Bellrock Offshore Wind Farm

Wind Farm Development Area

Environmental Impact Assessment Report - Volume II

Chapter 6: Marine Geology, Oceanography and Physical Processes

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Glossary of Terminology

Term	Definition
Applicant	Bellrock Offshore Wind Farm Limited, the legal entity submitting Section 36 Consent and Marine Licence applications for the Bellrock Offshore Wind Farm Development Area.
Bathymetry	Topography of the seabed.
Bedload	Sediment particles that travel near or on the bed.
Bellrock Offshore Wind Farm (or the Bellrock Project)	An offshore wind farm capable of exporting up to 1.8 GW of renewable energy to the National Electricity Transmission System. The Wind Farm Development Area is located 120 km east of Stonehaven, and will connect to the National Electricity Transmission System at the proposed SSEN Transmission Hurlie substation, west of Stonehaven in Aberdeenshire. The Bellrock Offshore Wind Farm comprises of the following Development Areas: ▪ Wind Farm Development Area; ▪ Offshore Transmission Development Area; and ▪ Onshore Transmission Development Area.
Cable protection	Protective measure to minimise the effects of scour and hazards along the inter-array cables, and protecting these cables at infrastructure crossing points.
Commencement of construction	Commencement of construction to install the Wind Farm Infrastructure as authorised by the Wind Farm Development Area Section 36 consent and Marine Licence (excluding site preparation works), being the earlier of: ▪ Intrusive pre-installation surveys; ▪ Placement on or installation in the seabed of anchors and associated scour protection, and mooring lines; ▪ Trench excavation for inter-array cables; or ▪ Trenching for, or laying of inter-array cables on or in the seabed.
Commercial Operation Date	The date that the site is fully transferred to the operations team which is likely to be the date of the taking over certificate of the last wind turbine generator to be installed.
Connector	Joint between a dynamic inter-array cable and a static inter-array cable.
Development Area	For consenting purposes, the area for which separate consents and/or Marine Licences will be sought by the Applicant, comprising: ▪ Wind Farm Development Area; ▪ Offshore Transmission Development Area; and ▪ Onshore Transmission Development Area.
Excursion limit	The maximum horizontal movement of a floating substructure from its design coordinates.
Floating offshore unit	The combined wind turbine generator and floating substructure.
Floating substructure	A floating structure which provides buoyancy and, in conjunction with the station keeping system, supports a superstructure (e.g. wind turbine generator or offshore substation), and maintaining its position within the structure's excursion limit.

Term	Definition
Inter-array cable	Armoured cable containing electrical and fibre optic cores, which link the wind turbine generators to each other and to the subsea cable hubs and/or the offshore substations and include dynamic inter-array cable and static inter-array cable sections.
Lowest Astronom ical Tide	The lowest level that can be expected to occur under average meteorological conditions and under any combination of astronomical conditions.
National Electricity Transmission System	The high-voltage electricity power transmission network serving Great Britain which receives electricity from generators (such as offshore wind farms) and transmits that electricity to anywhere on the National Electricity Transmission System to satisfy demand.
Numerical modelling	Refers to the analysis of coastal processes using computational models.
Operational life	The expected operational life of the Wind Farm Infrastructure from the Commercial Operation Date to the first floating offshore unit being decommissioned.
Oslo and Paris Convention for the Protection of the Marine Environment	Oslo and Paris Convention for the Protection of the Marine Environment (OSPAR) started in 1972 with the Oslo Convention against dumping and was broadened to cover land-based sources of marine pollution and the offshore industry by the Paris Convention of 1974. These two conventions were unified, updated and extended by the 1992 OSPAR Convention. OSPAR is so named because of the original Oslo and Paris Conventions ("OS" for Oslo and "PAR" for Paris).
Project design envelope	Includes all relevant technical, spatial and temporal elements of the Wind Farm Infrastructure, and the proposed methodology to be employed for construction, operations and maintenance, and decommissioning.
Quaternary	The last two million years of earth history.
Scour protection	Protective material positioned around anchors to avoid sediment being eroded as a result of the flow of water.
Sediment transport	The movement of a mass of sediment by the forces of currents and waves.
Site preparation works	Preparatory activities undertaken within the Wind Farm Development Area prior to the commencement of construction of the Wind Farm Infrastructure, which may comprise (and which may require separate consents): ▪ Geophysical surveys, geotechnical surveys, and non-archaeological/archaeological diver/ remotely operated vehicle surveys; ▪ Seabed preparation including sand wave levelling, slope levelling for gravity based anchors (if selected), boulder clearance, and pre-lay grapnel runs; ▪ Unexploded ordnance survey and/or clearance; ▪ Debris clearance; and ▪ Out of service cable/pipeline removal.
SSEN Transmission Hurlie substation	The onshore substation to be developed by SSEN Transmission, which will receive renewable electricity from the Bellrock Project onshore substation and allow supply of renewable electricity from the wind farm to the National Electricity Transmission System.
Station keeping system	The system (including mooring lines and anchors) used to hold a floating offshore unit within its excursion limit and maintain the intended orientation of the floating offshore unit.

Term	Definition
Stratification	Describes two distinct layers occupying the vertical water column in the sea with the near-surface layer less dense than the near-bed layer.
Subsea cable hub	A subsea device, with a gravel pad foundation, which allows the connection of multiple inter-array cables.
Suspended sediment	The sediment moving in suspension in a fluid kept up by the upward components of the turbulent currents or by the colloidal suspension.
Switchgear	Electrical equipment used to control, protect, and isolate electrical circuits and equipment.
Tidal current	The alternating horizontal movement of water associated with the rise and fall of the tide.
Wind Farm Development Area	The boundary within which the Wind Farm Infrastructure will be constructed, operated and maintained, and decommissioned.
Wind Farm Infrastructure	Infrastructure located within the Wind Farm Development Area including wind turbine generators; floating substructures, station keeping systems and associated scour protection; inter-array cables and associated cable protection; subsea cable hubs; and ancillary infrastructure including buoys (including activities associated with the Wind Farm Infrastructure construction, operation and maintenance, and decommissioning).
Wind turbine generator	A wind turbine generator converts wind energy into electrical energy. The main components include rotor assembly (composed of three blades and a hub); nacelle (containing the generator, shaft and gearbox, power electronic converter and transformer); and a tower (containing lifting equipment and switchgear).

Glossary of Abbreviations

Term	Definition
3D	Three dimensional
AL	Action Level
AL1	Action Level 1
AL2	Action Level 2
ANG	Aberdeen Ground Formation
BAC	Background Assessment Concentration
BERR	Department for Business, Enterprise and Regulatory Reform
BGS	British Geological Survey
BH	Borehole
BSF	Below sea floor
BWM Convention	The International Convention for the Control and Management of Ships' Ballast Water and Sediments
CBRA	Cable Burial Risk Assessment
CEA	Cumulative effects assessment
Cefas	Centre for Environment Fisheries and Aquaculture Science
CES	Crown Estate Scotland
Chl-a	Chlorophyll-a
CMS	Construction Method Statement
COP	Coal Pit Formation
CPA	Coast Protection Act
CPT	Cone Penetration Test
DDD	Drive – Drill – Drive
DP	Decommissioning Programme
DSLP	Development Specification and Layout Plan
EEZ	Exclusive Economic Zone
EIA	Environmental impact assessment
EMODnet	European Marine Observation and Data Network
EMP	Environmental Management Plan

Term	Definition
EO	Earth Observation
EPA	Environmental Protection Agency
EQS	Environmental Quality Standards
ERL	Effects Range-Low
EU	European Union
FEPA	Food and Environmental Protection Act
FOU	Floating offshore unit
FSS	Floating substructure
GBA	Gravity base anchor
GEN	General Policies
IAC	Inter-array cable
IA-CaP	Inter-array Cable Plan
ICES	International Council for the Exploration of the Sea
IMO	International Maritime Organisation
Kya	Thousand years before present
LAT	Low astronomical tide
MAR	Marr Bank Formation
MARPOL	International Convention for the Prevention of Pollution from Ships
MBES	Multi-beam Echo Sounder
MD-LOT	Marine Directorate – Licensing Operations Team
MD-SEDD	Marine Directorate - Science, Evidence, Data and Digital
MIS	Marine Isotope Stage
MMO	Marine Management Organisation
MPA	Marine Protected Area
MPCP	Marine Pollution Contingency Plan
MV	Main meltwater valley
MV1	Meltwater valley 1
MV2	Meltwater valley 2

Term	Definition
Mya	Million years before present
O&M	Operation and maintenance
OfTDA	Offshore Transmission Development Area
OMP	Operation and Maintenance Plan
OnTDA	Onshore Transmission Development Area
OSPAR	Oslo and Paris Convention for the Protection of the Marine Environment
OSWF	Offshore Wind Industry Council
OWC	Offshore Wind Consultants
OWF	Offshore Wind Farm
PAH	Polyaromatic hydrocarbons
PCB	Polychlorinated biphenyls
PDE	Project design envelope
PEA	Potential energy anomaly
PSA	Particle size analysis
QSR	Quality Status Report
SAMS	Scottish Association for Marine Science
SCM	Sub-surface chlorophyll maximum
SKS	Station keeping system
SMV	Subdued meltwater valley
S-P-R	Source-Pathway-Receptor
SSC	Suspended sediment concentration
SSM	Scottish Shelf Model
SSS	Side scan sonar
SST	Sea surface temperature
SSW-RS	Scottish Shelf Waters Reanalysis Service
THC	Total hydrocarbons
TKE	Turbulence kinetic energy
UK	United Kingdom

Term	Definition
UKAS	United Kingdom Accreditation Service
UKHO	United Kingdom Hydrographic Office
VMNSP	Vessel Management and Navigational Safety Plan
WCS	Worst-case scenario
WFD	Water Framework Directive
WFDA	Wind Farm Development Area
WODC	World Ocean Data Centre
WTG	Wind turbine generator
ZoI	Zone of Influence

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6 Marine Geology, Oceanography and Physical Processes

6.1 Introduction

1. This Chapter of the Bellrock Wind Farm Development Area (WFDA) Environmental Impact Assessment (EIA) Report presents an assessment of potential effects on marine geology, oceanography and physical processes (including water quality) from the construction, operation and maintenance (O&M) and decommissioning phases of the Bellrock Wind Farm Infrastructure.

2. The Bellrock Wind Farm Infrastructure comprises wind turbine generators (WTGs); floating substructures (FSSs), station keeping systems (SKSs) and associated scour protection; inter-array cables (IACs) and associated cable protection; subsea cable hubs; and ancillary infrastructure including buoys. Further detail on the Bellrock Wind Farm Infrastructure is provided in **Chapter 4: Project Description (Volume II)**.

3. This Chapter has been prepared to provide the Marine Directorate - Licensing and Operations Team (MD-LOT) (on behalf of Scottish Ministers) and stakeholders with sufficient information to determine the potential effect(s) of the Bellrock Wind Farm Infrastructure on marine geology, oceanography and physical processes receptors.

4. This Chapter should be read in conjunction with the following Chapters of the Bellrock WFDA EIA Report:

- **Chapter 7: Benthic Ecology;**
- **Chapter 8: Fish and Shellfish Ecology;**
- **Chapter 9: Marine Mammals;** and
- **Chapter 15: Marine Archaeology and Cultural Heritage.**

5. The marine geology, oceanography and physical processes assessment has key inter-relationships with the above topics, which will be considered appropriately throughout this Bellrock WFDA EIA Report.

6. Additional information to support the marine geology, oceanography and physical processes assessment includes:

- **Appendix 6.1: Shelf sea stratification, nutrient fluxes and primary production baseline for the Bellrock WFDA (Volume IV)**; and
- **Appendix 6.2: Stratification Analysis Report (Volume IV)**.

7. This Chapter was prepared by Haskoning.

6.2 Legislation, Policy and Guidance

8. **Table 6.1** describes the legislation, policy and guidance which have been considered in the preparation of this Chapter. The overarching legislation and policy relevant to the Bellrock Wind Farm Infrastructure is described in **Chapter 2: Policy and Legislative Context (Volume II)**.

9. Any legislation referred to in this EIA Report is as subsequently amended and as currently in force as at the date of this EIA Report.

Table 6.1: Summary of Relevant Legislation, Policy and Guidance for Marine Geology, Oceanography and Physical Processes

Relevant Legislation, Policy and Guidance	Relevance to the Assessment
Legislation and Policy	
The Marine Policy Statement (HM Government, 2011) provides the high-level approach to marine planning and general principles for decision making that contribute to achieving this vision. It also sets out the framework for environmental, social, and economic factors that need to be considered in marine planning	The key reference is Section 2.6.8.6 which states: "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." For water quality, the key reference is Section 2.6.4.1 which states: *"Developments and other activities at the coast and at sea can have adverse effects on transitional waters, coastal waters and marine waters. During the construction, operation and decommissioning phases of developments, there can be increased demand for water, discharges to water and adverse ecological effects resulting from physical modifications to the water environment. There may also be an increased risk of spills and leaks of pollutants into the water environment and the likelihood of transmission of invasive non-native species, for example through construction equipment, and their impacts on ecological water quality need to be considered."*
Scotland's National Marine Plan (Scottish Government, 2015) details strategic policies for the sustainable development of Scotland's marine resources out to 200 nautical miles	Policy GEN 8 Coastal Process and Flooding states*: "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 states: *"Marine planners and decision makers should also be satisfied that activities and developments will*

Relevant Legislation, Policy and Guidance	Relevance to the Assessment
	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." Policy GEN 12 Water Quality and Resource states: *"Developments and activities should not result in a deterioration of the quality of waters to which the Water Framework Directive (WFD), Marine Strategy Framework Directive or other related Directives apply".* Note that the WFD does not apply to the Bellrock WFDA given it is located offshore, 120 km east of Stonehaven and therefore, outside of WFD jurisdiction. However, the Marine Strategy Framework Directive will apply – see below. Paragraph 4.67 states: *"The Marine Strategy Framework Directive introduces requirements for targets on contamination and eutrophication for marine waters out to 200 nautical mile."* When published, Scotland's National Marine Plan 2 will be considered at the post-consent stage, as part of the discharge of relevant consent and licence conditions and the development and approval of post-consent plans and programmes. It is assumed that when published, Scotland's National Marine Plan 2 will supersede the existing National Marine Plan. Consultation on the SNMP ran from 5 November 2024 to 7 February 2025 and a consultation analysis report has been produced by the Scottish Government (2025).
International Convention for Prevention of Marine Pollution by Ships (MARPOL)	MARPOL is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes. It is a combination of two treaties adopted in 1973 and 1978 respectively and updated by amendments through the years. The Convention covers all the technical aspects of pollution from ships, except the disposal of waste into the sea by dumping, and applies to ships of all types, although it does not apply to pollution arising out of the exploration and exploitation of seabed mineral resources.
Guidance	
Centre for Environment Fisheries and Aquaculture Science (Cefas) (2004)	Offshore Wind Farms: Guidance Note for EIA in respect of Food and Environmental Protection Act (FEPA) and Coast Protection Act (CPA) 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.

Relevant Legislation, Policy and Guidance	Relevance to the Assessment
Lambkin et al. (2009)	Coastal Process Modelling for Offshore Windfarm EIA.
Cefas (2011)	Guidelines for Data Acquisition to Support Marine Environmental Assessments of Offshore Renewable Energy Projects.
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.

6.3 Consultation

10. Consultation undertaken to date for the Bellrock Wind Farm Infrastructure relevant to marine geology, oceanography and physical processes has been undertaken in line with the general process described in **Chapter 5: EIA Methodology (Volume II)**. Key consultation pertinent to this Chapter is provided **in Table 6.2** below.

Table 6.2: Consultation Relevant to Marine Geology, Oceanography and Physical Processes

Consultee	Date/Document	Comment	How/where Comment is Addressed
Marine Directorate-Science, Evidence, Data Digital (MD-SEDD)	15 December 2023, email response to Bellrock WFDA Scoping Workshop held 30 October 2023.	*Do you agree with the identified impacts?* MD-SEDD advise that the conceptual modelling approach is considered to be proportionate for the operational phase. A strong evidence base should be presented to describe the prevailing conditions and sediment transport pathways. A more rigorous quantitative consideration of changes to sediment transport and the fate of sediment plumes from dredging and bed preparations should be performed for the installation phase, including installation of structures (including anchors etc) on the seabed within the wind farm and the installation of cables along the length of the cable route, especially in the nearshore environment. The proposed wind farm is in a region of shelf sea that probably experiences seasonal (and intermittent) stratification (van Leeuwen et al. 2015). MD-SEDD advise an additional impact that should be investigated is the potential changes to water column structure including magnitude, timing and extent of seasonal stratification. MD-SEDD advise the prevailing baseline water column conditions should be described in the EIA. The baseline description should include details of stratification including what the water column structure is like through the year (e.g. seasonal 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 (PEA)). The strength of stratification should be noted, as well as what additional mixing would be required to alter the timing and extent of stratification. Typical frontal positions in the region should also be noted. The link between stratification and fronts to primary productivity and higher trophic levels and ecosystem services should be noted. A wind farm could change water column mixing, by the structures generating turbulent wakes, and/or by altering the near sea surface wind speeds (Christiansen et al. 2022, Dorrell et al. 2022). Qualitatively considering how the wind farm could alter these processes may be a pragmatic/proportional approach as long as sufficient evidence is provided, e.g. good baseline description, using data from three dimensional (3D) hydrodynamics models, and citing research evidence. If there are uncertainties as to how the wind farm may change	All impacts scoped into the assessment are outlined in **Section 6.7.1**. The details of potential impacts are included in **Section 6.7.3** and **Section 6.8**. Specifically the potential impacts on stratification are included in **Section 6.7.3.8** and **Section 6.8.2.3**.

Consultee	Date/Document	Comment	How/where Comment is Addressed
		stratification then 3D hydrodynamic modelling may be required. Changes to mixing have the potential to impact other receptors, such as productivity as well as higher trophic levels, and this should also be qualitatively considered in the EIA. Impact on Nature Conservation Marine Protected Areas (MPAs) where fronts are a designated feature should be considered. Cumulative impacts on mixing and stratification due to neighbouring wind farms should be considered. Given the current lack of methodologies and tools available to applicants, MD-SEDD advises that the proposed qualitative assessment approach is considered to be adequate and proportionate. <u>References</u> Emergence of Large-Scale Hydrodynamic Structures Due to Atmospheric Offshore Wind Farm Wakes[1] Anthropogenic Mixing in Seasonally Stratified Shelf Seas by Offshore Wind Farm Infrastructure[2] Stratified and nonstratified areas in the North Sea: Long-term variability and biological and policy implications[3]	
NatureScot	20 December 2023, email response to Bellrock WFDA Scoping Workshop held 30 October 2023	*Do you agree with the identified impacts?* In relation to the potential impact 'changes in seabed level due to foundation and array cable installation', NatureScot recommend that this should incorporate changes due to bedform levelling/clearance. Regarding, the potential impact 'changes to waves due to the presence of the foundation structures on the seabed' – NatureScot suspect that as the array area is likely to be in deep water any wave effects due to foundations could be insignificant. If any wave effects are to be assessed, it should be those associated with the WTGs, notwithstanding that they would be floating. In addition, NatureScot advise that scour should be included within the assessment, and this could be incorporated within the 'changes in sediment transport…' impact. Finally, in relation to the 'loss of seabed area due to the foundations' footprints' potential impact – NatureScot advise that this should also incorporate the effects of other seabed infrastructure e.g. cable protection.	Changes in seabed level due to bedform levelling/clearance are included in **Sections 6.7.3.4** and **6.7.3.7**. Scour is considered in **Section 6.7.3.7**. Loss of seabed area due to the footprint of anchor and scour protection, unburied IAC and associated cable protection, and subsea cable hubs is of particular relevance to benthic receptors and is therefore considered in **Chapter 7: Benthic Ecology.**

Consultee	Date/Document	Comment	How/where Comment is Addressed
NatureScot	20 December 2023, email response to Bellrock WFDA Scoping Workshop held 30 October 2023	*Do you agree with the conceptual modelling approach?* NatureScot is content that no numerical modelling of physical processes is proposed. The suggested Source-Pathway-Receptor (S-P-R) is more of a concept modelling approach – what is most important is the assessment methods. Therefore, we agree that Expert Geomorphological Assessment will be required. The use of empirical formulae should also be anticipated, and consideration should be given to applying results of assessment undertaken (if robust) for similar offshore wind farms in the vicinity. Please note that if a potential impact regarding waves to be assessed then this approach should include waves.	Noted. The details of the assessment methodology can be found in **Section 6.4**, The data and site-specific assessments used are in **Section 6.5.2**. The assessment considers the outputs from numerical modelling from other, nearby offshore wind farms, as outlined in **Section 6.7**.
MD-SEDD	22 May 2024 - Scoping Consultation (SCOP-0043)	*Do you agree with the sensitive receptor categories?* MD-SEDD agree with the receptors/processes considered in the scoping report, and that those proposed to be scoped in should be. MD-SEDD advise that water column stratification and mixing, and the potential influence on nutrient fluxes and primary production, be scoped in because the Bellrock development site consistently undergoes seasonal stratification during the summery months. MD-SEDD recognise that preliminary work has been undertaken (Scottish Association for Marine Science (SAMS), 2023) to understand the impacts of floating structures on shelf sea stratification, and this evidence should be presented in the EIA. The report confirms that the Bellrock development undergoes seasonal stratification and is typically stratified during the summer months. This report considers the potential for structures to enhance turbulent mixing and compares this with background mixing (due to seabed friction). The report estimates that the energy converted to turbulence kinetic energy (TKE) by structures could be around 10% of that due to bed friction. The EIA should consider whether this change in mixing could delay the onset of stratification, and what impact this could have on primary production and the wider ecosystem (e.g. potential for this change in physical processes acting as a pathway of change to biological receptors). Furthermore, the potential wind-wake impact (e.g. Christiansen et al. 2023) should also be considered and compared with the potential structure mixing impact. MD-SEDD note the potential net-gain	Water column stratification has been scoped into the assessment. See **Section 6.7.3.8** for an assessment of potential changes due to the Bellrock Wind farm Infrastructure, **Section 6.8.2.3** for an assessment of effects on the water column as a receptor and **Section 6.9.3.1.1** for a cumulative assessment on the water column. The preliminary work undertaken by SAMS is included in **Appendix 6.1: Shelf sea stratification, nutrient fluxes and primary production baseline for the Bellrock WFDA (Volume IV)**, last updated in 2026. For clarity, this appendix is an updated but equivalent version of the SAMS report referenced in the consultee comment, this has been reflected in the consultee comments reference list. The updated assessment presented in **Section 6.7.3.8** no longer uses this approach and is based on the methods outlined in Carpenter et al. (2016) which are becoming the industry standard

Consultee	Date/Document	Comment	How/where Comment is Addressed
		associated with enhance mixing in the form of potential for enhanced primary production (SAMS, 2023).	approach to the assessment of changes to water column structure (**Appendix 6.2: Stratification Analysis Report (Volume IV)**).
MD-SEDD	22 May 2024 - Scoping Consultation (SCOP-0043)	*Do you agree with conceptual evidence-based assessment of tidal currents, waves, sediment dispersion and stratification?* MD-SEDD agree that the assessment methodology, for the processes currently scoped in, is appropriate and proportionate.	Noted. The methodology as outlined and agreed at scoping is outlined and expanded upon in **Section 6.4**.
MD-SEDD	22 May 2024 - Scoping Consultation (SCOP-0043)	*Do you have any other matters or information sources that you wish to present?* MD-SEDD advise that there are no suggested data sources in Table 5.3 of the Scoping Report, coving water column structure including stratification. MD-SEDD advise the use of existing 3D model outputs to describe the physical water column in the study area. Daily mean (or hourly) output of temperature and salinity could be used to describe stratification (magnitude, extent, timing) and hourly current speed data could be used to describe flow conditions. The northwest European shelf reanalysis model runs available on Copernicus Marine (e.g. https://doi.org/10.48670/moi-00059 and https://doi.org/10.48670/moi-00054), or Scottish Shelf Model (SSM) (https://marine.gov.scot/themes/scottish-shelf-model) would be sensible model choices. Note there is a climatology available from the SSM (widely used by the aquaculture industry) which could be used, but there is also a 27 year reanalysis available from the Scottish Shelf Waters Reanalysis Service (SSW-RS) (https://tinyurl.com/SSW-Reanalysis) that can be used to study inter-annual variability (and how this might compare with potential impacts). References: The largescale impact of anthropogenic mixing by offshore wind turbine foundations in the shallow North Sea[4]. Understanding the impacts of floating turbine structures on shelf sea stratification, nutrient fluxes and primary productivity[5].	Noted. Data from the SSM Reanalysis Service has been used to characterise the baseline for water column structure in **Section 6.6.10** (see **Section 6.5.2.2**)

Consultee	Date/Document	Comment	How/where Comment is Addressed
NatureScot	13 May 2024 - Scoping Consultation (CNS/REN/OSWF/E1 – Bellrock – Pre-application)	Following the Bellrock Scoping workshop NatureScot provided written advice on physical processes (advice issued 20 December 2023). NatureScot welcome the acknowledgement of their advice and note the inclusion of reference to points raised regarding bedform levelling/clearance and scour and loss of seabed within Section 5.6.1.1. NatureScot note that further consideration will be detailed within the Bellrock WFDA EIA Report.	Noted. Changes in seabed level due to bedform levelling/clearance are included in **Sections 6.7.3.4** and **6.7.3.7**. Scour is considered in **Section 6.7.3.7**. Loss of seabed area due to the footprint of anchor and scour protection, unburied IAC and associated cable protection, and subsea cable hubs is of particular relevance to benthic receptors and is therefore considered in **Chapter 7: Benthic Ecology.**
NatureScot	13 May 2024 - Scoping Consultation (CNS/REN/OSWF/E1 – Bellrock – Pre-application)	With regards to the Scoping questions included in Section 5.8, NatureScot advise that they do not currently have in-house expertise regarding physical processes so far offshore (WFDA located approximately 120 km from shore), as such we note that MD-SEDD may wish to provide advice regarding Section 5 of this Scoping Report.	Noted. MD-SEDD advice also sought during the scoping process and accounted for in this assessment.
MD-LOT	**Appendix 1.2: Bellrock WFDA Scoping Opinion (Volume IV)**, Paragraph 5.2.1	MD-LOT confirm that they are content with the proposed study area described in Section 5.4.1.	Noted. The marine geology, oceanography and physical processes study area can be found in **Section 6.5.1**.
MD-LOT	**Appendix 1.2: Bellrock WFDA Scoping Opinion (Volume IV)**, Paragraph 5.2.2	MD-LOT confirm that they are broadly content with the proposed data sources used to characterise the baseline in Section 5.4.2, however, highlight the MD-SEDD advice regarding 3D model use to characterise the water column structure including stratification and request that this must be fully addressed and implemented in the EIA Report.	Noted. The data sources and site-specific surveys utilised in this assessment are described in **Section 6.5.2.** Data from the SSM Reanalysis Service (see **Section 6.5.2.2**) has been used to characterise the baseline for water column structure in **Appendix 6.2: Stratification**

Consultee	Date/Document	Comment	How/where Comment is Addressed
			Analysis Report (Volume IV) and **Section 6.6.10**.
MD-LOT	**Appendix 1.2: Bellrock WFDA Scoping Opinion (Volume IV)**, Paragraph 5.2.3	Table 5.5 summarises the impacts to be scoped in and out of the assessment. MD-LOT advise that they broadly agree with the impacts proposed to be scoped in. However, in line with advice from MD-SEDD, advise that water column stratification and mixing, and the potential influence on nutrient fluxes and primary production is also scoped in due to consistent seasonal stratification. MD-LOT also highlight the references provided by MD-SEDD on this topic and advise that they should be considered within the EIA Report.	Noted. Data from the SSM Reanalysis Service (see **Section 6.5.2.2**) has been used to characterise the baseline for water column structure in **Section 6.5.2.2**.
MD-LOT	**Appendix 1.2: Bellrock WFDA Scoping Opinion (Volume IV)**, Paragraph 5.2.4	MD-LOT advise that they are content with the approach to the assessment set out in Section 5.7 of the Scoping Report.	Noted. The methodology as outlined and agreed at scoping is outlined and expanded upon in **Section 6.4**.
MD-LOT	**Appendix 1.2: Bellrock WFDA Scoping Opinion (Volume IV)**, Paragraph 5.2.5	MD-LOT advise that they are content with the mitigation set out in Section 5.5.1 of the Scoping Report. In line with the representation from NatureScot, they advise that the full range of mitigation measures, published guidance, and monitoring requirements are discussed in the EIA Report.	Noted. Mitigation measures and monitoring requirements are outlined in **Section 6.7.5**. Guidance is outlined in **Section 6.2**.
MD-LOT	**Appendix 1.2: Bellrock WFDA Scoping Opinion (Volume IV)**, Paragraph 5.2.6	MD-LOT note that potential cumulative effects are summarised in Section 5.6.3 of the Scoping Report and they are content with this approach.	Noted. The Cumulative Effect Assessment is presented in **Section 6.9**.
MD-LOT	**Appendix 1.2: Bellrock WFDA Scoping Opinion (Volume IV)**, Paragraph 5.2.7	MD-LOT advise that they are in agreement that transboundary impacts can be scoped out of the EIA for Marine Geology, Oceanography and Physical Processes, as discussed in Section 5.6.4 of the Scoping Report.	Noted.
Notes:			

Consultee	Date/Document	Comment	How/where Comment is Addressed
[1] Christiansen, N., Daewel, U., Djath, B., and Schrum, C. (2022). Emergence of Large-Scale Hydrodynamic Structures Due to Atmospheric Offshore Wind Farm Wakes. Frontiers in Marine Science, 9. https://doi.org/10.3389/fmars.2022.818501. [2] Dorrell, R. M., Lloyd, C. J., Lincoln, B. J., Rippeth, T. P., Taylor, J. R., Caulfield, C. P., Sharples, J., Polton, J. A., Scannell, B. D., Greaves, D. M., Hall, R. A., and Simpson, J. H. (2022). Anthropogenic Mixing in Seasonally Stratified Shelf Seas by Offshore Wind Farm Infrastructure. Frontiers in Marine Science, 9. https://doi.org/10.3389/fmars.2022.830927. [3] van Leeuwen, S., P. Tett, D. Mills, and J. van der Molen (2015), Stratified and nonstratified areas in the North Sea: Long-term variability and biological and policy implications, J. Geophys. Res. Oceans, 120, 4670–4686, https://doi.org/10.1002/2014JC010485. [4] Christiansen, N., Carpenter, J. R., Daewel, U., Suzuki, N., and Schrum, C. 2023. The largescale impact of anthropogenic mixing by offshore wind turbine foundations in the shallow North Sea. Frontiers in Marine Science, 10. https://www.frontiersin.org/articles/10.3389/fmars.2023.1178330. [5] SAMS, 2023: **Appendix 6.1: Shelf sea stratification, nutrient fluxes and primary production baseline for the Bellrock WFDA (Volume IV).**			

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6.4 Assessment Methodology

6.4.1 Impact Assessment Methodology

11. In **Chapter 5: EIA Methodology (Volume II)** an overarching method is presented for enabling assessments of the potential impacts arising from the Bellrock Wind Farm Infrastructure on the receptors under consideration. Such assessments incorporate a combination of the sensitivity of the receptor, its value (if applicable) and the magnitude of the impact to determine a significance of effect. This method has been followed for the assessment of marine geology, oceanography and physical processes receptors.

