and are therefore considered to be **not significant**. With respect to the Offshore Development, the overall effect is again considered at worst to be **minor** and **not significant** (Table 7.18).

Table 7.18 Summary of significance of effects from construction impacts

Summary of Effect	Receptor	Sensitivity	Magnitude of impact	Rationale	Consequence	Significance of Effect	Additional Mitigation Requirements	Residual Effect
Increase in suspended sediment concentration – PFOWF Array Area	Water column	Negligible	Low	The value and sensitivity for the PFOWF Array Area is considered to be **negligible**. Based on the near-bed and short duration of impacts and low frequency of construction/installation events, the impact magnitude is considered to be **low**. Therefore, the overall effect is assessed as **negligible** and **not significant**.	Negligible Effects	Not Significant	No additional mitigation measures have been identified for this effect above and beyond the embedded Offshore Development mitigation listed in Section 7.5.6 as it was concluded that the effect was Not Significant.	Not Significant
Increase in suspended sediment concentration – OECC		Low	Low	The value of the OECC is considered to be **medium**, due to the overlap with a designated site which includes the water column, and the sensitivity is considered to be **low** due to its recoverability to short-term increases in SSC. Based on the near-bed and short duration of impacts and low frequency of construction/installation events, the impact magnitude is considered to be **low**. Therefore, the overall effect is assessed as **minor** and **not significant**.	Minor Effects	Not Significant		Not Significant
Loss/ alteration of physical seabed characteristics – PFOWF Array Area	Seabed	Low	Moderate	The value and sensitivity is considered to be **negligible**. The semi-permanent loss of seabed up to approximately 1.78% of the PFOWF Array Area, means the impact magnitude is considered to be a **moderate**. Therefore, the overall effect is assessed as **minor** and **not significant**.	Minor Effects	Not Significant	No additional mitigation measures have been identified for this effect above and beyond the embedded Offshore Development mitigation listed in Section 7.5.6 as it was concluded that the effect was Not Significant.	Not Significant
Loss/ alteration of physical seabed characteristics – OECC		Low	Low	The value of the OECC is considered to be **medium**, due to the overlap with a designated site which includes the water column, and the sensitivity is **low** due to its recoverability to short-term increases in SSC**.** The impact magnitude is considered to be **low** due to the small impact footprint. Therefore, the overall effect is assessed as **minor** and **not significant**	Minor Effects	Not Significant		Not Significant

7.6.2 Effects During Operation and Maintenance

7.6.2.1 Changes to tide and wave regime

In comparative terms, a floating offshore wind farm structure would be expected to have a much lesser blockage effect on tidal flows and waves than a fixed foundation structure which has a cross-sectional influence throughout the whole of the water column.

Changes to the tide and wave regime will occur when structures floating on the sea surface, or fixed to the seabed have the capacity to locally block the incident tidal flows and waves. These changes may have associated consequences on the water column and seabed.

The scale of any blockage relates to the cross-sectional area of floating objects presented to the incident flows and waves, as well as the cross-sectional area of fixed objects on the seabed and their protruding heights (both anchors and cable protection).

The potential changes to flows and waves are considered here, whilst the onward impacts to marine physical process conditions, such as the sediment transport regime and fronts and stratification are considered in their respective impact assessments in Section 7.6.2.2 and Section 7.6.2.4 respectively. The potential for the introduction of scour is assessed in Section 7.6.2.3.

7.6.2.1.1 Flows

The semi-submersible substructure has a submerged cross-section profile which is up to 125 m wide and 20 m deep as summarised in the Project Envelope in Table 7 14. Within this cross-section there are main columns and cross-braces with large spaces in-between which reduce the "solidity" ratio compared to a solid structure. The orientation of the floating structure would largely be fixed and optimised to face the prevailing site conditions (wind/wave/current), but it would be able to roll, pitch and, to a lesser degree yaw with the wind and / or sea conditions due to the compliance within the mooring system. This way the structure would largely have minimal frontal area onto incident horizontal flows (i.e. face on rather than diagonal). For a floating structure with a high solidity ratio, the incident flows would bifurcate on the face of the structure to stream either side and then develop turbulent leeward wakes which would stream off the sides of the structure in the direction of main flows. A smaller proportion of incident flows would also be deflected to pass underneath the structure, also contributing to the leeward wake effects. If the structure has a moderate to low solidity ratio then the scale of turbulence would be reduced.

Given the width of the structure, the wakes from each side are expected to be separate at the outset but become close together further downstream to then quickly dissipate over distance, expected to be several hundred metres. Wakes would last for the duration of the flood and ebb periods before, reversing in the opposite direction. There will be a maximum of seven WTGs across the PFOWF Array Area, with a minimum separation of 800 m between each WTG, to reduce the influence of wind wakes in the lee of the WTGs. The 800 m separation will in turn be applied to the floating substructures. Therefore, depending on the WTG layout there is the potential for the wakes from the floating substructures to interact to some degree, particularly during the fastest flows. Assuming a solid floating substructure, the percentage physical presence within the PFOWF Array Area would be approximately 1.1%, but based on the side of the floating structure providing a representative blockage width of 125 m, the blockage density (m/m^2) for all floating substructures across the PFOWF Array Area is 0.01%.

The installation of scour or remedial cable protection would, at worst, have a profile height of 1 m above the seabed. In deeper water, as present within the PFOWF Array Area and parts of the OECC, the presence of the protection would be indiscernible. Empirical formulae determining the depth-averaged flow speed above a submerged near-bed structure from the Construction Industry Research and Information Association (CIRIA) rock manual (CIRIA, 2007) was applied to investigate if the presence of remedial protection could influence flows at shallower depths that occur within the OECC. The data used in the calculation included:

- Water depths at a mid-tide state (in line with when peak speeds occur), upstream, downstream and above the proposed remedial protection at primarily the shallowest depth within the OECC (at approximately 20 m LAT). Varying water depths along the OECC and within the PFOWF Array Area (ranging from 20 m LAT up to the 85 m LAT observed within the PFOWF Array Area), were also analysed;

- Peak spring and neap near-bed flow speeds as presented in Section 7.4.4.7;
- Water levels across the Offshore Site as presented in Section 7.4.4.1; and
- A discharge coefficient of one, which is relevant for a vertical closure, subcritical flow (CIRIA, 2007), which is characteristic of the site conditions with a remedial protection in place.

Results for the varying depths are summarised in Table 7.19 and indicate that there would be negligible change to the tidal flow speeds with the remedial protection in place at any water depth, as there is no change to the water levels downstream of the structure.

Table 7.19 Downstream flow speed changes due to remedial protection

Location	Analysed water depths (mLAT)	Flow speed (m/s)[1]		Spring [2]		Neap [2]	
		Spring	Neap	Downstream flow speed	Percentage change	Downstream flow speed	Percentage change
OECC	20, 45 and 70	0.31	0.10	0.28	0.03%	0.09	0.01%
PFOWF Array Area	66 and 102	0.54	0.30	0.49	0.05%	0.27	0.03%

[1]: Flow speed across the Offshore Site, informed by the baseline characterisation (Section 7.4.4.7); and

[2]: Assessed changes to flow speeds as a result of the 1 m high scour or remedial protection.

7.6.2.1.2 Waves

Wave energy is transmitted through a water body as an oscillatory motion which is strongest at the sea surface but reduces exponentially over depth. Long-period swell-waves transmit the greatest amount of wave energy and with a deeper influence through a water body compared to short-crested wind-waves which transmit most of their energy close to the sea surface.

Waves which pass through the PFOWF Array Area have the potential to be modified by the presence of floating structures exerting a local blockage effect to wave energy transmission. The scale of any modification to waves interacting with individual floating structures will be in proportion to their width, depth, solidity, mass and mooring arrangements. Modifications to waves will be limited to near-surface waters (i.e. the depth of the floating structure) and are expected to include wave energy absorption, reflection and diffraction effects. The net effect of the array of seven floating structures will be in proportional to their layout and spacing (notionally 800 m).

Short-crested wind-waves are expected to be reflected off and absorbed onto the floating structure leading to a heavily dampened wave environment on the leeward side which will eventually be closed up by wave diffraction. In contrast, long-period swell-waves will experience far less dampening with a large proportion of wave energy transmission passing underneath the floating structure unimpeded and onward towards the coast. The minimum spacing of 800 m between adjacent floating structures is judged to be sufficient to moderate the possibility of any wave interactions between devices. Fixed structures on the seabed are considered to be too deep to interfere with waves, noting the exponential reduction in wave energy with increasing water depth.

