NORTH FALLS

Offshore Wind Farm

Further Information Regarding Seabed and Bedform Mobility, and Implications for Sand Wave Recovery after Levelling

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Glossary of Acronyms

DCO	Development Consent Order
ES	Environmental Statement
GGOW	Greater Gabbard Offshore Wind Farm
GIS	Geographic Information System
HHW	Haisborough, Hammond and Winterton
KKE	Kentish Knock East
Km	Kilometre
m	Metre
MCZ	Marine Conservation Zone
mm	Millimetre
NFOW	North Falls Offshore Wind Farm Ltd
NSIP	Nationally Significant Infrastructure Project
OCC	Offshore Cable Corridor
OECC	Offshore Export Cable Corridor
RWE	Renewables UK Swindon Limited
SAC	Special Area of Conservation
SSER	SSE Renewables Offshore Windfarm Holdings Limited

Glossary of Terminology

Array area	The offshore wind farm area, within which the wind turbine generators, array cables, platform interconnector cable, offshore substation platform(s) and/or offshore converter platform will be located.
Array cables	Cables which link the wind turbine generators with each other and the offshore substation platform(s) and/or the offshore converter platform.
Bedforms	Features on the seabed (e.g. sand waves, ripples) resulting from the movement of sediment over it.
Bedload	Sediment particles that travel near or on the bed.
Offshore cable corridor	The corridor of seabed from Array Area to the landfall within which the offshore export cables will be located.
Offshore project area	The overall area of the Array Area and the Offshore Cable Corridor.
Sand wave	Bedforms with wavelengths of 10 to 100m, with amplitudes of 1 to 10m.
Sediment transport	The movement of a mass of sediment by the forces of currents and waves.
The Applicant	North Falls Offshore Wind Farm Limited (NFOW).
The Project Or 'North Falls'	North Falls Offshore Wind Farm, including all onshore and offshore infrastructure.
Tidal current	The alternating horizontal movement of water associated with the rise and fall of the tide.

1 Introduction

1. This document provides further information in relation to marine geology, oceanography and physical processes, in response to the following comments (see Table 1.1) set out Relevant Representations (RR) of Natural England [**RR-243**].

Table 1.1 Relevant Representation comments addressed in this document

Comments addressed	Section comment is addressed
NE-16 P5 NE-21 P10 NE-84 B4 NE-98 B18 NE-102 B22 NE-106 B26	These comments have been addressed in Section 2.

2. Responses to the other comments regarding marine geology, oceanography and physical processes from Natural England (in **RR-243**) and the MMO (in **RR-216**) are provided in the following documents, respectively:

- 9.1 Applicant's Responses to Relevant Representations Received from Natural England (REP1-044); and
- 9.2 Applicant's Responses to Relevant Representations Received from Statutory Consultees and Non Prescribed Consultees (REP1-045).

2 Further Information Regarding Marine Geology, Oceanography and Physical Processes

3. This section provides further information in relation to marine geology, oceanography and physical processes, specifically seabed and bedform mobility, and implications for sand wave recovery after levelling, in response to Natural England Relevant Representations NE-16 P5, NE-21 P10, NE-84 B4, NE-98 B18, NE-102 B22, NE-106 B26. A shortened summary of each Relevant Representation including the key elements of each is provided below.

4. **NE-16 P5**:

Natural England highlights that uncertainty remains in relation to assessment conclusions regarding sediment deposition during construction, seabed mobility and erosion, and sand wave recovery. Natural England advises that further detail and updated assessments are provided by the Applicant.

5. **NE-21 P10**:

Natural England advises that a more robust assessment is needed regarding the anticipated worst-case sediment deposition parameters due to sand wave levelling/ seabed preparation activities in the vicinity of KKE MCZ.

6. **NE-84 B4**:

Natural England highlights that there is a lack of detailed information regarding bedform mobility, stability and longevity to support the predictions of sand wave recovery. Natural England advises that the anticipated location(s) of sand wave levelling should be provided and the affected bedforms should be characterised (in terms of their mobility and stability, direction of movement).

7. **NE-98 B18**:

Natural England has identified the following data gaps:

- *Up to date sediment transport pathways at the array and indication of sediment transport rates*
- *Characterisation of significant bedforms along the OECC and within/adjacent to the array.*
- *Seabed mobility/susceptibility to scour.*

8. **NE-102 B22**:

Currently there is a lack of information regarding seabed mobility and seabed erosion/deposition potential to allow us to agree with the assessment conclusions in terms of impacts to bedload transport and secondary scour due to the placement of cable protection in the array. Natural England advises that an indication should be provided of the areas where cable protection is considered necessary, if available. The seabed mobility and seabed erosion/deposition potential need to be considered and assessed. Full consideration should be given to these impacts over the course of the Project and beyond.

9. **NE-106 B26**:

More detailed information is needed to identify and characterise the bedforms likely to be affected by sand wave levelling/seabed preparation etc. Natural England advises that the anticipated location(s) where sand wave levelling is considered necessary should be provided and the bedforms likely to be affected should be characterised. Consideration should be given to their mobility, rate of change, and direction of movement.

2.1 Methodology

10. Bathymetric surveys of the Array Area and Offshore Cable Corridor (OCC) were undertaken by Fugro between May and September 2021 (Fugro, 2021a, b). These data have been compiled and interpreted in a Geographic Information System (GIS) to understand bedform geometry. The data presented here is the same data presented in the Environmental Statement (ES).

2.2 Geometry of Sand Waves

11. The North Falls Offshore Project Area contains two sand wave fields. Sand waves occur along an 8km stretch of the central part of the OCC and across the eastern part of the Array Area (Figure 2.1). Parts of these sand waves are likely to require levelling as part of the construction phase for cable and

foundation installation. The purpose of this note is to characterise the bedforms in these areas to support assessment of seabed mobility and stability, direction of movement, and the potential for sand wave recovery after they have been levelled.

12. The sand waves are divided into four fields: offshore cable corridor west; offshore cable corridor east; array south; and array north (shown in Figure 2.1 and discussed further in the sections below).

