Environmental Impact
Assessment Report

NISA
North Irish Sea Array

Volume 9: Appendices (Offshore)

Appendix 10.1
Marine Processes Review of Project Options

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NORTH IRISH SEA ARRAY (NISA) OFFSHORE WIND FARM. APPENDIX 10.1: MARINE PROCESSES. REVIEW OF PROJECT OPTIONS

MetOceanWorks, GoBe

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Abbreviations

COWRIE	Collaborative Offshore Wind Research Into the Environment
DCCAE	Department of Communications, Climate Action & Environment
ECC	Export Cable Corridor
EIA	Environmental Impact Assessment
EIAR	Environmental Impact Assessment Report
EPA	Environmental Protection Agency
HDD	Horizontal Directional Drilling
LAT	Lowest Astronomical Tide
LWM	Low Water Mark
MFE	Mass Flow Excavator
MW	Megawatt
NISA	North Irish Sea Array
OSP	Offshore Substation Platform
PSA	Particle Size Analysis
TSHD	Trailer Suction Hopper Dredger
UTM	Universal Transverse Mercator
WTG	Wind Turbine Generator

1. Introduction

This technical appendix (Appendix 10.1) reviews Project Option 1 and Project Option 2 proposed for the North Irish Sea Array (NISA) Offshore Wind Farm (hereafter referred to as the 'proposed development') to establish the design options which are likely to develop the largest scale of effect on marine processes. This appendix supports Chapter 10 Marine Geology, Oceanography and Physical Processes of the Environmental Impact Assessment Report (EIAR).

Where relevant, a particular design option also defines source terms for modelling tools (Appendix 10.2) which are used to more fully assess the spread of effects (impact pathways) across the marine environment. Where these impact pathways encounter a sensitive environmental receptor, then the scale of the potential impact is assessed in the associated chapter.

1.1. Document structure

Section 1 explains the scope and purpose of the technical appendix.

Section 2 identifies the primary marine physical processes interactions anticipated from an offshore wind farm development on the marine and coastal environment.

Section 3 establishes the likely greatest effects through each phase of the project development cycle.

Section 4 provides a reference list of the literature cited in this document.

1.2. Supporting documents

The assessment of design options likely to develop the greatest effects on marine processes are established from the following documents:

- Volume 2, Chapter 6: Description of the Proposed Development – Offshore
- Volume 2, Chapter 8: Construction Strategy – Offshore
- COWRIE (2009). Coastal Process Modelling for Offshore Wind Farm Environmental Impact Assessment: Best Practice Guide. COWRIE Coast-07-08
- DCCAE (2107). Guidance on EIS and NIS Preparation for Offshore Renewable Energy Projects
- EPA (2020). Guidelines on the information to be contained in Environmental Impact Assessment Reports

- Fugro (2022). Geophysical Survey Results Report | Ireland, Irish Sea. Results Report - Fugro Mercator. F202831-REP-003. Issue 1. For North Irish Sea Array Windfarm Limited
- N-Sea. (2023). North Irish Sea Array Windfarm Ltd. Interim Geophysical Survey. Results Report. DOC NO: NSW-PJ00293-RR-DC-SUR-001
- Natural Power (2022). NISA Benthic Ecology Baseline. Array Area Benthic Survey Report
- Natural Power (2023). NISA Benthic Ecology Baseline. Cable Route Benthic Survey Report

1.3. Geodetic parameters

All mapping is referenced to UTM Zone 30N.

1.4. Sediment classification

Folk-7 (seven sediment classes, including rock, Kaskela, et al., 2019) is adopted as the common descriptive sediment classification scheme for the presentation and interpretation of surficial sediment types (based on the relative combination of Mud (M), Sand (S) and Gravel (G)) from all available data sources. In addition, the Wentworth scale is also applied to further distinguish sediment particle size between very fine, fine, medium, coarse, and very coarse classes (Wentworth, 1922).

2. Design options

A review of design options has considered all methods of construction under consideration as well as the different array layouts and foundation types representing Project Option 1 and Project Option 2. This review establishes the options which have the greatest potential to develop a likely significant effect on marine processes for each stage of project development. These options also establish source terms for modelling tools (Appendix 10.2) which are used to more fully assess the spread of effects (impact pathways) across the marine environment. Where these impact pathways encounter a sensitive environmental receptor then the scale of the potential impact is assessed in the chapter associated with such receptor.

Table 1 provides a high-level summary of the key differences between Project Option 1 and Project Option 2. For the purposes of the model, the construction methodology assumes drilling will be required at some foundation sites. The largest amount of sites that could require drilling has been assumed, however, the final installation methodology will be confirmed following detailed site investigation surveys post-consent and detailed design.

Table 1. High-level comparison between Project Options

Parameter	Project Option 1	Project Option 2
Number of foundations – Wind Turbine Generator (WTG)	49	35
Foundation type – WTG	Monopile	Monopile or jackets (3 or 4-legged)
Number of foundations – Offshore Substation Platform (OSP)	1	1
Foundation type – OSP	Dual monopile or 4-legged jacket	Dual monopile or 4-legged jacket
Seabed levelling at foundations	OSP jacket option only	50% of all jacket options only
Provision for drilling of piles	75% of sites	100% of sites
Likely number of piles to be drilled	37 monopiles and 4 4-legged jacket piles	36 monopiles or 144 4-legged jackets
Length of inter-array cables (km)	111	91
Length of export cables (km)	36 (two export cables each 18 km long)	36 (two export cables each 18 km long)

Only the design option that has greatest potential to develop a likely significant effect has been modelled, noting that the alternative design option would not be expected to lead to any greater scale of effect and therefore does not require additional modelling since the results will be representative of both project options, albeit the alternative design option having slightly lower magnitudes.

3. Marine physical processes interactions

The anticipated interactions between marine physical processes and an offshore wind farm development can be grouped into two main types of effects:

a. **Seabed disturbance** - seabed response to short-term mechanical activities, anticipated mainly during construction and decommissioning periods, which are likely to develop sediment plumes that temporarily and locally increase turbidity (suspended sediment) in the water column. Subsequent deposition of material may also lead to smothering of seabed receptors. In addition, some seabed disturbance activities may also occur during the operational & maintenance period, notably if remedial work is required for cable repairs, etc. Examples of activities which may lead to seabed disturbance include; seabed levelling, disposal of spoil, pile drilling, cable trenching, punch-out of Horizontal Directional Drilling (HDD), etc.

b. **Blockage** – the interaction of installed structures (across the array and along the cable routes) with waves and flows over the duration of the operational period (the longest period in the development cycle) may result in local modifications to wave energy transmission towards the coast and / or development of local flow wakes which may increase turbulence and mixing, induce local scour and interfere with general sediment transport processes.

4. Project development cycle

4.1. Overview

A consideration of offshore activities which are planned during each phase of the proposed project development cycle provides the basis to identify the type, magnitude, location, and duration of marine physical processes effects which are expected to occur. Where the spread of these effects (i.e., impact pathways) needs to be explored in greater detail, relevant source terms are established for modelling scenarios based on the identified option likely to develop the largest effect on marine processes. Appendix 10.2 provides further details of the modelling carried out.

For clarity, the identified impact pathways are assigned a unique reference which is formed of a prefix to identify the phase of activity (i.e., C = Construction, O = Operation, M = Maintenance, D = Decommissioning) along with a unique sequential number for each phase.

For the purposes of the modelling described in this document the locations of WTGs within the array area for the proposed development have been numbered to aid identification in the model.

4.2. Construction Phase

The main effects on the marine environment during the construction phase are expected to be related to seabed preparation around jacket foundations, drilling for piled foundations (where ground conditions require), inter-array and export cable trenching, and HDD activities in the nearshore. These activities will each develop different rates and volumes of sediment disturbance into the water column based on the construction methods employed. The subsequent fate of this disturbed sediment depends on several factors, notably:

- vertical position in the water column of the disturbed sediment and local water depths;
- settling velocity of the different sediment particle sizes involved, which influences the time spent in the water column; and
- the local hydrodynamic currents which can act on the particles during settling and advect the sediments further afield.