The proportion of the PFOWF Array Area occupied by a limited number of floating structures is very small at around 0.04% (of the plan area), meaning that the array scale effects on waves are expected to be minimal and localised to each floating structure. As a result, there is not anticipated to be any measurable change to wave energy transmission reaching the coast.

7.6.2.1.3 Impact Assessment

The water column and flow conditions within the PFOWF Array Area are considered to be of **negligible** value, due to the absence of designated sites. The sensitivity to changes is considered to be **negligible**, due to the deep water environment and the fact that the region experiences variable wave and tide conditions. With a minimum separation distance of 800 m separation between WTGs, the floating substructures overall present a very low blockage density to tidal flows and waves at only around 0.01%, whilst scour and remedial protection measures do not alter flow conditions downstream of the protection. However, there is still the potential for wakes in the lee of the floating substructures to interact over a small extent, and therefore, the magnitude of impact is considered to be **low**.

Therefore, based on the above, the overall effect for the PFOWF Array Area is considered to be **negligible** and **not significant**.

The water column and flow conditions within the OECC are considered to be of medium value, due to the overlap with North Caithness Cliffs SPA. This is designated for breeding seabird assemblages, but also includes the seabed, water column and sea surface, although it is noted that the water column is not a designated interest feature. The sensitivity to changes is considered to be **low**, due to the shallower water along the OECC, where changes at the sea surface may be discernible at the seabed. There are no floating substructures and the cable remedial protection measures have been shown to not alter flow conditions downstream of the protection and therefore, the magnitude of impact is considered to be **negligible**.

Therefore based on the above, the overall effect for the OECC is considered to be **negligible** and **not significant**.

Based on the assessment for both the PFOWF Array Area and OECC, the overall effect of the Offshore Development is considered at worst to be **negligible** and **not significant**.

7.6.2.2 Changes to sediment transport regime

This impact considers the potential for changes to the sediment transport regime, based on the pathways by which the changes might occur in light of the Project Design. The pathways that have been identified and discussed in the following sections are as follows:

- Changes to the wave and tide regime with resulting onward modification of sediment transport, either as bedload or in suspension;
- Blockage effect from infrastructure on the seabed; and
- Increases in suspended sediment associated with mooring movement.

7.6.2.2.1 Changes to sediment transport as a result of changes to wave and tide regime

As demonstrated in the assessment for potential changes to tides and waves (Section 7.6.2.1) above, the presence of floating substructures or seabed structures does not ultimately alter the wave and tidal regime across the Offshore Site. With no change to waves and tides, there is not anticipated to be any onward changes to the sediment transport regime across the Offshore Site.

7.6.2.2.2 Changes to sediment transport as a result of blockage from scour and remedial protection

Current speeds across the Offshore Site as described in in Section 7.4.4.7 above are in the order of 0.54 m/s and 0.31 m/s on the spring and neap tides respectively. The shallowest depth within the OECC within which remedial protection could be placed would be near the HDD exit point, at depths of around 20 m LAT. The worst case height and coverage of remedial protection would be 1 m and 50% of the export cable route (12.5 km in total), in water depths ranging between 20 m LAT and 75 m LAT as described in the Project Envelope in Table 7.14.

The sediment mobility thresholds (Table 7.7) demonstrates that for the different grain sizes that occur across the Offshore Site, only a small proportion would be mobilised based on the current conditions, with some amplification from waves. Due to the coarse sediment fraction, i.e. sand and gravels, any movement of sediment would primarily be by bedload transport (Section 7.4.4.8). Of the amount available for transport, only a proportion could theoretically be trapped with the scour or remedial cable protection in place, and the exact amount would vary in relation to the tidal processes, wave energy and sediment grain size. There would be an increasing dependence on current-driven transport (with associated reduction in wave energy and contribution) with increasing depth along the OECC and into the PFOWF Array Area. Any changes to tidal processes could therefore have a greater effect on the transport regime, so the potential for varying current speeds and any onward effects on suspended sediment transport was investigated.

As demonstrated in the assessment for potential changes to tides and waves (Section 7.6.2.1) above, the presence of scour or remedial cable protection does not alter water levels downstream of the protection. Therefore, there is no change to flow properties, which is still the case at the shallowest location within the OECC (Table 7.19). With no variation in tidal flow speeds, the sands and gravels that comprise the majority of the seabed sediment across the Offshore Site would not be disrupted. At the same time, any silt sediment would remain in suspension. This evidence indicates that the sediments would not be disrupted by the presence of the remedial protection.

Waves observed across the Offshore Site would exert an almost constant influence on the seabed at the potential shallowest placement of remedial protection (i.e. around 20 m below LAT), (Section 7.4.4.5) potentially moving coarse grained sediment. As the remedial cable protection would also be a porous structure, the material transported as bedload due to waves could potentially be trapped within the voids of the remedial protection, meaning the structure could initially act as a localised sink for coarser sediments. This effect, however, would only be temporary and in the short-term, for the section of the remedial protection where wave action interacts with the seabed, based on observations of beach groynes where sediment entrapment is the primary purpose. This is broadly analogous to submerged cross-shore groyne structures in the nearshore zone (which are designed to trap sediment up to a certain point, before by-passing occurs). With time and as the voids within the remedial protection fills or colonises with benthic communities, sediment previously deposited locally, would bypass, pass through or overtop the protection. The remedial protection structure is therefore unlikely to cause any hindrance to the transport of coarse sediment in the medium to long-term.

7.6.2.2.3 Changes to sediment transport as a result of increases in suspended sediment

Although no changes to the wave and tide regime are anticipated, it is noted that during the operational life of the Offshore Development, the mooring line for the floating substructures would periodically come in contact with the seabed with the rise and fall of the tide. It is anticipated that during the periods when the mooring may be touching down or lifting off the seabed, there is likely to be some seabed disturbance and a very localised and short-term increase in suspended sediment of any finer particles present (i.e. silts).

As detailed in the Project Design Envelope in Table 7.14, the maximum length of each mooring that could come in contact with the seabed is 1,485 m per line and a total of approximately 94 km for all mooring lines within the OWF. Each line is expected to move over an approximate sweep area of 0.035 km^2 per line, equating to a total of approximately 2.2 km^2 across the OWF. The degree of disturbance and increase in suspended sediment will be variable in relation to the speed of touch down or lift off (associated with the change in water level from high to low water and vice versa) along with the flow speed. Although it is not possible to exactly quantify the increase in suspended sediment, it is anticipated that the sediment disturbance would be relatively minimal compared to the volumes assessed associated with construction activities (Section 7.6.1.1). For any disturbance that occurs, it would be gradual and transient along the mooring, being localised to the mooring line spatially and within a few metres of the seabed vertically. As described for the construction impact assessment in Section 7.6.1.1, it is anticipated that the coarser fraction within the disturbed sediment would quickly be redeposited back on the to seabed, whilst the silt fraction (i.e. the finer sediment, comprising less than 5% of the sediment, Section 7.4.4.2.1) may be advected away by the near-bed flow. It is noted that SPM levels across the Offshore Site are generally low at between 1 to 2 mg/l (Section 7.4.4.8.2). Any disturbance would remain near-bed and is not expected to alter water column sediment concentrations above background levels that would be expected with the tidal flow.

7.6.2.2.4 Impact Assessment

The worst case changes to sediment transport is assessed to occur in relation to the potential for a blockage effect within the PFOWF Array Area as a result of the combination of the installed anchor option with scour protection and remedial protection for inter-array cables. The impact pathways associated with changes in the wave and tide regime or increases in suspended sediment are considered to be minimal. The seabed within the PFOWF Array Area is considered to be of **negligible** value, due to the absence of designated features. The sensitivity to blockages is considered to be **low**, despite the deeper water environment, the presence of a structure on the seabed could be an obstruction to bedload transport. As there is no alteration to the wave and tide regime across the Offshore Site, there are not anticipated to be any changes to sediment transport processes. Furthermore, the scour and remedial protection height has been shown to not disrupt flow conditions, so no blockage to sediment transport is expected across the PFOWF Array Area. Therefore, the magnitude of impact is considered to be **negligible**.

Therefore, based on the above, the overall effect for the PFOWF Array Area is **negligible** and **not significant**.

The worst case changes to sediment transport is again assessed to occur in relation to the potential for a blockage effect within the OECC as a result of with the presence of remedial protection. The seabed within the OECC is considered to be of **medium** value, due to the overlap with designated sites covering the seabed, although it is noted that the seabed is not a designated interest feature. The sensitivity to blockages is considered to be **low** as the presence of a structure on the seabed could be an obstruction to bedload transport. As there is no alteration to the wave and tide regime across the Offshore Site, there is not anticipated to be any changes to sediment transport processes. Furthermore, remedial protection height has been shown to not disrupt flows conditions, so no blockage to sediment transport is expected. However, the influence of waves on the seabed have been shown to be more constant at the shallower depths present within the nearshore locations of the OECC. The remedial protection could act as a localised sink to wave-driven bedload transport in the short-term, but in the medium to long-term wave-driven sediment transport would bypass any remedial protection. Therefore, the magnitude of impact is considered to be **low**.