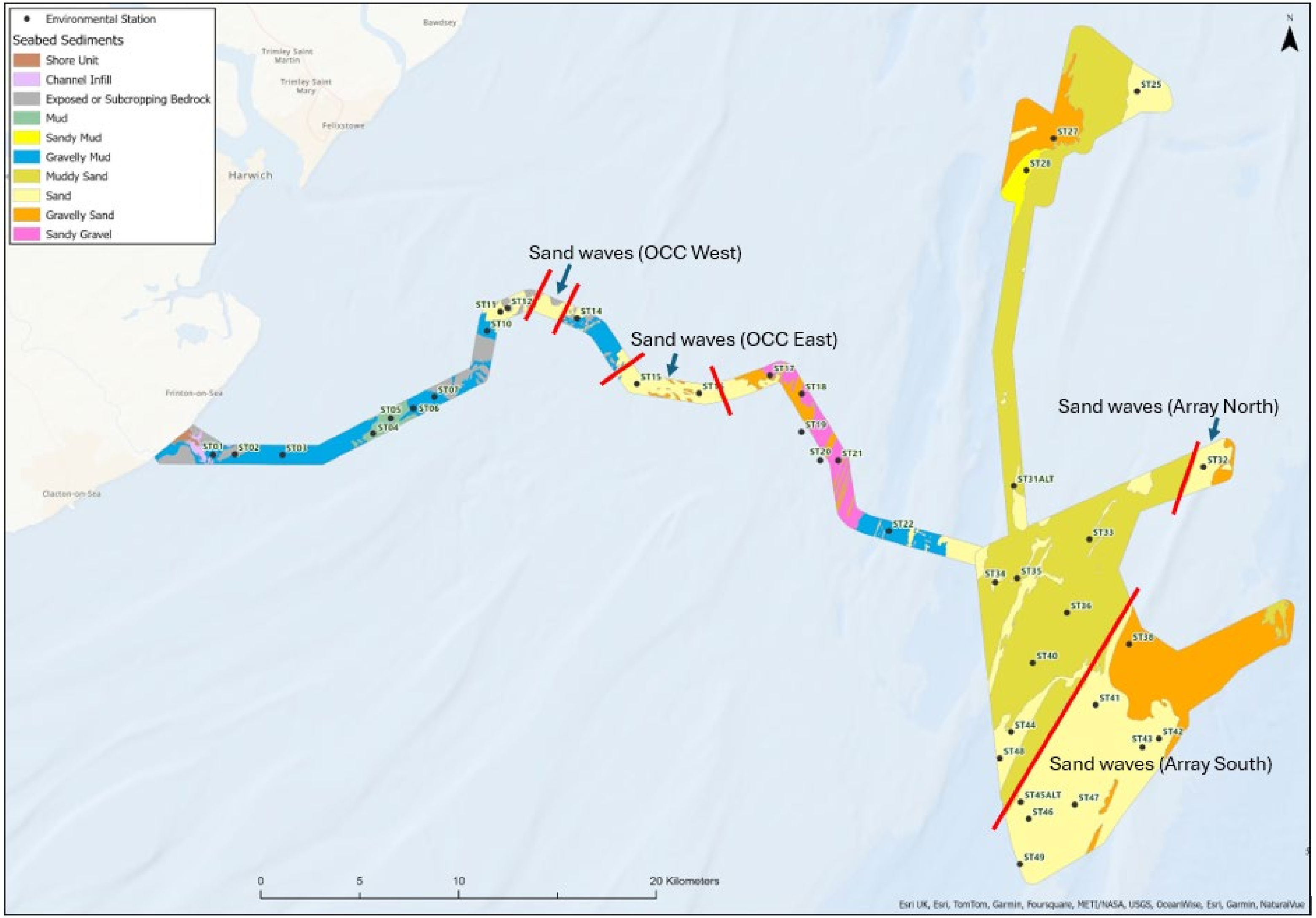

Figure 2.1 Location of sand waves in the Offshore Project Area

2.2.1 Offshore Cable Corridor West

13. The location of sand waves in the OCC (OCC West) is shown on Figure 2.2 and a single section traversing perpendicular to the crests of the sand waves is shown in Figure 2.3. They are 1-2m high with typical wavelengths of about 40m. The largest sand waves have their steeper sides facing north. The steeper sides of the sand waves typically face the direction of net migration and dominant sand transport. Hence, the asymmetry of the sand waves implies a northerly migration of the sand waves and hence a northerly movement of bedload sand, driven by the residual northerly flowing tidal currents. The large size of the bedforms indicates that they are in dynamic equilibrium with the driving physical processes and would not be prone to significant changes in geometry and direction of movement in the future (i.e. their size or migration direction is unlikely to change) and would be stable over the long-term.

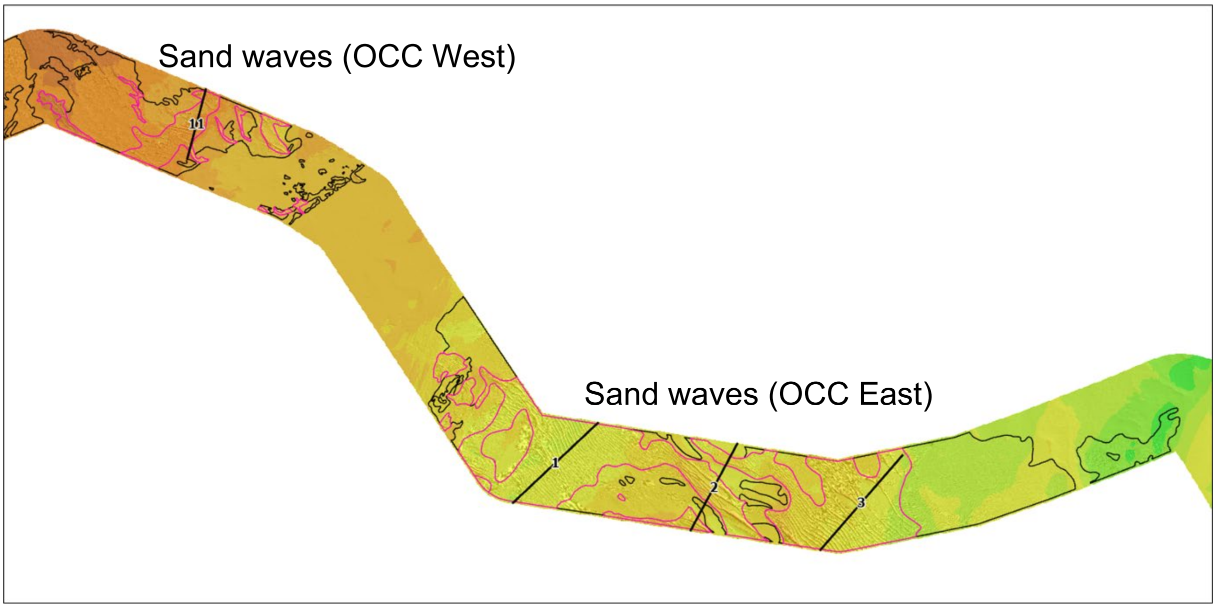

Figure 2.2 Location of sand waves along the Offshore Cable Corridor (OCC) and sections through them

