MachairWind Offshore Windfarm

Chapter 7 Marine Physical Environment

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TABLE OF CONTENTS

List of Tables

List of Figures

List of Plates

List of Appendices

GLOSSARY OF ACRONYMS

Acronym	Definition
ABPmer	ABP Marine Environmental Research
BERR	Department for Business, Enterprise and Regulatory Reform
BGS	British Geological Survey
BSF	Below Sea Floor
CBRA	Cable Burial Risk Assessment
CEA	Cumulative Effects Assessment
Cefas	Centre for Environment Fisheries and Aquaculture Science
CES	Crown Estate Scotland
DDV	Drop-Down Video
ECC	Export Cable Corridor
EEA	European Economic Area
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EIAR	Environmental Impact Assessment Report
EMODnet	European Marine Observation and Data Network
EO	Earth Observation
ETG	Expert Topic Group
GBS	Gravity Base Structure
Hs	Significant Wave Height
IAC	Inter-Array Cable
INTOG	Innovation and Targeted Oil & Gas
LAT	Lowest Astronomical Tide
LSE	Likely Significant Effects
MBES	Multi-Beam Echo Sounder
MD-LOT	Marine Directorate Licensing and Operations Team
MD-SEDD	Marine Directorate Science Evidence, Data and Digital
ncMPA	Nature Conservation Marine Protected Areas
NMP	National Marine Plan
NRW	Natural Resources Wales
O&M	Operation and Maintenance
OAA	Option Agreement Area
OnTDA	Onshore Transmission Development Area

Acronym	Definition
OSP	Offshore Substation Platform
PDE	Project Design Envelope
PEA	Potential Energy Anomaly
POA	Plan Option Area
SMP-OWE	Sectoral Marine Plan for Offshore Wind Energy
S-P-R	Source-Pathway-Receptor
SSC	Suspended Sediment Concentration
SSSI	Site of Special Scientific Interest
SSW-RS	Scottish Shelf Waters Reanalysis Service
TKE	Turbulent Kinetic Energy
UXO	Un-exploded Ordnance
WDA	Windfarm Development Area
WTG	Wind Turbine Generator
ZoI	Zone of Influence

GLOSSARY OF TERMS

Term	Definition
Bathymetry	Topography of the seabed.
Bedforms	Features on the seabed (e.g. sand waves, ripples) resulting from the movement of sediment over it.
Bedload	Sediment particles that travel near or on the seabed.
Cable protection	Protective measure to minimise the effects of scour and hazards along the offshore cables (e.g. to prevent cable exposure or snagging of vessel anchors or fishing gear), as well as for protecting these cables at infrastructure crossing points.
Clay	Fine sediment with a typical particle size of less than 0.002mm.
Combined Assessment	A whole-Project assessment considering interactions between the Windfarm Development Area, Offshore Export Cable Corridor and Onshore Transmission Development Area (i.e. considering impact interactions and additive effects to determine if any effects would be materially elevated from those assessed for the Windfarm Development Area-alone assessment). Due to long delays in securing confirmation of the Project’s grid connection location, the level of detail available for the Offshore Export Cable Corridor and Onshore Transmission Development Area is limited and therefore the assessment is commensurate with the level of detail available at the time of carrying out the assessment. When it is time to progress the Offshore Export Cable Corridor and Onshore Transmission Development Area consent applications, their respective scoping and Environmental Impact Assessment Report / Environmental Report will take account of all likely effects predicted within the WDA EIA and present updated combined assessments using the latest available information covering all aspects of the Project.
Critical Shield’s parameter	A dimensionless value which determines if seabed sediment is mobilised, depending on if the value exceeds a predetermined critical Shields value.
Cumulative Effects Assessment	Assessment of likely significant effects resulting from the incremental change caused by other past, present and reasonably foreseeable projects / activities together with the Project. This is separate to combined effects arising between the Project’s separate Development Areas.
Current	Flow of water generated by a variety of forcing mechanisms (e.g. waves, tides, wind).
Development Area	Application boundary for consenting purposes which, for the Project, consists of a Windfarm Development Area, Offshore Export Cable Corridor, and Onshore Transmission Development Area. Separate consent and marine licence applications will be submitted for each Development Area where applicable.
Ebb Tide	The falling tide, immediately following the period of high water and preceding the period of low water.
Effect	An effect is the consequence of an impact when considered in combination with the receptor’s sensitivity / value / importance, defined in terms of significance.
Embedded mitigation measure	Mitigation measures, including industry good practice measures, that are directly incorporated into the design for the MachairWind Windfarm Development Area to avoid or reduce environmental effects.
Environmental Impact Assessment (EIA)	The process of evaluating the likely significant environmental effects of a proposed development over and above the existing circumstances (or ‘baseline’).
Erosion	Wearing away of the land or seabed by natural forces (e.g. wind, waves, currents and chemical weathering).

Term	Definition
Expert Topic Group (ETG)	A forum for targeted technical engagement with relevant stakeholders through the EPP
Flood Tide	The rising tide, immediately following the period of low water and preceding the period of high water.
Gravel	Loose, rounded fragments of rock larger than sand but smaller than cobbles. Sediment larger than 2mm (as classified by the Wentworth scale used in sedimentology).
Halocline	A layer of the water column structure characterised by a rapid change in salinity with depth.
High Water	Maximum level reached by the rising tide.
Holocene	The last 10,000 years of earth history.
Hydrodynamic	The process and science associated with the flow and motion in water produced by applied forces.
Impact	A change resulting from an activity associated with the Project, defined in terms of magnitude.
Inter-array cables (IACs)	Armoured cable containing electrical and fibre optic cores which link the wind turbine generators to each other and to the offshore substation platform(s).
Long-term	Refers to a time of decades to centuries.
Low Water	The minimum height reached by the falling tide.
Lowest Astronomical Tide (LAT)	The lowest level that can be expected to occur under average meteorological conditions and under any combination of astronomical conditions.
MachairWind Offshore Windfarm	An offshore windfarm capable of exporting around 2 GW of renewable energy to the National Electricity Transmission System. MachairWind Offshore Windfarm comprises three Development Areas: • The WDA – located on the west coast of Scotland to the northwest of Islay and west of Colonsay; • The Offshore Export Cable Corridor – a preliminary boundary extending from the WDA to mean high water springs at a landfall location near Girvan, South Ayrshire; and • The Onshore Transmission Development Area – a preliminary boundary which extends landward from mean low water springs and includes the land required for the landfall of the offshore export cable(s) and their route up to but not including the proposed high voltage direct current switching station which will be developed and constructed by Transmission Owner, ScottishPower Transmission. Separate consent and licence applications will be submitted for each Development Area.
Mean High Water Springs	The average, over a year, of the heights of two successive high waters during those periods of 24 hours (once every fortnight) when the range of the tide is greatest.
Mean Low Water Spring	The average, over a year, of the heights of two successive low waters during those periods of 24 hours (once every fortnight) when the range of the tide is greatest.
Megaripples	Bedforms with a wavelength of 0.6m to 10.0m and a height of 0.1m to 1.0m. These features are smaller than sand waves but larger than ripples.
Mitigation	Any action or process designed to avoid, prevent, reduce or, if possible, offset potentially significant adverse effects of a development. All mitigation measures adopted by the Project are provided in the Commitments Register.
Mixing	The effect of breaking down layers within the water column, generated due to alterations in the water column structures properties. The opposite of a stratification.

Term	Definition
Monitoring	Measures to ensure the systematic and ongoing collection, analysis and evaluation of data related to the implementation and performance of a development. Monitoring can be undertaken to monitor conditions in the future to verify any environmental effects identified by the EIA, the effectiveness of mitigation or enhancement measures or ensure remedial action are taken should adverse effects above a set threshold occur. All monitoring measures adopted by the Project are provided in the Commitments Register.
Neap Tide	A tide that occurs when the tide-generating forces of the sun and moon are acting at right angles to each other, so the tidal range is lower than average.
Numerical Modelling	Refers to the analysis of coastal processes using computational models.
Oceanographic fronts (Fronts)	The horizontal and vertical boundary between bodies of water with different water column structures, caused by differences between the physical and chemical characteristics within a wider waterbody.
Offshore	Area seaward of nearshore in which the transport of sediment is not caused by wave activity.
Offshore cables	The collective term for all offshore cables i.e. IACs, offshore substation platform link cables, offshore export cable(s) and associated fibre optic cables.
Offshore ECC infrastructure	The offshore transmission infrastructure located within the boundary of the Offshore Export Cable Corridor, namely the offshore export cable(s).
Offshore export cable	Armoured cable containing electrical cores between the offshore substation platform(s) and landfall. Offshore export cable(s) will include bundled fibre optic cables. The offshore export cable(s) are subject to Marine Licence applications under the Marine (Scotland) Act 2010. The portion of the offshore export cable(s) located within the WDA is assessed as part of this MachairWind WDA EIA and a marine licence application to construct, alter or improve this portion has been submitted alongside the WDA application. A separate marine licence application will be submitted for the portion of the offshore export cable(s) from the WDA boundary to mean high water Mean High Water Springs.
Offshore Export Cable Corridor (ECC)	The preliminary boundary extending from the WDA to mean high water springs near Girvan, South Ayrshire and within which the offshore export cable(s) will be located. A separate marine licence application will be submitted for the offshore export cable(s) located within the Offshore ECC.
Offshore Substation Platform (OSP)	An offshore platform with a fixed foundation located within the WDA which houses electrical equipment such as transformers, switchgear, protection and control systems, and enables the windfarm's renewable electricity to be collected via inter-array cables and exported to the National Electricity Transmission System via offshore export cable(s).
Offshore Substation Platform (OSP) link cables	Electrical cables which link OSPs (if more than one OSP is required). These cables will include fibre optic cores or bundled fibre optic cables. OSP link cables will be wholly located within the WDA.
Onshore Transmission Development Area (OnTDA)	The preliminary boundary which extends landward from mean low water springs and includes the land required for the landfall of the offshore export cable(s) and their route up to but not including the proposed high voltage direct current switching station which will be developed and constructed by Transmission Owner, ScottishPower Transmission. The Transmission Owner is responsible for consenting the high voltage direct current switching station and onward connections to the National Electricity Transmission System. Where relevant, these are considered as part of cumulative effects assessment in the EIA.
OnTDA infrastructure	The onshore transmission infrastructure, for which the Applicant is responsible, that is located primarily within the OnTDA, up to mean low water springs, and includes but is not limited to: landfall(s), onshore export cable(s), transition joint bays, telecom/SCADA infrastructure including vehicular access, joint bays, link boxes and temporary construction

Term	Definition
	compounds. The OnTDA infrastructure will be subject to a planning application under the Town and Country Planning (Scotland) Act 1997.
Operational life	The operational life is the expected length of time from final commissioning of the WDA until the cessation of commercial operations. This is anticipated to be 35 years.
Option Agreement Area (OAA)	The seabed area awarded to ScottishPower Renewables in January 2022 through the ScotWind leasing round.
Pleistocene	An epoch of the Quaternary Period (between about 2 million and 10,000 years ago) characterised by several glacial ages.
Pre-construction works	Pre-construction works are activities undertaken prior to formal commencement of construction. Examples include survey works such as geotechnical and geophysical surveys and seabed preparation activities.
Primary productivity	How active the organisms at the base of the marine food web are and subsequently how quickly new organic matter is created.
Quaternary Period	The last 2 million years of earth history incorporating the Pleistocene ice ages and the post-glacial (Holocene) Period.
Sand	Sediment particles, mainly of quartz with a diameter of between 0.063mm and 2mm. Sand is generally classified as fine, medium, or coarse.
Sand Wave	Bedforms with wavelengths of 10m to 100m, with amplitudes of 1m to 10m.
Scoping Opinion	A written opinion issued by the Planning Inspectorate on behalf of the Secretary of State regarding the scope and level of detail of the information to be provided in the Applicant's Environmental Statement.
Scoping Report	A request by the Applicant made to the Planning Inspectorate for a Scoping Opinion on behalf of the Secretary of State.
ScotWind	A Crown Estate Scotland seabed leasing round which enabled developers to propose offshore wind projects and apply for seabed rights to plan and build windfarms in Scottish waters.
Scour protection	Protective measures to avoid sediment being eroded away from the base of the wind turbine generator foundations as a result of the flow of water.
Sea Level	Generally, refers to 'still water level' (excluding wave influences) averaged over a period such that periodic changes in level (e.g. due to the tides) are averaged out.
Short-term	Refers to a time of months to years.
Significant Wave Height	The average height of the highest of one third of the waves in a given sea state.
Silt	Sediment particles with a grain size between 0.002mm and 0.063mm, i.e. coarser than clay, but finer than sand.
Spring Tide	A tide that occurs when the tide-generating forces of the sun and moon are acting in the same directions, so the tidal range is higher than average.
Stratification	The effect of layers forming within the water column, generated due to vertical differences in the water column structures properties. The opposite of a mixing.
Stratified	The state of the water column structure when layers of water with unique physical and chemical characteristics are present. The opposite of a well-mixed water column.

Term	Definition
Suspended Sediment	Sediment moving in suspension in a fluid kept up by the upward components of the turbulent currents or by the colloidal suspension.
The Applicant	The legal entity submitting consent applications for the MachairWind Offshore Windfarm, namely MachairWind Limited.
The Lighthouse	The Dubh Artach lighthouse.
The Project	MachairWind Offshore Windfarm including all its Development Areas and associated infrastructure.
Thermocline	A layer of the water column structure characterised by a rapid change in temperature with depth.
Tidal Current	The alternating horizontal movement of water associated with the rise and fall of the tide.
Tidal excursion ellipse	A visual representation of the magnitude and direction of regular tidal flows over a full tidal cycle.
Tidal Range	Difference in height between high and low water levels at a point.
Turbidity	The measure of water clarity, how clear or how cloudy the water is.
Water column	A vertical section of water from the sea surface to seabed
Water column structure	The term used to refer to the physical and chemical characteristics of water, and how these properties change, at different depths within a water column.
Wave Climate	Average condition of the waves at a given place over a period of years, as shown by height, period, direction etc.
Wave Height	The vertical distance between the crest and the trough.
Wavelength	The horizontal distance between consecutive wave crests (or alternative troughs).
WDA infrastructure	The offshore generation and transmission infrastructure located within the WDA including but not limited to: WTGs, WTG fixed foundations (and associated scour protection), OSP(s), OSP fixed foundations (and associated scour protection), IACs, OSP link and offshore export cable(s) and their associated external cable protection (insofar as these are located within the WDA) and fibre optic cables.
Well mixed	The state of the water column structure when layers of water with unique physical and chemical characteristics have fully broken down. The opposite of a stratified water column.
Wind Turbine	Power generating device that converts kinetic energy from wind into electricity.
Wind Turbine Generator (WTG)	A wind turbine generator which converts wind energy into electrical energy. Each wind turbine generator is a complex system composed of a high number of components. Typically, the main components include the rotor assembly (composed of three blades and a hub); the nacelle (containing a generator, shaft and gearbox, power electronic converter and transformer); and the tower (containing lifting equipment and the switchgear).
Windfarm Development Area (WDA)	The application boundary within the OAA where consent will be sought for the proposed WDA infrastructure. The WDA infrastructure is subject to Section 36 consent and marine licence applications (generation and transmission) which are being applied for separately from the Offshore ECC infrastructure and OnTDA infrastructure.

7 MARINE PHYSICAL ENVIRONMENT

7.1 INTRODUCTION

1. This chapter presents an assessment of potential impacts and likely significant effects (LSE) on the Marine Physical Environment that may arise from the construction, operation and maintenance (O&M), and decommissioning of the MachairWind Offshore Windfarm Development Area (WDA) infrastructure.

2. The grid connection location for the Project was confirmed in August 2025 following lengthy delays stemming from the National Electricity System Operator's 2022 Holistic Network Design (HND) process (see **Chapter 1 Introduction** for further information). Consequently, this topic chapter considers the WDA Study Area and existing environment only. Separate consent and marine licence applications will be sought for the Offshore Export Cable Corridor (ECC) and Onshore Transmission Development Area (OnTDA). A combined assessment of the construction, O&M and decommissioning of the WDA activities, Offshore Export Cable Corridor (ECC) and Onshore Transmission Development Area (OnTDA) activities (commensurate with the level of detail that is available at the time of carrying out that appraisal) is also provided. This approach will ensure a holistic view is undertaken of the entire Project. As noted in **Chapter 1 Introduction**, the assessment of potential effects on all receptors associated with the Offshore ECC and OnTDA will be presented in individual Environmental Impact Assessment (EIA) Reports (EIARs) / Environmental Reports, which will be submitted separately in accordance with the relevant EIA Regulations.

3. This chapter considers the following WDA infrastructure: wind turbine generators (WTGs), Offshore Substation Platforms (OSP) and associated fixed foundations and scour protection, inter-array cables (IACs), OSP link cables, the portion of the offshore export cable located within the WDA and associated cable protection.

4. This chapter has been prepared to provide Marine Directorate - Licensing and Operations Team (MD-LOT) (on behalf of the Scottish Ministers) and stakeholders with sufficient information to determine the likely significant effect(s) of the Project on the receiving environment.

5. This chapter should be read in conjunction with the following related EIAR chapters:

   - **Chapter 8 Benthic Ecology** – provides a detailed account of benthic habitats present. The Marine Physical Environment chapter describes the shallow geology and bedload sediment transport surrounding these habitats;
   - **Chapter 9 Fish (including Basking Shark) and Shellfish** – provides a detailed account of biological conditions and organisms present. The Marine Physical Environment chapter describes the physical processes and environment surrounding these organisms;
   - **Chapter 10 Marine Mammals and Leatherback Turtle –** provides a detailed account of marine mammals present. The Marine Physical Environment chapter describes the Water Column Structure and sediment transport processes in the environment surrounding these organisms;
   - **Chapter 12 Commercial Fisheries –** provides detailed consideration of commercial impacts associated with active fishing. The Marine Physical Environment chapter describes the physical processes and environment surrounding fishing activity; and
   - **Chapter 14 Offshore Archaeology and Cultural Heritage** – provides detailed consideration of archaeological and cultural heritage assets present. The Marine Physical Environment chapter describes the physical processes and environment surrounding heritage assets.

6. Key inter-relationships between this chapter and those listed above will be considered where relevant and presented in this chapter.

7. Additional information to support the Marine Physical Environment assessment includes:

- **Appendix 7.1 Marine Physical Environment Numerical Modelling;**
- **Appendix 7.2 Marine Physical Environment Stratification Analysis; and**
- **Appendix 7.3 Phase 1 Geophysical and Habitat Interpretative Report.**

8. This chapter was prepared by Haskoning.

7.2 LEGISLATION, POLICY AND GUIDANCE

9. The overarching policy and legislation relevant to the EIA is described in **Chapter 2 Policy and Legislative Context**. **Table 7.1** sets out the relevant legislation, policy and guidance that informs the assessment for the Marine Physical Environment.

Table 7.1 Summary of relevant legislation, policy and guidance for the Marine Physical Environment

Relevant Policy or Guidance	Relevance to the Assessment
Legislation	
The Marine Environment (Amendment) (European Union Exit) Regulations 2018	These regulations address failures of retained EU law to operate effectively and other deficiencies arising from the withdrawal of the UK from the EU. The Regulations amend primary and subordinate domestic legislation (Marine and Coastal Access Act 2010, The Marine Strategy Regulations 2010) and directly applicable EU legislation (Commission Decision (EU) 2017/848) that form part of domestic law after the UK's exit from the EU.
Policy	
The Marine Policy Statement, UK Government, 2020	**The key references are:** **Section 2.6.8.6:** *"Marine plan authorities should not consider development which may affect areas at high risk and probability of coastal change unless the impacts upon it can be managed. Marine plan authorities should seek to minimise and mitigate any geomorphological changes that an activity or development will have on coastal processes, including sediment movement."*
Scotland's National Marine Plan (Scottish Government, 2015) (reviewed in 2024)	**The key references are:** **Policy GEN 8 Coastal process and flooding:** *"Developments and activities in the marine environment should be resilient to coastal change and flooding and not have unacceptable adverse impact on coastal processes or contribute to coastal flooding."* **Paragraph 4.36:** *"Marine planners and decision makers should also be satisfied that activities and developments will be resilient to risks from coastal change and flooding over their lifetime and will not have an unacceptable impact on coastal change. They should seek to ensure that any geomorphological changes that an activity or development bring about in coastal processes, including sediment movement and wave patterns, are minimised, and mitigated, bearing in mind the potential impact on commercial interests such as fisheries and conservation of the natural environment and key coastal heritage sites. Developments which may affect areas at high risk and increase the probability of coastal change should not be permitted unless the impacts upon the area can be managed effectively."*

Relevant Policy or Guidance	Relevance to the Assessment
	When published, Scotland's National Marine Plan (NMP)2 will also be considered and is assumed to supersede the existing NMP.
Argyll and Bute Local Development Plan 2 (2024)	**The relevant policies are:** **Policy 4**: **Sustainable Development** – *"In preparing new development proposals, developers should seek to demonstrate the following sustainable development principles, which the planning authority will also use in deciding whether or not to grant planning permission…"* **Policy 28: Supporting Sustainable Aquatic and Coastal Development** – *"Proposals for marine and freshwater aquaculture, marine and coastal developments will be supported where it can be demonstrated that there will be no significant adverse effects, directly, indirectly or cumulatively on: The landscape/coastal character, seascape or visual amenity (including Isolated Coast, Wild Land and National Scenic Areas) …"*
Sectoral Marine Plan for Offshore Wind Energy (Scottish Government, 2020a) and Scottish Government (2025) Draft updated Sectoral Marine Plan for Offshore Wind Energy, Option Area W1 – May 2025	The Sectoral Marine Plan for Offshore Wind Energy (SMP-OWE) identifies sustainable areas for the future development of commercial scale offshore wind energy in Scotland, including a spatial strategy to inform the seabed leasing process for the purposes of offshore wind energy (Scottish Government, 2020b). The WDA is located in Plan Option Area (POA) W1. The SMP-OWE and associated impact assessment identified relevant characteristics of POA W1 and key risks to be addressed in project level assessments and associated consenting applications. Notably the SMP-OWE reports only Option Area N4 as being expected to have potentially significant environmental effects relevant to the Marine Physical Environment. This being effects on soil and water quality receptors as a result of changes in the hydrodynamic and sediment regime. The SMP-OWE, should guide licensing and consenting decision-making and support projects to further progress through the leasing process, in accordance with the objectives and marine planning polices set out in the adopted NMP.
Guidance	
Centre for Environment Fisheries and Aquaculture Science (Cefas) (2004)	Offshore Wind Farms: Guidance Note for Environmental Impact Assessment (EIA) in respect of Food and Environmental Protection Act and Coast Protection Act requirements: Version 2.
Department for Business, Enterprise and Regulatory Reform (BERR) (2008)	Review of Cabling Techniques and Environmental Effects applicable to the Offshore Windfarm Industry.
Lambkin et al. (2009)	Coastal Process Modelling for Offshore Windfarm (OWF) EIA.
Centre for Environment Fisheries and Aquaculture Science (Cefas) (2011)	Guidelines for Data Acquisition to Support Marine Environmental Assessments of Offshore Renewable Energy Projects.
Institute of Marine Engineering, Science and Technology (2024)	Metocean Procedures Guide for Offshore Renewables.
Natural Resources Wales (NRW) (2025) Marine Physical Processes Guidance to inform Environmental Impact Assessment (EIA)	Guidance on Best Practice for Marine and Coastal Physical Processes Baseline Survey and Monitoring Requirements to inform EIA of Major Development Projects, published by NRW. This

Relevant Policy or Guidance	Relevance to the Assessment
	guidance is applicable to inform EIAs UK wide, due to the generalised nature of the concepts described within the guidance.
Pye et al. (2017)	Advice to Inform Development of Guidance on Marine, Coastal and Estuarine Physical Processes Numerical Modelling Assessment, published for NRW.
Marine Scotland (2017) Pre-disposal Sampling Guidance Version 2 – November 2017	Sampling and analysis relating to sea disposal of dredged material – the guidance includes Action Levels for contaminants to assist in assessing risk to the water environment
MD-SEDD (2025) Standing advice on potential impact on shelf sea stratification – May 2025	Advice to inform on the most recent best practice methodology for describing baseline and potential future changes to Water Column Structure.

7.3 CONSULTATION

10. This Marine Physical Environment chapter has been informed by engagement with stakeholders, including those listed below:

- Argyll and Bute Council;
- MD-LOT;
- Marine Directorate Science Evidence, Data and Digital (MD-SEDD); and
- NatureScot.

11. As part of the consultation process, the Applicant presented the approach to assessment to stakeholders to offer transparency around the assessment methodology and rationale, capture stakeholder advice and guidance, and incorporate stakeholder feedback, where appropriate. A summary of the approach to stakeholder communication and consultation is outlined in **Chapter 6 Consultation and Stakeholder Engagement**.

12. The consultation outcomes in relation to the Marine Physical Environment chapter are outlined in **Table 7.2**, which summarises stakeholder feedback, outlines how the Applicant has responded to the feedback received, and details how it has been considered within this chapter.

13. In addition to the engagement outlined in **Table 7.2**, the points of agreement between the Applicant and NatureScot are listed below:

- Agreement on the baseline data sources identified;
- Agreement on the potential impacts proposed to be scoped in;
- Agreement on the proposed assessment approach (Source-Pathway-Receptor);
- Agreement on the proposed receptors;
- Agreement on the approach to wave, hydrodynamic and plume dispersion modelling; and
- Agreement on the approach to assessment for water column stratification.

Table 7.2 Summary of consultation relevant to the Marine Physical Environment chapter

I.D.	Consultee	Date/Engagement Activity	Stakeholder Comment	Applicant Response
Pre-Scoping Opinion (including Scoping Workshop and Expert Topic Groups)				
1.	NatureScot	03 June 2024: Marine Physical Environment Scoping Workshop - Written Feedback	NatureScot noted that in addition to Annex 1 Reef, additional Marine Physical Environment receptors should be included, namely: Coastal Geomorphology feature (saltmarsh) of Gruinart Flats Site of Special Scientific Interest (SSSI); and Dalradian feature (bedrock cliffs) of Glac na Criche SSSI and Gruinart Flats SSSI.	The Applicant has scoped in these receptors which are assessed in **Section 7.11.3**. Annex 1 Reef is assessed in **Chapter 8 Benthic Ecology**
2.			For assessments of changes to tidal currents, waves, and sediment transport, NatureScot agree that numerical modelling may be ‘disproportionate to the potential effect’, however consider that the proposed ‘Source-Pathway-Receptor Conceptual Model approach’ is not an assessment method. Instead, the assessment would need to use specific reference to relevant assessments of other similar offshore windfarm proposals that have used numerical modelling and / or use spreadsheet-based / standard equation calculations.	The Applicant has undertaken numerical modelling including hydrodynamic, wave and sediment dispersion modelling. As advised by NatureScot, other offshore windfarm projects’ numerical modelling may also be referred to, where appropriate. The assessment methodology will be based on the industry standard Source-Pathway-Receptor approach. However, to quantify changes to the marine physical environment as a pathway to impact, the outputs of the Project-specific numerical modelling will be used where possible (**Appendix 7.1 Marine Physical Environment Numerical Modelling Technical Report**). A semi-quantitative (conceptual) assessment will be applied building on the numerical modelling for impacts that cannot be assessed using model outputs alone.
3.	MD-SEDD	14 May 2024: Marine Physical Environment Scoping Meeting	MD-SEDD advised quantitative analysis of sediment plumes and 3D model outputs be used to inform the baseline data and advised using hydrodynamic models (such as Scottish Shelf Model).	The Applicant has undertaken sediment dispersion modelling to quantify changes to the marine physical environment which underpins the assessment (**Appendix 7.1 Marine Physical**

I.D.	Consultee	Date/Engagement Activity	Stakeholder Comment	Applicant Response
				Environment Numerical Modelling). The Scottish Shelf Model will also be used to characterise Water Column Structure.
4.			MD-SEDD confirmed they were in agreement with the scoped in and out impacts with the exception of mixing and stratification.	Changes to Water Column Structure have been scoped into the EIA and are assessed in **Section 7.11.2.7** and **7.12.1.3**.
5.		17 June 2024: Marine Physical Environment - Written Feedback	In relation to the summary of key datasets and information sources, MD-SEDD advised that the Scottish Shelf Waters Reanalysis Service be used (1993-2019).	The Applicant has added the Scottish Shelf Waters Reanalysis Service (1993-2019) to the list of key datasets and information (**Table 7.3**).
Scoping Opinion				
6.	Argyll and Bute Council	09 January 2025: Scoping Opinion	Do you agree with the receptors outlined? Yes, all marine physical environmental receptors appear to have been discussed.	Noted.
7.	Argyll and Bute Council	09 January 2025: Scoping Opinion	Have all the relevant data sources been identified in this Scoping Report? Yes, all relevant data sources appear to have been identified within the Scoping Report.	Noted.
8.	Argyll and Bute Council	09 January 2025: Scoping Opinion	Do you agree that the embedded mitigation measures described provide a suitable means for managing and mitigating the potential effects of the WDA on marine physical environment receptors? Yes. With reference to M-8 Cable Plan, I would advise that where environmental conditions allow cable burial should be at a minimum depth of 1.5 m below the seabed. This would avoid significant effects on benthic receptors, as per discussed in Table 8.8 Potential impacts scoped in or scoped out for benthic ecology.	Noted A detailed response to this comment is provided in **Chapter 8 Benthic Ecology**, Consultation ID 6.
9.	Argyll and Bute Council	09 January 2025: Scoping Opinion	Do you agree with the marine physical environment impacts that have been scoped in and out from further consideration within the EIA? Yes, in agreement with the scoping in and out of the EIA.	Noted.

I.D.	Consultee	Date/Engagement Activity	Stakeholder Comment	Applicant Response
10.	Argyll and Bute Council	09 January 2025: Scoping Opinion	Do you agree that water quality impacts can be scoped out of the assessment due to the negligible concentrations of contaminants present in the WDA and the use of industry-practice mitigation measures in the embedded mitigation? Yes	Noted.
11.	Argyll and Bute Council	09 January 2025: Scoping Opinion	Do you agree with the proposed approach to assessment with specific reference to numerical modelling? Yes, but this is more of a question for NatureScot to consider.	Noted.
12.	Argyll and Bute Council	09 January 2025: Scoping Opinion	Do you have any other matters or information sources that you wish to be presented in the EIAR? No	Noted.
13.	MD-SEDD)	09 January 2025: Scoping Opinion	Do you agree with the receptors outlined? Yes, the relevant receptors have been identified.	Noted.
14.	MD-SEDD	09 January 2025: Scoping Opinion	Have all the relevant data sources been identified in this Scoping Report? Yes	Noted.
15.	MD-SEDD	09 January 2025: Scoping Opinion	Do you agree that the embedded mitigation measures described provide a suitable means for managing and mitigating the potential effects of the WDA on marine physical environment receptors? Yes, the measures outlined in Table 6.6 are appropriate and pragmatic.	Noted.
16.	MD-SEDD	09 January 2025: Scoping Opinion	Do you agree with the marine physical environment impacts that have been scoped in and out from further consideration within the EIA? MD-SEDD advise that a qualitative assessment of the potential impacts on mixing and stratification is scoped into the EIA. MD-SEDD advise that within the Scoping Report, not enough evidence has been provided to justify this potential impact being scoped out of the EIA. The Scoping Report presents outputs from an analysis of whether the WDA waters are stratified or well mixed, and concludes that “the WDA is situated within regions of intermittently stratified and permanently mixed marine environments (Figure 6.6). On average, the WDA is stratified between 20 and 40 days per year and mixed between 250 to 345 days each year”. It is not clear from the	The Applicant has analysed the Scottish Shelf Waters Reanalysis Service (1993-2019) to characterise the baseline Water Column Structure (**Appendix 7.2 Marine Physical Environment Stratification**). The Applicant has also undertaken a semi-quantitative assessment of changes to Water Column Structure and oceanographic fronts within **Section 7.11.2.7**.

I.D.	Consultee	Date/Engagement Activity	Stakeholder Comment	Applicant Response
			Scoping Report whether this intermediate stratification occurs for a short period of time every spring neap tidal cycle, or whether this only occurs during the summer months. MD-SEDD advise that evidence be supplied showing the typical time of onset and decay of stratification, e.g. from a 3D hydrodynamic model such as Scottish Shelf Waters Reanalysis Service (SSW-RS) or data available from the Copernicus Marine Service, and a qualitative assessment of the potential impact of the OWF be conducted using best available evidence (e.g. https://doi.org/10.3389/fmars.2022.830927, https://doi.org/10.3389/fmars.2023.1178330). MD-SEDD advise the baseline description should include a description of prevailing baseline water column conditions, including the timing of stratification and frontal positions. This should include the evolution of Water Column Structure through the year (e.g. weekly to monthly temperature, salinity, density profiles) and when typically the region stratifies, and how key parameters change through the year (e.g. surface mixed layer depth and potential energy anomaly). MD-SEDD agree with the other potential impacts scoped in/out of the EIA.	
17.	MD-SEDD	09 January 2025: Scoping Opinion	Do you agree that water quality impacts can be scoped out of the assessment due to the negligible concentrations of contaminants present in the WDA and the use of industry-practice mitigation measures in the embedded mitigation? MD-SEDD lack the adequate expertise to advise on this aspect of the Scoping Report.	Noted.
18.	MD-SEDD	09 January 2025: Scoping Opinion	Do you agree with the proposed approach to assessment with specific reference to numerical modelling? There were little details provided on the assessment approach utilising numerical models, other than to say that appropriate models will be used. MD-SEDD advise that the following approach be adopted. A 2D hydrodynamic (tidal) model coupled to a spectral wave model be developed for the wider area. This model should be coupled in some form to bedload and suspended sediment transport models used for the assessment of the potential impacts outlined in Table 6.7. The spatial domain of the models should be sufficiently large to allow for	The Applicant has undertaken hydrodynamic, wave and sediment dispersion modelling. Full details of model set up, validation, calibration and results are provided in **Appendix 7.1 Marine Physical Environment Numerical Modelling**. The numerical modelling has been used to inform the assessment of impacts in **Section 7.11.2.7** and **7.12.1.3**.

I.D.	Consultee	Date/Engagement Activity	Stakeholder Comment	Applicant Response
			assessment of impact on the WDA and relevant receptors identified as being potentially impacted by changes to modelled parameters (waves, currents, bedload and suspended sediment transport). This should include the physical receptors listed in Table 6.7 but also the relevant biological receptors identified in other chapters, such as benthic habitat. The windfarm structures will have to be appropriately parameterised within the models.	Numerical modelling of bedload sediment transport was not undertaken. Instead, the Applicant has adopted a semi-quantitative approach, which consists of deriving the combined wave and tidal bed shear stress values (baseline and due to the Project) from the hydrodynamic model to determine the total bed shear stress exerted on the seabed. They have then used the Shields parameter (baseline and influence of the Project) to link the total bed shear stress to sediment mobility to assess any changes to these processes due to the Project (see **Section 7.11.2.6**).
19.	MD-SEDD	09 January 2025: Scoping Opinion	Do you have any other matters or information sources that you wish to be presented in the EIAR? No	Noted.
20.	MD-LOT	09 January 2025: Scoping Opinion	The Scottish Ministers are broadly content with the proposed study area described in Section 6.6, however, highlight the NatureScot representation regarding the definition of 'short distance' and request that this must be fully addressed and implemented in the EIA Report.	Noted.
21.	MD-LOT	09 January 2025: Scoping Opinion	The Scottish Ministers are content with the proposed data sources used to characterise the baseline in Section 6.4.	Noted.
22.	MD-LOT	09 January 2025: Scoping Opinion	Table 6.7 of the Scoping Report summarises the impacts to be scoped in and out of the assessment. The Scottish Ministers broadly agree with the impacts proposed to be scoped in. However, in line with advice from MD-SEDD and representation from NatureScot, advise that impacts on mixing and stratification is also scoped in due to consistent seasonal stratification. The Scottish Ministers highlight the advice provided by MD-SEDD on this topic and advise that this should be fully addressed and implemented in the EIA Report. In addition, the Scottish Ministers note the representation from NatureScot which states that 'seabed morphology and bedload sediment transport' and the potential impact on 'bedload sediment transport' are not	Noted. Impacts on mixing and stratification are now scoped in under Impact 3: Changes to Water Column Structure (**Section 7.12.1.3**). The impacts 'changes to bedload sediment transport' and 'seabed morphology' have been merged and are considered as one (see Impact 2, **Section 7.12.1.2**).

I.D.	Consultee	Date/Engagement Activity	Stakeholder Comment	Applicant Response
			well differentiated within the EIA Report and recommends that these two impacts are merged into one within the EIA Report to provide a more holistic assessment of these impacts. The Scottish Ministers request that this approach is undertaken within the EIA Report in line with these representations.	
23.	MD-LOT	09 January 2025: Scoping Opinion	The Scottish Ministers are broadly content with the approach to the assessment, as set out in Section 6.12 of the Scoping Report, however, highlight the advice from MD-SEDD and representation from NatureScot regarding the use of numerical, and Source-Pathway-Receptor conceptual models and advise that this be fully addressed and implemented in the EIA Report, and further consultation is undertaken with NatureScot regarding the proposed methodology.	Noted. An update in the approach to the assessment for the Marine Physical Environment assessment is outlined in **Section 7.10** outlining the Source-Pathway-Receptor approach to the assessment, as is typical for Marine Physical Environment assessments. The evidence base underpinning the Source-Pathway-Receptor approach is based on a combination of numerical, semi-quantitative and conceptual (qualitative) models. Further consultation with NatureScot outlining the approach and modelling techniques was undertaken through the Seabed Expert Topic Group (ETG) on 13 November 2025.
24.	MD-LOT	09 January 2025: Scoping Opinion	The Scottish Ministers highlight the representation from NatureScot regarding the proposed approach to mitigation and request that this must be fully addressed and implemented in the EIA Report.	Noted. Please see **Section 7.9** which outlines all embedded mitigation measures relevant to the Marine Physical Environment assessment.
25.	MD-LOT	09 January 2025: Scoping Opinion	Potential cumulative effects are summarised in Section 6.10 of the Scoping Report and the Scottish Ministers are content with this approach.	Noted.
26.	MD-LOT	09 January 2025: Scoping Opinion	The Scottish Ministers are in agreement that transboundary impacts can be scoped out of the EIA for marine physical environment receptors, as discussed in Section 6.11 of the Scoping Report.	Noted.