Therefore, based on the above the overall effect for OECC is **minor** and **not significant**.

Based on the assessment for both the PFOWF Array Area and OECC, the **overall effect** of the Offshore Development is considered at worst to be **minor** and **not significant**.

7.6.2.3 Introduction of Scour

7.6.2.3.1 Introduction of scour

Turbulent wakes formed by floating structures would tend to remain in surface waters without any capacity to influence the seabed, noting total water depths are at least 75 m across PFOWF Array Area. However, a similar wake effect would also occur on the seabed, due to protruding fixed structures, leading to local scouring of any mobile sediments around the base of the protruding structure, but only if no scour protection was provided. The embedded project mitigation is for the prevention of scour by the installation of scour protection around the anchor. The requirement for scour protection will be informed by scour assessment studies and the selected anchor solution. The fixed seabed structure with the largest cross-sectional area and protruding height is the 25 m wide gravity anchor. If these structures were installed diagonally to the direction of incident flows then their effective width could be up to 35 m.

Empirical formulae as outline in Whitehouse (1998) and Whitehouse *et al.*, (2011) were used to calculate the potential equilibrium scour depth and extent for the different anchor options associated with the Offshore Development. Results of the equilibrium scour properties are summarised in Table 7.20, which demonstrate that the largest scour footprint is anticipated with the hammer pile anchor option.

Table 7.20 Calculated equilibrium scour properties for the different anchor options

Anchor	Size (m)	Scour depth (m)	Scour extent (m)	Scour footprint (m^2)
Gravity [1]	125 x 125	1.4	2.2	191.8
Drag embedment [1]	20 x 10	0.6	1.0	48.1
Suction bucket [3]	10	6.5	10.4	503.3
Vertical load [1]	20 x 10	0.6	1.0	48.1
Drilled / screw piles [2]	3	3.9	6.2	181.2
Hammer / drive piles [2]	5	6.5	10.4	503.3
[1]: Calculated using Whitehouse *et al.*, (2011); [2]: Calculated using Whitehouse, (1998); and				

Anchor	Size (m)	Scour depth (m)	Scour extent (m)	Scour footprint (m^2)
[3]: Assumes same scour parameters as hammer piles.				

Despite the calculation of scour properties, it should be noted that the use of scour protection around the anchors is a Project Embedded Mitigation as presented in Section 7.5.6 (Table 7.15). Therefore, this would negate the potential of any scour development.

7.6.2.3.2 Impact Assessment

The potential introduction of scour is considered to primarily relate to the PFOWF Array Area, due to the presence of anchors, and as such is only assessed with respect to this area. The seabed within the PFOWF Array Area is considered to be of **negligible** value, due to the absence of designated features. The sensitivity to scour is considered to be **low**, as the presence of a structure on the seabed can be considered to disrupt the flow to induce scour. Due to the installation of scour protection, if required, around each anchor as part of the Project Embedded Mitigation, no scour development is anticipated, so the magnitude of impact is considered to be **negligible**. Therefore, the overall effect is considered to be **negligible** and **not significant**.

No assessment is completed for OECC due to the proposed burial, and the application of remedial protection of the cables in the instance target burial depth is not achieved, the impact of which is assessed in Section 7.6.2.2.2.

Based on the above, the overall effect of the Offshore Development is considered at worst to be **negligible** and **not significant**.

7.6.2.4 Impacts on fronts and stratification

7.6.2.4.1 Changes to fronts and stratification as a result of changes to wave and tide regime

During the period of expected seasonal stratification (Figure 7.18) in the upper water column (10 to 20 m depth), any increase in turbulence due to wakes forming in the lee of each floating structure (up to 20 m deep) would increase mixing in the surface layer. If this increased mixing was sufficient to overcome the buoyancy forces in the surface layer then local stratification within the footprint of each wake could be disrupted. This is expected to be a very localised near-field effect.

Presently, there is no observational evidence on how floating structures might lead to increased mixing and any consequences to stratification, however, some evidence is available for fixed monopile structures. Schultze *et al*. (2020) report on monitoring the thermal water structure in the lee wake of a foundation (6 m diameter monopile in a water depth of 24 m) of the DanTsyk offshore wind farm off the west coast of Denmark (in the German EEZ). Monitoring on 25 May 2015 was considered to exhibit a relatively weak level of thermal stratification (Figure 7.28). The temperature difference between the sea surface layer (circa 10 m deep) and bottom water was around 0.5 °C (Figure 7.28). When the towed chain of CTD (deployed on an 8 m vertical string) moved past the monopile (blue areas on figure, the first at around 300 m and the second at around 450 m downstream) increased mixing appears to narrow down the spread of temperatures from around 0.5 to around 0.2 to 0.3 °C.

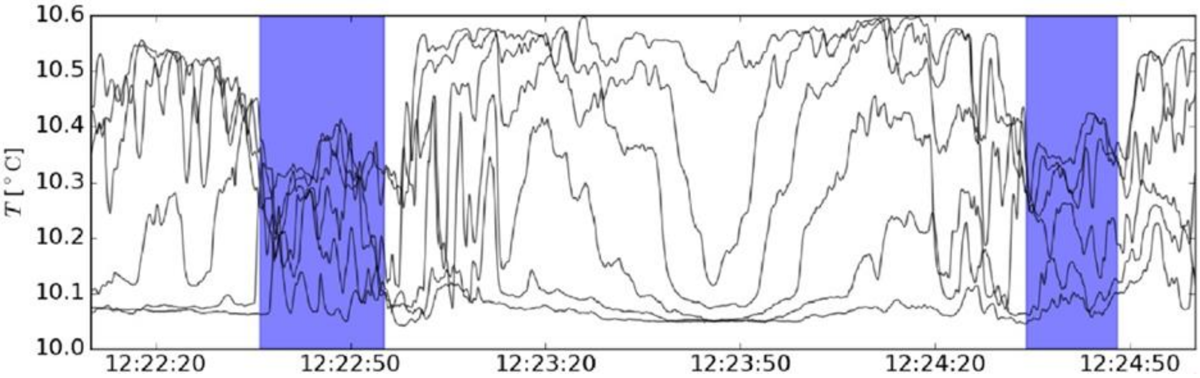

Figure 7.28 Time series of vertical temperature measurements towed past a monopile (from Shultze *et al*. (2020)

A second period of monitoring took place on 19 July 2017 on a different part of the wind farm. The stratification on this date was considered to be stronger than the conditions from 2015 with a temperature difference of around 2.1 °C between the surface layer and lower bottom water. Despite the apparent stronger water column stratification at this time no clear influence of increased mixing due to the monopile foundation was observed, even at the closest transects at 200 and 400 m (n.b. increased mixing within 200 m of the foundation may still have disrupted the stratification in the near-field region but no observations were obtained at this closer distance). One possible explanation for the lack of influence from >200 m is that stronger buoyancy in the more developed stratified water remained the dominant effect over increased mixing from the foundation (which dissipates exponentially in magnitude away from the foundation). For reference, modelled temperature data for the PFOWF Array Area (Figure 7.15 Current rose developed from the near-bed flow observations) shows a temperature difference of up to 3.7 °C between near-surface and near-bed temperatures, suggesting stratification (and buoyancy forces in the surface layer) at this time would be relatively strong.

7.6.2.4.2 Impact Assessment

Consideration of the potential impacts to fronts and stratification is only applicable to the PFOWF Array Area, due to the presence of the floating substructures, and as such an assessment is only completed for this area. The water column within the PFOWF Array Area, with the potential for seasonal stratification and fronts is considered to be of **negligible** value, due to the absence of designated sites. The **sensitivity** to changes is considered to be **low**, due to the deep water environment and the fact that the region does experience variable wave and tide conditions. The discussion presented above demonstrates that the presence of floating structures is only likely to influence the surface layer of the water column. The presence of floating structures is not expected to introduce mixing throughout the water column across the PFOWF Array Area, and therefore, the magnitude of impact is considered to be **low**.

Therefore, based on the above, the overall effect for the PFOWF Array Area is considered to be **minor** and **not significant** and the overall effect of the Offshore Development is considered at worst to be **minor** and **not significant**.