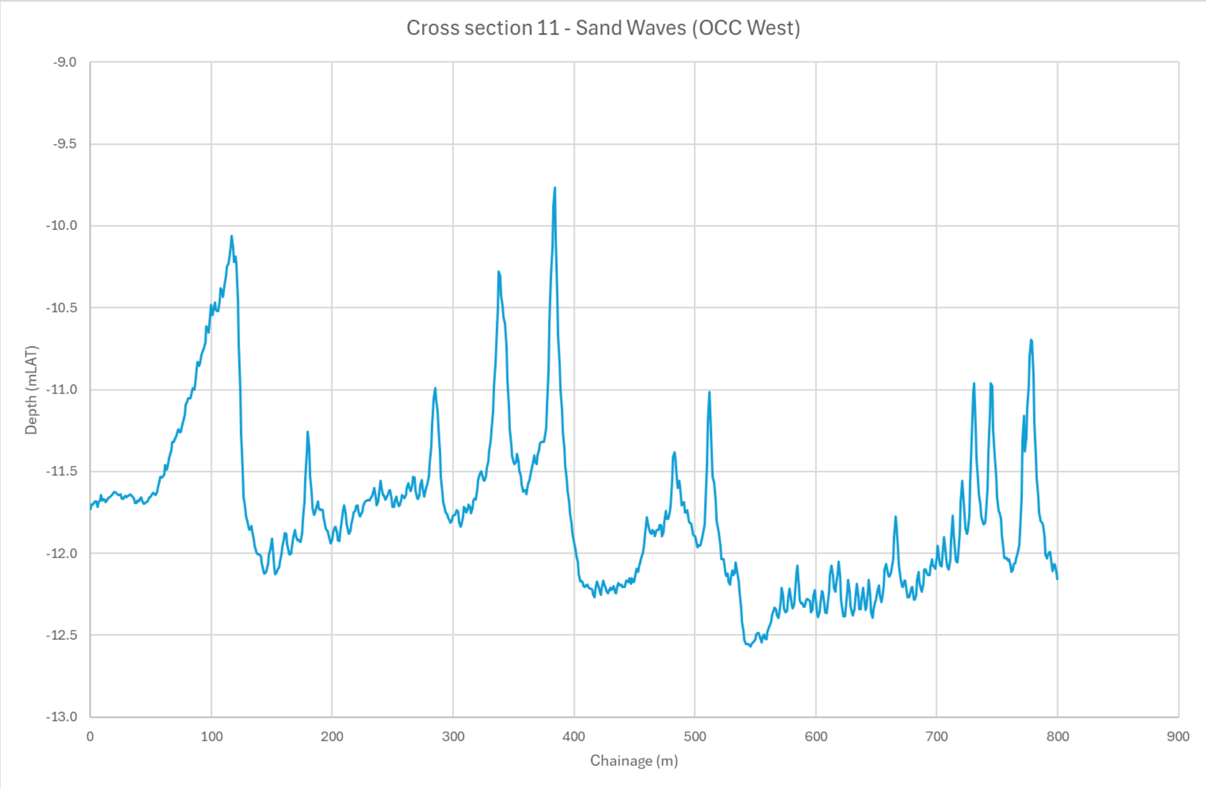

Figure 2.3 Cross-section 11 across sand waves (OCC West). South is to the left and north is to the right

2.2.2 Offshore Cable Corridor East

14. The location of sand waves (OCC East) is shown on Figure 2.1 and Figure 2.2 and three sections traversing perpendicular to the crests of the sand waves are shown in Figure 2.4, Figure 2.5 and Figure 2.6. Along Section 1, the sand waves are up to 1.7m high, but typically 0.5-1.0m high, with wavelengths of about 50m (Figure 2.4). The larger sand waves have steeper sides facing to the southwest. The steeper sides of the sand waves typically face the direction of net migration and dominant sand transport. Hence, the asymmetry of the sand waves implies a south-westerly migration of the sand waves and hence a south-westerly movement of bedload sand, driven by the residual south-westerly flowing tidal currents. This direction is opposite to those in OCC West.

15. Along Section 2, the sand waves are sparser than along Section 1, but they are significantly higher. They are up to 3.0m high, with smaller sand waves up to 1m high (Figure 2.5). Wavelengths vary from 20m to 80m depending on wave height. The largest waves face south indicating a southerly migration and sediment transport direction.

16. The sand waves along Section 3 (Figure 2.6) are between 1.5m and 3.0m high, with wavelengths between 40m and 140m. The steeper side of the sand waves faces southwest indicating a south-westerly migration and sediment transport direction.