When present in the disturbed sediment, the coarse fraction (i.e., very fine gravel to medium sand) will have the fastest settling velocities, falling rapidly back to the seabed and with limited opportunity to advect away. This fraction will therefore remain relatively close to the source of disturbance (or discharge). The fine sediment fraction (i.e., fine sand to silts and muds) will have the slowest settling velocities which means these sediment particles will take longer to settle back to the seabed. During the longer settling period, this fraction is susceptible to advection and dispersion by hydrodynamic currents, transporting material away from the source of disturbance (or discharge) in the form of sediment plumes with material eventually settling elsewhere.

Table 2 provides indictive settling velocities (based on Soulsby, 1997) for representative sediment types present across the development area, based on the Wentworth scale (Wentworth, 1922).

Table 2. Theoretical settling velocities for representative sediment types

Sediment type		Size range (mm)	Representative size (mm)	Settling velocity (m/s)
Coarse fraction	Gravel	> 2.000	3.000	0.216
	Very coarse sand	1.000 to 2.000	1.500	0.147
	Coarse sand	0.500 to 1.000	0.750	0.093
	Medium sand	0.250 to 0.500	0.375	0.049
Fine fraction	Fine sand	0.125 to 0.250	0.188	0.018
	Very fine sand	0.063 to 0.125	0.094	0.005
	Coarse silt	0.031 to 0.063	0.047	0.0014
	Medium silt / muds	< 0.0031	0.023	0.0003

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4.2.1. Seabed clearance

An initial activity during the construction phase is seabed clearance to deal with obstructions that might interfere with cable trenching (e.g., anthropogenic seabed debris and boulders). The clearance process (using techniques such as a Pre-Lay Grapnel Run) may lead to relatively minor disturbance of the surficial sediments and over a notional width of 40 m along the length of all cables (111 km for inter-array for Project Option 1 and 91 km for Project Option 2, plus 36 km for export cables for both Project Option 1 and project Option 2).

Geophysical survey evidence collected for the proposed development indicates that the seabed profile is relatively smooth with no sandwaves present in either the array area (Fugro, 2022) or along the export cable corridor (ECC) (N-Sea, 2023). On this basis, there is no anticipated requirement for sandwave clearance prior to cable laying.

4.2.1.1. Seabed levelling

Jacket foundations may require seabed levelling prior to placement of scour protection. For Project Option 1 this is only applicable in the case of the OSP adopting a 4-legged jacket foundation. For Project Option 2 a provision is made to level up to 50% of all sites in the case that jacket foundations are selected.

Two levelling options are being considered; a trailer suction hopper dredger (TSHD) or a mass flow excavator (MFE). The TSHD option is considered to lead to the largest effect on marine processes for the following reasons:

- The MFE option only develops a near-seabed sediment disturbance around each of the relevant WTG / OSP locations.

- The TSHD option initially develops a near-surface release of overspill of mainly fine sediments around each of the WTG / OSP locations towards the end of the loading cycle, followed by a subsequent rapid release of the filled hopper as spoil disposal elsewhere. The fine sediment fraction in these releases has the potential for wider advection and dispersion in comparison to the near-bed disturbance developed by MFE. The remainder of the hopper load will form a spoil mound on the seabed.

The diameter of scour protection around the WTG jacket foundation is planned to be up to 77 m. The preparatory dredging will extend this diameter to 87 m to remove the top 1 m of seabed sediment. This equates to an in-situ sediment volume of 5,945 m^3 per foundation. Seabed levelling is not anticipated to be required around all jacket foundations, with a provision made for dredging at up to 50% of all locations (equivalent to 18 locations). In total, this equates to a potential removal of 107,004 m^3 for WTG jacket foundations.

Two foundation types are considered as potential options for the OSP foundation (two monopiles or 4-legged jacket). A single scour protection diameter has been assumed irrespective of the option; the diameter of which is up to 78 m. The preparatory dredging will extend this diameter to 88 m to remove the top 1 m of seabed sediment. This equates to an in-situ sediment volume of 6,082 m^3 (for either Project Option 1 or Option 2).

The total volume of sediment to be removed for the WTG jacket and OSP foundation option is therefore up to 113,086 m^3 for Project Option 2.

When a consolidated seabed is dredged the sediment material disaggregates and bulks up in volume. A bulking factor of 1.25 has been assumed for present purposes which is mid-range of 1.10 to 1.40 for ‘silts, consolidated’ (Bray, Bates, & Land, 1996) and represents the most common sediment type across the array area. The total bulked up volume of dredged sediment is therefore expected to be around 141,358 m^3.

The dredging scenario assumes a ‘large’ category TSHD with a hopper capacity in the range 8,000 to 15,000 m^3 and the ability to dredge in depths up to 60 m (n.b., the deepest WTG in the array area is located in a water depth of around 57 m below LAT). In comparison, a ‘small’ category TSHD is unlikely to be able to dredge at the depths found across the array area. A THSD with a capacity of around 15,000 m^3 is selected as a conservative option to enable up to two foundation locations to be dredged, one after the other, followed by a single spoil disposal of the total hopper load close by. On this basis, up to ten dredging cycles are anticipated to achieve the required seabed levelling across the array area.

The loading rate of the hopper is expected to be in the range 5,000 to 10,000 m^3/hour. The faster loading is expected to develop the higher rate of overspill losses discharged back to sea. Overspill is only anticipated to occur at the second dredging location as the hopper will only be partially filled after dredging the first location.

The cumulative overspill loss is expected to be up to 42.6% of the pumped-in volume of sediment for a large TSHD loading very fine sands (Miedema, 2013). The time to complete dredging at each WTG location is estimated to be around 0.85 hours, and 0.87 hours for the OSP location. After dredging the first site, the half-loaded TSHD is assumed to raise the draghead and transit to an adjacent WTG requiring seabed levelling where the draghead will be lowered to recommence dredging. The transit and repositioning time is estimated to be around 0.5 hours. Dredging will continue until the hopper is filled. During the final stage of filling, the excess water is discharged to the sea surface via overflow pipes. This overspill is likely to contain fine sediments in suspension which will develop a sediment plume.

The period of overspill is estimated to be around 0.68 hours of the total dredging period of 0.85 hours at the second location (i.e. 80% of the duration of the second loading cycle). The total sediment overspill volume in this period is expected to be around 2,532 m^3 with an equivalent discharge rate of 1.45 tonnes/s.

A potential dredging location in the array area expected to have the largest contribution of fine sediments, as established by grab sample #5 from the benthic array survey (Volume 9, Appendix 12.1: Array Area Benthic Survey Report), is in the vicinity of WTG-T44 (assumed initial dredging location of scenario) and WTG-T43 (second dredging location to complete hopper load) in the north-eastern part of the array (Figure 1). Notably, the sediment gradings from sample #5 identify 100% of material is fine sediments (overall Folk classification of ‘muddy Sand’) with no coarse sediments. Water depths for this area in the array are estimated to be around 46 to 47 m below LAT (Fugro, 2022).

The potential dredging at these locations is used to develop an indicative scenario to represent the fate of fine sediment from overspill and hopper discharge, noting other sites with lower contents of fine sediment are expected to develop comparable sediment plumes but with slightly lower concentrations.