7.6.2.5 Summary of Operation and Maintenance related effects relevant to other EIA topics

- Given the width of the floating substructures, the wakes from each structure are expected to be separate at the outset, become close together further downstream, and to then quickly dissipate over distance, expected to be several hundred metres. Depending on the WTG layout there is the potential for the wakes from the floating substructures to interact to some degree, particularly during the fastest flows. However, the effects of wakes are not expected to extend much beyond the extent of the Offshore Development and will largely be at the surface in relation to the floating substructure;
- Waves which pass through the PFOWF Array Area have the potential to be modified by the presence of floating substructures exerting a local blockage effect to wave energy transmission. Modifications to waves will be limited to surface waters (i.e. the depth of the floating structure) and are expected to include absorption, reflection and diffraction effects. The net effect of the array of seven floating structures will be proportional to their layout and spacing (notionally 800 m). The minimum spacing of 800 m between adjacent floating structures is judged to be sufficient to moderate the possibility of any wave interactions;
- The presence of anchors and moorings on the seabed within the PFOWF Array Area and remedial protection across the Offshore Site does not alter water levels downstream of the structure, there is therefore no change to flow properties. With no variation in tidal flow speeds, the sands and gravels that comprise the majority of the seabed sediment across the Offshore Site would be moved and silt would remain in suspension, so there will be no change to the sediment transport regime across the Offshore Site;
- In the shallowest depths of the OECC where remedial protection could be installed (around 20 m LAT), the protection could act as a localised sink for coarser sediment in the short-term, However, due to the porosity of the structure, which would fill, sediment would bypass the structure in the short to medium term, without long-term changes to the sediment transport regime;
- Presently, there is no observational evidence on how floating structures might lead to increased mixing and any consequences to stratification. Although observations from fixed offshore wind farm developments indicate the potential for increased mixing in close proximity to the development, increased mixing or reduction in water column temperature (and changes to stratification) are not consistently or repeatedly observed as suggested by Schultze et al. (2020). In the context of the PFOWF Array Area, there is not strong evidence to suggest the presence of strong frontal activity and
- Assessed impacts relating to the to the tide wave and sediment transport regime, the introduction of scour and impacts on fronts and stratification were assessed to have **negligible to minor** overall effect across both the PFOWF Array Area and OECC, and are therefore considered to be **not significant** (Table 7.21).

Table 7.21 Summary of significance of effects from Operation and Maintenance impacts

Summary of Effect	Receptor	Sensitivity	Magnitude of impact	Rationale	Consequence	Significance of Effect	Additional Mitigation Requirements*	Residual Effects
Changes to tide and wave regime – PFOWF Array Area	Water column	Negligible	Low	The value and sensitivity of the PFOWF Array Area is considered to be **negligible**. The floating substructures provide a very low blockage density, but there is the potential for wakes to interact, so the impact magnitude is considered to be **low** for the PFOWF Array Area. Therefore, the overall effect is assessed as **negligible** and **not significant.**	Negligible Effects	Not Significant	No additional mitigation measures have been identified for this effect above and beyond the embedded Offshore Development mitigation listed in Section 7.5.6 as it was concluded that the effect was not significant.	Not Significant
Changes to tide and wave regime – OECC		Low	Negligible	The value of the OECC, valu**e** is considered to be **medium,** due to the overlap with a designated site, and the sensitivity is considered to be **low.** For the OECC, any remedial protection would not alter the tides or waves, so the impact magnitude is considered to be **negligible.** Therefore, the overall effect is assessed as **negligible** and **not significant.**	Negligible Effects	Not Significant		Not Significant
Changes to sediment transport regime – PFOWF Array Area	Seabed	Low	Negligible	The value of the PFOWF Array Area is considered to be **negligible**, but the sensitivity is considered to be **low**. The deep water across the PFOWF Array Area, results in no change to flows or wave-driven transport and therefore the impact magnitude is considered to be **negligible**. Therefore, the overall effect is assessed as **negligible** and **not significant.**	Negligible Effects	Not Significant	No additional mitigation measures have been identified for this effect above and beyond the embedded Offshore Development mitigation listed in Section 7.5.6 as it was concluded that the effect was not significant.	Not Significant
Changes to sediment transport regime – OECC		Low	Low	The value of the OECC is considered to be **medium,** due to the overlap with a designated site and the sensitivity is considered to be **low**. Along the OECC, the remedial protection can act as a localised sink in the short-term, so the impact magnitude is considered to be **low**. Therefore, the overall effect is assessed as **minor** and **not significant.**	Minor Effects	Not Significant		Not Significant
Introduction of scour – PFOWF Array Area Only	Water column	Low	Negligible	The value of the PFOWF Array area is considered to be **negligible**, but the sensitivity to scour is considered to be **low**. Due to the embedded mitigation measures involving the installation of scour protection, where required, the impact magnitude is considered to be **negligible**, and the overall effect is assessed as **negligible** and **not significant**.	Negligible Effects	Not Significant	No additional mitigation measures have been identified for this effect above and beyond the embedded Offshore Development mitigation listed in Section 7.5.6 as it was concluded that the effect was not significant.	Not Significant
Impacts on fronts and stratification – PFOWF Array Area Only	Water column, fronts and stratification	Low	Low	The value and sensitivity of the PFOWF Array Area is considered to be **low**. The floating substructures are not expected to introduce mixing throughout the water column, and therefore the impact magnitude is considered to be **low**. The overall effect is assessed as **negligible** and **not significant** for the PFOWF Array Area.	Minor Effects	Not Significant	No additional mitigation measures have been identified for this effect above and beyond the embedded Offshore Development mitigation listed in Section 7.5.6 as it was concluded that the effect was not significant.	Not Significant

7.6.3 Effects during Decommissioning

Decommissioning will involve the dismantling and removal of the seven WTGs and associated floating substructures, anchoring systems and the removal of the dynamic and seabed laid cables (unless there is compelling evidence to leave the buried sections in situ). Scour protection may be left in situ as it may not be practical to remove and; anchor piles may also be cut to a depth of 1 m below the seabed, with the remainder left in situ. Detail on the decommissioning of the Offshore Development infrastructure is limited at this time as this will occur after the 30 year operational life of the Offshore Development. A Decommissioning Programme will be developed pre-construction to address the principal decommissioning measures for the Offshore Development, this will be written in accordance with applicable guidance and will detail the management, environmental management and schedule for decommissioning. The decommissioning programme will be reviewed and updated throughout the life-cycle of the Offshore Development to account for changing best practice.

Given the nature of the decommissioning activities, which will largely be a reversal of the installation process, the impacts during decommissioning are expected to be similar to, or less than those assessed for the construction phase discussed in Section 7.6.1. In the absence of detailed information regarding decommissioning works, the implications for Marine Physical Processes are considered analogous with or likely less than those identified and assessed for the construction phase. It is also assumed that the receptor sensitivities will not materially change over the life-cycle of the Offshore Development.

The primary impact considered to apply to the decommissioning stage is the increase in suspended sediment as a result of removing infrastructure. The instantaneous and largest increases in suspended sediment concentrations associated with decommissioning activities will most likely be near the seabed. As assessed for construction impacts, similar or smaller disturbance rates are assumed to apply. With the same seabed sediment characteristics and flow regime, similar or shorter sediment concentrations and advection distance are considered to apply.

Therefore, impacts associated with decommissioning activities considered to have **negligible** to **minor overall effect**, on the basis the assessment completed for construction activities (Table 7.18), and as a result are **not significant**.

7.7 Assessment of Cumulative Effects

7.7.1 Introduction

The consideration of projects which could result in potential cumulative effects is based on the results of the Marine Physical Processes Study Area specific impact assessment together with the expert judgement of the specialist consultant.

Projects within 20 km of the Offshore Site are considered to have the potential to result in cumulative effects for Marine Physical Processes. A wider zone of influence (i.e. 20 km) than was applied for the Study Area was used to inform the cumulative projects list, to try and capture potential overlapping maximum excursion extents from the nearby projects. The projects that will be considered for the cumulative impact assessment are listed in Table 7.22 and illustrated in Figure 7.29.

The approach to the assessment of projects includes:

> Quantitative assessment of projects submitted to Scoping up to six months prior to PFOWF application submission;

> Qualitative assessment of projects submitted to Scoping up to five months prior to PFOWF application submission; and

> Acknowledgement of projects submitted to Scoping between five and two months prior to PFOWF application submission.

This approach was shared with MS-LOT and agreement was confirmed via email on 6 December 2021.

The list of projects proposed to be considered for cumulative effects assessment was submitted to MS-LOT and consultees for comment; this can be found in Offshore EIA (Volume 3) Appendix 6.1. All relevant responses and actions in association with cumulative comments in relation to Marine Physical Processes are discussed in Section 7.3.