I.D.	Consultee	Date/Engagement Activity	Stakeholder Comment	Applicant Response
27.	NatureScot	09 January 2025: Scoping Opinion	The study area is based on the maximum tidal excursion extent from the WDA, which extends to 23 km in a southerly direction and a 'short distance' in all other directions as per Paragraph 282 and Figure 6.1, however we note that this short distance is not defined. It is stated that the tidal excursion extent has been estimated from publicly available data and encompasses the area for which suspended sediment could be transported following disturbance to the seabed – we are content with the study area proposed, but request that the 'short distance' is identified within the assessment.	The Zone of Influence (ZoI) has been redefined since scoping, following changes to the size of the WDA. The latest ZoI boundary and the details of the ZoI's dimensions have been described in **Section 7.8.1.3** and **Figure 7.1**.
28.	NatureScot	09 January 2025: Scoping Opinion	Existing data sources are provided in Table 6.3 and site-specific survey data in Table 6.4 – it is noted that these will be used to inform the EIA. We are content that the combination of existing data sources and site-specific surveys should provide adequate information to characterise the baseline environment.	Noted.
29.	NatureScot	09 January 2025: Scoping Opinion	The potential impacts proposed to be scoped in and out of the assessment are detailed in Table 6.7. We are generally content with these, subject to our comments below. It is noted in the table that 'Impacts on mixing and stratification' is proposed to be scoped out for all phases. However, in Table 6.2 it states that "Changes to ocean stratification has been scoped into the EIA" following advice from MD-SEDD. We would support this aspect being scoped in. The potential impact on 'seabed morphology and bedload sediment transport' and the potential impact on 'bedload sediment transport' are not well differentiated (Table 6.7). We recommend that these two impacts are merged into one for the EIA to provide a more holistic assessment of these impacts. Furthermore, Seabed Bedforms should be considered as a receptor for this merged impact as changes to them could affect receptors in other EIA chapters.	Noted. Impacts on mixing and stratification are now scoped in under Impact 3: Changes to Water Column Structure (**Section 7.12.1.3**). The impacts 'changes to bedload sediment transport' and 'seabed morphology' have been merged and are considered as one (see Impact 2 **Section 7.12.1.2**). Seabed Bedforms have been included as a receptor (**Section 7.11.3**).
30.	NatureScot	09 January 2025: Scoping Opinion	Some information has been provided on potential receptors in Section 6.12, which we are generally content with. Following the Scoping Workshop, we advised that in addition to Annex 1 reef, the Coastal Geomorphology feature (saltmarsh) of Gruinart Flats Site of Special Scientific Interest (SSSI) and the	Noted. Seabed Bedforms have been included as a receptor (**Section 7.11.3**).

I.D.	Consultee	Date/Engagement Activity	Stakeholder Comment	Applicant Response
			Dalradian feature (bedrock cliffs) of Glac na Criche SSSI and Gruinart Flats SSSI should be included as receptors, which they have, and we welcome. In addition, as advised above, Seabed Bedforms should be considered as a receptor for the potential impact on 'seabed morphology and bedload sediment transport'.	
31.	NatureScot	09 January 2025: Scoping Opinion	It is noted in Section 6.12 that the assessment of effects on marine environment receptors will be based on a combination of numerical models and a Source-Pathway-Receptor conceptual model. We are not yet able to confirm whether this is appropriate as no further detail is provided and therefore strongly recommend further consultation as soon as possible on the modelling methodology.	An update in the approach to the assessment for the Marine Physical Environment is outlined in **Section 7.10** outlining the Source-Pathway-Receptor approach to the assessment, as is typical for Marine Physical Environment assessments. The evidence base underpinning the Source-Pathway-Receptor approach is based on a combination of numerical, semi-quantitative and conceptual (qualitative) models. Further consultation with NatureScot outlining the approach and modelling techniques was undertaken through the Seabed ETG on 13 November 2025.
32.	NatureScot	09 January 2025: Scoping Opinion	Section 6.10 notes that the Cumulative Effects Assessment (CEA) will follow the approach outlined in Chapter 4 (Approach to Scoping and EIA), which appears appropriate. It is also noted that the Applicant will seek agreement with MD-LOT on the list of projects and/or plans to be included in the CEA, which we support.	Noted. **Appendix 5.1 Cumulative Projects Long and Short-List** was shared with MD-LOT in January 2025.
33.	NatureScot	09 January 2025: Scoping Opinion	We welcome the identification of embedded mitigation described in Section 6.8 and summarised in Appendix A (Mitigation Register). However, as noted in the cover letter, much of the embedded mitigation includes adherence to post-consent plans / programmes. Plans do not strictly constitute mitigation as it is the measures contained within the plans / programmes that will mitigate impacts for which no detail has yet been provided. Furthermore, just to note that should significant effects be identified during the EIA, the	Noted. Please see **Section 7.9** for an outline of all embedded mitigation measures relevant to the Marine Physical Environment assessment. No significant residual effects on Marine Physical Environment receptors have been identified.

I.D.	Consultee	Date/Engagement Activity	Stakeholder Comment	Applicant Response
			embedded mitigation measures detailed in Section 6.8 may not be sufficient to mitigate impacts.	Therefore, no additional mitigation is recommended.
34.	NatureScot	09 January 2025: Scoping Opinion	We agree that transboundary impacts on marine physical environment receptors can be scoped out from further consideration.	Noted.
35.	NatureScot	09 January 2025: Scoping Opinion	A nature conservation Marine Protected Area (ncMPA) Screening Report (Appendix H) has been provided alongside the Scoping Report. Having reviewed the information contained within the screening report – we agree that geodiversity features of all the ncMPAs considered can be screened out from further assessment.	Noted. See the **Report to Inform Marine Protected Area Assessment (Application Document 3)**, for the full ncMPA assessment.
Post Scoping Opinion				
36.	MD-SEDD	Seabed ETG on 13 November 2025: 13/11/2025	MD-SEDD recognise there is no pragmatic and proportionate methodology or guidance available on how to assess the impact of windfarm structures on stratification. A pragmatic approach would be to semi-analytically investigate how turbine structures could change Turbulent Kinetic Energy (TKE) and assess the mixing and advective time scales in the region (e.g. Carpenter et al. 2016). The potential impact of these changes in TKE on the timing of stratification should be included, and whether fronts are likely to be affected.	The Applicant has consulted with the MD-LOT appointed oceanographic advisor through the Seabed ETG meeting (13 November 2025) and a follow up meeting (02 December 2025) with the aim of providing a robust assessment that maximises the available research whilst recognising there is limited guidance. The Applicant explored using the method outlined in Carpenter et al. (2016) to define mixing and advective timescales. However, as the Potential Energy Anomaly within the WDA was low, indicating a mixed water body, the method was not applicable as it would calculate the time taken to mix an already mixed water body. Given the baseline water column structure is mixed and that the water column will remain mixed throughout the O&M phase of the Project, there is no change in water column structure due to the Project. However, acknowledging the development of a weak thermocline within the WDA, and the presence of a tidal mixing front along the southern

I.D.	Consultee	Date/Engagement Activity	Stakeholder Comment	Applicant Response
				boundary of the WDA, a qualitative assessment has been undertaken as outlined in **Section 7.12.1.3**.

7.4 EXISTING DATA SOURCES

14. **Table 7.3** sets out the information and data sources that have been used to inform this chapter.

Table 7.3 Summary of key datasets and information sources

Dataset	Description	Citation
Digital Bathymetry	Bathymetry of Europe's sea basins.	European Marine Observation and Data Network (EMODnet), 2022
Seabed Sediments 250k	Seabed sediments of the United Kingdom (UK) Continental Shelf.	British Geological Survey (BGS), 2023a
Offshore Bedrock 250k	Offshore bedrock of the UK Continental Shelf.	BGS, 2023b
Quaternary Deposits Summary Lithologies	Quaternary deposits of the UK Continental Shelf.	BGS, 2023c
Geological Factor Maps, Quaternary Deposits Thickness	Thickness of Quaternary deposits on the UK Continental Shelf.	BGS, 2023d
Atlas of UK Marine Renewable Energy Resources, Spring Peak Flow	Spring peak current flows for the UK Continental Shelf.	ABP Marine Environmental Research (ABPmer), 2008a
Atlas of UK Marine Renewable Energy Resources, Annual Wave Height	Annual average wave heights for the UK Continental Shelf.	ABPmer, 2008b
Shelf-wide Regions of Dominant Stratification and Mixing Regimes	Dominant stratification and mixing regimes for the UK Continental Shelf, from 1996 to 2010.	van Leeuwen et al., 2015
Suspended Sediment Climatologies around the UK	Suspended Sediment Concentrations (SSCs) for the UK Continental Shelf, from 1996 to 2010.	Centre for Environment Fisheries and Aquaculture Science (Cefas), 2016
Scottish Shelf Waters Reanalysis Service	3D model output from a 27 year reanalysis of the Scottish Shelf Model, from 1993 to 2019.	Barton et al., 2022

7.5 SITE-SPECIFIC SURVEY DATA

15. In addition to the existing data sources identified in (**Section 7.4**), the Project has undertaken site-specific surveys to inform the EIA (**Table 7.4**).

Table 7.4 Site-specific survey data

Dataset	Year(s)	Description
Third-party benthic survey	2021	A Benthic survey was undertaken by a third-party which overlaps with the Option Agreement Area (OAA). The benthic survey was undertaken by Briggs Marine and comprised the following: • 60 benthic sediment grab samples for contaminant, faunal, biomass and particle size distribution analysis; and • 20 transects of Drop-Down Video (DDV). This data was acquired by the Applicant to supplement the Project's site investigation survey data which together was used to characterise the Windfarm Development Area (WDA). See **Appendix B Third-Party Benthic Subtidal Survey Interpretative Report** submitted with the MachairWind Scoping Report.[1]
Project's site investigation	2023	A site Investigation survey was undertaken by the Project across the OAA. The following works were undertaken by Fugro: • Geophysical survey; • Side Scan Sonar; • Multibeam Echosounder; • Sub Bottom Profiler; • Magnetometer; • 57 benthic sediment grabs for contaminant, faunal, biomass and particle size distribution analysis; • 59 transects of DDV with seabed photographs; and • 29 water samples for environmental DNA analysis See **Appendix C Contaminants Survey Report**, **Appendix D MachairWind 2023 Benthic Characterisation Report** and **Appendix E Environmental DNA Survey Interpretative Report** submitted with the MachairWind Scoping Report.[2]
Project's Metocean Survey	2023 / 2025	A metocean survey was undertaken by the Project. Two surface buoys (SWM and SWLB) and one seabed mounted frame (SIG) were deployed for two years from 2023 to 2025 within the WDA to measure: • Wind profile up to 300 m (speed and direction); • Wind data at 4 m (speed and direction); • Meteorological parameters at 4 m (air temperature, pressure, density); • Wave parameters (height, period, direction); • Current profile (speed and direction); • Sea surface temperature and salinity; • Near bed current (speed and direction); • Seabed temperature and salinity; • Seabed turbidity; and • Water level. Outside of the WDA a surface buoy and seabed lander were deployed off the coast of Islay. The 2023/2024 metocean data has been incorporated into the baseline.

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[1] https://marine.gov.scot/?q=node/25686

[2] https://marine.gov.scot/?q=node/25686

Dataset	Year(s)	Description
Project's geophysical survey	2025	A geophysical survey covering a portion of the WDA was undertaken in 2025 and included: • Side Scan Sonar; • Multibeam Echosounder; • Sub Bottom Profiler; and • Magnetometer.

7.6 MARINE PHYSICAL ENVIRONMENT STUDY AREA

16. The Zone of Influence (ZoI) is the spatial extent of a change that may arise due to the Project. The ZoI varies depending on activity/infrastructure type and the changes introduced. It is determined from all available data and information (**Section 7.8** and **Section 7.11.2**), including numerical modelling outputs, where appropriate. The Marine Physical Environment ZoI for different pathways are defined in **Table 7.5**. The total ZoI is the sum of the spatial extent of the WDA and the maximum ZoI for all impacts, moderated by the direction and length of the tidal ellipse excursions across the site (**Figure 7.1**) and is used to define the Marine Physical Environment Study Area.

Table 7.5 Definition of Zones of Influence (ZoI) for different Marine Physical Environment effects

Pathway	Maximum Zone of Influence (ZoI)	Source
Changes to wave regime	Length: up to 12 km within and at the southern boundary of the WDA. Direction: northwest to southeast	Spectral wave numerical modelling (see **Appendix 7.1 Marine Physical Environment Numerical Modelling Technical Report**)
Changes to tidal regime	Length: up to 7 km from the northeast boundary of the WDA Direction: south (southwest) to north (northeast)	Hydrodynamic numerical modelling (see **Appendix 7.1 Marine Physical Environment Numerical Modelling Technical Report**)
Changes to water column structure	The maximum ZoI for changes to water circulation is expected to be comparable to the ZoI for wave and tidal regime (above).	Spectral wave and hydrodynamic numerical modelling (see **Appendix 7.1 Marine Physical Environment Numerical Modelling Technical Report**)
Change to suspended sediment concentration	Up to 3 km north of the northern boundary of the WDA, up to 8 km south of the southern boundary of the WDA.	Plume dispersion numerical modelling (see **Appendix 7.1 Marine Physical Environment Numerical Modelling Technical Report**)
Changes to bedload sediment transport	Change in Shield's parameter not high enough to induce change in sediment regime.	Sheild's parameter (see **Section 7.11.2.6**)
Tidal excursion ellipse	Length: Between 4 to 7 km within and at the northern boundary of the WDA. Between 7 and 11 km at the southern boundary of the WDA. Direction: Ellipses are oriented north (northeast) to south (southwest).	**Figure 7.1**, ABPmer, 2008[3]

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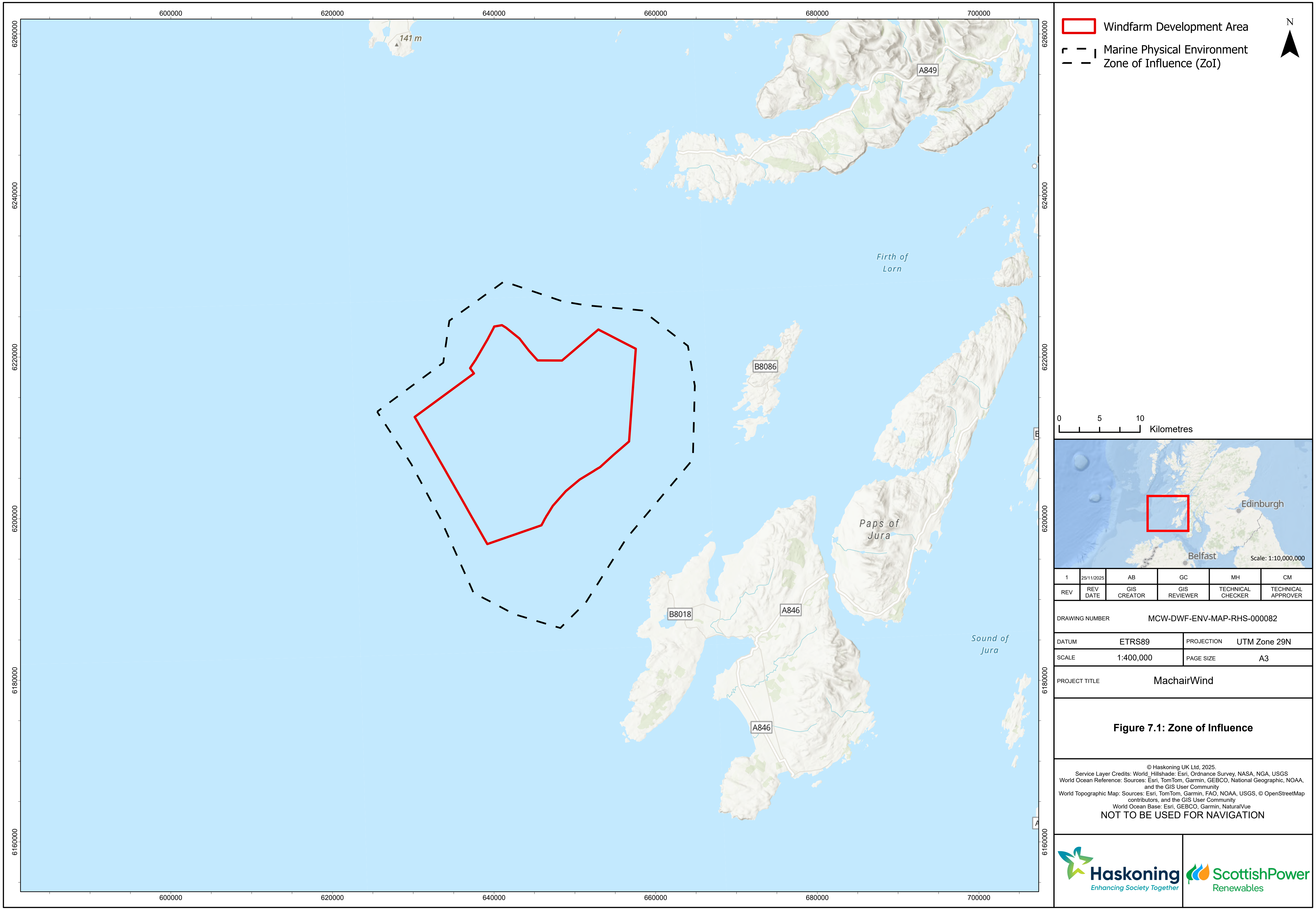
[3] Explore the ABPmer UK Renewables Atlas



1	25/11/2025	AB	GC	MH	CM
REV	REV DATE	GIS CREATOR	GIS REVIEWER	TECHNICAL CHECKER	TECHNICAL APPROVER

DRAWING NUMBER	MCW-DWF-ENV-MAP-RHS-000082		
DATUM	ETRS89	PROJECTION	UTM Zone 29N
SCALE	1:400,000	PAGE SIZE	A3
PROJECT TITLE	MachairWind		

Figure 7.1: Zone of Influence

Service Layer Credits: World_Hillshade: Esri, Ordnance Survey, NASA, NGA, USGS
World Ocean Reference: Sources: Esri, TomTom, Garmin, GEBCO, National Geographic, NOAA, and the GIS User Community
World Topographic Map: Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community
World Ocean Base: Esri, GEBCO, Garmin, NaturalVue

NOT TO BE USED FOR NAVIGATION

Haskoning
Enhancing Society Together

ScottishPower
Renewables

Project: C:\Users\304634\OneDrive - Royal HaskoningDHV\WIP\03 GIS\A02_Figures\03_EIA\01_WDA\Chap_07_MPE\MCW_EIA_WDA_MPE.aprx
Name: Fig_7-1_MCW-DWF-ENV-MAP-RHS-000082_ZOI

7.7 REALISTIC WORST-CASE SCENARIOS

17. The final design of the WDA will be confirmed by detailed engineering studies post-consent. To undertake a robust and precautionary impact assessment, the realistic worst-case design scenarios (i.e., those that would cause the greatest impact) are defined from the Project Design Envelope (PDE); ensuring that all other design scenarios would have equal or less impact. Please see **Chapter 5 EIA Methodology** for further details on the design envelope approach.

18. The realistic worst-case scenarios for the Marine Physical Environment assessment are summarised in **Table 7.6** below. These are based on the Project design as described in **Chapter 3 Project Description**.

Table 7.6 Realistic worst-case scenarios for impacts on the Marine Physical Environment

Impact	Realistic Worst-Case Scenario	Rationale
Impact 1: Changes in suspended sediment concentrations (SSCs) and seabed levels		
Construction	**Seabed preparation disturbance volume prior to foundation and scour protection installation (WTGs and OSPs) = 5,961,073.28 m^3** - Worst-case WTG foundation type = suction bucket jacket; - Worst-case OSP foundation type = gravity base structure (GBS); - Maximum number of WTGs = 144; - Maximum number of OSPs = 2; - Maximum WTG suction bucket foundation diameter = 15 m; - Maximum OSP GBS foundation dimensions = 125 m x 120 m (length and width respectively); - Maximum proportion of foundations with scour protection = 100%; - Maximum volume of dredging per WTG foundation = 39,870.37 m^3; - Maximum volume of dredging per OSP foundation = 109,870 m^3; - Maximum volume of dredging for all WTGs = 5,741,333.28 m^3; and - Maximum volume of dredging for all OSPs = 219,740 m^3. **WTG foundation installation (with drilling) total volume of disturbance = 501,728.16 m^3** - Worst-case foundation type with drilling for total volume = monopile; - Worst-case drilling volumes are associated with the larger number of smaller WTGs; - Maximum number of foundations = 144; - Maximum foundation diameter associated with the smallest WTG = 13 m; - Maximum drill penetration depth: 45 m; - Maximum volume of drill arisings per WTG (for the smallest WTG) = 10,452.67 m^3; and - Total volume of sediment disturbed due to foundation arisings assuming up to a third of foundation locations require drilling (48 of 144) = 501,728.16 m^3. **OSP foundation installation (with drilling) total volume of disturbance = 49,480 m^3** - Worst-case foundation type with drilling for total volume = pin-pile; - Maximum number of piles per OSP = 16 (2 OSPs = 32 legs total;)	Disturbance of seabed sediment resulting in changes to SSCs in the water column could occur due to the following construction activities: **Seabed preparation prior to foundation and scour protection installation** Seabed preparation works, including sandwave clearance/levelling, could be required prior to installation of foundations and associated scour protection. The realistic worst-case scenario is the foundations that have the greatest seabed footprint which are suction bucket foundations for WTGs and gravity-base structure foundations for OSPs. **Foundation installation** The installation of foundations will likely result in the release of disturbed sediments. The greatest sediment release is anticipated to be from the installation of monopile foundations for WTGs and pin-pile foundations for OSPs, if drilling is required. Drilling would result in the release of seabed and subseabed sediments, which will be deposited adjacent to each drilled foundation location. **Seabed preparation prior to cable installation** Seabed preparation works, including sandwave clearance/levelling, could be required prior to installation of IACs. Based on preliminary layouts of OSPs (see **Appendix 7.1 Marine Physical Environment Numerical Modelling**), seabed preparation for export cable and OSP link cables is not anticipated.

Impact	Realistic Worst-Case Scenario	Rationale
	- Maximum pin-pile diameter = 4.5 m; - Maximum volume of drill arisings per pile = 1,546.25 m^3; and - Total volume of sediment disturbed due to foundation arisings assuming all foundation locations require drilling = 49,480 m^3. **Sandwave levelling / dredging disturbance volume prior to IAC installation = 4,011,700 m^3**. **IAC installation total volume of displaced sediment = 6,694,850 m^3** - Worst-case length of IACs is associated with a scenario where only 1 OSP is required; - Worst-case IAC sediment displacement volume calculated assuming a cable plough creating a 'v'-shaped trench; - Maximum length of IACs = 572,000 m; - Maximum seabed route length of IACs = 521,000 m - Maximum disturbance width = 20 m; - Maximum disturbance depth = 3 m; - Volume of sediment displaced per metre of cable instillation = 12.85 m^3; and - Total volume of sediment disturbed due to IAC installation = 6,694,850 m^3. **OSP link cable installation total volume of displaced sediment = 1,747,600 m^3** - Worst-case OSP link cable sediment displacement volume calculated assuming a cable plough creating a 'v'-shaped trench; - Maximum length of OSP link trenches = 136,000 m; - Maximum disturbance width = 20 m; - Maximum disturbance depth = 3 m; - Volume of sediment displaced per metre of cable instillation = 12.85 m^3; and - Total volume of sediment disturbed due to OSP link cable installation = 1,747,600 m^3. **Offshore export cable (within the WDA) installation total volume of disturbance = 1,285,000 m^3**	**Cable installation** Offshore cable sediment displacement volume has been calculated assuming a cable plough creating a 'v'-shaped trench at 35 degree stability however cable installation may require a combination of jetting and or ploughing installation techniques. Maximum seabed route length of IACs does not account for additional IAC length for assumed length between seabed and WTGs / OSPs however this additional length would not manifest an increase in sediment arisings. **Alignment of figures with Appendix 7.1 Marine Physical Environment Numerical Modelling** Note some inconsistencies between the volume calculations presented here and in the above appendix may occur however these are due either to rounding or the requirement for indicative cable routes to feed into the numerical modelling. Rounding would not have a material effect on the results of the modelling and the parameters which have fed into the model are considered to be conservative.

Impact	Realistic Worst-Case Scenario	Rationale
	- Worst-case offshore export cable sediment displacement volume calculated assuming a cable plough creating a 'v'-shaped trench; - Maximum length of offshore export cable trench within the WDA = 100,000 m; - Maximum disturbance width = 20 m; - Maximum disturbance depth = 3 m; - Volume of sediment displaced per metre of cable instillation = 12.85 m^3; and - Total volume of sediment disturbed due to offshore export cable (within the WDA) installation = 1,285,000 m^3. **Worst-case scenario for total temporary increases in SSCs = <u>20,251,431.44 m^3</u>**	
Operation and Maintenance	**Cable repair and reburial total volume of sediment disturbed per year = 63,600 m^3** - **IAC repair / replacement:** Assuming 10 repair / replacement events over the project lifetime with 10,000 m of cable replaced per event = total IAC repair / replacement footprint of 500,000 m^2 - **OSP Link Cables repair / replacement:** Assuming 4 repair / replacement events over the project lifetime with 1,000 m of cable replaced per event = total OSP Link Cables repair / replacement footprint of 20,000 m^2 - **Offshore export cables (within the WDA) repair / replacement:** Assuming 2 repair / replacement events over the project lifetime with up to 2,000 m of cable replaced per event = total offshore export cables (within the WDA) repair / replacement footprint of 20,000 m^2 - **IAC reburial:** Assuming 28,600 m of cable reburied over the project lifetime = total IAC reburial footprint of 143,000 m^2 - **OSP link cables reburial:** Assuming 6,800 m of cable trench reburied over the project lifetime = total OSP link cables reburial footprint of 34,000 m^2 - **Offshore export cables (within the WDA) reburial:** Assuming 5,000 m of cable trench reburied over the project lifetime = total offshore export cables (within the WDA) reburial footprint of 25,000 m^2 - Maximum disturbance depth of cable repair and reburial = 3 m (assumed to be the equal to maximum cable burial depth) - Area of sediment disturbed due to all cable repair or replacement events = 540,000 m^2 - Area of sediment disturbed due to all cable remedial reburial events = 202,000 m^2 - Total area of sediment disturbed due to cable repair and reburial during operational life of 35 years = 742,000 m^2 - Total volume of sediment disturbed due to cable repair and reburial during operational life of 35 years = 2,226,000 m^3 (742,000 m^2 x 3 m)	Disturbance of seabed sediment resulting in changes to SSCs in the water column could occur due to the following O&M activities: **Cable repair and reburial** Temporary increases in SSCs would result from cable repair, replacement and reburial activities. The total disturbance footprint and volume over the 35-year operational period is based on yearly averages and thus assumes, for example, that there may be no cable repair in one year and then longer lengths of cable repair/replacement and/or reburial in other years. The worst-case assumes a maximum 5 m jetting disturbance width and 3 m disturbance depth for all repair or replacement and reburial events, and a maximum 5% of the length of each cable could require reburial over the Project's operational life. Further detail on maximum temporary O&M footprints in the WDA are provided in Table 1.5 of **Chapter 3 Project Description**.

Impact	Realistic Worst-Case Scenario	Rationale
	- Total volume of sediment disturbed per year due to cable repair / replacement and reburial = 63,600 m^3 (2,226,000 m^3 / 35 years)	
Decommissioning	**The worst-case scenarios for decommissioning would be similar to those defined in the construction phase.**	The impacts of decommissioning are primarily linked to the removal of infrastructure from the seabed. These activities may cause temporary disturbance to the seabed changing SSCs and seabed levels. However, it is anticipated that the overall environmental impacts associated with decommissioning will be equal to, or potentially less than, those experienced during the construction phase.
Impact 2: Changes to sediment transport regime and seabed morphology		
Construction	**See Construction Impact 1 for worst-case related to seabed preparation.**	Changes to sediment transport regime and seabed morphology may occur during construction due to the following activities: **Seabed preparation for foundation and cable installation.** Seabed preparation will directly alter the morphology and potentially the sediment composition of the seabed, for example due to sandwave clearance.
Operation and Maintenance	**Presence of WTG foundations in the water column** - Worst-case foundation design for blockage effects = monopile; - Maximum number of foundations = 144; - Maximum diameter of foundations = 13 m; and - Minimum WTG foundation separation distance = approximately 944 m. **Presence of OSP foundations in the water column** - Worst-case foundation design for blockage effects = GBS; - Maximum number of foundations = 2; - Maximum dimensions of foundations = 125 m x 120 m; and - OSPs are irregularly located in discrete locations (no standard spacing).	**Presence of infrastructure in the water column and on the seabed** There is potential for WDA infrastructure (foundations and cable and scour protection measures to directly influence wave and hydrodynamic regimes locally by creating blockage effects. As currents are the primary driver of bedload sediment transport, this could indirectly lead to a change in sediment transport regime and seabed morphology. It is assumed that there is no requirement for IAC or export cable crossings and therefore all crossings are

Impact	Realistic Worst-Case Scenario	Rationale
	Presence of WTG foundation and associated scour protection on the seabed - Worst-case foundation type = suction bucket jacket; - Maximum footprint of suction bucket jacket foundation including scour protection per foundation = 38,170.35 m^2; - Maximum footprint of suction bucket jacket foundations including scour protection for 144 foundations = 5,496,530.51 m^2 - Maximum height above seabed of scour protection for foundations = 1.5 m; - Total volume of scour protection for total WTG = 8,244,795.76m^3. **Presence of OSP GBS foundations and associated scour protection on the seabed** - Maximum footprint of scour protection per foundation = 120,000 m^2; - Maximum footprint of scour protection for 2 foundations = 240,000 m^2; - Maximum height above seabed of scour protection for foundations = 1.5 m; - Total volume of scour protection for 2 OSPs = 360,000 m^3; - Maximum footprint of GBS foundation per platform (excluding scour protection) = 15,000 m^2; - Maximum footprint of GBS foundation for 2 platforms = 30,000 m^2; and - Maximum footprint of foundations and scour protection = 270,000 m^2. **Presence of IAC cable protection measures** - Maximum IAC seabed route length = 521,000 m; - Maximum amount of IAC requiring cable protection due to ground conditions = 52,100m (10% of total length); - Maximum length of cable protection required for unburied IAC on approach to WTG – 50 m per WTG x 144 = 7,200 m; - Maximum cable protection width = 13 m - Maximum footprint of cable protection for IACs = 770,900 m^2; and - Maximum height above seabed of cable protection for IACs = 3 m - Maximum volume of IAC cable protection = 2,312,700 m^3.	associated with OSP link cables crossing IACs. There are no known third-party cables or pipelines within the WDA.

Impact	Realistic Worst-Case Scenario	Rationale
	Presence of OSP link cable protection measures due to unsuitable ground conditions for cable burial • Maximum length of OSP link cable trenches = 136,000 m; • Maximum length of OSP link cable trenches with cable protection = 13,600 m (10% of total length); • Maximum cable protection width = 13 m • Maximum footprint of cable protection for OSP link cables = 176,800 m^2; • Maximum height above seabed of cable protection for OSP link cables = 3 m; and • Maximum volume of OSP link cable protection = 530,400 m^3. **Presence of offshore export cable protection measures (within the WDA) due to unsuitable ground conditions for cable burial** • Maximum length of offshore export cable trenches within the WDA = 100,000 m; • Maximum length of offshore export cable within the WDA requiring cable protection = 5,000 m (5% of total length); • Maximum footprint of offshore export cable protection within the WDA = 65,000 m^2; and • Maximum height above seabed of cable protection for offshore export cable(s) = 3 m; and • Maximum volume of offshore export cable protection measures within the WDA = 195,000 m^3. **Presence of cable protection at OSP link cable crossings within the WDA** • Up to 2 crossings of 250 m length each; • Maximum area of cable protection for cable crossings (at 18 m width) = 9,000 m^2; • Maximum height above seabed of cable protection for cable crossings = 3 m; and • Maximum volume of cable protection for cable crossing = 27,000 m^3.	
Decommissioning	**The worst-case scenarios for decommissioning would be similar to those defined in the construction phase.**	The impacts of decommissioning are primarily linked to the removal of infrastructure from the seabed. These activities may alter the seabed morphology, potentially creating localised depressions within the footprint of the infrastructure being removed. Wave, hydrodynamic and

Impact	Realistic Worst-Case Scenario	Rationale
		sediment transport regimes will return to baseline conditions once the structures are removed. It is anticipated that the overall environmental impacts associated with decommissioning will be equal to, or potentially less than, those experienced during the construction phase.
Impact 3: Changes to Water Column Structure		
Operation and Maintenance	**See Operation and Maintenance Impact 2 for worst-case related to the presence of structures in the water column.**	**Presence of infrastructure in the water column and on the seabed** Changes to wave and hydrodynamic regimes in the wake of structures occupying a large proportion of the water column (e.g. foundations) have the potential to change Water Column Structure potentially leading to enhanced mixing which could weaken or break down stratification impacting oceanographic fronts. Interactions between planned infrastructure and wave and hydrodynamic regimes may result in localised changes to current speeds, wave energy and turbulence. These changes result in the generation of localised turbulent wakes (Dorrell et al., 2022), potentially leading to enhanced mixing which could weaken or break down stratification impacting oceanographic fronts**.**

7.8 EXISTING ENVIRONMENT

7.8.1 Existing Baseline

7.8.1.1 Bathymetry and Seabed Features

19. Multi-beam Echo Sounder (MBES) bathymetry data (Fugro, 2024 and Sulmara, 2025 – **Appendix 8.1** of this EIAR) shows that the minimum and maximum water depths across the WDA are between approximately 21.6 m below Lowest Astronomical Tide (LAT) and 81.7 m below LAT respectively (**Figure 7.2**).

20. The seabed in the west of the WDA comprises sandwaves (**Plate 7.1**) with a sand bank present in the southwest. The maximum sandwave height in this region is approximately 6.6 m with wavelengths generally exceeding 200 m (Fugro, 2024). The crests of these bedforms vary in orientation, from east-north-east by west-south-west through to east-south-east by west-north-west (Fugro, 2024). The bedforms are asymmetrical in profile which indicates a general bedform migration direction towards the northwest (Fugro, 2024). Between the troughs of the sandwaves and the western boundary of the central (bathymetric low) zone, small sinuous channels are present (**Plate 7.2**).

21. In the central area of the WDA there is a linear trough orientated southwest to northeast. To the east of this trough, ripples (**Plate 7.2**) and mega ripples (**Plate 7.3**) are present but larger scale seabed features such as sandwaves and sand banks are not present. The ripples and mega ripples are generally orientated north-north-east by south-south-east, indicating an east-north-east to west-south-west migration direction (Fugro, 2024).

22. Bedrock outcrops (**Plate 7.4**) are present to the north and northeast of the WDA, these create a rugged seabed with slopes of up to 83° on the scarps (Fugro, 2024). The bedrock outcrops form distinctive bathymetric highs compared to the surrounding seabed, generally between 30 m to 22 m below LAT.