12. The assessment of potential impacts arising from the Bellrock Wind Farm Infrastructure is based on an S-P-R model. This approach identifies the origin (source) of a potential impact, the changes that occur because of the impact and how they may affect a particular receptor (pathway), with the receptor being the element that is affected by the impact. In the context of marine geology, oceanography and physical processes, 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 (numerical modelling) approaches.

13. An example of a S-P-R model, in the context of marine geology, oceanography and physical processes, is where cable installation disturbs the seabed and sediment becomes suspended (the source), this leads to a change in suspended sediment concentrations (SSCs) in the water column relative to the baseline, and as this sediment is redeposited, seabed levels (and potential seabed sediment composition) change (the pathway). The spatial extent (defined as the Zone of Influence (ZoI) 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 ZoI, and therefore potentially impacted by the change.

14. With respect to the assessment of impacts related to marine geology, oceanography and physical processes, the principal receptors are coastal or marine features with an inherent oceanographic, geological or geomorphological value or function which may be affected by the Bellrock Wind Farm Infrastructure. These may include:

- Seabed morphological features (e.g. sandbanks, sandwaves, channels, paleochannels/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.

15. However, in addition to these impacts to morphological and water quality receptors, changes to marine geology, oceanography and physical processes can also create a pathway to impact for receptors assessed for other topics, as defined in **Table 6.15**.

16. Consideration of the potential effects on marine geology, oceanography and physical processes is carried out at the following spatial scales:

- Individual structure scale (< 1 km);
- Bellrock WFDA scale (10s of kms); and
- Regional scale (> 100 km).

17. Following the S-P-R model approach, the assessment presented in this Chapter is split into two phases: the first describes predicted changes to marine geology, oceanography and physical processes arising from the Bellrock Wind Farm Infrastructure, and defines a ZoI to screen receptors (**Section 6.5.1**). Where these changes directly affect marine geology, oceanography and physical processes receptors, the second phase determines the significance of effect (**Section 6.8**), based on an assessment of the magnitude of impact and sensitivity of the receptor, following the criteria presented in **Section 6.4.1.1** below. In cases where predicted changes to marine geology, oceanography and physical processes could manifest in impacts upon other receptors, the degree of change is determined in this Chapter, but the assessment of effect on these other receptors is made within the relevant chapters of the EIA.

6.4.1.1 Definitions of Sensitivity and Magnitude

18. The sensitivity of a marine geology, oceanography and physical processes, and water quality receptors 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 6.3** and these are assessed using expert judgement.

Table 6.3: Definitions of Sensitivity Levels for Marine Geology, Oceanography and Physical Processes Receptors

Sensitivity	Definition
High	Tolerance: Receptor has very limited tolerance to 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 the impact. Recoverability: Receptor able to recover to an acceptable status over the medium term (5-10 years).

Sensitivity	Definition
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 (1-5 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).

19. In addition, a value component may also be considered when assessing a receptor. This ascribes whether the receptor is rare, protected or threatened (**Table 6.4**). 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 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 6.4: Definition of the Value Levels for Marine Geology, Oceanography and Physical Processes Receptors

Value	Definition
High	Receptor is designated and/or of national or international importance for marine geology, oceanography, physical processes and or designated with requirements to protect additional water quality parameters (for example a designated bathing water). Likely to be rare with minimal potential for substitution. May also be of significant wider-scale, functional or strategic importance. This category may also include water bodies with low capacity to tolerate any changes to baseline conditions.
Medium	Receptor is not designated but is of local to regional importance for marine geology, oceanography, physical processes or water quality. This category may also include water bodies with low capacity to tolerate any changes to baseline conditions.
Low	Receptor is not designated but is of local importance for marine geology, oceanography, physical processes or water quality. This category may also include water bodies which have a high capacity to accommodate change to water quality status due, for example, to large relative size of the receiving water and capacity for dilution.
Negligible	Receptor is not considered to be particularly important or rare. This category may also include water bodies which have a very high capacity to accommodate change to water quality status due, for example, to large relative size of the receiving water and capacity for dilution.

20. 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 6.5**.

Table 6.5: Definition of the Magnitude Levels for Marine Geology, Oceanography and Physical Processes 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	No measurable or discernible change from baseline conditions. The Does not result in any alternation to the receptor.

6.4.1.2 Effect Significance

21. 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 (Volume II)** for further details). A matrix is used (**Table 6.6**) as a framework to determine the significance of an effect. Definitions of each level of significance are provided in **Table 6.7**. Impacts and effects may be either positive (beneficial) or negative (adverse).

Table 6.6: Matrix for Evaluating the Significance of an Effect

Sensitivity	Magnitude				
	High	Medium	Low	Negligible	No Change
High	Major	Major	Moderate	Minor	No effect
Medium	Major	Moderate	Minor	Negligible	No effect
Low	Moderate	Minor	Minor	Negligible	No effect
Negligible	Minor	Negligible	Negligible	Negligible	No effect

22. For the purposes of this Bellrock WFDA EIA Report, '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.

23. 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 6.7: Definitions of Effect Significance

Effect Significance	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 change in receptor condition; therefore, no effect.

6.4.2 Cumulative Effects Assessment Methodology

24. The Cumulative Effects Assessment (CEA) considered the likely **significant** effects of impacts arising from the Bellrock Wind Farm Infrastructure cumulatively with other relevant plans, projects and activities. The general approach to the CEA for marine geology, oceanography and physical processes included defining a CEA plans and projects screening area of search, identifying a short list of plans and projects for consideration, identifying potential cumulative impacts, and evaluating the significance of cumulative effects. The screening for this Chapter has been based on a four-month cut off period for other projects and plans, which represents a shorter cut-off than the six months that was proposed in the Scoping Report **(Appendix 1.1: Bellrock WFDA Scoping Report (Volume IV**). MD-LOT were consulted during the screening process as part of ongoing consultation in the pre-application phase. **Chapter 5: EIA Methodology (Volume II)** provides further details on the general approach to the CEA, including the CEA with the Bellrock Offshore Transmission Development Area (OfTDA) and Onshore Transmission Development Area (OnTDA).

25. The plans and projects selected as relevant to the CEA for marine geology, oceanography and physical processes are based upon the results of a screening exercise (see **Appendix 5.3: Cumulative Effect Assessment Long List of Projects (Volume IV)** for details). Each plan or project has been considered on a case-by-case basis for screening in or out of this assessment based upon data confidence, impact-receptor pathways and the spatial/temporal scales involved.

26. The likely significant effects of the Bellrock Wind Farm Infrastructure together with the Bellrock Offshore Transmission Infrastructure and Onshore Transmission Infrastructure, so far as these can be ascertained at this stage, are assessed as part of this Bellrock WFDA EIA Report.

27. Further assessment of the effects of the Bellrock Project as a whole will be included within the Bellrock OfTDA EIA Report and OnTDA EIA Report, which will include updated assessments of cumulative environmental impacts of the different components of the Bellrock Project.

28. In line with the methodology set out in **Chapter 5: EIA Methodology (Volume II),** three tiers have been applied to the Bellrock WFDA CEA. As the site selection process for the Bellrock OfTDA and OnTDA is ongoing (see **Chapter 4: Project Description (Volume II)** for details), activities and infrastructure associated with the Bellrock OfTDA and Bellrock OnTDA will be treated as 'other projects' for the purposes of the CEA, but have been considered within Tier 1 where relevant, due to their essential requirement for the function of the Bellrock Project.

29. The three tiers for CEA are:

- Tier 1 assessment: The Bellrock WFDA plus plans/projects which are operational, under construction, those with consent or a consent application submitted but not yet determined, plus the Bellrock OfTDA and Bellrock OnTDA;
- Tier 2 assessment: The Bellrock WFDA plus all plans/projects assessed under Tier 1, plus projects with a Scoping Report and/or Scoping Opinion; and
- Tier 3 assessment: The Bellrock WFDA plus all plans/projects assessed under Tier 1 and Tier 2, plus those projects likely to come forward where a Crown Estate Scotland Option to Lease Agreement or equivalent has been granted.

6.4.3 Transboundary Effects Assessment Methodology

30. As agreed by MD-LOT in **Appendix 1.2: Bellrock WFDA Scoping Opinion** in **Volume IV**, Paragraph 5.2.7, Transboundary effects on marine geology, oceanography and physical processes, have been scoped out, recognising that the Bellrock WFDA is approximately 125 km from the Exclusive Economic Zone (EEZ) of Norway. Given that the likely effects will be restricted to near-field change, coupled with their location at distance from the EEZ boundary, there would be no pathway for transboundary effects. Transboundary effects are not discussed further within this Chapter.

6.5 Scope of the Assessment

6.5.1 Study area

31. The marine geology, oceanography and physical processes study area is defined by the direct footprint of the Bellrock WFDA and wider areas of the marine environment that could potentially be affected by the impacts being assessed.

32. The ZoI is the spatial extent of a change that may arise due to the Bellrock Wind Farm Infrastructure. The ZoI varies depending on activity/infrastructure type and the changes introduced. It is determined from all available data and information (**Sections 6.6**, **6.7.2** and **6.7.3**), including numerical modelling outputs, where appropriate. The marine geology, oceanography and physical processes zones of influence for different pathways are defined in **Table 6.8** as shown in **Figure 6.1** (**Volume III**). The total ZoI is the sum of the spatial extent of the Bellrock WFDA and the zones of influence for all impacts, moderated by the direction and length of the tidal ellipse excursions across the Bellrock WFDA.

Table 6.8: Definition of Zones of Influence for Different Marine Geology, Oceanography and Physical Processes Effects

Pathway	Maximum Zone of Influence	Source
Changes to wave regime	72 km to the south, 63 km to the west, 30 km to the north and 26 km to the east of the Bellrock WFDA.	Analogous numerical modelling (see **Section 6.7.3.6**)
Changes to tidal regime	5 km from the southern boundary of the Bellrock WFDA. Direction: south (southwest) to north (northeast).	Analogous numerical modelling (see **Section 6.7.3.5**)
Changes to water circulation	The maximum ZoI for changes to water circulation is expected to be comparable to the ZoI for wave and tidal regime (above).	Analogous numerical modelling.
Change to SSC	Up to 5 km from the boundary of the Bellrock WFDA.	Tidal excursion ellipse supported by analogous numerical modelling (**Section 6.7.3.3**)
Changes to bedload sediment transport	Up to 5 km from the boundary of the Bellrock WFDA.	Tidal excursion ellipse supported by analogous numerical modelling (see **Section 6.7.3.7**)
Tidal excursion ellipse	Length: Between 3.8 km in the north, south and southeast, and between 4.0 km and 4.7 km in the west and northeast. Direction: Ellipses are oriented north to south.	**Figure 6.1 (Volume III)** (ABPmer 2008).

6.5.2 Data and Information Sources

33. **Table 6.9** sets out the key desk-based information and data sources that have been used to inform the marine geology, oceanography and physical processes baseline.

Table 6.9: Key Data and Information Sources for Marine Geology, Oceanography and Physical Processes

Dataset	Year(s)	Description
European Marine Observation and Data Network (EMODnet) (EMODnet, 2024)	2020	Bathymetry
United Kingdom (UK) Marine Renewables Atlas (ABPmer, 2008)	2008	Tidal excursion ellipses and tidal stream
UK Met Office's Wave Watch III model (CMEMS, 2025)	2025	Waves
British Geological Survey (BGS) (BGS 1985a, 1985b)	Pre-1985	Seabed sediments and Quaternary geology
Cefas (Cefas, 2016)	1998 - 2015	SSCs
OSPAR Quality Status Reports (QSR) (OSPAR, 2023a, 2023b)	Latest report 2023	Region II – Greater North Sea. Concentrations of contaminants in sediments/overall pollution status of each region
SSW-RS (Barton et al., 2022)	2018	Stratification (temperature and salinity)
Muir Mhòr Offshore Wind Farm Marine Processes Modelling Report (Muir Mhòr, 2024)	2023 - 2024	Outputs from hydrodynamic, wave and plume dispersion modelling
Renewables UK Dogger Banks South Offshore Wind Farm Marine Physical Processes Modelling Technical Report (RWE, 2025)	2022 - 2023	Outputs from hydrodynamic, wave and plume dispersion modelling

6.5.2.1 Site-specific Surveys

34. Site-specific surveys have been undertaken to support the desk-study by providing accurate and detailed environmental information. **Table 6.10** summarises the site-specific surveys relevant to marine geology, oceanography and physical processes undertaken to date.

Table 6.10: Summary of Site-specific Surveys for Marine Geology, Oceanography and Physical Processes

Survey	Spatial Coverage	Year(s)
Geophysical survey (bathymetry and shallow geology)	Bellrock WFDA	June to Aug. 2023
Grab sampling and particle size analysis	74 sample stations across the Bellrock WFDA	July 2023

Survey	Spatial Coverage	Year(s)
Sediment contaminant analysis	15 sample stations across the Bellrock WFDA	July 2023
Geotechnical survey (BHs and CPTu)	Bellrock WFDA	Sept. to Nov. 2023

6.5.2.2 Scottish Shelf Reanalysis Service

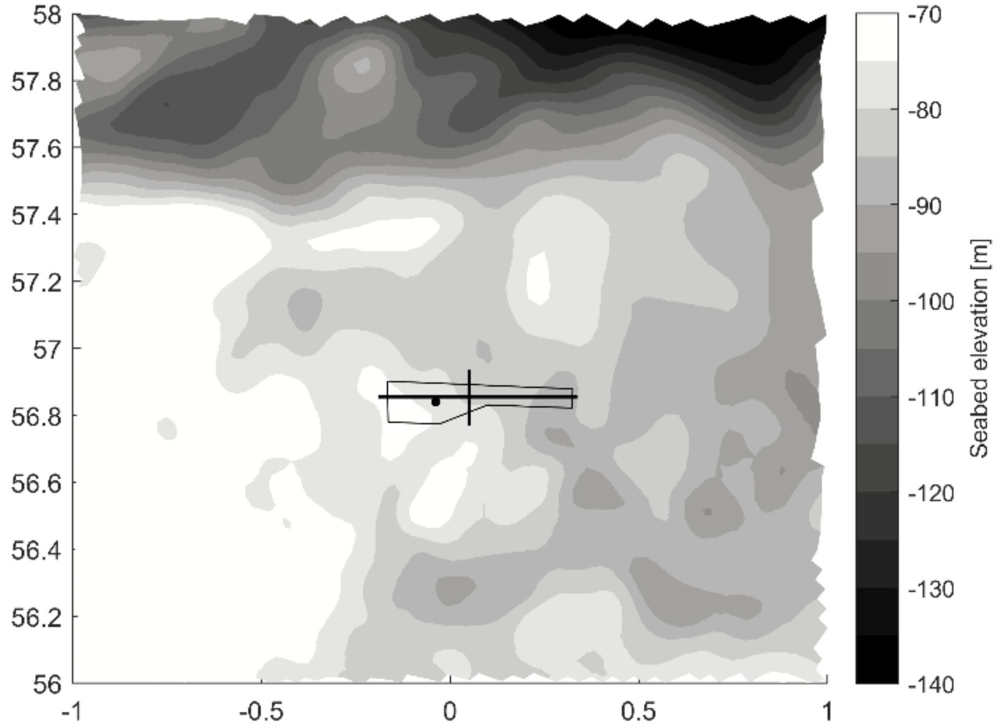
35. The temperature and salinity data used for the water column structure analysis (**Appendix 6.2: Stratification Analysis Report (Volume IV)**) was obtained from the SSW-RS (Barton et al., 2022), which gives a reanalysis of the 1993-2019 SSM output. The SSM covers most UK waters, including the area of Scottish Shelf where the Bellrock WFDA is located.

36. The model operates on an unstructured mesh, with a 1 km resolution at the coast and a 20 km resolution further offshore. The resolution at the Bellrock WFDA is approximately 2 km. Since water depths at the Bellrock WFDA do not exceed 120 m (**Plate 6.1**) the model has 20 vertical layers (sigma layers), each occupying 5% of the water column. For depths of 70 - 90 m, this gives a vertical resolution ranging between 3.5 m and 4.5 m. For this analysis daily mean outputs of temperature and salinity have been used.

37. Further offshore, the SSM is forced with the Copernicus Marine Environment Monitoring Service products: Atlantic – European North West Shelf for tidal levels, – Ocean Physics Reanalysis and Baltic Sea Physics Reanalysis for temperature and salinity. Atmospheric forcing derives from European Centre for Medium-Range Weather Forecasts ERA 5 data. Data assimilation is conducted with ODYSSEA L3 sea surface temperature (SST) data.

38. Full details of the data used, analysis undertaken and results outlining baseline water column structure are presented in **Appendix 6.2: Stratification Analysis Report (Volume IV).** Vertical profiles were extracted at a single point with the Bellrock WFDA extent.

Plate 6.1: Model Bathymetry and Bellrock Wind Farm Development Area Eextent



39. Cross sections showing spatial variation in water column structure were extracted along the horizontal and vertical lines in **Plate 6.1** representing longitudinal and latitudinal transects.

6.5.2.3 Assumptions and Limitations

40. Given the large amount of data that was collected for the site-specific surveys there is a good baseline understanding of marine geology, oceanography and physical processes within the Bellrock WFDA. There have been a number of wave, hydrodynamic and sediment dispersion numerical modelling studies undertaken in the central North Sea to support the EIAs of various offshore wind farms, including Muir Mhòr (Muir Mhòr, 2024), Ossian (Ossian Offshore Wind Farm, 2024) and Cenos (Cenos Offshore Wind Farm, 2024). The spatial extent of these studies covers the area of seabed within the Bellrock WFDA and the worst-case scenarios for these projects are comparable to those defined for the Bellrock Wind Farm Infrastructure. Therefore, these modelling studies have been used to characterise the baseline for wave and tidal regime and where appropriate, to inform the assessment of effects.

6.6 Existing Environment

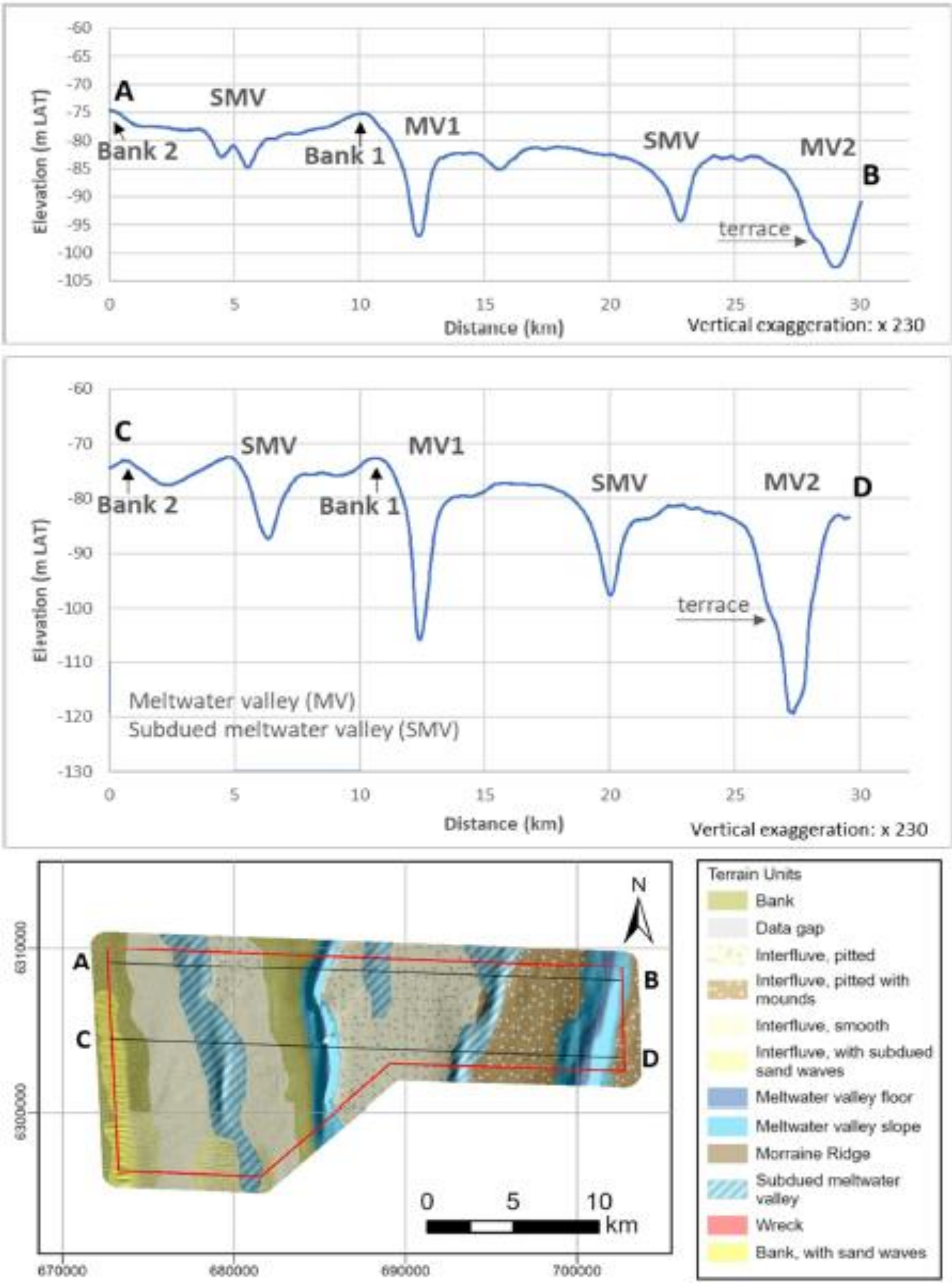
6.6.1 Bathymetry and Seabed Features

41. Multi-beam Echo Sounder (MBES) bathymetry data (OWC, 2024) shows that the minimum and maximum water depths across the Bellrock WFDA are between 70 m below Lowest Astronomical Tide (LAT) and 122 m below LAT, respectively (**Figure 6.2 (Volume III)**). Where seabed features can be related to specific geological units (**Figure 6.3 (Volume III)**) these are noted here, with more detail on those deposits outlined in **Section 6.6.2**. Bathymetric profiles presented in OWC (2024) show that the seabed elevation gradually slopes downward from west to east, but is punctuated by a series of troughs aligned broadly north-south across the Bellrock WFDA (**Plate 6.2**, **Figure 6.4 (Volume III)**).

42. An assessment of side scan sonar (SSS) and MBES backscatter data undertaken by OWC (2024) was used to produce a terrain model for the Bellrock WFDA that was based on morphological mapping of seabed features. This defined twelve 'Terrain Units', including four types of interfluve (including smooth and pitted interfluves, interfluves pitted with mounds, and interfluves with subdued sand waves), meltwater valley floor and slope, subdued meltwater valley (SMV), bank, bank with sand waves and moraine ridge (**Plate 6.2**, **Figure 6.4 (Volume III)**). Seabed conditions, and potentially shallow soils, vary with these Terrain Units.

43. A key geomorphological feature of the Bellrock WFDA is a series of meltwater valleys that are evident in the seabed bathymetry. The ground model records five broadly north-south aligned meltwater valleys that traverse the Bellrock WFDA, interpreted as relict glacial meltwater valleys (or tunnel valleys). The meltwater valleys can be separated into three that are relatively shallow (subdued), with depths ranging from 1.5 to 15 m), and two that are 10 to 30 m deep (**Plate 6.2**, **Figure 6.4 (Volume III)**). The deeper meltwater valleys (MV1 and MV2) have a valley floor that is 1.25 to 3.4 km wide and is relatively flat, with a gentle gradient from north to south. The valley sides have an average gradient of 2° with a maximum of 10°, and a smooth texture with occasional boulders (OWC, 2024). MV2 has a stepped (or terraced) valley slope on its western side. Areas of coarser sediment and boulders indicate glacial till at or near surface. The SMVs have a shallower U-shaped form, ranging in width from 0.8 to 3 km with valley slopes under 1° (OWC, 2024). Coarser surface deposits with boulders within these valleys also likely indicates that glacial till is present at or near surface.