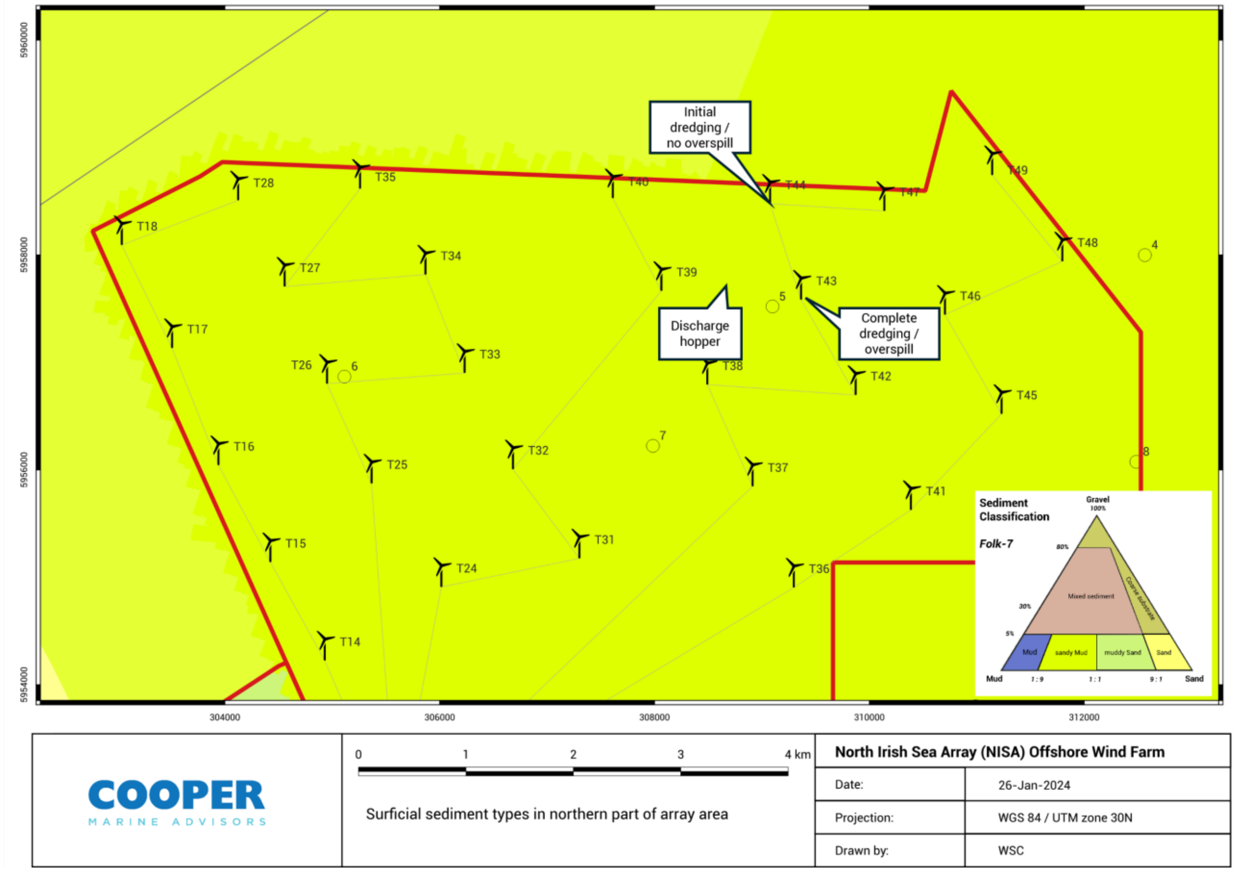

Figure 1. Surficial sediment types in northern part of array area

Table 3 provides details of anticipated overspill rates for fine sediments likely to be discharged back to sea from the TSHD dredging at WTG-T43. These rates are apportioned to the representative contributions of fine sand, very fine sand, coarse silt, and medium silt established from grab sample #5. The estimated time for different fine sediment types to fall out of suspension from the sea surface to the local water depth is also provided, indicating that the smallest particles (medium silt and smaller) could take at least 42 hours to fully settle out.

Table 3. Overspill discharge rates of fine sediments from seabed levelling around WTG-T43

Sediment type	Size range (mm)	Time to fall out of suspension (s)	% Contribution	Mass input (tonnes/s)
Fine sand	0.125 to 0.250	2,566	5.6	0.08
Very fine sand	0.063 to 0.125	9,200	18.8	0.27
coarse silt	0.031 to 0.063	32,857	18.6	0.27
medium silt / muds	< 0.0031	153,333	56.9	0.83

When the loading cycle is complete, the dredger will transit to a suitable location nearby for disposal of spoil through the bottom doors of the hopper. Each spoil disposal event represents the largest volume of near-instantaneous sediment release during the dredging cycle.

Figure 2 provides a conceptual illustration of the fate of spoil released from a TSHD (PNNL, 2006). The spoil will initially fall towards the seabed as a density driven convective flow with a partial loss of low-density material during the descent phase. The convective flow will impact on the seabed with a dynamic collapse which creates a 'sediment cloud' and then a spoil mound. Some of the finer sediment fraction involved in the dynamic collapse will be susceptible to wider advection and dispersion during the diffusive phase. The spoil mound will still contain large amounts of finer sediments,but will also become susceptible to tidal forces which may winnow away surficial material over the medium and long-term.

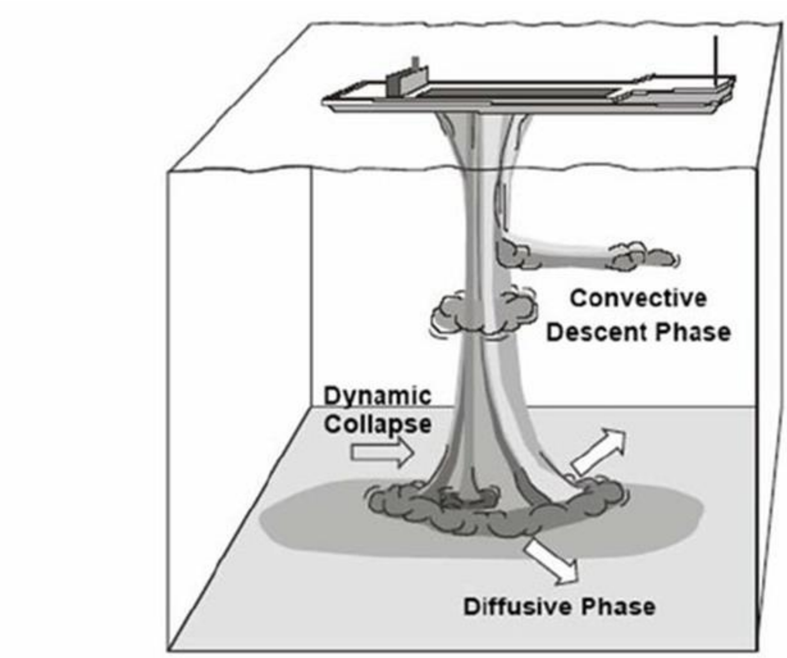

Figure 2. Spoil disposal phases following sediment release from dredger (PNNL, 2006)

The assumed location for spoil disposal is mid-way between WTG-T43 and the next adjacent dredging location of WTG-T39. The geophysical survey data (Fugro, 2022) suggests the sediment type at this location remains as 'sandy Mud', comparable to the sediments expected to be dredged from WTG-T44 and WTG-T43, hence the spoil sediment is discharged at a location with a similar(equivalent) sediment type at the seafloor. Water depths at the spoil disposal location are expected to be around 45 m below LAT, with the dynamic collapse cloud estimated to be around 16 m below the sea surface (calculated by STFATE, see Appendix 10.3).

Table 4 provides estimated release rates for fine sediments discharged from the hopper over a period of around 6 minutes, as well as the time to fall out of suspension for a depth of 30 m above the seabed (accounting for depth of hopper).

Table 4. Spoil disposal rates of fine sediments from seabed levelling around WTG-T44 and -T43

Sediment type	Size range (mm)	Time to fall out of suspension (s)	% Contribution	Mass input (tonnes/s)
Fine sand	0.125 to 0.250	1,667	5.6	2.05
Very fine sand	0.063 to 0.125	6,000	18.8	6.83
coarse silt	0.031 to 0.063	21,429	18.6	6.78
medium silt / muds	< 0.0031	100,000	56.9	20.72

The consequence of sediment plumes which develop from this scenario of seabed levelling are investigated with suitable modelling tools as impact pathway C-01. Appendix 10.2 discusses the modelling of far-field dispersion of fine sediment from overspill and spoil disposal, and Appendix 10.3 the predicted form of the near-field spoil mound.

4.2.2. Drilling for foundation installation

a. Seabed geology

An assessment of geophysical survey evidence across the array area has identified the likely requirement for drilling into shallow bedrock for both monopiles and jacket foundations. The geophysical survey (Fugro, 2022) interprets reflector H50 as the top of bedrock representing two formations, a layer of Dinantian Limestone and a layer of Innishkeen Formation (sandstone). Across the array area, the depth below seabed to rockhead varies between 5 m at the very southern limit to 65 m slightly further north (due to abrupt dipping) which is likely to be associated with the boundary between these two rock types. The majority of the array area has a depth below seabed of between 20 to 30 m to the top of the Innishkeen Formation (Figure 3).