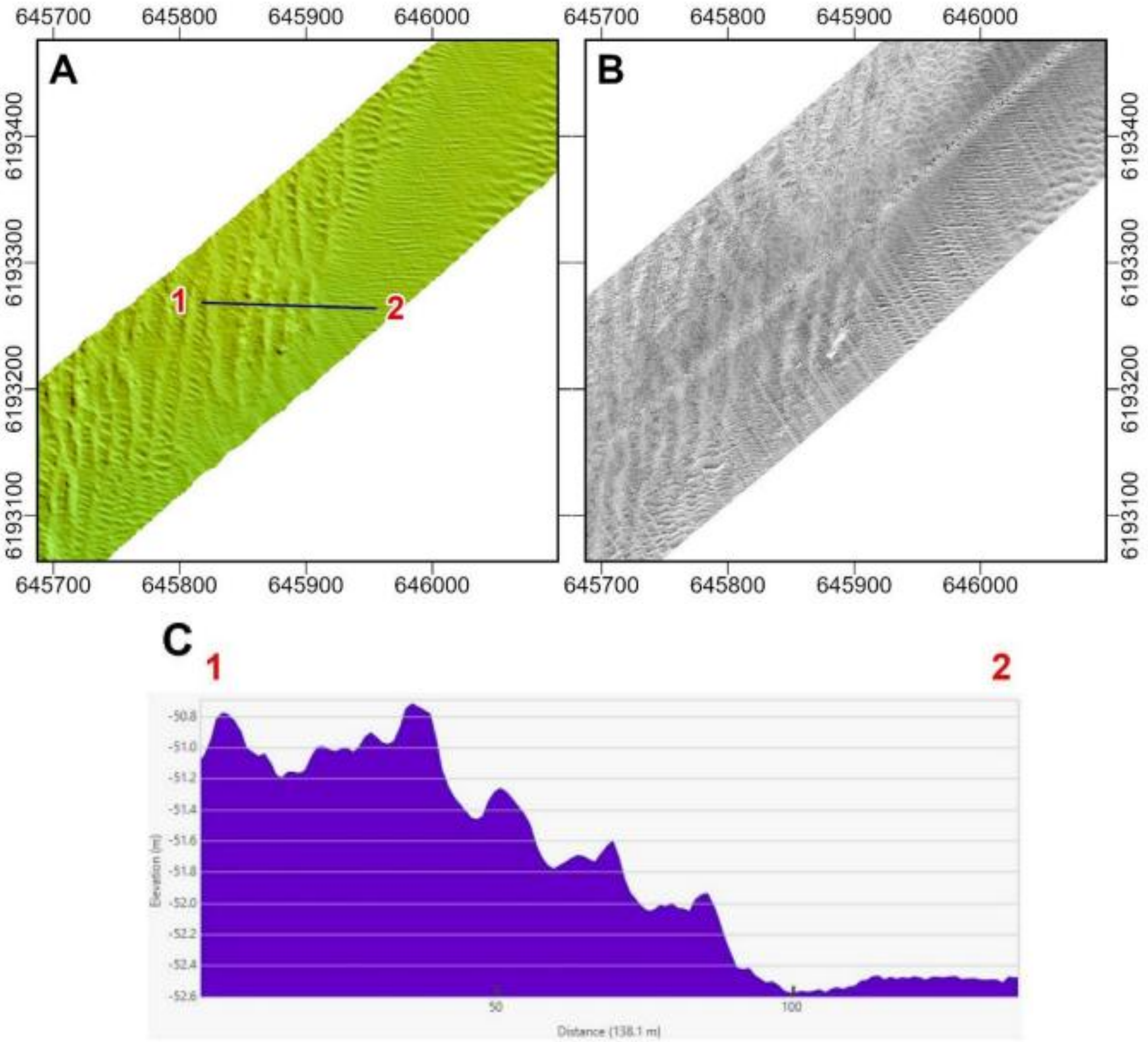


Plate 7.1 Example of sandwaves within the Fugro MachairWind Offshore Windfarm survey area. A – Shaded relief bathymetry. B – High Frequency side scan sonar. C – Cross profile. (Fugro, 2024)

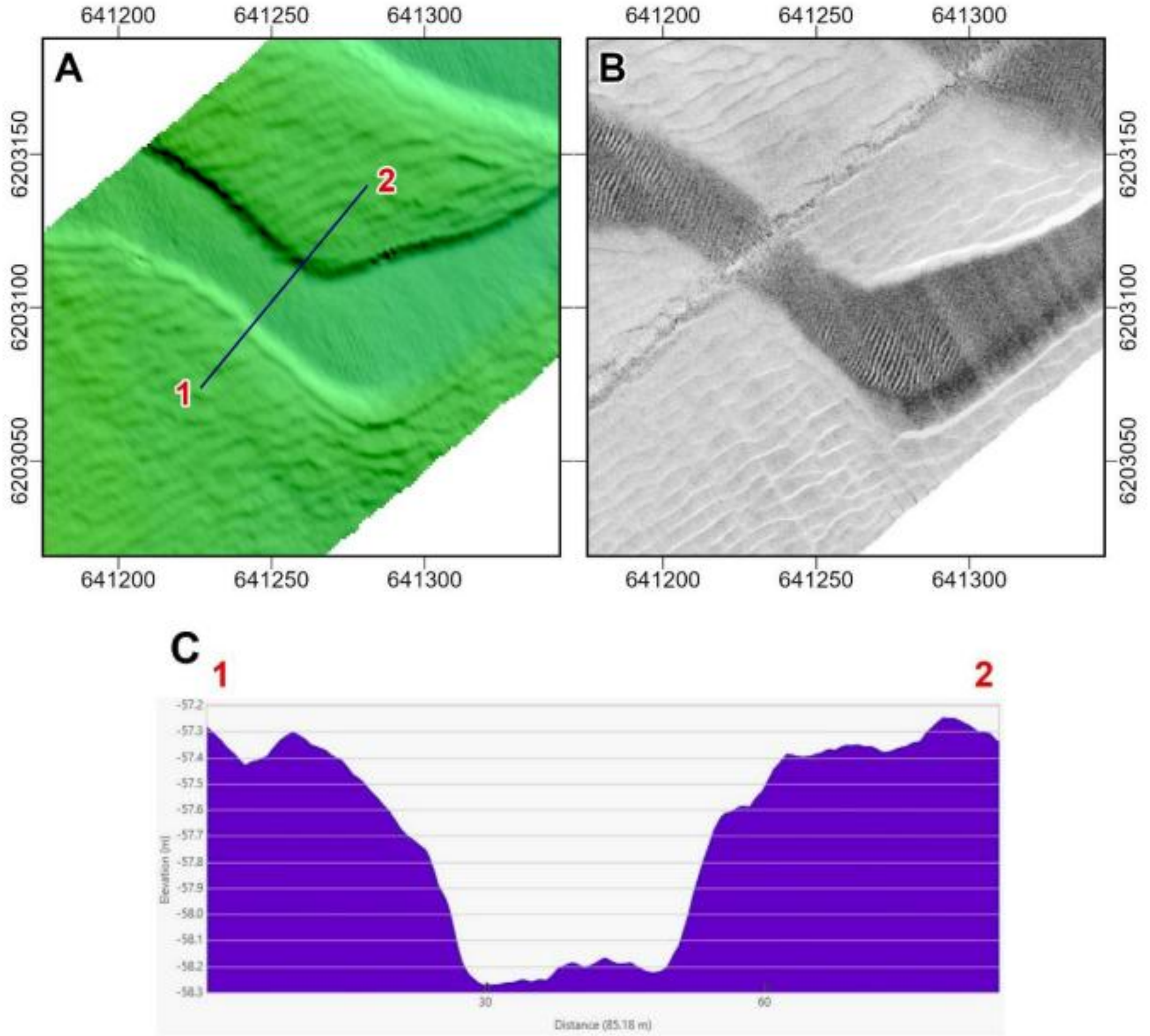


Plate 7.2 Example of the small sinuous channels and ripples within the Fugro MachairWind Offshore Windfarm survey area. A – Shaded relief bathymetry. B – High Frequency side scan sonar. C – Cross profile. (Fugro, 2024)

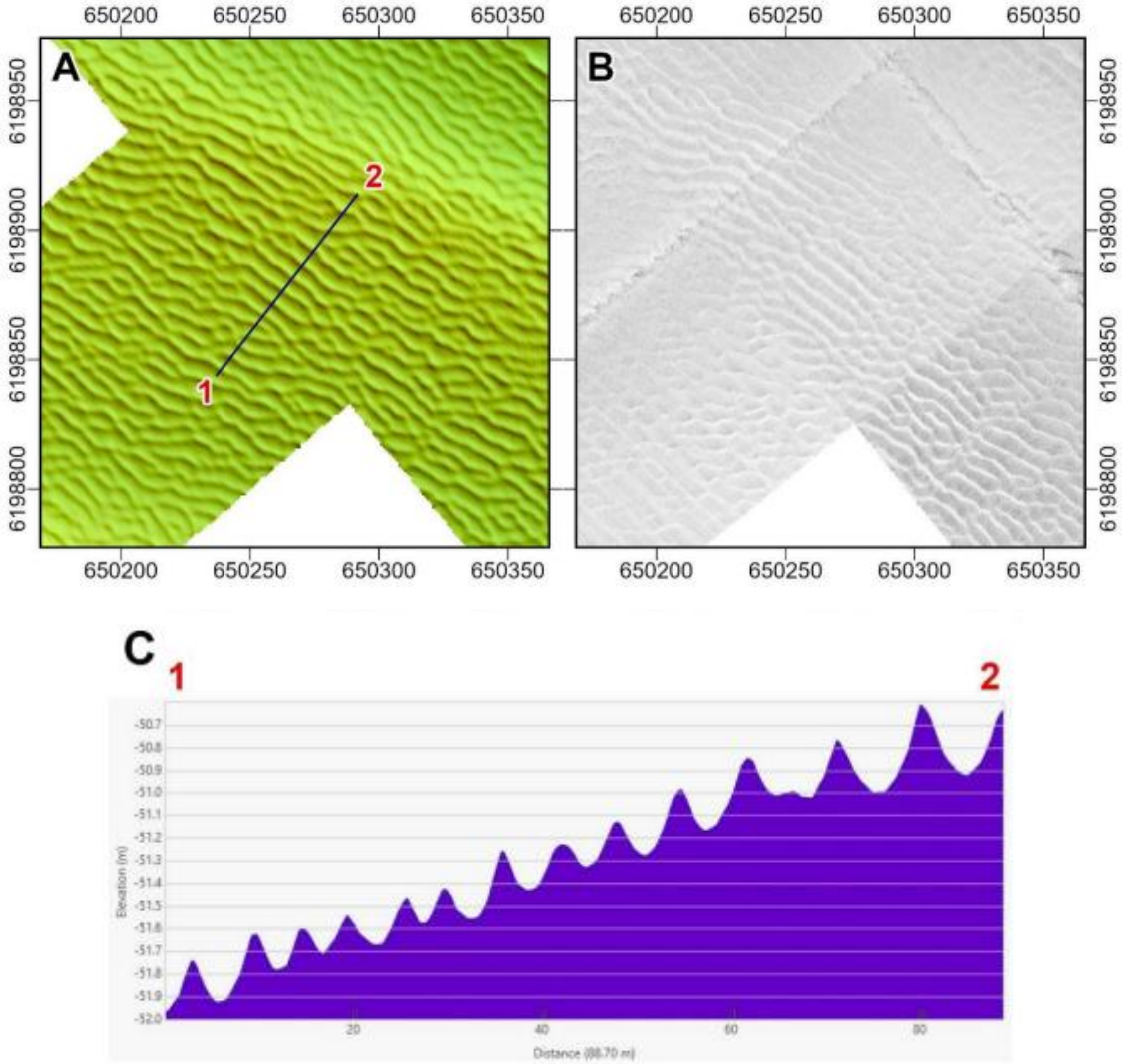


Plate 7.3 Example of the mega ripples within the Fugro MachairWind Offshore Windfarm survey area. A – Shaded relief bathymetry. B – High Frequency side scan sonar. C – Cross profile. (Fugro, 2024)

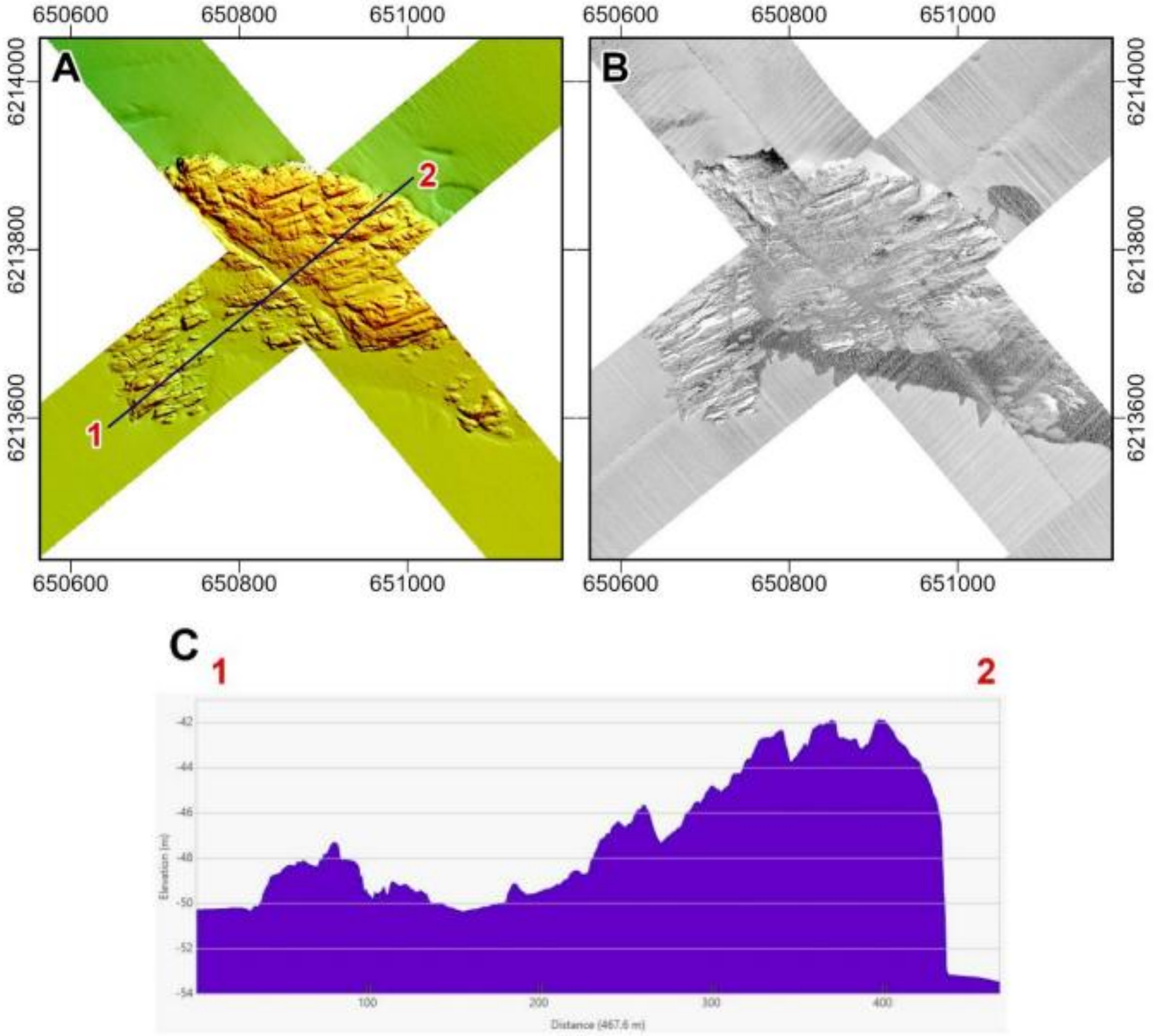
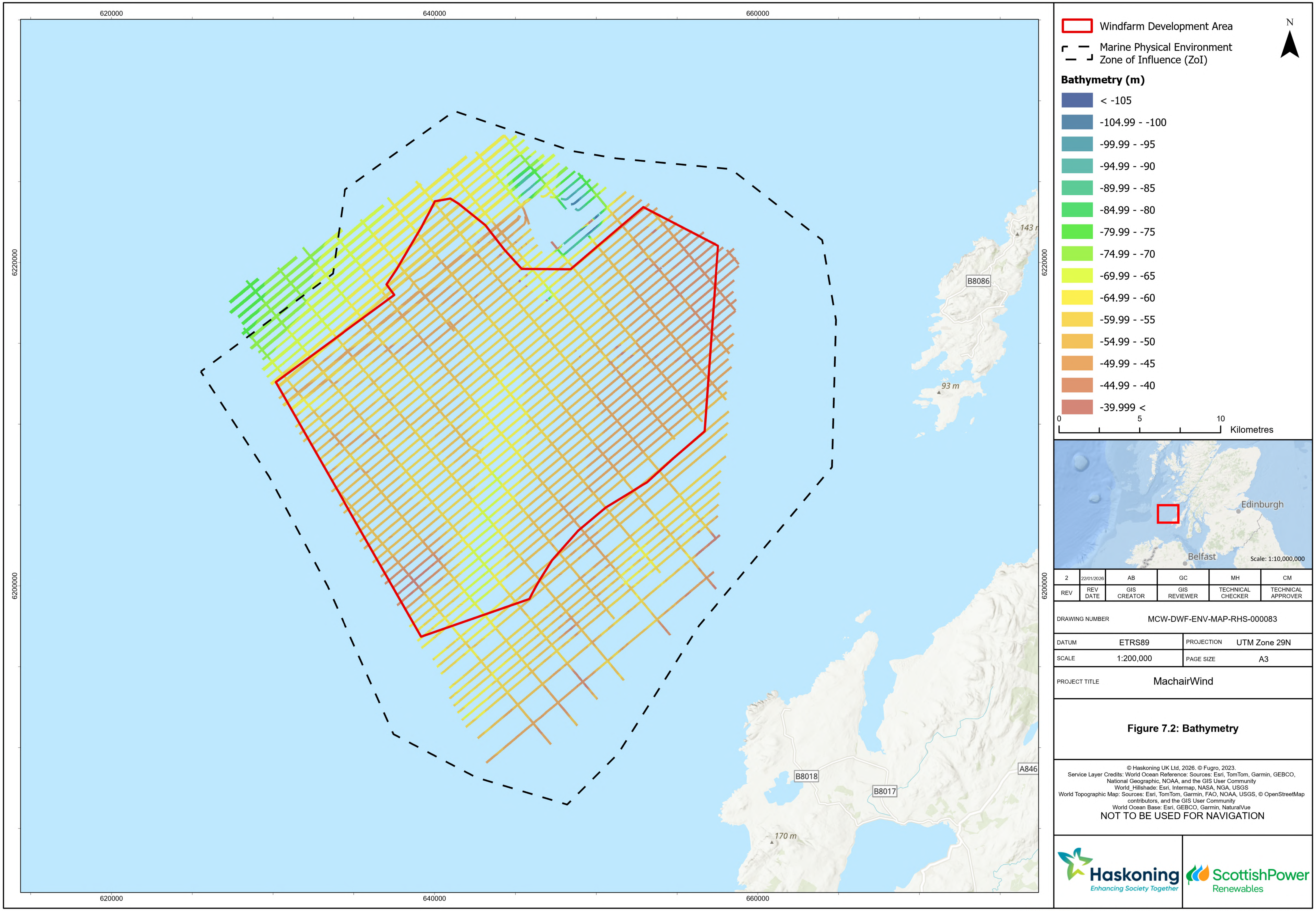


Plate 7.4 Example of the bedrock outcrops within the Fugro MachairWind Offshore Windfarm survey area. A – Shaded relief bathymetry. B – High Frequency side scan sonar. C – Cross profile. (Fugro, 2024)



2	22/01/2026	AB	GC	MH	CM
REV	REV DATE	GIS CREATOR	GIS REVIEWER	TECHNICAL CHECKER	TECHNICAL APPROVER

DRAWING NUMBER MCW-DWF-ENV-MAP-RHS-000083

DATUM ETRS89
PROJECTION UTM Zone 29N
SCALE 1:200,000
PAGE SIZE A3

PROJECT TITLE MachairWind

Figure 7.2: Bathymetry

Service Layer Credits: World Ocean Reference: Sources: Esri, TomTom, Garmin, GEBCO, National Geographic, NOAA, and the GIS User Community
World_Hillshade: Esri, Intermap, NASA, NGA, USGS
World Topographic Map: Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community
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Project: C:\Users\304634\OneDrive - Royal HaskoningDHV\WIP\03 GIS\A02_Figures\03_EIA\01_WDA\Chap_07_MPE\MCW_EIA_WDA_MPE.aprx
Name: Fig_7-2_MCW-DWF-ENV-MAP-RHS-000083_Bathymetry

7.8.1.1.1 Shallow Geology

23. The bedrock towards the north of the WDA consists of undifferentiated rocks, including mudstone, sandstone and limestone (BGS, 2023b). Across the centre of the WDA (east to west) a greater variety of undifferentiated rocks are present, comprising mudstone, sandstone, limestone, siliciclastic and argillaceous. In the south of the WDA, the bedrock is mainly metamorphic (metasedimentary) rocks (BGS, 2023b).

24. Within the WDA, bedrock is partially exposed in outcrops, as highlighted in **Section 7.8.1.1**. Outside of the WDA, immediately to the north, the area surrounding the Lighthouse consists of a patch of igneous rocks. These outcrops may represent minor intrusions extending from the region of igneous rocks.

25. The Quaternary geology of the WDA is described by the BGS (2023c) as soft mud, with the exception of some undifferentiated sands in the south (**Figure 7.3**). Across the WDA, Quaternary deposit thickness ranges from 5 to 20 m in the south and up to 30 m to greater than 50 m across the centre and north (BGS, 2023d). Sediments currently present at the seabed are outlined in **Section 7.8.1.2**. BGS mapping (1:250,000 Series Malin Sheet 55°N-08°W and Tiree Sheet 56°N-08°W) shows the surficial geology in the western area of the WDA as the Jura Formation, with undifferentiated Quaternary deposits and bedrock outcrop mapped closer to the coast.

26. The Phase 1 Geophysical and Environmental Survey undertaken in the OAA by Fugro (2024) demonstrated that the shallow geology here comprises Late Pleistocene to Holocene deposits of the Jura Formation, overlying Pleistocene sediments of the Barra Formation and undifferentiated tills, in turn overlying pre-Quaternary bedrock. The latter is observed to outcrop at the seafloor in places within the WDA.

27. The Jura Formation is described by Fugro (2024) as lithologically variable, comprising sand with shell, gravelly sand, and low strength clay. The base of this Formation varies between <0.5 and 12 m, thinning to absence in localised areas. The depth of the base of the Formation increases in the area of sand dunes in the north-west, within channels that incise into the underlying Barra Formation (predominantly in the centre of the WDA), and along areas of scouring around bedrock outcrops in the east, north and north-east (see Fugro, 2024).

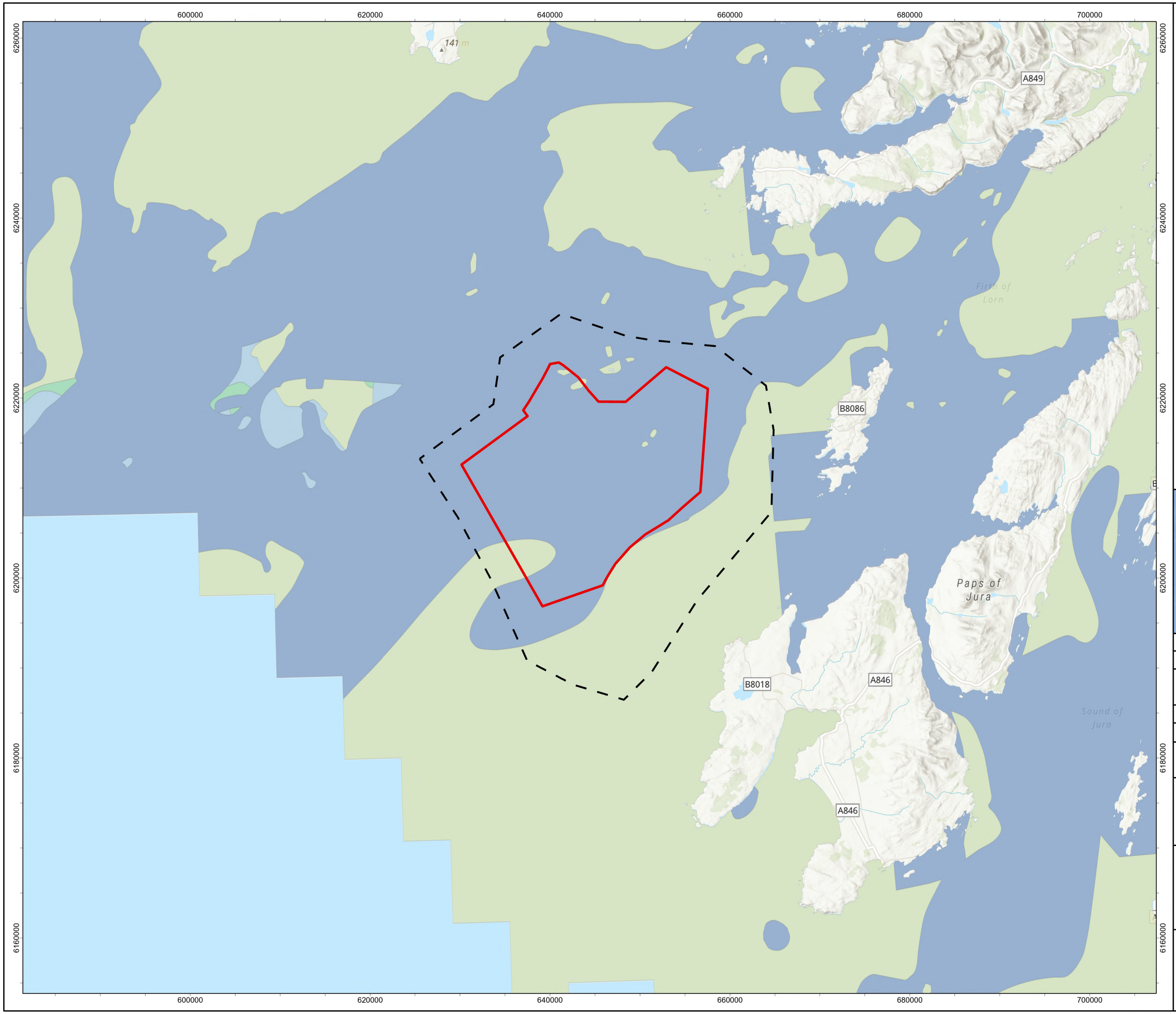
28. Fugro (2024) identified a ‘cobble’ layer, comprising gravel, cobbles and boulders, near the base of the Jura Formation, showing similar acoustic characteristics to a unit identified by the BGS near the top of the Jura Formation in the approaches to the Firth of Lorne. This layer has a ‘patchy’ distribution within the WDA in areas that coincide with bathymetric lows, one located in the north-west of the site, and another broadly following an elongated depression orientated south-south-west to north-north-east across the centre of the WDA (Fugro, 2024). The top of the ‘cobble’ layer is interpreted by Fugro (2024) to vary between <1 m Below Sea Floor (BSF) and 13 m BSF.

29. The Pleistocene Barra Formation, comprising very low strength to medium strength clay with gravel, is interpreted by Fugro (2024) as present across the majority of the survey area underlying the Jura Formation, thinning to absence in the north-east, east, south-west and south-east of the WDA. The base of the Barra Formation is generally present at depths between 30 and 60 m BSF, increasing in parts of the WDA to 85 m BSF. In places, possible shallow gas obscures the base of the Barra Formation. Notably, the shallow gas often coincides with numerous channels observed predominantly near the top of the Barra Formation (Fugro, 2024).

30. High strength to extremely high strength clay with gravel, cobbles and boulders of the Minch and/or Stanton Formations are the oldest Quaternary deposit expected to be present within the WDA,

observed by Fugro (2024) in parts of the north, east, and across the south-west, south and south-east of the WDA. The top of the Minch/Stanton Formations varies from relatively flat to mound-or ridge-like in places, tentatively interpreted as moraines or drumlins by Fugro (2024), similar to features (including grooved bedrock) observed by Dove et al. (2015) on high-resolution bathymetry northwest of Islay. This unit outcrops in parts of the WDA.

31. The bedrock, expected to include rocks of sedimentary, metamorphic and igneous origin, comprising strong to very strong sandstone, mudstone, phyllite, and strong to very strong basaltic intrusions, is expected to underlie the Minch/Stanton Formations across the majority of the WDA, although in localised areas in the north, north-east, south-west, south and south-east of the site the bedrock outcrops at the seafloor (Fugro, 2024).



🟥 Windfarm Development Area

Marine Physical Environment Zone of Influence (ZoI)

Quaternary lithologies

🟩 Diamict

🟦 Soft mud

🟨 Undifferentiated

Notes: Base BGS data shows Scottish waters only

0 5 10 Kilometres

REV	REV DATE	GIS CREATOR	GIS REVIEWER	TECHNICAL CHECKER	TECHNICAL APPROVER
1	25/11/2025	AB	GC	MH	CM

DRAWING NUMBER MCW-DWF-ENV-MAP-RHS-000084

DATUM	ETRS89	PROJECTION	UTM Zone 29N
SCALE	1:400,000	PAGE SIZE	A3

PROJECT TITLE MachairWind

Figure 7.3: Shallow Geology

© Haskoning UK Ltd, 2025. © BGS, 2025.
Service Layer Credits: World_Hillshade: Esri, Ordnance Survey, NASA, NGA, USGS
Offshore_Factor_Maps_WMS:
World Ocean Reference: Sources: Esri, TomTom, Garmin, GEBCO, National Geographic, NOAA, and the GIS User Community
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World Ocean Base: Esri, GEBCO, Garmin, NaturalVue

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7.8.1.2 Seabed Sediments

32. Seabed sediments within the WDA are described by the data collected in the Project site investigation survey completed by Fugro over the course of 2023 (Fugro, 2024, **Figure 7.4**). The grab samples collected during this survey show the seabed of WDA to be dominated by sand. The exception to this being a small area of sandy gravel (Station 91) in the south of the WDA.

33. Particle size analysis undertaken on the samples from the WDA categorises the deposits as predominantly medium sand, the majority of the remaining sediment fraction consists of mainly fine and coarse sand (**Plate 7.5**). The average sediment fraction of all the samples is provided in **Table 7.7**, summarising the seabed sediment compositions within the WDA.

Table 7.7 Summarised average sediment fraction distribution across all grab samples (Fugro, 2024)

Type	Aperture [µm]	Total Fractional [%]
Gravel/Cobble	>1300	2.56
Coarse Sand	>300 to ≤1300	17.22
Medium Sand	>130 to ≤300	56.38
Fine Sand	>31 to ≤130	23.71
Silt/Clay	≤31	0.14

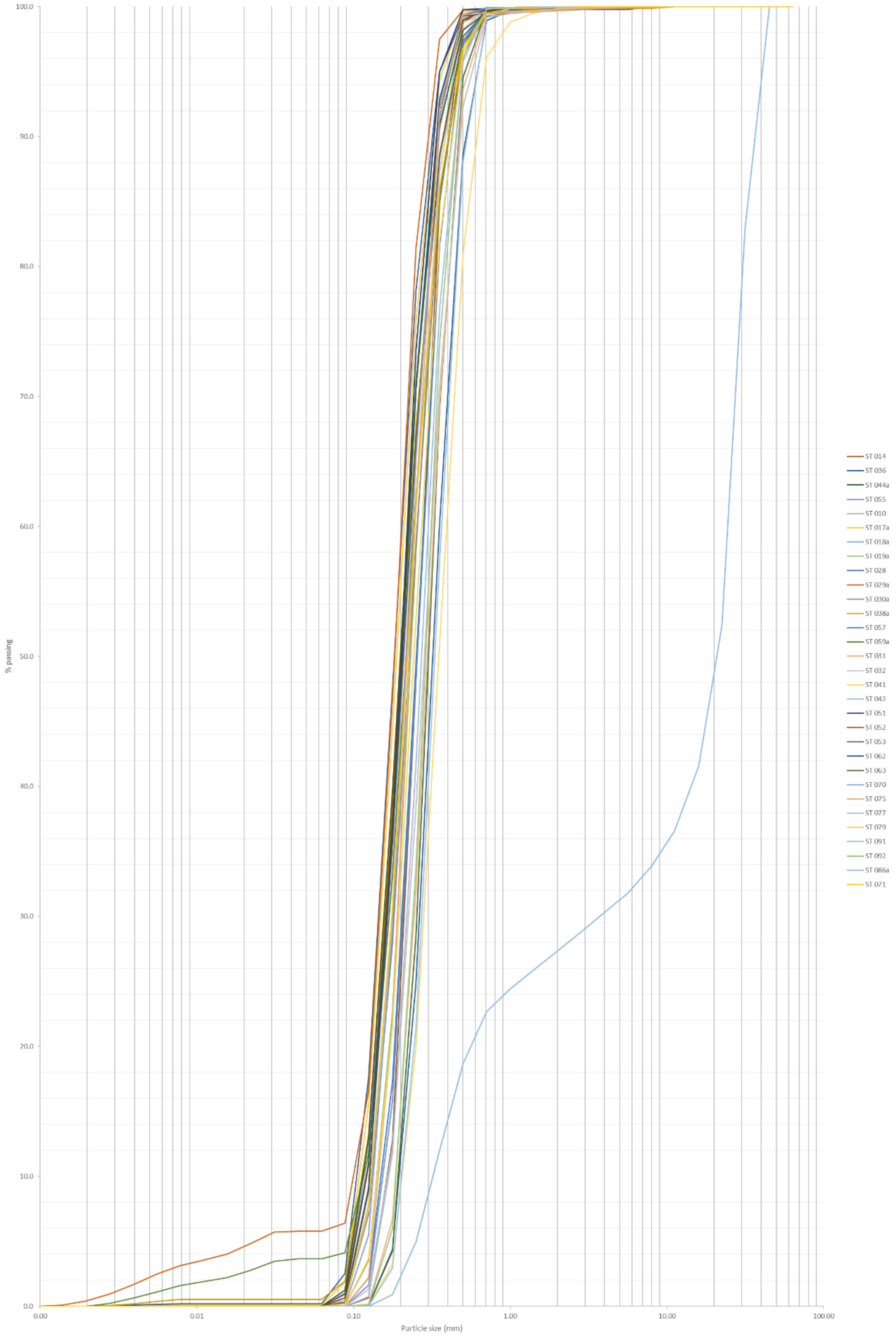
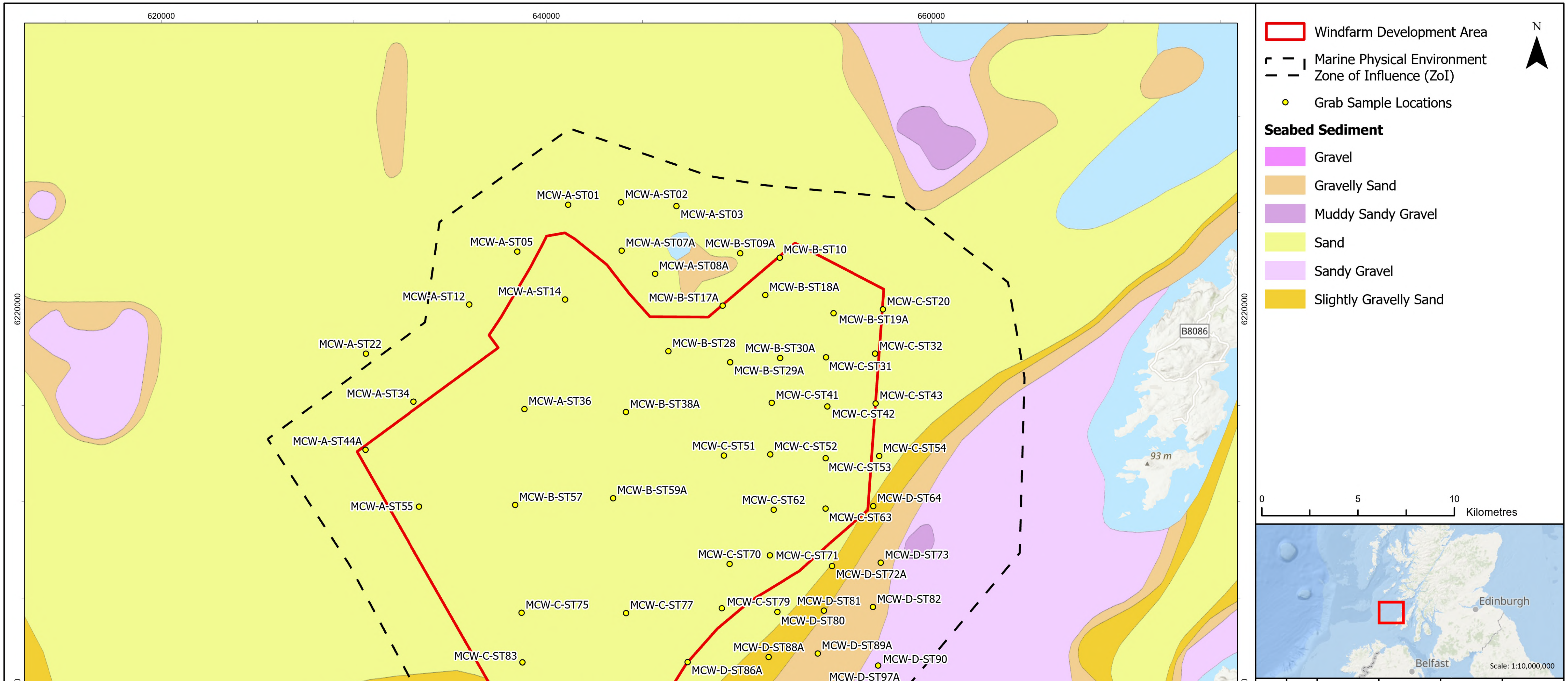


Plate 7.5 Particle size distribution across all grab samples (Fugro, 2024)



2	22/01/2026	AB	GC	MH	CM
REV	REV DATE	GIS CREATOR	GIS REVIEWER	TECHNICAL CHECKER	TECHNICAL APPROVER

DRAWING NUMBER	MCW-DWF-ENV-MAP-RHS-000085		
DATUM	ETRS89	PROJECTION	UTM Zone 29N
SCALE	1:200,000	PAGE SIZE	A3
PROJECT TITLE	MachairWind		

Figure 7.4: Grab Samples (Seabed Sediments)

Service Layer Credits: World Ocean Reference: Sources: Esri, TomTom, Garmin, GEBCO, National Geographic, NOAA, and the GIS User Community
GBR BGS British Geological Survey (BGS) offshore marine products:
World_Hillshade: Esri, Intermap, NASA, NGA, USGS
World Topographic Map: Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community
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7.8.1.3 Tidal Currents

34. The hydrodynamic conditions within the WDA have been characterised using the MIKE21-HD model calibrated with measured water levels and current speeds at two metocean stations as shown on (**Plate 7.6**). Full details on the setup and running of the model are available in **Appendix 7.1 Marine Physical Environment Numerical Modelling**.

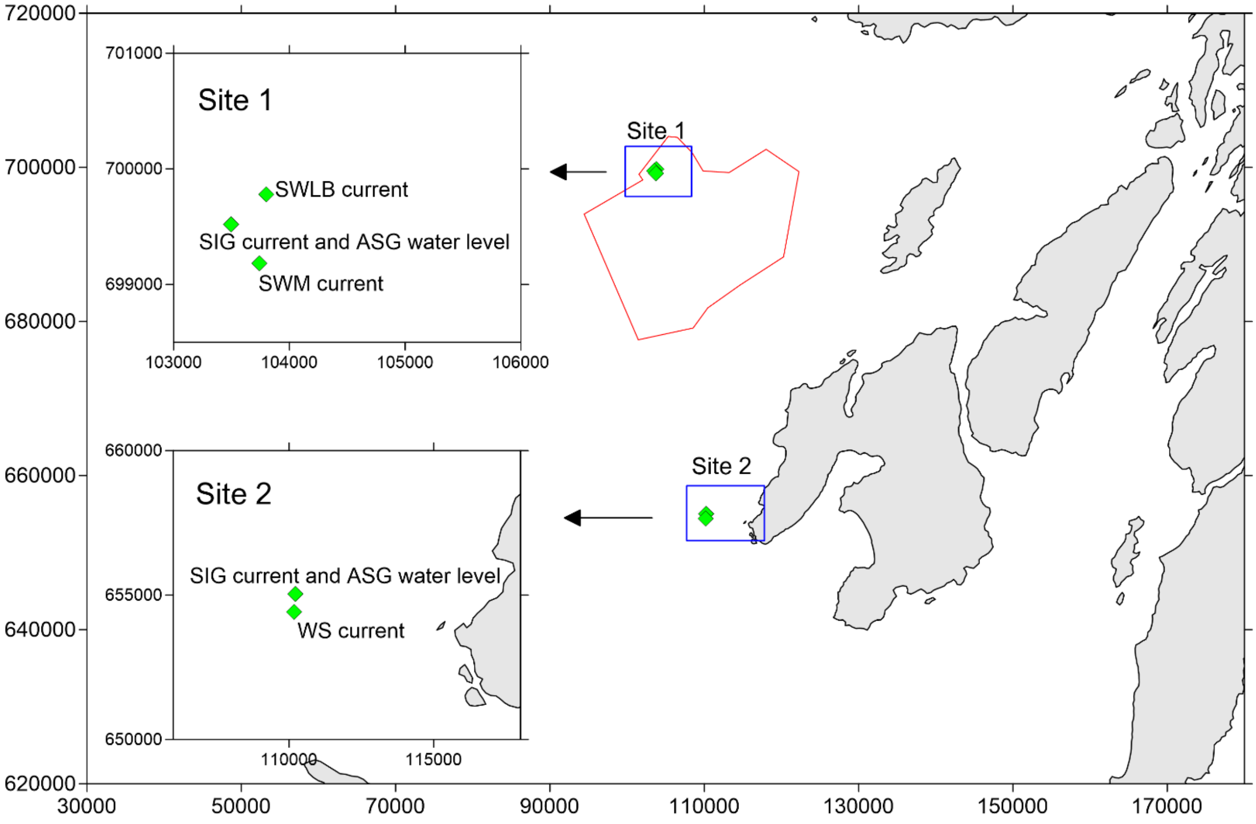

Plate 7.6 Location of current and water level measurements

35. The outputs of this modelling form predictions of current speeds and directions relative to different tidal conditions, including during spring tide for peak flood (**Plate 7.7**) and peak ebb (**Plate 7.8**) and during neap tide for peak flood (**Plate 7.9**) and peak ebb (**Plate 7.10**).