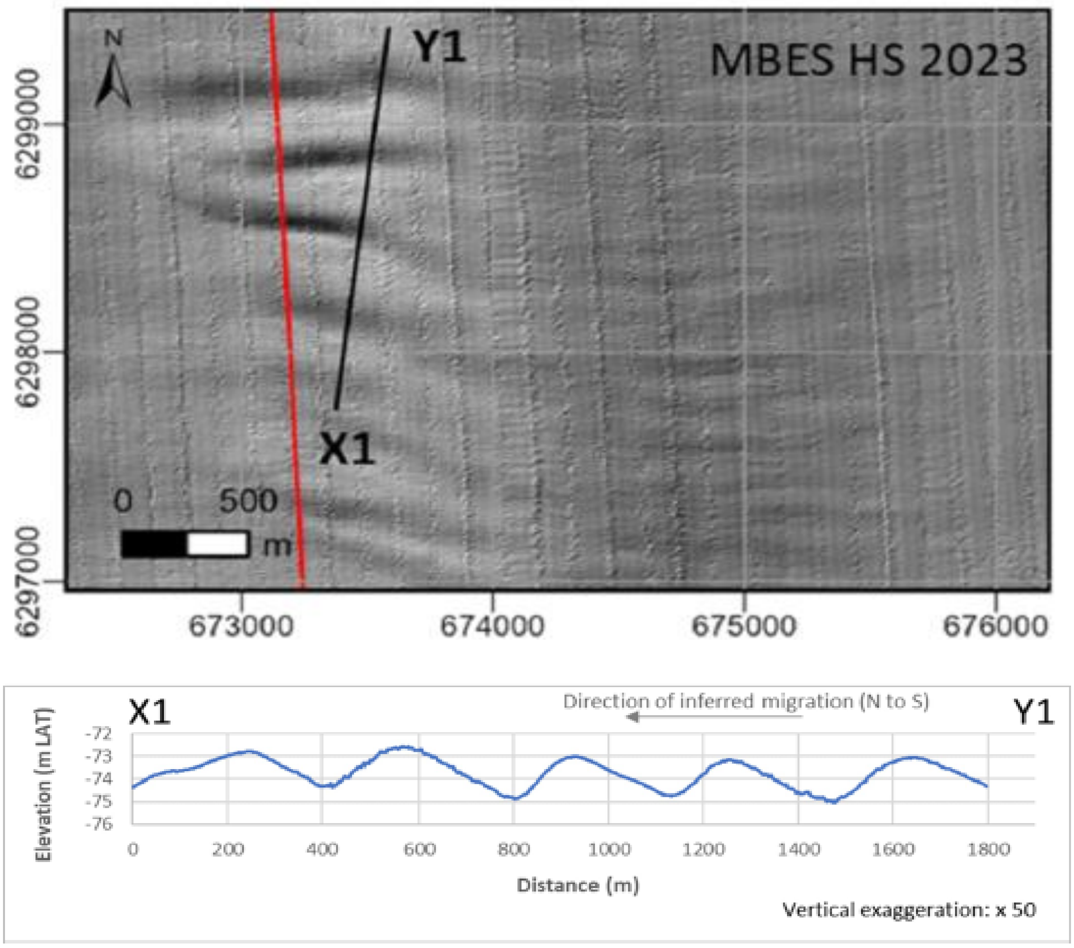
Plate 6.2: Seabed Profile from Bathymetry Data Acquired in 2023 Across the Bellrock Wind Farm Development Area Showing Terrain Units, Main Meltwater Valleys (MV), Subdued Meltwater Valley (SMV), Banks and Interfluves (OWC, 2024)



44. The ground model has identified two banks orientated north-south across the Bellrock WFDA, located on the western edge of meltwater valley MV1 (Bank 1) and the western edge of the site (Bank 2) (**Plate 6.3**, **Figure 6.4 (Volume III)**). Bank 1 is 1.7 to 4 km wide and 4.8 km in length, and is interpreted as a sand bank that formed on top of a moraine ridge (OWC, 2024). The surficial deposits in the area of this bank are smoother in the north and south and coarser in the central section, with boulders more frequent on the eastern side; the sands and silts forming the present day bank are interpreted as part of the Forth Formation (Whitehorn Member) and surficial Holocene seabed sediments.

45. An elongated ridge orientated north to south on the western margin of the Bellrock WFDA (Bank 2) is superimposed with megaripples and sand waves with wavelengths ranging from 350 to 550 m, and wave heights from 0.3 to 2.6 m (OWC, 2024). Some of the sand waves have an asymmetrical profile indicating a migration direction from north to south (**Plate 6.3**, **Figure 6.4 (Volume III)**). The ground model interprets Bank 2 as a sand bank that has formed on top of a subdued ridge of glacial till.

Plate 6.3: Profile of Sand Waves on Bank 2 (OWC, 2024)



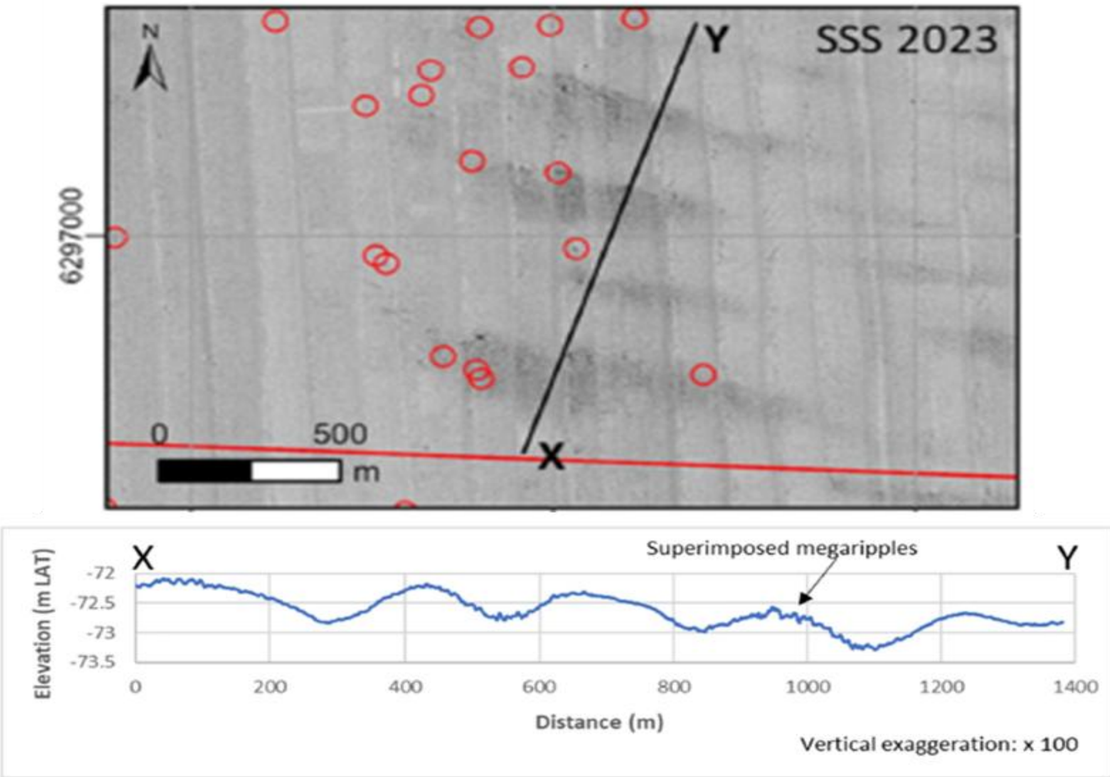
46. An elevated area of seafloor with a very rough surface texture is interpreted as a moraine ridge orientated north-south, 1.3 km long, 0.5 km wide and 2.5 m high (**Plate 6.3**, **Figure 6.4 (Volume III)**). The ground model interprets the rougher seafloor and numerous boulders associated with this ridge as corresponding to glacial till at the surface, representing an outcrop of the Marr Bank Formation (MAR) (OWC, 2024).

47. Interfluves, forming the Terrain Units between the meltwater valleys, are shown in the ground model as smooth, pitted, pitted with mounds or 'with subdued sand waves' (OWC, 2024). The seafloor in the smooth interfluve has some gentle undulations but is generally smooth in texture, and is interpreted as Forth Formation overlain with surficial Holocene seabed sediments (OWC, 2024). The pitted interfluve has a rugged texture with pits from 3 to 20 m wide and under 0.2 m deep, with some containing boulders; concentrations of pits are greatest on breaks of slope. The pitted texture is interpreted in the ground model as indicating coarser-grained sediments at seabed, with some pits containing either gravel or boulders (OWC, 2024).

48. The pitted interfluve with mounds has an undulating seafloor with irregular-shaped mounds that range from 0.2 to 1.5 m in height and 200 to 800 mm in diameter, and clusters of boulders on top of ridges and mounds; the ground model interprets these as glacial tills at or near surface, most likely of the MAR. Trawler marks are noted in this Terrain Unit (OWC, 2024).

49. Megaripples and sand waves with wavelength ranges from 230 to 320 m and heights from 0.3 to 0.6 m are recorded on interfluves towards the west of the Bellrock WFDA (**Plate 6.4**, **Figure 6.4 (Volume III)**). These have a symmetrical profile with rounded crests, and are interpreted as relict or inactive but with some sediment movement likely occurring, indicated by the presence of megaripples (OWC, 2024).

Plate 6.4: Profile of Subdued Sand Waves (OWC, 2024)



6.6.2 Shallow Geology

50. Information on the shallow geology likely to be present within the Bellrock WFDA was provided in the ground model (OWC, 2024) and in a review of the chronostratigraphy of deposits based on geophysical and hydrographic survey data (MSDS Marine, 2024). The units identified in the ground model, and their thickness, are presented in **Plate 6.5** and summarised in **Table 6.11.**

51. The shallow (Quaternary) geology of the study area comprises a sequence of Pleistocene sands, silts and clays, which in places are anticipated to be greater than 100 m in thickness and the thickness generally increases eastward, overlain by Holocene marine sands (BGS, 1985a, 1985b; OWC, 2024) (**Figure 6.3 (Volume III)**). Four main Quaternary BGS Formations are anticipated to be present, including the Forth Formation (FH), MAR, Coal Pit Formation (COP) and Aberdeen Ground Formation (ANG) (**Table 6.11**). These overlie bedrock mapped by the BGS as siliciclastic, argillaceous rock and sandstone (undifferentiated) of Palaeogene to Neogene age.

52. A geotechnical survey undertaken in 2023 within the Bellrock WFDA acquired 20 Cone Penetration Test (CPTu) locations with a target depth of 20 m below sea floor (BSF) and 20 boreholes (BH) to 6 m BSF, with an additional location conducted to 52.5 m BSF. These were reviewed as part of the ground model (OWS, 2024).

53. The lowermost of the deposits are high strength grey clays, with beds of sandy clay, of the ANG, deposited in deltaic to pro-deltaic and marine environments in its lower part and subglacial to glaciomarine environments in its upper part. These deposits are of Praetiglian to Elsterian age (**Table 6.11**) and may be greater than 100 m in thickness in places, but were not bottomed during the geotechnical survey. The ground model (OWC, 2024) and CPTu logs indicate that the ANG is encountered at depths between 10 and 55 m BSF.

54. The ANG is stratigraphically overlain by the COP, comprising sandy silty clay and interlaminated clay and silty sand with abundant shell in places. The COP is of Saalian to Weichselian date, and is described by the BGS as comprising two units, the lower of which was deposited in a glaciomarine environment whilst the upper was deposited in an intertidal setting. The ground model (OWC, 2024) indicates that the COP is encountered at depths between 4 and 22 m BSF, and can be separated into three units on the basis of geophysical characteristics.

55. Silty sands of the MAR stratigraphically overlie the COP across the Bellrock WFDA. These are interpreted as shallow glaciomarine deposits of Late Weichselian date, present in thicknesses between 10 and 25 m and encountered at depths between 5 and 40 m BSF.

56. The Forth Formation can be divided into two units comprising the Whitehorn Member and the Fitzroy Member. These are described in the ground model as interlaminated clayey fine sand and slightly sandy clay (Fitzroy Member) and silty sand with shell in places (Whitethorn Member). The ground model (OWC, 2024) describes the Whitehorn Member as a medium sand with rare shell. The Fitzroy Member is interpreted as Late Weichselian to early Holocene in age, deposited in low energy, marginal marine to terrestrial conditions, whilst the Whitethorn Member is thought to be of Holocene age and deposited in a shallow marine environment.

57. On the basis of the ground model, the Forth Formation is expected to be encountered across the entire site, albeit very thin (<0.5 m) in places (OWC, 2024). The Fitzroy Member is present in thicknesses of up to 60 m, with the Whitethorn Member present in thicknesses up to 30 m. The greatest thickness of both Members is recorded within a series of broadly north-south aligned troughs that cut across the Bellrock WFDA (**Plate 6.5**).

58. The character and thickness of deposits in the stratigraphic sequence across the Bellrock WFDA is influenced by five north-south orientated troughs that have been identified in geophysical and hydrographic survey data, interpreted as relict glacial meltwater valleys (tunnel valleys) that cross-cut the site. Three of these are shallow and cut into the Marr Bank and COPs, with depths ranging from 1.2 to 15 m, whilst two are 10 to 30 m deep and in places incise into the surface of the ANG.

59. The channels are characterised in the ground model as either Type 1 or Type 2 channels. The Type 1 channels are thought likely to have been incised by rivers during sub-aerial exposure in the Late Weichselian, and are infilled with Forth Formation deposits, with sedimentation continuing into the Holocene. The Type 2 channels, formed sub-glacially earlier in the Pleistocene, are infilled with Pleistocene sediments including the COP. Evidence suggests that the Type 2 channels were only partially infilled and their ground topography may have influenced the formation of the Type 1 channels (OWC, 2024).

60. The uppermost sediments recorded across the Bellrock WFDA are Holocene seabed sediments described in the ground model as shelly fine sand with some gravel (OWC, 2024). These sediments

are likely present as a thin veneer across much of the site but increase in thickness within some of the Type 1 and 2 channels (**Plate 6.5,** source: OWC, 2024).

Plate 6.5: Thickness of units identified in the ground model interpreted from Cone Penetration Test (CPT) and Borehole (BH) logs. A1 – Holocene Seabed Sediment; A2 – Forth Formation (Whitehorn Member); B – Forth Formation (Fitzroy Member); C – MAR; D1 – Coal Pit

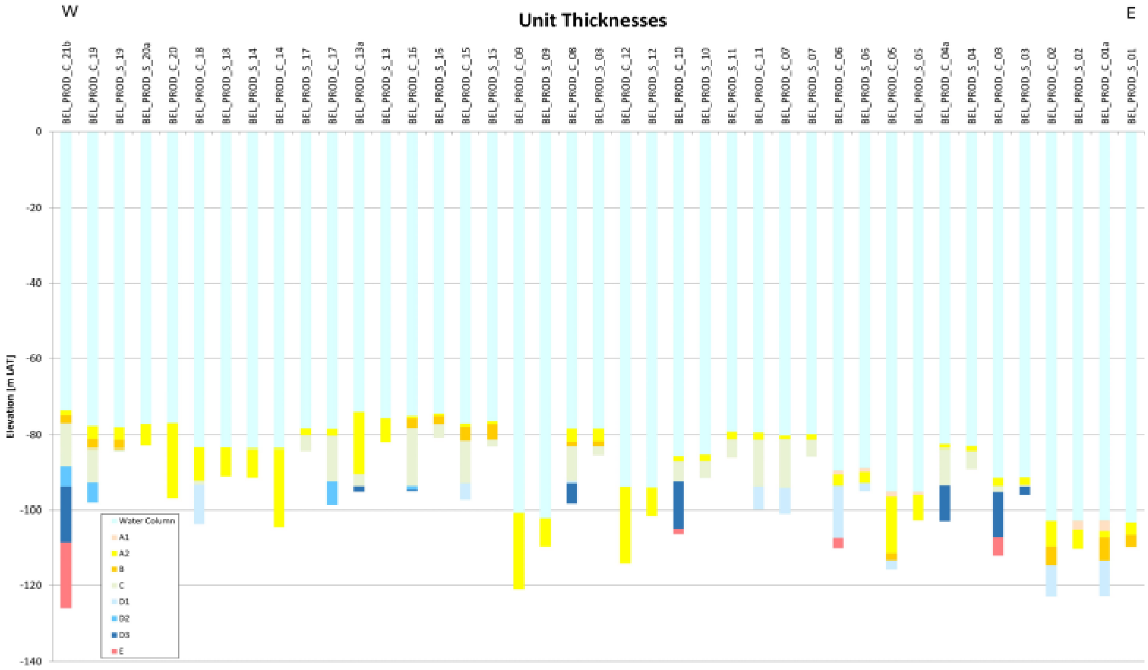


Table 6.11: Geological Formations Present Beneath the Bellrock Wind Farm Development Area

Epoch	Stage	BGS Formation	Marine Isotope Stage (MIS)	Age[1]	Anticipated lithology
Holocene	-	-	1	11.7 Kya - present	Dark greyish brown shell-rich fine sand to slightly gravelly sand. Gravel expected to be < 5% of total mass
Pleistocene	Weichselian	Forth, Whitethorn Member	1	~11.7 Kya	Very fine-grained lithic sand with rare shell fragments
		Forth, Fitzroy Member	1-2	29 - 11.7 Kya	Soft clay and silty clay often with black sulphide laminae and dropstones, significantly less consolidated than underlying sediments. Possibly interlaminated with slightly clayey fine sand
		Marr Bank	2	29 - 22 Kya	Sand, fine-grained, poor- to well-sorted, soft to firm, grey to red brown with abundant lithic granules and pebbles. Locally silty
	Eemian Saalian	Coal Pit	3-6	191 - 29 Kya	Sandy silty clay and interlaminated clay and fine-grained silty sand; clay generally stiff and overconsolidated with some pebbles. Shell fragments and complete valves abundant in places
	Praetiglian to Elsterian	Aberdeen Ground	13-100	2.52 Mya - 191 Kya	High strength, heavily overconsolidated, commonly fissured, grey clay. Sporadic shell fragments and plant remains. Lenses and laminae of silt and fine-grained sand increasing in content towards the west

Notes:

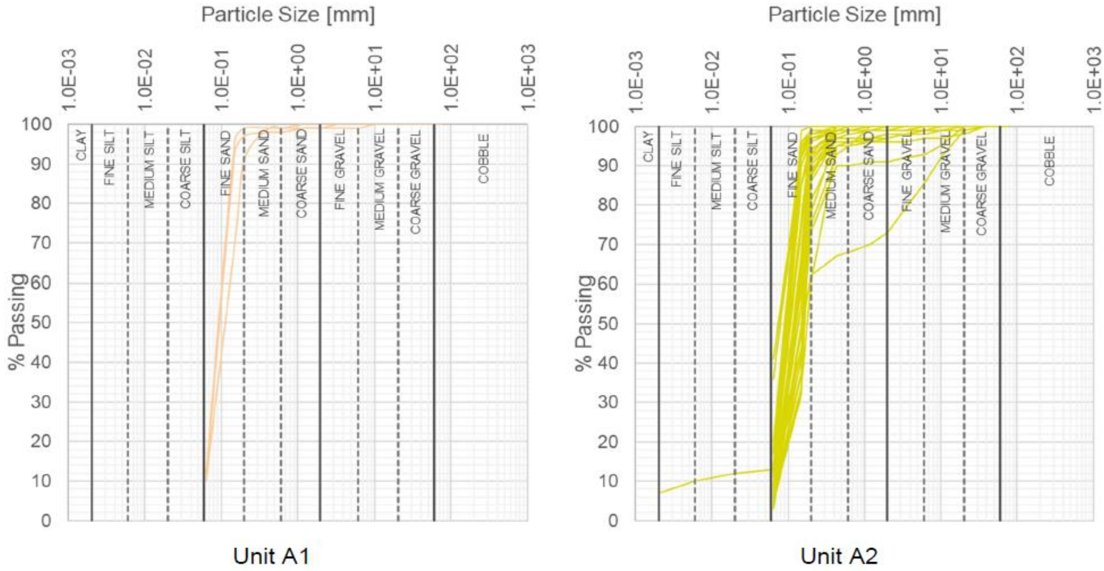
[1] Age in thousand years before present (Kya) or million years before present (Mya).

6.6.3 Seabed Sediments

61. Seabed sediments within the Bellrock WFDA are described by the BGS as sand with the exception of small areas of gravelly sand and muddy sand, the latter confined to the Devil's Hole trough (**Figure 6.5 (Volume III)**). The ground model (OWC, 2024) and BH and CPTu logs provide further information on the character of the seabed sediments, where they are mainly described as a dark

greyish brown shell-rich fine sand to slightly gravelly sand, generally less than 0.5 m thick but locally present in thicknesses up to 5.0 m. Particle size analysis undertaken on five samples from the Holocene seabed sediments (Unit A2; **Plate 6.6**, source: OWC, 2024) categorises the deposits as predominantly fine sand with a small medium to coarse sand and fine gravel component (OWC, 2024).

Plate 6.6: Particle Size Distribution of Units A1 (Holocene Seabed Sediment) and A2 (Forth Formation, Whitehorn Member), within Bellrock Wind Farm Development Area



6.6.4 Tidal Currents

62. Regional scale modelled tidal currents across the Bellrock WFDA, as shown in **Figure 6.6 (Volume III)** range from approximately 0.25 m/s to 0.5 m/s (ABPmer, 2008). At a finer resolution, hydrodynamic modelling undertaken for the Muir Mhòr Offshore Wind Farm predicts that during the spring tide, peak flows within the Bellrock WFDA are <0.4 m/s and during the neap tide, they are slightly lower at <0.2 m/s (MMOWF Limited, 2024).

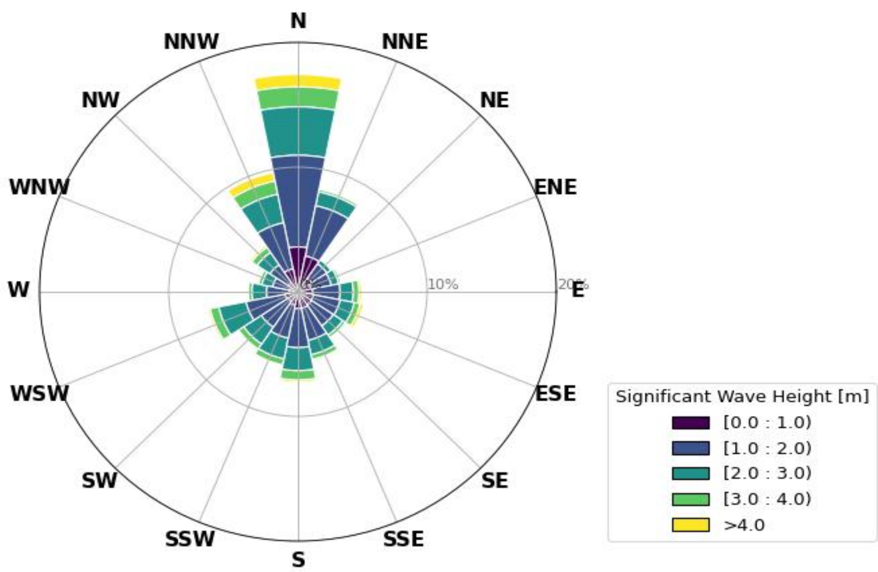
63. Tidal excursion ellipses within the Bellrock WFDA are aligned broadly north to south (ABPmer, 2008). The length of tidal ellipses vary across the Bellrock WFDA from approximately 3.8 km in the north, south and southeast, and between 4.0 km and 4.7 km in the west and northeast. Hydrodynamic modelling indicates flood currents are to the south and ebb currents are to the north (MMOWF Limited, 2024).

64. Residual currents are generally low on both the peak spring and neap tide, at <0.05 m/s, but there are small residual flows towards the south in the eastern part of the Bellrock WFDA and towards the southwest and west in the central and western part of the Bellrock WFDA (see Figure 9 of MMOWF Limited. 2024).

6.6.5 Waves

65. The wave climate within the Bellrock WFDA has been characterised using wave hindcast data covering 44 years (1980 to 2024), derived from the UK MetOffice's Wave Watch III model (CMEMS, 2025) (**Plate 6.7** and **Table 6.12**). Wave direction within the Bellrock WFDA across all seasons is predominantly from the north (33.5% to 23.6%), followed by the south (15.0% to 11.0%) and southwest (15.4% to 9.0%). A smaller minority of waves originate from the east (6.5% to 11.8%) and northeast (5.0% to 9.5%). Results from Physical characteristics and ocean acidification: Wave climate (Scottish Government, 2020) highlight that waves from the north are most common during the summer months in the North Sea near the Bellrock WFDA and are generally varied across the year. Scottish Government (2020) also shows similar wave heights as those presented in **Plate 6.7** (source, CMEMS, 2025), typical heights ranging from 1 to 3 m across the year.

Plate 6.7: Wave Rose Showing Direction and Significant Wave Height (Hs) at a Centre Point within the Bellrock Wind Farm Development Area



66. The hindcast data shows an overall average H_{rms}[1] wave height of 1.27 m at a centre point within the Bellrock WFDA, with a maximum H_{rms} wave height of 6.41 m over the period 1980 to 2024. The overall average H_{max}[2] wave height value is 3.34 m and the maximum H_{max} value is 16.87 m (**Table 6.12**).

67. The wave climate within the Bellrock WFDA shows seasonality. The season with the largest wave heights is winter. During this season, average H_{rms} and H_{max} are 1.65 m and 4.34 m respectively, and the maximum H_{rms} and H_{max} are 6.41 m and 16.87 m (**Table 6.12**). During summer, the average

[1] H_{rms}, or root mean square wave height, is a statistical measure representing the average wave height in a wave record. It is calculated as the square root of the mean of the squares of individual wave heights, considering all waves, while Hs focuses on the larger waves. Therefore, Hs is often greater than H_{rms} for the same set of waves.

[2] The maximum wave height (H_{max}) is an estimate of the largest single wave that will occur in a particular tidal level. For measured wave heights, this will be the single largest distance measured from peak to trough.

H_{rms} and H_{max} are 0.85 m and 2.25 m, and the maximum H_{rms} and H_{max} are 3.85 m and 10.12 m. The largest waves occur during the winter and originate from the north and north-northwest, with a minor component from the east and east-southeast (**Table 6.12**, source: Copernicus Marine Service Information; CMEMS, 2025).

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Table 6.12: Modelled Seasonal Data of Wave Size and Directional Wave Percentage from the Centre of the Bellrock WFDA for the Period 1980 to 2024

Season	Hrms (m)		Hmax (m)		Wave Direction (%)								
	Mean	Max	Mean	Max	N	NE	E	SE	S	SW	W	NW	Total
Spring	1.18	5.70	3.11	14.98	33.1%	9.5%	11.8%	10.2%	11.0%	9.0%	6.9%	8.4%	100%
Summer	0.85	3.85	2.25	10.12	33.5%	9.1%	6.5%	9.7%	13.5%	11.7%	7.3%	8.7%	100%
Autumn	1.39	5.60	3.66	14.73	25.1%	6.0%	10.3%	10.4%	15.0%	12.9%	9.0%	11.3%	100%
Winter	1.65	6.41	4.34	16.87	23.6%	5.0%	8.9%	8.5%	14.7%	15.4%	12.1%	11.8%	100%

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6.6.6 Bedload Sediment Transport and Seabed Mobility

68. Bedload sediment transport across the Bellrock WFDA is driven by the prevailing tidal regime (**Section 6.6.4**), seabed morphology (**Section 6.6.1**) and the composition of seabed sediments (**Section 6.6.3**).