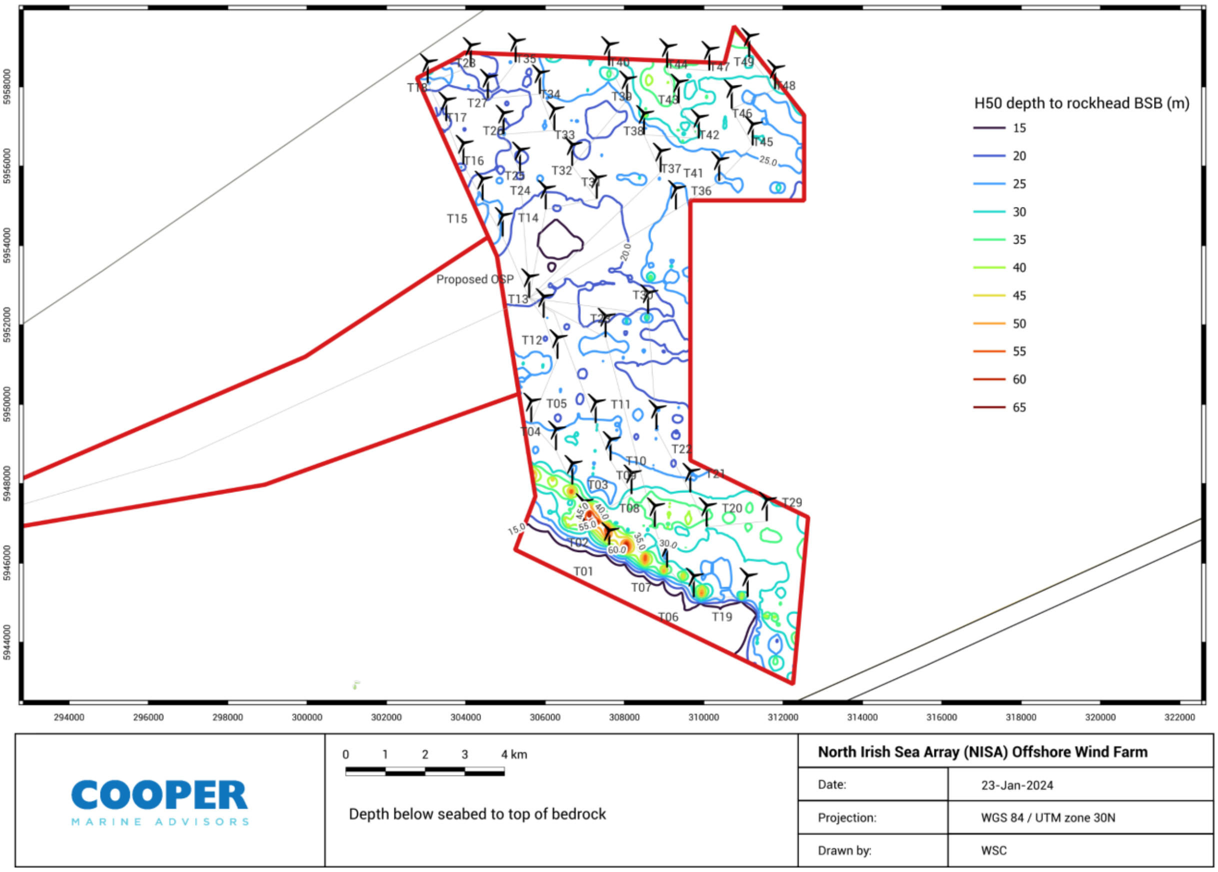

Figure 3. Isopach contours to top of bedrock across the array area

b. Drilling requirements

Both monopile and jacket foundation options have embedment depths which are expected to require drilling depending on their location in the array area relative to the depth below seabed of the underlying bedrock. Project Option 1 is expected to require drilling at 75% of all 49 WTG sites (equivalent to 37 locations) and 100% of all WTG sites for Project Option 2 (equivalent to 35 locations). In addition, drilling is also required at the single OSP location.

The conservative estimate for drill arisings is based on drilling out the entire pile embedment depth which is expected to include layers of quaternary sediments and glacial till (creating soil arisings) over a bedrock layer (creating rock cuttings). All material will be taken back to the pile installation vessel to be disposed of at sea from a fall pipe stationed up to 100 m away. The sediment discharge is therefore close to the sea surface.

The volume of arisings is estimated as the volume of the pile over the total embedment depth multiplied by a bulking factor of 150%.

Table 5 provides a summary of drill arising parameters for each foundation type and project option. According to this information, the OSP two monopile option is expected to produce the highest volume of drill arisings from a single location, whereas the array option which is expected to generate the largest overall volume of drill arisings from all drilling locations relates to 35 jacket type foundations associated with Project Option 2.

Table 5. Summary of drill arising

Project Option	**Project Option 1**	**Project Option 2**	
Number of WTG foundations	49	35	
Foundation type	Monopiles	Monopiles	Jackets
Embedment depth (m)	50	50	60
Number of piles per foundation	1	1	4
Pile diameter (m)	12.5	12.5	6
Drilling requirements (% of sites)	75	100	100
Volume of arisings per WTG (m^3)	9,204	9,204	**10,179**
Total volume of arisings (m^3)	338,243	322,136	**356,257**
Number of OSP foundations	1	1	1
Foundation type	Monopiles	Monopiles	Jackets
Embedment depth (m)	60	60	60
Number of piles per foundation	2	2	4
Pile diameter	12.5	12.5	6
Total volume of arisings (m^3)	**22,089**	**22,089**	10,179

c. Drill arisings scenario

Since drilling for the OSP monopile option develops the largest anticipated volume of arisings from a single location, this case is used to establish source terms for a modelling scenario which serves to investigate the fate of drill cuttings discharged back to the marine environment. In comparison, all other foundation types and locations are considered to develop a lower volume of arisings with lesser effects. Accordingly, the OSP monopile option represents the greatest potential for likely significant effects on the marine environment over the sequence of drilling activities.

The geophysical survey (Fugro, 2022) identifies the depth to bedrock at the location of the OSP is around 18 m below seabed (Figure 3) with the shallower stratigraphic horizons of soils generally described as shallow muddy sands (H05 to 3 m, H10 to 8 m, H15 to 10 m below seabed) over reworked glacial material (H25b to 13 m below seabed).

The drilling rate establishes the production rate of arisings discharged into the sea. Faster rates have the potential to develop higher concentrations of fines in the near-field. Indicative drilling rates into bedrock are expected to be between 0.5 m/hr. This rate depends on many factors, including; diameter of the pile, soil type and drill pressure, amongst others. The soil layers are expected to be drilled out relatively quickly (estimated rate of 10 m/hr) followed by drilling out of more resistant bedrock from 18 to 60 m below seabed.

Along with the drilling rate, the bulk density and volumes of soil and bedrock establish the discharge properties of the drill arisings. There are presently a limited number of vibrocore logs in this part of the array area with available information suggesting the upper layer of soil (to around 3 m below seabed) is 'muddy Sand' with a 'wet' soil density of around 2.0 g/cm^3 (GDG, 2020). The equivalent "dry" density of this soil type is expected to be around 1.86 g/cm^3. This value has been adopted for the top layers of sediment assessed to be 'muddy Sand'; H05, H10 and H15. Below H15 is a layer of reworked glacial till to 18 m below seabed, H25b. The dry bulk density for this type of sediment is approximated as 2.12 g/cm^3 (Terzaghi, Peck, & Mesri, 1996). The bedrock layer (H50) is expected to be sandstone with a bulk density estimated to be up to 2.57 g/cm^3 (GDG, 2021).

The particle size distribution of the surface layers (seabed, H05, H10 to H15) is established from the closest grab sample (#10) from the benthic array survey (Natural Power, 2022), which is formed entirely of fine sediments (fine sand to silts) and is described as a very poorly sorted 'sandy Mud'. The underlying layers of glacial till (H15 to H25b) is described as gravels with muds and sands to cobbles (Fugro, 2022) and is therefore expected to contain a higher percentage of coarser sediments (sands and gravels) along with finer sediments, although the action of the drill may still develop a modified particle size distribution. The particle size distribution of rock cuttings (H50 to pile depth) remains unknown, so conservative assumptions are offered in terms of the quantity of fine sediments that may be created and subject to wider dispersion.

The release profile of drill arisings for each OSP monopile is summarised in

Table 6. The estimated time to complete the drilling out for the first monopile is around 84 hours.