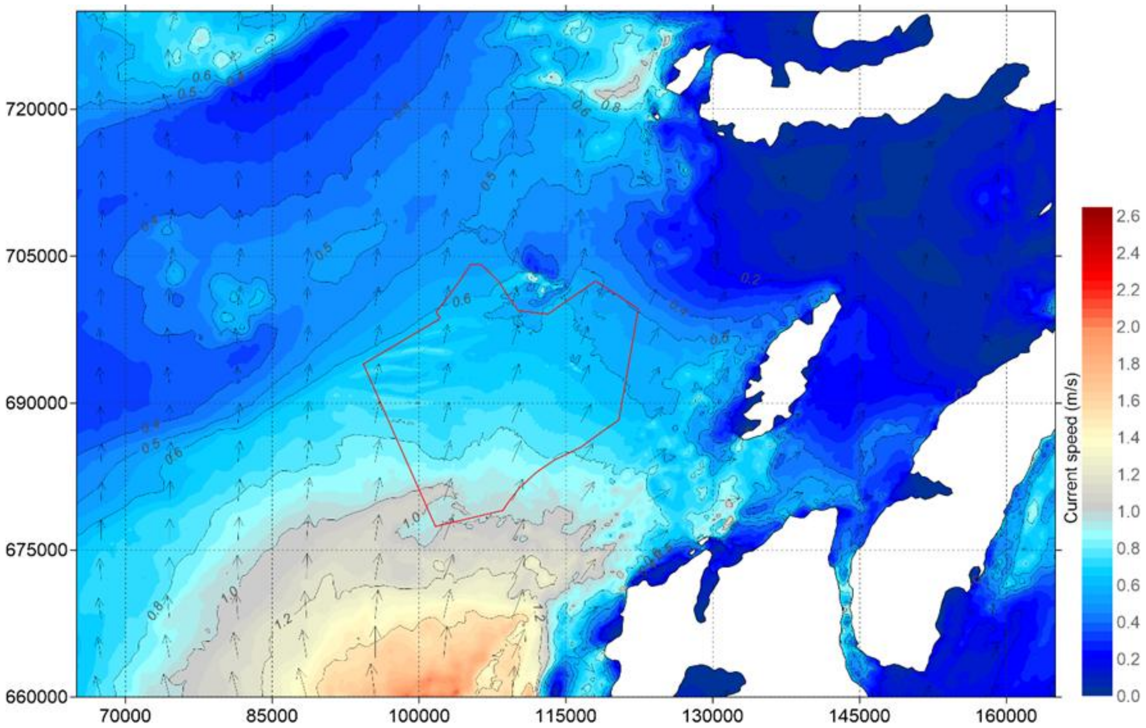

Plate 7.7 Current speed in the WDA (outlined) during spring tide - peak flood

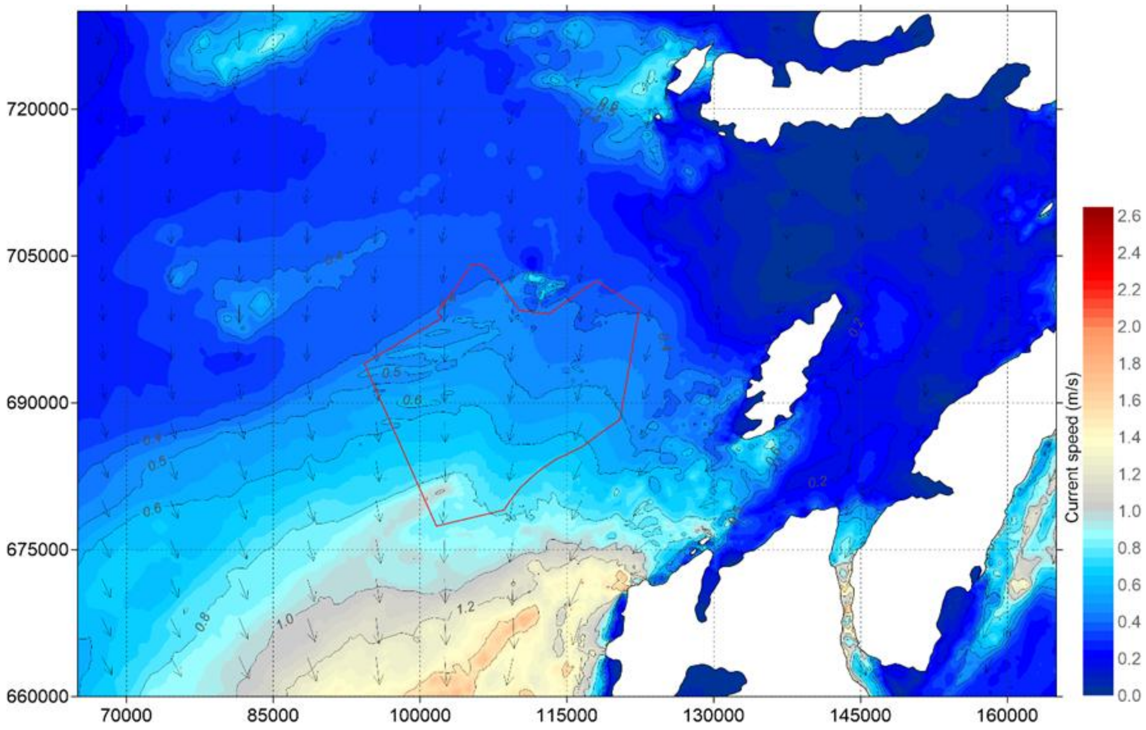

Plate 7.8 Current speed in the WDA (outlined) during spring tide - peak ebb

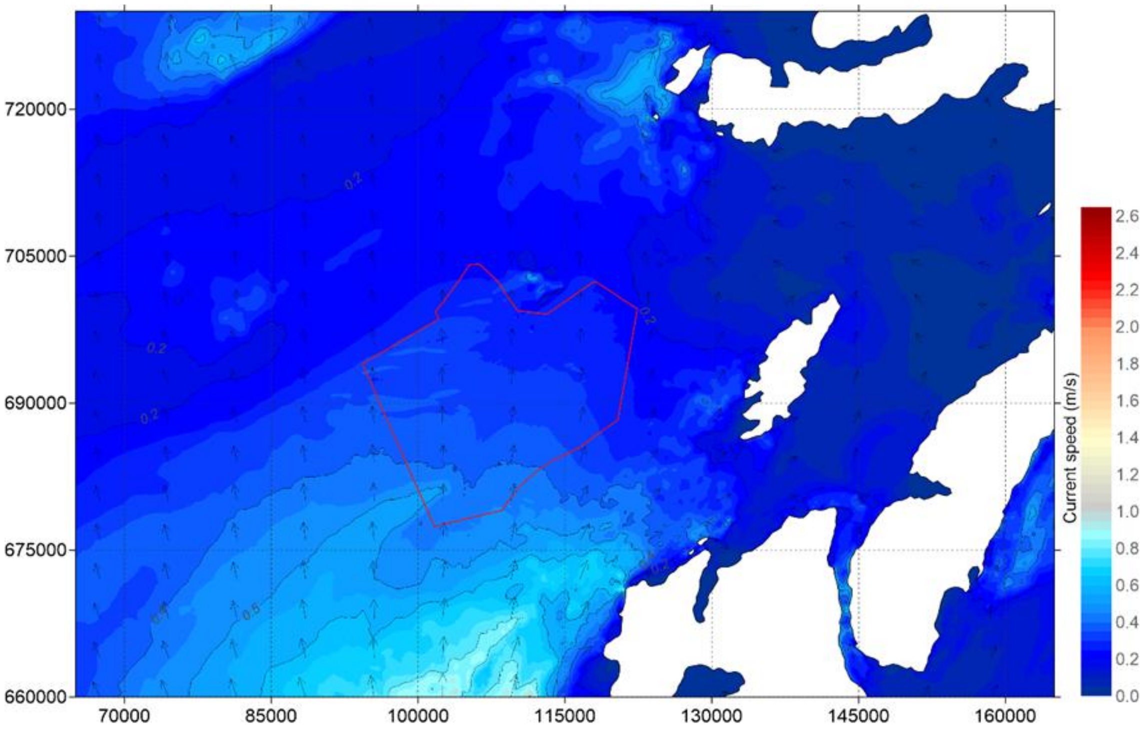

Plate 7.9 Current speed in the WDA (outlined) during neap tide - peak flood

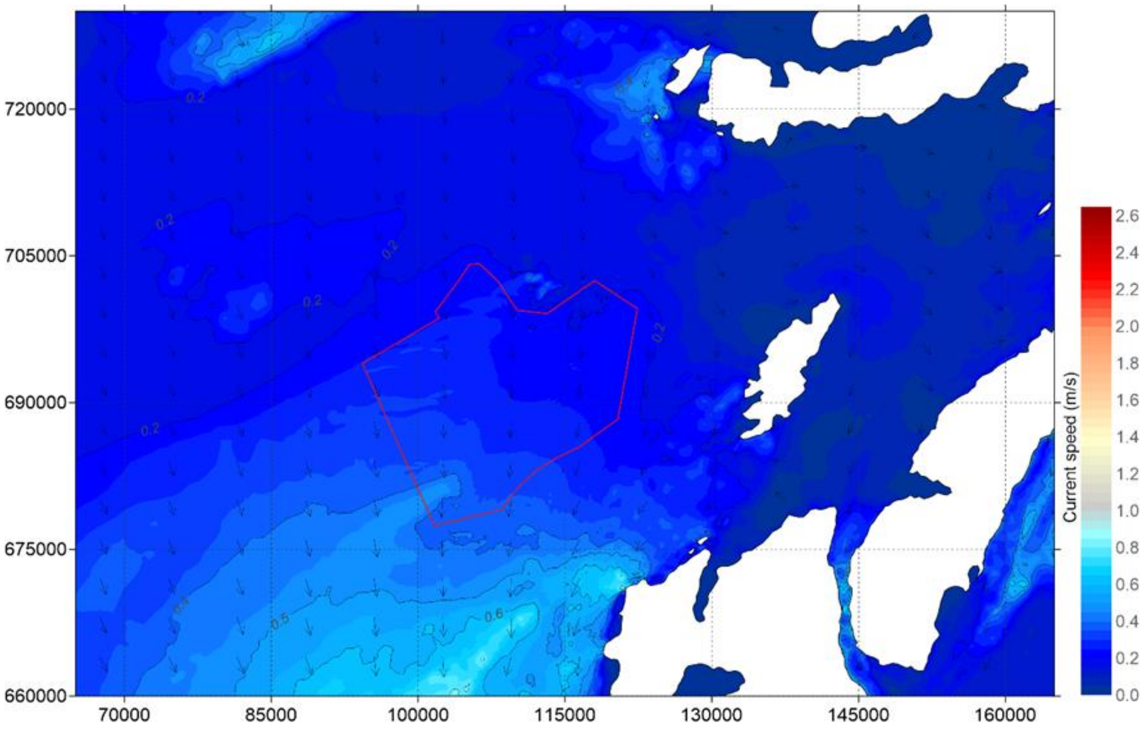

Plate 7.10 Current speed in the WDA (outlined) during neap tide - peak ebb

36. Hydrodynamic modelling undertaken for the WDA predicts that during the spring tide (**Plate 7.7** and **Plate 7.8**) peak flood flows are between 0.5 to 1.2 m/s and ebb flows are between 0.4 to 1 m/s. Spring tide peak flood flows travel across the WDA from south-south-west to north-north-east, ebb flows occur from the north to south. The strongest spring tide current speeds occur in the south of the WDA, becoming weaker towards the north.

37. During the neap tide (**Plate 7.9** and **Plate 7.10**), peak flood flows within the WDA are between 0.1 to 0.5 m/s and during the neap tide, they are slightly lower at between 0.1 to 0.4 m/s. Neap tide peak flood flows travel across the WDA from south to north, ebb flows occur from the north to south. The strongest neap tide current speeds occur in the south of the WDA, becoming weaker towards the north.

38. For both the spring and neap tide in the WDA, flood tides generally flow from south to north, whilst ebb tides flow from north to south. Additionally, current speeds are strongest in the south weakening towards the north for the duration of the spring and neap tide in the WDA. Modelling of maximum current speeds across the full spring-neap tidal cycle highlights this trend in current speed conditions within the WDA (**Plate 7.11**).

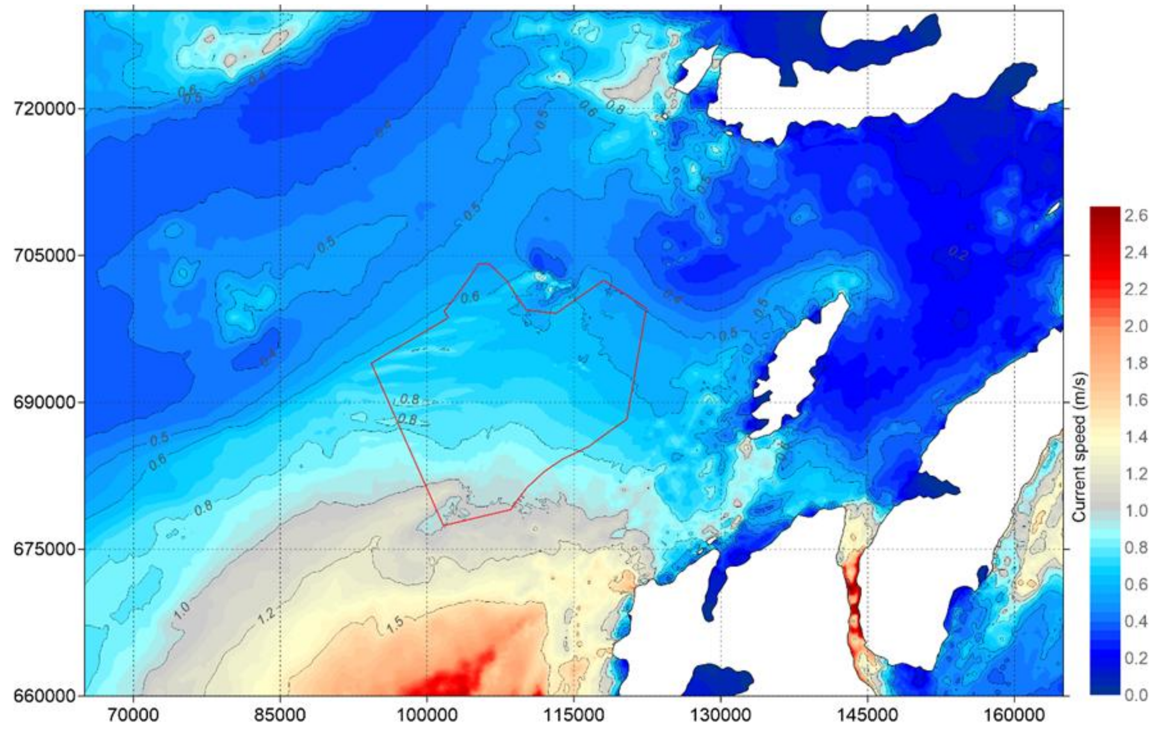

Plate 7.11 Maximum current speed in the WDA over 15 days

39. Residual currents were also simulated as part of the hydrodynamic modelling WDA (**Plate 7.12**). This provides an outline of the net current speed and direction within the WDA over multiple tidal cycles. Residual current flow direction is similar across the majority of the WDA, orientated south-south-west to north-north-east. In the southwest, currents enter the WDA aligned more southwest to northeast, likely due to the current flow interacting with a sand bank in this region (see **Section 7.8.1.1**). This sand bank area is characterised by very slow current flow speeds of <0.018 m/s. The rest of the WDA is characterised by residual current speeds ranging between 0.018 m/s and 0.060 m/s. Higher current speeds are visible through the centre of the WDA, aligned to the north-north-east to south-south-west bathymetric low zone, as well as along the western edge of sandwaves, outlined in **Section 7.8.1.1**.

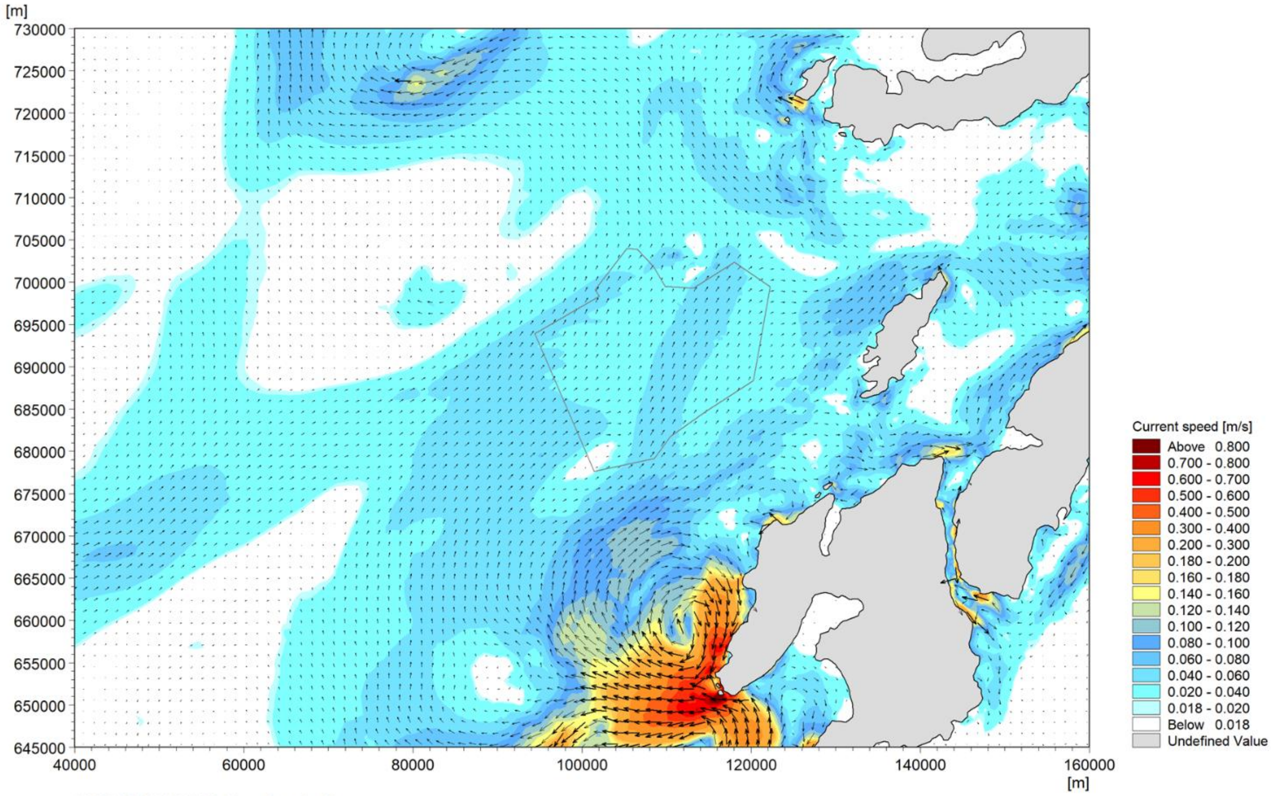

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Plate 7.12 Residual current flow in the WDA over 28.5 days

40. Modelling by ABPmer (2008) provides a prediction of tidal excursion ellipses within the WDA. Tidal excursion ellipses are aligned broadly northeast to southwest in the north of the WDA (ABPmer, 2008). The ellipses gradually become more north to south aligned towards the south of the WDA (ABPmer, 2008). The length of the tidal ellipses varies across the WDA, from approximately 4 to 7 km in the north and centre and between 7 and 11 km towards the south (ABPmer, 2008).

41. Based on the predicted length of tidal excursion ellipses closest to the boundary of the WDA a predicted zone of influence has been created, as shown in **Figure 7.1**. Notably the alignment of the tidal excursion ellipses generates a tidal excursion area excluding coastal receptors.

7.8.1.4 Waves

42. The wave climate within the WDA has been characterised using Metocean survey data collected at two locations SWM (S1) and SIG (S2) from April 2023 to May 2024 (**Plate 7.6**).

43. These locations produced the most complete wave datasets, covering the full survey period. The wave climates recorded at these locations are described by the wave roses in **Plate 7.13** (S1) and **Plate 7.14** (S2).

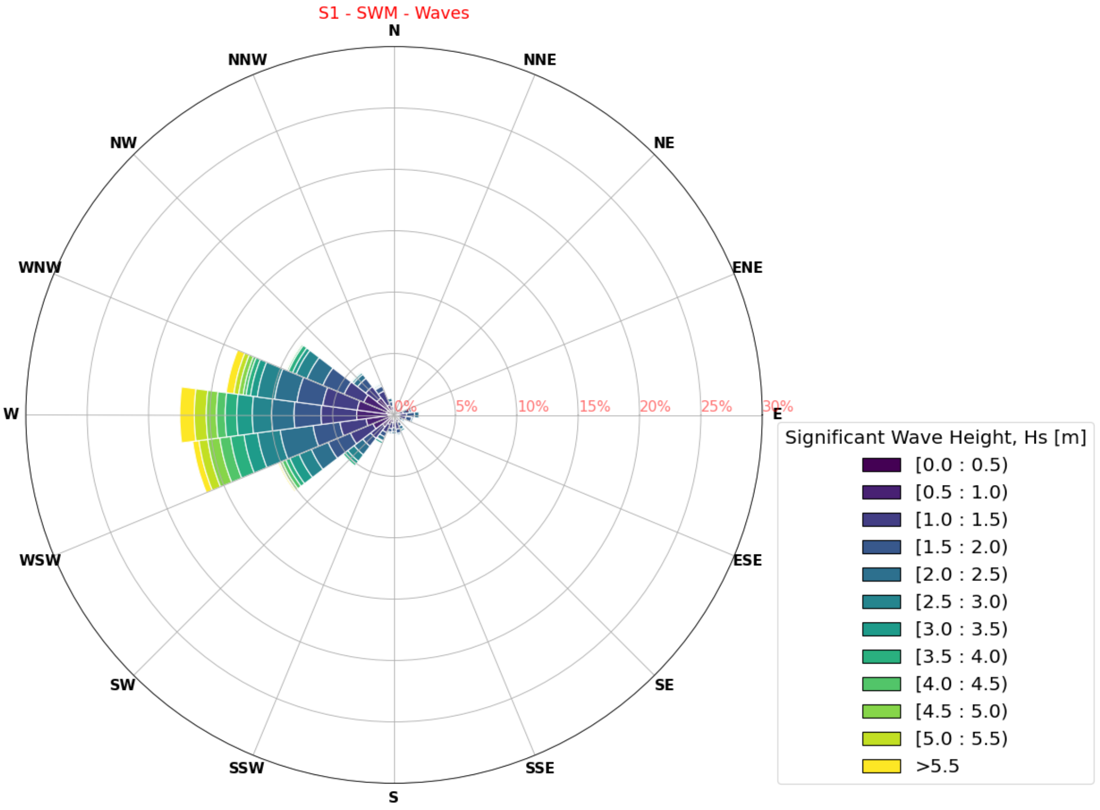


Plate 7.13 Measured significant wave height (Hs) at S1 – SMW

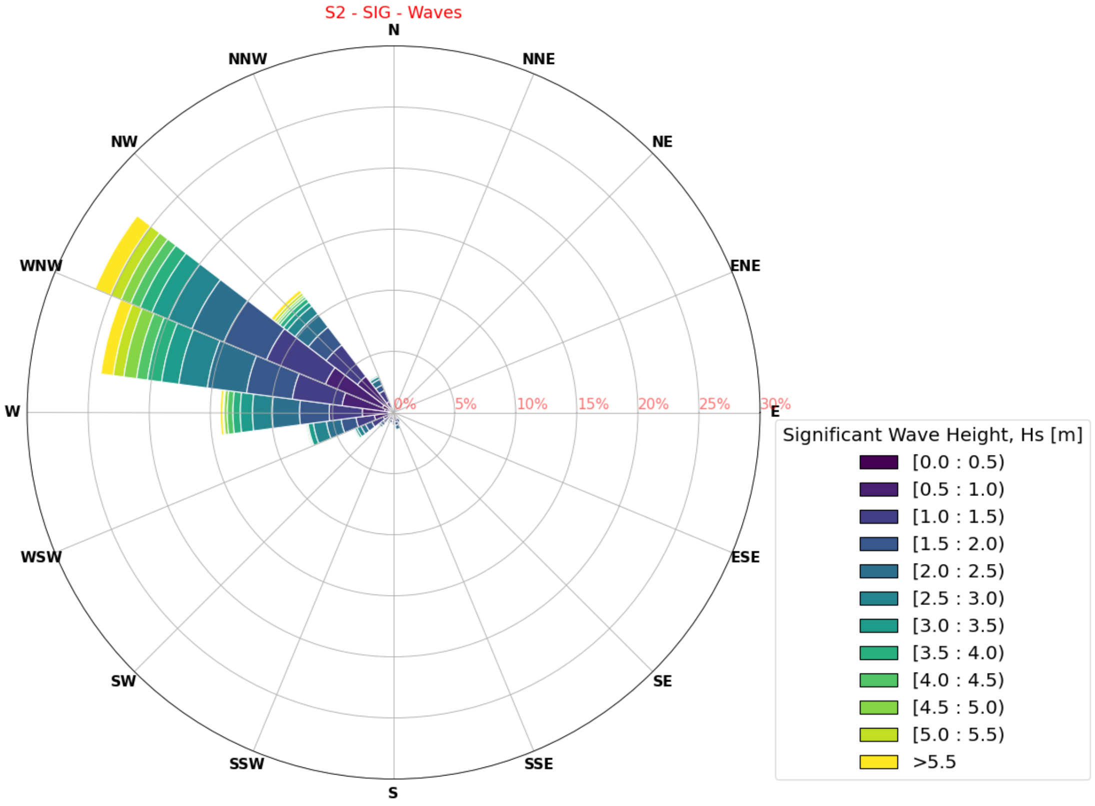


Plate 7.14 Measured significant wave height (Hs) at S2 – SIG

44. Comparing the wave conditions at S1 and S2 characterises the wave conditions within the WDA. Within the WDA, across all seasons, waves predominantly approach from the west-north-west (S1: 23%, S2: 55%) and west (S1: 19%, S2: 14%), followed by the west-south-west (S1: 37%, S2: 9%) and northwest (S1: 4%, S2: 14%). A smaller number of waves originate from the southwest (S1: 5%, S2: 4%) and north-north-west (S1: 4%, S2: 4%). The remaining 8% of waves at S1 approach from a variety of minor directions. During the survey period, a maximum significant wave height of 8.97 m was recorded during a winter storm event; the majority of significant wave heights (approximately 80%) were between 0 to 3 m.

7.8.1.5 Sediment Transport Regime and Seabed Mobility

45. Sediment transport across the WDA is mainly driven by the tidal regime (**Section 7.8.1.3**), seabed morphology (**Section 7.8.1.1**) and the composition of seabed sediments (**Section 7.8.1.2**).

46. Across most of the WDA, sand is the dominant seabed sediment type (**Plate 7.5**). The seabed sediment is sculpted into flow-transverse bedforms at numerous locations across the WDA, including ripples, megaripples, sandwaves and a sand bank (Fugro, 2024) (**Section 7.8.1.1**).

47. **Plate 7.15** shows the critical Shield’s parameter calculated using the Soulsby (1997) formula, across the WDA. When the Shield’s parameter exceeds this critical value then sediments are set in motion and sediment transport is generated.

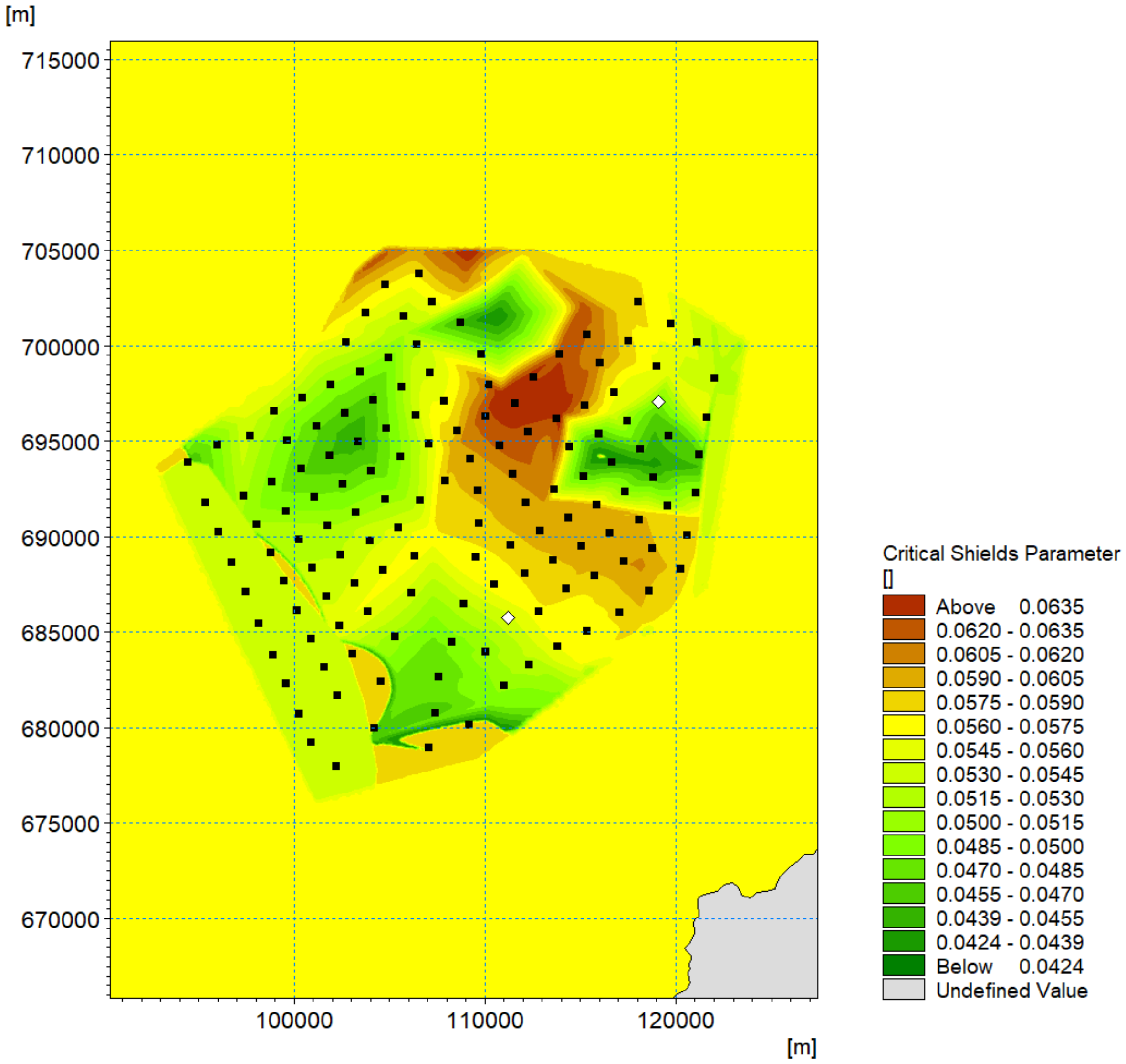


Plate 7.15 Critical Shield's parameter for onset of sediments. Black squares indicate indicative WTG locations, white squares indicate indicative OSP locations.

48. As expected, the critical Shields values range between 0.04 and 0.06 in agreement with the average Shield's of 0.05 suggested by Nielsen (1992). The spring-neap averaged bottom shear stresses from the hydrodynamic modelling were summed to the highest wave condition-induced bottom shear stress, calculated following Soulsby (1997), to account for the largest wave-induced bed shear stress. Shield's parameters were calculated ignoring the additional roughness induced by the existing bedforms. **Plate 7.16** shows the Shield's parameter associated with this total bed shear stress. Inside the WDA, Shield's values range between 0.04 to 1.0 meaning that the dominant sediment transport regime is ripples (or bedforms) with a weak sheet-flow generating on top of the existing bedforms where Shield's exceeds the threshold of 0.8. Only in the south-west part of the WDA are values of Shield's larger than 1.0 noticeable, meaning that sediments there are transported in a more energetic sheet-flow type of sediment transport regime.

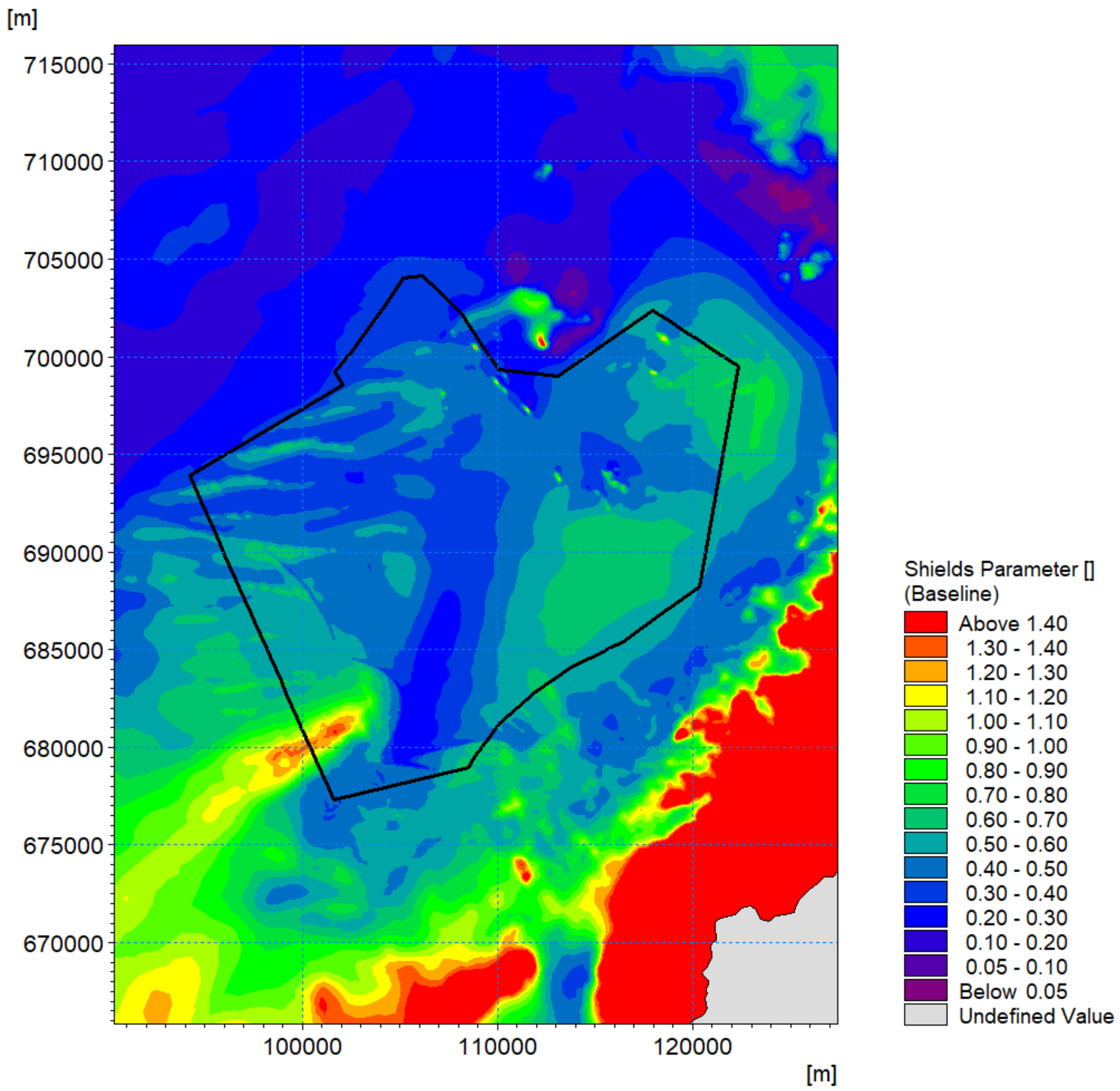


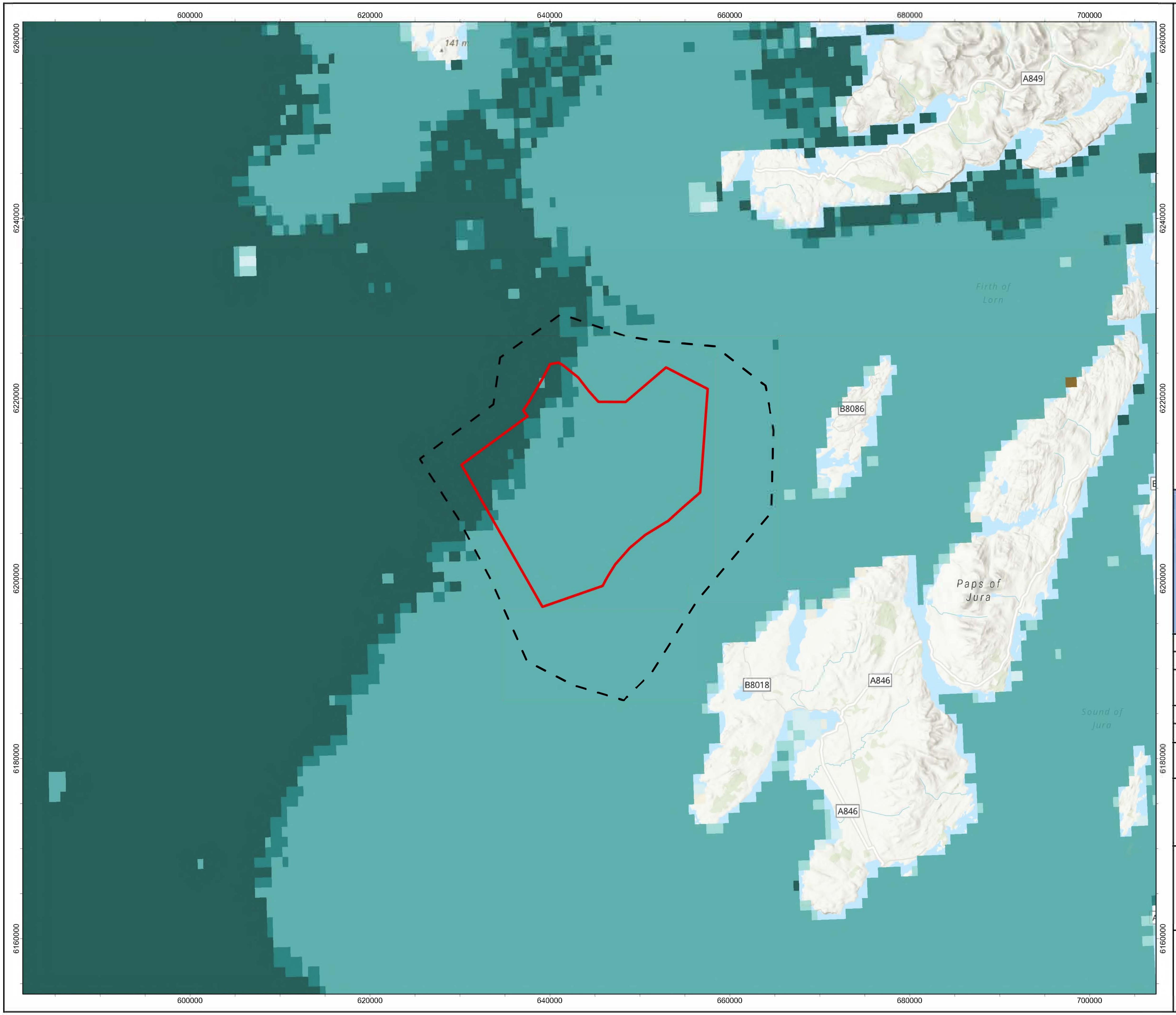
Plate 7.16 Spring-Neap averaged Shield's parameter

49. Comparisons by Fugro (2024) with EMODnet bathymetry data (EMODnet, 2022) suggests little migration of these bedforms has occurred over two years, but the types of bedforms observed (ripples to large dunes) suggest reorientation and migration could occur over a longer period, within the Project lifetime.