69. Hydrodynamic modelling indicates there is a slight southwards and south-westward to westward residual current direction across the Bellrock WFDA which could result in a net bedload sediment transport direction from north to south and/or east to west. Bathymetric data indicates there are up to three broadly north to south aligned bank features in the western part of the Bellrock WFDA and two of these are superimposed with megaripples and sand waves with crests-oriented west to east indicating the seabed is potentially mobile. Where sand waves are asymmetric in profile, they indicate a migration direction from north to south, as predicted by the hydrodynamic modelling. There is no morphological evidence of migration in an east to west direction.

70. Interpretation of bathymetric, including backscatter, and side-scan sonar survey data indicates glacial till is present at seabed and there are clusters of boulders and coarser grained sediment present in some areas, suggesting the seabed is immobile or being actively eroded in some areas, potentially winnowing out the finer-grained sediment, leaving coarser material behind. HR Wallingford (2009) has reported that sand transport rates are relatively low over much of the central North Sea, due to increased water depth and lower tidal current speeds than other regions. A sediment mobility assessment was undertaken for the adjacent Muir Mhòr Offshore Wind Farm (OWF) and the results indicated that the seabed is immobile during neap tides but during spring tides, silt, very fine sand and sand could be mobilised between 3 and 6% of the time (Muir Mhòr, 2024).

6.6.7 Suspended Sediment Concentrations

71. Cefas (2016) mapped the spatial distribution of average annual SSCs across the UK continental shelf between 1998 and 2015. The Bellrock WFDA is characterised predominantly by values between 0.6 mg/l and 0.8 mg/l (**Figure 6.7 (Volume III)**). Large areas of the central North Sea are characterised by similar SSCs, with values becoming greater in shallower water towards the coast.

6.6.8 Sediment Contaminants

72. In addition to PSA sampling, the site-specific survey also collected 15 sediment samples for contaminant analysis for the following parameters:

- Total hydrocarbons (THC);
- Polyaromatic hydrocarbons (PAH);
- Polychlorinated biphenyls (PCB);
- Organotins; and
- Trace metals – arsenic, cadmium, chromium, copper, lead, mercury, nickel, mercury and zinc.

73. The chemical contaminant analysis was undertaken by SOCOTEC UK Limited, an accredited laboratory both with UKAS and the Marine Management Organisation (MMO) for sea sediment analysis.

74. There is no specific guidance available for the impact assessment of marine sediment chemical concentrations on water quality however, sediment quality guidelines are available as detailed in **Table 6.13** as a first stage in assessing the potential risk. With respect to OSPAR, assessments are undertaken using Background Assessment Concentration (BAC) and the US Environmental Protection Agency's (EPA) Effects Range-Low (ERL). The ERL value is defined as the lower tenth percentile of the data set of concentrations in sediments which were associated with biological effects. Adverse effects on organisms are rarely observed when concentrations fall below the ERL value. BACs are statistical tools defined in relation to the background concentrations which enable statistical testing of whether observed concentrations can be considered to be near background concentrations.

75. In the UK, licensing authorities for dredge material disposal to sea, regulate the activity using guidelines, part of which require characterisation of the sediments for disposal to enable the consideration of potential adverse environmental effects. To undertake this assessment, regulating authorities apply action levels (ALs) (sediment quality criteria) for contaminants on a primary list. These ALs are then used as part of a 'weight of evidence' approach to decision making on the disposal of dredged material. There are two levels – Action Level 1 (AL1) and Action Level 2 (AL2). Contaminant levels below AL1 are generally assumed to be of no concern and are unlikely to influence the licensing decision. Contaminant levels between Level 1 and 2 generally trigger further investigation of the material, and contaminants in dredged material above AL2 are generally considered unsuitable for sea disposal (MMO, 2015).

76. In summary, no samples exceeded the sediment quality guidelines for metals, with respect to PAHs, the majority of results recorded below the limit of detection. Where a positive result was returned, no values exceeded the sediment quality guidelines. For organotins and PCBs, all samples were reported to be below the limits of detection. THC concentrations were consistently low across the survey area with 9 stations registering values below the limit of detection. The remaining stations exhibited very low values, significantly lower that AL1. Full results are presented in **Appendix 7.2: Bellrock WFDA Environmental Baseline Survey 2023 Report (Volume IV)**.

Table 6.13: Sediment Quality Guidelines

Contaminant	Units	OSPAR		Marine Scotland	
		BAC	ERL	AL1	AL2
Arsenic	mg/kg	25	-	20	70
Cadmium		0.31	1.2	0.4	4
Chromium		81	81	50	370
Copper		27	34	30	300
Mercury		0.07	0.15	0.25	1.5
Nickel		36	21	30	150

Contaminant	Units	OSPAR		Marine Scotland	
		BAC	ERL	AL1	AL2
Lead	µg/kg	38	47	50	400
Zinc		122	150	130	600
Tributyltins		-	-	0.1	0.5
PCBs				0.02	0.18
Anthracene		5	85	100[1]	-
Benz(a)anthracene		16	261	100	-
Benzo(a)pyrene		30	430	100	-
Chrysene		20	384	100	-
Fluoranthene		39	600	100	-
Naphthalene		8	160	100	-
Phenanthrene		32	240	100	-
Pyrene		24	665	100	-
Benzo(ghi)perylene		80	85	100	-
Indeno[1,2,3-cd pyrene		103	240	100	-

Notes:

[1] All AL1s for PAHs monitored by Marine Scotland are the same at 100 µg/kg with the exception of dibenzo[a,h]anthracene which is 10 µg/kg.

6.6.9 Water Quality

77. OSPAR is the mechanism by which 15 governments and the European Union (EU) cooperate to protect the marine environment of the Northeast Atlantic (OSPAR, 2019). Recognising the importance of clean, healthy, and productive seas to this region and to the world, OSPAR has committed to systematic periodic assessments of the drivers of degradation, the multiple pressures exerted on marine systems including the monitoring of chemicals in sediments and nutrients in the water. These assessments are reported in QSR (OSPAR, 2023a). OSPAR has divided its Maritime Area into five regions; the Bellrock WFDA is located in Region II – Greater North Sea.

78. The QSR 2023 highlights that concentrations of many of the most serious hazardous substances, such as PCBs, PAHs and organochlorine insecticides, have decreased substantially compared with the 1980s and 1990s (OSPAR, 2023b). The last four assessments have described a steady improvement in the eutrophication status of three OSPAR Regions including the Greater North Sea region. The first assessment covering the period 1990 – 2000 was characterised by poor conditions in much of the North Sea (OSPAR, 2000). With respect to hazardous substances, in most cases,

the trends for assessed hazardous organic substances are downward, and most OSPAR Regions are also seeing a decline in heavy metal pollution. In the last two decades the downward trends have been smaller than in former decades, when decreases were driven by the elimination of large industrial point sources of contamination. Most metals follow the same pattern, but in the more populated OSPAR Regions (Greater North Sea being one) upward trends are seen in some places for selected substances such as mercury.

6.6.10 Stratification and Frontal Systems

6.6.10.1 Water Column Structure

79. 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.

80. 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 the thermocline, which forms a barrier to vertical exchange of heat, salt, nutrients and momentum (Dorrell et al. 2022).

81. 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 >80 m) and can result in a warmer surface water layer of 5 - 40 m thick (Dorrell et al. 2022).

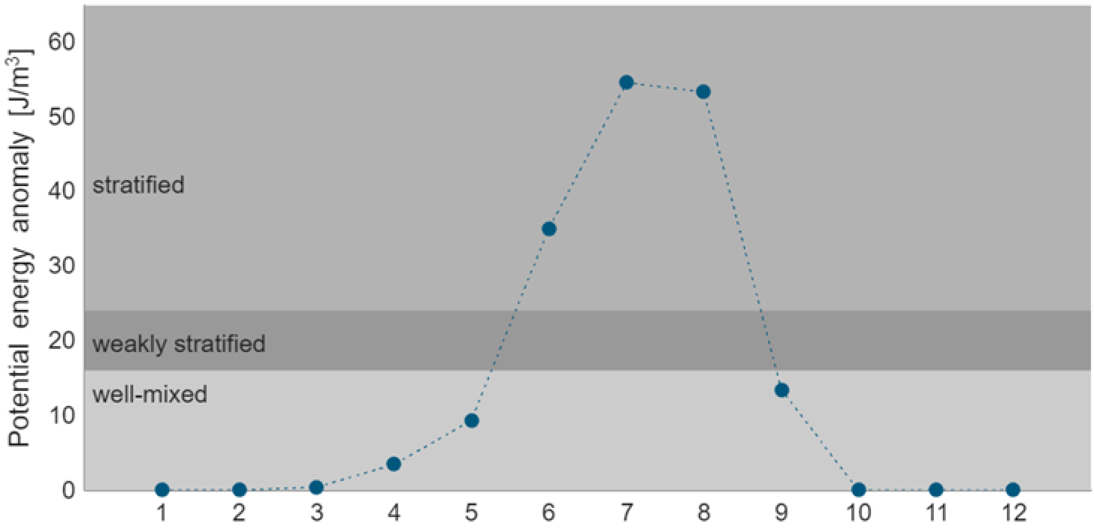
82. To characterise water column structure within the Bellrock WFDA, monthly mean sea surface and sea bottom temperature and salinity from the SSW-RS (Barton et al., 2022), averaged across the Bellrock WFDA for the year 2019, were compared. A full explanation of the methodology, results and outputs are available in **Appendix 6.2: Stratification Analysis Report (Volume IV)**.

83. The outputs show thermal stratification develops each April resulting in a thermocline between 10 and 20 m below the sea surface, reaching a peak in July and August when surface waters are 4°C warmer than bottom waters. By October, the water column is fully mixed and remains mixed for the remainder of the year. Stratification develops in the eastern part of the Bellrock WFDA first in April and by May the entire Bellrock WFDA is stratified.

84. 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 PEA (Φ), which represents the mechanical energy per unit volume (in Joules per cubic metre, J/m³) 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 (Moffat et al, 2020).

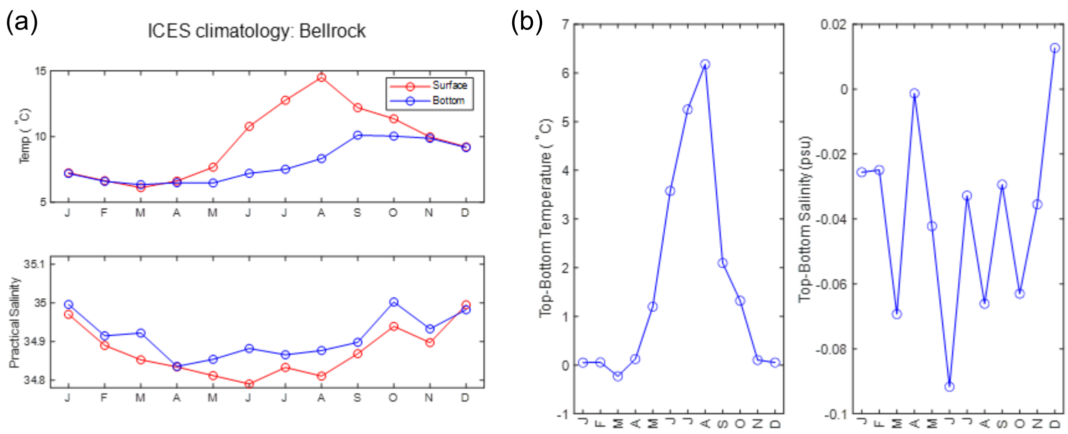
85. Using the SSW-RS outputs, instantaneous vertical profiles of water density were derived and used to calculate the PEA. The analysis shows the water column is stratified from June to August and is mixed throughout the remainder of the year (**Plate 6.8**). Spatial variation within the PEA shows that stratification is strongest in the east of the Bellrock WFDA.

Plate 6.8: Monthly Spatially Averaged Potential Energy Anomaly Within the Bellrock WFDA



86. The analysis presented in **Appendix 6.2: Stratification Analysis Report (Volume IV)** is based on monthly averages for the year 2019. To understand inter-annual variability, ICES/WODC climatological values of temperature and salinity based on historical observational data for the period 1971-2000 were reviewed (Berx and Hughes, 2009). The outputs show that stratification develops in May, peaks in August and weakens through September to October until the water column becomes fully mixed by November (**Plate 6.9**). The climatology suggests over a multi-decadal period, stratification may persist into the autumn, and that temperature differences between the sea surface and bottom could reach 6°C (**Appendix 6.1: Shelf sea stratification, nutrient fluxes and primary production baseline for the Bellrock WFDA (Volume IV)**). A review of individual temperature profiles shows there is variability in the depth of the thermocline ranging from 10 m to 40 m. This suggests the thermocline may extend deeper than the SSW-RS (Barton et al. 2022) and regional climatologies (Berx and Hughes, 2009) predict.

Plate 6.9: (a) Monthly International Council for the Exploration of the Sea (ICES) Climatological Values for Surface (Red) and Bottom (Blue) Temperature and Salinity at Bellrock Wind Farm Development Area. (b) Monthly Top to Bottom Difference in ICES Climatological Temperature and Salinity at Bellrock WFDA



6.6.10.2 Tidal Mixing Fronts

87. 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 SST or colour (e.g. Miller and Christodoulou 2014).

88. 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 SST data and seven years of sea surface colour (Chlorophyll-a) data forming UK wide grids representing average strength and persistence of fronts (**Plate 6.10** (source: Plymouth Marine Laboratory, 2025) and **Plate 6.11** (source: Plymouth Marine Laboratory, 2025)).

89. The FRONTWARD analysis shows there is no clear surface expression of tidal mixing fronts based on observations of SST or chlorophyll within the Bellrock WFDA, or wider study area (**Plate 6.10** and **Plate 6.11**).

90. This aligns with the analysis undertaken by Miller et al. (2014) which also shows there is no sea surface expression of mixing fronts within the Bellrock WFDA.

Plate 6.10: Long Term Average of Sea Surface Thermal Front Strength from April to September for the Period 2010 to 2019

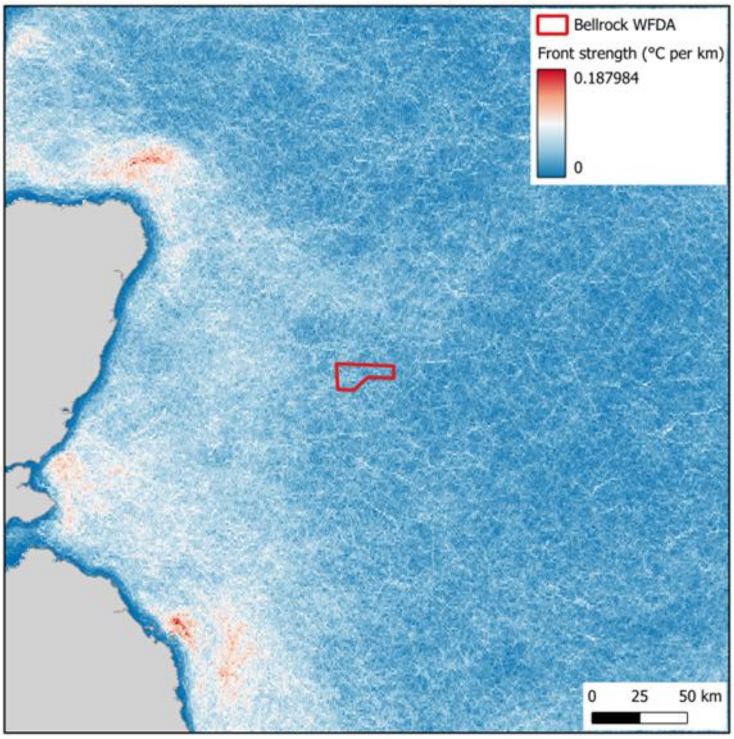
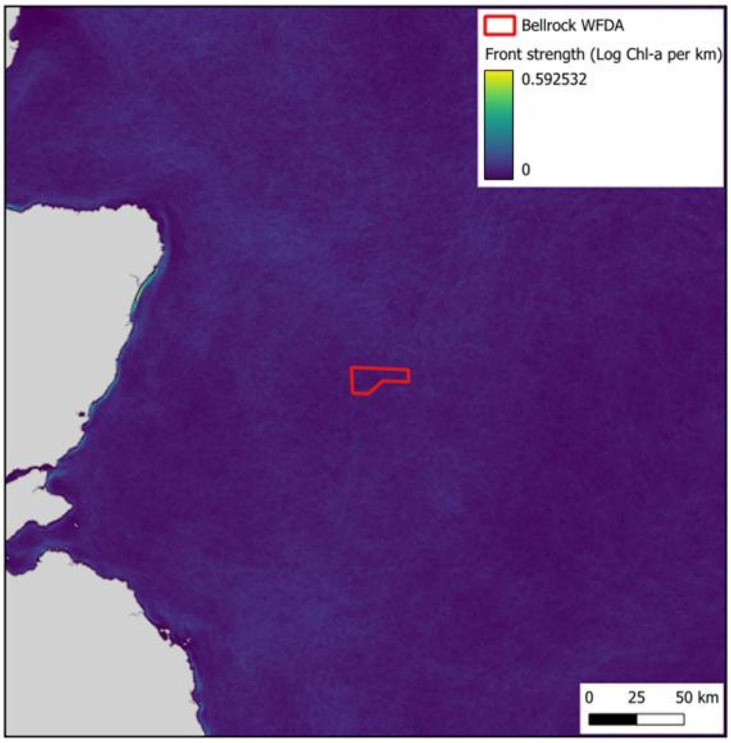


Plate 6.11: Long Term Average of Sea Surface Chlorophyll-a (Chl-a) Front Strength from April to September for the Period 2016 to 2023

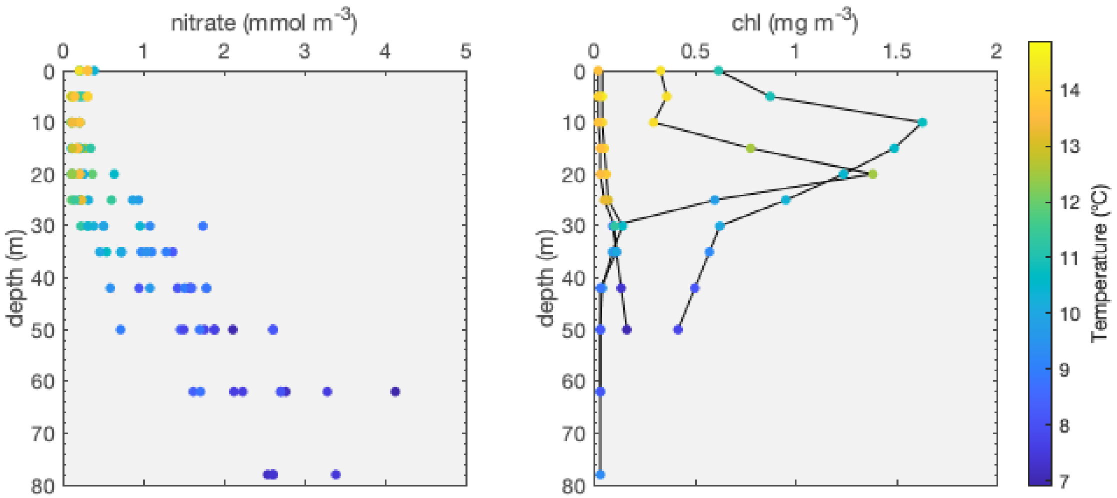


6.6.10.3 Nutrient Fluxes and Primary Productivity

91. To characterise the baseline biogeochemistry, nutrient, chlorophyll and oxygen data were extracted from the North Sea Biogeochemical Climatology, presented in **Plate 6.12** (Integrated Climate Data Center, 2025). The full methodology, results and outputs are presented in **Appendix 6.1: Shelf sea stratification, nutrient fluxes and primary production baseline for the Bellrock WFDA (Volume IV).**

92. In summer months when thermal stratification develops, the warmer surface waters are separated from bottom nutrient rich waters. Nutrients and chlorophyll concentrations are low in the surface waters within the Bellrock WFDA up to a depth of 20 m below sea surface (**Plate 6.12**, source: Integrated Climate Data Center, 2025). This likely limits primary productivity within the upper 20 m of the water column.

Plate 6.12: Nitrate and Chlorophyll Profiles at the Bellrock Wind Farm Development Area (WFDA) in July with Temperature Shown in Colour



6.6.11 Designated Sites

93. The closest designated site, the East of Gannet and Montrose Fields MPA is approximately 47 km to the northeast of the Bellrock WFDA.

6.6.12 Predicted Future Baseline (Without Bellrock Wind Farm Infrastructure)

94. The baseline conditions for marine geology, oceanography and physical processes will continue to be controlled by waves and tidal currents driving changes in bedload sediment transport and then seabed morphology. However, over longer timescales, these drivers may be affected by climate change and sea-level rise. These broadscale environmental changes will occur regardless of the presence or absence of the Bellrock Wind Farm Infrastructure. Further information on climate change predictions is contained in **Chapter 18: Climate Change Risk**.

95. 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.

96. Considering the water depths across the Bellrock WFDA, any projected changes in sea level are unlikely to be significant enough to alter future tidal dynamics. However, changes in wave climate may occur due to changing meteorological conditions, particularly storminess, storm tracks and resulting wind and wave heights. 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. Noting the uncertainty and low confidence in predictions outlined above, wave heights within the Bellrock WFDA may be lower than the present day (Bricheno et al. 2025).

97. With respect to water quality, the existing environment is largely shaped by a combination of physical processes as outlined above and anthropogenic inputs (which influence pollutant levels). These processes will continue to influence the area although any release of pollutants should continue to reduce due to better understanding of pollutant behaviour and improved regulation. Long term established patterns may be affected by climate change driven sea-level rise and changes in storminess however, this is likely to be more noticeable along the coastline.

98. Global temperatures are predicted to rise due to climate change leading to warming of ocean water bodies and increased SSTs. 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 Bellrock Wind Farm Infrastructure.

99. 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.

6.7 Potential Impacts

6.7.1 Scope

Table 6.14 sets out the impacts that have been scoped in to and out of the Bellrock WFDA EIA Report, in line with the relevant Scoping Opinion for the Bellrock WFDA (**Appendix 1.2: Bellrock WFDA Scoping Opinion (Volume IV)**).

In line with the impact assessment methodology set out in **Section 6.4.1**, the ‘impacts’ defined in the Scoping Report (**Table 6.14**) 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 marine geology, oceanography and physical processes receptors, their significance of effect is assessed in **Section 6.8** with reference to three impacts as defined in **Table 6.15**, and outlined below.

- Impact 1: Changes in SSCs and seabed levels (Section 6.8.1.1 and 6.8.2.1) includes:
  - Changes to SSCs and transport;
  - Changes in seabed level due to deposition of SSC; and
  - Changes to water quality due to remobilisation of chemicals bound to the sediments into the water column.
- Impact 2: Changes in bedload sediment transport regime and seabed morphology (**Section 6.8.1.2 and 6.8.2.2**) 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 6.8.2.3**) includes:
  - Changes to tide and wave regime; and
  - Changes to water column stratification influencing nutrient fluxes and primary productivity.

Table 6.14: Potential Impacts Scoped In and Scoped Out of the Environmental Impact Assessment for Marine Geology, Oceanography and Physical Processes

Potential Impact	Construction	Operation and Maintenance	Decommissioning
	Advised within Appendix 1.2: Bellrock WFDA Scoping Opinion (Volume IV)		
Changes to SSC and transport	✓	✓	✓
Changes to chemical contaminant concentrations associated with increases in suspended sediment	✓	✓	✓
Changes to tidal currents and waves	x	✓	x
Changes to bedload sediment transport and seabed morphological change	✓	✓	✓
Indentations on the seabed due to installation and decommissioning vessels	x	x	x
Changes water column stratification influencing	x	✓	✓

Potential Impact	Construction	Operation and Maintenance	Decommissioning
	Advised within Appendix 1.2: Bellrock WFDA Scoping Opinion (Volume IV)		
nutrient fluxes and primary production			
Transboundary impacts	x	x	x

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Table 6.15: Source-Pathway-Receptor Model for Marine Geology, Oceanography and Physical Processes Receptors

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 (C1)** ▪ Seabed preparation; and ▪ Installation of the SKSs, subsea cable hubs and IACs. **Operation (O1)** ▪ Sweeping of the seabed by mooring lines; and ▪ Maintenance activities including cable repairs and/or reburial. **Decommissioning (D1)** ▪ Reversal of process for construction (C1).	Changes in SSC and transport	Changes in seabed level due to deposition of suspended sediment. Changes to water quality due to remobilisation of chemicals bound to the sediments into the water column.	▪ Elevated SSC have the potential to impact SSC in the water column outside of natural variation; ▪ Elevated SSC have the potential to remobilise chemicals bound to the sediments into the water column that may affect water quality; ▪ Deposition of suspended sediment has the potential to change the composition of seabed sediments; and ▪ Deposition of suspended sediment has the potential to change seabed levels.	▪ Seabed sediments; ▪ Seabed level; and ▪ Water quality.	**Chapter 6: Marine Geology, Oceanography and Physical Processes (Volume II), Sections 6.8.1.1 and 6.8.2.1.**
				▪ Increased SSCs have the potential to affect benthic ecology receptors by causing physical damage or injury, blocking feeding apparatus and by smothering sessile species upon redeposition; and ▪ 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 7: Benthic Ecology (Volume II)**
				▪ 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; and ▪ Elevated SSC have the potential to remobilise chemicals bound to the sediments into the	▪ Fish and shellfish habitats and species.	**Chapter 8: Fish and Shellfish Ecology (Volume II)**

Impact Group	Source (Activity)	Pathway		Impact	Potential Receptors	Where is it Assessed?
		Direct Change	Indirect Change			
				water column, that may impact fish and shellfish species.		
				▪ Elevated SSCs reduce visibility and visual hunting strategy success; and ▪ Elevated SSC sediments have the potential to remobilise chemicals bound to the sediments into the water column, that may adversely impact marine mammal species.	▪ Marine mammal species.	**Chapter 9: Marine Mammals (Volume II)**
				▪ 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 15: Marine Archaeology and Cultural Heritage (Volume II)**
Impact 2	**Construction (C2)** ▪ Seabed preparation. **Operation (O2)** ▪ The presence of infrastructure in the water column; and ▪ The presence of infrastructure on the seabed (e.g. anchors and scour protection, cable protection, and subsea cable hubs).	Changes to wave and tide regime Changes to seabed morphology	Changes in bedload sediment transport and seabed morphology	▪ Changes in 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 bedload sediment transport pathways through erosion (scour) and deposition; ▪ Changes to bedload sediment transport processes resulting in erosion (scour) and deposition has the potential to change seabed morphology; ▪ Changes in bedload sediment transport resulting in erosion (scour) could potentially remobilise chemicals bound to the sediments into the water column that may affect water quality;	▪ Seabed morphology; ▪ Seabed sediments; and ▪ Water and sediment quality.	**Chapter 6: Marine Geology, Oceanography and Physical Processes (Volume II) Sections 6.8.1.2 and 6.8.2.2.**

Impact Group	Source (Activity)	Pathway		Impact	Potential Receptors	Where is it Assessed?
		Direct Change	Indirect Change			
	Decommissioning (D2) ▪ Reversal of process for Construction (C2).			▪ There is potential for seabed preparation to directly change the morphology of the seabed; and ▪ There is also potential for changes to the wave and tide regime to indirectly change the morphology of the seabed.		
				▪ Changes in bedload sediment transport regimes has the potential to change the composition of seabed sediments potentially affecting the habitats and species they support; and ▪ Changes in seabed morphology have the potential to change the composition of seabed sediments potentially affecting the habitats and species they support (e.g. removal of sand waves could expose underlying sediments of a different composition).	▪ Benthic habitats and species.	**Chapter 7: Benthic Ecology (Volume II)**
				▪ Changes in bedload 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.	▪ Fish and shellfish habitats and species.	**Chapter 8: Fish and Shellfish Ecology (Volume II)**
				▪ Changes in bedload sediment transport regime and seabed morphology will not directly affect marine mammals. However, as mentioned above, it may affect the benthic and fish communities which will then in turn effect marine mammals. Thereby improving or degrading the suitability of prey species for	▪ Marine mammal species.	**Chapter 9: Marine Mammals (Volume II)**

Impact Group	Source (Activity)	Pathway		Impact	Potential Receptors	Where is it Assessed?
		Direct Change	Indirect Change			
				marine mammal species that have specific substrate requirements.		
				▪ Changes in bedload 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 15: Marine Archaeology and Cultural Heritage (Volume II)**
Impact 3	▪ Operation (O3) ▪ The presence of infrastructure in the water column.	Changes to wave and tide regime	Changes in water column stratification influencing nutrient fluxes and primary productivity.	▪ 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; and ▪ There is potential for changes in primary productivity due to changes in water column structure.	▪ Oceanographic fronts and water column structure.	**Chapter 6: Marine Geology, Oceanography and Physical Processes (Volume II), Section 6.8.2.3.**
				▪ Changes in primary productivity may lead to localised changes in food availability for benthic species.	▪ Benthic habitats and species.	**Chapter 7: Benthic Ecology (Volume II)**
				▪ 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; and ▪ Changes in primary productivity may lead to localised changes in the food web, leading to	▪ Fish and shellfish habitats and species.	**Chapter 8: Fish and Shellfish Ecology (Volume II)**

Impact Group	Source (Activity)	Pathway		Impact	Potential Receptors	Where is it Assessed?
		Direct Change	Indirect Change			
				changes in predator-prey dynamics and distribution of fish and shellfish species.		
				▪ As mentioned above for fish and shellfish, changes in primary productivity may lead to localised change in availability for planktonic fish and shellfish larvae, alongside filter feeders; and ▪ These changes may lead to localised changes in the food web, leading to changes in predator-prey dynamics and distribution of effected 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 9: Marine Mammals (Volume II)**

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6.7.2 Realistic Worst-case Scenario

100. The final design of the Bellrock Wind Farm Infrastructure will be confirmed during detailed engineering studies post-consent. In order to undertake a robust and precautionary impact assessment, the realistic worst-case design scenario has been defined. Realistic worst-case scenarios (i.e. those that cause the greatest impact) are derived from the project design envelope (PDE) to ensure that all other design scenarios would have equal or less impact. Please see **Chapter 5: EIA Methodology (Volume II)** for further details on the design envelope approach.