There are limited project details for offshore wind farms sites awarded Option Agreements within the ScotWind leasing round. As noted above, the cut-off date for a qualitative assessment of projects in the Scoping stage was February 2022, therefore, the ScotWind Projects will be acknowledged but no assessment will be conducted. The sites with the greatest potential to act cumulatively with the Offshore Development include the West of Orkney Windfarm (within the N1 Plan Option [PO]). The project will undertake a more detailed cumulative assessment with the PFOWF to support their application for development consent. However, it is envisaged that there will be no overlap with the PFOWF Offshore Development activities due to Project schedules.

Table 7.22 List of projects considered for the Marine Physical Processes Cumulative Impact Assessment

Development Type	Project Name	Status	Phase	Location	Data Confidence	Relevant Receptors
Cable	SHE Transmission Orkney – Caithness Project	Consented	Construction timelines unknown.	Pentland Firth (overlap with OECC)	Medium	All
Dredge disposal site	Scrabster Extension dredge disposal site	Open	Open with intermittent activity taking place.	Located within 18 km of the Offshore Development,	High	All

The following sections summarise the nature of the potential cumulative effects for each potential stage of the Offshore Development.

The following impacts have been taken forward for the cumulative assessment:

- Construction and Decommissioning:
  - Increase in suspended sediment; and
  - Loss / alteration of physical seabed characteristics.
- Operation and Maintenance:
  - Changes to tide and wave regime;
  - Changes to sediment transport regime;
  - Introduction of scour; and
  - Impacts on fronts and stratification.

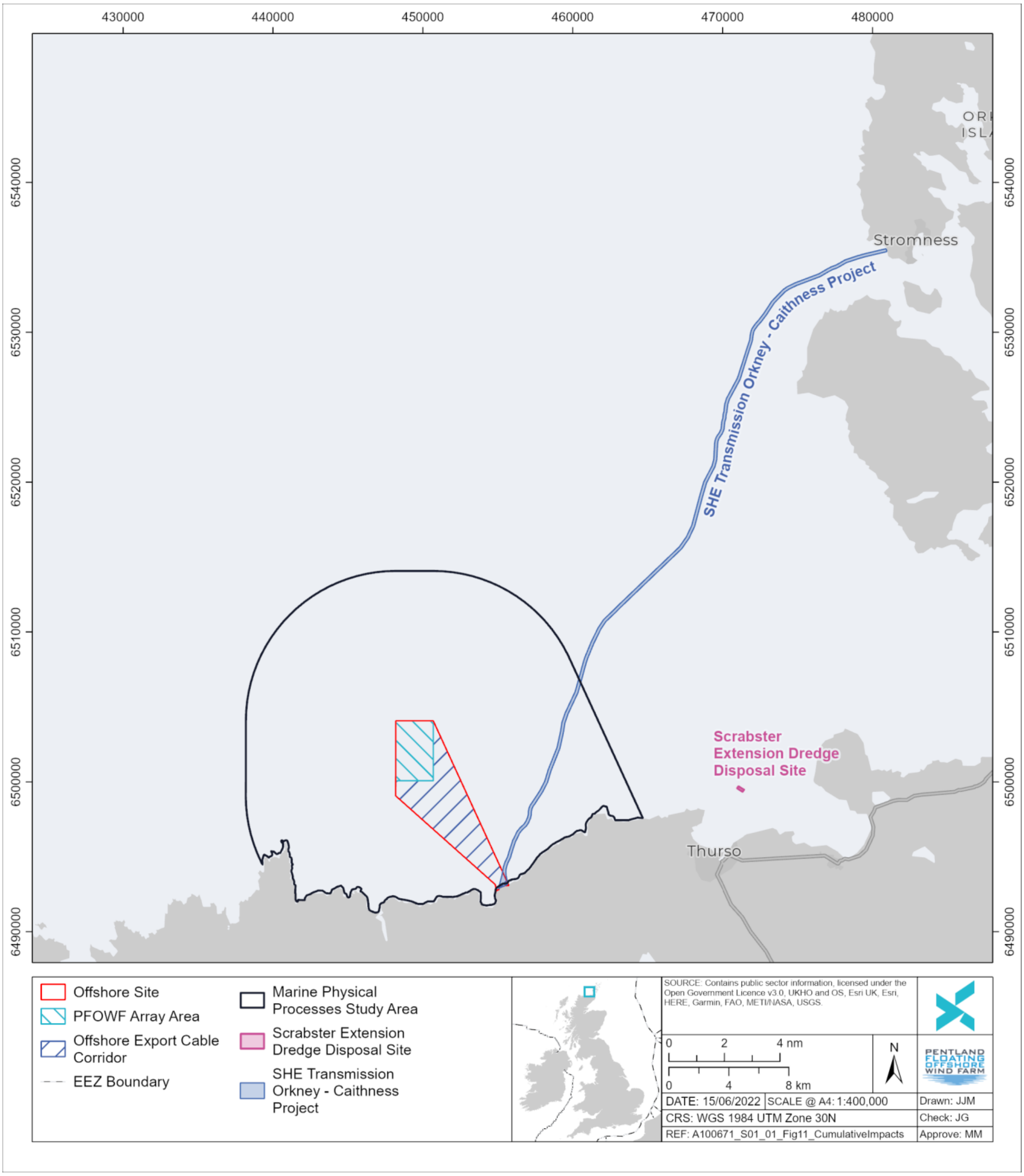

Figure 7.29 Cumulative project associated with Water and Sediment Quality

7.7.2 Cumulative Construction Effects

7.7.2.1 Increase in suspended sediment

A presented in the Marine Physical Processes impact assessment in Section 7.6.1.1, the value and sensitivity of the receiving environment (i.e. the water column) across the PFOWF Array Area is **negligible**. However, for the OECC, the **value** is considered to be **medium,** due to the overlap with a protected site**,** but the **sensitivity** is considered to be **low,** due to a high degree of recoverability from short-term increases in suspended sediment concentrations.

Considering the overlap with the SHE Transmission Orkney – Caithness Project there is the potential for cumulative effects to occur. The construction timelines for the cable project are presently unknown, whilst the main installation of the Offshore Development is anticipated to take place within the spring/summer months of Stage 1 or Stage 2 of the construction phase. The main area of overlap between the projects is in relation to the installation of the Offshore Export Cable, where there could be sediment disturbance and increased suspended sediment as a result of cable installation activities from both projects. Should the installation period coincide, using similar trenching methods, there could be the coalescing of sediment plumes, depending on the installation methodology for the SHE Transmission Orkney – Caithness Project, which is also unknown. With respect to cable installation within the OECC (associated with the Offshore Development and as described in Section 7.6.1.1.2), the majority of the disturbed sediment during trenching would be deposited within the 500 m of the disturbance. Only the silt fraction (less than 5% of the sediment fraction would form a plume, with a maximum sediment plume extent of 3.3 km to the east, with a duration of 4.7-hours on a flood tide release and plume extent of around 2.4 km and a duration of less than 4 hours on an ebb release, informed by the completed analyses. Similar plume development could occur with the SHE Transmission Orkney – Caithness Project. In both cases the plume would disperse with the tidal and wave currents in the nearshore area within a few hours and a tidal cycle (Section 7.6.1.1.2). Ahead of Stage 1 of the construction phase of the Offshore Development, the installation of the PFOWF HDD at the landfall could take place in 2024, but the actual disturbance from this will be very limited and localised to the exit point, with a maximum release of 264 m^3 of fluid. Overall, little to no cumulative impacts or effects are anticipated with the SHE Transmission Orkney – Caithness Project.

The Scrabster Extension dredge disposal site does not overlap with the Offshore Site or the Marine Physical Processes Study Area and is also beyond the mean spring tidal excursion from the Offshore Site. The disposal site is active, so there is the potential for plume development associated with construction activities within the PFOWF Array Area or OECC and also independently during dredge disposal operations within the Scrabster Extension dredge disposal site. As the disposal site is beyond the tidal excursion from the Offshore Site, the potential for the coalescence of sediment plumes is low, but it would be primarily dependent on the dredged material and disposal operations. Should the Offshore Development construction activities (i.e. within the PFOWF Array Area or OECC) coincide with dredge disposal activities, rapid dilution of suspended sediment concentrations can be expected, reducing the potential for the coalescence of sediment plumes from each independent activity. The potential from each Offshore Development area is considered below.