50. An integrated assessment of residual currents, bed shear stress, calculations of Shield's parameter and seabed sediment composition and morphology, indicate that active bedload sediment transport occurs within the WDA creating a range of seabed features that are visible on the bathymetry. Sediment is also mobile where these features are absent but, in these cases, sediment is transported as a sheet. The net sediment transport direction is broadly orientated south-south-west to north-north-east.

7.8.1.6 Suspended Sediment Concentrations (SSCs)

51. Cefas (2016) mapped the spatial distribution of average annual SSCs across the UK continental shelf between 1998 and 2015. The WDA is characterised predominantly by values between 1 mg/l and 2 mg/l, with small areas in the west and north-west of the WDA with values of ≤1 mg/l (**Figure 7.5**). Large areas of the Sea of the Hebrides are characterised by similar SSCs, with values generally becoming greater in shallower water towards the coast.



1	25/11/2025	AB	GC	MH	CM
REV	REV DATE	GIS CREATOR	GIS REVIEWER	TECHNICAL CHECKER	TECHNICAL APPROVER

DRAWING NUMBER	MCW-DWF-ENV-MAP-RHS-000086		
DATUM	ETRS89	PROJECTION	UTM Zone 29N
SCALE	1:400,000	PAGE SIZE	A3
PROJECT TITLE	MachairWind		

Figure 7.5: Suspended Sediment Concentrations

Service Layer Credits: World_Hillshade: Esri, Ordnance Survey, NASA, NGA, USGS
World Ocean Reference: Sources: Esri, TomTom, Garmin, GEBCO, National Geographic, NOAA, and the GIS User Community
World Topographic Map: Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community
World Ocean Base: Esri, GEBCO, Garmin, NaturalVue

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7.8.1.7 Stratification and Frontal Systems

7.8.1.7.1 Water Column Structure

52. Ocean stratification refers to the natural vertical layering of seawater based on density differences, primarily driven by variations in temperature and salinity. This vertical structure regulates global climate and marine health, as it governs the exchange of heat, carbon, and nutrients between water surface and deeper depths.

53. In shelf seas, stratification develops when surface waters are heated through insolation, creating a warmer, more buoyant body of water that overlies cooler, denser bottom waters. In shallow waters, turbulent mixing generated by a combination of tidal currents and wind/wave action is high and surface heating is not sufficient to generate stratification resulting in a homogenous water column. In deeper waters, where current speeds are lower, the effect of turbulent mixing is lower and warmer buoyant surface waters can persist creating stratification. This creates a sharp temperature difference between surface and bottom waters known as thermocline, which forms a barrier to vertical exchange of heat, salt, nutrients and momentum (Dorrell et al. 2022).

54. In northern European shelf seas, stratification is spatially and temporally variable (van Leeuwen et al. 2015). It is seasonal and strongest during the summer months when solar insolation is at its highest. It typically occurs in deeper water (water depths >80m) and can result in a warmer surface water layer of 5-40m thick (Dorrell et al. 2022).

55. To characterise water column structure within the WDA, monthly mean sea surface and sea bottom temperature and salinity from the SSW-RS (Barton et al., 2022), averaged across the WDA for the year 2019, were compared. A full explanation of the methodology, results and outputs are available in **Appendix 7.2 Marine Physical Environment Stratification**.

56. The outputs show very weak thermal stratification develops in May resulting in a thermocline at ~20m below the sea surface, reaching a peak in July when surface waters are 0.75°C warmer than bottom waters. By September, the water column is fully mixed and remains mixed for the remainder of the year. This very weak thermal stratification is spatially restricted to the northern and eastern part of the WDA. The southern part of the WDA remains well mixed throughout the year.

57. When a water body is stratified, a vertical density gradient establishes the gravitational potential energy distribution within the water column. To disrupt this state and mix the layers, external work must be performed. This external work is often quantified by the Potential Energy Anomaly (PEA) (Φ), which represents the mechanical energy per unit volume (in Joules per cubic meter, J/m^3) required to fully mix the water column. The PEA is used to determine the strength of stratification (Dorrell et al. 2022) with a threshold ≥ 20 J/m^3 typically indicating stratification (Berx and Hindson, 2020).

58. Using the SSW-RS outputs, instantaneous vertical profiles of water density were derived and used to calculate the PEA. The analysis shows the water column is well mixed throughout the year (**Plate 7.17**) as PEA values are lower than 20 J/m^3. Spatial variation within the PEA shows the nearest stratified water body is located 6 km to the west of the WDA during summer months.

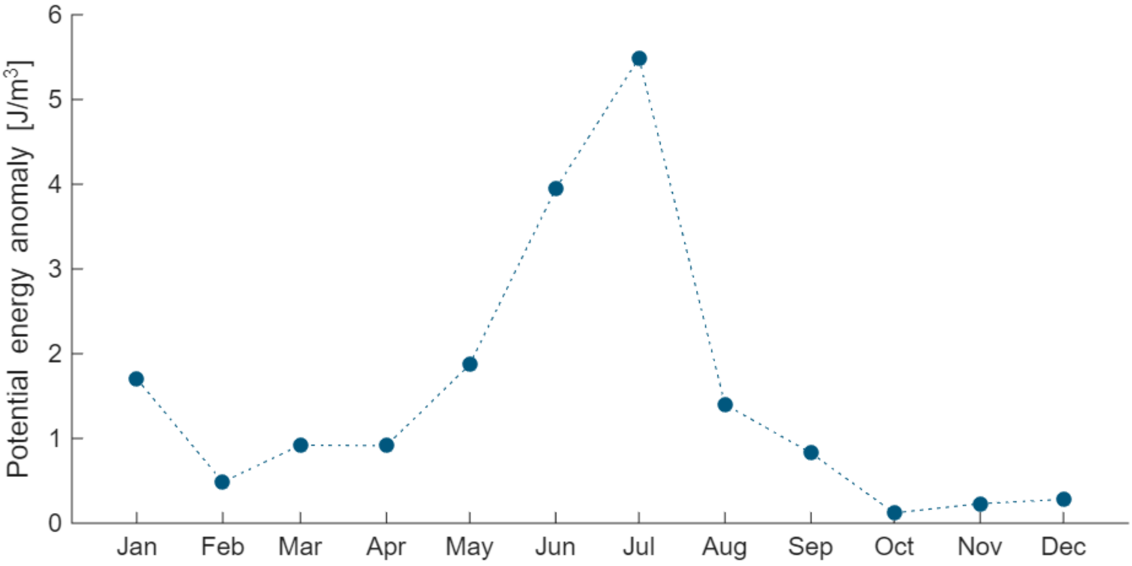


Plate 7.17 Monthly and spatially averaged Potential Energy Anomaly inside the WFDA

59. The analysis presented in **Appendix 7.2 Marine Physical Environment Stratification** is based on monthly averages for the year 2019. Recognising there may be inter annual variability in stratification strength, monthly PEA from 2010 to 2023 calculated from the Copernicus reanalysis dataset for the central North Sea (Thistle Wind Partners, 2025) were reviewed. The strength of stratification was greatest in 2023, weakest in 2015 and intermediate in 2019. This suggests that at a broad-scale, 2019 was a typical year but as the WDA is located in the Sea of Hebrides where sea surface temperature is typically warmer (Berx and Hughes, 2009) and water depth shallower, it does not account for regional variability.

60. Regional climatologies of sea surface and bottom temperature could be used to determine if 2019 was a typical year, or if stratification was weaker or stronger than usual. However, published climatologies do not cover recent years, including 2019 (Sharples et al., 2006; Berx and Hughes, 2009). An assessment of intra-annual variability in stratification from 1958 to 2008 by van Leeuwen et al. (2015) predicts the northern part of the WDA is “intermittently stratified” (defined as the water column being stratified <40 days of the year) and the southern part is “permanently mixed”. This broadly reflects the spatial patterns seen in the monthly averaged sea surface and bottom temperature outputs for 2019 from the SSW-RS (**Appendix 7.2 Marine Physical Environment Stratification**). In contrast, calculated PEA values based on the Copernicus reanalysis dataset indicate that the WDA is located in a water body classified as being mixed (Thistle Wind Partners 2025; Cenos 2025), which coincides with the calculated PEA for the WDA outlined in **Appendix 7.2 Marine Physical Environment Stratification**.

7.8.1.7.2 Fronts

61. Tidal mixing fronts separate seasonally stratified water bodies from well mixed water bodies and are regions of high biological productivity associated with elevated concentrations of Chlorophyll-a (a proxy for primary productivity). These fronts can be observed from satellite images of sea surface temperature or colour (e.g. Miller and Christodoulou, 2014).

62. The FRONTWARD project (Plymouth Marine Laboratory, 2025) analysed Earth Observation (EO) datasets to characterise the location and persistence of oceanographic fronts at the sea surface for the whole of the UK. FRONTWARD combines 10 years of sea surface temperature data and seven

years of sea surface colour (Chlorophyll-a) data forming UK wide grids representing average strength and persistence of fronts.

63. The outputs indicate a thermal front is present along the southern boundary of the WDA from April to August (**Plate 7.18** and **Plate 7.19**), running broadly east-northeast to west-southwest from the coast of Colonsay. This front likely forms at the boundary between thermally stratified water to the north and mixed water to the south, as indicated by the analysis of SSW-RS outputs (**Appendix 7.2 Marine Physical Environment Stratification**).

64. The strength and persistence of the front within the WDA is lower than the front observed to the west and southwest, off the coast of Ireland. Here, a complex frontal system known as the Islay Front develops in spring and summer (Hill and Simpson, 1988; Gowan et al., 1999). The front within the WDA may be an extension of the Islay Front.

65. There are no strong colour fronts within the WDA. However, chlorophyll concentration is higher in the northern part of the WDA, when compared to surrounding waters. The area of chlorophyll is strongest in April and May, likely marking the onset of the Spring Bloom and an increase in phytoplankton growth. This suggests that whilst the calculated PEA value indicates the water across the WDA is mixed (based on a threshold for stratification of 20 J/m^3), the development of weak thermal stratification in the north of the WDA may be sufficient to enhances primary productivity.

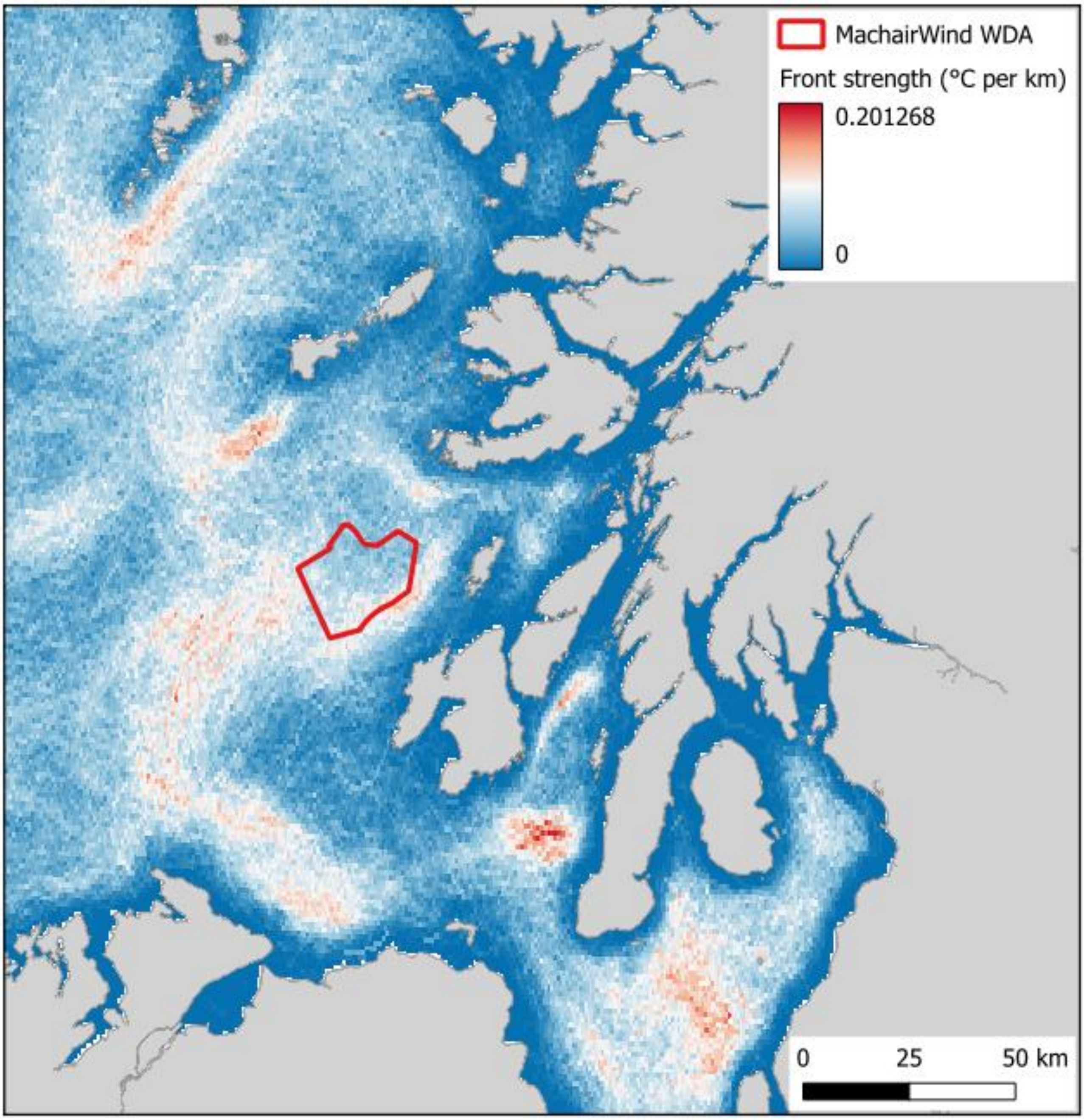


Plate 7.18 Long term average of sea surface thermal front strength from April to September for the period 2010 to 2019 (Plymouth Marine Laboratory, 2025)

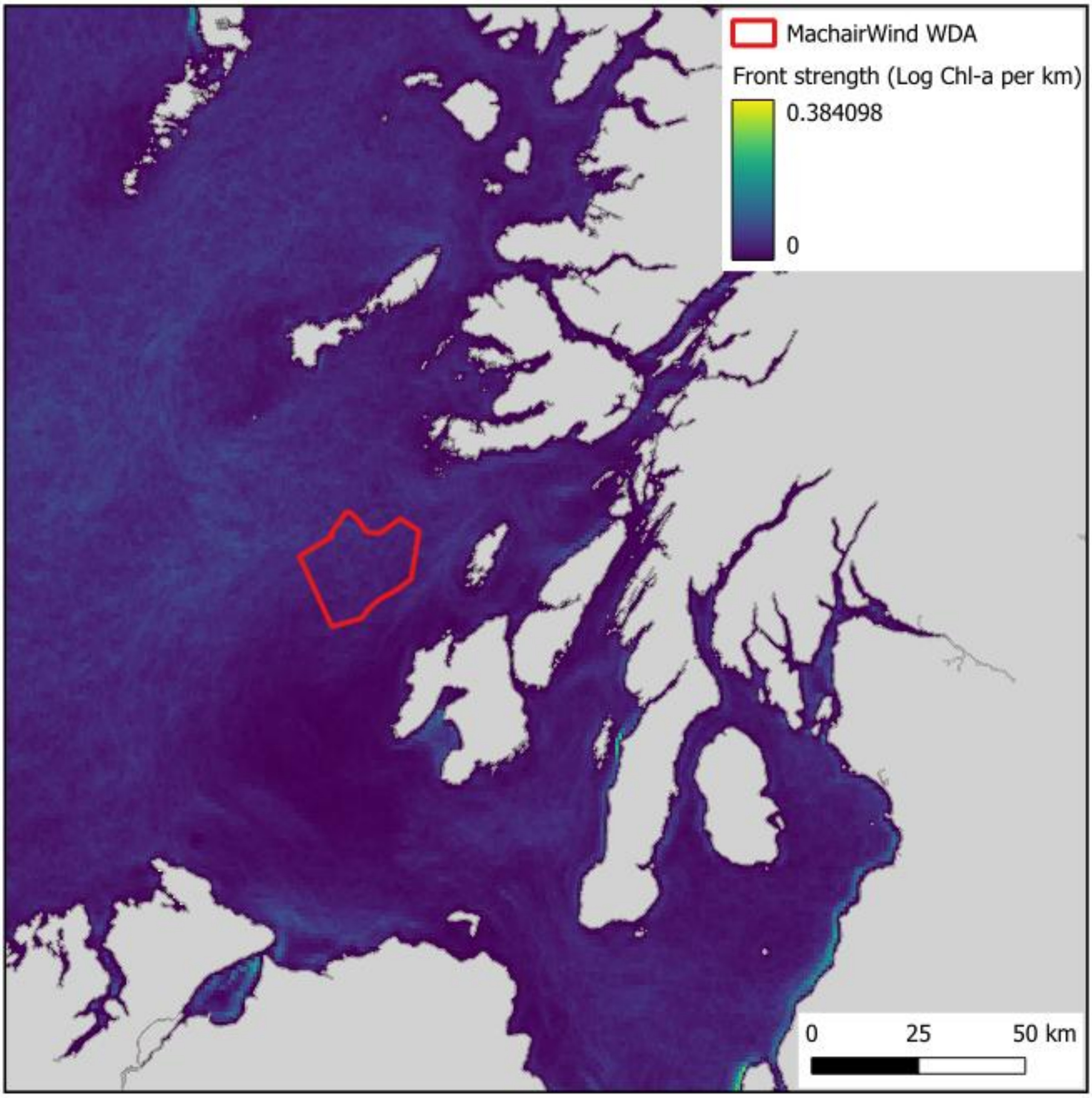


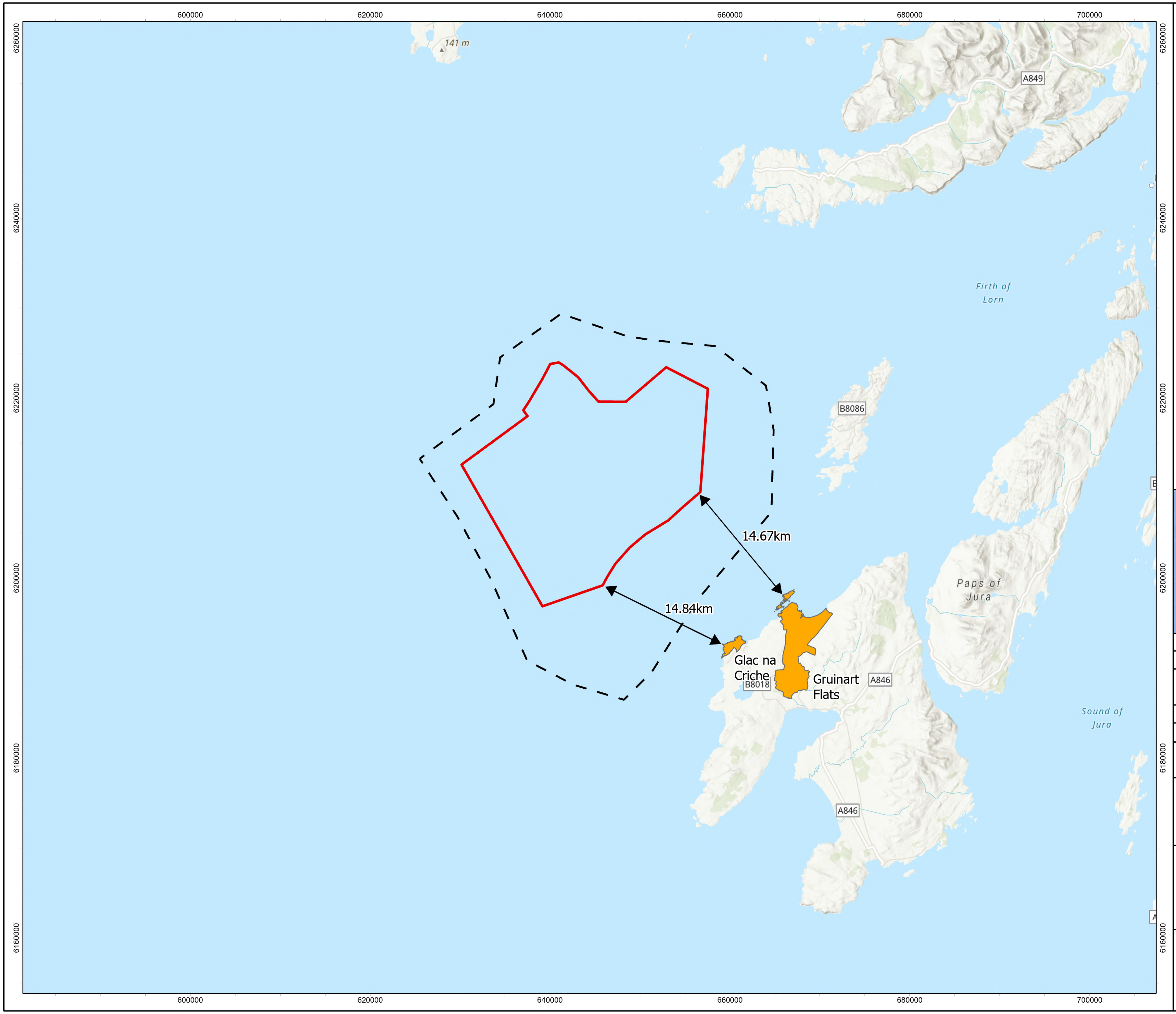
Plate 7.19 Long term average of sea surface chlorophyll-a (Chl-a) front strength from April to September for the period 2016 to 2023 (Plymouth Marine Laboratory, 2025)

7.8.1.7.3 Summary

66. In summary, calculated PEA values suggest the WDA is in a water body classified as being mixed. However, a weak thermocline can develop in the northern part of the WDA during the summer months (May to August) and observational evidence from satellite imagery suggest a thermal front and associated phytoplankton growth develops within the WDA during spring and summer months.

7.8.1.8 Designated Sites

67. The closest designated sites with relevant features for marine physical processes are at the coast: Gruinart Flats Site of Special Scientific Interest (SSSI) and Glac na Criche SSSI. These SSSIs are approximately 14.7 and 14.8 km respectively southeast of the WDA (**Figure 7.6**).



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REV	REV DATE	GIS CREATOR	GIS REVIEWER	TECHNICAL CHECKER	TECHNICAL APPROVER

DRAWING NUMBER MCW-DWF-ENV-MAP-RHS-000153

DATUM	ETRS89	PROJECTION	UTM Zone 29N
SCALE	1:400,000	PAGE SIZE	A3

PROJECT TITLE MachairWind

Figure 7.6: Distance between MachairWind WDA and the closest protected sites

Service Layer Credits: World_Hillshade: Esri, Ordnance Survey, NASA, NGA, USGS
World Ocean Reference: Sources: Esri, TomTom, Garmin, GEBCO, National Geographic, NOAA, and the GIS User Community
World Topographic Map: Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community
World Ocean Base: Esri, GEBCO, Garmin, NaturalVue

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7.8.2 Predicted Future Baseline

68. The baseline conditions for marine physical processes will continue to be controlled by waves and tidal currents driving changes in sediment transport and then seabed morphology. However, over long-term timescales, established performance of these drivers may be affected by environmental changes including climate change and associated sea-level rise. These broadscale environmental changes will occur regardless of the presence or absence of the Project infrastructure.

69. Considering the water depths across the WDA, any projected changes in sea level are unlikely to be significant enough to alter future tidal dynamics.

70. Changes to wave regimes may occur due to climate change. In principle, any changes will be related to increased water depths and changes to the frequency, duration and severity of storms. However, predicting these changes is extremely challenging. Bricheno et al. (2025) documents a shift in storm tracks in the UK since the 1990s and an increase in the annual mean number of storms. This has resulted in a reduction in mean significant wave height in the northern UK waters with an increase in the south. However, the authors acknowledge they have low confidence in predictions as the observed changes in storms and waves cannot be directly attributed to climate change due to the high degree of natural variability and limited understanding of associated mechanisms.

71. Global temperatures are predicted to rise due to climate change leading to warming of ocean water bodies and increased sea surface temperatures. The strength and timing of stratification is controlled by the interaction between solar insolation, tidal mixing and to a lesser extent, surface mixing by wind and waves. Changing meteorological conditions may therefore alter the baseline water column structure and frontal positions over the operational lifetime of the Project.

72. Understanding the effect of climate change on stratification is an emerging field of research. Initial model outputs from Sharples et al. (2022) suggest that by 2100, thermal stratification will develop up to one week earlier than at present, and extend 5-10 days later, extending the overall stratification period by up to two weeks. The model also predicts the strength of stratification will increase.

7.8.3 Data Limitations and Assumptions

73. Given the large amount of data that was collected for the site-specific surveys, there is a good baseline understanding of the marine physical environment at the WDA.

74. Any data limitations to the modelled results are outlined in the relevant appendices **Appendix 7.1 Marine Physical Environment Numerical Modelling** and **Appendix 7.2 Marine Physical Environment Stratification Analysis**.

7.9 EMBEDDED MITIGATION MEASURES

75. This section outlines the embedded mitigation relevant to the Marine Physical Environment assessment (as shown in **Table 7.8** below). Where additional mitigation measures are required to mitigate potentially significant effects (in EIA terms), these are detailed in the impact assessment (**Section 7.12**).

Table 7.8 Embedded mitigation measures for the Marine Physical Environment

ID	Mitigation Measure	Description	Securing Mechanism
M-1	Use of scour protection	Where necessary, foundations will include scour protection which will minimise the amount of scour and sediment released / transported due to scour.	Section 36 and marine licence consent conditions. Secured via the requirement for a Development Specification and Layout Plan, which will be submitted to Scottish Ministers for approval prior to the commencement of construction.
M-2	Piling	For piled foundation types, such as monopiles, pile-driving will be used in preference to drilling where it is practicable to do so (i.e. where ground conditions allow). This would minimise the quantity of subsurface sediment released into the water column from the installation process.	Section 36 and marine licence consent conditions. Secured via the requirement for a Development Specification and Layout Plan, which will be submitted to Scottish Ministers for approval prior to the commencement of construction.
M-8	Cable Plan	Development of, and adherence to, a Cable Plan (incorporating a Cable Burial Risk Assessment (CBRA)). The Cable Plan will confirm planned cable routeing, burial, and any additional external cable protection, and will set out methods for post-installation cable monitoring. Furthermore, this plan will detail environmental sensitivities and design considerations to mitigate, as far as practicable, the effects of offshore cable laying and associated protection during installation and operation of the WDA infrastructure. The amount of cable protection utilised will be minimised where practicable; protection will be used only where design burial depths are not achievable or where crossings require it. Benthic ecology receptors will be considered in the drafting of the Cable Plan.	Section 36 and marine licence consent conditions. Secured via the requirement for a Cable Plan, to be developed and submitted to the Scottish Ministers for approval before commencement of construction.
M-14	Micro-siting	Micro-siting of infrastructure, where practicable, around any identified sensitive habitats and identified anomalies of archaeological interest. Micro-siting mitigation would be agreed through consultation with MD-LOT and NatureScot on the identified sensitive benthic features (e.g. Annex I geogenic reef), and MD-LOT and historic environment advisors on anomalies	Section 36 and marine licenses consent conditions. Infrastructure will be micro-sited, where practicable, to avoid identified sensitive habitats and archaeological anomalies, following site-

ID	Mitigation Measure	Description	Securing Mechanism
		of archaeological interest, which are required to be avoided. Final agreement will be through the Development Specification and Layout Plan.	specific surveys and design reviews in accordance with **Appendix 6 Outline EMP**. Section 36 and marine licence consent conditions. Secured via **Appendix 11 Offshore Written Scheme of Investigation (WSI) and Protocol for Archaeological Discoveries (PAD)**.
M-46	Decommissioning Programme	Development and adherence to a Decommissioning Programme. This programme will identify all the items of equipment, infrastructure and materials that have been installed or drilled and describe the decommissioning solution for each, whilst considering the potential environmental effects of each method alongside appropriate mitigation techniques that can be implemented.	Section 36 and marine licence consent conditions. Secured via a Decommissioning Programme, which will be developed and submitted to Scottish Ministers for approval before commencement of construction.

7.10 APPROACH TO ASSESSMENT

76. As noted above, this topic chapter considers the WDA Study Area and existing environment only. A combined assessment of the construction, O&M and decommissioning of the WDA activities, Offshore ECC and OnTDA activities (commensurate with the level of detail that is available at the time of carrying out that appraisal) is also provided and the methodology for this is described in **Section 7.10.2**. This approach will ensure a holistic view is undertaken of the entire Project.

7.10.1 Windfarm Development Area-Alone

7.10.1.1 Methodology

77. **Chapter 5 EIA Methodology** provides a summary of the general impact assessment methodology applied in this WDA EIAR. The assessment uses the 'source-pathway-receptor' approach which identifies potential impacts resulting from the proposed activities on the environment and sensitive receptors within it. This method has been followed for the assessment of Marine Physical Environment receptors.

78. The Source-Pathway-Receptor (S-P-R) approach identifies the source of a potential impact (e.g. the activity/structure), the changes that occur because of the source and the impact on a particular receptor (pathway), with the receptor being the element that is affected by the impact. In the context of Marine Physical Environment, the pathway to impact is often represented by a sequence of inter linked changes that collectively lead to an effect. S-P-R models are conceptual in their basis; however, they are underpinned by an evidence base that integrates theoretical (e.g. expert judgment), empirical (e.g. observational) and numerical (e.g. numerical modelling) approaches.

79. An example of a S-P-R model in the context of Marine Physical Environment is: cable installation disturbs the seabed and sediment becomes suspended (the source), this leads to a change in SSCs in the water column relative to the baseline, and as this sediment is redeposited, seabed levels (and potential seabed sediment composition) change. The spatial extent (defined as the zone of influence) of this impact is determined by the tidal regime and how far the suspended sediment can travel before being redeposited. The receptors are any features that are sensitive to changes in SSCs, seabed level and sediment composition, that are present within the zone of influence for this impact.

80. With respect to the assessment of impacts related to Marine Physical Environment, the principal receptors are coastal or marine features with an inherent oceanographic, geological or geomorphological value or function which may be affected by the Project. These may include:

- Seabed morphological features (e.g. sandbanks, sandwaves, channels, palaeochannels / valleys);
- Coastal morphology features (e.g. beaches, estuaries, spits, adjacent coastline);
- Geodiversity (e.g. geomorphological/geological features and/or sedimentary deposits);
- Water column structure and features; and
- Coastal and marine recreational sites.

81. However, in addition to these receptors, changes to the Marine Physical Environment can also create a pathway to impact for receptors assessed for other topics, as defined in **Table 7.15**.

82. Consideration of the potential effects on the Marine Physical Environment is carried out at the following spatial scales:

- Individual structure scale (<1 km);
- Array scale (10s of kilometres); and

- Regional scale (>100 km).

83. Following the S-P-R approach, the assessment presented in this chapter is split into two phases: the first describes predicted changes to the Marine Physical Environment arising from the Project, and defines a zone of influence to screen receptors (**Section 7.11.2**). Where these changes directly affect Marine Physical Environment receptors, the second phase determines the significance of effect (**Section 7.12**), based on an assessment of the magnitude of impact and sensitivity of the receptor, following the criteria presented in **Section 7.10.1.3** to **Section 7.10.4** below. In cases where predicted changes to the Marine Physical Environment could manifest in impacts upon the receptors, the degree of change is determined in this chapter, but the assessment of significance of effect on other receptors is made within the relevant chapters of the EIA.

7.10.1.2 Definitions of Sensitivity and Magnitude

84. The sensitivity of a Marine Physical Environment receptor is dependent on the extent to which a receptor is adversely affected by an impact (tolerance), its ability to adapt to an impact to avoid adverse effects (adaptation), and its ability to return to a state at, or close to, that which existed before the effect caused a change (recoverability). The criteria for determining the sensitivity of a receptor are given in (**Table 7.9**) and these are assessed using expert judgement.

Table 7.9 Definitions of sensitivity for Marine Physical Environment receptors

Sensitivity	Definition
High	Tolerance: Receptor has very limited tolerance the impact Adaptability: Receptor unable to adapt to the impact Recoverability: Receptor unable to recover resulting in permanent or long-term (greater than ten years) change
Medium	Tolerance: Receptor has limited tolerance of the impact Adaptability: Receptor has limited ability to adapt to impact Recoverability: Receptor able to recover to an acceptable status over the medium term (five to ten years)
Low	Tolerance: Receptor has some tolerance of the impact Adaptability: Receptor has some ability to adapt to the impact Recoverability: Receptor able to recover to an acceptable status over the short term (one to five years)
Negligible	Tolerance: Receptor generally tolerant of the impact Adaptability: Receptor can completely adapt to the impact with no detectable changes Recoverability: Receptor able to recover to an acceptable status near instantaneously (less than one year)

85. In addition, a value component may also be considered when assessing a receptor. This ascribes whether the receptor is rare, protected or threatened (**Table 7.10**). It is important to understand that high value and high sensitivity are not necessarily linked within a particular effect. A receptor could be of high value (e.g. designated) but have a low or negligible physical sensitivity to an effect. Similarly, low value does not equate to low sensitivity and sensitivity is judged on a receptor-by-receptor basis. The value will be considered, where relevant, as a modifier for the sensitivity assigned to the receptor, based on expert judgement. In such situations, care has to be taken to not inflate

effect significance just because a feature is 'valued' and the narrative behind the assessment is important.

Table 7.10 Definition of the value for Marine Physical Environment receptors

Value	Definition
High	Receptor is designated and/or of national or international importance for marine physical environment. Likely to be rare with minimal potential for substitution. May also be of significant wider-scale, functional or strategic importance.
Medium	Receptor is not designated but is of local to regional importance for marine geology, oceanography or physical processes.
Low	Receptor is not designated but is of local importance for marine geology, oceanography or physical processes.
Negligible	Receptor is not considered to be particularly important or rare.

86. The probability of an impact occurring will be discussed as part of the narrative description for each impact along with a description of the nature of the change relative to the baseline. Definitions of the magnitude levels are given in **Table 7.11**.

Table 7.11 Definition of the magnitude for Marine Physical Environment receptors

Magnitude	Definition
High	Fundamental, permanent / irreversible changes, over the whole receptor, and / or fundamental alteration to key characteristics or features of the particular receptors character or distinctiveness
Medium	Considerable, permanent / irreversible changes, over the majority of the receptor, and / or discernible alteration to key characteristics or features of the particular receptors character or distinctiveness.
Low	Discernible, temporary (throughout project duration) change, over a minority of the receptor, and / or limited but discernible alteration to key characteristics or features of the particular receptors character or distinctiveness.
Negligible	Discernible, temporary (for part of the Project duration) change, or barely discernible change for any length of time, over a small area of the receptor, and/or slight alteration to key characteristics or features of the particular receptors character or distinctiveness.
No change	A change may occur but this change does not materialise into an effect on a receptor as there is no pathway to impact.

7.10.1.3 Significance of Effect

87. The potential significance of effect for a given impact is a function of the overall sensitivity and the magnitude of the impact (see **Chapter 5 EIA Methodology** for further details). A matrix is used (**Table 7.12**) as a framework to determine the significance of an effect. Definitions of each level of significance are provided in **Table 7.13**. Impacts and effects may be either positive (beneficial) or negative (adverse).

88. In applying this methodology, professional judgement contributes to concluding significance of effects. This judgement draws on the assessor's technical expertise, knowledge of the receiving environment, and understanding of how similar developments have influenced comparable receptors. Judgement also considers the quality and confidence of the available data (**Section 7.8.3**),

the level of uncertainty associated with predicted impacts, and any relevant guidance or industry standards. Professional judgement ensures that the matrix outputs are interpreted in context, allowing the assessor to account for site-specific conditions, receptor sensitivities that may cut across criteria, and the nature of the predicted changes. This approach ensures that the determination of significance is robust, transparent and proportionate

Table 7.12 Significance of effect matrix

Sensitivity	**Adverse Magnitude**				**Beneficial Magnitude**			
	High	**Medium**	**Low**	**Negligible**	**Negligible**	**Low**	**Medium**	**High**
High	Major	Major	Moderate	Minor	Minor	Moderate	Major	Major
Medium	Major	Moderate	Minor	Negligible	Negligible	Minor	Moderate	Major
Low	Moderate	Minor	Minor	Negligible	Negligible	Minor	Minor	Moderate
Negligible	Minor	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Minor

89. For the purposes of this WDA EIAR, ‘major’ and ‘moderate’ effects are deemed to be significant (in EIA terms). In addition, whilst ‘minor’ effects may not be significant, it is important to distinguish these from other non-significant (negligible) effects as they may contribute to significant effects cumulatively.

90. Following initial assessment, if the impact does not require additional mitigation (or none is possible) the residual effect will remain the same. If, additional mitigation is proposed there will be an assessment of the post-mitigation residual effect.

Table 7.13 Definition of significance of effect

Significance of Effect	**Definition**
Major	Very large or large change in receptor condition, both adverse or beneficial, which are likely to be important considerations at a regional or district level because they contribute to achieving national, regional or local objectives, or could result in exceedance of statutory objectives and / or breaches of legislation.
Moderate	Intermediate change in receptor condition, which are likely to be important considerations at a local level.
Minor	Small change in receptor condition, which may be raised as local issues but are unlikely to be important in the decision-making process.
Negligible	No discernible change in receptor condition.
No effect	No effect, therefore, no change in receptor condition.

7.10.2 Combined Assessment: Windfarm Development Area, Offshore ECC and Onshore Transmission Development Area Methodology

91. This section presents how the Applicant will assess interactions between the WDA, Offshore ECC and OnTDA (i.e. considering impact interactions and additive effects to determine if any effects would be materially elevated from those assessed for the WDA-alone assessment). The approach enables potential interactions between each Development Area to be identified and assessed, ensuring a whole Project assessment is undertaken in a manner that is meaningful and proportionate. This is referred to as the combined assessment.