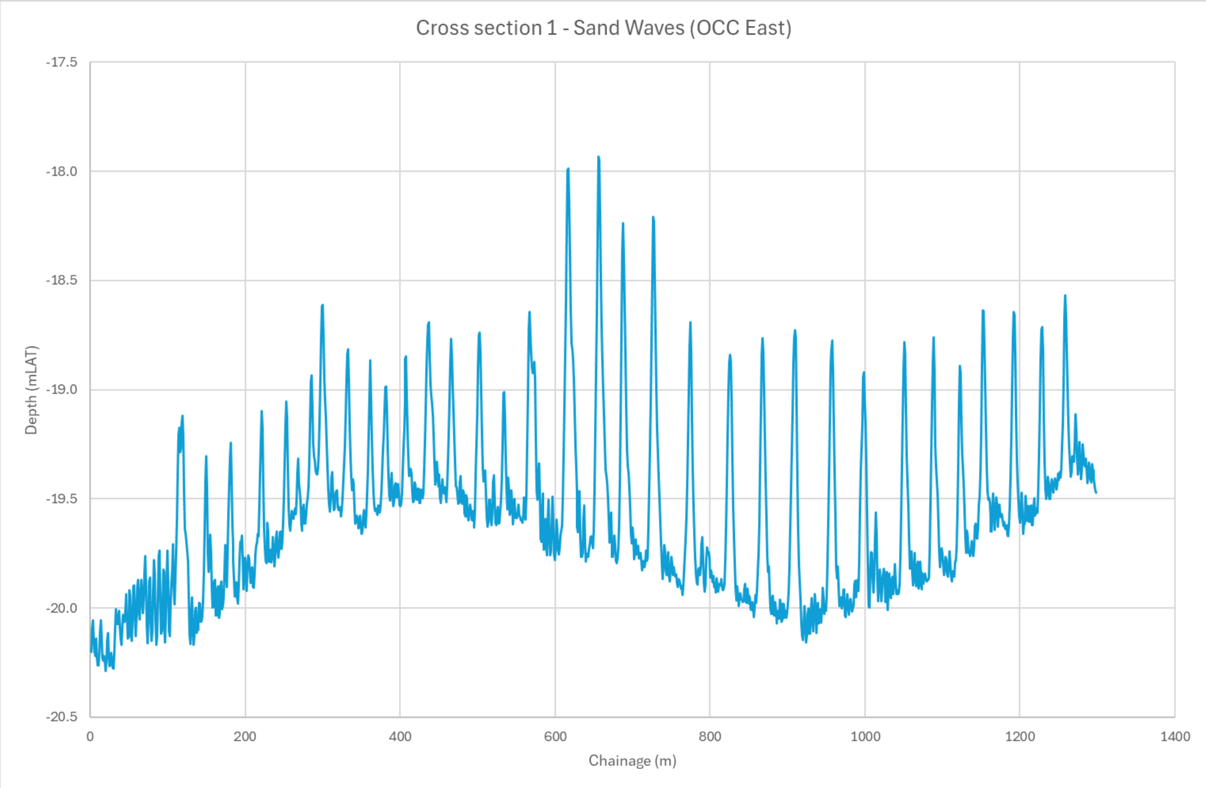

Figure 2.4 Cross-section 1 across sand waves (OCC West). Southwest is to the left and northeast is to the right

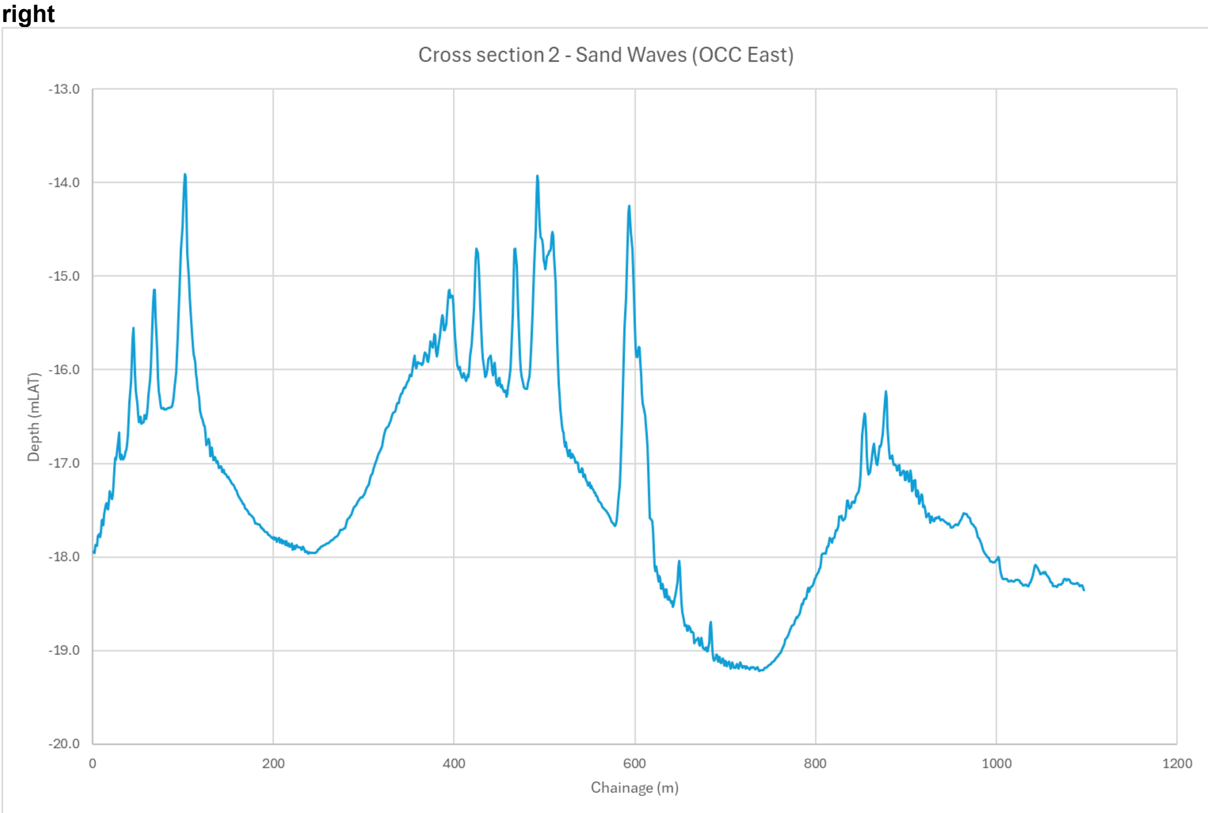

Figure 2.5 Cross-section 2 across sand waves (OCC West). South is to the left and north is to the right