101. The realistic worst-case scenarios for the marine geology, oceanography and physical processes assessment are summarised in **Table 6.16** below. These are based on the project design as described in **Chapter 4: Project Description (Volume II)**.

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Table 6.16: Realistic Worst-Case Scenarios for Impacts on Marine Geology, Oceanography and Physical Processes

Impact	Realistic Worst-Case Scenario	Rationale
Construction		
C1 - Changes in SSCs and Seabed Levels	**Total SSC released due to construction activities (including site preparation works[1]) = 0.0014 km^3 (1,394,530 m^3)** **Seabed preparation total volume of disturbance = 793,032 m^3** ▪ Slope levelling prior to GBA installation (if selected) = 373,032 m^3 ▪ Sand wave levelling prior to IAC installation = 420,000 m^3 **Anchor installation (with drilling (Drive – Drill – Drive (DDD)) total volume of disturbance = 94,052 m^3** ▪ Worst-case anchor type in relation to sediment mobilisation = driven pile (installed via DDD) ▪ Total volume of sediment disturbed due to pile drill arisings for up to 10% anchor locations and assuming 80% depth of drilling required **Installation of mooring buoys = 588 m^3** ▪ Maximum number of mooring buoys = 2 ▪ Maximum number of anchors per mooring = 3 ▪ Maximum footprint per mooring buoy = 147 m^2 ▪ Maximum footprint for all mooring buoys = 294 m^2 ▪ Maximum seabed penetration= 2 m ▪ Maximum volume of all sediment disturbance mooring buoys = 588 m^3 **IAC installation total volume of disturbance = 506,250 m^3** ▪ Worst-case IAC installation method = Jet trenching ▪ 225 km of IAC to be buried ▪ Maximum jet trenching disturbance width = 3 m ▪ Maximum jet trenching disturbance depth = 2.5 m	Defining the worst-case scenario for sediment disturbance activities is highly complex as the disturbance will be temporally and spatially variable (depending upon the metocean conditions at the time). **Anchor installation (with drilling)** For changes in SSC, the worst-case scenario will be defined by the anchor design and construction methodology that results in the greatest mobilisation of sediment into the water column. Of the anchoring options under consideration, the greatest sediment release is anticipated to be from the drilling of driven pile anchors. While some of the other options could result in the release of large sediment volumes (for example drag-embedment anchors), the impact of these options are expected to be less as the sediment will predominantly be displaced (e.g. pushed aside or compressed by the structure). As a worst-case, an assumption has been made that the drill arisings will be released at the surface of the water column meaning 100% of the sediment disturbed will enter the water column. It is estimated that up to 10% of piles may require DDD, to 80% depth of the pile. **Seabed preparation prior to anchor installation** Seabed preparation works could be required prior to installation of anchors. The worst-case scenario is for the option that disturbs the greatest volume of sediment which is gravity-base solution anchors as they have the largest seabed footprint. **Seabed preparation disturbance prior to cable installation (sand wave levelling)**

Impact	Realistic Worst-Case Scenario	Rationale
	▪ Assuming 30% suspension of sediment **Installation of subsea cable hubs = 608.4 m^3** ▪ Up to 18 subsea hubs with a footprint of 13 m x 13 m and a height of maximum 3.5 m (including gravel pad of maximum 0.5 m above the seabed) = 591.5 m^3; ▪ Maximum volume of subsea cable hub disturbance depth = 0.2 m ▪ Maximum volume of subsea cable hub disturbance = 608.4 m^3	Seabed sediments could be disturbed due to sand wave levelling. An assumption has been made that 20% of the IACs could require sand wave levelling and that the levelling depth would be 1 m based on a 2 m sand wave height. **IAC installation** Cable installation may require jet trenching, mechanical trenching and/or ploughing installation techniques. Jet trenching is the worst-case installation method as it has the greatest potential to fluidise and suspend fine sediments and therefore result in the largest amount of displaced sediment in the water column, The parameters provided include buried static IAC and exclude lengths of dynamic cable and lengths of cable that will be surface laid.
C2 - Changes to bedload sediment transport regime and seabed morphology	**See construction Impact 1 for the worst-case related to seabed preparation**	Changes to bedload sediment transport regime and seabed morphology may occur during construction due to the following activities: **Seabed preparation prior to anchor and cable installation** Seabed preparation will directly alter the morphology and potentially the sediment composition of the seabed, for example due to sand wave levelling.
O&M		
O1 - Changes to SSC and seabed levels	**Cable repair total volume of disturbance = 69,300 m^3 per year (2,425,500 m^3 across the operational life of the Bellrock Wind Farm Infrastructure)** ▪ Average cable repair or replacement sediment volume (per event) = 38,500 m^3 ▪ Cable failure rate per year = 1.8 ▪ Total cable failure events over operational period (35 years) = 63 **Swept area of the catenary mooring lines total volume of disturbance = 23,100,000 m^3** ▪ 132 FOUs with up to 9 catenary mooring lines per FOU = 1,118 total	Disturbance of seabed sediment resulting in changes to SSCs in the water column could occur due to following O&M activities: **Cable repair** There is potential for cables to fail in places which would require recovery of the failed lengths and installation of a new section of cable. As a worst-case, if a cable fails it is assumed the full length of the IAC between FOUs would need to be removed/replaced. Over the 35-year operational period, there will likely be multiple failure events which are

Impact	Realistic Worst-Case Scenario	Rationale
	▪ Maximum area of seabed disturbed by catenary mooring lines (all mooring lines) = 46,200,000 m^2 (350,000 m^2 *132) ▪ Maximum depth of seabed disturbed by one mooring line = 0.5 m	parameterised as total number of failures, or failure rate per year. **Disturbance from the movement of catenary mooring lines** There is the potential for the introduction of localised seabed abrasion associated with windfarm infrastructure that moves, for example anchor or mooring lines, under the influence of waves, currents, and movement of the FOUs. This could result in localised change to seabed morphology and potential changes in increased SSC. The worst-case scenario for this impact is considered to be disturbance from catenary mooring lines. The total volume of sediment potentially disturbed represents the footprint and depth of seabed that could be impacted at any given time throughout the duration of the O&M phase. As interaction with the seabed will be infrequent, and will not occur over the entire footprint, the total volume will never be released simultaneously during a single event.
O2 - Changes to bedload sediment transport regime and seabed morphology	**Presence of FSSs, mooring lines, anchors and IACs in the water column** **FSSs** ▪ Maximum volume for each FSS = 546,750 m^3 ▪ Maximum total volume for 132 FSSs = 72,171,000 m^3 **Mooring lines** ▪ Up to 9 mooring lines per FSS ▪ Maximum mooring line radius from the FSS to anchor (i.e. length of mooring line in the water column) = 1,300 m ▪ Mooring line diameter = 0.32 ▪ Maximum volume of mooring lines per FSS = 941 m^3 ▪ Maximum volume of mooring lines for all 132 FSS = 124,146 m^3	The presence of the cable and any cable protection also has the potential to change the form and function of the seabed locally, potentially influencing bedload sediment transport patterns. Presence **of infrastructure in the water column and on the seabed** There is potential for the presence of infrastructure (FSSs, mooring lines, dynamic cables, anchors, subsea cable hubs and scour and cable 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 bedload sediment transport regime and seabed morphology. The presence of dynamic cables or mooring lines in the water column has not been defined here as their diameter

Impact	Realistic Worst-Case Scenario	Rationale
	Anchors ▪ Maximum anchor footprint area (suction pile) = 2,862 m^2 (9 x 318 m^2) ▪ Maximum height above seabed = 5 m ▪ Maximum volume of suction piles for each FSS = 14,310 m^3 ▪ Total volume of suction pile anchors = 1,888,920 m^3 **Presence of IACs in the water column** ▪ Maximum length of dynamic IAC sections = 92.40 km ▪ Maximum external cable diameters = 0.27 m ▪ Total volume of dynamic IAC sections = 5,295 m^3 **Presence of subsea cable hubs** ▪ Up to 18 subsea hubs with a footprint of 13 m x 13 m and a height of maximum 3.5 m (including gravel pad of maximum 0.5 m above the seabed) = 591.5 m^3 ▪ Maximum volume of subsea cable hub present in water column = 10,647 m^3 (591.5 m^3 * 18) **Presence of moorings buoys** ▪ Maximum number of mooring buoys = 2 ▪ Maximum number of anchors per mooring = 3 ▪ Maximum footprint per vessel mooring = 147 m^2 ▪ Maximum footprint for all vessel moorings = 294 m^2 ▪ Maximum height of anchor above seabed = 5 m ▪ Maximum volume of all vessel's moorings = 1,470 m^3 **Presence of metocean buoys** ▪ Maximum number of metocean buoys = 2 ▪ Maximum seabed footprint per buoy = 15 m^2 ▪ Maximum seabed footprint for all metocean buoys = 30 m^2	(ranging from 0.27 m to 0.32 m as a worst-case scenario) is extremely small in relation to the volume of water present within the Bellrock WFDA. Therefore, any impacts due to these specific features of the infrastructure in the Bellrock WFDA will be much less than is being assessed for FSSs and anchor fixed bottom structures. There is potential for additional cable protection to be installed during the O&M phase, if for example a portion of the cable becomes exposed creating a risk. This would result in additional structures cable protection within the water column/on the seabed.

Impact	Realistic Worst-Case Scenario	Rationale
	▪ Maximum height above the seabed = 4 m ▪ Maximum volume of all metocean buoy anchors = 120 m^3 **Presence of scour and cable protection on the seabed** ▪ Options include concrete mattresses, rock placement (berm or rock bags), grout bags and/or artificial frond mats **IAC** ▪ Maximum volume of cable protection = 58,730 m^3 **IAC crossings** ▪ Up to 3 crossings ▪ Maximum volume of cable protection for each cable crossing = 139.16 m^3 ▪ Maximum volume of cable protection for 3 cable crossings considering rock berm protection for crossings = 417.49 m^3 **Anchors** ▪ Maximum area of scour protection per anchor (excluding the anchor) = 2,036 m^2 to a maximum height of 2 m ▪ Maximum volume of scour protection (excluding the anchor) per anchor = 4,072 m^3 ▪ Maximum volume of scour protection for all anchors (excluding the anchor) = 4,837,947 m^3 **Cable protection (reburial due to exposure)** ▪ Maximum length of IACs potentially requiring reburial = 21,000 m ▪ Maximum area of cable protection used for reburial = 100,800 m^2 ▪ Total volume of cable protection used for reburial = 47,07360 m^3 **Additional considerations:** ▪ Minimum FOU separation distance = approximately 1,150 m ▪ Operational lifetime = 35 years	

Impact	Realistic Worst-Case Scenario	Rationale
O3 - Changes to water column structure	**See O&M Impact 2 for worst-case O&M scenario values related to the presence of structures in the water column (e.g. FSSs, mooring lines, anchors, IACs, subsea cable hubs, mooring buoys and metocean buoys, scour protection, and cable protection)**	Changes to wave and hydrodynamic regimes in the wake of structures occupying a large proportion of the water column (e.g. FSSs) 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.
Decommissioning		
D1 - Changes in SSCs and Seabed Levels D2 - Changes to bedload sediment transport regime and seabed morphology	The sequence of decommissioning is likely to be the reverse of the construction sequence, taking around seven years, with similar types and numbers of vessels and equipment expected to be involved. It is expected that the Bellrock Wind Farm Infrastructure will be fully removed at the end of its operational life. The removal and dismantling of the FOUs will largely be a reversal of the installation process. Generally, the FOUs will be towed from the Bellrock WFDA to a suitable port for decommissioning. Mooring lines and anchors will be recovered and removed from the WFDA. For FOU driven pile anchors, these are expected to be either fully removed or cut off below seabed level with a proportion remaining in-situ (due to anticipated excessive cost in their complete removal) following good practice and consideration of environmental conditions and sensitivities. Subsea cable hubs are expected to be fully removed from the seabed. The dynamic sections of the IACs within the water column will be cut at the connector with the static IAC and fully removed. The approach for decommissioning the static IACs on the seabed is yet to be determined, however, this will be reviewed	The detail and scope of the decommissioning works would be determined by the relevant legislation and guidance at the time. For the purposes of the worst-case scenario, it is anticipated that the impacts would be comparable to those identified for the construction phase.

Impact	Realistic Worst-Case Scenario	Rationale
	throughout the lifetime of the Bellrock WFDA and good practice guidance at time of decommissioning will be followed. Subject to the material used and environmental sensitivities, it may be preferable to leave scour protection in-situ to preserve the marine habitat that may have developed over the life of the Bellrock WFDA. The approach for decommissioning cable protection will be similar to scour protection. Relevant stakeholders and regulators will be consulted to establish the best approach. Good practice guidance at time of decommissioning will be followed.	
Notes: [1] Site preparation works will commence up to one year before commencement of construction (year 0), at which point they may continue albeit as construction works (rather than site preparation works) these activities have been considered in the assessments of this Chapter, for completeness.		

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6.7.3 Pathways to Impact

6.7.3.1 Introduction

102. This section of the chapter predicts the changes in marine geology, oceanography and physical processes that may occur due to the Bellrock Wind Farm Infrastructure. These changes are presented independent of the assessment of effects in **Section 6.8** as they have the potential to effect receptors assessed for other topics, as defined in **Table 6.3**.

103. The degree of change with respect to marine geology, oceanography and physical processes is established through consideration of the scale (i.e. size, extent or intensity), duration (short term to long term) and frequency of occurrence (**Table 6.17**). This is used to inform the assessment of magnitude of impact in **Section 6.8**.

Table 6.17: Definition of the Degree of Change in Marine Geology, Oceanography and Physical Processes

Degree of change	Definition
High	Scale: A change which would extend beyond the natural variations in background conditions. Water quality status degraded to the extent that a permanent or long term change occurs. Inability to meet (for example) Environmental Quality Standards (EQS) is likely. 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. With respect to water quality, medium scale changes to key characteristics of water quality status taking account of the receptor volume, mixing capacity, flow rate, etc. 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. With respect to water quality, noticeable but not substantial changes taking account of the receiving water features. Activity not likely to alter local status to the extent that water quality characteristics change considerably or EQSs are compromised. 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. With respect to water quality, changes are not noticeable/EQSs are not compromised Duration: Change persists for less than one year. Frequency: The change would occur highly infrequently.
No change	No change

6.7.3.2 Evidence Base

104. Assessments of changes to marine geology, oceanography and physical processes often focus on numerical modelling, however, as outlined in NRW (2025), numerical modelling should not be viewed as an essential requirement. A desk-based review of numerical modelling for offshore wind projects within the central to northern North Sea was undertaken to inform this assessment and it was concluded that there was a sufficient evidence base available in the public domain to inform understanding of potential changes due to the Bellrock Wind Farm Infrastructure. This evidence base includes a review of numerical modelling undertaken for the nearby Muir Mhòr, Cenos and Caledonia projects (Muir Mhòr, 2024., Cenos, 2024., Caledonia, 2024) and the Dogger Bank South OWF, which is located further afield, but undertook comprehensive numerical modelling of marine physical processes (RWE 2025). Upon completion of this review, the Muir Mhòr modelling was selected as being the most appropriate and analogous evidence base for the Bellrock WFDA but it did not model seabed preparation activities. To address this, the modelling undertaken for Dogger Bank South has been used to provide an evidence base for this activity specifically. A summary of key project parameters in relation to the site conditions of the Bellrock WFDA and Muir Mhòr Array Area (their equivalent term for WFDA) worst-case scenario for the Bellrock Wind Farm Infrastructure is provided in **Table 6.18**. Within the following sections, reference will be made to the most appropriate evidence base, highlighting where gaps in understanding and uncertainty exist.

Table 6.18: Similarities and Difference in Site Conditions and Construction Activity within the Bellrock Wind Farm Development Area and Muir Mhòr Array Area

Parameter	Bellrock WFDA	Muir Mhòr Array Area
Distance from Bellrock WFDA (km)	52.36	
Environmental Setting		
Water depth (m below LAT)	69 - 121 m below LAT	62 - 98 m below LAT
Tidal current speed (m/s)	0.2 - 0.5 m/s	0.4 - 0.8 m/s
Length of the tidal excursion ellipse	3.5 - 5.0 km	15 km
Residual tidal current direction	Southwards	Southwards
Baseline SSC (mg/l)	<0.8 mg/l	<5 mg/l
Predominant wave direction	From the north	From the north
Maximum annual significant wave height	<4 m	2.0 - 2.75 m
Sediment composition	Muddy sand to sand	Sand with a localised area of muddy sand
Summary of Worst-case Scenarios During Construction		
Total volume of sediment released during drilling	94,052 m^3	478,782 m^3
Total volume of sediment released during IAC installation	506,250 m^3	1,500,000 m^3

Parameter	Bellrock WFDA	Muir Mhòr Array Area
Total volume of sediment released during seabed preparation	793,032 m^3	4,776,000 m^3
Worst-case cable installation method	Jet trenching	Jet trenching
O&M		
WTG Type	Floating	Floating
WTG maximum number	132	67
WTG cross sectional dimensions	The FSSs have maximum dimensions of up to 135 m x 135 m and a maximum draught of 30 m. Each FSS is connected to the seabed by up to nine 1,300 m mooring lines. The anchors for the mooring lines protrude 5 m above the seabed over an area of 2,295 m^2 per FSS.	These FSSs have a central column of 20 m diameter and a maximum draught of 40 m. Each FSSs is connected to three legs, each 87 m in length, with a diameter of 20 m, as well as 12 mooring lines with a length of 1,450 m. The anchors for the mooring lines of each FSSs protrude 10 m above the seabed with a diameter of 15 m.
Minimum spacing	1,150 m	1,000 m
Number of anchors per floating wind turbine	9	12
Maximum height above seabed per anchor	5 m	10 m

6.7.3.3 Changes in Suspended Sediment Concentration

6.7.3.3.1 Construction

105. During the construction phase, the following activities are considered the worst-case scenario in relation to seabed and/or sub-surface sediment disturbance as the greatest volumes of sediments will be released into the water column potentially changing SSC:

- Anchor installation (with DDD);
- Seabed preparation prior to anchor installation;
- Seabed preparation prior to cable installation (sand wave levelling), and;
- IAC installation.

106. The worst-case volume, footprint and depth for each of the construction activities is presented in **Table 6.16**. Here, we define the degree of change predicted for each of these activities. The activities, seabed preparation (without levelling), anchor installation (without drilling), buoy

installation and subsea cable hub installation have the potential to disturb sediment but the volumes are much lower by comparison, therefore, they are not assessed individually.

107. To understand the scale and duration of changes in SSC due to construction activities, analogous numerical modelling undertaken across the offshore wind farm industry was reviewed. In particular, the outputs from numerical modelling at the Muir Mhòr Offshore Wind Farm were considered given the similarities in environmental setting and the project design, as summarised in **Table 6.18**. The modelling was supported by an extended evidence-base obtained from research into the physical impacts of marine aggregate dredging on sediment plumes and seabed deposits (Whiteside et al., 1995; John et al., 2000; Hiscock and Bell, 2004; Newell et al., 2004; Tillin et al., 2011; Cooper and Brew, 2013).

6.7.3.3.1.1 Anchor Installation with Drilling

108. Of the anchor types under consideration, the greatest volume of sediment released would be from driven pile anchors using the DDD method. Sediments below the seabed would become disturbed during the drilling activities and released into the water column. This would cause a temporary increase in SSC at the point of discharge of the drill arisings within the Bellrock WFDA. Coarser - grained sediment, or aggregates clasts would settle relatively quickly close to the point of discharge, and finer sediment would remain in suspension in the water column and be dispersed more widely by tidal currents.

109. Changes in SSC due to the release of drill arisings from piled foundation drilling operations was also modelled within the Muir Mhòr array area. The modelling indicates that small increases of SSC of no more than 5 mg/l can occur at the immediate location of the disturbance and the associated plume extent can reach 12 km, although this was based on the assumption that drilling will occur continuously over a period of 30 days. In reality, SSC will return to background levels soon after the activity ceases.

110. Predicting changes in SSC from drilling activities depends on the composition of seabed and subsurface sediments which can be highly variable depending on ground conditions and the depth drilled. Therefore, the modelling provides an example of the changes that could occur, but local variation within any single WFDA, and between different projects may occur. Changes in SSC due to the release of drill arisings has been simulated across multiple offshore wind farm projects (Awel y Môr Offshore Wind Farm Limited., 2022a; RWE 2025), and despite subtle differences in drill rates, hydrodynamic regime and geological conditions between the projects, they all show the changes in SSC due to the release of drill arising are short lived (the plume disperses within hours) typically below 50 mg/l and occur within 5 km of the activity. Therefore, a similar degree of change can be expected from any drilling activities within the Bellrock WFDA.

111. Based on the outputs of the numerical modelling, the degree of change in SSC due to the worst-case scenario for anchor installation using DDD is defined as being **Low** at the point of disturbance and **Low** at the Bellrock WFDA scale (**Table 6.19**). **No Change** is predicted at the regional scale.

6.7.3.3.1.2 Seabed Preparation Prior to Anchor Installation

112. During the construction phase, there is the potential for seabed preparation (sand wave levelling prior to anchor installation which would disturb sediment, potentially resulting in changes in SSCs. If levelling is required, the worst-case assumes any overspill is discharged into the water column from the sea surface, creating a sediment plume, with coarser sediment settling faster than finer

sediment. This process would cause local and short-term increases in suspended sediment at the point of excavation at the seabed, at the point of its discharge back into the water column and again following remobilisation on subsequent tides. The disposal of any sediment that would be disturbed or removed during seabed preparation would occur within the Bellrock WFDA, likely close to the point of disturbance.

113. Numerical modelling of seabed preparation activities prior to anchor installation was not undertaken for the Muir Mhòr, Cenos or Caledonia projects. Seabed preparation for fixed bottom substructure installation was simulated at the Dogger Bank South OWF (RWE, 2025) and the outputs showed very small changes in SSC of up to 2 mg/l immediately adjacent to the point of disturbance. The extent of the plume was extremely localised and within the resolution of the model.

114. The limited evidence base for changes in SSC due to preparation prior to fixed bottom substructure installation likely reflects the fact that changes are so small, almost undetectable, as proven by the Dogger Bank South OWF modelling. Therefore, the degree of change due to the worst-case scenario for seabed preparation prior to anchor installation is defined as **negligible** at local and Bellrock WFDA scales. **no change** is predicted at the regional scale.

6.7.3.3.1.3 Seabed Preparation Prior to IAC Installation

115. Considering the morphology of the Bellrock WFDA, it is unlikely sand wave levelling will be required prior to IAC installation. However, recognising that there are bedforms present in the southwest of the Bellrock WFDA, changes in SSC due to seabed preparation prior to IAC installation is considered here. The worst-case scenario volume of sediment disturbed due to this activity is presented in **Table 6.16**. If levelling is required, the worst-case assumes any overspill is discharged into the water column from the sea surface, creating a sediment plume, with coarser sediment settling faster than finer sediment.

116. Numerical modelling of sand wave levelling was not undertaken for the Muir Mhòr, Cenos or Caledonia projects. Sand wave levelling was modelled at the Dogger Bank South OWF (RWE, 2025) and the results show changes in SSC do not exceed 5 mg/l, occur for less than 2 hours and the plume reaches a maximum of 8 km from the point of disturbance. The tidal excursion ellipses reach up to 6 km within the area modelled at Dogger Bank South OWF, which is slightly smaller than the modelled plume extent but at its farthest, the changes in SSC are barely noticeable at <0.1 mg/l. Therefore, the tidal ellipses are considered representative of plume extent.

117. The degree of change due to the worst-case scenario for seabed preparation prior to IAC installation is defined as **low** at point of disturbance and **low** at the Bellrock WFDA scale (**Table 6.19**). **No change** is predicted at the regional scale.

6.7.3.3.1.4 IAC Installation

118. IAC installation is responsible for the largest footprint and volume of seabed disturbance (**Table 6.16**). The worst-case cable laying technique is jet trenching as this method disperses more sediment into the water column compared to other methods (e.g. ploughing) which pushes sediment to the sides. The worst-case volume of sediment released is presented in **Table 6.16** Although it should be noted this volume of sediment will be released intermittently during discrete phases of activities over construction period.

119. IAC installation activity with comparable worst-case volumes of sediment disturbance was simulated using numerical modelling within the Muir Mhòr array area and the results show that increases in SSC of up to 200 mg/l are observed immediately adjacent to the point of disturbance but these concentrations decrease with distance from the point of disturbance to around 15 mg/l within 10 km of the Muir Mhòr array area reaching background levels of 5 mg/l 20 km southwest of the Muir Mhòr array area (Muir Mhòr, 2024). The modelling also shows that the changes in SSC are temporally restricted and return to background levels within hours of the disturbance.

120. The extent of the sediment plume created due to the disturbance from IAC installation depends on a range of factors, including the volume of sediment disturbed, installation methods, water depth, tidal currents speeds and sediment composition. The similarities and differences in these parameters between the Bellrock WFDA and Muir Mhòr array area are presented in **Table 6.18** as a basis to justify the use of the Muir Mhòr numerical modelling to inform the assessment of changes to SSC within the Bellrock WFDA.