92. In this context, interactions are considered where there may be spatial overlap of effects and additive effects are considered where there may be incremental effects on the same receptor, including increased temporal effects.

93. Worst-case scenarios for all WDA infrastructure (which includes OSPs, OSP link cables and up to 200 km of the offshore export cable(s) which could be located within the WDA) has been incorporated into the worst-case scenario for the WDA-alone assessment (**Table 7.6** and **Section 7.12.1**).

94. To inform the combined assessment, a set of assumptions were developed which includes a preliminary boundary for the Offshore ECC and OnTDA (connect point new Girvan, South Ayrshire), anticipated project components and associated construction methods and timelines. These are set out in **Chapter 3 Project Description**, Sections 3.7 and 3.8. Offshore and onshore engineering and environmental surveys enabling Offshore ECC and OnTDA corridor refinement are anticipated to take place after the WDA EIAR has been submitted to the consenting authorities.

95. Within the upcoming Offshore ECC and OnTDA consent applications, their respective scoping and EIARs will take account of all likely effects predicted within the WDA EIA and present updated combined assessments using the latest available information covering all aspects of the Project.

96. **Section 7.12.2** includes a qualitative discussion where potential interactions and additive effects between the WDA and the Offshore ECC and OnTDA have been identified, with the aim of determining whether effects could result in those of greater significance than assessed for the WDA-alone assessment. To accompany the description, a combined assessment summary table is provided. Only residual effects from the WDA-alone assessment are taken forward for consideration in the combined assessment.

7.10.3 Cumulative Effects Assessment Methodology

97. The CEA considers the impacts arising from the activities and infrastructure associated with the whole-Project (i.e. the WDA, Offshore ECC and OnTDA) as well as cumulatively with other relevant plans, projects and activities. The general approach to the CEA for the Marine Physical Environment includes identifying potential cumulative effects, identifying a short list of plans and projects for consideration and evaluating the significance of cumulative effects. **Chapter 5 EIA Methodology** provides further details on the general approach to the CEA.

98. In line with the methodology set out in **Chapter 5 EIA Methodology**, the CEA is considered in two main stages with stage 1 split into two steps:

- **Stage 1a**: Screening of Potential Cumulative Impacts;
- **Stage 1b**: Screening of other plans, projects and activities; and
- **Stage 2:** CEA.

99. Stage 1a involves the screening / identification of which whole-Project impacts could have a cumulative effect with other plans, projects and activities (described as ‘impact screening’). Stage 1b is the screening of other plans, projects and activities. In accordance with guidance documents discussed in **Chapter 5 EIA Methodology,** other plans or projects that are deemed likely to go ahead or are going ahead, and for which sufficient information is available to conduct a meaningful assessment, have been taken forward for consideration in **Appendix 5.1 Cumulative Projects Long and Short Lists**. If sufficient detail is not available, it is not possible to conduct a meaningful assessment of potential cumulative effects and therefore, these developments are not considered further. For the purposes of the CEA Long-List, the criteria of other plans or projects that are proposed for consideration include those which are ‘reasonably foreseeable’ such as those:

- Which have become operational since baseline data was collected;
- Under construction;
- Permitted application(s), but not yet implemented;
- Submitted application(s) not yet determined; and
- Plans and projects with design information in the public domain, including those that requested a Scoping Opinion up to six months prior to submission of the WDA application date as follows:
    - Projects in Scottish waters;
    - Projects in English, Welsh and Northern Irish waters, or other non-UK waters if considered to be relevant, have connectivity, or the potential for a cumulative effect;
    - Offshore wind projects granted an Option Agreement or Agreement for Lease; and
    - Non-wind projects.

100. The CEA Long-List has been developed based on the above criteria, and has been screened for each potential impact-receptor pathway using the following process:

- **Conceptual overlap**: an impact-receptor pathway describes an impact which has the potential to directly or indirectly affect the receptor(s) in question;
- **Physical overlap**: ability for impacts arising from the WDA, Offshore ECC and OnTDA to overlap with those from other plans or projects on a receptor basis. An overlap of the Zone of Influences (ZoIs) arising from the two (or more) projects/plans must be established for a cumulative effect to arise. There are exceptions to this for certain mobile receptors that are potentially subject to impacts from multiple plans or projects; and
- **Temporal overlap**: for a cumulative effect to arise from two or more plans or projects, a temporal overlap of impacts arising from each must be established. Some impacts are active only during certain phases of the WDA (e.g. piling noise during construction). However, the absence of a strict overlap may not necessarily mean there is no potential for cumulative effect, as receptors may become further affected by additional, non-temporally overlapping projects.

101. Stage 2 is the assessment of cumulative effects. A tiered approach is used to provide a framework for placing relative weight on the potential for each plan or project to be included in the CEA, based on the plan's or project's current stage of maturity, certainty in the design or effects and overall availability of detail on which to carry out an assessment. Projects or plans that will be assessed in Stage 2 will use the following tiers:

- Tier 1 assessment: projects which are operational (but not part of the baseline), under construction, those with consent and those projects where an application has been submitted but not yet determined;
- Tier 2 assessment: all plans/projects assessed under Tier 1, plus those projects with a Scoping Report and/or Scoping Opinion; and
- Tier 3 assessment: all plans/projects assessed under Tier 1 and Tier 2, plus those projects likely to come forward where a Crown Estate Scotland (CES) Option to Lease Agreement or equivalent has been granted (i.e., ScotWind and Innovation and Targeted Oil & Gas (INTOG) projects).

7.10.4 Transboundary Effects Assessment Methodology

102. The transboundary effect assessment considers the potential for effects to occur as a result of the WDA on Marine Physical Environment receptors within the Exclusive Economic Zone (EEZ) of other European Economic Area (EEA) member states or other interests of EEA member states. **Chapter 5 EIA Methodology** provides further details on the approach to the transboundary effect assessment.

103. As agreed with NatureScot (**Table 7.2**), transboundary effects on the Marine Physical Environment, have been screened out recognising that the WDA is approximately 33 km from the EEZ of the Republic of Ireland (**Section 7.14**). Given that the likely effects will be restricted to individual structure

and array scale change, coupled with their location at distance from the EEZ boundary, there would be no pathway for transboundary effects.

7.11 POTENTIAL IMPACTS

7.11.1 Scope

104. **Table 7.14** sets out the impacts that have been scoped in to and out of the Marine Physical Environment chapter, in line with the relevant Scoping Opinion for the WDA (**Appendix 2**).

105. In line with the impact assessment methodology set out in **Section 7.10**, the 'impacts' defined in the Scoping Report (**Table 7.14**) are described in this chapter as 'changes' that result in impacts that have an effect on a receptor. Where these changes have an effect on the marine physical environment, their significance of effect is assessed in **Section 7.12**, with reference to three impacts as defined in **Table 7.15**, and outlined below.

- Impact 1: Changes in suspended sediment concentrations (SSCs) and seabed levels (**Section 7.12.1.1**) includes:
    - Changes to SSC and transport; and
    - Changes in seabed level due to deposition of SSC.
- Impact 2: Changes in sediment transport regime and seabed morphology (**Section 7.12.1.2**) includes:
    - Changes to tide regime;
    - Changes to wave regime;
    - Changes to bedload sediment transport; and
    - Changes to seabed morphology.
- Impact 3: Changes to Water Column Structure (**Section 7.12.1.3**) includes:
    - Changes to water column stratification influencing nutrient fluxes and primary productivity;
    - Changes to tide regime; and
    - Changes to wave regime.

Table 7.14 Potential impacts scoped in and out of the EIA for Marine Physical Environment

Potential Impact	**Construction**		**Operation and Maintenance**		**Decommissioning**	
	Scoping Report	**Scoping Opinion**	**Scoping Report**	**Scoping Opinion**	**Scoping Report**	**Scoping Opinion**
Changes in SSCs and seabed levels	✓	✓	✓	✓	✓	✓
Changes to chemical contaminant concentrations associated with increases in suspended sediment	✘	✘	✘	✘	✘	✘
Changes to Water Column Structure	✘	✘	✓	✓	✘	✘
Changes in sediment transport regime and seabed morphology	✓	✓	✓	✓	✓	✓
Indentations on the seabed due to installation and decommissioning vessels	✘	✘	✘	✘	✘	✘
Changes water column stratification influencing nutrient fluxes and primary production	✘	✘	✘	✓	✘	✘

Table 7.15 Source-Pathway-Receptor Model for Marine Physical Environment

Impact Group	Source (Activity)	Pathway		Impact	Potential Receptors	Where is it assessed?
		Direct Change	Indirect Change			
Impact 1	Disturbance of seabed sediments due to: **Construction** - Seabed preparation (e.g. seabed levelling, sandwave clearance) - Installation of the WDA infrastructure **Operation** - Maintenance activities including cable repairs or reburial.	Changes in SSCs	Changes in seabed level due to deposition of suspended sediment	- Elevated SSC has the potential to impact SSC in the water column outside of natural variation. - Deposition of suspended sediment has the potential to change the composition of seabed sediments. - Deposition of suspended sediment has the potential to change seabed levels.	Seabed sediments Seabed level Seabed morphology Coastal receptors	**Chapter 7 Marine Physical Environment**
				- Increased SSCs has the potential to affect benthic ecology receptors by causing physical damage or injury, blocking feeding apparatus and by smothering sessile species upon redeposition. - Deposition of suspended sediment has the potential to change the composition of seabed sediments potentially affecting the habitats they support.	Benthic habitats and species	**Chapter 8 Benthic Ecology**
				- Elevated SSCs reduce visibility and visual hunting strategy success, reduce photosynthetic efficiency of phytoplankton (due to reduced light intensity and altered spectrum) and smothering affects filter-feeding species and eggs and / or larvae.	Fish and shellfish habitats and species	**Chapter 9 Fish (including Basking Shark) and Shellfish**
				- Elevated SSCs reduce visibility and visual hunting strategy success.	Marine mammal species	**Chapter 10 Marine Mammals and Leatherback Turtle**
				- Elevated SSCs reduce visibility and visual hunting strategy success, reduce photosynthetic efficiency of phytoplankton (due to reduced light intensity and altered spectrum) and smothering affects filter-feeding species and eggs and / or larvae.	Fishing activity success	**Chapter 12 Commercial Fisheries**
				- Changes to seabed level can result in an exposed heritage asset becoming buried, improving preservation conditions.	Cultural significance of known and potential heritage assets	**Chapter 14 Offshore Archaeology and Cultural Heritage**
Impact 2	**Construction** - Seabed preparation (e.g. seabed levelling, sandwave clearance) **Operation** - The presence of WDA infrastructure in the water column - The presence of WDA infrastructure on the seabed (e.g. scour and cable protection)	Changes to wave and tide regime Changes to seabed morphology	Changes in sediment transport regime and seabed morphology	- Changes in wave and tidal regime will alter seabed currents and bed shear stress in the wake of structures in the water column potentially leading to a change in sediment transport pathways through erosion (scour) and deposition. - There is potential for seabed preparation to directly change the morphology of the seabed. - There is also potential for changes to the wave and tide regime to indirectly change the morphology of the seabed by changing sediment transport regimes.	Seabed morphology Seabed sediments Coastal receptors	**Chapter 7 Marine Physical Environment**
				- Changes in sediment transport regimes has the potential to change the composition of seabed sediments potentially affecting the habitats they support. - Changes in seabed morphology have the potential to change the composition of seabed sediments potentially affecting the habitats they support (e.g. removal of sandwave could expose underlying sediments of a different composition).	Benthic habitats and species	**Chapter 8 Benthic Ecology**
				- Changes in sediment transport regime and seabed morphology may cause changes in sediment composition, thereby improving or degrading habitat	Fish and shellfish habitats and species	**Chapter 9 Fish (including Basking Shark) and Shellfish**

Impact Group	Source (Activity)	Pathway		Impact	Potential Receptors	Where is it assessed?
		Direct Change	Indirect Change			
				suitability for fish and shellfish species that have specific substrate requirements.		
				• Changes in sediment transport regime and seabed morphology will not directly affect marine mammals. However, it may indirectly affect the benthic and fish communities which will in turn effect marine mammals, thereby improving or degrading the suitability of prey species for marine mammal species that have specific substrate requirements.	Marine mammal species	**Chapter 10 Marine Mammals and Leatherback Turtle**
				• Changes in sediment transport regime and seabed morphology may cause changes in sediment composition, thereby improving or degrading habitat suitability for fish and shellfish species that have specific substrate requirements.	Fishing activity success	**Chapter 12 Commercial Fisheries**
				• Changes in sediment transport regime or seabed morphology can result in an exposed heritage asset becoming buried, improving preservation conditions, or buried heritage assets becoming exposed, compromising preservation conditions.	Cultural significance of known and potential heritage assets	**Chapter 14 Offshore Archaeology and Cultural Heritage**
Impact 3	**Operation** • The presence of WDA infrastructure in the water column	Changes to wave and tide regime	Changes in water stratification and mixing	• There is potential for change in tidal currents in the wake of structures in the water column to enhance water column mixing. • There is potential for a change in wind generated waves in the wake of structures above the sea surface to reduce water column mixing. • There is potential for changes in primary productivity due to changes in Water Column Structure.	Oceanographic fronts and Water Column Structure	**Chapter 7 Marine Physical Environment**
				• Changes in primary productivity could lead to disruptions of energy transfer through trophic levels and affect the biodiversity of the benthic habitats.	Benthic habitats and species	**Chapter 8 Benthic Ecology**
				• Changes in primary productivity may directly lead to localised change in food availability for planktonic fish and shellfish larvae, and phytoplankton filter-feeding shellfish such as bivalves. • Changes in primary productivity may lead to localised changes in the food web, leading to changes in predator-prey dynamics and distribution of fish and shellfish species.	Fish and shellfish habitats and species	**Chapter 9 Fish (including Basking Shark) and Shellfish**
				• Changes in primary productivity may lead to a localised change in availability for planktonic fish and shellfish larvae, alongside filter feeders. • These changes may lead to localised changes in the food web, leading to changes in predator-prey dynamics and distribution of affected species, which in turn will affect marine mammal species, such as the baleen whales who feed on species such as krill.	Marine mammal species	**Chapter 10 Marine Mammals and Leatherback Turtle**
				• Changes in primary productivity may directly lead to localised change in food availability for planktonic fish and shellfish larvae, and phytoplankton filter-feeding shellfish such as bivalves. • •	Fishing activity success	**Chapter 12 Commercial Fisheries**

7.11.2 Pathways to Impact

7.11.2.1 Introduction

106. This section presents the predicted changes in the marine physical environment that may occur due to activities and infrastructure associated with the Project. These changes are presented independent of the assessment of significance in **Section 7.12** as they have the potential to effect receptors assessed for other topics, as defined in **Table 7.15**.

107. The degree of change with respect to the marine physical environment is established through consideration of the scale (i.e. size, extent or intensity), duration (short term to long term) and frequency of occurrence (**Table 7.16)**. This is used to inform the assessment of magnitude of impact in **Section 7.12**.

Table 7.16 Definition of the degree of change in Marine Physical Environment

Degree of change	Definition
High	Scale: A change which would extend beyond the natural variations in background conditions. Duration: Change persists for more than ten years. Frequency: The change would always occur.
Medium	Scale: A change which would be noticeable from monitoring but remains within the range of natural variations in background conditions. Duration: Change persists for five to ten years. Frequency: The change would occur regularly but not all the time.
Low	Scale: A change which would barely be noticeable from monitoring and is small compared to natural variations in background conditions. Duration: Change persists for one to five years. Frequency: The change would occur occasionally but not all the time.
Negligible	Scale: A change which would not be noticeable from monitoring and is extremely small compared to natural variations in background conditions. Duration: Change persists for less than one year. Frequency: The change would occur highly infrequently.
No change	No change

7.11.2.2 Impact 1: Changes in Suspended Sediment Concentration (SSC)

108. During the construction of the Project there is potential for the installation of the WDA infrastructure to cause changes to the SSC, particularly near the seabed, due to the nature of construction activities. By disturbing seabed sediments to install infrastructure, SSCs within the water column are increased for a limited period of time, focused around the ongoing construction activity. SSC returns to baseline conditions with increasing distance from the construction activity and over time at the location of the construction activity (once construction is completed). The distance and time required to return to baseline conditions during and following construction, respectively, depends on the type and subsequent intensity of construction works.

109. Numerical modelling of changes in SSC due to the worst-case construction activities and Project layout in the WDA was undertaken. This provides an evidence base to assess the effects of construction on the SSC (**Appendix 7.1 Marine Physical Environment Numerical Modelling**).

7.11.2.2.1 Drilling for WTG and OSP Foundations

110. Drilling is considered the worst-case scenario for installation of foundations within the WDA. The SSCs during drilling are greatest (1 to 5 mg/l) near the seabed, typically within 300 m of the structures (**Plate 7.20**). In the south of the WDA, larger sediment plumes form, extending up to 4 km beyond the WDA southwards.

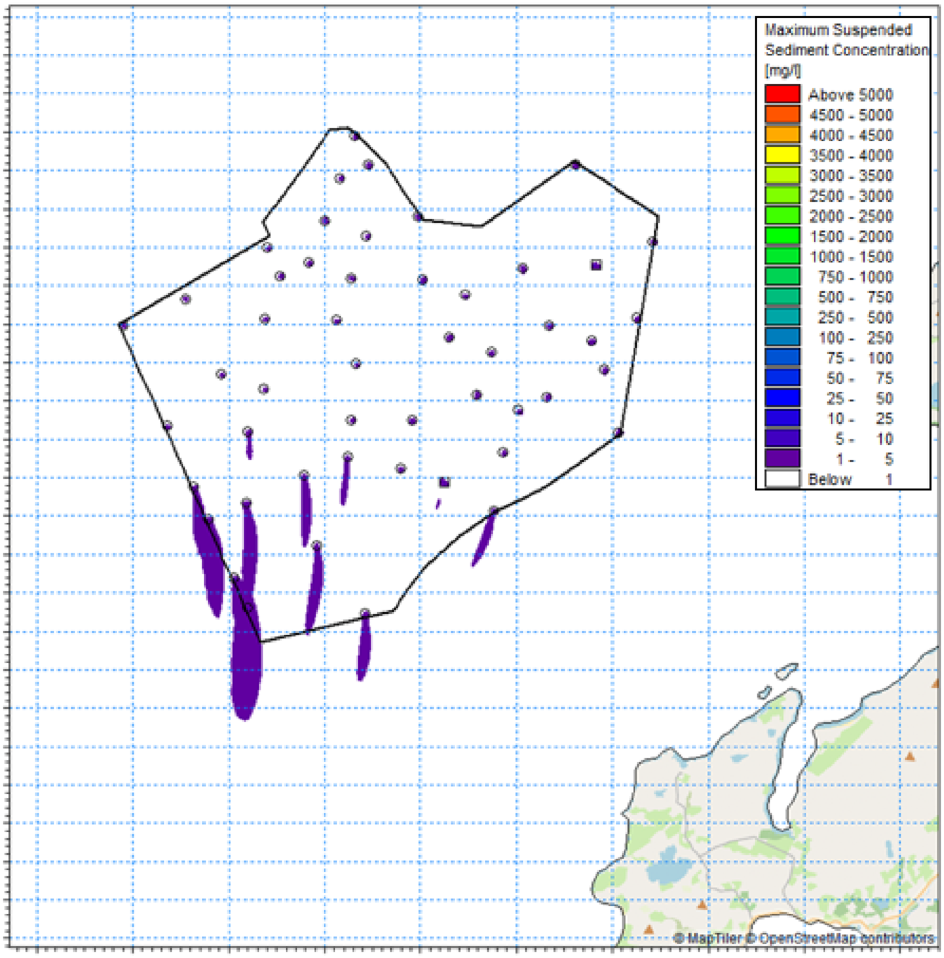


Plate 7.20 Maximum SSC during drilling activities for structures occurring near the seabed

7.11.2.2.2 Seabed Preparation for WTGs and OSPs

111. The maximum SSCs during seabed preparation for foundation installation occur near the seabed and typically occur within 4 km of the area of disturbance, resulting in concentrations between 1 and 4 mg/l (**Plate 7.21**). The model outputs provide an indication of the maximum extent and concentration of multiple plumes created over the full duration of the seabed preparation activity. However, each plume is short-lived and baseline conditions return rapidly within hours of the disturbance as shown on **Plate 7.22**. Therefore, one plume will disperse fully before the next one is created minimising overlapping effects between plumes.

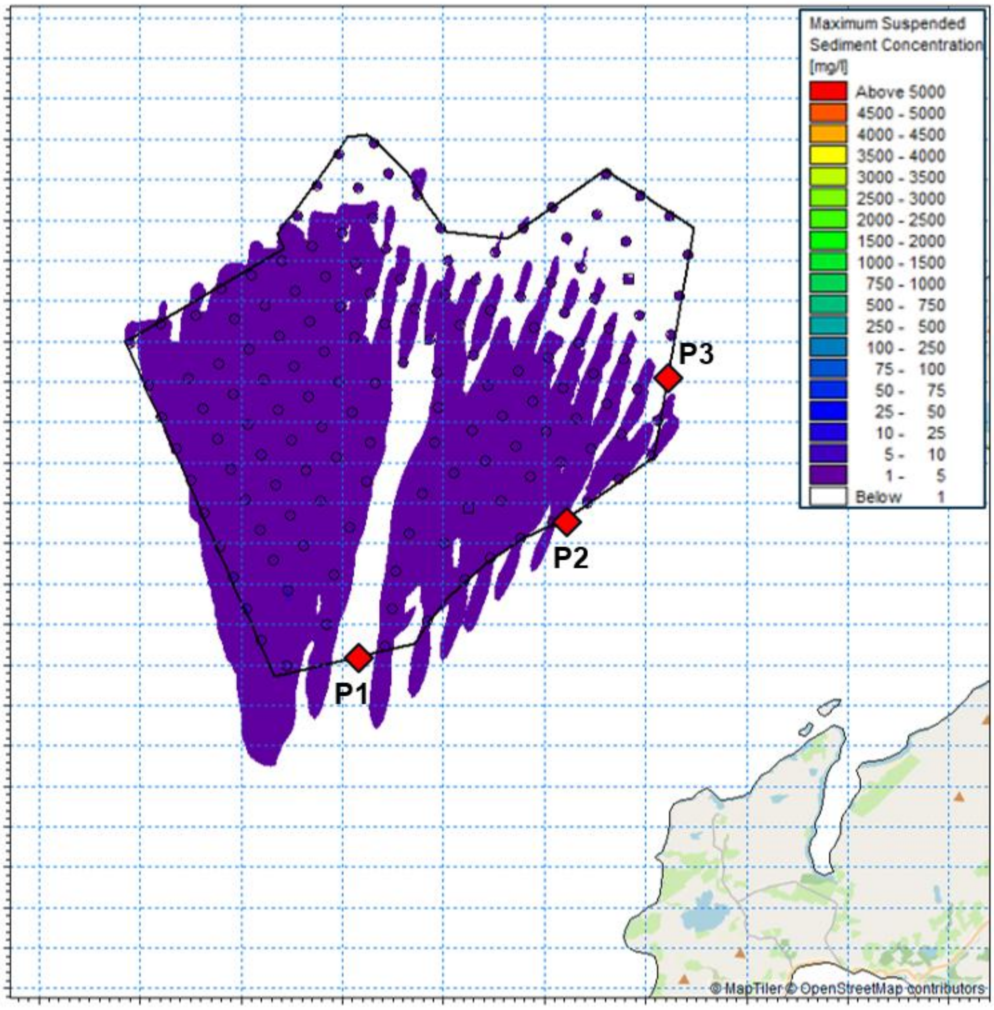


Plate 7.21 Maximum suspended sediment concentration (SSC) during bed preparation activities for structures occurring near the seabed

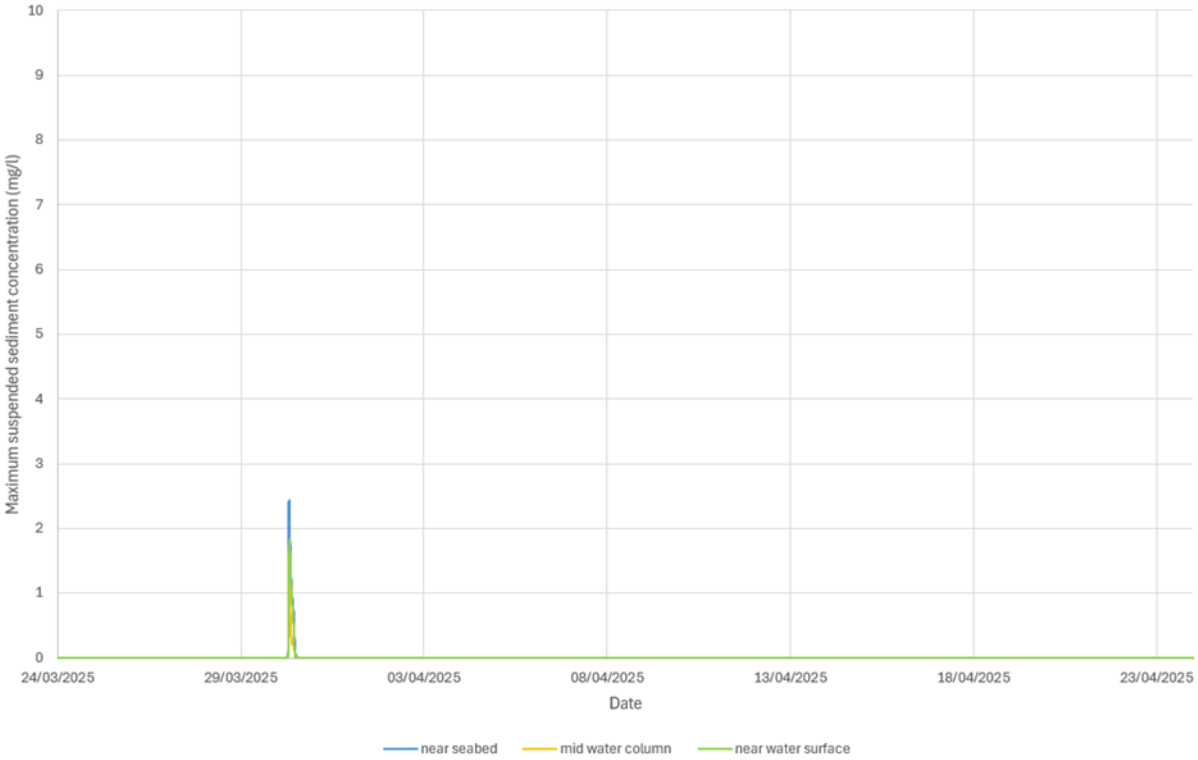
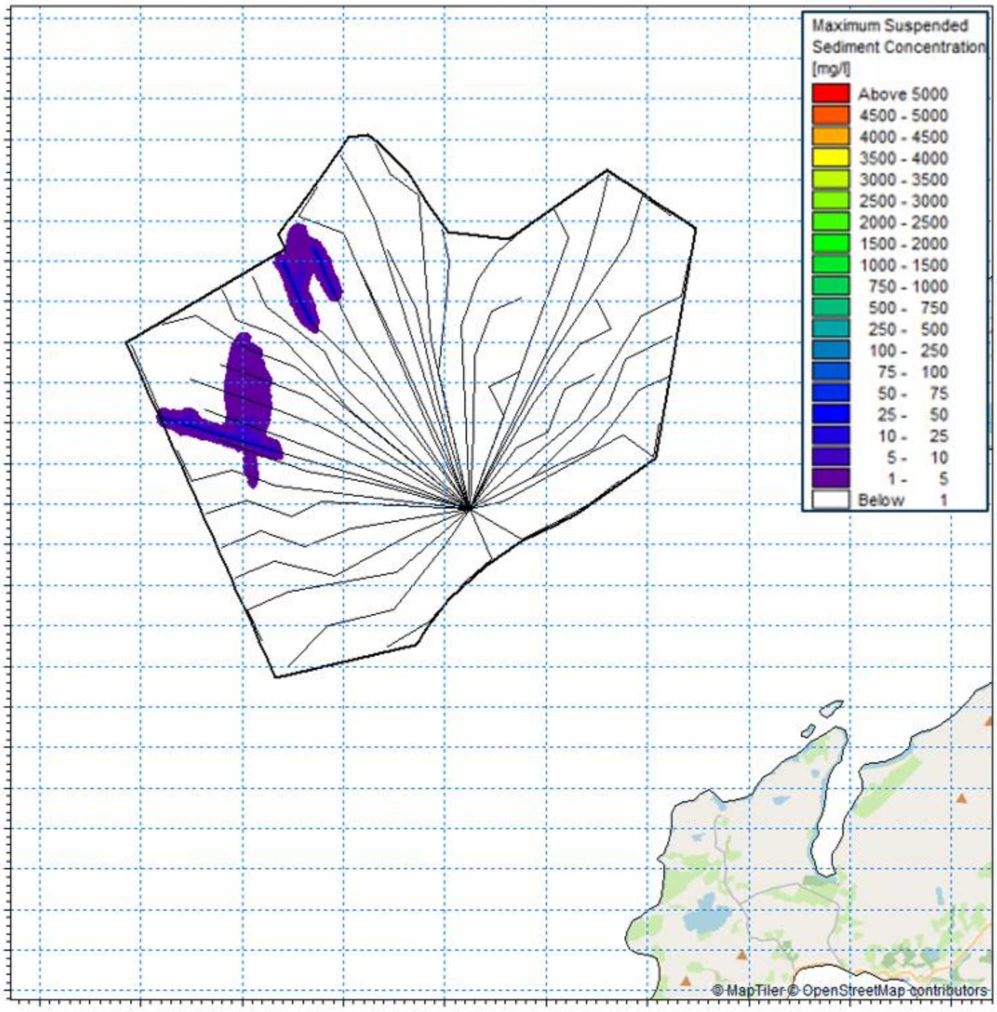


Plate 7.22 Time series of suspended sediment concentration (SSC) at P2 during bed preparation activities for structures near seabed, middle of water column and near water surface

7.11.2.2.3 Sandwave Levelling for Cable Installation

112. Changes in SSC due to sandwave clearance were modelled in areas of the WDA where sandwaves are present on the seabed (**Appendix 7.1 Marine Physical Environment Numerical Modelling**). SSCs during sandwave levelling could reach a maximum of between 25 and 40 mg/l near the seabed within 140 m of the area of disturbance. Typically, SSCs of between 5 and 25 mg/l occur within 250 m of the area of disturbance and SSCs between 1 and 5 mg/l occur within 5 km (**Plate 7.23**).



© MapTiler © OpenStreetMap contributors

Plate 7.23 Maximum suspended sediment concentration (SSC) during sandwave clearance levelling activities for structures occurring near the seabed

7.11.2.2.4 Ploughing for Cable Installation

113. Cable installation was simulated using a cable plough creating a ‘v’-shaped trench with a sediment release rate of is 2,275.52 kg/s and with the material being released near the seabed (**Appendix 7.1 Marine Physical Environment Numerical Modelling**). The results show changes in SSC are greatest near the seabed, gradually reducing towards the water surface. Changes in SSC levels of ≤5 mg/s (near the seabed) may occur across the entire WDA and extend approximately 8 km southwards and 3 km northwards beyond the WDA boundary (**Plate 7.24**), but they will not occur simultaneously. The model output in **Plate 7.24** shows the maximum concentration over the full installation period and does not account for dispersion which occurs within hours of disturbance (**Plate 7.25**). Therefore, the highest concentrations represent cumulative changes in SSC at a particular point due to multiple phases of cable installation. In reality, SSC levels will be lower as a plume will disperse before the next phase of disturbance. Changes in SSC levels close to the cables are on average between 1,500 and 2,500 mg/l, extending up to 150 m either side of the cable.

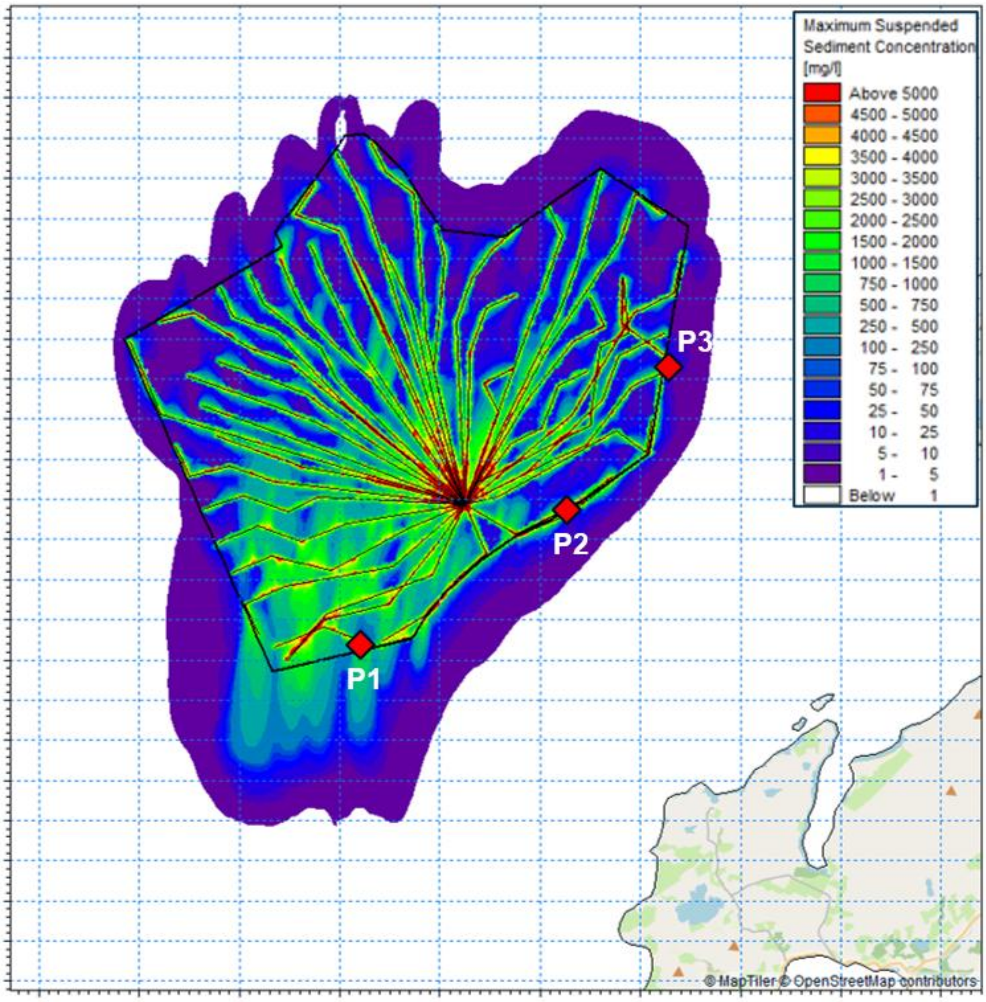


Plate 7.24 Maximum SSC during cable installation activities for structures occurring near the seabed

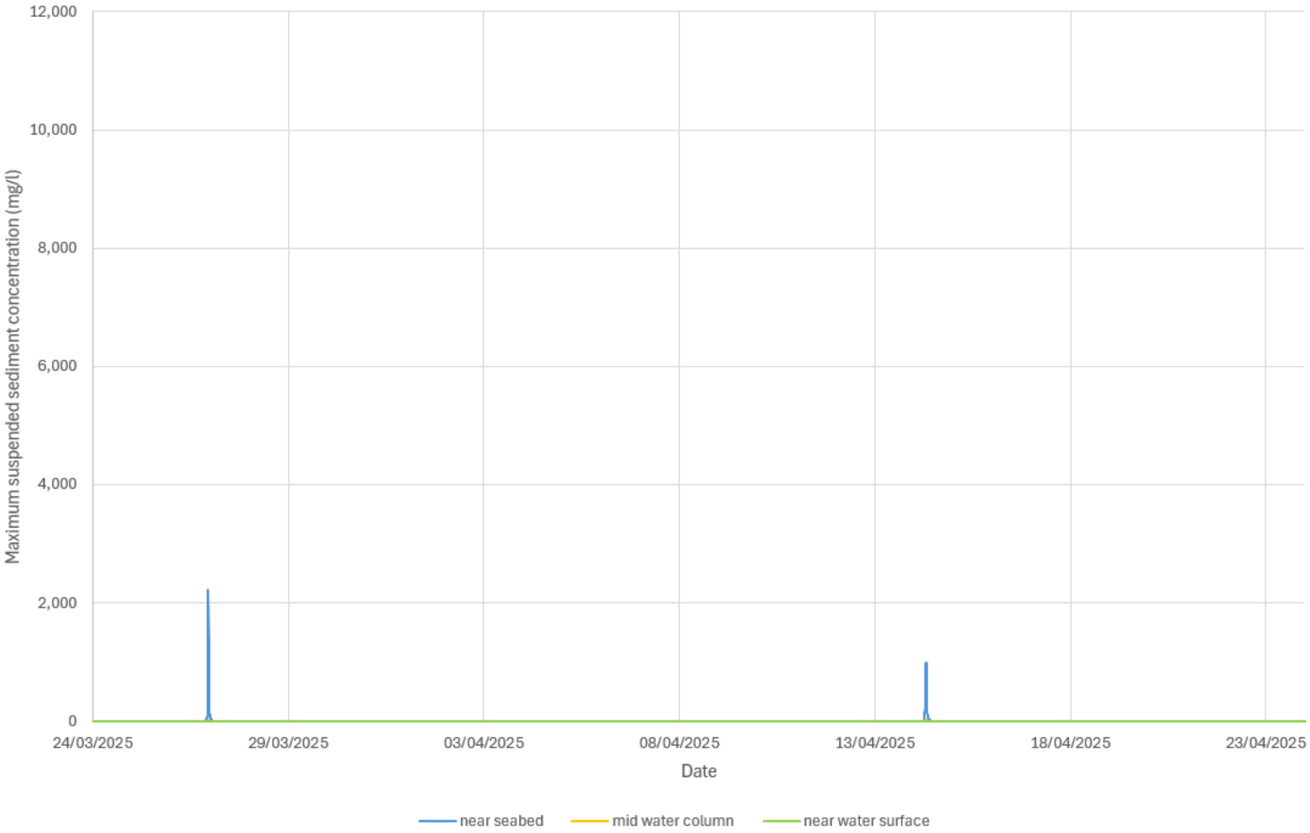


Plate 7.25 Time series of suspended sediment concentration at P2 during cable installation activities for structures near seabed, middle of water column and near water surface

7.11.2.2.5 Summary

114. Changes in SSCs due to drilling of WTG and OSP foundations, seabed preparation for foundations, sandwave levelling for cable installation and ploughing for cable installation result in both localised individual structure-scale and array-scale effects, no changes occur at the regional scale. During disturbance, SSCs exceed background levels and would be noticeable from monitoring with the resulting plumes extending up to a maximum of 5 km from the point of disturbance. However, individual plumes persist for a very short time (less than a few hours) meaning one plume will have dispersed before the next one is created, and the effect will occur infrequently during construction. The Degree of Change is therefore defined as Low at the individual structure and array scale (**Table 7.17**).