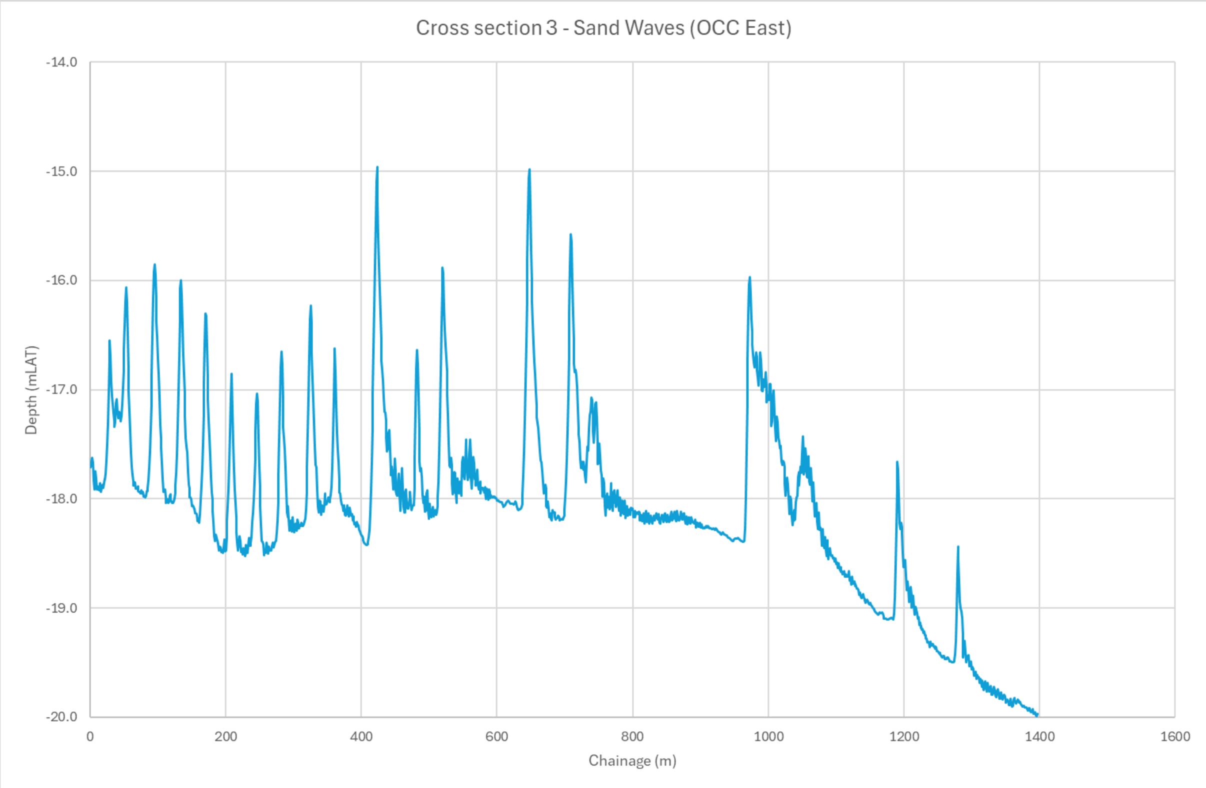

Figure 2.6 Cross-section 3 across sand waves (OCC West). Southwest is to the left and northeast is to the right

2.2.3 Array South

17. The location of sand waves (Array South) is shown on Figure 2.7 and six sections traversing perpendicular to the crests of the sand waves are shown in Figure 2.8, Figure 2.9, Figure 2.10, Figure 2.11, Figure 2.12, and Figure 2.13. The southwest part of this sand wave field in the Array Area continues outside the Array Area into Kentish Knock East (KKE) Marine Conservation Zone (MCZ).

18. Along Section 4 in the northwest of the field, the sand waves are more akin to sand ridges. The highest reach heights of 16m and wavelengths of 250m (Figure 2.8). The steeper sides face southwest indicating a south-westerly migration of the sand waves and hence a south-westerly movement of bedload sand.

19. Along Sections 5 and 6, within the central part of the field, the sand waves are up to 10m high, with smaller sand waves up to 6m high (Figure 2.9 and Figure 2.10). Wavelengths vary from 100m to 180m depending on wave height. The sand waves are predominantly symmetrical with occasional south facing and north facing ones, implying complex sediment transport pathways.

20. Sand waves along Section 7 are located along the western flank of a sand bank. Here they are mainly 4-6m high, with wavelengths of about 120m (Figure 2.11). The steeper sides of the sand waves face north indicating a northerly migration

and sediment transport direction. The sand waves are likely part of a clockwise circulation of sediment transport around the flanks of the sand bank, driven by the residual northerly directed current on its west side and the residual southerly directed current on its east side.

21. The southern end of the sand bank contains sand waves shown in Section 8 (Figure 2.12). They are 3-6m high with wavelengths of 80-130m. The steeper sides face southwest suggesting sediment transport to the southwest. This is potentially driven by the southerly flowing residual tidal current along the east flank of the sand bank.

22. Section 9 is in a south-central position across the sand wave field. Here, the sand waves are predominantly 5m high (with a few greater than 6m), with wavelengths of 120-140m (Figure 2.13). The largest sand waves have their steeper sides facing to the south, whereas the 5m high waves are approximately symmetrical.

23. The sand waves across the southern part of the array (and into KKE MCZ) are very large (3-16m high). This indicates they are in equilibrium with the tidal currents that drive their formation and movement across the seabed. They are, therefore, stable, and would not be subject to geometric change into the future and would be stable over the long-term.