With respect to the PFOWF Array Area, the worst case increases in suspended sediment concentration are associated with the seabed preparation and installation of the gravity anchors occurring within the PFOWF Array Area, which is some distance from the Scrabster Extension dredge disposal site. The results of the completed analyses demonstrate that although the instantaneous increases in concentration associated with the redeposition of sediment around the gravity anchor are very high, at several orders of magnitude above representative background concentrations of 1 – 2 mg/l. However, this high concentration is only in the immediate vicinity of the fall pipe and gravity anchor, and sediment concentrations quickly reduce (by an order of magnitude) within 500 m of the release. The maximum sediment advection occurs with medium silts associated with a release on flood spring tides. In this release scenario, silt sediment can remain in suspension for around six hours, with a maximum advection distance of 5.5 km, which would largely remain within 3 m of the seabed. The intervening distance between the PFOWF Array Area and the Scrabster Extension dredge disposal site, means the plumes from coincident operations are unlikely to coalesce. The impact magnitude is therefore considered to remain **low**.

Therefore, based on the above, the overall effect is considered to be **negligible** and **not significant** for the PFOWF Array Area.

With respect to the OECC, the worst case increases in suspended sediment concentration are associated with the jetting cable installation method. The OECC overlaps the SHE Transmission Orkney – Caithness Project but is over 10 km from the Scrabster Extension dredge disposal site. Plumes associated with the cable installation for the Offshore Development (and also assumed to be representative of the SHE Transmission Orkney – Caithness Project) would be temporary and transient as the installation progressed, due to the narrow cable trench and a maximum of two cables installed for the Offshore Development, combined with the very low silt fraction in sediment within the OECC. Therefore the actual volume of sediment released into the water column to form a plume will be minimal. Instantaneous increases in concentration associated with jetting are high, with concentrations largely reducing several orders of magnitude less than 500 m from the release. The increases in concentration would remain near-bed and disperse a maximum distance of around 3.3 km, remaining in suspension for around 4.7 hours. Concentration levels would quickly return to background levels within one tidal cycle, so any increases are temporary, informed by the completed analyses (Section 7.6.1.1.2). As the flow axis are approximately east to west, even in the nearshore environment in the shallowest location along the export cable route, the concentration increases would not interact with the coast. Therefore, impact magnitude from the cable installation through jetting is considered to be **low**.

Therefore, based on the above, the overall effect is therefore considered to be **minor** and **not significant** for the OECC.

7.7.2.2 Loss / alteration of physical seabed characteristics

The value and sensitivity of the receiving environment (i.e. the seabed) is considered to be **negligible** for the PFOWF Array Area. For the OECC, the value is considered to be **medium**, due to the overlap with a protected site, however, the sensitivity is considered to be **low** as changes may be discernible due to the shallower environment in the nearshore.

Due to the location of the SHE Transmission Orkney – Caithness Project, the potential for impacts is considered to be limited, as the installation plan is for cable burial for both the Offshore Development and the SHE Transmission Orkney – Caithness Project. However, should there be the need for remedial protection, there is the potential for cumulative effects associated with installation within the OECC only, no cumulative effects are anticipated for the PFOWF Array Area. Should remedial cable protection be required, less than 0.3% of the seabed within the whole OECC would be semi-permanently buried with the use of remedial cable protection for the export cables associated with the Offshore Development. The region of overlap between the two projects is approximately a 500 m section off the coast, so depending on the HDD exit point, which is estimated to be between 400 m and 700 m off the coast, no overlap may occur. Should the HDD be at the closest point to the coast (i.e. 400 m offshore from the coast), there would be a short distance, (approximately 100 m) where remedial cable protection could be used for both projects in the nearshore area. Due to very limited potential (as burial is intended) and short distance (100 m) of overlap between the Projects where remedial cable protection could be used if required, the impact magnitude is still considered to be **low**, despite the long-term nature of the projects.

With respect to the Scrabster Extension dredge disposal site, the site is already open and does not overlap with the Offshore Site or the Marine Physical Processes Study Area. The site is also beyond the mean spring tidal excursion from the Offshore Site. Therefore, no cumulative effects associated with the loss or alteration of physical seabed characteristics are anticipated for both Projects.

Therefore, on the basis that the potential for cumulative impact only arises with the OECC, associated with the SHE Transmission Orkney – Caithness Project, the overall effect is considered to be **minor** and **not significant**.

7.7.3 Cumulative Operation and Maintenance Effects

7.7.3.1 Changes to tide and wave regime

As presented in the Marine Physical Processes impact assessment in Section 7.6.2.4, the value and sensitivity of the receiving environment (i.e. the water column) across the PFOWF Array Area is **negligible**. However, for the OECC, the value is considered to be **medium,** due to the overlap with a protected site**,** but the sensitivity is considered to be **low** as a result of the shallower water environment.

The SHE Transmission Orkney – Caithness Project is a project to install a cable that passes near to the Offshore Export Cable HDD landfall. The worst case for potential changes to tide and wave regime have been demonstrated to relate to the presence of floating substructures within the PFOWF Array Area and therefore, no cumulative effects are anticipated with respect to changes to the tide and wave regime.

With respect to the Scrabster Extension dredge disposal site, operations at the site relate to the disposal and release of dredged material. As the site does not overlap with the Offshore Site or the Marine Physical Processes study area and is also beyond the mean spring tidal excursion from the Offshore Site, no cumulative effects are anticipated.

Based on the above, the impact magnitude, is considered to be **negligible**, and the overall effect is considered to be **negligible** and **not significant**.

7.7.3.2 Changes to sediment transport regime

The value and sensitivity of the receiving environment (i.e. the seabed) is considered to be **negligible** for the PFOWF Array Area. For the OECC, the value is considered to be **medium,** due to the overlap with a protected site**,** but the sensitivity is considered to be **low** as a result of the shallower water environment.

The location of the SHE Transmission Orkney – Caithness Project with respect to the Offshore Development means there is the potential for cumulative effects associated with the OECC only, should remedial cable protection be installed for both Projects, which may lead to blockage of sediment transport. No cumulative effects are anticipated associated with impacts within PFOWF Array Area.

For the potential cumulative effects associated with the installation of remedial cable protection within the OECC, the cumulative assessment completed in Section 7.7.2.2, in relation to the Loss / alteration of physical seabed characteristics, demonstrated that there could be a short distance (estimated to be approximately 100 m), where remedial cable protection could be installed for both projects. The completed assessment of potential changes to sediment transport regime (Section 7.6.2.2) demonstrated that there is no alteration to the wave and tide regime across the Offshore Site, and therefore there are no anticipated changes to sediment transport processes. Furthermore, remedial protection height has been shown not to disrupt flows conditions, so no blockage to sediment transport is expected. However, the influence of waves on the seabed have been shown to be more constant at the shallower depths present within the nearshore locations of the OECC. Therefore, remedial cable protection could act as a localised sink to wave-driven bedload transport in the short-term, but in the medium to long-term wave-driven sediment transport would bypass any remedial cable protection. With the potential for remedial cable protection associated with the SHE Transmission Orkney – Caithness Project, the same processes, whereby the remedial protection could act as a localised sediment sink in the short to medium-term, but in the long-term will not be a barrier to the sediment transport regime are considered to apply to any installed remedial protection. Therefore, the impact magnitude is still considered to be **low**.

In terms of the Scrabster Extension dredge disposal site, operations at the site relate to the disposal and release of dredged material. As the site does not overlap with the Offshore Site or the Marine Physical Processes Study Area and is also beyond the mean spring tidal excursion from the Offshore Site, no cumulative effects are anticipated.

Therefore, based on the above, the potential cumulative impact only relates to the OECC and is considered to have an overall effect of **minor** and **not significant**.

7.7.3.3 Introduction of scour

The value and sensitivity of the receiving environment (i.e. the seabed) is considered to be **negligible** for the PFOWF Array Area. For the OECC, the value is considered to be **medium,** due to the overlap with a protected site, but the sensitivity is considered to be **low** as a result of the shallower water environment.

The potential introduction of scour is considered to primarily relate to the PFOWF Array Area, due to the presence of anchors. However, due to the intervening distance between the PFOWF Array Area and the SHE Transmission Orkney – Caithness Project and Scrabster Extension dredge disposal sites, there are not anticipated to be any cumulative effects.

Therefore the impact magnitude is considered to be **negligible**, so the overall effect is **negligible** and **not significant**.

7.7.3.4 Impacts on fronts and stratification

As presented in the Marine Physical Processes impact assessment in Section 7.6.2.4, the value and sensitivity of the receiving environment (i.e. the water column) across the PFOWF Array Area is **negligible**. However, for the OECC, the value is considered to be **medium,** due to the overlap with a protected site, but the sensitivity is considered to be **low** due to a high degree of recoverability.