Table 7.17 Summary of changes to SSCs

Activity	Extent	Scale	Duration	Frequency	Degree of change
Construction					
Drilling for WTG and OSP Foundations	Individual structure/ activity scale (<1 km)	High	Negligible	Negligible	Low
	Array scale (10s of kilometers)	High	Negligible	Negligible	Low

Activity	Extent	Scale	Duration	Frequency	Degree of change
	Regional scale (>100 km)	-	-	-	No Change
Seabed Preparation for WTGs and OSPs	Individual structure/ activity scale (<1 km)	High	Negligible	Negligible	Low
	Array scale (10s of kilometers)	High	Negligible	Negligible	Low
	Regional scale (>100 km)	-	-	-	No Change
Sandwave levelling for cable installation	Individual structure/ activity scale (<1 km)	High	Negligible	Negligible	Low
	Array scale (10s of kilometers)	High	Negligible	Negligible	Low
	Regional scale (>100 km)	-	-	-	No Change
Ploughing for cable installation	Individual structure/ activity scale (<1 km)	High	Negligible	Negligible	Low
	Array scale (10s of kilometers)	High	Negligible	Negligible	Low
	Regional scale (>100 km)	-	-	-	No Change
Operation					
It is anticipated that the degree of change associated with operation will be less than those experienced during the construction phase. Whilst activities such as cable repair and reburial will occur over the full duration of the operational lifetime, they will be infrequent and the changes will be short-lived in duration.					
Decommissioning					
It is anticipated that the degree of change associated with decommissioning will be equal to, or potentially less than, those experienced during the construction phase.					

7.11.2.3 Impact 1: Changes to Seabed Level

115. During the construction of the Project there is potential for the installation of the WDA infrastructure to cause changes to the SSC, as described in **Section 7.11.2.2**. When suspended sediment settles out of the water column it is deposited onto the seabed potentially leading to changes in seabed levels.

116. Numerical modelling of changes to seabed level due to the worst-case construction activities and WTG / OSP layout in the WDA was undertaken. This provides an evidence base to assess the effects of construction on seabed level change (**Appendix 7.1 Marine Physical Environment Numerical Modelling**).

117. Changes in SSC for the following construction activities resulted in changes in seabed levels of less than 5 cm:

- Drilling for WTG and OSP foundations;
- Seabed preparation for WTGs and OSPs; and
- Sandwave levelling for cable installation.

118. Given the scale of these changes, they are not described in detail here as the modelling outputs indicate changes of less than 5 cm are highly localised and occur within meters of the area of disturbance which are indistinguishable at the spatial scale of the model.

7.11.2.3.1 Cable Installation

119. Based on the worst-case scenario, ploughing for cable installation is predicted to change seabed level above the 5 cm threshold (**Plate 7.26**). Deposition of SSC occurs up to 200 m either side of the cable trenches, reaching levels of between 0.1 and 0.2 m on average. Deposition between 0.2 and 0.3 m occurs up to 100 m either side of the trench. Where several cables are close together deposition may reach levels between 0.3 and 0.4 m. Predicted deposition is highest where all the cables ‘meet’ at the OSPs, with levels ≤4.0 m. However, these levels are an artefact of the modelling which assumes sediment is deposited cumulatively and that there is no redeposition between different phases of cable installation. In reality, once SSC is deposited, seabed levels will change but baseline bedload sediment transport processes will redistribute the sediment before installation of the adjacent cable which would deposit more sediment and change seabed levels again. Once construction is complete, all sediment deposited will be redistributed given the seabed is highly dynamic.

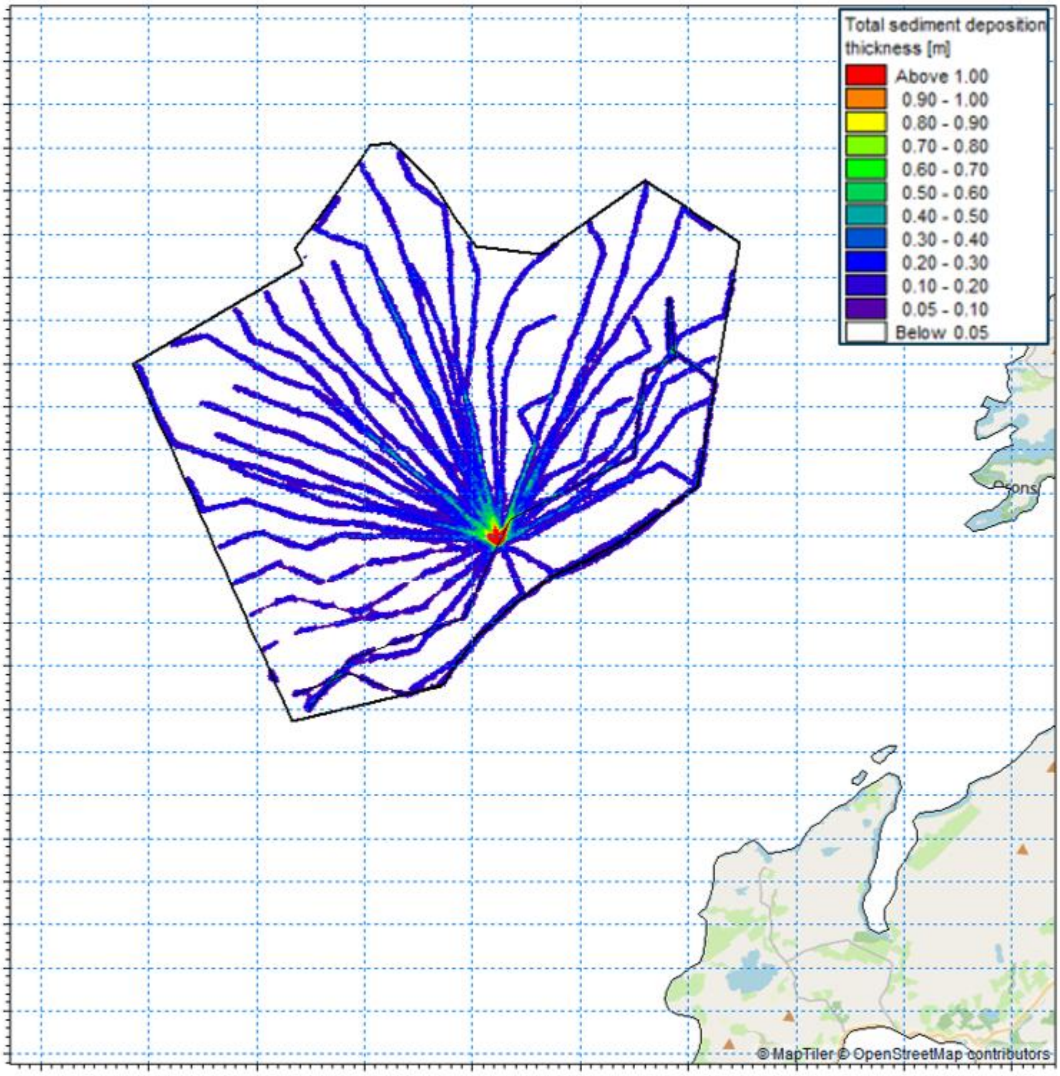


Plate 7.26 Total sediment deposition thickness during ploughing activities for cable installation

7.11.2.3.2 Summary

120. The majority of construction activities will not generate seabed level change ≥5 cm. As a worst-case scenario, ploughing for cable installation is predicted to generate deposition of up to 4 m but this is an artefact of the modelling as outlined in **Section 7.11.2.3.1**. During the ploughing process, changes in seabed level are typically predicted to be <0.3 m within the WDA, changes do not extend beyond the boundary of the WDA. Given the sand-dominated nature of seabed sediments (**Table 7.7**) this sediment will likely be transported as bedload by prevailing tidal currents and with time, the seabed will return to previous levels.

Table 7.18 Summary of changes to seabed level

Activity	Extent	Scale	Duration	Frequency	Degree of change
Construction					
	Individual structure/ activity scale (<1 km)	Negligible	Negligible	Negligible	Negligible

Activity	Extent	Scale	Duration	Frequency	Degree of change
Drilling for WTG and OSP foundations	Array scale (10s of kilometers)	-	-	-	No Change
	Regional scale (>100km)	-	-	-	No Change
Seabed preparation for WTGs and OSPs	Individual structure/ activity scale (<1 km)	Negligible	Negligible	Negligible	Negligible
	Array scale (10s of kilometers)	-	-	-	No Change
	Regional scale (>100 km)	-	-	-	No Change
Sandwave levelling for cable installation	Individual structure/ activity scale (<1 km)	Negligible	Negligible	Negligible	Negligible
	Array scale (10s of kilometers)	-	-	-	No Change
	Regional scale (>100 km)	-	-	-	No Change
Ploughing for cable installation	Individual structure/ activity scale (<1 km)	Low	Negligible	Negligible	Low
	Array scale (10s of kilometers)	-	-	-	No Change
	Regional scale (>100 km)	-	-	-	No Change
Operation					
It is anticipated that the degree of change associated with operation will be less than those experienced during the construction phase as whilst activities such as cable repair and reburial will occur over the full duration of the operational lifetime, they will be infrequent, and the changes will be short-lived in duration.					
Decommissioning					
It is anticipated that the degree of change associated with decommissioning will be equal to, or potentially less than, those experienced during the construction phase.					

7.11.2.4 Impact 2 and 3: Changes to Tidal Regime

121. During the operation of the Project there is potential for the presence of foundations to cause changes to the tidal regime, particularly tidal currents, due to physical blockage effects. The foundations create obstacles, modifying the characteristics of flow around the structures. Currents return to baseline conditions with increasing distance from each foundation. The distance required to return to baseline conditions depends on the foundations spacing and individual foundations type and size.

122. Numerical modelling of changes in hydrodynamic regime due to the worst-case foundation type, size, number and layout in the WDA was undertaken to provide an evidence base to assess the effects of the WDA infrastructure on the tidal regime (**Appendix 7.1 Marine Physical Environment Numerical Modelling**).

123. The maximum change in current speeds is -0.06 m/s during the peak flood stage of the spring tide, within <5 km of the OSP foundations (**Plate 7.27**). Changes in current speed due to WTGs are lower at <-0.02 m/s - this occurs locally during the peak flood stage of the spring tide within a kilometre of the foundations. At peak flood, the percentage difference compared to baseline current speed is a reduction of up to 1% extending up to 2.5 km north of the WDA (**Plate 7.28**). At peak ebb, there is a reduction of up to 1% extending 8 km north-west of the WDA and an increase of up to 2% extending 7 km north-east of the WDA (**Plate 7.29**).

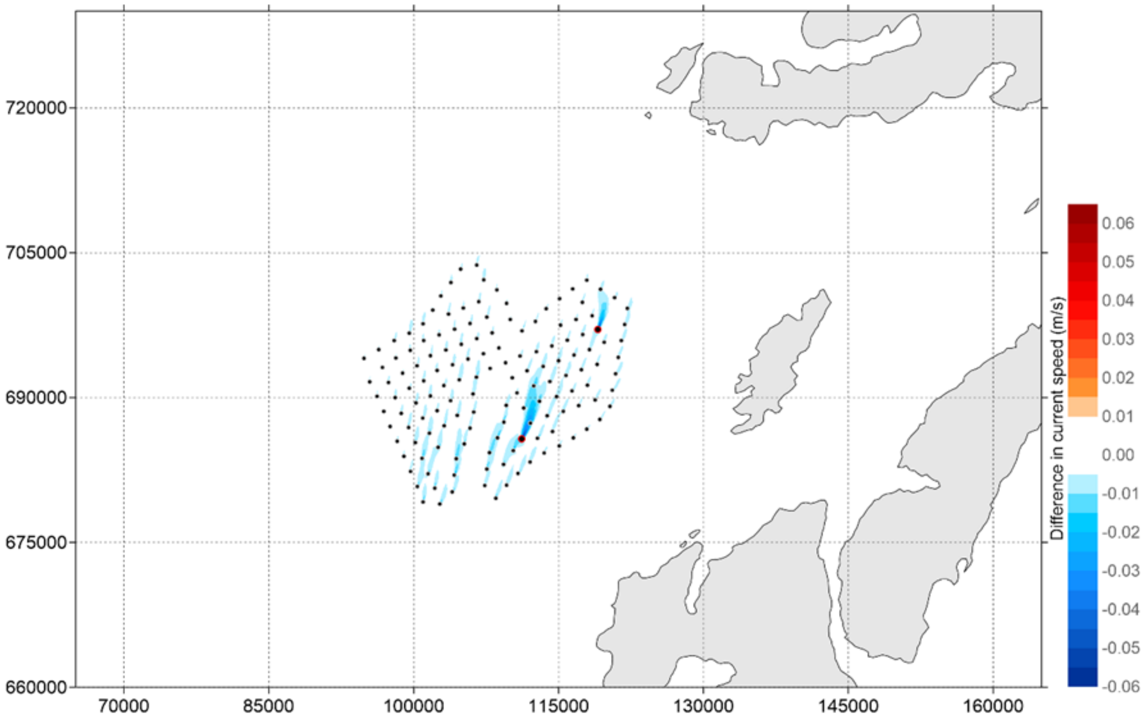


Plate 7.27 Change in peak spring flood tide current speed due to worst-case scenario for changes in tidal regime due to the presence of infrastructure

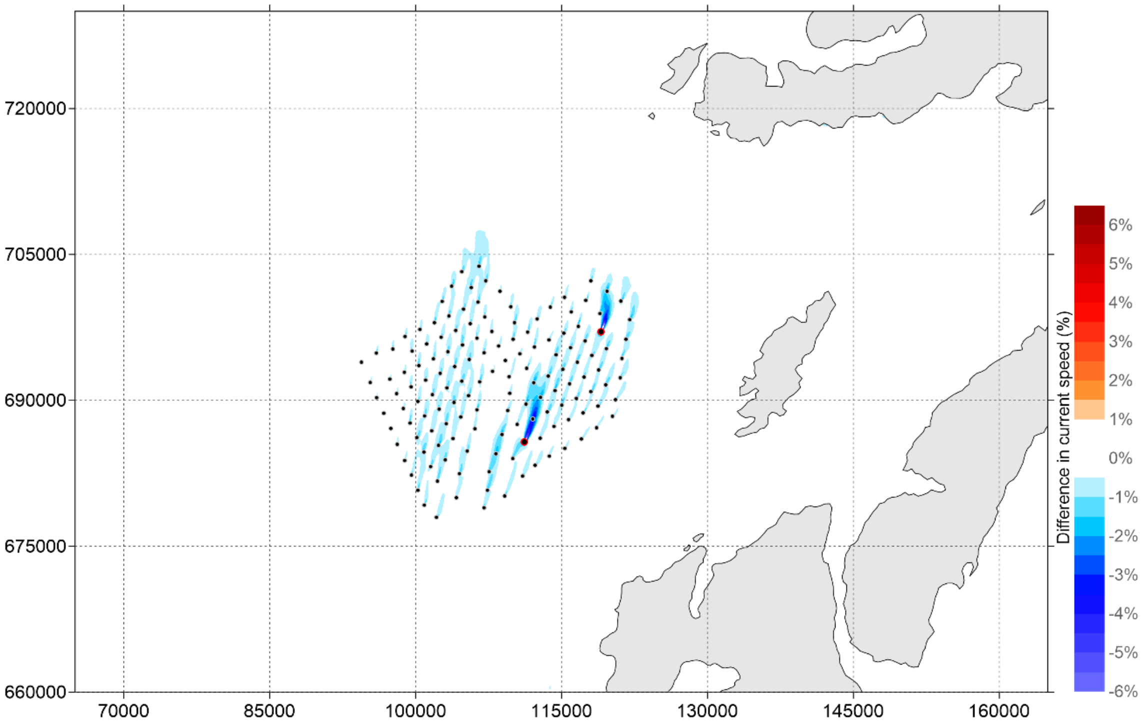


Plate 7.28 Percentage change of current speed between ‘Baseline’ and ’15 MW - Even Spread layout’ during spring tide (positive means increase of current speed by layout and vice versa) - peak flood

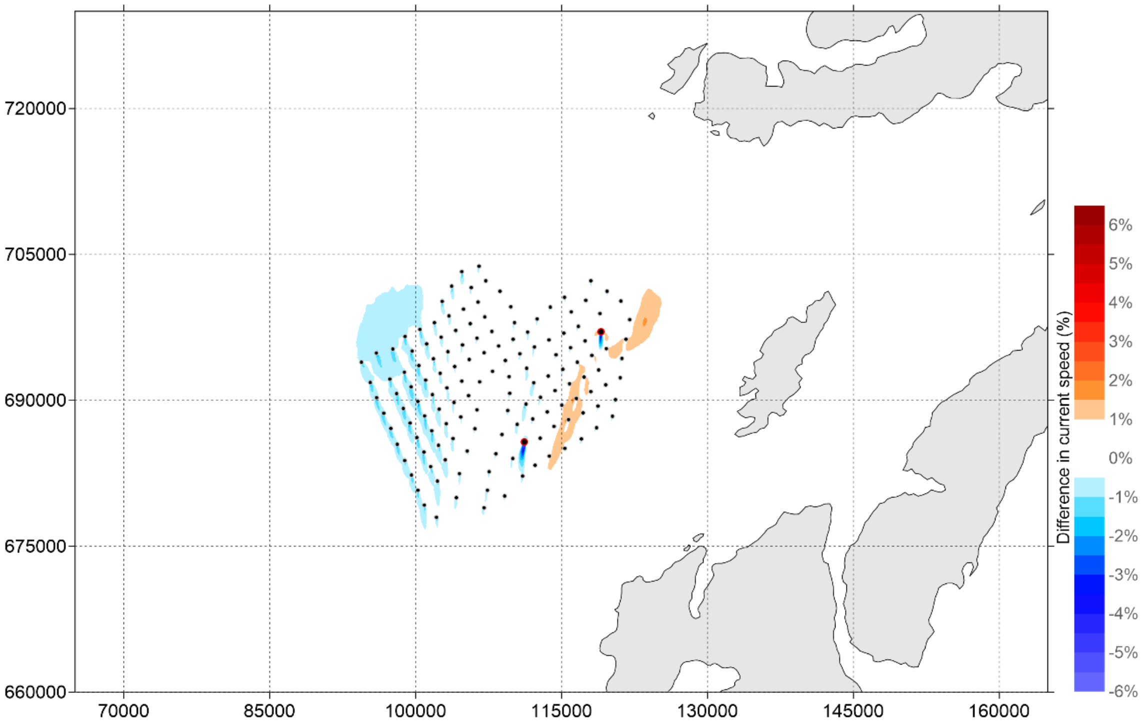


Plate 7.29 Percentage change of current speed between ‘Baseline’ and ’15 MW - Even Spread layout’ during spring tide (positive means increase of current speed by layout and vice versa) - peak ebb

7.11.2.4.1 Summary

124. Changes in tidal regime, due to the physical blockage effect of structures in the water column, results in both localised individual structure-scale and array-scale effects; no changes occur at the regional scale. During disturbance, changes to current speeds may be noticeable from monitoring with changes extending up to a maximum of 8 km from the point of blockage. This effect will occur for the duration of the Project's O&M period. However, the effect on tidal current speed is very low; changes of no greater than 2% compared to the baseline conditions are predicted. The Degree of Change is therefore defined as **Medium** and **Low** at the individual structure and array scale respectively (**Table 7.19**).

Table 7.19 Summary of changes to tidal regime

Activity	Extent	Scale	Duration	Frequency	Degree of change
Operation					
Blockage effect of structures in the water column	Individual structure/ activity scale (<1 km)	Low	High	Medium	Low
	Array scale (10s of kilometers)	Negligible	High	Medium	Negligible
	Regional scale (>100 km)	-	-	-	No Change

7.11.2.5 Impact 2 and 3: Changes to Wave Regime

125. During the operation of the Project there is potential for the presence of foundations to cause changes to the wave regime, particularly in the wave heights and directions, due to the physical blockage effect. The foundations create obstacles, modifying the characteristics of the waves passing between and around them. Generally, this causes a small wave shadow effect locally and wave heights return to baseline conditions with increasing distance from the foundation. The distance required to return to baseline conditions depends on the foundations spacing, individual foundations type and foundation size.

126. Numerical modelling of changes in wave regime due to the worst-case foundation type, size, number and layout in the WDA was undertaken to provide an evidence base to assess the effects of infrastructure on the wave regime (**Appendix 7.1 Marine Physical Environment Numerical Modelling**).

127. The greatest change in wave regime occurs during a 1 in 1 year event for waves approaching from the northwest. A wave shadow is generated to the southeast of the WDA, changes of 0.5% occur within 12 km and changes up to 1% occur within 5 km (but do not reach the coast). An area of increased wave height occurs to the northwest where changes of 0.5% occur within 10 km and changes of 1% occur within 1.5 km. These changes are extremely small, amounting to changes in wave height of <3 cm over the majority of the WDA and wider ZoI (note the scale of these changes are within the error margins of the model). Changes in wave height in the locality of the OSPs can reach up to 5 cm.

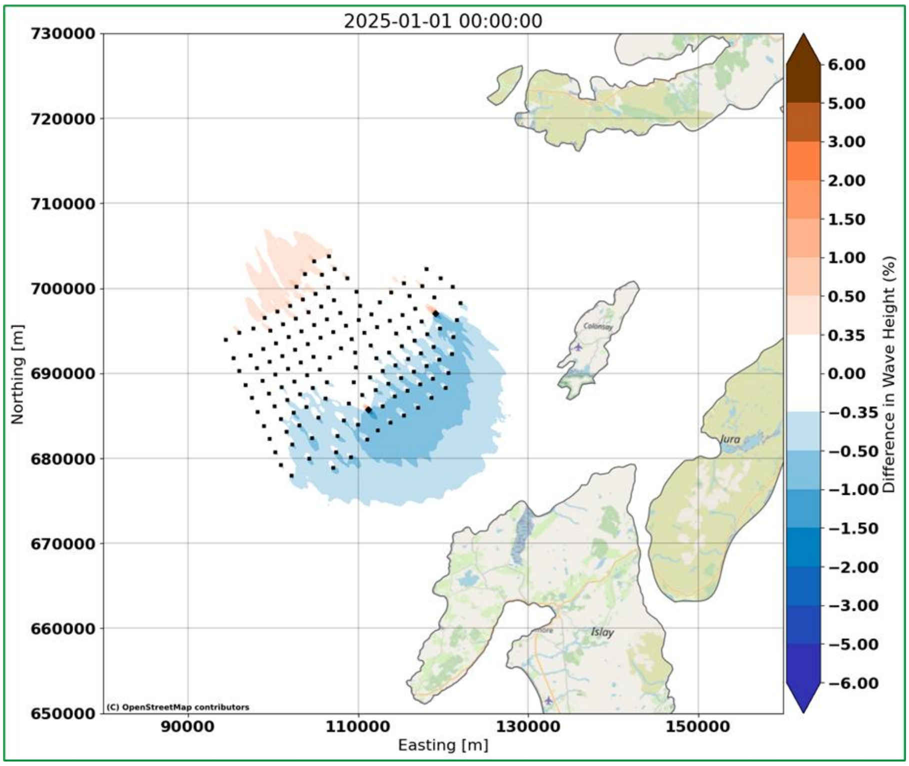


Plate 7.30 Difference in wave height (%) for 1 in 1 year from 330°N – 15 MW even spread monopile

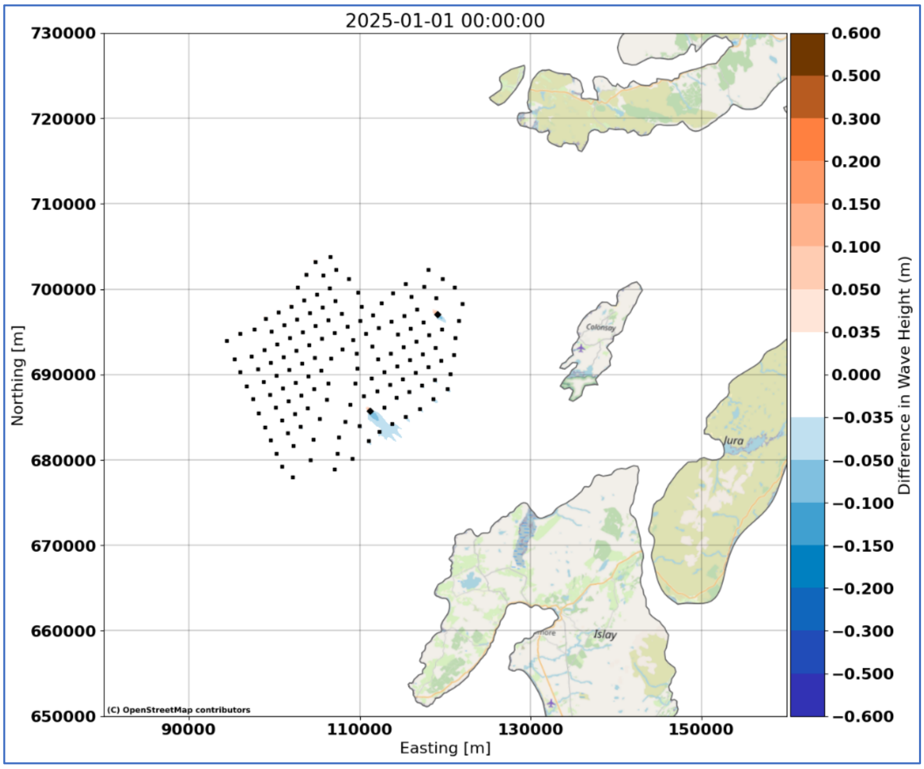


Plate 7.31 Difference in wave height (m) for 1 in 1 year from 330°N – 15 MW even spread monopile

7.11.2.5.1 Summary

128. Changes in wave regime, due to the physical blockage effect of structures in the water column, results in both localised individual structure-scale and array-scale effects; no changes occur at the regional scale. During disturbance, changes to current speeds may be noticeable from monitoring with changes extending up to a maximum of 12 km from the point of blockage. This effect will occur for the duration of the O&M period. However, the effect on wave height is very low; changes of no greater than 1% compared to the baseline conditions are predicted. The only exception to this being the changes within the immediate vicinity of the OSP foundations. The Degree of Change is therefore defined as **Medium** and **Low** at the individual structure and array scale respectively (**Table 7.20**).

Table 7.20 Summary of changes to wave regime

Activity	Extent	Scale	Duration	Frequency	Degree of change
Operation					
Blockage effect of structures in the water column	Individual structure/ activity scale (<1 km)	Low	High	Medium	Low
	Array scale (10s of kilometres)	Negligible	High	Medium	Negligible
	Regional scale (> 100 km)	-	-	-	No Change

7.11.2.6 Impact 2: Changes to Sediment Transport Regime and Seabed Morphology

129. During construction, changes to seabed morphology may occur due to seabed preparation for foundations or sandwave levelling for cable installation. These activities would directly alter the seabed morphology but the changes would be restricted to the footprint of the infrastructure as defined by the worst-case scenario in **Table 7.6**. In the case of sandwave levelling, once the cable is installed, the prevailing bedload transport regime will resume, and the sandwaves will repair with time. This is evidenced by monitoring for various windfarms in the North Sea. Considering the WDA is a dynamic sedimentary environment, seabed morphology is expected to recover quickly.

130. Modifications to the tidal regime and / or the wave regime due to the presence of the foundation structures during the operational phase may lead to changes in sediment transport regime and seabed morphology. Considering water depths across the WDA, centimeter-scale changes in wave height are unlikely to have an effect on the sediment transport regime. Changes to the tidal regime could change bed shear stress and sediment transport.

131. Shield’s parameter is an expression of the shear stress required to mobilise sediment. The Shield’s parameter was calculated as in **Section 7.8.1.5** using the hydrodynamic and wave model results across the WDA for the baseline and worst-case operational layout to understand changes in this parameter due to the presence of structures (**Plate 7.32**).

132. The modelling shows the Shield’s parameter remains higher than the critical Shield’s parameter which indicates the seabed will continue to be mobile. **Plate 7.32** shows the percentage change in Shield’s parameter across the WDA. There is a 1 to 2% reduction to the south-east of the WDA. This area of change is characterised by a small Shield’s parameter (between 0.4 and 0.8). To generate a change in sediment transport regime, e.g. from a bedforms transport regime to a sheet-flow transport regime (Shield’s larger than 0.8 – 1.0), or from a bedform transport regime to non-movable bed

(Shield's smaller than Shield's critical), the percentage of change would need to be greater than 15%. Therefore, the presence of structures does not change broad-scale sediment transport regimes and the bed will remain mobile with no net loss or gain in sediment budget predicted.

133. At the scale of individual structures, changes in tidal current speed due to turbulent wakes can enhance seabed mobility and in turn modify seabed morphology (McCarron et al. 2019; Couldrey et al. 2020; Austin et al. 2025). Where mobile bedforms are present, changes in bed shear stress could flatten bedforms as they migrate "through" a structure. However, baseline sediment transport regimes will return with increasing distance from the WTGs.

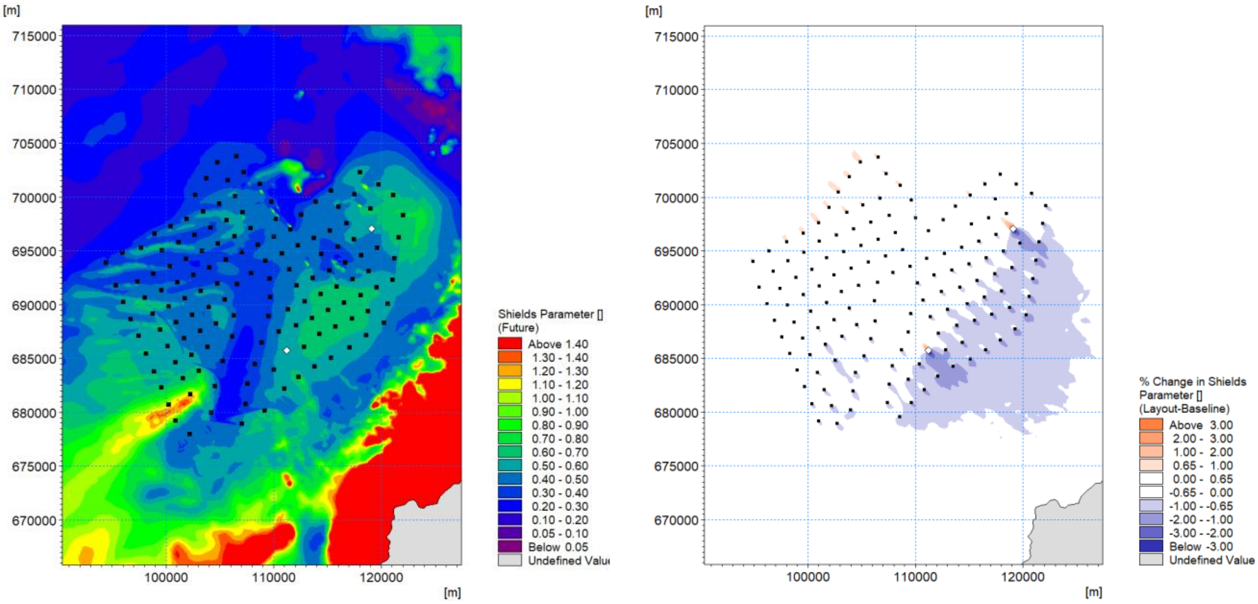


Plate 7.32 Spring-Neap averaged Shield's parameter with WDA (left). Percentage change in Shield's parameter (right)

7.11.2.6.1 Summary

134. Changes in seabed morphology during construction due to seabed preparation and sandwave levelling have the potential to directly alter seabed morphology at the location of the activity. No changes occur at the array or regional scale during construction. Preparation and levelling of the seabed would change the seabed morphology beyond natural variation but the change will be short lived as baseline sediment transport processes would prevail and the seabed would be expected to recover, and the activity would occur infrequently (likely once) within the construction period. The Degree of Change is therefore defined as **low** for the construction phase (**Table 7.21**).

135. Changes in bedload sediment transport and seabed morphology during the O&M phase may occur due to changes in tidal regime at the individual structure and array scale. No changes occur at the regional scale during O&M.

136. At an individual structure scale, sediment transport regimes will be modified by turbulent wake effects. The scale of change in close proximity to the structures is not well represented by numerical modelling with a coarser mesh resolution. However, considering the relatively homogeneous seabed composition across the WDA, it is unlikely there would be a noticeable change in seabed composition and the inclusion of scour protection as embedded mitigation would minimise the effects of scour. The Degree of Change is therefore defined as being **low**.

137. At the array scale, modelled changes to the Shield's parameter within the WDA are not sufficient to change the sediment transport regime or sediment mobility. The changes would occur regularly (in sync with the tide) over the full duration of the O&M phase but as the changes are extremely small, the overall Degree of Change is defined as **negligible**.

Table 7.21 Summary of changes to sediment transport regime and seabed morphology

Activity	Extent	Scale	Duration	Frequency	Degree of change
Construction					
Seabed preparation for WTG and OSP foundations	Individual structure/ activity scale (<1 km)	High	Negligible	Negligible	Low
	Array scale (10s of kilometers)	-	-	-	No Change
	Regional scale (>100 km)	-	-	-	No Change
Sandwave levelling for cable installation	Individual structure/ activity scale (<1 km)	High	Negligible	Negligible	Low
	Array scale (10s of kilometers)	-	-	-	No Change
	Regional scale (>100 km)	-	-	-	No Change
Operation					
Presence of structures in the water column	Individual structure/ activity scale (<1 km)	Low	High	Medium	Low
	Array scale (10s of kilometers)	Negligible	High	Medium	Negligible
	Regional scale (>100 km)	-	-	-	No Change
Decommissioning					
It is anticipated that the degree of change associated with decommissioning will be equal to, or potentially less than, those experienced during the construction phase.					

7.11.2.7 Impact 3: Changes to Water Column Structure

138. The introduction of offshore windfarm structures into seasonally stratified shelf seas has the potential to alter the timing, location and duration of stratification which plays a key role in driving primary productivity and associated ecosystem and biogeochemical functioning (Dorrell et al. 2022).

139. Turbulent mixing occurs naturally within the water column due to a combination of tidal currents interacting with the seabed and wind and wave action at the sea surface. However, the presence of structures such as monopiles within the water column creates a blockage effect on both tide and wind field and induces a new source of TKE that can enhance mixing. In an already mixed water column, this enhanced mixing will not change the baseline water column structure. However, where stratification occurs, there is potential for the enhanced mixing to change the strength or duration of stratification, or as a worst-case, completely break down stratification. In contrast, a reduction in wind

speed over the WDA could lead to reduced mixing which could prolong stratified seasons (Christiansen et al., 2022). However, while the wind wake benefits are noticeable at a regional scale, at a local scale tidal wakes play a more important role (Dorrell et al. 2022).

140. Within the WDA, the water column is mixed, therefore, the WTG foundations may enhance mixing but there will be no net change to water column structure due to their presence. However, it is acknowledged that there is a weak thermocline to the north of the WDA and the Islay Front may be present within the WDA at times (**Plate 7.18 and Plate 7.19**). Therefore, it is important to establish if there will be any changes to the thermal structure of the water column, or to the frontal position.

141. The effect of offshore windfarms on stratification is an emerging research field with limited evidence to base predictions of change on. Carpenter et al. (2016) developed an empirical method based on the assumption that stratification can only breakdown if mixing induced by the structures occurs over a timescale that is shorter than the time it takes for water to travel through the array under the prevailing current regime. For example, if stratified water enters an array area it will travel through the array and interact with one or more structures during its journey, experiencing enhanced TKE that will induce mixing. Depending on a range of factors such as the strength of initial stratification, TKE strength, the number of structures it interacts with and the duration of the interaction (driven by current speed), the water will leave the array area in a modified state (e.g. the strength of stratification may be lower) or in the same state as when it entered the array (no change).

142. The method of Carpenter et al. (2016) uses site specific PEA values as an input to calculate the time required to mix the water column. The PEA values for the WDA are low (<6 J/m^3) and the water column is defined as being mixed using a threshold for stratification of 20 J/m^3 (Berx and Hindson 2020). Therefore, the method of Carpenter et al. (2016) is not applicable to the WDA as it would underestimate the mixing timescale given the input values are lower than the threshold for stratification.

143. The front within the WDA (potentially part of the Islay Front) is dynamic and variable over seasonal and annual timescales but at its maximum, it could reach up to 45 km in length (**Plate 7.18** and **Plate 7.19**). This means, if it passes through the WDA along an east-northeast to west-southwest orientation, as a worst-case scenario, it would cross the entire WDA which is ~28 km wide along the axis of the front. Using a worst-case scenario layout that includes the maximum number of structures (144) and the maximum diameter of a monopile (15 m) (**Appendix 7.1 Marine Physical Environment Numerical Modelling**), up to 16 structures could interact with the front at any given time.

144. The turbulence induced by the monopile foundation will occur in the wake of the structure and dissipate with increasing distance from the foundation until background levels are reached. This distance is important for understanding the spatial extent of potential enhanced mixing. Existing research suggests the TKE will dissipate within 8.3 pile diameters downstream and 3.5 pile diameters to the side of the structures (Miles et al. 2017). With a pile diameter of 15 m, this suggests baseline conditions would return within 125 m of the foundation in a broadly north-northwest to south-southeast-direction (based on the dominant tidal flow direction) and 53 m in an east-northeast to west-southwest direction (along the axis of the front). At its maximum length, this means the proportion of the front influenced by enhanced TKE would be 850 m which equates to 3% of the length of the feature. At this scale, it is unlikely the WDA would lead to changes to water column or frontal dynamics beyond what could occur due to natural variability.

145. In principle, a change to frontal dynamics or water column structure could influence primary productivity that would have inter-related effects on the wider ecosystem. Observational evidence shows there is a region of higher Chlorophyll-a within the northern part of the WDA, suggesting it is

an important region of primary production. As this region coincides with a water body defined as being mixed, it is suggested nutrient flux to surface waters is maintained throughout the year but in spring, an increase in solar insolation enhances primary productivity. As the water column will remain mixed during the operation lifetime of the Project, no changes in primary productivity beyond what occurs due to natural variability are expected.

146. Over the O&M phase of the Project, global warming could increase the strength of stratification or extend the period shelf seas are stratified (Sharples et al. 2022). Within the WDA, where the water is mixed all year round and there is a very weak thermal stratification (maximum of 0.75°C between surface and bottom waters), the thermocline could become more pronounced but as this will occur against a background of ocean warming which is predicted to be between 1 and 3 degrees by 2100 (IPCC AR6), it is difficult to predict how the changes in water column structure induced by climate change will be moderated by the WDA structures. Given the low PEA values (<6 J/m3) within the WDA, significant changes in ocean dynamics would be required to create a seasonally stratified water body. Therefore, even with climate change, it is likely the water column within the WDA will remain mixed over the full duration of the O&M period.