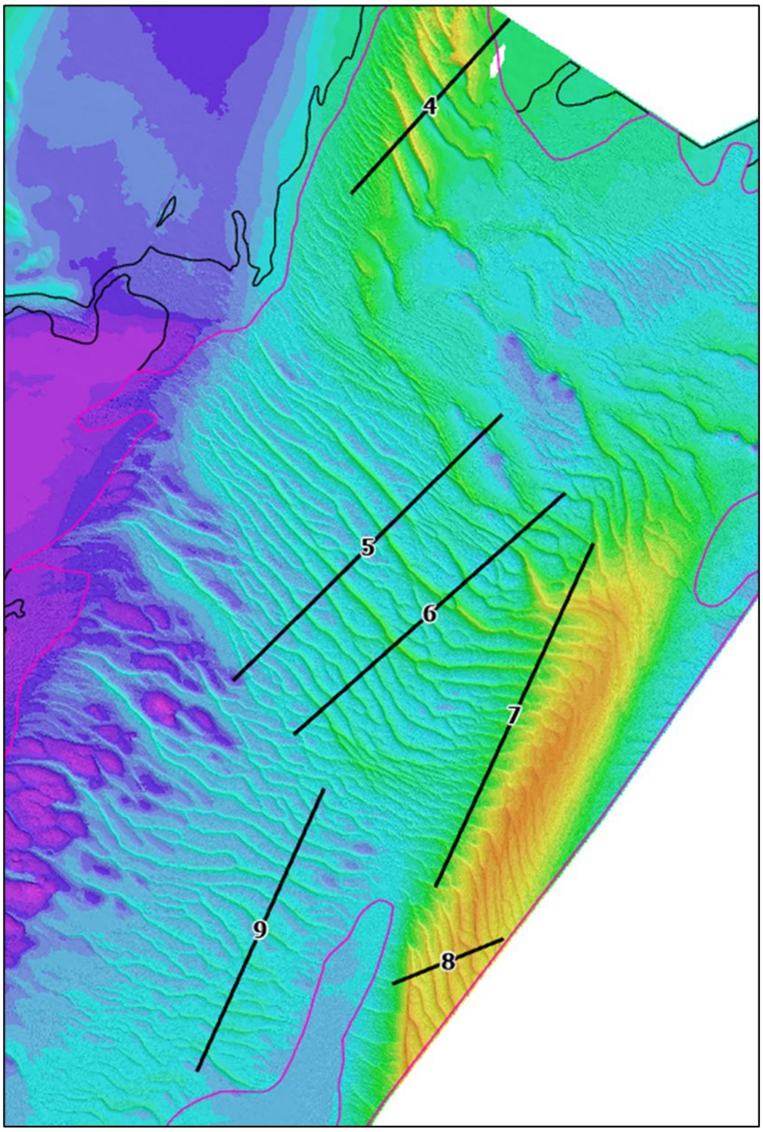

Figure 2.7 Location of sand waves in the Array Area (south) and sections through them

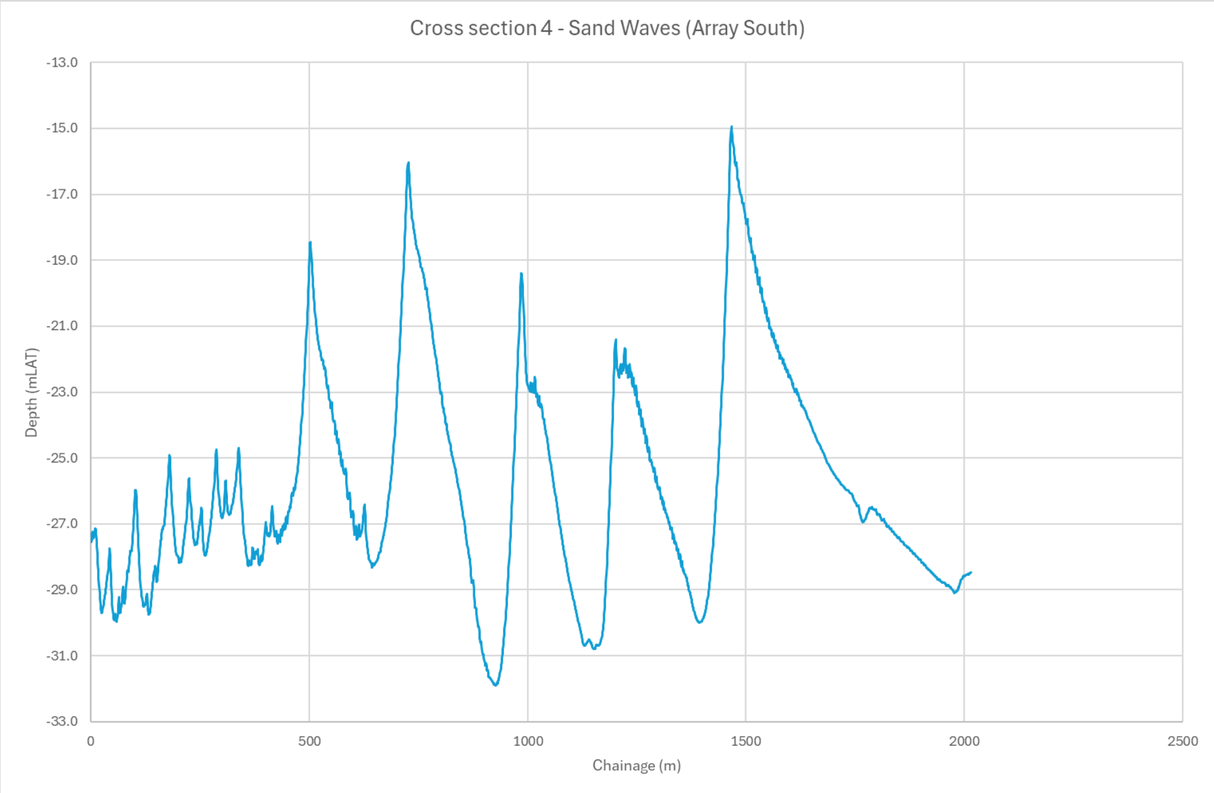

Figure 2.8 Cross-section 4 across sand waves (Array South). Southwest is to the left and northeast is to the right