The potential for impacts on fronts and stratification is considered to primarily relate to the PFOWF Array Area, due to the presence of anchors. However, due to the intervening distance between the PFOWF Array Area and the SHE Transmission Orkney – Caithness Project and Scrabster Extension dredge disposal sites, there are not anticipated to be any cumulative effects.

Therefore, based on the above, the impact magnitude is considered to be **negligible**, and the overall effect is negligible and not significant.

7.7.4 Cumulative Decommissioning Effects

There is limited information on cumulative projects applicable to the decommissioning phase of the Offshore Development. As there is limited information on the decommissioning of the Offshore Development and that of other projects, it is not possible to provide a meaningful cumulative assessment at this stage. However, the cumulative effects are expected to be less than or equal to the construction phase and decommissioning of multiple other projects would not be expected to occur at the same time as the decommissioning phase of the Offshore Development.

A Decommissioning Programme will be developed pre-construction to address the principal decommissioning measures for the Offshore Development, this will be written in accordance with applicable guidance and detail the management, environmental management and schedule for decommissioning. The decommissioning programme will be reviewed and updated throughout the life-cycle of the Offshore Development to account for changing best practice. The cumulative construction impacts discussed in Section 7.7.2 are anticipated to be similar during the decommissioning phase. Any impacts will be the same, or less, than those identified during the construction phase.

7.8 Assessment of Transboundary Effects

In terms of the changes to Marine Physical Process conditions (i.e. seabed, water column, wave, tide and sediment transport regime and fronts and stratification), impacts will be largely localised to the extent of the assessed Study Area. Based on the completed analyses the largest extent is associated with the potential for sediment plumes, which could extend up to 5.5 km away from the source. Although the extent could be beyond the Offshore Site, it would be within the Study Area, which is based on a 10 km buffer around the Offshore Site. This maximum extent of any changes and the entire Study Area are still within UK waters and given the intervening distance to neighbouring European Economic Area (EEA) states, there is no potential for transboundary impacts and resultant effects to occur.

7.9 Assessment of Impacts Cumulatively with the Onshore Development

The Onshore Development components are summarised in Chapter 5: Project Description and these Project aspects have been considered in relation to the impacts assessed within this Chapter.

The Onshore Development will undertake HDD operations above MHWS, with an HDD exit point occurring between 400 and 700 m offshore. The impacts from the HDD exit point on Marine Physical Processes have been assessed in full in Section 7.6. It is not anticipated that there will be any additional impacts from the Onshore Development on Marine Physical Processes receptors, as all other activities from the Onshore Development are fully terrestrial.

7.10 Mitigation and Monitoring Requirements

There is no requirement for additional mitigation over and above the embedded measures for the Offshore Development proposed in Section 7.5.6. Furthermore, no monitoring specific to Marine Physical Processes receptors is proposed.

7.11 Inter-relationships

Interrelated effects describe the potential interaction of multiple project impacts upon one receptor which may interact to create a more significant impact on a receptor than when considered in isolation. Interrelated effects may have a temporal or spatial element and may be short term, temporary or longer term over the life-cycle of the Offshore Development.

In line with the Scoping Opinion and Scoping Addendum Opinion received, this Chapter has assessed all impacts that are relevant to Marine Physical Processes receptors during the construction, operation and maintenance, and decommissioning phases of the Offshore Development. Therefore, it is considered that the assessment and conclusions presented in Section 7.12 provides a complete and robust assessment of all potential impacts relevant to Marine Physical Processes. The assessment has also considered the potential for inter-related effects in relation to Marine Physical Processes, and no additional inter-related effects beyond those presented in Section 7.6 have been identified.

Where the assessment contained in this Chapter is considered within other assessment chapters, a summary of these inter-relationships is presented below in Table 7.23.

Table 7.23 Inter-relationships identified with Marine Physical Processes and other receptors in this Offshore EIAR

Receptor	Impacts	Description
Water and Sediment Quality	In-direct impacts on water quality and status of receptors from suspended sediments.	Changes in marine physical processes could lead to suspension of sediments which may in turn result in temporary changes to water quality and status of receptors. These impacts are discussed in Section 7.6.1.1 and Section 7.6.2.3 of this Chapter.
Benthic Ecology	In-direct impacts on benthic habitats and species from increases in sediment concentration, seabed loss / alteration and scour or changes to wave and tide regime.	Increases in suspended sediment concentration from seabed disturbance, loss of seabed and seabed scour can result in impacts to benthic habitats which are sensitive to turbidity and habitat change or impacts on primary productivity. These impacts are discussed in Section 7.6.1, Section 7.6.2.2 and Section 7.6.2.3 of this Chapter.
Fish and Shellfish Ecology	In-direct impacts on benthic pelagic species from increases in sediment concentration and changes to wave and tide regime.	Increases in suspended sediment concentration or changes to wave and tide regime can result in in-direct impacts to fish and shellfish ecology which are sensitive to sediment concentrations or impact on primary productivity. These impacts are

Receptor	Impacts	Description
		discussed in Section 7.6.1.1 and Section 7.6.2.2 of this Chapter.
Marine Mammals	In-direct impacts on marine mammal species from increases in sediment concentration and changes to wave and tide regime.	Increases in suspended sediment concentration or changes to wave and tide regime can result in in-direct impacts to marine mammals which are sensitive to sediment concentrations or impact on primary productivity. These impacts are discussed in Section 7.6.1.1 and Section 7.6.2.2 of this Chapter.
Marine Ornithology	In-direct impacts on seabird species from increases in sediment concentration, which affects feeding and diving patterns.	Increases in suspended sediment concentration or changes to wave and tide regime can result in in-direct impacts to marine ornithology receptors which are sensitive to sediment concentrations or impact on primary productivity. These impacts are discussed in Section 7.6.1.1 of this Chapter.
Commercial Fisheries	In-direct impacts on stock availability from increases in sediment concentration or disruption of fronts and stratification influencing primary productive and fish distribution.	Increases in suspended sediment concentration or changes to wave and tide regime can result in in-direct impacts to commercial fish species which are sensitive to sediment concentrations or impact on primary productivity. These impacts are discussed in Section 7.6.1.1 and Section 7.6.2.4 of this Chapter.
Marine Archaeology	In-direct impacts on exposure and erosion of marine archaeological assets with the introduction of scour or blockage to sediment transport.	The introduction of scour or the changes to the sediment transport regime may lead to the exposure of marine archaeological assets that may be presently buried across the Offshore Site. These impacts are discussed in Section 7.6.2.2 and Section 7.6.2.3 of this Chapter.
Other Users of the Marine Environment	In-direct impacts on other users from increases in sediment concentration and changes to wave and tide regime.	Increases in suspended sediment concentration or changes to wave and tide regime can result in in-direct impacts to other marine users and their use of the marine environment. These impacts are discussed in Section 7.6.1.1 and Section 7.6.2.2 of this Chapter.

7.12 Summary and Residual Effects

Table 7.24 summarises the effects for all impacts assessed.

Table 7.24 Summary of residual effects for Marine Physical Processes

Predicted Effect	Receptor	Assessment Consequence	Significance	Mitigation identified	Significance of Residual Effect
Construction and Decommissioning					
Increase in suspended sediment concentration – PFOWF Array Area	Water column	Negligible Effects	Not Significant	No additional mitigation measures have been identified for this effect above and beyond the embedded Offshore Development mitigation listed in Section 7.5.6 as it was concluded that the effect was not significant.	Not Significant
Increase in suspended sediment concentration – OECC		Minor Effects	Not Significant		Not Significant
Loss/ alteration of physical seabed characteristics – PFOWF Array Area	Seabed	Minor Effects	Not Significant	No additional mitigation measures have been identified for this effect above and beyond the embedded Offshore Development mitigation listed in Section 7.5.6 as it was concluded that the effect was not significant.	Not Significant
Loss/ alteration of physical seabed characteristics – OECC		Minor Effects	Not Significant		Not Significant
Operation and Maintenance					
Changes to tide and wave regime – PFOWF Array Area	Water column	Negligible Effects	Not Significant	No additional mitigation measures have been identified for this effect above and beyond the embedded Offshore Development mitigation listed in Section 7.5.6 as it was concluded that the effect was not significant.	Not Significant
Changes to tide and wave regime – OECC		Negligible Effects	Not Significant		Not Significant
Changes to sediment transport regime – PFOWF Array Area	Seabed	Negligible Effects	Not Significant	No additional mitigation measures have been identified for this effect above and beyond the	Not Significant