7.11.2.7.1 Summary

147. At the scale on an individual structure, enhanced TKE can mix the water column but as the water column is already mixed, the scale of the change would be within the range of background variability and would not be noticeable from monitoring. For example, if a density profile was measured at the location of an individual structure prior to construction, it would show no pycnocline, and if it was measured again after construction in the lee of a structure, it would also show no pycnocline. The forcing mechanism would occur for the full duration of the O&M phase of the Project but the change would not occur all the time due to the seasonal nature of potential stratification and variations in current strength and direction over a range of tidal cycles. The Degree of Change is therefore defined as **negligible** at the individual structure scale (**Table 7.22**).

148. At the array scale, there is potential for multiple structures to interact with the water column and tidal mixing fronts. However, considering the enhanced TKE is predicted to occur within 125m of the structure as a worst case and that WTGs would be spaced at least 944 m apart, the scale of change on large scale features is considered to be low as it would be barely noticeable and small compared to background variability. The Degree of Change is therefore defined as **low** at the array scale. No change is predicted at the regional scale.

Table 7.22 Summary of changes to Water Column Structure

Activity	**Extent**	**Scale**	**Duration**	**Frequency**	**Degree of change**
Operation					
Presence of structures in the water column	Individual structure/ activity scale (<1 km)	Negligible	High	Medium	Negligible
	Array scale (10s of kilometres)	Low	High	Medium	Low
	Regional scale (>100 km)	-	-	-	No change

7.11.3 Receptors

149. The receptors scoped in for **Chapter 7 Marine Physical Environment** are outlined in **Table 7.23**.

Table 7.23 Receptors scoped in for Chapter 7 Marine Physical Environment

Receptors	Construction	Operation and Maintenance	Decommissioning
Seabed Bedforms	✓	✓	✓
Water Column Structure (including the Islay Front)	✗	✓	✗
Gruinart Flats SSSI (saltmarsh)*	✓	✓	✓
Glac na Criche SSSI (bedrock cliffs)*	✓	✓	✓

* Note that whilst both of these SSSIs are located outside of the ZoI established based on tidal ellipses (**Section 7.8.1.3**), they have been included as receptors following feedback from NatureScot (**Table 7.2**).

7.12 ASSESSMENT OF SIGNIFICANCE

7.12.1 Windfarm Development Area-Alone Assessment of Significance

150. The potential effects on the Marine Physical Environment receptors that may occur during construction, operation and decommissioning of the WDA are assessed in the following sections. The assessment follows the methodology set out in **Section 7.10.1** and is based on the realistic worst-case scenarios defined in **Section 7.7**, with consideration of embedded mitigation measures identified in **Section 7.9**. A summary of the significance of effect for all impacts is presented in **Table 7.31.**

151. This assessment has been undertaken on the basis of all embedded mitigation measures outlined in **Table 7.8**. The embedded mitigation measures relevant for each impact are listed in the summary **Table 7.31**.

7.12.1.1 Impact 1: Changes in Suspended Sediment Concentrations and Seabed Levels

152. Construction activities including seabed preparation (e.g. seabed levelling and sandwave clearance, including disposal) and installation of the WDA infrastructure, and O&M activities (cable repairs or reburial) may cause changes in SSCs and seabed level due to redeposition of suspended sediment.

153. Receptor(s) which may be affected by Impact 1 include, Seabed Bedforms, Gruinart Flats SSSI (saltmarsh) and Glac na Criche SSSI (bedrock cliffs).

7.12.1.1.1 Sensitivity and Value

7.12.1.1.1.1 Seabed Bedforms

154. Seabed Bedforms, namely the sand bank and sandwaves outlined in **Section 7.8.1.1**, are not designated but are of local importance for marine geology, oceanography and physical processes. Redeposition of sediment disturbed during construction activities could change the morphology of these features. However, as the sediment deposited would be of a similar composition to the features given the homogeneity of the seabed, the receptors will generally be tolerant of the impact. Considering the dynamic and mobile nature of the seabed, the receptors will adapt to the impact and recover near instantaneously.

155. The sensitivity of Seabed Bedforms to changes in SSCs and seabed levels is therefore defined as **negligible**.

7.12.1.1.1.2 Gruinart Flats SSSI (saltmarsh)

156. Gruinart Flats SSSI is an important and protected designated site, notably hosting a saltmarsh. This receptor is outside of the Marine Physical Environment ZoI (**Section 7.8.1.3**) and the maximum modelled sediment dispersion extent (**Section 7.11.2**) but has been included as a receptor following advice from NatureScot.

157. Saltmarsh environments are sensitive to changes in SSC as deposition of SSC on the saltmarsh can influence sediment accumulation rates changing the ecological and physical dynamics of the saltmarsh. Saltmarsh environments likely have some tolerance to deposition of SSC which are typically higher and more variable in coastal settings. They also have some ability to adapt and recover from short-lived changes in SSC.

158. The sensitivity of Gruinart Flats SSSI (saltmarsh) to changes in SSCs and seabed levels is therefore defined as **low**.

7.12.1.1.1.3 Glac na Criche SSSI (bedrock cliffs)

159. Glac na Criche SSSI is an important and protected designated site, notably hosting bedrock cliffs. This receptor is outside of the Marine Physical Environment ZoI (**Section 7.8.1.3**) and the maximum modelled sediment dispersion extent (**Section 7.11.2**) but has been included following advice from NatureScot.

160. Bedrock cliffs are highly tolerant of changes in SSC and seabed levels. The sensitivity of Glac na Criche SSSI (bedrock cliffs) is defined as **negligible**.

7.12.1.1.2 Magnitude of Impact

161. The magnitude of impact for Impact 1 has been determined based on an assessment of the Degree of Change (see **Section 7.11.2**) and how that would manifest as an impact upon receptors.

162. The magnitude of Impact 1 is described for each receptor which may be affected by Impact 1, for each phase of the Project, as follows.

7.12.1.1.2.1 Construction

163. The magnitude of impact on Seabed Bedforms is defined as **negligible** as changes in seabed level due to deposition of SSC will result in a temporary, barely discernible change over a small area of the receptor.

164. There is no pathway to impact for changes in SSCs and seabed levels on Gruinart Flats SSSI (saltmarsh) and Glac na Criche SSSI (bedrock cliffs) as the plume created by construction activities does not reach these receptors. This results in a magnitude of impact definition of **no change** for these receptors.

7.12.1.1.2.2 Operation and Maintenance

165. The magnitude of impact on Seabed Bedforms for Impact 1 during the O&M phase of the Project will be less than or equal to that defined during construction (**Section 7.12.1.1.2.1**). During O&M, the volumes of sediment disturbed during each activity will be less but there will be multiple disturbance events over the Project lifespan. However, SSCs will return to baseline within hours of disturbance and any sediment deposited on the seabed will become redistributed by bedload transport regimes. Therefore, there will be no combined effect on SSC and seabed levels from multiple activities over the O&M phase. Overall, the magnitude of impact on Seabed Bedforms is defined as **negligible.**

166. As defined in **Section 7.12.1.1.2.1**, there is no pathway to impact on Gruinart Flats SSSI (saltmarsh) and Glac na Criche SSSI (bedrock cliffs), the magnitude of impact for these receptors is therefore **no change**.

7.12.1.1.2.3 Decommissioning

167. During decommissioning, the magnitude of Impact 1 is expected to be equal to or less than the magnitude expected during construction. Therefore, the magnitude is defined as **negligible.**

7.12.1.1.3 Significance of Effect

168. The magnitude of impact for changes in SSC and seabed levels is **negligible** and the sensitivity of Seabed Bedforms as a marine physical environment receptor is **negligible** resulting in a **negligible adverse** significance of effect which is **not significant** in EIA terms. No additional mitigation is proposed.

169. Considering the magnitude of impact is **no change** for Gruinart Flats SSSI (saltmarsh) and Glac na Criche SSSI (bedrock cliffs), there is no pathway to impact, which means there is no significance of effect in relation to these receptors due to Impact 1: Changes in SSCs and seabed levels.

7.12.1.2 Impact 2: Changes in Sediment Transport Regime and Seabed Morphology

170. Changes in sediment transport regime and seabed morphology may occur due to construction activities, including seabed preparation for foundations and sandwave levelling (see **Section 7.11.2**) and due to changes in wave and hydrodynamic regime in the wake of structures in the water column during operation.

171. Receptor(s) which may be affected by Impact 2 include, Seabed Bedforms, the Gruinart Flats SSSI (saltmarsh) and the Glac na Criche SSSI (bedrock cliffs).

7.12.1.2.1 Sensitivity and Value

7.12.1.2.1.1 Seabed Bedforms

172. Seabed Bedforms, namely the sand bank and sandwaves outlined in **Section 7.8.1.1**, will be directly altered in localised areas during construction due to sandwave levelling (as outlined in **Section 7.11.2**). Once the construction activity ceases, the features will reform within months to years, due to prevailing bedload sediment transport processes (Roulund et al., 2023).

173. During operation, turbulent wake effects within the immediate vicinity of foundations may change bedload sediment transport regimes. Considering the crest and wave length of the Seabed Bedforms in the WDA (sandwave heights of approximately 6.6 m and wave lengths exceeding 200 m), they will generally be highly tolerant to changes at the scale of individual structures and they will be able to recover relatively quickly as once they pass the structures, they will reform as the prevailing hydrodynamic regimes resumes in this dynamic environment.

174. These features are not designated but are of local importance for marine geology, oceanography and physical processes. They are common and of local importance, with high tolerance and recoverability.

175. The sensitivity of Seabed Bedforms to changes in sediment transport regimes and seabed morphology is defined as **low**.

7.12.1.2.1.2 Gruinart Flats SSSI (saltmarsh)

176. Gruinart Flats SSSI is an important and protected designated site, notably hosting a saltmarsh. This receptor is outside of the Marine Physical Environment ZoI (**Section 7.8.1.3**) but has been included as a receptor following advice from NatureScot.

177. Changes in bedload sediment transport processes and seabed morphology could affect saltmarsh environments if the changes lead to changes in coastal morphology, nearshore tidal regime or sediment supply. Considering the WDA is located approximately 15.2 km offshore of the Gruinart Flats SSSI, the receptor would be tolerant of any changes within the WDA as they would not manifest as changes within the nearshore.

178. The sensitivity of Gruinart Flats SSSI (saltmarsh) to changes in sediment transport regime and seabed morphology is therefore defined as **negligible**.

7.12.1.2.1.3 Glac na Criche SSSI (bedrock cliffs)

179. Glac na Criche SSSI is an important and protected designated site, notably hosting bedrock cliffs. This receptor is outside of the Marine Physical Environment ZoI (**Section 7.8.1.3**) but has been included following advice from NatureScot.

180. Bedrock cliffs are highly tolerant of changes in bedload sediment transport and (superficial) seabed morphology. The sensitivity of Glac na Criche SSSI (bedrock cliffs) is therefore defined as **negligible**.

7.12.1.2.2 Magnitude of Impact

181. The magnitude of impact for Impact 2 has been determined based on an assessment of direct changes to wave and tidal regime (see **Sections 7.11.2.5 and 7.11.2.4**) and direct changes to seabed morphology (see **Section 7.11.2.6**) and subsequent indirect changes to sediment transport regime and seabed morphology (see **Section 7.11.2.6**).

7.12.1.2.2.1 Construction

182. The magnitude of impact on Seabed Bedforms is defined as **low** as changes in sediment transport regime and seabed morphology will result in temporary, discernible changes over a minority of the receptor, for only part of the Project duration.

183. There is no pathway to impact for changes in sediment transport regime and seabed morphology and on the Gruinart Flats SSSI (saltmarsh) and the Glac na Criche SSSI (bedrock cliffs) as the changes are not regional in scale and do not affect coastal morphology and sediment transport processes. This results in a magnitude of impact definition of **no change** for these receptors.

7.12.1.2.2.2 Operation and Maintenance

184. The magnitude of impact for changes to sediment transport regimes and seabed morphology during the O&M phase of the Project will be less than or equal to that defined during construction. During O&M, localised changes in sediment transport regime will occur in the wake of foundations. The magnitude of impact on Seabed Bedforms is therefore defined as **low** as changes in sediment transport regime and seabed morphology will result in temporary, discernible changes over a minority of the receptor, throughout the Project duration.

185. As defined in **Section 7.12.1.2.2.1**, there is no pathway to impact on Gruinart Flats SSSI (saltmarsh) and Glac na Criche SSSI (bedrock cliffs), the magnitude of impact for these receptors is therefore **no change**.

7.12.1.2.2.3 Decommissioning

186. During decommissioning the magnitude of Impact 2 is expected to be equal to or less than the magnitude(s) expected during construction. Therefore, the magnitude is defined as **no change**.

7.12.1.2.3 Significance of Effect

187. The magnitude of impact for changes in sediment transport regimes and seabed morphology is **low** and the sensitivity of Seabed Bedforms as a marine physical environment receptor is **low** resulting in a **minor adverse** significance of effect which is **not significant** in EIA terms. No additional mitigation is proposed.

188. Considering the magnitude of impact is **no change** for Gruinart Flats SSSI (saltmarsh) and Glac na Criche SSSI (bedrock cliffs), there is no pathway to impact, which means there is no significance of effect in relation to these receptors due to Impact 2: Changes in sediment transport regime and seabed morphology.

7.12.1.3 Impact 3: Changes to Water Column Structure

189. During the operation phase, blockage effects due to the presence of WDA infrastructure, most notably foundations for WTGs and OSPs, may enhance turbulence around the structures and change water column structure.

190. Receptor(s) which may be affected by Impact 3 include Water Column Structure (including the Islay Front).

7.12.1.3.1 Sensitivity and Value

7.12.1.3.1.1 Water Column Structure (including the Islay Front)

191. The water column within the WDA is defined as being mixed (see **Section 7.8.1.7.1**) and can therefore tolerate any mixing induced by the structures during the O&M phase of the Project with no detectable changes in the receptor's form or function.

192. The Water Column (including the Islay Front) is not designated but is of regional importance for oceanography and physical processes.

193. The sensitivity and value of the Water Column (including the Islay Front) to changes to water column structure is defined as **low**.

7.12.1.3.2 Magnitude of Impact

194. The magnitude of impact for Impact 3 has been determined based on an assessment of changes to water column structure outlined in **Section 7.11.2.7**. As the greatest impact to the water column structure (including the Islay Front) will occur during the O&M phase when all structures have been constructed and are present in the water column, Impact 3 is not assessed in the O&M or decommissioning phases of the Project (see **Table 7.14**).

7.12.1.3.2.1 Operation and Maintenance

195. During the O&M phase, localised enhanced TKE will occur in the wake of foundations. At the scale of the WDA, multiple WTGs will interact with the water column structure (including the Islay Front) but as the scale of change is small relative to background variability, and will only affect a small portion of the receptor, the magnitude of impact on water column structure (including the Islay Front) is defined as **negligible** with no alteration to the feature's characteristics or distinctiveness.

7.12.1.3.3 Significance of Effect

196. The magnitude of impact for changes in water column structure is **negligible** and the sensitivity of water column structure (including the Islay Front) is **low** resulting in a **negligible** significance of effect which is **not significant** in EIA terms. No additional mitigation is proposed.

7.12.2 Combined Assessment: Windfarm Development Area, Offshore Export Cable Corridor and Onshore Transmission Development Area

7.12.2.1 Impact 1

197. Changes in SSCs and seabed levels (Impact 1) have been shown to affect areas outside of the WDA, through the sediment dispersion modelling in **Sections 7.11.2.2** and **7.11.2.3**. Depending on the timing of seabed preparation activities and foundation and cable installation, there is potential for overlapping construction activities within the Offshore ECC. However, as plumes disperse within hours of disturbance, it is highly unlikely a combined effect will occur.

7.12.2.2 Impact 2

198. During construction, if sandwave levelling is required within the Offshore ECC, the combined WDA and Offshore ECC area of seabed that could be morphologically altered will be greater, but will remain small when compared to the extent of Seabed Bedforms across the Project.

199. There will be no additional structures in the water column during operation due to the combination of the WDA and Offshore ECC. The combined assessment of effects on tidal regime, manifested as changes in sediment transport regime, will therefore not be greater than WDA-alone assessment.

7.12.2.3 Impact 3

200. As with Impact 2, no additional structures are included within the Offshore ECC. Therefore, the combined assessment of effects on Water Column Structure will not be greater than WDA-alone assessment.

7.12.2.4 Combined Assessment Summary

Table 7.24 Marine Physical Environment combined assessment summary

Receptor/Topic	WDA Residual Effect	Offshore ECC Assessment of Effects	OnTDA Assessment of Effects	Combined Assessment
Impact 1: Changes in SSCs and seabed levels	Not Significant (Negligible Adverse).	Likely Not Significant (Negligible to Minor Adverse).	N/A – no pathway to receptors.	A greater volume of sediment will be disturbed but it is highly unlikely to generate a combined effect as plumes will disperse rapidly after disturbance limiting the potential for overlapping plumes.
Impact 2: Changes in sediment transport regime and seabed morphology	Not Significant (Minor Adverse)	Likely Not Significant (Negligible to Minor Adverse).	N/A – no pathway to receptors.	A greater area of seabed will be affected by morphological change but the total will remain small when compared to the area covered by Seabed Bedforms.
Impact 3: Changes to water column structure	Not Significant (Negligible Adverse)	Not Significant (Negligible Adverse)	N/A – no pathway to receptors	No additional infrastructure that would increase blockage effects.

7.13 CUMULATIVE EFFECTS

7.13.1 Screening of Potential Cumulative Impacts

201. The first step in the CEA is the screening / identification of which whole-Project impacts could have a cumulative effect with other plans, projects and activities (described as ‘impact screening’). This

information is set out in **Table 7.25**, together with consideration of the confidence in the data that is available to inform a detailed assessment and the associated rationale.

Table 7.25 Potential cumulative impacts (impact screening)

Impact	Potential for Cumulative Impact	Data Confidence	Rationale
Construction			
Impact 1: Changes in SSCs and seabed levels	Yes	High	Depending on the construction timetable from nearby projects / activities there is potential for temporal overlap in construction periods which could have a cumulative effect.
Impact 2: Changes in sediment transport regime and seabed morphology	Yes	High	Depending on the construction timetable from nearby projects / activities there is potential for temporal overlap in construction periods which could have a cumulative effect.
Operation and Maintenance			
Impact 1: Changes in SSCs and seabed levels	Yes	High	Depending on the maintenance requirements from nearby projects / activities there is potential for temporal overlap in maintenance periods which could have a cumulative effect.
Impact 2: Changes in sediment transport regime and seabed morphology	Yes	High	Depending on the maintenance requirement from nearby projects / activities there is potential for temporal overlap in maintenance periods which could have a cumulative effect. Additionally, depending on what structures are within nearby projects there is potential for greater blockage effects in the water column which could have a cumulative effect.
Impact 3: Changes to Water Column Structure	Yes	High	Depending on what structures are within nearby projects / activities there is potential for greater blockage effects in the water column which could have a cumulative effect.
Decommissioning			
Impact 1: Changes in SSCs and seabed levels	Yes	High	Depending on the decommissioning timetable from nearby projects / activities there is potential for temporal overlap in decommissioning activities which could have a cumulative effect.
Impact 2: Changes in sediment transport regime and seabed morphology	Yes	High	Depending on the decommissioning timetable from nearby projects / activities there is potential for temporal overlap in decommissioning activities which could have a cumulative effect.

7.13.2 Screening of Other Plans, Projects and Activities

202. The second screening step in the CEA is the identification of the other plans, projects and activities that may result in cumulative impacts for inclusion in the CEA (described as ‘project screening’). This information is set out in **Table 7.26**, together with consideration of the relevant details of each, including current status (e.g. under construction), planned construction period, closest distance to the Project, status of available data and rationale for including or excluding from the assessment.

203. The project screening has been informed by the development of a CEA Long List which forms an exhaustive list of plans, projects and activities in a very large Study Area relevant to the Project. The list has been appraised, based on the confidence in being able to undertake an assessment from the information and data available, enabling individual plans, projects and activities to be screened in or out. As described in **Section 7.10.3**, this has been undertaken using a tiered approach to provide a framework for placing relative weight on the potential for each plan or project to be included in the CEA for this topic.

204. An appropriate ZoI to identify overlapping projects/activities is presented in **Figure 7.1** and outlined in **Table 7.5** for the WDA. As the ZoI is moderated by the direction and length of the tidal ellipse excursions across the Project, a precautionary larger ZoI has been considered in the CEA to account for the Combined Assessment of the WDA, Offshore ECC and Onshore Transmission Development Area. The Offshore ECC will potentially be located in an area of very rapid tidal current speeds to the south of the WDA where tidal ellipses reach lengths up to 30 km, oriented north (northeast) to south (southwest). A ZoI of 30 km is therefore defined for this CEA.

Table 7.26 Planned projects within 30 km of the Project

Project / Plan	Status	Closest Distance from the WDA (km)	Closest Distance from the Offshore ECC (km)	Description of Project / Plan	Construction Period	Operational Period	Data Confidence	Overlap with the WDA	Included in the CEA	Rationale
Tier 1 projects / plans (projects which are operational (but not part of the baseline), under construction, those with consent and submitted but not yet determined)										
Dubh Artach Lighthouse Refurbishment	Operational	1.5 (North)	28 (North)	Refurbishment of necessary lighthouse infrastructure.	2027-2032	5 years	High	Yes, spatial and temporal.	No	The potential effects relevant to the Marine Physical Environment impact assessment will not be influenced by this project because there is no subsurface/marine activity planned during the refurbishment works.
All other Tier 1 projects are located outside the ZoI for Marine Physical Environment.										
Tier 2 projects / plans (all plans/projects assessed under Tier 1, plus those projects with a Scoping Report and/or Scoping Opinion)										
LirIC interconnector	Development	125 (South)	Overlap	Electricity Interconnector	2032	Unknown	High	No	Yes	Potential overlap with the Project’s Offshore ECC construction and O&M activities.
All other Tier 2 projects are located outside the ZoI for Marine Physical Environment.										
Tier 3 projects / plans (all plans/projects assessed under Tier 1 and Tier 2, plus those projects likely to come forward where a CES Option to Lease Agreement or equivalent has been granted (i.e., ScotWind and INTOG projects)										
Malin Sea Wind	Early Planning	48 (South)	14 (South)	Offshore Windfarm	2030-2031	25+ years	High	Yes, temporal overlap	Yes	Potential overlap with the Project’s Offshore ECC construction and O&M activities
Western Link 2	Early Planning	104 (South)	Overlap	Electricity Transmission Cable	Unknown	Unknown	High	No	Yes	Potential overlap with the Project’s Offshore ECC construction and O&M activities.
All other Tier 3 projects are located outside the ZoI for Marine Physical Environment.										

7.13.3 Cumulative Effects Assessment

205. Following the screening process outlined in **Section 7.13.1** and **Section 7.13.2**, Impact 1: Changes in Suspended Sediment Concentrations and Seabed Levels and Impact 2: Changes in Sediment Transport Regime and Seabed Morphology have been considered within the CEA.

206. No Tier 1 projects or plans within the extent of the ZoIs, outlined in **Section 7.13.2** will have an effect on the impacts relevant to the Marine Physical Environment impact assessment. Tier 2 and Tier 3 projects outlined in **Table 7.26** may have an effect on impacts relevant to the Marine Physical Environment impact assessment as these projects overlap with the Offshore ECC ZoI of 30 km.

207. The Tier 2 and Tier 3 projects being assessed are >12 km from the WDA. Therefore, these projects will only be assessed against the potential influence on Impact 1 and Impact 2 caused by the Offshore ECC and Tier 2 and Tier 3 projects during construction, O&M and decommissioning.

208. Impact 3: Changes to Water Column Structure is not considered within the CEA as no new infrastructure will be constructed in the water column as part of the Offshore ECC.

7.13.3.1 Impact 1

7.13.3.1.1 Sensitivity and Value

209. The sensitivity of the receptors relevant to Impact 1 are defined as **negligible** to **low**, as outlined in **Section 7.12.1.1.1**.

7.13.3.1.2 Magnitude of Cumulative Impact

210. Changes in SSCs and seabed levels (Impact 1) during construction may affect areas within and outside of the Offshore ECC, through seabed preparation activities and cable installation. Seabed preparation may require (Un-exploded Ordnance) UXO clearance, boulder clearance, pre-lay grapnel run and sandwave levelling. Cable burial will be achieved by either ploughing, jetting, mechanical trenching or hybrid jetting and cutting tool. There is potential for multiple seabed preparation and cable burial activities to occur at similar times and for sediment plumes to overlap spatially, due to the Tier 2 and Tier 3 projects that are also expected to cause changes in SSCs and seabed levels through similar seabed preparation and cable burial activities.

211. The sediment dispersion modelling in **Section 7.11.2.2.2** to **Section 7.11.2.3.2** provides an overview of the potential extent of changes in SSCs and seabed levels due to similar seabed preparation and burial methods. This sediment dispersion modelling was undertaken for the WDA, and construction activities in the Offshore ECC may have a different spatial footprint due to different current regimes. However, as plumes disperse within hours of disturbance, it is highly unlikely a cumulative effect will occur during construction and decommissioning as background conditions will return to the baseline before additional activities from other cable installation activities occur.

212. The comparisons used to describe potential changes in SSCs and seabed levels for construction also apply to O&M activities, such as cable reburial. Although, disturbance events will be fewer in number and smaller in scale than during construction. Therefore, during O&M, cumulative effects will be even less likely to occur.

213. Changes in SSCs and seabed levels caused by decommissioning of the Offshore ECC will be equal to or less than those expected during construction.

214. Based on the information available to date for the Offshore ECC, the magnitude of cumulative impact is considered to be the same as or less than the combined assessment (**Section 7.12.2.1**) and is defined as **negligible**.

7.13.3.1.3 Significance of Cumulative Impact

215. Overall, it is predicted that sensitivity/value of the receptor is **low** and the magnitude of cumulative impact is **negligible**. The cumulative effect is therefore of **minor adverse** significance, which is **not significant** in EIA terms.

216. No additional mitigation is required to manage the potential cumulative effects from changes to SSCs and seabed levels.

7.13.3.2 Impact 2

7.13.3.2.1 Sensitivity and Value

217. The sensitivity of the receptors relevant to Impact 2 are defined as **negligible** to **low**, as outlined in **Section 7.12.1.2.1**.

7.13.3.2.2 Magnitude of Cumulative Impact

218. Changes in Sediment Transport Regime and Seabed Morphology (Impact 2) during construction may affect areas within and outside of the Offshore ECC, through seabed preparation (such as sandwave levelling). This could lead to multiple seabed preparation activities occurring at similar times due to the Tier 2 and Tier 3 projects that are also expected to change seabed morphology through seabed preparation and other construction activities (such as foundation installation).

219. If sandwave levelling is required during construction within the Offshore ECC, changes in Sediment Transport Regime and Seabed Morphology will be highly localised. Once the cable is installed, the prevailing bedload transport regime will resume, and the sandwaves will repair with time. It is therefore highly unlikely a cumulative effect will occur.

220. Changes in Sediment Transport Regime and Seabed Morphology caused by decommissioning of the Offshore ECC will be equal to or less than those expected during construction.

221. Changes in Sediment Transport Regime and Seabed Morphology (Impact 2) during O&M may affect areas within and outside of the Offshore ECC, through installation of external cable protection. External cable protection may be required in areas where ground conditions are unsuitable for cable burial or at cable crossings of which a number is yet to be determined. This could lead to multiple blockage effects being combined due to the similar operating times and overlapping spaces influenced by the Project and the Tier 2 and Tier 3 projects, which may also deploy infrastructure and protection measures at the seabed.

222. The installation of external cable protection may influence wave and hydrodynamic regimes locally by creating blockage effects causing changes in Sediment Transport Regime and Seabed Morphology, as currents are the primary driver of bedload sediment transport. This effect would be most prominent during the O&M phase of the Project. However, due to the small scale of the external cable protection, changes in Sediment Transport Regime and Seabed Morphology will be highly localised and the area of seabed that could be morphologically altered will remain small when compared to the extent of seabed bedforms across the Project.

223. Based on the information available to date for the Offshore ECC, the magnitude of cumulative impact is considered to be the same as or less than the combined assessment (**Section 7.12.2.2**) and is defined as **negligible**.

7.13.3.2.3 Significance of Cumulative Impact

224. Overall, it is predicted that sensitivity/value of the receptor is **low** and the magnitude of cumulative impact is **negligible**. The cumulative effect is therefore of **minor adverse** significance, which is **not significant** in EIA terms.

225. No additional mitigation is required to manage the potential cumulative effects from changes in sediment transport regime and seabed morphology.

7.14 TRANSBOUNDARY EFFECTS

226. No potential for significant transboundary effects from the WDA on Marine Physical Environment receptors within the EEZ of other EEA member states or other interests of EEA member states have been identified. Therefore, transboundary effects have been **scoped out** of the EIA, in line with the **Scoping Opinion (Appendix 2)**.

7.15 INTER-RELATED AND INTERACTING IMPACTS

7.15.1 Inter-Relationships

227. A summary of the key inter-relationships between Marine Physical Environment and other technical chapters is provided in **Section 7.11.1**, **Table 7.15**.

7.15.2 Interactions

228. The impacts identified and assessed in this chapter have the potential to interact with each other. Areas of potential interaction between impacts are presented in **Table 7.27**, **Table 7.28**, and **Table** 7.29 below.

229. The impacts are assessed relative to each development phase (i.e. construction, O&M or decommissioning) to see if (for example) multiple construction impacts affecting the same receptor could increase the magnitude of impact upon that receptor.

230. A subsequent lifetime assessment has been undertaken which considers the impact interactions identified and the potential for impacts to affect receptors relevant to this chapter across all development phases (**Table 7.30**).

Table 7.27 Potential interaction between pathways to impact – construction

Potential Interactions Between Construction Pathways to Impact					
	Changes in SSCs (Impact 1)	**Changes in seabed level due to deposition of suspended sediment (Impact 1)**	**Changes to seabed morphology (Impact 2)**	**Changes in sediment transport regime (Impact 2)**	**Changes to wave and tide regime (Impact 2)**
Changes in SSCs (Impact 1)		No	No	No	No
Changes in seabed level due to deposition of suspended sediment (Impact 1)	No		Yes	Yes	Yes
Changes to seabed morphology (Impact 2)	No	Yes		Yes	Yes
Changes in sediment transport regime and seabed morphology (Impact 2)	No	Yes	Yes		Yes
Changes to wave and tide regime (Impact 2)	No	Yes	Yes	Yes	

Table 7.28 Potential interactions between pathways to impact – operation and maintenance

Potential Interactions Between Operation and Maintenance Pathways to Impact						
	Changes in SSCs (Impact 1)	**Changes in seabed level due to deposition of suspended sediment (Impact 1)**	**Changes to seabed morphology (Impact 2)**	**Changes in sediment transport regime and seabed morphology (Impact 2)**	**Changes to wave and tide regime (Impact 2 and 3)**	**Changes in water stratification and mixing (Impact 3)**
Changes in SSCs (Impact 1)		No	No	No	No	No
Changes in seabed level due to deposition of suspended sediment (Impact 1)	No		Yes	Yes	Yes	No
Changes to seabed morphology (Impact 2)	No	Yes		Yes	Yes	No
Changes in sediment transport regime and seabed morphology (Impact 2)	No	Yes	Yes		Yes	No
Changes to wave and tide regime (Impact 2 and 3)	No	Yes	Yes	Yes		No
Changes in water stratification and mixing (Impact 3)	No	No	No	No	No	

Table 7.29 Potential interaction between pathways to impact – decommissioning

Potential Interactions Between Decommissioning Pathways to Impact					
	Changes in SSCs (Impact 1)	**Changes in seabed level due to deposition of suspended sediment (Impact 1)**	**Changes to seabed morphology (Impact 2)**	**Changes in sediment transport regime and seabed morphology (Impact 2)**	**Changes to wave and tide regime (Impact 2)**
Changes in SSCs (Impact 1)		No	No	No	No
Changes in seabed level due to deposition of suspended sediment (Impact 1)	No		Yes	Yes	Yes
Changes to seabed morphology (Impact 2)	No	Yes		Yes	Yes
Changes in sediment transport regime and seabed morphology (Impact 2)	No	Yes	Yes		Yes
Changes to wave and tide regime (Impact 2)	No	Yes	Yes	Yes	

Table 7.30 Potential interactions between impacts – phase and lifetime assessment

Summary of Potential Interactions Between Impacts					
Receptor	**Construction**	**Operation and Maintenance**	**Decommissioning**	**Phase Assessment**	**Lifetime Assessment**
Seabed Bedforms	Negligible adverse	Negligible adverse	Negligible adverse	No greater than individually assessed impacts for each phase. Seabed Bedforms will recover quickly from disturbance during each individual phase of the Project (within days to a maximum of a year), Additionally, the bedforms are likely mobile so will adapt to permanent disturbance (such as installation of foundations).	No greater than individually assessed impacts.
Water Column Structure (including the Islay Front)	N/A	Negligible adverse	N/A	No greater than individually assessed impacts for the O&M phase. The Water Column Structure is only affected by the presence of structures that cause blockage effects in the water column altering the turbulence within the water column due to additional friction. All blockage effects occur during the O&M phase.	No greater than individually assessed impacts.
Gruinart Flats SSSI (saltmarsh)	No change	No change	No change	No pathway to impact	No pathway to impact
Glac na Criche SSSI (bedrock cliffs)	No change	No change	No change	No pathway to impact	No pathway to impact

7.16 POTENTIAL MONITORING REQUIREMENTS

231. No monitoring is currently proposed in relation to the marine physical environment. This is on account of the outcomes of this assessment, which has concluded that all of the potential impacts considered will result in, at worst, a **minor adverse** significance of effect. The conclusions are made using project specific bathymetric, sedimentological and metocean data, numerical hydrodynamic, wave, and sediment dispersion modelling, semi quantitative sediment transport and water column assessments and an accumulation of evidence from a range of studies and other existing windfarms. Overall, this leads to a high degree of confidence in the conclusions of the assessment, although it is acknowledged that research into the effects of offshore windfarms on Water Column Structure is rapidly evolving.

232. The greatest significance of effect within the assessment of the Marine Physical Environment is **minor adverse** which is **not significant** in EIA terms. However, as is typical for development projects of this nature, a range of geophysical surveys will be carried out both before and after construction for engineering / asset integrity purposes and to feed into the requirements for other environmental topics such as benthic ecology and archaeology.

7.17 SUMMARY

233. **Table 7.31** presents a summary of the assessment of potential effects on Marine Physical Environment receptors during the construction, O&M and decommissioning phases of the Project.

234. The assessment has established that the WDA would result in effects of **negligible adverse** to **minor adverse** (**not significant** in EIA terms) only.

Table 7.31 Summary of potential effects for Marine Physical Environment

Potential Impact	Receptor(s)	Relevant Embedded Mitigation Measures	Sensitivity	Magnitude of Impact	Significance of Effect	Additional Mitigation	Residual Significance of Effect	Proposed Monitoring	Combined Assessment	Cumulative Residual Significance of Effect
Construction										
Impact 1: Changes in SSCs and seabed levels	Seabed Bedforms	M-1; M-2; M-8; M-14	Negligible	Negligible	Not significant (Negligible Adverse)	N/A	Not significant (Negligible Adverse)	N/A	Not significant	Not significant (Negligible Adverse)
	Gruinart Flats SSSI (saltmarsh)		Low	No Change	Not significant (No Change)		Not significant (No Change)			Not significant (No Change)
	Glac na Criche SSSI (bedrock cliffs)		Negligible	No Change	Not significant (No Change		Not significant (No Change			Not significant (No Change
Impact 2: Changes in sediment transport regime and seabed morphology	Seabed Bedforms	M-8; M-14	Low	Low	Not significant (Minor Adverse)	N/A	Not significant (Minor Adverse)	N/A	Not significant	Not significant (Minor Adverse)
	Gruinart Flats SSSI (saltmarsh)		Negligible	No Change	Not assessed, no pathway to impact		Not assessed, no pathway to impact			Not significant (No Change)
	Glac na Criche SSSI (bedrock cliffs)		Negligible	No Change	Not assessed, no pathway to impact		Not assessed, no pathway to impact			Not significant (No Change)
Operation and Maintenance										
Impact 1: Changes in SSCs and seabed levels	Seabed Bedforms	M-1	Low	Negligible	Not significant (Negligible Adverse)	N/A	Not significant (Negligible Adverse)	N/A	Not significant	Not significant (Negligible Adverse)
	Gruinart Flats SSSI (saltmarsh)		Negligible	No Change	Not assessed, no pathway to impact		Not assessed, no pathway to impact			Not significant (No Change)
	Glac na Criche SSSI (bedrock cliffs)		Negligible	No Change	Not assessed, no pathway to impact		Not assessed, no pathway to impact			Not significant (No Change)
Impact 2: Changes in sediment transport regime and seabed morphology	Seabed Bedforms	M-8	Low	Low	Not significant (Minor Adverse)	N/A	Not significant (Minor Adverse)	N/A	Not significant	Not significant (Minor Adverse)
	Gruinart Flats SSSI (saltmarsh)		Negligible	No Change	Not assessed, no pathway to impact		Not assessed, no pathway to impact			Not significant (No Change)
	Glac na Criche SSSI (bedrock cliffs)		Negligible	No Change	Not assessed, no pathway to impact		Not assessed, no pathway to impact			Not significant (No Change)
Impact 3: Changes to Water Column Structure	Water Column Structure (including the Islay Front)	N/A	Low	Negligible	Not significant (Negligible Adverse)	N/A	Not significant (Negligible Adverse)	N/A	Not significant	Not significant (Negligible Adverse)
Decommissioning										
Impact 1: Changes in SSCs and seabed levels	Seabed Bedforms	M-46	During decommissioning, the receptors, sensitivity, magnitude and significance of effect for Impact 1 and Impact 2 is expected to be equal to or less than the receptors, sensitivity, magnitude and significance of effect during construction.							
	Gruinart Flats SSSI (saltmarsh)									
	Glac na Criche SSSI (bedrock cliffs)									

Potential Impact	Receptor(s)	Relevant Embedded Mitigation Measures	Sensitivity	Magnitude of Impact	Significance of Effect	Additional Mitigation	Residual Significance of Effect	Proposed Monitoring	Combined Assessment	Cumulative Residual Significance of Effect
Impact 2: Changes in sediment transport regime and seabed morphology	Seabed Bedforms									
	Gruinart Flats SSSI (saltmarsh)									
	Glac na Criche SSSI (bedrock cliffs)									

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