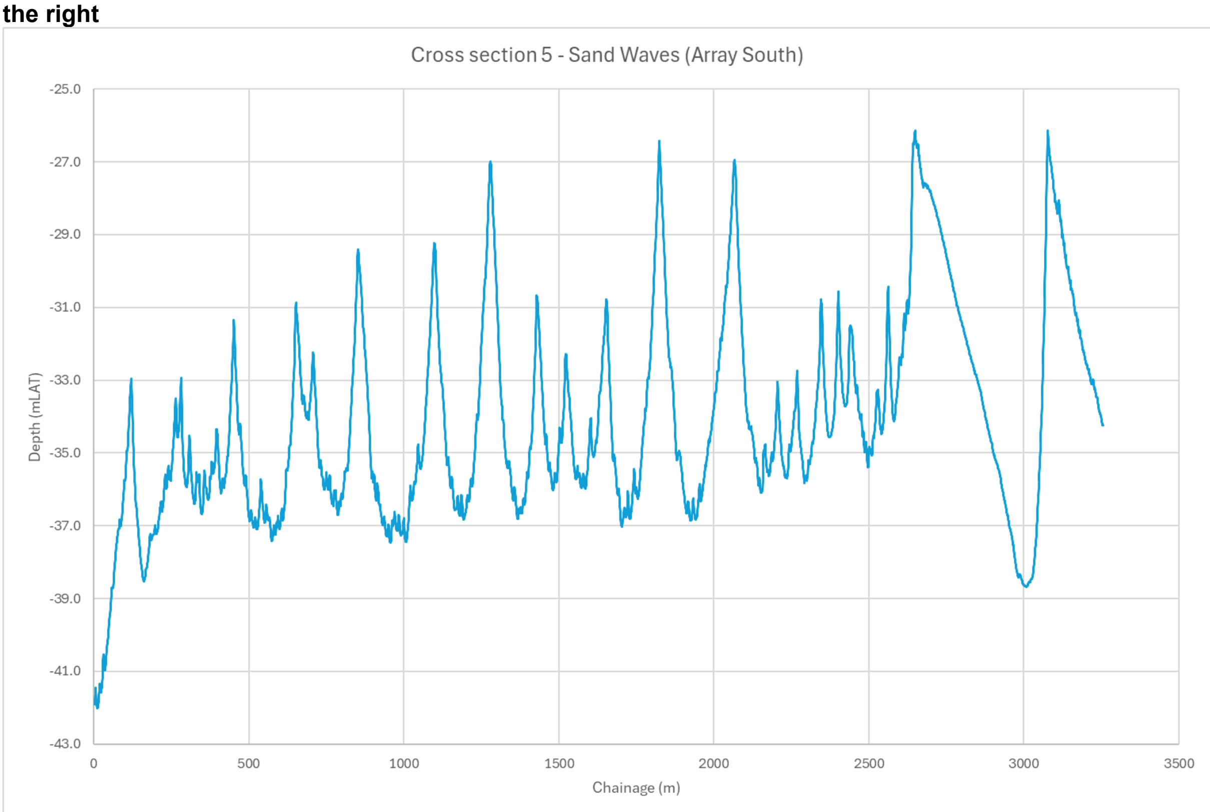

Figure 2.9 Cross-section 5 across sand waves (Array South). Southwest is to the left and northeast is to the right

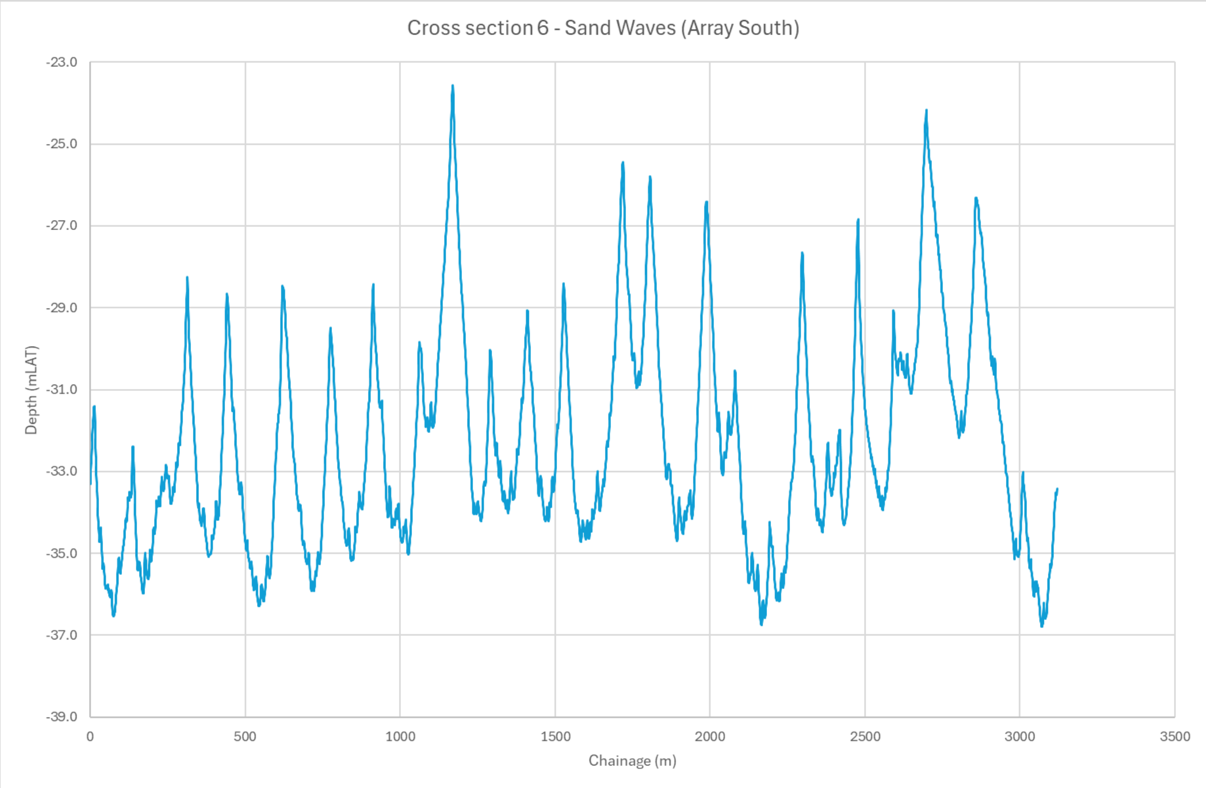

Figure 2.10 Cross-section 6 across sand waves (Array South). Southwest is to the left and northeast is to the right