Table 6. Release rates of fine sediments from drilling a single OSP monopile

Seabed layer	Time to complete (s)	Fine sand (tonnes/s)	Very fine sand (tonnes/s)	Coarse silt (tonnes/s)	Medium silt (tonnes/s)
Seabed, H05 to H10	2,880	0.0090	0.0139	0.0074	0.0243
H10 to H15	720	0.0096	0.0147	0.0078	0.0258
H15 to H25b	1,080	0.0101	0.0156	0.0083	0.0273
H25b to H50	3,600	0.0072	0.0036	0.0018	0.0018
H50 to pile depth	302,400	0.0009	0.0004	0.0002	0.0002

This release profile is assumed to pause for a short period of four hours to allow repositioning of the drill onto the second pile hole and then repeated. The full period for drilling both OSP monopiles is conservatively estimated to be around 172 hours, although a longer interval could be required which would likely develop two separate periods of drill cuttings release rather than a near-continuous release.

In comparison to the OSP scenario, all alternative foundation piles (monopiles and jackets) are considered to have shorter release periods. Once drilling is completed at a single location there is expected to be an interval of around three days to reposition the drill rig to the next location. This period is considered sufficient to allow full dispersion of any sediment plumes prior to the commencement of subsequent drilling.

The consequence of sediment plumes developed from drilling has been assessed with suitable modelling tools as impact pathway C-02 and is discussed in Appendix 10.2.

4.2.3. Cable installation

Various options are being considered to develop the cable trench for inter-array and export cables, including mechanical trenching (for harder soils), jetting or ploughing.

a. Trench dimension

The target trench depth is 1m - 3 m with a trench width of 1 m. The maximum trench cross-section is therefore up to 3 m^2.

b. Trenching method

The trenching option which is likely to develop the greatest level of seabed disturbance is considered to be the fluidisation of seabed sediments by a jetting tool, in contrast to say, ploughing. For jetting, the finer sediments have the potential to be raised into suspension above the seabed. The initial height of suspension is conservatively taken to be equal to the depth of excavation.

Finer sediments have the longest period of settlement and during this period have the potential to be advected and dispersed furthest away from the trench by hydrodynamic currents. In contrast, coarse grained sediments will settle quickly back into the trench without the opportunity for being advected further away.

c. Trenching rate

For the prevalent soil conditions across the offshore development area for the proposed development, the trenching rate has been estimated to be 300 m/hr using a jetting type tool.

d. Trenching scenarios

The fate of fine sediments disturbed by cable trenching with a jetting tool is investigated in two model scenarios:

- Inter-array cable trenching in the array area; and
- Export cable installation.

For each location, a section of the cable trench is selected where the content of fine sediments is expected to be greatest and therefore leads to the highest concentration of suspended sediment in associated sediment plumes. In comparison, all other sections of cables with a lower content of fine sediment are considered to develop a weaker concentration of suspended sediments.

e. Array area scenario

Based on the indicative array layouts, and available sediment information from the geophysical survey (Fugro, 2022) and benthic survey (Natural Power, 2022), trenching in the north-eastern part of the array area is likely to encounter the highest proportion of fine sediments with the potential to form a sediment plume, as established by grab sample #5 from the benthic survey. Accordingly, the array area cable trenching scenario applies a 1.9 km section of inter-array cables for this location, running between WTG-T47 to WTG-T-43 (Figure 1). This length of inter-array trenching is expected to take around 6.5 hours to complete.

The particle size analysis (PSA) of grab sample #5 establishes local surficial sediment as very poorly sorted “sandy Mud” with 100% of material considered to be fine sediments (fine sand, very fine sand, coarse silts and medium silts). This sediment classification is also consistent with the interpretation from the geophysical survey (Fugro, 2022) which maps “sandy Mud” across the majority of the array area. The equivalent wet bulk density for this sediment is assessed to be around 1.8 g/cm^3 (Coughlan, et al., 2023) which is estimated to be around 1.4 g/cm^3 for an equivalent dry density.

Table 7 provides a breakdown of the mass input for the various categories of fine sediment based on the worst-case trenching option. These quantities are applied to the far-field modelling of sediment plumes for this location. The estimated time for different particle sizes to fall out of suspension from a height of 3 m above the seabed is also provided, indicating that the smallest particles (medium silt and smaller) may take over two hours to fully settle out (in still water conditions).

Table 7. Mass input of fine sediments from inter-array jetting between WTG-T47 to T43

Sediment type	Size range (mm)	Time to fall out of suspension (s)	% Contribution in Sample	Mass input (tonnes/s)
Fine sand	0.125 to 0.250	167	5.6	0.0020
Very fine sand	0.063 to 0.125	600	18.8	0.0066
coarse silt	0.031 to 0.063	2,143	18.6	0.0065
medium silt / muds	< 0.0031	10,000	56.9	0.0199

The consequence of sediment plumes developed from cable installation in the array area has been assessed with suitable modelling tools as impact pathway C-03 and discussed in Appendix 10.2.

f. ECC scenario

Along the ECC there will be two export cables laid in parallel with trenches separated by around 50 m. Each export cable is 18 km in length for both Project Options and is expected to be laid in sequence by a single cable laying vessel.

The area considered to have the highest content of fine sediments along the ECC is where the geophysical survey (N-Sea, 2023) interprets a region of muddy Sand (clayey Sand) immediately seaward of the shallow sand ridge emanating to the north-west of Rockabill (Figure 4). This location is also to the north of the Rockabill Special Protection Area (SPA) and Rockabill to Dalkey Island Special Area of Conservation (SAC).

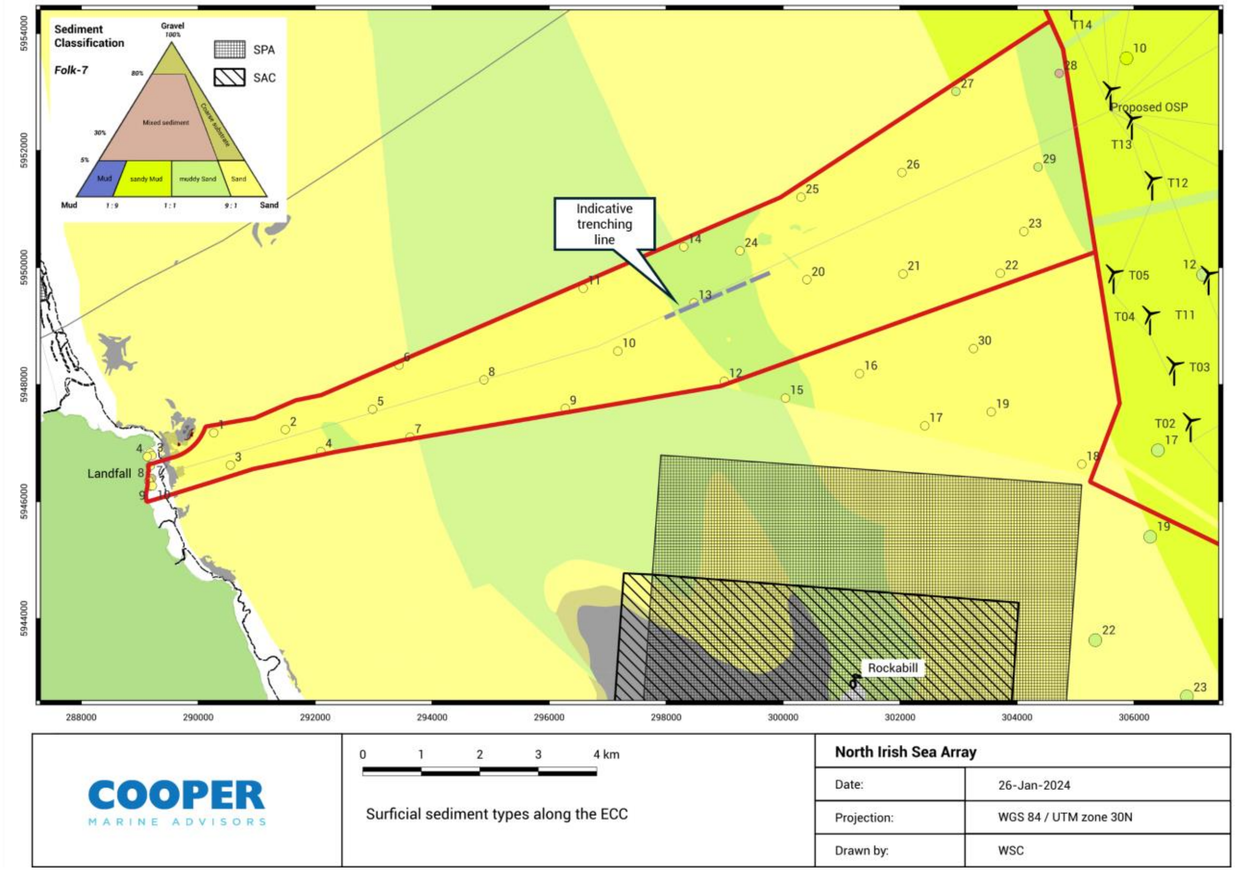

Figure 4. Surficial sediment types along the ECC

The distance for the indicative export cable alignment to cross the area of 'muddy Sand' is estimated to be at least 1.47 km. To note, the interpretation of seabed sediments provided by INFOMAR suggests the area of muddy Sand could be much wider and also extend further to the west.