Predicted Effect	Receptor	Assessment Consequence	Significance	Mitigation identified	Significance of Residual Effect
Changes to sediment transport regime – OECC		Minor Effects	Not Significant	embedded Offshore Development mitigation listed in Section 7.5.6 as it was concluded that the effect was not significant.	Not Significant
Introduction of scour – PFOWF Array Area Only	Seabed	Negligible Effects	Not Significant	No additional mitigation measures have been identified for this effect above and beyond the embedded Offshore Development mitigation listed in Section 7.5.6 as it was concluded that the effect was not significant.	Not Significant
Impacts on fronts and stratification – PFOWF Array Area Only	Water column	Minor Effects	Not Significant	No additional mitigation measures have been identified for this effect above and beyond the embedded Offshore Development mitigation listed in Section 7.5.6 as it was concluded that the effect was not significant.	Not Significant
Cumulative					
Increase in suspended sediment concentration – PFOWF Array Area	Water column	Negligible Effects	Not Significant	No additional mitigation measures have been identified for this effect above and beyond the embedded Offshore Development mitigation listed in Section 7.5.6 as it was concluded that the effect was not significant.	Not Significant
Increase in suspended sediment concentration – OECC		Minor Effects	Not Significant		Not Significant
Loss / alteration of physical seabed characteristics – OECC only	Seabed	Minor Effects	Not Significant	No additional mitigation measures have been identified for this effect above and beyond the embedded Offshore Development mitigation listed in	Not Significant

Predicted Effect	Receptor	Assessment Consequence	Significance	Mitigation identified	Significance of Residual Effect
				Section 7.5.6 as it was concluded that the effect was not significant.	
Changes to tide and wave regime – PFOWF Array Area	Water column	Negligible Effects	Not Significant	No additional mitigation measures have been identified for this effect above and beyond the embedded Offshore Development mitigation listed in Section 7.5.6 as it was concluded that the effect was not significant.	Not Significant
Changes to tide and wave regime – OECC		Negligible Effects	Not Significant		Not Significant
Changes to sediment transport regime – OECC only	Seabed	Minor Effects	Not Significant	No additional mitigation measures have been identified for this effect above and beyond the embedded Offshore Development mitigation listed in Section 7.5.6 as it was concluded that the effect was not significant.	Not Significant
Introduction of scour – PFOWF Array Area only	Seabed	Negligible Effects	Not Significant	No additional mitigation measures have been identified for this effect above and beyond the embedded Offshore Development mitigation listed in Section 7.5.6 as it was concluded that the effect was not significant.	Not Significant
Impacts on fronts and stratification - PFOWF Array Area only	Water column	Negligible Effects	Not Significant	No additional mitigation measures have been identified for this effect above and beyond the embedded Offshore Development mitigation listed in Section 7.5.6 as it was concluded that the effect was not significant.	Not Significant

7.13 References

BGS, 2022. BGS Offshore GeoIndex. Available at: https://mapapps2.bgs.ac.uk/geoindex_offshore/home.html?_ga=2.53031727.641647902.1655812172-2025367756.1627475166. [Accessed 21/04/2022].

Cefas, 2016. Suspended Sediment Climatologies around the UK. Report for the UK Department for Business, Energy & Industrial Strategy offshore energy Strategic Environmental Assessment programme.

Construction Industry Research and Information Association (CIRIA), 2007. The Rock Manual. The use of rock in hydraulic engineering, 2nd edition. CIRIA Special Publication Volume 83, CIRIA C683

DHI, 2021. Pentland Floating Offshore Wind Farm. Metocean Hindcast Data and Analysis. Prepared for Highland Wind Limited. 01 December 2021.

Farr, F., Ruttenberg, B., Walter, R.K., Wang, Y., and White, C., 2021. Potential environmental effects of deep water floating offshore wind energy facilities. Ocean and Coastal Management 207 (2021) 105611.

Fitton, J.M., Hansom, J.D., and Rennie, A.F. (2017) DynamicCoast - National Coastal Change Assessment: Cell 4 - Duncansby Head to Cape Wrath, CRW2014/2.

Folk, R.L., 1954. The Distinction between Grain Size and Mineral Composition in Sedimentary-Rock Nomenclature. The Journal of Geology, 62 (4), 344-359. https://doi.org/10.1086/626171. Accessed 21/04/2022].

Fugro, 2021. Pentland Floating Offshore Wind Farm. Investigation Results. Geotechnics. F184395/01 | 03 | 17 December 2021.

Highland Wind Limited, 2021. Pentland Floating Offshore Wind Farm EIA. Method Statement to Inform the Marine Physical Processes Impact Assessment. A-100671-S01-REPT-007.

Horsburgh, K., Rennie, A. and Palmer, M. (2020). Impacts of climate change on sea-level rise relevant to the coastal and marine environment around the UK. MCCIP Science Review 2020, 116–131

Lowe, J.A., Bernie, D., Bett, P., Bricheno, L., Brown, S., Calvert, D., Clark, R., Eagle, K., Edwards, T., Giorgia Fosser, G., Fung, F., Gohar, L., Good, P., Gregory, J., Harris, G., Howard, T., Kaye, N., Kendon, E., Krijnen, J., Maisey, P., McDonald, R., McInnes, R., McSweeney, C., Mitchell, J.F.B., Murphy, J., Palmer, M., Roberts, C., Rostron, J., Sexton, D., Thornton, H., Tinker, J., Tucker, S., Yamazaki, K., and Belcher, S. (2018). UKCP18 Science Overview Report. Available online at: https://www.metoffice.gov.uk/pub/data/weather/uk/ukcp18/science-reports/UKCP18-Overview-report.pdf. Accessed 21/04/2022].

Marine Scotland. Offshore Wind Energy in Scottish Waters. Regional Locational Guidance. Prepared by ABPmer. October 2020.

Marine Scotland – Licensing Operations Team, 2021. Scoping Opinion for Pentland Floating Offshore Wind Farm. 28 September 2021.

Marine Scotland, 2016. The Scottish Shelf Model. Part 2: Pentland Firth and Orkney Waters Sub-Domain Scottish Marine and Freshwater Science Vol 7 No 4. DOI: 10.7489/1693-1.

Masselink, G., Russell, P., Rennie, A., Brooks, S. and Spencer, T. (2020) Impacts of climate change on coastal geomorphology and coastal erosion relevant to the coastal and marine environment around the UK. MCCIP Science Review 2020, 158–189

Miller, P. I., & Christodoulou, S., 2014. Frequent locations of oceanic fronts as an indicator of pelagic diversity: Application to marine protected areas and renewables. Marine Policy, 45, 318-329.

MMT, 2021. Pentland Floating Offshore Wind Farm. Geophysical & Environmental Survey. Pentland Firth. June – July 2021. 103760-HWL-MMT-SUR-REP-ENVEBSRE Revision 0. Client Review. October 2021.

O'Hara Murray, R. and Campbell, L. 2021. Pentland Firth and Orkney Waters Climatology 1.02. DOI: 10.7489/12041-1

O'Hara Murray, R. and Gallego, A. 2017. A modelling study of the tidal stream resource of the Pentland Firth, Scotland. Renewable Energy 102, 326-340.

Ramsay, D.L. and Brampton, A.H., 2000. Coastal Cells in Scotland: Cel– 4 - Duncansby Head to Cape Wrath. Scottish Natural Heritage Research, Survey and Monitoring Report No 146.

Schultze, L. K. P., Merckelbach, L. M., Horstmann, J., Raasch, S., & Carpenter, J. R., 2020. Increased mixing and turbulence in the wake of offshore wind farm foundations. Journal of Geophysical Research: Oceans, 125, https://doi.org/10.1029/2019JC015858. Accessed 21/04/2022].

SNH, 2014. Seasonal shelf-sea front mapping using satellite ocean colour to support development of the Scottish MPA network. Scottish Natural Heritage. Commissioned Report No. 538.

Soulsby, R.L., 1997. Dynamics of marine sands. A manual for practical applications. Thomas Telford.

Tonani, M., Ascione, A., Saulter, A., 2022. Ocean Physical Wave Analysis and Forecast Product Northwestshelf_Analysis_Forecast_Phy_004_013, Northwestshelf_Analysis_Forecast_Phy_004_014, Issue 1.3.

Whitehouse, R.J.S., 1998. Scour at marine structures: A manual for practical applications. Thomas Telford, London, 198 pp.

Whitehouse, R. J. S., Sutherland J., and Harris, J. M., 2011. Evaluating scour at marine gravity structures. In Maritime Engineering, Volume 164 Issue 3, December 2011, pp 143-157.

Wolf, J., Woolf, D. and Bricheno, L. (2020) Impacts of climate change on storms and waves relevant to the coastal and marine environment around the UK. MCCIP Science Review 2020, 132–157.