121. Tidal current speeds are slightly higher in Muir Mhòr array area, which is reflected by a longer tidal excursion ellipse. Therefore, the plume extent due to IAC installation within the Bellrock WFDA will likely be smaller than predicted for Muir Mhòr array area. There is an area within the Bellrock WFDA where muddy sand is mapped (see **Figure 6.5 (Volume III)**). If the proportion of fines within seabed sediment is greater within the Bellrock WFDA, this could lead to higher values of SSC when compared to Muir Mhòr array area. However, higher concentrations do not directly result in a larger plume extent as the length of the tidal ellipse will determine the maximum distance the suspended sediment can be transported before the tide turns and the direction of travel is reversed.

122. Changes in SSC above background levels are predicted to extend 5 km of the Bellrock WFDA, based on the tidal excursion ellipse. This is corroborated by the Muir Mhòr array area modelling as changes in SSC >5 mg/l occur within 10 km of the Muir Mhòr array area, which is the length of the tidal ellipse at this location. Considering the southwards residual tidal currents at both locations, the plume is predicted to extend further in a south to southwest direction of the Bellrock WFDA, when compared to the north.

123. Based on the outputs of the numerical modelling, the degree of change in SSC due to the worst-case for IAC installation within the Bellrock WFDA is defined as being **low** both at the point of disturbance and at the Bellrock WFDA scale (**Table 6.19**). **No change** is predicted at the regional scale.

6.7.3.3.2 Operation and Maintenance

124. During the operation phase, there is potential for the following activities to disturb seabed and/or sub-surface sediments, releasing them into the water column which would change SSC:

- Cable repair; and
- Disturbance from the movement of catenary mooring lines.

6.7.3.3.2.1 Cable Repair

125. Maintenance activities during the O&M phase of the Bellrock Wind Farm Infrastructure may include cable repairs that could disturb the seabed leading to changes in SSC. However, the disturbance areas and volumes are much smaller in comparison to IAC installation during the construction phase (see **Table 6.16**) and whilst the frequency of activities will be greater over the full operational lifetime of the Bellrock Wind Farm Infrastructure, the changes in SSC will be short-lived and will disperse before the next phase of activity. Therefore, the degree of change will be no greater than **low** at the point of disturbance and **negligible** at the Bellrock WFDA scale (**Table 6.19**). **No change** is predicted at the regional scale.

6.7.3.3.2.2 Movement of Catenary Mooring Lines

126. During operation, the seabed in the vicinity of the FSSs may be affected by the movement of the catenary mooring line as the worst-case option. However, this action is expected to be limited will have the greatest impact during large storm events. The worst-case area and depth of seabed potentially affected per floating substructure is defined in **Table 6.16**. When the mooring lines sweep the seabed, seabed sediments will be disturbed and become entrained into suspension in the water column, potentially changing SSC levels. The coarser sand fraction of the seabed sediments will redeposit on the seabed close to the point of disturbance whereas the finer muddy fraction will reside in the water column for longer so will be redeposited over a wider area depending on the tidal regime.

127. There are no analogous modelling studies that simulate changes in SSC due to disturbance of seabed sediment by the movement of the catenary mooring lines. The potential footprint of seabed potentially effected by mooring lines is relatively large. However, the mooring lines will interact with the seabed infrequently, for example only during storms events due to the increased slackening and straining of mooring lines depending on storm conditions. During more frequent events, there will be limited interaction with the seabed as mooring lines will remain suspended in the water column. Any sediment disturbed will settle quickly and become redistributed by bedload sediment transport processes in between the individual disturbance events. The degree of change will therefore be no greater than **low** at both the point of disturbance and at the Bellrock WFDA scale (**Table 6.19**). **No change** is predicted at the regional scale.

6.7.3.3.3 Decommissioning

128. The sequence of decommissioning is likely to be the reverse of the construction sequence, taking around seven years, with similar types and numbers of vessels and equipment expected to be involved. In general, it is expected that all structures above the seabed will be fully removed at the end of Bellrock Wind Farm Infrastructure’s operational lifetime. Legislation, guidance and good practice will be kept under review throughout the lifetime of the Wind Farm Infrastructure and will be followed at the time of decommissioning.

129. The removal and dismantling of the FOUs will largely be a reversal of the installation process. Generally, the FOUs will be towed from the Bellrock WFDA to a suitable port for decommissioning. Mooring lines will be fully removed and anchors are expected to be either fully removed or cut off below seabed level with a proportion remaining in-situ following good practice and consideration of environmental conditions and sensitivities. Subsea cable hubs are expected to be fully removed from the seabed. The dynamic sections of the IACs within the water column will be cut at the connector with the static IAC and fully removed. The approach for decommissioning the static IACs

on the seabed is yet to be determined, however, this will be reviewed throughout the lifetime of the Bellrock Wind Farm Infrastructure and good practice guidance at time of decommissioning will be followed. Subject to the material used, it may be preferable to leave scour protection in-situ to preserve the marine habitat that may have developed over the life of the Bellrock Wind Farm Infrastructure. The approach for decommissioning cable protection will be similar to scour protection. Relevant stakeholders and regulators will be consulted to establish the best approach. Good practice guidance at time of decommissioning will be followed.

130. These details will be included in a Decommissioning Programme which will be developed prior to the commencement of construction, and which will be updated prior to commencement of the decommissioning process. A description of decommissioning activities is provided in **Chapter 4: Project Description (Volume II)**.

131. The scale, duration, frequency and subsequent degree of change for changes in SSC would be comparable to or less than those identified for the construction phase (**Section 6.7.3.3.1**). Implementing embedded mitigation measures throughout the decommissioning phase would further limit changes (see **Section 6.7.5**).

6.7.3.3.4 Summary

132. The worst-case changes in SSCs due to the construction, operation and decommissioning of Bellrock Wind Farm Infrastructure are summarised in **Table 6.19**. Changes occur at the point of disturbance and plumes can extend across and beyond the Bellrock WFDA resulting in Bellrock WFDA-scale effects, no changes occur at a regional scale.

133. 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 (Scale = High). 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 (Duration = Negligible), and the effect will occur infrequently (Frequency = Negligible) during construction.

134. The Degree of Change is therefore defined as Low at the individual structure and Bellrock WFDA scale (**Table 6.19**).

Table 6.19: Summary of Changes to Suspended Sediment Concentrations

Activity	Extent	Scale	Duration	Frequency	Degree of Change
Construction and Decommissioning[1]					
Anchor installation (with drilling)	Individual structure/activity scale (< 1 km)	High	Negligible	Negligible	Low
	Bellrock WFDA scale (10 s of km)	High	Negligible	Negligible	Low
	Regional scale (> 100 km)	-	-	-	No change

Activity	Extent	Scale	Duration	Frequency	Degree of Change
Seabed preparation prior to anchor installation	Individual structure/activity scale (< 1 km)	Low	Negligible	Negligible	Negligible
	Bellrock WFDA scale (10 s of kms)	Negligible	Negligible	Negligible	Negligible
	Regional scale (> 100 km)	-	-	-	No change
Seabed preparation prior to IAC installation	Individual structure/activity scale (< 1 km)	High	Negligible	Negligible	Low
	Bellrock WFDA scale (10 s of kms)	High	Negligible	Negligible	Low
	Regional scale (> 100 km)	-	-	-	No change
IAC installation	Individual structure/activity scale (< 1 km)	High	Negligible	Negligible	Low
	Bellrock WFDA scale (10 s of kms)	High	Negligible	Negligible	Low
	Regional scale (> 100 km)	-	-	-	No change
O&M					
Cable repair	Individual structure/activity scale (< 1 km)	High	Negligible	Negligible	Low
	Bellrock WFDA scale (10 s of kms)	Low	Negligible	Negligible	Negligible
	Regional scale (> 100 km)	-	-	-	No change
Movement of the catenary mooring line option	Individual structure/activity scale (< 1 km)	High	Negligible	Negligible	Low
	Bellrock WFDA scale (10 s of kms)	High	Negligible	Negligible	Low
	Regional scale (> 100 km)	-	-	-	No change

Notes:

[1] 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.

6.7.3.4 Changes to Seabed Level

6.7.3.4.1 Construction

135. During the construction of the Bellrock Wind Farm Infrastructure, changes in SSC as outlined in **Section 6.7.3.3** may lead to changes in seabed level as the disturbed sediment settles out of suspension. This may occur due to the following activities:

- Anchor installation (DDD method);
- Seabed preparation prior to anchor installation;
- Seabed preparation prior to cable installation (sand wave levelling); and
- IAC installation.

136. The worst-case volume, footprint and depth for each of the construction activities is presented in **Table 6.16.** Here, we define the degree of change predicted for each of these activities as they release the greatest volumes of sediment into the water column and therefore, have the greatest potential to change seabed levels. The activities, seabed preparation (without levelling), anchor installation (without drilling), buoy installation and subsea cable hub installation have the potential to disturb sediment but the volumes are much lower by comparison, therefore, they are not assessed individually.

137. Plume dispersion modelling undertaken for the Muir Mhòr array area is used to provide the evidence base to assess changes in seabed level within the Bellrock WFDA. The similarities and differences between the Bellrock WFDA and Muir Mhòr array area are outlined in **Section 6.7.3.3.1** and **Table 6.18**.

6.7.3.4.1.1 Anchor Installation Using the DDD Method

138. Changes in seabed level due to drilling for anchor installation within the Muir Mhòr array area shows changes of 1 to 2 mm within the array area and of <1 mm up to 10 km south-southeast from the simulated point of drilling. These values are extremely small, and arguably beyond detection using standard bathymetric survey techniques. It is also important to note that re-suspension of the re-deposited sediment will be redistributed by the prevailing tidal regime meaning the changes in bed-level will likely be short lived.

139. Within the Bellrock WFDA, a similar level of deposition is expected as the volumes of sediment released for each anchor (796 m^3) is comparable to that modelled for Muir Mhòr array area (754 m^3). Considering tidal current speeds are lower within the Bellrock WFDA when compared to the Muir Mhòr array area, the extent of seabed impacted by deposition of suspended sediment will likely be less than at predicted in the Muir Mhòr assessment and will not exceed 5 km from the point of disturbance, based on the length of the tidal excursion ellipse. However, given seabed sediment composition is slightly different at Bellrock WFDA, with slightly more fines present, the changes in seabed level within the Bellrock WFDA could in principle be relatively higher, but balanced against lower current speeds, the overall change is predicted to be broadly comparable.

140. Based on the outputs of the analogous numerical modelling, the degree of change in seabed levels due to deposition of suspended sediment is defined as being **negligible** at the point of disturbance. Changes at the Bellrock WFDA-scale will be <1mm while will be undetectable and difficult to distinguish from natural variation resulting in a definition of **no change** at the Bellrock WFDA-scale and regional scale (**Table 6.20**).

6.7.3.4.1.2 Seabed Preparation Prior to Anchor Installation

141. There is a limited evidence base to assess changes in seabed levels due to deposition of SSC from disturbance during seabed preparation prior to anchor installation as the changes are expected to be extremely small. Numerical modelling undertaken at the Dogger Bank South OWF (RWE, 2025) shows that changes are extremely small at <5 mm. Therefore, within the Bellrock WFDA these changes would be highly localised, within a few hundred of meters of the point of disturbance. The degree of change is therefore defined as **negligible** at the point of disturbance and **no change** at the Bellrock WFDA scale and regional scale (**Table 6.20**).

6.7.3.4.1.3 Seabed Preparation Prior to IAC Installation

142. Numerical modelling of seabed level changes has not been undertaken for the Muir Mhòr, Cenos or Caledonia projects as the changes are expected to be extremely small. If sand wave levelling is required, the changes to SSC are predicted to be less than during IAC installation, and comparable to those during anchor installation (DDD method) based on modelling undertaken for the Dogger Bank South OWF (RWE, 2025). The degree of change is therefore defined as **negligible** at the point of disturbance and **no change** at the Bellrock WFDA scale and regional scale (**Table 6.20**).

6.7.3.4.1.4 IAC Installation

143. Plume dispersion modelling of IAC installation in the Muir Mhòr array area indicates the greatest amount of seabed level change occurs within the centre of the Muir Mhòr array area, where multiple IAC cables converge. However, this is an artefact of the modelling which looks at the cumulative change in seabed levels over the full installation period, and doesn't account for sediment redistribution in between periods of activity. Seabed level change is typically between 3 and 10 mm across the Muir Mhòr array area, but can reach 100 mm locally at the point of disturbance. The changes in seabed level due to IAC installation are predicted to occur up to 15 km southwest of the Muir Mhòr array area but at this distance values are much lower, typically <3 mm.

144. As outlined in **Section 6.7.3.4.1.1**, within the Bellrock WFDA, current speeds are slightly lower resulting in a shorter tidal ellipse (and plume extent) but there is a potentially higher fines content, when compared to Muir Mhòr array area. Recognising these differences, the overall effect from IAC installation is expected to be comparable to Muir Mhòr.

145. The degree of change in seabed levels due to deposition of suspended sediment disturbed during IAC installation is defined as being **low** at the point of disturbance. Changes at the Bellrock WFDA-scale will be <10 mm and are therefore defined as **negligible**. **No change** will occur at the regional scale (**Table 6.20)**.

6.7.3.4.2 Operation and Maintenance

146. During the O&M phase, there is potential for the following activities to disturb seabed and/or sub-surface sediments, releasing them into the water column which would change SSC:

- Cable repair; and
- Disturbance from the movement of catenary mooring lines.

6.7.3.4.2.1 Cable Repair

147. The volume of sediment disturbed due to cable repair and reburial during the O&M period will be much lower than during construction (see **Table 6.16**). Therefore, the degree of change will be no greater than **Low** at the point of disturbance and **negligible** at the Bellrock WFDA scale (**Table 6.20**). **No change** is predicted at the regional scale.

6.7.3.4.2.2 Movement of Catenary Mooring Lines

148. As discussed in **Section 6.7.3.3.2**, changes to SSC may occur due to the movement of the catenary mooring lines. As this sediment settles after disturbance, it may lead to changes in localised seabed level. However, the changes will be temporary, episodic and much lower than the changes expected during the construction phase, and the re-deposited sediment will be redistributed by bedload sediment transport processes in between the individual disturbance events. Therefore, the degree of change will be no greater than **low** at both the point of disturbance and at the Bellrock WFDA scale (**Table 6.20**). **No change** is predicted at the regional scale.

6.7.3.4.3 Decommissioning

149. Decommissioning activities are expected to broadly reverse the construction sequence, involving similar types of vessels and equipment. FOUs, SKSs, dynamic IAC sections, mooring lines, and subsea cable hubs are anticipated to be fully removed. The approach for decommissioning the static portion of the IACs and cable protection on the seabed is yet to be determined.

150. As decommissioning methods will be finalised at a later stage, the extent and nature of associated environmental interactions cannot currently be defined in detail. For WCS purposes, the decommissioning WCS is determined to be equal to or less than the WCS for construction, noting that:

- Activities generally involve reversing the installation sequence;
- Decommissioning typically requires fewer direct seabed interventions; and
- Established good practice seeks to minimise disturbance and only remove infrastructure where appropriate.

151. The scale, duration, frequency and subsequent degree of change for changes to seabed levels due to deposition of suspended sediment would be comparable to those identified for the construction phase (**Section 6.7.3.3.3**). Implementing embedded mitigation measures throughout the decommissioning phase would further limit changes (see **Section 6.7.5**).

6.7.3.4.4 Summary

152. The worst-case changes in seabed level due to the construction, O&M and decommissioning of the Bellrock Wind Farm Infrastructure are summarised in **Table 6.20**. Changes occur at the point of disturbance and for certain activities, can extend across and beyond the Bellrock WFDA resulting in Bellrock WFDA-scale effects, **no changes** occur at a regional scale. The greatest degree of change to seabed level occurs as a result of IAC installation during the construction and decommissioning phase and due to cable repair activities during the O&M phase. Seabed level change due to these activities would be noticeable from monitoring but they are small (mm scale) when compared to natural variations (**scale = low**).

153. However, the change will persist for a short period time (less than a year) as prevailing bedload sediment transport processes would remobilise the sediment (**duration = negligible**) and as the activities will be infrequent over the full lifecycle of the Bellrock Wind Farm Infrastructure (**frequency = negligible**), the overall degree of change would be **low** at the individual structure scale. Considering the scale of change is much lower (**scale = negligible**) at the Bellrock WFDA scale, the degree of change would be **negligible**.

154. Movement of the catenary mooring lines during the O&M phase would also result in a low degree of change at the individual structure scale as the volume of sediment disturbed, and resultant deposition of this sediment would be small compared to natural variation (Scale = Low), and as the change will only occur during or immediately after a storm event (**duration = negligible; frequency = negligible**). Considering the length of mooring lines extending up to 1.3 km from each individual structure, the degree of change at the Bellrock WFDA scale will be comparable to that of an individual structure and is also defined as **low**.

Table 6.20: Summary of Changes to Seabed Level

Activity	Extent	Scale	Duration	Frequency	Degree of Change
Construction and Decommissioning[1]					
Anchor installation (with drilling)	Individual structure/activity scale (<1 km)	Negligible	Negligible	Negligible	Negligible
	Bellrock WFDA scale (10s of kms)	-	-	-	No change
	Regional scale (>100 km)	-	-	-	No change
Seabed preparation prior to anchor installation	Individual structure/activity scale (<1 km)	Negligible	Negligible	Negligible	Negligible
	Bellrock WFDA scale (10s of kms)	-	-	-	No change
	Regional scale (>100 km)	-	-	-	No change

Activity	Extent	Scale	Duration	Frequency	Degree of Change
Seabed preparation prior to IAC installation	Individual structure/activity scale (<1 km)	Negligible	Negligible	Negligible	Negligible
	Bellrock WFDA scale (10s of kms)	-	-	-	No change
	Regional scale (>100 km)	-	-	-	No change
IAC installation	Individual structure/activity scale (<1 km)	Low	Negligible	Negligible	Low
	Bellrock WFDA scale (10s of kms)	Negligible	Negligible	Negligible	Negligible
	Regional scale (>100 km)	-	-	-	No change
O&M					
Cable repair	Individual structure/activity scale (<1 km)	Low	Negligible	Negligible	Low
	Bellrock WFDA scale (10s of kms)	Negligible	Negligible	Negligible	Negligible
	Regional scale (>100 km)	-	-	-	No change
Movement of the catenary mooring lines	Individual structure/activity scale (<1 km)	Low	Negligible	Negligible	Low
	Bellrock WFDA scale (10s of kms)	Low	Negligible	Negligible	Low
	Regional scale (>100 km)	-	-	-	No change
Notes: [1] 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.					

6.7.3.5 Changes to Tidal Regime

6.7.3.5.1 Operation and Maintenance

155. During operation, there is potential for structures in the water column to change the tidal regime, in particular tidal currents, due to physical blockage effects. The blockage effect from the FOUs is caused by a combination of the draught of the FSS in the upper water column, the mooring lines throughout the full water column and the anchors and associated scour protection on the seabed. Additionally, blockages can be caused by IAC and cable protection measures where they protrude above the seabed.

156. The structures present an obstacle to the passage of currents locally, causing a small modification to the height and/or phase of the water levels and a wake in the current flow. The wake is caused by a deceleration of flow immediately upstream and downstream of each structure and an acceleration of flow around the sides of each structure. Current speeds progressively return to baseline conditions with increasing distance from each structure, depending on the size and underwater geometry, and the prevailing tidal regime. Depending on the spacing of structure, there may be potential for individual wakes to overlap.

157. Within the Bellrock WFDA, the greatest blockage effect is caused by FSSs with a maximum draught of 30 m and suction pile anchors that protrude above the seabed by 5 m. The effects of mooring lines are much smaller in comparison as they have a maximum diameter of 0.32 m. Considering the water depths across the site (between 70 m and 120 m below LAT) the combined vertical blockage effect of the FSSs and anchors would be 29-50% of the water column at each individual structure.

158. Subsea cable hubs, mooring buoy anchors and scour/cable protection on the seabed also have the potential to change tidal currents. See **Table 6.16** for details of the worst-case scenario for this Bellrock Wind Farm Infrastructure. These structures are smaller in size and number and therefore create less of a blockage effect at an individual structure scale when compared to FSSs and anchors. However, they contribute to the total blockage of 79,095,450.09 m^3 which is 0.31% of the water column within the Bellrock WFDA (calculated using an average water depth of 90 m).

159. To understand the potential degree of change caused by the Bellrock WFDA, analogous modelling undertaken for the Muir Mhòr array area was reviewed. A summary of the similarities and differences in hydrodynamic regimes and design parameters is given in **Table 6.18**.

160. For the Muir Mhòr array area (Muir Mhòr, 2024) maximum changes in current speeds are approximately -0.05 m/s during the peak ebb stage of the spring tide, within a kilometre of the Muir Mhòr turbine fixed bottom substructures. Spaces between the Muir Mhòr turbine fixed bottom substructures and along the western edge of the Muir Mhòr array area current speeds change by up to +0.05 m/s during the peak ebb stage of the spring tide, extending no greater than 3 km from the Muir Mhòr array area boundary. At peak ebb, reductions in current speeds extend no further than 5 km south of the Muir Mhòr array area, increases in current speeds extend no further than 5 km to the east, south and west of the Muir Mhòr array area. At peak flood of the spring tide, the change in current speed is no greater than ± 0.02 m/s, extending up to 2 km north of the Muir Mhòr array area.

161. Overall, the extent of changes to the tidal regime predicted for Muir Mhòr are less than the length of the tidal ellipse (15 km). Comparing the design parameters for Muir Mhòr array area and Bellrock Wind Farm Infrastructure shows that Bellrock has a smaller infrastructure footprint in the water column. This is highlighted when comparing the specifications of infrastructure, for Muir Mhòr and Bellrock. Muir Mhòr is expected to have FSSs with a 40 m draught and anchors 10 m above the seabed, in a minimum water depth of 62 m. Bellrock is expected to have FSSs with a 30 m draught and anchors 5 m above the seabed in a minimum water depth of 70 m. FSS spacing for Muir Mhòr is 1,000 m, FSS spacing (centre to centre) for Bellrock is 1,150 m.

162. As Bellrock has a smaller maximum tidal ellipse (a 5 km ZoI), with less infrastructure presence than Muir Mhòr, the effects predicted for Muir Mhòr will likely be greater than or equal to those which the Bellrock infrastructure may cause. However, it is worth noting the Bellrock infrastructure has a slightly larger separation distance in FSSs than Muir Mhòr. This could mean interactions between induvial FSSs which may occur in the Muir Mhòr array area modelling would not occur in the Bellrock WFDA. Considering the Bellrock infrastructure also has smaller footprint, this will further offset the potential for interactions between individual FSSs.

6.7.3.5.2 Summary

163. Changes in tidal regime, due to the physical blockage effect of structures in the water column, will likely result in both localised individual structure-scale and Bellrock WFDA-scale effects; no changes will occur at the regional scale. Using the Muir Mhòr modelling as an analogue, changes will extend ≤5 km from the structure. The changes will occur for the duration of the Bellrock Wind Farm Infrastructures O&M period (**duration = high**). However, the effect on tidal current speed is very low; with changes ≤±0.05 m/s (**scale = low**) at the individual structure scale, becoming lower at the Bellrock WFDA scale with increasing distance from the structures (**scale = negligible**).

164. Given the cyclic nature of tides, the changes will not occur at all times (**frequency = medium**). The degree of change is therefore defined as **low** and **negligible** at the individual structure and Bellrock WFDA scale respectively. The worst-case changes to tidal regime due to the operation of Bellrock Wind Farm Infrastructure are summarised in **Table 6.21**.

Table 6.21: Summary of Changes to Tidal Regime

Activity	Extent	Scale	Duration	Frequency	Degree of Change
Operation and Maintenance					
Blockage effect of structures in the water column, including the presence of FSSs, anchors, mooring lines, IACs, subsea cable hubs, mooring buoys and cable protection in the water column	Individual structure/activity scale (<1 km)	Low	High	Medium	Low
	Bellrock WFDA scale (10s of kms)	Negligible	High	Medium	Negligible
	Regional scale (>100 km)	-	-	-	No change

6.7.3.6 Changes to Wave Regime

6.7.3.6.1 Operation and Maintenance

165. During the operation of the Bellrock Wind Farm Infrastructure there is potential for the presence of FSSs to cause changes to the wave regime, particularly in the wave heights and directions, due to the physical blockage effect. The FSSs 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 FSSs. The distance required to return to baseline conditions depends on the FSSs spacing, individual FSS type and FSS size. The parameters of the Bellrock Wind Farm Infrastructure relevant to changes in wave regime is equal to the parameters for changes in tidal regime, outlined in **Section 6.7.3.5**.

166. Analogous modelling of changes in wave regime due to the worst-case FSS type, size, number and layout in the Bellrock WFDA was undertaken for Muir Mhòr array area (Muir Mhòr, 2024). To understand the potential degree of change caused by the Bellrock Wind Farm Infrastructure, Muir Mhòr array area modelling was reviewed. The summary of similarities and differences in wave regime and design parameters is given in **Table 6.18**.

167. For the Muir Mhòr array area (Muir Mhòr, 2024) typical changes in wave height are predicted to be approximately <20 cm. The greatest change in wave regime in the Muir Mhòr array area is predicted during a 1 in 10 year event for waves approaching from the north-northwest. Changes of up to -0.8 m (7%) in significant wave height for a 1 in 10 year event are predicted to occur within the Muir Mhòr array area, generally in the immediate vicinity of FSSs. The 1 in 10 year event for waves approaching from the north-northwest also predicts a wave shadow will be generated to the south-southeast of the Muir Mhòr array area, extending up to 72 km. This wave shadow is characterised by changes in significant wave height for a 1 in 10 year event up to -0.1 m (1%).

168. Overall, for Muir Mhòr array area the extent of change caused by changes to the wave regime is considered to be low. Comparing baseline modelling of wave regime for the Muir Mhòr array area and Bellrock WFDA provides a reference for how comparable the Muir Mhòr array area degree of change modelling is. Wave direction in the Muir Mhòr array area across all seasons is predominantly from the northwest-north-northeast, followed by the southeast-south-southwest and east. A smaller minority of waves originate from the west. Mean annual significant wave heights within the Muir Mhòr array area are modelled to be approximately 2 m, reaching a maximum of 2.75 in winter months. As detailed in **Section 6.6.5**, modelling of the wave characteristics for the Bellrock WFDA are comparable to the values predicted in Muir Mhòr array area modelling. Bellrock WFDA modelling shows waves predominantly approach from the northern and southern sides of the WFDA with the east and west being weaker. Mean annual significant wave heights within the Bellrock WFDA are modelled to be from 1 to 3 m. The comparison of infrastructure parameters described in **Section 6.7.3.5** should also be considered relevant for changes to wave regime. As the Bellrock WFDA has comparable baseline wave regime characteristics to the Muir Mhòr array area and a smaller infrastructure footprint compared to Muir Mhòr, the effects predicted for the Muir Mhòr array area will likely be greater than or equal to those within the Bellrock WFDA.

6.7.3.6.2 Summary

169. Changes in wave regime, due to the physical blockage effect of structures in the water column, will likely result in both individual structure-scale and Bellrock WFDA-scale effects. **No changes** occur at the regional scale. During disturbance, changes will be small when compared to natural variability in background conditions (**scale = low**) and based on the Muir Mhòr modelling, changes will extend up to a maximum of 72 km from the point of blockage although at these distances, the changes will be extremely small (**scale = low**). This effect will occur for the duration of the O&M phase of the Wind Farm Infrastructure (**duration = high**).

170. However, the changes will not occur at all times, and will depend on wave conditions and their interaction with the structures (**frequency = medium**). The degree of change is therefore defined as **low** at the individual structure and **negligible** at the Bellrock WFDA scale. The worst-case changes to wave regime due to the operation of Bellrock Wind Farm Infrastructure are summarised in **Table 6.22**.