Grab sample #13 from the ECC benthic survey (Natural Power, 2023) provides the basis for quantifying particle size distributions in the area expected to have the highest amount of fine sediments along the export cable route. For reference, the sediment samples in this area are generally characterised as 'Sand' according to Folk-7, with samples #10 (landward) and #20 (seaward) along the indicative alignment indicating a slightly lower amount of fine sediment in comparison to sample #13.

Given the potential uncertainty in the width of the 'muddy Sand', a length of 1.9 km has been conservatively selected (which also provides equivalence with the length and volume of sediment released in the trenching scenario in the array area) with a trenching rate of up to 300 m/hr. This distance is expected to be completed within a period of around six hours with a continuous release of fine sediments. The starting point for the ECC trenching scenario is 299,740 E, 5,949,895 N extending to 298,010 E, 5,949,156 N (Figure 4).

Table 8 provides details of the mass input for the various categories of fine sediment for the ECC trenching scenario. The estimated time for different particle sizes to fall out of suspension from a height of 3 m above the seabed is also provided indicating that the smallest particles (medium silt and smaller) may take over two hours to fully settle out.

Table 8. Mass input of fine sediments from ECC trenching across 'muddy Sand'

Sediment type	Size range (mm)	Time to fall out of suspension (s)	% Contribution	Mass input (tonnes/s)
Fine sand	0.125 to 0.250	167	67.2	0.0235
Very fine sand	0.063 to 0.125	600	20.1	0.0070
coarse silt	0.031 to 0.063	2,143	2.1	0.0007
medium silt / muds	< 0.0031	10,000	2.1	0.0007

Given that there are two export cables to be laid in parallel, then trenching for the second cable is expected to replicate the same effects as laying the first cable although for a subsequent period. For fine sediments there will be separate phases of sediment plumes in the short-term from each period of cable trenching but a combined effect for sediment deposition in the long-term.

The consequence of sediment plumes developed from cable installation along the ECC has been assessed with suitable modelling tools as impact pathway C-04 and discussed in Appendix 10.2.

4.2.4. Horizontal direction drilling

Whilst HDD is generally considered a more environmentally acceptable option in comparison to open cut trenching across the intertidal, there are still expected to be localised and short-term effects due to:

- Excavation and backfilling of nearshore exit pits, and
- Potential release of bentonite during punch-out from nearshore exit pits.

a. Exit pits

There are two sub-tidal locations being investigated for nearshore exit pits, with separate pits for each circuit, side-by-side (minimum separation of 20 m, maximum of 200 m). The approximate locations for the nearshore exit pits are presented below with the final location being determined following detailed site investigation surveys:

- Northern location is around 178 m from the low water mark (LWM) in a water depth of around 2 m below LAT.
- Central location is around 625 m from LWM in a water depth of around 4 m below LAT.

The HDD exit pit option which is likely to encounter the largest quantity of fine sediment is considered to be the central location which is also furthest offshore. In contrast, the northern location is slightly closer to shore and in shallower water, a site which is likely to be under a greater influence of wave-driven currents leading to comparatively coarser sediment distributions. The geophysical survey of the ECC interprets surficial sediments in this area as ‘Sand’ (N-Sea, 2023) with the particle size analysis of grab sample #3 from the ECC benthic survey (Volume 9, Appendix 12.1: Array Area Benthic Survey Report) indicating 91.9% of the excavated material will be fine sediments and the remaining 8.1% being coarse sediment. Overall, the grab sample is also classified as ‘Sand’.

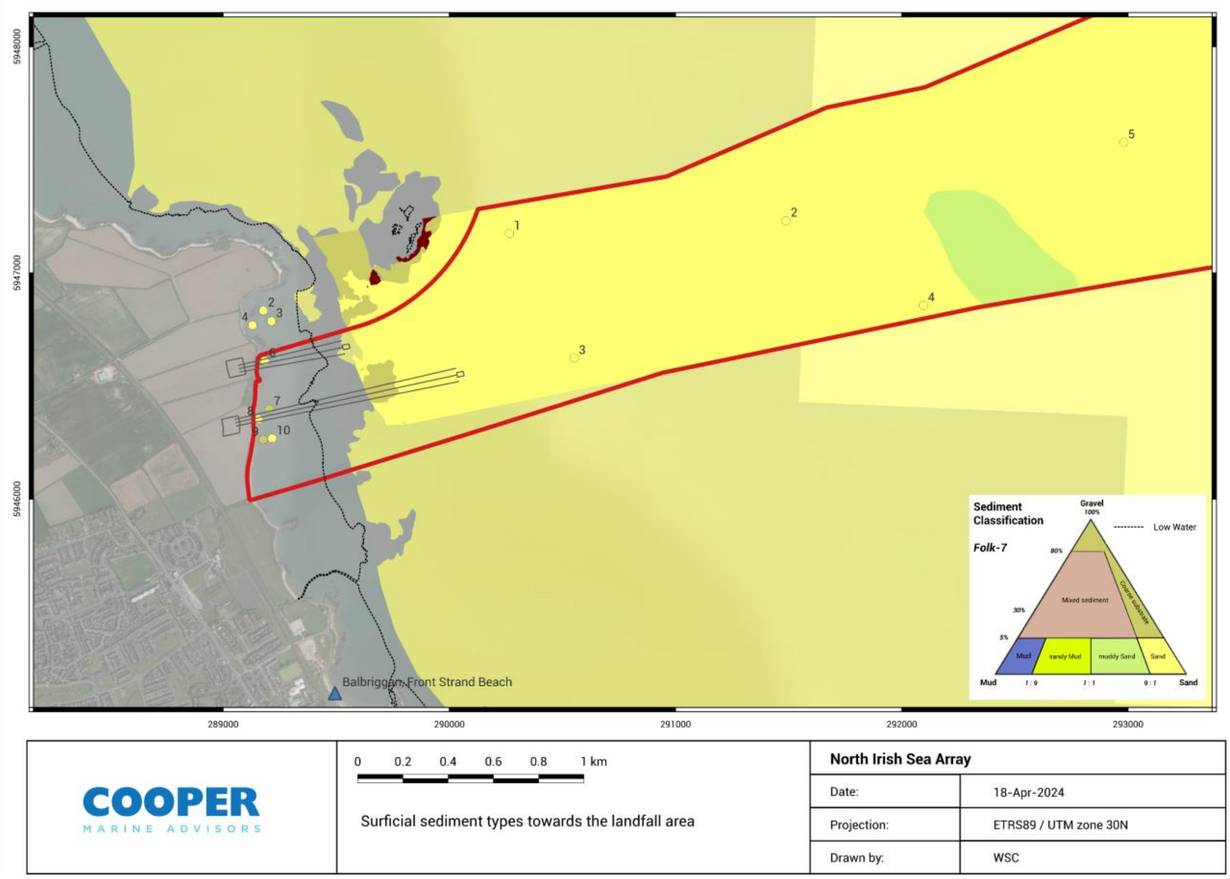

Figure 5. Surficial sediment types towards the landfall area

The exit pits will be at least 20 m wide and 30 m long, orientated broadly perpendicular to the adjacent coastline. Each pit will be 2.5 m deep at the seaward end reducing to 1.5 m at the landward end. The equivalent volume of each exit pit is at least 1,200 m^3, up to a maximum of 1,440 m^3. In addition to exit pits, there will be a transition zone which is at least 6 m wide and 50 m long, excavated to a depth of 1.5 m to develop an equivalent volume of at least 450 m^3, up to a maximum of 540 m^3. The maximum volume of excavation for two exit pits, along with associated transition zones, is up to 3,960 m^3.

The planned method of excavation is either dredging with a backhoe from a barge, or using a MFE. The two exit pits and associated transition zones are expected to take around 24 hours to complete with a single backhoe working sequentially. A one-hour period is assumed between completing the first exit pit and commencing excavation of the second pit.

The dredging method would aim to cast the removed spoil to the side of the exit pit with this material intended to be available for backfilling the exit pit once the nearshore cable pulling operation is complete. The estimated scale of any spoil mound is an area of around 960 m^2 for each exit pit, assuming an average height of 1.5 m. There is a potential for some of the fine material to disperse away during the mechanical dredging and backfilling process as well as some winnowing of fines from the spoil mound by the action of waves and tides during the intervening period. This period is likely to remain short-term but no more than a few months.

In contrast to dredging, the MFE option needs to sufficiently fluidise sediments to clear out the exit pit. The fluidised finer sediments, which settle slowest, will become susceptible to wider advection and dispersion by tidal flows whereas any coarser sediments (i.e., medium sands, coarse sands, very coarse sands and gravels) will settle out quicker to either deposit close by or settle back within the exit pit. On this basis, MFE represents the excavation option likely to lead to the greatest level of seabed disturbance and the potential development of sediment plumes. Backfilling of the exit pit would make use of available spoil material close by to reinstate pre-excavation conditions as far as practicable.

Table 9 presents a breakdown of the mass input for the various categories of fine sediment based on the MFE excavation option which is considered to develop the greatest level of seabed disturbance. The time for various fractions of fine sediment to settle out from a nominal height of displacement of 2.5 m above the seabed is also provided, noting the coarser sediment types would tend to fall out of suspension in around 12 to 51 seconds so would not be subject to wider dispersion in this relatively short period.

Table 9. Mass input of fine sediments from excavation of exit pits by MFE

Sediment type	Size range (mm)	Time to fall out of suspension (s)	% Contribution	Mass input (tonnes/s)
Fine sand	0.125 to 0.250	139	38.5	0.0032
Very fine sand	0.063 to 0.125	500	48.7	0.0041
coarse silt	0.031 to 0.063	1,786	2.4	0.0002
medium silt / muds	< 0.0031	8,333	2.4	0.0002

The consequence of sediment plumes developed from excavation of HDD exit pits has been assessed with suitable modelling tools as impact pathway C-05 and presented in Appendix 10.2.

b. Bentonite release

On completion of each HDD process the drill will emerge in the nearshore exit pit with the potential to release around 30 tonnes of drilling muds (e.g., bentonite slurry with a concentration of 80 kg/m^3) as a near-bed discharge, as well as coarser drill cuttings.

There is expected to be an initial near-instantaneous release of 10 tonnes of drilling muds at punch-out (estimated to last for around 200 seconds), followed by a longer period of around 24 hours during reaming and pull-back with a release of 20 tonnes of drilling muds.

The northern HDD exit pits represent the shallowest option for a marine discharge of bentonite and is also the closest option to the coastline. This option is considered to have the greatest potential to develop a likely significant effect on turbidity, albeit limited to the short-term.

When the bentonite slurry mixes with seawater some flocculation is anticipated. Based on laboratory measurements, the settling velocity for bentonite in seawater is expected to be around 0.000108 m/s (Krahl, Vowinckel, Ye, Hsu, & Manning, 2022).

The consequence of a bentonite release has been investigated with suitable modelling tools as impact pathway C-06 and discussed in Appendix 10.2.

4.3. Operation and Maintenance

4.3.1. Cable crossings

Although there are presently no pipelines and cables overlapping the proposed development area, a contingency for up to five cable crossings is included to provide flexibility in the design of the inter-array cable layout. There are no cable crossing planned for along the ECC.

Initially, a pre-lay rock berm will be laid along the first cable which has a dimension of 15 m length, 5 m, width and a height of 0.5 m. The second cable will be installed at around 90° to the pre-lay berm and will be protected by a post-lay berm covering a length of 100 m, width of 3 m, and a height of 2 m. Based on these details, each crossing will cover a seabed area of up to 360 m^2, with all five crossings covering up to 1,800 m^2.

The greatest potential effect is represented by the inclusion of all five cable crossings within the array area, although the locations are not yet known and are subject to further design iterations. Similar to the placement of cable protection, there is the potential for the development of local scour around the periphery of each cable crossing, although wave-related effects are not expected to occur due to sufficiently deep water across the array area.

4.3.2. Cable repairs

During the operation and maintenance period, export cables and inter-array cables may require repair, a process which would involve de-burial, recovery and relaying of cables. This activity is considered to be infrequent and limited to short-sections of cables up to 200 m in length on each occasion. The de-burial activity is likely to use either MFE or jetting tools to clear away sediments to expose the damaged cable. This de-burial process has the potential to develop short-term periods of sediment disturbance and associated plumes of fine sediment, where present. The scale of any sediment plume is considered to be comparable to the original cable laying process occurring during construction phase for the same location, environmental conditions, and for the same method of disturbance, however, repairs are limited to only a short section of cable on each occasion which means the period of disturbance is substantially shorter.

4.3.3. Cable protection

Cable protection (e.g., rock armour or mattresses) may be required when full cable burial is not possible during installation or when remedial repairs are needed during the operational phase to help maintain cable burial.

The notional dimensions for cable protection are a base width up to 5 m and a height of 2 m with a cross-section in the form of a trapezoid. Assuming a crest width of 1 m, this provides a vertical cross-section of 6 m^2. The typical size of rock armour cable protection material is 0.45 m.

A contingency provision of 20% of the total cable length (inter-array and export cables) is made for use of cable protection over the lifetime of the project, noting the full amount may not be needed. In addition, the locations and occasions where cable protection may be required remain unknown at this time. The greatest level of effect due to cable installation is represented by the full utilisation of the cable protection provisions over the project lifetime, however, this is also considered a highly unlikely situation. In addition, no cable protection measures are expected inshore of HDD exit pits.

For the inter-array cables, a maximum of 111 km of cables would be installed (Project Option 1). This reduces to 91 km of cables for Project Option 2. For the ECC, there is up to 36 km of export cables (two cables each 18 km in length). Table 9 summarises the maximum provisions for cable protection for the inter-array and ECC areas.

Table 10. Quantities of cable protection provisions

Location	Total length (km)	Total seabed area (m^2)	Total volume (m^3)
Inter-array – Project Option 1	22.2	111,000	133,200
Inter-array – Project Option 2	18.2	91,000	109,200
ECC	7.2	36,000	43,200

When required, the placement of cable protection will be in discrete short lengths and represent a localised change of substrate type as well as introducing a small-scale modification to the seabed profile. Depending on the rock size, local water depth, alignment relative to wave and tidal flows, and local seabed mobility conditions, there is also the potential for the development of local scour around the periphery of the cable protection in some cases. This effect is more likely towards shallower sites than deeper sites. A suitable analogy for the scale of such scour is evidenced from the geophysical surveys (Fugro, 2022 and N-Sea, 2023) where local depressions are observed around larger seabed contacts.

4.3.4. Array-scale blockage

During the operation and maintenance phase the main effects on the marine environment are expected to be related to array-scale blockage effects on waves and currents due to the presence of multiple WTG and OSP foundations, as well as associated scour protection.

An individual foundation will locally interfere with passing waves and currents (depending on its relative size, shape and solidity ratio) with a group of foundation structures having the potential to develop an array-scale blockage effect where the number and spacing of foundations is also considered. The identification of the array-scale option likely to develop the greatest level of blockage is based on a comparative assessment of the various foundation types, sizes, numbers and layouts.

a. Foundation types

There are two main types of piled foundations being considered for use by the proposed development; monopile and jacket with pin-piles. In addition, the design for the jacket foundation may be either three or four-legged. The foundation type with the largest vertical profile (effective area) to incident waves and flows is established on a comparative basis. N.B. the effective area is different to the surface area of the whole structure.

For a nominal water depth of 42 m (below LAT), taken as being representative for the array area, the 12.5 m diameter monopile option would have an effective area of 525 m^2 facing incident waves and flows.