Table 6.22: Summary of Changes to Wave Regime

Activity	Extent	Scale	Duration	Frequency	Degree of Change
Operation and Maintenance					
Blockage effect of structures in the water column, including the presence of FSSs, anchors, mooring lines, IACs, subsea cable hubs, mooring buoys and cable protection in the water column	Individual structure/activity scale (<1 km)	Low	High	Medium	Low
	Bellrock WFDA scale (10s of kms)	Negligible	High	Medium	Negligible
	Regional scale (> 100 km)	-	-	-	No change

6.7.3.7 Changes to the Bedload Sediment Transport Regime and Seabed Morphology

6.7.3.7.1 Construction

171. During construction, changes to seabed morphology may occur due to:

- Seabed preparation prior to anchor installation; and
- Seabed preparation prior to IAC installation.

172. These activities would directly alter the seabed morphology but the changes would be restricted to the footprint of the seabed preparation for anchor and IAC installation as defined by the worst-case scenario in **Table 6.16**. In the case of sand wave levelling, once the IAC is installed, the prevailing bedload transport regime will resume, and the sand waves will repair with time. However,

considering the relative immobility of the seabed and low bedload sediment transport rates, this recovery is expected to be slower than would be expected in other parts of the North Sea where current speeds are higher.

173. The degree of change is defined as **low** at individual structure scale, **no change** at the Bellrock WFDA scale and regional scale (**Table 6.20**).

6.7.3.7.2 Operation and Maintenance

174. Modifications to the tidal regime and/or the wave regime due to the presence of structures in the water column during the O&M phase may lead to changes in bedload sediment transport regime and seabed morphology. Considering water depths across the Bellrock WFDA, centimetre-scale changes in wave height are unlikely to have an effect on the bedload sediment transport regime and changes to tidal regime, in particular changes to current speeds near the seabed in the wake of structures, have the greatest potential to change bedload sediment transport regime and seabed morphology as a result (McCarron et al. 2019; Couldrey et al. 2020; Austin et al. 2025).

175. Where mobile bedforms are present, changes in bed shear stress could flatten bedforms as they migrate “through” a structure. However, baseline bedload sediment transport regimes will return with increasing distance from the turbine.

176. Using Muir Mhòr array area modelling as an analogue, bedload sediment transport rates are expected to be very low within the Bellrock WFDA. Coarse sediment is immobile and finer sediment (silt to fine sand fractions) is only mobile over <6% of a spring tide cycle. A reduction in tidal current speeds of up to ±0.05 m/s is predicted in the wake of structures which is a change that represents a maximum of 12.5-25% of the baseline during spring tides only. Changes in current speed are much lower at the Bellrock WFDA scale where ±0.01 m/s represents 2.5 – 5% of the baseline. Where current speeds are lower, fine sediment will be immobile for an even shorter period of time and in contrast, where current speeds are slightly higher a greater proportion of coarser sediment up to medium sand will be mobilised or fine sediment will be mobilised for a longer within a spring tide cycle. Given the dominant grain size within the Bellrock WFDA is fine sand, changes in tidal current speeds are unlikely to significantly alter the bedload sediment transport regime.

177. The degree of change will therefore be no greater than **low** at an individual structure scale and **no change** at the Bellrock WFDA scale and regional scale (**Table 6.20**).

6.7.3.7.3 Decommissioning

178. The approach to decommissioning works is the same as outlined in **Section 6.7.3.3.3**. The scale, duration, frequency and subsequent degree of change for changes to the bedload sediment transport regime and seabed morphology would be comparable to or less than those identified for the construction phase (**Section 6.7.3.7.1**). Implementing embedded mitigation measures throughout the decommissioning phase would further limit changes (see **Section 6.7.5**).

6.7.3.7.4 Summary

179. Changes in seabed morphology during construction due to seabed preparation and sand wave levelling have the potential to directly alter seabed morphology at the location of the activity. No changes occur at the Bellrock WFDA or regional scale during construction. Preparation and levelling of the seabed would change the seabed morphology beyond natural variations (**scale = high)** but the change will be short lived (**duration = low)** as baseline bedload sediment transport processes would prevail and the seabed would recover, and the activity would occur infrequently (likely once) within the construction period (**frequency = negligible**). The degree of change is therefore defined as **low** at the individual structure scale and **no change** at the Bellrock WFDA scale and regional scale for the construction phase (**Table 6.23**).

180. 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 Bellrock WFDA scale. **No changes** occur at the regional scale during O&M.

181. At an individual structure scale, bedload sediment transport regimes will be modified by turbulent wake effects but the changes will be small compared to natural variability in background conditions and considering the relatively homogeneous seabed composition across the WFDA, it is unlikely there would be a noticeable change in seabed composition, especially as the inclusion of scour protection as embedded mitigation would minimise the effects of scour (**scale = low**). The changes would occur regularly (**frequency = medium**) throughout the full duration of the O&M phase (**duration = high).** The degree of change is therefore defined as **low** at the individual structure scale for the O&M phase.

182. At the Bellrock WFDA scale, modelled changes to tidal current speeds are considered too small to change the bedload sediment transport regime or sediment mobility. The changes would occur regularly (in sync with the tide) (**frequency = medium**) over the full duration of the O&M phase (**duration = high**) but as the changes are extremely small (**scale = negligible**), the overall degree of change is defined as **negligible**.

Table 6.23: Summary of Changes to Bedload Sediment Transport Regime and Seabed Morphology

Activity	Extent	Scale	Duration	Frequency	Degree of Change
Construction and Decommissioning[1]					
Seabed preparation prior to anchor and IAC installation	Individual structure/activity scale (<1 km)	High	Low	Negligible	Low
	Bellrock WFDA scale (10s of kilometers)	-	-	-	No Change
	Regional scale (>100 km)	-	-	-	No Change

Activity	Extent	Scale	Duration	Frequency	Degree of Change
Operation and Maintenance					
Presence of structures in the water column	Individual structure/activity scale (<1 km)	Low	High	Medium	Low
	Bellrock WFDA scale (10s of kms)	Negligibl e	High	Medium	Negligible
	Regional scale (>100 km)	-	-	-	No Change
Notes: [1] 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.					

6.7.3.8 Changes to Water Column Structure

6.7.3.8.1 Operation and Maintenance

183. The introduction of offshore wind farm 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).

184. 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 FOUs (including the FSS in the upper water column, IACs, the mooring lines throughout the full water column, and the anchors and associated scour protection on the seabed) within the water column creates a blockage effect and induces a new source of turbulent kinetic energy (TKE) that can enhance mixing. In an already mixed water column, this enhanced mixing will not change the baseline water column structure.

185. 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, although this could be counteracted by wind wake effects which can enhance stratification in surface waters (Christiansen et al. 2022). The relative importance of wind wake vs tidal wake effects is poorly understood at present, but evidence suggests at the scale of a single array area, tidal wake plays a more important role.

186. The Bellrock WFDA is seasonally stratified resulting in the development of a thermocline at depths between 10 and 40 m from May to October. As a worst-case, the FSSs could have a draught of 30 m which means it is likely turbulence induced by flow around the structures will enhance mixing above baseline conditions which could change water column structure.

187. The effect of offshore wind farms 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 (T_{mix}) that is shorter than the time it takes for water to travel through the array under the prevailing current regime (T_{adv}). 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.

188. 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). This change of state is represented by T_{adv}/T_{mix} where a ratio ≥1 indicates there is enough time/energy to fully mix the water column as it travels through the Bellrock WFDA. A T_{adv}/T_{mix} of ≤1 indicates there is not sufficient time to fully mix the water as it travels through the array, but stratification may be weakened to some degree.

189. The analysis outlined in Carpenter et al. (2016) has been applied to assess the effects of the Bellrock FSSs on water column. Mooring lines have not been incorporated in the calculations as they create a considerably lower blockage effect when compared to the FSSs and have a complex 3-dimensional footprint that cannot be parametrised using the methods in Carpenter et al. (2016). Anchors are also excluded as they are much smaller in cross sectional area and their location on the seabed bed (to a maximum height of 5 m above seabed) means they will not interact directly with the pycnocline.

190. Following Carpenter et al. (2016), T_{mix} was obtained as $\phi_{max}H/R_fP_{str}\,b$, where ϕ_{max} is the maximum PEA per unit length (5225 J/m^2), H is the average water depth in the WDFA (95 m), R_f =0.17 is the Richardson number, P_{str} is the average power, per unit area of WDFA, removed from the water column by the structures (0.06W/m^2), and b is the stratification thickness (10 m). This gave a value for T_{mix} of 56 days.

191. The advective time was calculated with the simplistic assumption that T_{adv}=L/u, where L is the characteristic length across the WDFA in the direction of the tidal flow (13 km), and u is the residual current speed (0.05 m/s). This gives a value for T_{adv} of 3 days.

192. The results indicate that the time required to fully mix the water column (T_{mix}) is much greater than the time required for the water to travel through the Bellrock WFDA (T_{adv}). This indicates that the presence of the FSS's in the water column may weaken stratification, but it is considered they would completely break it down.

193. Carpenter et al. (2016) considers broad, array-scale changes in water column structure. Within the Bellrock WFDA, FOUs will be spaced at least 1,150 m apart. The turbulence induced by the FOUs will occur in the wake of the structure and dissipate with increasing distance from the fixed bottom substructure until background levels are reached. This distance is important for understanding the spatial extent of potential enhanced mixing. Existing research suggests that for monopile structures, TKE will dissipate within 8.3 pile diameters downstream and 3.5 pile diameters to the side of the structures (Miles et al. 2017).

194. There is no comparable research for FOUs but conceptually, if it is assumed that the maximum width of the FSSs is 135 m, turbulence could occur up to 1,148 m downstream. At this distance, there could be overlapping effects laterally between the turbulence induced by individual structures, although this will be limited to within 30 m of the sea surface, and at these distances, the enhanced TKE will be extremely low (approaching background levels) due to dissipation. It is also important to consider the effect of vertical mixing, appose to lateral mixing, is of greater importance when considering a stratified water column.

195. Over the O&M phase of the Bellrock Wind Farm Infrastructure, global warming could increase the strength of stratification or extend the period shelf seas are stratified (Sharples et al. 2022). This could in principle counteract the effect of enhanced mixing due to the presence of FOUs, although it is difficult to quantify the scale of the changes driven by both climate change and the FOUs with the precision required to understand long term effects.

196. When the surface waters of the North Sea develop thermal stratification, the spring bloom of phytoplankton depletes surface nutrients and growth becomes limited by the lack of nutrients in the surface layer. Surface waters are then isolated from the higher nutrient waters below during the summer. The sub-surface chlorophyll maximum (SCM) typically develops at 20 – 40 m below the surface and is sustained by a balance between sufficient sunlight from the surface and sufficient nutrient supply by turbulent mixing which drives an upward flux across the thermocline. The SCM may account for up to 50% of annual primary production in seasonally stratified seas (Hickman et al., 2012).

197. The evidence presented herein suggests the FOUs within the Bellrock WFDA will enhance mixing, which could increase nutrient availability to the SCM and therefore enhance primary productivity. This change in primary productivity is a pathway to impact on ecological receptors, which is assessed in **Chapter 8: Fish and Shellfish Ecology, Chapter 9: Marine Mammals and Chapter 10: Offshore Ornithology (Volume II).**

6.7.3.8.2 Summary

198. The evidence presented herein suggests there is potential for the FOUs within the Bellrock WFDA to enhance turbulent mixing which could change the strength, timing or duration of stratification during summer months. Considering the time required to mix the water column is much longer than the time it takes for stratified water to travel through the Bellrock WFDA, the changes to stratification will likely be small (**scale = low**) at both the individual structure scale and Bellrock WFDA scale. The forcing mechanism would occur for the full duration of the O&M phase of the Bellrock Wind Farm Infrastructure (**duration = high**), but the change would not occur all the time due to the seasonal nature of stratification and variations in the PEA over a range of tidal cycles (**frequency = medium**). The Degree of Change is therefore defined as **low** (**Table 6.24**).

Table 6.24: Summary of Changes to Water Column Structure

Activity	Extent	Scale	Duration	Frequency	Degree of Change
Operation					
The presence of Wind Farm Infrastructure in the water column	Individual structure/activity scale (<1 km)	Low	High	Medium	Low
	Bellrock WFDA scale (10s of kms)	Low	High	Medium	Low
	Regional scale (>100 km)	-	-	-	No Change

6.7.3.9 Changes to Water Quality

199. Given sediment contaminant concentrations are below sediment quality guidelines, a change in water quality associated with sediment disturbance is not predicted for the construction, O&M and decommissioning phases of the Bellrock Wind Farm Infrastructure. The degree of change is therefore defined as **no change**, according to the criteria in **Table 6.17**.

6.7.4 Receptors

The receptors scoped in for **Chapter 6: Marine Geology Oceanography, Physical Processes and Water Quality** are summarised in **Table 6.25**.

Table 6.25: Chapter 6 Marine Geology Oceanography, Physical Processes and Water Quality Receptors

Receptors	Construction	O&M	Decommissioning
Seabed Bedforms	✓	✓	✓
Relict Geomorphological Features	✓	✓	✓
Water Column	x	✓	x
Water quality	✓	✓	✓

200. The closest designated site, the East of Gannet and Montrose Fields MPA, is approximately 47 km to the northeast of the Bellrock WFDA. Based on the assessments of change within **Section 6.7.3**, there is no pathway to impact for any construction or O&M impacts on the East of Ganet and Montrose Fields MPA. Therefore, there are no designated receptors identified within the ZoI for marine geology, oceanography and physical processes.

201. During scoping (see **Appendix 1.1: Bellrock WFDA Scoping Report (Volume IV) (Bellrock Offshore Wind, 2024)**), a conservative approach was taken when assigning receptors. Non-designated sand banks and rock reefs (Annex 1 habitats) were highlighted as the main receptors for potential effects from marine geology, oceanography and physical processes. This approach was taken to represent the receptors which could have been affected by the Bellrock Wind Farm Infrastructure and were most likely to be present within the Bellrock WFDA. This prediction was based on potential key seabed features as identified in nearby designated sites, the closest being East of Gannet and Montrose Fields MPA.

202. Since scoping, site-specific surveys were undertaken and no Annex I habitats have been identified within or near the Bellrock WFDA, see **Figure 6.8 (Volume III)** (OWC, 2024). This is reinforced by data and information presented in **Chapter 7: Benthic Ecology (Volume II)**. These features are therefore no longer considered as marine geology, oceanography and physical processes receptors.

203. However, relict (meltwater valleys and sand banks) and active (megaripples and sand waves) geomorphological features have been identified within the Bellrock WFDA, as outlined in **Section 6.6.1**. Therefore, Seabed Bedforms and Relict Geomorphological Features will be considered as marine geology, oceanography and physical processes receptors.

204. Water quality as a receptor covers the Greater North Sea.

6.7.5 Embedded Mitigation Measures

205. This section outlines the embedded mitigation relevant to the marine geology, oceanography and physical processes assessment (as shown in **Table 6.26** below). Where additional mitigation measures are proposed, these are detailed in the assessment of effects below (**Section 6.8**). **Appendix 5.1: Mitigation and Monitoring Register (Volume IV)** sets out all mitigation measures.

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Table 6.26: Embedded Mitigation Measures Relevant to Marine Geology, Oceanography and Physical Processes

Measure ID	Embedded Mitigation Measure(s)	Mitigation Type	Means of Implementation
WFDA-2	Minimum spacing of 1,150 m between FOUs (centre to centre) to avoid increasing the magnitude of impacts in localised areas, such as increased suspended sediment concentrations.	Primary	Secured in the s.36 Consent and Marine Licence via a condition requiring a Development Specification and Layout Plan (DSLP) to be developed and submitted to the Scottish Ministers for approval prior to commencement of construction.
WFDA-3	Minimum spacing of 1,150 m between FOUs (centre to centre) to reduce interaction between FSSs and to minimise potential changes to the local hydrodynamic regime. The adopted spacing will help to reduce the potential for interaction effects between individual FSSs and associated alterations to wave propagation and current patterns within and immediately surrounding the WFDA.	Primary	Secured in the s.36 Consent and Marine Licence via a condition requiring a DSLP to be developed and submitted to the Scottish Ministers for approval prior to commencement of construction.
WFDA-4	Where seabed preparation is required (e.g. seabed levelling), methods and equipment that have been designed to minimise the potential for sediment suspension and dispersal will be adopted as far as is reasonably practicable.	Primary	Secured in the s.36 Consent and Marine Licence via a condition requiring a Construction Method Statement (CMS) to be developed and submitted to the Scottish Ministers for approval prior to commencement of construction.
WFDA-5	Static sections of the IACs will be installed with a target burial depth of 0.5 to 2.5 m (if burial is required and where ground conditions allow), to avoid the need for external cable protection. External cable protection will only be used where adequate burial cannot be achieved and will be minimised so far as reasonably practicable, thereby limiting permanent benthic habitat disturbance and habitat loss. The requirement for, and extent of, any cable protection will be determined through a post-consent Cable Burial Risk Assessment (CBRA).	Primary	Secured in the s.36 Consent and Marine Licence, via a condition requiring an Inter-array Cable Plan (IA-CaP) to be developed and submitted to the Scottish Ministers for approval before commencement of construction.

Measure ID	Embedded Mitigation Measure(s)	Mitigation Type	Means of Implementation
WFDA-6	Scour protection (e.g. concrete mattresses, rock placement, grout bags, artificial frond mats), will prevent scour during the operational life of the Bellrock Wind Farm Infrastructure, therefore inherently reducing risk of scour-induced temporary benthic habitat loss and disturbance and increased suspended sediment concentrations.	Primary	Secured in the s.36 Consent and Marine Licence via a condition requiring a DSLP to be developed and submitted to the Scottish Ministers for approval before commencement of construction.
WFDA-8	IAC burial techniques could involve ploughing, trenching or jetting reducing the magnitude of disturbance/temporary habitat loss for benthic receptors compared to other alternative techniques.	Primary	Secured in the s.36 Consent and Marine Licence, via a condition requiring an IA-CaP to be developed and submitted to the Scottish Ministers for approval before commencement of construction.
WFDA-10	Material displaced during cable burial activities will be backfilled, where necessary, to promote recovery of benthic habitats.	Primary	Secured in the s.36 Consent and Marine Licence, via a condition requiring an IA-CaP to be developed and submitted to the Scottish Ministers for approval before commencement of construction.
WFDA-14	Development of and adherence to an IA-CaP. The IA-CaP will set out detailed IAC installation methods and techniques (based on final project design). The IA-CaP will confirm planned IAC routing, burial (if any), and any additional protection if required, and will set out methods for post-installation IAC monitoring.	Primary	Secured in the s.36 Consent and Marine Licence, via a condition requiring an IA-CaP to be developed and submitted to the Scottish Ministers for approval before commencement of construction.

Measure ID	Embedded Mitigation Measure(s)	Mitigation Type	Means of Implementation
WFDA-15	A detailed CBRA will be prepared where IACs are proposed to be buried to determine the target burial depth. The burial depths may vary and will be dependent on risk and ground conditions. The CBRA will also highlight instances where adequate burial cannot be achieved, and alternative protection is needed.	Primary	Secured in the s.36 Consent and Marine Licence, via a condition requiring an IA-CaP to be developed and submitted to the Scottish Ministers for approval before commencement of construction.
WFDA-19	Development of and adherence to a Marine Pollution Contingency Plan (MPCP) outlining the approach for managing and reducing risk of pollution and procedures to protect personnel and to be followed in the event of a pollution incident.	Tertiary	Secured in the s.36 Consent and Marine Licence, via a condition requiring a MPCP to be developed and submitted to the Scottish Ministers for approval before commencement of construction. A **MPCP (Volume V)** is submitted alongside the s.36 Consent application and Marine Licence application for the Bellrock Wind Farm Infrastructure.
WFDA-20	During the construction and O&M of the Wind Farm Infrastructure, periodic geophysical surveys would be required to ensure the IACs remain buried and if they do become exposed, remedial works will be undertaken.	Primary	Secured in the s.36 Consent and Marine Licence, via a condition requiring an IA-CaP to be developed and submitted to the Scottish Ministers for approval before commencement of construction.

Measure ID	Embedded Mitigation Measure(s)	Mitigation Type	Means of Implementation
WFDA-21	An Environmental Management Plan (EMP) will be prepared and implemented to set out the procedures to avoid, reduce, and manage potential environmental effects arising across the construction and O&M of the Bellrock Wind Farm Infrastructure, in accordance with relevant international and national legislation and guidance.	Tertiary	Secured in the s.36 Consent and Marine Licence via a condition requiring an EMP to be developed and submitted to the Scottish Ministers for approval before commencement of construction. An **Outline EMP (Volume V)** is submitted alongside the s.36 Consent application and Marine Licence application for the Bellrock Wind Farm Infrastructure.
WFDA-34	Adherence to the following international and national regulations and guidance, namely: ▪ International Convention for the Prevention of Pollution from Ships (MARPOL), which sets out requirements, including appropriate vessel maintenance; ▪ The International Convention for the Control and Management of Ships' Ballast Water and Sediments, which provides an international framework for the control of transfer of potentially invasive species from ballast water; and ▪ Consideration of guidance from the International Maritime Organisation (IMO, 2023) on the control and management of ships' biofouling to minimise the transfer of invasive aquatic species.	Tertiary	Secured in the s.36 Consent and Marine Licence via a condition requiring a Vessel Management and Navigational Safety Plan (VMNSP) to be developed and submitted to the Scottish Ministers for approval before commencement of construction. An **Outline VMNSP (Volume V)** is submitted alongside the s.36 Consent application and Marine Licence application for the Bellrock Wind Farm Infrastructure.
WFDA-47	Development of, and adherence to, a Decommissioning Programme (DP). The DP will set out the framework for the safe, orderly, and environmentally acceptable decommissioning and removal of the Bellrock Wind Farm Infrastructure, in the interests of safety and environmental protection.	Tertiary	Secured in the s.36 Consent and Marine Licence, via a condition requiring a DP to be developed and submitted to the Scottish Ministers for approval before commencement of construction.

Measure ID	Embedded Mitigation Measure(s)	Mitigation Type	Means of Implementation
	Climate change risk measures will be included in the DP to be developed prior to the commencement of construction and will include a review of site-specific weather and metocean conditions, recent extreme weather events and up-to-date climate change projection data will be undertaken to ensure risk assessments, H&S protocols and guidelines on safe working practices are suitable for future climate conditions at the time of decommissioning works. The DP will be refreshed prior to decommissioning activities commencing. The DP will mitigate the risk of climate change impacts on decommissioning site personnel, plant and equipment and other assets and the risk of delays to the decommissioning programme due to extreme weather events, which are becoming more frequent and intense due to climate change.		
WFDA-60	Development of, and adherence to, a CMS. The CMS will describe the methods for construction for all consented Wind Farm Infrastructure and set out the measures to be implemented to avoid or reduce adverse effects on the environment and legitimate users of the sea during the construction phase. This will include a clear definition of roles and responsibilities and reference to relevant H&S protocols. In relation to climate change, the CMS will incorporate measures to ensure construction activities are resilient to current and projected extreme weather and metocean conditions. This will include, as appropriate: ▪ Monitoring of site-specific weather and metocean conditions, including use of recognised forecasting and severe weather alert services; ▪ Programming and phasing of construction activities with regard to seasonality and short- to medium-term forecasts; ▪ Definition of safe working limits for vessel, lifting, and installation operations and procedures for suspension of works where thresholds are exceeded; ▪ Measures to secure plant, equipment, and materials during adverse weather; and ▪ Risk assessments and safety procedures that account for site-specific extreme weather risks. Through these measures, the CMS will mitigate risks to construction personnel, plant, and equipment, and reduce the potential for programme disruptions arising from extreme weather events.	Tertiary	Secured in the s.36 Consent and Marine Licence via a condition requiring a CMS to be developed and submitted to the Scottish Ministers for approval before commencement of construction.

Measure ID	Embedded Mitigation Measure(s)	Mitigation Type	Means of Implementation
WFDA-61	Regular and periodic inspections and maintenance of all components of the Wind Farm Infrastructure will be undertaken over their operational lifetime to identify and remediate any damage and deterioration and maintain good working conditions. These will be included in the Operation and Maintenance Plan (OMP). Monitoring of site-specific weather and metocean conditions, recent extreme weather events and up-to-date climate change projection data will be undertaken to provide a dynamic risk assessment of climate change impacts and inform operation and maintenance planning. The OMP will mitigate the risks of climate change impacts on the conditions and performance of the Wind Farm Infrastructure and ensures that it is adaptable to future climate conditions and remains resilient over its operational life. The O&M strategy will be adaptive, with the frequency of maintenance, repair and replacement activities being adjusted based on need (i.e. increasing planned O&M visits for components with higher deterioration rates than anticipated).	Tertiary	Secured in the s.36 Consent and Marine Licence via a condition requiring an OMP to be developed and submitted to the Scottish Ministers for approval prior to the commissioning of the first WTG.

6.8 Assessment of Effects

206. The potential effects to discrete morphological, oceanographic and water quality receptors that may occur during the construction, O&M and decommissioning phases of the Bellrock Wind Farm Infrastructure are assessed in the following sections. The assessment follows the methodology set out in **Section 6.4.1** and is based on the realistic worst-case scenarios defined in **Section 6.7.2**, with consideration of embedded mitigation measures identified in **Section 6.7.5**. The sensitivity and magnitude of impacts, and subsequent significance of effect, during decommissioning would be comparable to or less than those identified for the construction phase for **Chapter 6: Marine Geology, Oceanography and Physical Processes**. Decommissioning is therefore assessed alongside construction impacts.

207. Pathways to impact are defined in **Section 6.7.3**. In cases where the degree of change is defined as **no change** according to criteria outlined in **Table 6.17**, an assessment of effects in relation to marine geology, oceanography and physical processes receptors has not been undertaken as **no change** indicates there is no pathway to impact that would lead to an effect on a receptor. This applies to the following pathways to impact:

- Changes to water quality.

6.8.1 Potential Impacts During Construction

6.8.1.1 C1: Changes in SSCs and Seabed Levels

208. Construction activities, including seabed preparation prior to anchor and IAC installation, and anchor (DDD method) and IAC installation may cause changes in SSCs and seabed level due to redeposition of suspended sediment.

209. Receptor(s) which may be affected by C1 comprise Seabed Bedforms and Relict Geomorphological Features.

6.8.1.1.1 Sensitivity and Value

6.8.1.1.1.1 Seabed Bedforms

210. Seabed Bedforms, namely the megaripples and sand waves outlined in **Section 6.6.1**, 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. The presence of these features suggests the seabed is dynamic and mobile in places, therefore, the receptors will likely adapt to the impact and recover in a short time.

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

6.8.1.1.1.2 Relict Geomorphological Features

212. Morphological features such as meltwater valleys and banks (moraine ridges) outlined in Section **6.6.1** are not designated but are of local importance for marine geology, oceanography and physical processes. As receptors, these features will be highly tolerant to changes in seabed levels as their formation history is linked to the glacial history of the North Sea, rather than modern day active bedload sediment transport. As the receptor is relict, it cannot adapt or recover from the impact but given the changes are depositional (oppose the erosional), there will be no gross change to the receptor's morphology, especially as the changes are short lived.

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

6.8.1.1.2 Magnitude of Impact

214. The magnitude of impact for C1 has been determined based on an assessment of the degree of change (see **Section 6.7.3**.) and how that would manifest as an impact upon receptors.

215. The magnitude of impact on Seabed Bedforms and Relict Geomorphological Features 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.