For a three or four-legged jacket foundation option, orientated face-on to incident waves or currents, the equivalent effective area is estimated to be 666 and 491 m^2, respectively. For situations when the four-legged structure is orientated at 45° to incident waves or currents this value increases to 700 m^2. These values assume a conservative solidity ratio of 0.31 based on the indicative design.

b. Project options

Project Option 1 and Project Option 2 represent two alternative array layouts with 49 and 35 WTG, respectively. Project Option 1 will utilise monopile foundations, whereas Project Option 2 will use either monopile or 3 or 4-legged jacket foundations. For both project options, all foundations will be located in the same array area of 88.5 km^2. Each project option also includes a single OSP location with each respective layout.

The aggregate effective area represents the total vertical profile of all structures in the array area which has the potential to interrupt and block incident waves and flows at the array scale. A relative comparison between foundation types and project options is presented in Table 11 as the basis for determining the greatest potential of array-scale blockage affect. Values for the four-legged jacket relate to a 45° angle to incident waves or currents to develop the maximum effective area for this option, noting this would not occur all of the time.

Table 11. Aggregate effective blockage area (m^2) of foundation structures and project options

Project Option	**Project Option 1**	**Project Option 2**	
Number of WTG foundations	49	35	
Foundation type	Monopiles	Monopiles	4-legged Jackets
Effective area of all WTG	25,725	18,375	24,502
Number of OSP foundations	2	2	1
Effective area of OSP	1,050	1,050	700
Effective area – Array Total	**26,775**	19,425	25,552

According to Table 11, Project Option 1 presents the largest overall effective area compared with Project Option 2, noting that the 4-legged jacket foundation option for Project Option 2 has a fairly comparable blockage value, but only when this structure is assumed to be orientated at 45° to incident waves and flows (maximum width).

An additional consideration for array-scale blockage effects on waves is the direction of approaching waves relative to the alignment of WTG across the array. The annual wave rose within the array area provides a basis for considering relevant wave directions (Figure 6).

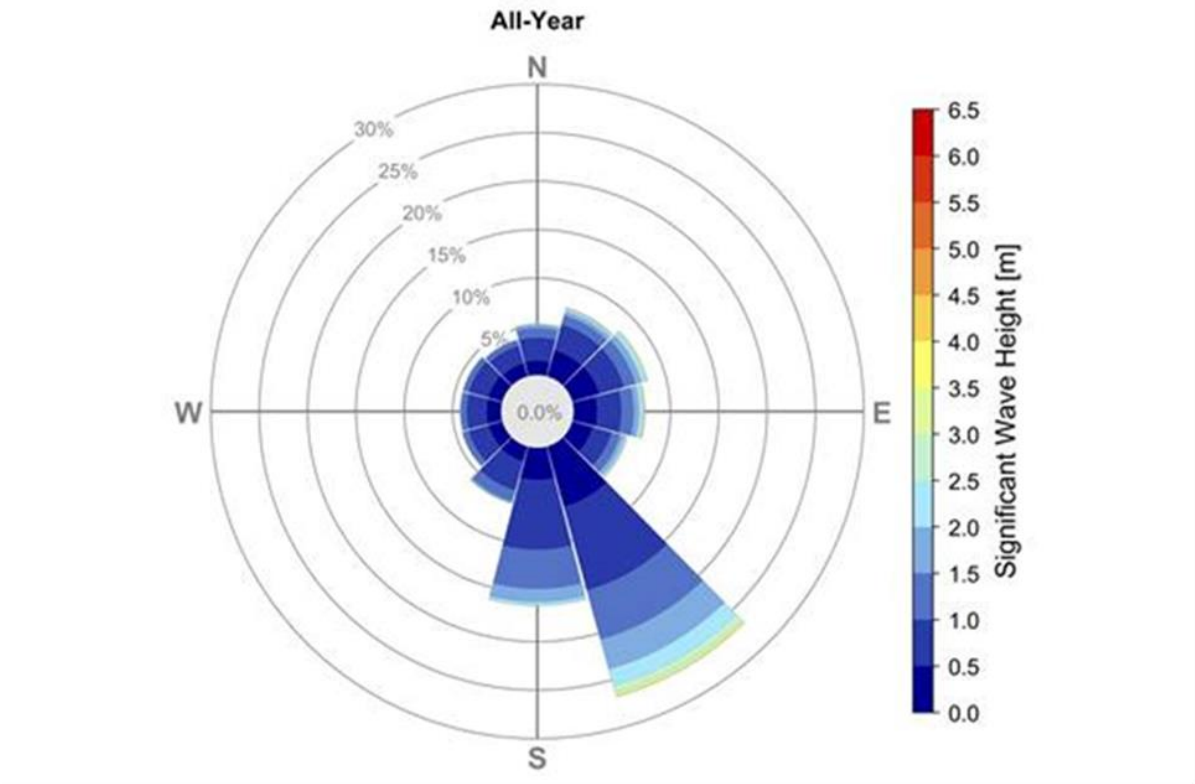

Figure 6. Annual wave rose within array area (MetOceanWorks, 2020)

The prevailing wave direction of 150° N (± 15°) appears to be aligned with the long axis of WTG across the array area, whereas waves from 060°N (± 15°) appear to be aligned with the short axis. Waves approaching from this direction also have the shortest distance to reach the adjacent coastline. These two wave directions are considered most relevant and are the focus of the wave blockage modelling assessment.

The consequence of array-scale blockage effects on waves has been assessed with suitable modelling tools as impact pathway O-01, with the consequence of blockage on flows investigated as impact pathway O-02. The modelling of these impact pathways are discussed in Appendix 10.2.

4.3.5. Scour protection

Rock, concrete mattresses or sand and gravel bags may be placed around the perimeter of foundations to protect structures from loss of seabed levels due to local scouring produced by accelerated currents around the structures. The geophysical evidence identifies local scour already exists in a few locations across the array area (Fugro, 2022) and along the ECC , where there are local seabed obstructions to currents, although not all obstructions may develop local scour. For example, the wreck of the SS Downshire in the southern part of the array area (present since 1915) is detected as a local height anomaly on the seabed with no distinctive local scour observed.

The largest seabed coverage of scour protection material around a foundation is where an initial filter layer (0.75 m high) is installed which is then covered with an armour layer (1 m high) providing a total height of

1.75 m. Typically, the size of rocks in the filter layer are smaller than those in the armour layer, with the filter layer extending slightly beyond the armour layer to grade down to the surrounding seabed sediments. This configuration is likely to lead to less cases of edge-related scour than a shorter width of an armour layer of larger rocks abruptly ending on the seabed. Depending on the rock size, height and width of scour protection, local water depth, wave, tidal and seabed mobility conditions then there is also the potential for the development of edge scour around the periphery of the scour protection.

Table 12 provides a summary of the areas covered with scour protection around each foundation type and the total for each array option.

Table 12. Summary of scour protection areas

Project Option	Project Option 1	Project Option 2	
Number of WTG foundations	49	35	
Foundation type	Monopiles	Monopiles	4-legged Jackets
Width of scour protection (m)	21.75	21.75	39
Scour protection area per WTG (m^2)	2,362	2,362	4,657
Scour protection area all WTG (m^2)	115,754	82,682	162,982
Scour protection area OSP ((m^2)	4,788	4,788	4,788
Total scour protection (m^2)	120,533	87,460	**167,760**

The array option plans to utilise the largest total area of scour protection on the seabed is Project Option 2 with 4-legged jacket foundations which covers an area of up to 167,760 m^2. This material would be placed around 35 WTG and a single OSP. Foundation blockage is the dominant influence on passing waves and currents with scour protection used to mitigate the effect of locally accelerated currents from scouring the local seabed. Scour protection is expected to have a secondary influence (relative to foundation structures) on waves and currents and is represented in the modelling for completeness.

4.4. Decommissioning

The general assumption is that sediment disturbance effects on the seabed during the decommissioning phase will be comparable in type, but no greater in magnitude and extent, than those which are identified to occur during the construction phase. On this basis, there is no additional modelling of sediment plumes during the decommissioning and results from the construction phase are considered instead as suitable indicator for a potential impact pathway.

If all subsea cables are removed, then there is anticipated to be a short period of sediment disturbance of comparable scale to the original cable trenching activity.

If topsides of installed WTG and OSP structures are removed, then the long-term risk remains for the buried structures to be exposed at some period in the future if areas are subject to high rates of seabed mobility which lowers the level of the seabed, however, the consequence of these exposed structures may be minimised if scour protection remains in place.

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