6.8.1.1.3 Significance of Effect

216. Overall, it is predicted that sensitivity of the receptor is **negligible** and the magnitude of impact is **negligible** during construction activities. The effect is therefore of **negligible adverse** significance, which is **not significant** in EIA terms.

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

6.8.1.2 C2: Changes to the Bedload Sediment Transport Regime and Seabed Morphology

218. Changes in bedload sediment transport regime and seabed morphology may occur due to seabed preparation prior to anchor and IAC installation (see **Section 6.7.3.3** and **Section 6.7.3.4**).

219. The receptor which may be affected by C2 is Seabed Bedforms.

6.8.1.2.1 Sensitivity and Value

6.8.1.2.1.1 Seabed Bedforms

220. Seabed Bedforms, namely the megaripples and sand waves outlined in **Section 6.6.1**, may be directly altered in localised areas during construction due to seabed preparation (as outlined in **Section 6.7.3.7**). The presence of these features suggests the seabed is dynamic and mobile in places, therefore, once the construction activity ceases, the features will reform within months to years, due to prevailing bedload sediment transport processes (e.g. Roulund et al., 2023).

221. 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.

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

6.8.1.2.2 Magnitude of Impact

223. The magnitude of impact for C2 has been determined based on an assessment of direct changes to wave and tidal regime (see **Sections 6.7.3.5** and **6.7.3.6**) and direct changes to seabed morphology and subsequent indirect changes to bedload sediment transport regime and seabed morphology (see **Section 6.7.3.7**).

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

6.8.1.2.3 Significance of Effect

225. Overall, it is predicted that sensitivity of the receptor is **low** and the magnitude of impact is **low** during construction activities. The effect is therefore of **minor adverse** significance, which is **not significant** in EIA terms.

226. No additional mitigation is required to manage the potential effects from changes to the sediment regime and seabed morphology.

6.8.2 Potential Impacts During Operation and Maintenance

6.8.2.1 O1: Changes in SSCs and Seabed Levels

227. O&M activities, including cable repair and movement of catenary mooring lines may disturb seabed sediment and cause changes in SSCs and seabed level due to redeposition of suspended sediment.

228. Receptor(s) which may be affected by O1 include, Seabed Bedforms and Relict Geomorphological Features.

6.8.2.1.1 Sensitivity and Value

6.8.2.1.1.1 Seabed Bedforms

229. The sensitivity of Seabed Bedforms to cable repair activities during the O&M phase will be the same as for construction and is defined as **negligible** (see **Section 6.8.1.1.1**).

6.8.2.1.1.2 Relict Geomorphological Features

230. The sensitivity of Relict Geomorphological Features to cable repair activities and changes in SSC due to seabed disturbance by the movement of catenary of mooring lines during the O&M phase will be the same as for construction and is defined as **negligible** (see **Section 6.8.1.2.1.1**).

6.8.2.1.2 Magnitude of Impact

231. The magnitude of impact for O1 has been determined based on an assessment of the Degree of Change (see **Section 6.7.3**) and how that would manifest as an impact upon receptors.

232. The magnitude of impact on Seabed Bedforms and Relict Geomorphological Features 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.

6.8.2.1.3 Significance of Effect

233. Overall, it is predicted that sensitivity of the receptor is **negligible** and the magnitude of impact is **negligible** during O&M activities. The effect is therefore of **negligible adverse** significance, which is **not significant** in EIA terms.

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

6.8.2.2 O2: Changes to Bedload Sediment Transport Regime and Seabed Morphology

235. Changes in bedload sediment transport regime and seabed morphology during the O&M phase may occur due to direct disturbance of the seabed during cable repair events and from the movement of catenary of mooring lines. Indirect changes to bedload sediment transport and seabed morphology may also occur due to changes in wave and hydrodynamic regime in the wake of structures in the water column (see **Section 6.7.3**).

236. Receptor(s) which may be affected by Impact 2 include, Seabed Bedforms and Relict Geomorphological Features.

6.8.2.2.1 Sensitivity and Value

6.8.2.2.1.1 Seabed Bedforms

237. The sensitivity of Seabed Bedforms to cable repair activities during the O&M phase will be the same as for construction and is defined as **low** (see **Section 6.8.1.2.1.1**).

238. Seabed Bedforms may become swept by the movement of catenary of mooring lines which would alter their morphology. They have some tolerance to this impact as the only the uppermost 0.5 m of the features will likely be affected and features with a wave height of <0.5 m (e.g. ripples) are extremely dynamic and will recover near instantaneously. Larger features such as megaripples and sand waves will recover at a slower rate, but considering movement of catenary mooring lines will be infrequent, mainly during storm events, the seabed will likely recover in between individual events. The sensitivity of Seabed Bedforms to movement of catenary mooring lines is therefore defined as **negligible**.

239. During O&M, turbulent wake effects within the immediate vicinity of fixed bottom substructures may change bedload sediment transport regimes. Considering the crest and wave length of the Seabed Bedforms within the Bellrock WFDA (sand wave heights of less than 2.6 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. The sensitivity of Seabed Bedforms to changes in bedload sediment transport regime due to the presence of structures in the water column is therefore defined as **low**.

240. 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.

241. Overall, the sensitivity of Seabed Bedforms to changes in bedload sediment transport regimes and seabed morphology is defined as **low**.

6.8.2.2.1.2 Relict Geomorphological Features

242. Relict Geomorphological Features are highly tolerant of potential changes in seabed morphology due to sweeping of the seabed by the movement of catenary mooring lines as the scale of these features (kilometres in length and >100 m deep) means they can accommodate superficial changes in morphology. As the receptor is relict, it cannot adapt or recover from the impact but given the changes are extremely small in scale, there will be no gross change to the features form or function. The sensitivity of Relict Geomorphological Features to movement of catenary mooring lines is therefore defined as **negligible**.

6.8.2.2.2 Magnitude of Impact

243. The magnitude of impact for O2 has been determined based on an assessment of the Degree of Change (see **Section 6.7.3**) and how that would manifest as an impact upon receptors.

244. The magnitude of impact on Seabed Bedforms and Relict Geomorphological Features is defined as **low** as changes in bedload sediment transport regime and seabed morphology will result in temporary, discernible changes over a minority of the receptor, throughout the duration of the Project Wind Farm Infrastructure.

6.8.2.2.3 Significance of Effect

245. Overall, it is predicted that sensitivity of the receptors is **low** and the magnitude of impact is **low** during O&M activities. The effect is therefore of **minor adverse** significance, which is **not significant** in EIA terms.

246. No additional mitigation is required to manage the potential effects from changes to the sediment regime and seabed morphology.

6.8.2.3 O3: Changes to Water Column Structure

247. During the O&M phase, blockage effects due the presence of FOUs in the water column may cause turbulence around structures which will enhance mixing, potentially changing the strength, timing and duration of seasonal stratification.

248. Receptor(s) which may be affected by Impact 3 include the water column.

6.8.2.3.1 Sensitivity and Value

6.8.2.3.1.1 Water Column

249. The water column within the Bellrock WFDA is seasonally stratified during summer months, for the remainer of the year, it is mixed. During summer, stratification occurs when surface waters are warmed through solar heating and become buoyant enough to overcome vertical mixing driven by turbulence at the seabed. This turbulent mixing is highly variable spatially and temporally

depending on the strength of stratification, flow speeds over tidal cycles and bed shear stress. The water column therefore has some tolerance to changes in turbulent kinetic energy induced by FOU's and once the structures are removed, the water column will recover fully.

250. The water column is not designated but is of regional importance for oceanography and physical processes.

251. The sensitivity and value of the water column to changes in water column structure is considered to be **low**.

6.8.2.3.2 Magnitude of Impact

252. The magnitude of impact for O3 has been determined based on an assessment of the degree of change (see **Section 6.6.10**) and how that would manifest as an impact upon receptors.

253. The magnitude of impact on the water column is defined as **low** as changes in water column structure will result in a discernible, spatially and temporally variable change over a minority of the receptor (vertically and spatially) with limited alteration to the key characteristics of the feature.

6.8.2.3.3 Significance of Effect

254. Overall, it is predicted that sensitivity/value of the receptor is **low** and the magnitude of impact is **low** during O&M activities. The effect is therefore of **minor adverse** significance, which is **not significant** in EIA terms.

255. No additional mitigation is required to manage the potential effects from changes to water column structure.

6.8.3 Potential Impacts During Decommissioning

256. The approach to decommissioning works is the same as outlined in **Section 6.7.3.3.3**.

257. Marine geology, oceanography and physical processes impacts scoped in for decommissioning include:

- D1: Changes in SSCs and seabed levels; and
- D2: Changes to the Sediment Regime and Seabed Morphology.

258. The sensitivity and magnitude of impacts during decommissioning would be comparable to or less than those identified for the construction phase (**Section 6.8.1**). Implementing embedded mitigation measures throughout the decommissioning phase would further limit effects (see **Section 6.7.5**)

259. The effect of changes in SSCs and seabed levels, D1, from the Bellrock Wind Farm Infrastructure during decommissioning has been assessed as **negligible adverse** which is **not significant** in EIA terms. The effect of changes to the sediment regime and seabed morphology, D2, from the Bellrock Wind Farm Infrastructure during decommissioning has been assessed as **minor adverse** which is **not significant** in EIA terms.

6.9 Cumulative Effects

260. The CEA follows the methodology set out in **Chapter 5: EIA Methodology (Volume II)** and summarised in **Section 6.4.2**.

6.9.1 Screening of Potential Cumulative Impacts

261. The first step in the CEA is the screening/identification of which impacts from the Bellrock Wind Farm Infrastructure could have a cumulative effect with other plans, projects and activities (described as 'impact screening'). This information is set out in **Table 6.27**, together with consideration of the confidence in the data that is available to inform a detailed assessment and the associated rationale.

Table 6.27: Potential Cumulative Impacts (Impact Screening)

Impact	Potential for Cumulative Impact	Data Confidence	Rationale
Construction			
C1: Changes in SSCs and seabed levels	No	High	Effects occur at discrete locations for a time-limited duration
C2: Changes in bedload sediment transport regime and seabed morphology	No	High	Effects occur at discrete locations for a time-limited duration
Operation and Maintenance			
O1: Changes in SSCs and seabed levels	No	High	Effects occur at discrete locations, infrequently over the O&M phase, and for a time-limited duration
O2: Changes in bedload sediment transport regime and seabed morphology	Yes	High	There is potential for cumulative changes to wave regime. However, waves have minimal influence on bedload sediment transport within the Bellrock WFDA given the water depths. There is potential for cumulative changes to tidal regime due to the presence of the Bellrock Wind Farm Infrastructure alongside nearby schemes which could lead to cumulative changes in bedload sediment transport and seabed morphology.
O3: Changes to water column structure	Yes	High	There is potential for cumulative changes to water column structure due to the presence of the Bellrock Wind Farm Infrastructure alongside nearby schemes. Stratification may be weaker compared to the baseline after travelling through the Bellrock

Impact	Potential for Cumulative Impact	Data Confidence	Rationale
			WFDA. If a water body does not recover to baseline conditions before entering another wind farm array, the cumulative mixing effect will be greater than that of the Bellrock Wind Farm Infrastructure alone.
Decommissioning			
D1: Changes in SSCs and seabed levels	No	High	Effects occur at discrete locations for a time-limited duration
D2: Changes in bedload sediment transport regime and seabed morphology	No	High	Effects occur at discrete locations for a time-limited duration

6.9.2 Screening of Other Plans, Projects and Activities

262. 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 6.28**, together with consideration of the relevant details of each, including current status (e.g. under construction), planned construction period, closest distance to the Bellrock WFDA, status of available data and rationale for including or excluding from the assessment.

263. The project screening has been informed by the development of a CEA Long List (**Appendix 5.3: Cumulative Effect Assessment Long List of Projects (Volume IV)**) which forms an exhaustive list of plans, projects and activities in a very large study area relevant to the Bellrock Wind Farm Infrastructure. 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 6.4.2**, 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.

264. An appropriate ZoI (with up to up to 72 km calculated as the maximum extent of changes to wave regime that could theoretically change stratification) to identify overlapping projects/activities is presented in **Figure 6.1 (Volume III)** and outlined in **Table 6.8**.

Table 6.28: Planned Projects within the Zone of Influence of the Bellrock Wind Farm Development Area

Project/Plan	Status at the Time of Assessment	Closest Distance from the Bellrock WFDA (km)	Type of Development	Construction Period	Operation Period	Data Confidence	Included in the CEA	Rationale
Tier 1 plans/projects (projects which are operational (but not part of the baseline), under construction, those with consent and submitted but not yet determined)								
Cenos	In Planning (Application submitted)	61	Offshore Wind Farm	2030 to 2034	2035 onwards	High	Yes	There is potential for cumulative effects in relation to Impact 3: Changes to water column structure due to the cumulative presence of structures.
Muir Mhòr	Planning (Application submitted)	52	Offshore Wind Farm	2028 to 2031	2032 onwards	High	Yes	There is potential for cumulative effects in relation to Impact 3: Changes to water column structure due to the cumulative presence of structures.
Ossian	Planning (Application submitted)	9	Offshore Wind Farm	2031 to 2038	2038 onwards	High	Yes	There is potential for cumulative effects in relation to Impact 3: Changes to water column structure due to the cumulative presence of structures.
Bellrock OfTDA	Pre-Planning	0	Offshore Wind Farm (offshore export cables)	2031 to 2036	2036 onwards	High	Yes	There is potential for cumulative effects in relation to Impact 3: Changes to water column structure due to the cumulative presence of structures.
All other Tier 1 projects are located outside the ZoI for Marine Physical Environment.								
Tier 2 plans/projects (all plans/projects assessed under Tier 1, plus those projects with a Scoping Report and/or Scoping Opinion)								
Bowdun Offshore Wind Farm	In Planning (Scoping Submitted)	62	Offshore Wind Farm	2031 to 2032	2033 onwards	High	Yes	There is potential for cumulative effects in relation to Impact 3: Changes to water column structure due to the cumulative presence of structures.

Project/Plan	**Status at the Time of Assessment**	**Closest Distance from the Bellrock WFDA (km)**	**Type of Development**	**Construction Period**	**Operation Period**	**Data Confidence**	**Included in the CEA**	**Rationale**
CampionWind[1]	In Planning (Scoping Submitted)	24	Offshore Wind Farm	Unknown	Unknown	Medium	Yes	There is potential for cumulative effects in relation to Impact 3: Changes to water column structure due to the cumulative presence of structures.
Morven Offshore Wind Farm (North and South)	Planning (Scoping report submitted)	35	Offshore Wind Farm	2027 to 2030	2030 onwards	Medium	Yes	There is potential for cumulative effects in relation to Impact 3: Changes to water column structure due to the cumulative presence of structures.
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[2].								
Cedar	Pre-Planning	21	Offshore Wind Farm	Unknown	Unknown	Low	Yes	There is potential for cumulative effects in relation to Impact 3: Changes to water column structure due to the cumulative presence of structures.
Notes: [1] In November 2025, Shell returned the Option to Lease for the CampionWind project to CES. In agreement with MD-LOT, CampionWind is included in this CEA screening process. [2] All other Tier 3 projects are located outside the ZoI for Marine Physical Environment.								

6.9.3 Cumulative Effects Assessment

265. Following the screening process outlined in **Section 6.9.1** and **Section 6.9.2**, O2 Changes to Bedload Sediment Transport Regime and Seabed Morphology and O3: Changes to Water Column Structure is being considered within the CEA.

266. For O2, projects and plans that include infrastructure in the water column that create a blockage effect have been screened into the assessment using the maximum ZoI for changes to tidal regime (**Table 6.8**) as the dominant driver of bedload sediment transport. This has resulted in the Bellrock OfTDA project being screened into the CEA for O2.

267. For O3, projects and plans that include infrastructure in the water column that create a blockage effect have been screened into the assessment using the maximum ZoI for changes to wave regime defined in **Table 6.8**. This conservative approach has resulted in the Cenos, Muir Mhòr, Ossian, Bowdun Offshore Wind Farm, CampionWind, The Morven Offshore Wind Farm (North and South), Bellrock OfTDA and Cedar projects and plans being screened into the CEA for O3.

6.9.3.1 Potential Cumulative Impacts During Operation

6.9.3.1.1 Changes to Bedload Sediment Transport and Seabed Morphology

6.9.3.1.1.1 Sensitivity of Receptors

268. The sensitivity of Seabed Bedforms to changes in bedload sediment transport regimes and seabed morphology is defined as low, as outlined in **Section 6.8.2.2.1.1**. The sensitivity of Relict Geomorphological Features is defined as negligible (see **Section 6.8.2.2.1.2**).

6.9.3.1.1.2 Magnitude of Cumulative Impact

269. For the Bellrock WFDA-alone assessment, the Magnitude of Impact on Seabed Bedforms and Relict Geomorphological Features was defined as **low** as changes in bedload sediment transport regime and seabed morphology will result in temporary, discernible changes over a minority of the receptor, throughout the duration of the Project (**Section 6.8.2.2.2**).

270. There is potential the Bellrock OfTDA will include a requirement for cable protection measures which will add additional structures onto the seabed that could alter bedload sediment transport regimes and seabed morphology due to localised changes in hydrodynamic regime and associated scour and depositional processes around the structures. If the Bellrock OfTDA project design includes additional platforms to support transmission, these structures would create an additional blockage effect that could potentially alter hydrodynamic and sediment transport regimes. Development of both projects could lead to a greater number of structures. However, as the effects would be highly localised the magnitude of cumulative impact is considered to be the same as for the Bellrock WFDA-alone assessment and is defined a **low**.

6.9.3.1.1.3 Significance of Cumulative Effect

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

272. No additional mitigation is required to manage the potential cumulative effects from changes to bedload sediment transport and seabed morphology.

6.9.3.1.2 Changes to Water Column Structure

6.9.3.1.2.1 Sensitivity of Receptors

273. The sensitivity of the water column to changes in water column structure is defined as **low**, as outlined in in **Section 6.8.2.3.1**.

6.9.3.1.2.2 Magnitude of Cumulative Impact

274. The Magnitude of Impact for the Bellrock WFDA-alone is defined as Low as changes in water column structure will result in discernible, spatially and temporally variable change over a minority of the receptor (vertically and spatially) with limited alteration to the key characteristics of the feature.

275. The development of multiple offshore wind projects within a region of sea that is seasonally stratified could lead to a greater magnitude of impact than for a single project alone. In principle, if stratification of a water body is weakened as it travels through an individual array, and there isn't sufficient time for stratification to recover before that water body enters a new array, this could result in cumulative weakening of stratification.

276. Predicting the effect of multiple arrays is extremely complex as it depends on the initial strength of stratification (which is currently poorly understood due to limited observational records), how much stratification is weakened as it travels through an array (which is also poorly understood as it requires computationally complex numerical modelling and there is limited observational evidence) and flow pathways between individual projects (e.g. does a parcel of water interact with multiple arrays).

277. It is acknowledged that there is relatively little research undertaken to date that allows a semi-quantitative assessment of changes to water column structure due to presence of multiple offshore wind farms.

278. Christiansen et al. (2022) simulated changes to water column structure due to wind wake effects in the southern North Sea resulting from >2,500 structures located in close proximity. They predict clusters of offshore wind farms could change salinity and temperature and change the duration and timing of stratification. However, this study is based on wind wake effects alone, doesn't consider tidal wake effects, assumes fixed monopile structures rather than floating structures which will dominate projects in the central North Sea, and was in a shallow sea with weak seasonal stratification.

279. Assessments of changes to water column structure being undertaken for multiple projects located in the central North Sea indicate the onset of stratification is rapid and its strength grows over a period of weeks (**Appendix 6.1: Shelf sea stratification, nutrient fluxes and primary production baseline for the Bellrock WFDA (Volume IV)**; **Appendix 6.2 Stratification Analysis Report (Volume IV)**; Marram Wind Offshore Wind Farm, 2025; Thistle Wind Partners, 2025). This suggests that stratification could potentially recover quickly from the effects of enhanced turbulent kinetic energy induced by wind farm structures, reducing the likelihood that if the affected water body interacts with another project, it will be an already weakened state relative to the baseline.

280. The residual current direction at the Bellrock WFDA is to the southwest. The closest project and plan screened into the CEA is Ossian which is located 8.68 km to the southwest of the Bellrock WFDA. Considering baseline current speeds are low at 0.05 m/s, in theory, it would take 20 days for a water body to travel from the Bellrock WFDA to the Ossian array which would be sufficient time for the water column to recover to baseline conditions. However, it is acknowledged that the recovery speed would be fastest during the peak months, but the effects may be greater at the onset and decay of stratification.

281. Based on the evidence and research available to date, the magnitude of cumulative impact is considered to be the same as for the Bellrock WFDA-alone assessment and is defined a **low**.

6.9.3.1.2.3 Significance of Cumulative Impact

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

283. No additional mitigation is required to manage the potential cumulative effects from changes to water column structure.

6.10 Inter-related and Interacting Impacts

6.10.1 Inter-relationships

284. The key inter-relationships between marine geology, oceanography and physical processes and other technical chapters are described in **Section 6.7.1** (**Table 6.15**).

6.10.2 Interactions

285. 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 6.29**, **Table 6.30** and **Table 6.31** below. 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.

286. A subsequent lifetime assessment has been undertaken which considers the impact interactions identified and the potential for impacts to effect receptors relevant to this Chapter across all development phases (**Table 6.32**).

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Table 6.29: Potential Interaction Between Impacts – Construction

Potential Interaction Between Construction Impacts					
	Changes in SSCs (C1)	**Changes in seabed level due to deposition of suspended sediment (C1)**	**Changes to seabed morphology (C2)**	**Changes in bedload sediment transport regime (C2)**	**Changes to wave and tide regime (C2)**
Changes in SSCs (C1)		No	No	No	No
Changes in seabed level due to deposition of suspended sediment (C1)	No		Yes	Yes	Yes
Changes to seabed morphology (C2)	No	Yes		Yes	Yes
Changes in bedload sediment transport regime and seabed morphology (C2)	No	Yes	Yes		Yes
Changes to wave and tide regime (C2)	No	Yes	Yes	Yes	

Table 6.30: Potential Interaction Between Impacts – Operation and Maintenance

Potential Interaction Between O&M Impacts						
	Changes in SSCs (O1)	**Changes in seabed level due to deposition of suspended sediment (O1)**	**Changes to seabed morphology (O2)**	**Changes in bedload sediment transport regime (O2)**	**Changes to wave and tide regime (O2 and O3)**	**Changes in water stratification and mixing (O3)**
Changes in SSCs (O1)		No	No	No	No	No
Changes in seabed level due to deposition of suspended sediment (O1)	No		Yes	Yes	Yes	No
Changes to seabed morphology (O2)	No	Yes		Yes	Yes	No
Changes in bedload sediment transport regime and seabed morphology (O2)	No	Yes	Yes		Yes	No
Changes to wave and tide regime (O2 and O3)	No	Yes	Yes	Yes		No
Changes in water stratification and mixing (O3)	No	No	No	No	No	

Table 6.31: Potential Interaction Between Impacts – Decommissioning

Potential Interaction Between Decommissioning Impacts					
	Changes in SSCs (D1)	**Changes in seabed level due to deposition of suspended sediment (D1)**	**Changes to seabed morphology (D2)**	**Changes in bedload sediment transport regime (D2)**	**Changes to wave and tide regime (D2)**
Changes in SSCs (D1)		No	No	No	No
Changes in seabed level due to deposition of suspended sediment (D1)	No		Yes	Yes	Yes
Changes to seabed morphology (D2)	No	Yes		Yes	Yes
Changes in bedload sediment transport regime and seabed morphology (D2)	No	Yes	Yes		Yes
Changes to wave and tide regime (D2)	No	Yes	Yes	Yes	

Table 6.32: Potential Interactions Between Impacts - Phase and Lifetime Assessment

Highest Significance of Effect Level					
Receptor	**Construction**	**O&M**	**Decommissioning**	**Phase Assessment**	**Lifetime Assessment**
Seabed Bedforms	Minor adverse	Minor adverse	Minor adverse	No greater than individually assessed impacts for each phase. Seabed Bedforms will recover quickly from disturbance during each individual phase of the Bellrock Wind Farm Infrastructure as the seabed is dynamic (within days to a maximum of a year), Additionally, the bedforms are likely mobile in places so will adapt to permanent disturbance (such as installation of anchors).	No greater than individually assessed impacts.
Relict Geomorphological Features	Minor adverse	Minor adverse	Minor adverse	No greater than individually assessed impacts for each phase. Relict Geomorphological Features will be highly tolerant to changes in seabed levels as their formation history is linked to the glacial history of the North Sea, rather than modern day active bedload sediment transport. This receptor cannot adapt or recover but given the changes are depositional (oppose the erosional), there will be no gross change to the receptor's morphology (especially as the changes are short lived).	No greater than individually assessed impacts.
Water column structure	N/A	Minor 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 permanent structures in the water column. Any structures during the construction phase will be transient and short lived.	No greater than individually assessed impacts.

6.11 Summary

287. **Table 6.33** presents a summary of the assessment of potential effects on marine geology, oceanography and physical processes during the construction, O&M and decommissioning phases of the Bellrock Wind Farm Infrastructure.

288. The assessment has established that the Bellrock Wind Farm Infrastructure would result in effects of **negligible adverse** to **minor adverse**, which is **not significant** in EIA terms.

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Table 6.33: Summary of Potential Effects for Marine Geology, Oceanography and Physical Processes

Potential Impact	Receptor(s)	Sensitivity	Magnitude of Impact	Significance of Effect	Secondary Mitigation	Residual Significance of Effect	Cumulative Residual Significance of Effect
Construction							
Impact 1: Changes in SSCs and seabed levels	Seabed Bedforms	Negligible	Negligible	Negligible adverse	None	Negligible adverse (not significant)	Negligible adverse (not significant)
	Relict Geomorphological Features	Negligible	Negligible	Negligible adverse	None	Negligible adverse (not significant)	Negligible adverse (not significant)
Impact 2: Changes in bedload sediment transport regime and seabed morphology	Seabed Bedforms	Low	Low	Minor adverse	None	Minor adverse (not significant)	Minor adverse (not significant)
Operation and Maintenance							
Impact 1: Changes in SSCs and seabed levels	Seabed Bedforms	Negligible	Negligible	Negligible adverse	None	Negligible adverse (not significant)	Negligible adverse (not significant)
	Relict Geomorphological Features	Negligible	Negligible	Negligible adverse	None	Negligible adverse (not significant)	Negligible adverse (not significant)
Impact 2: Changes in bedload sediment transport regime and seabed morphology	Seabed Bedform	Low	Low	Minor adverse	None	Minor adverse (not significant)	Minor adverse (not significant)
	Relict Geomorphological Features	Negligible	Low	Minor adverse	None	Minor adverse (not significant)	Minor adverse (not significant)

<table>
<tr><th>Potential Impact</th><th>Receptor(s)</th><th>Sensitivity</th><th>Magnitude of Impact</th><th>Significance of Effect</th><th>Secondary Mitigation</th><th>Residual Significance of Effect</th><th>Cumulative Residual Significance of Effect</th></tr>
<tr><td>Impact 3: Changes to Water Column Structure</td><td>Water Column Structure</td><td>Low</td><td>Low</td><td>Minor adverse</td><td>None</td><td>Minor adverse
(not significant)</td><td>Minor adverse
(not significant)</td></tr>
<tr><td colspan="8">Decommissioning</td></tr>
<tr><td>Impact 1: Changes in SSCs and seabed levels</td><td colspan="7" rowspan="2">During decommissioning, the receptors, sensitivity, magnitude and significance of effect for D1 and D2 is expected to be equal to or less than the receptors, sensitivity, magnitude and significance of effect during construction.</td></tr>
<tr><td>Impact 2: Changes in bedload sediment transport regime and seabed morphology</td></tr>
</table>

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