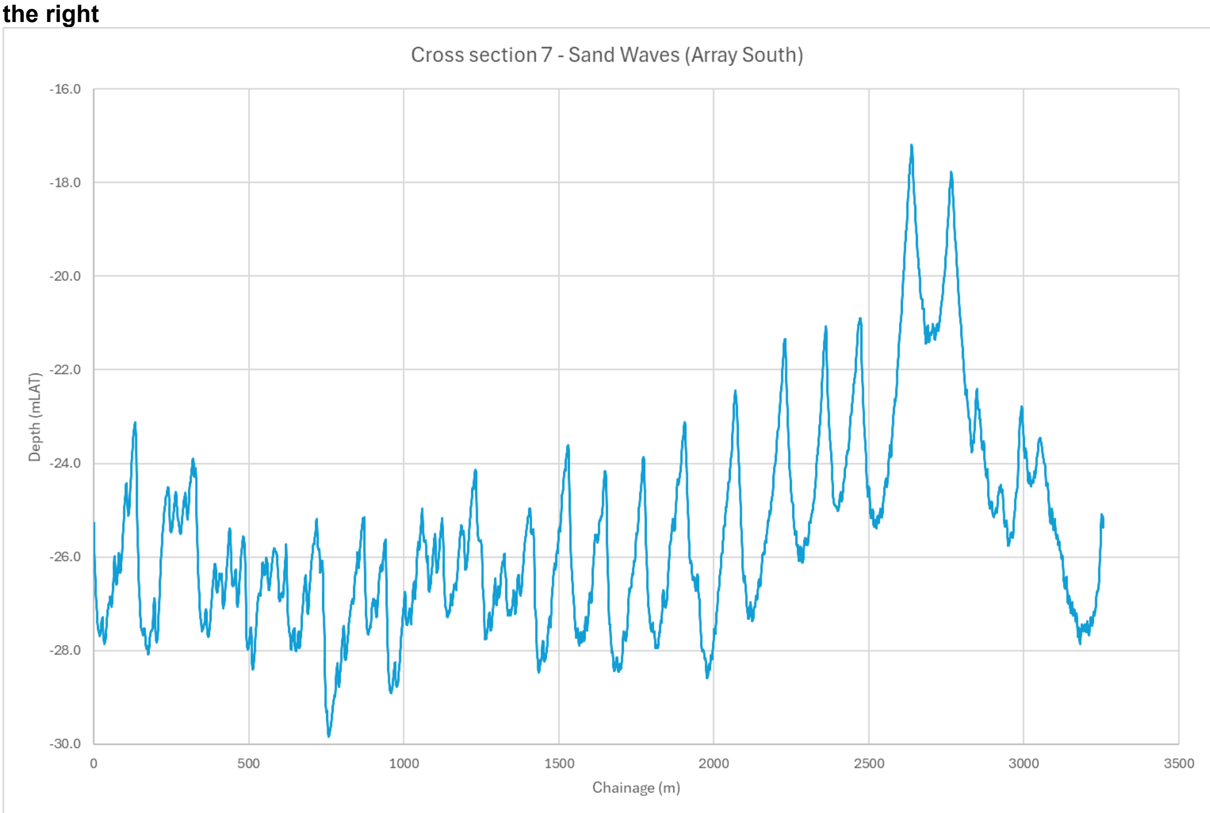

Figure 2.11 Cross-section 7 across sand waves (Array South). South is to the left and north is to the right

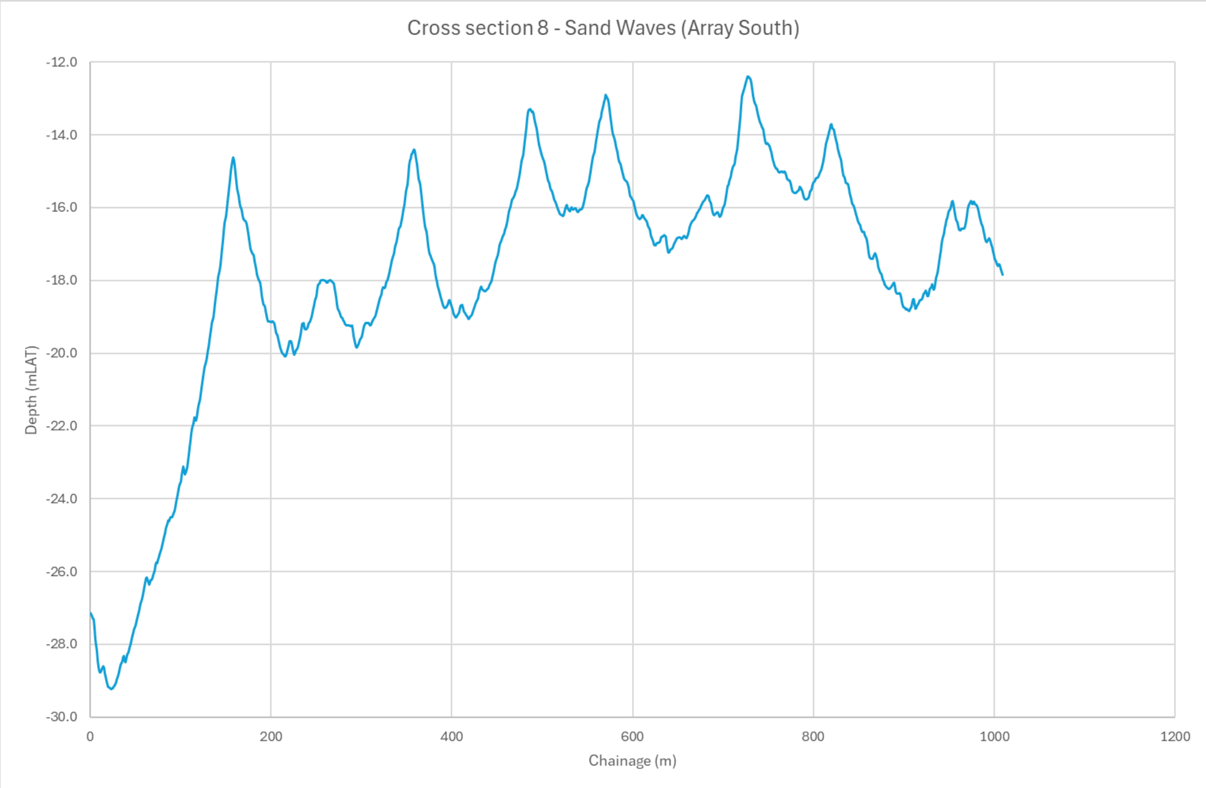

Figure 2.12 Cross-section 8 across sand waves (Array South). Southwest is to the left and northeast is to the right

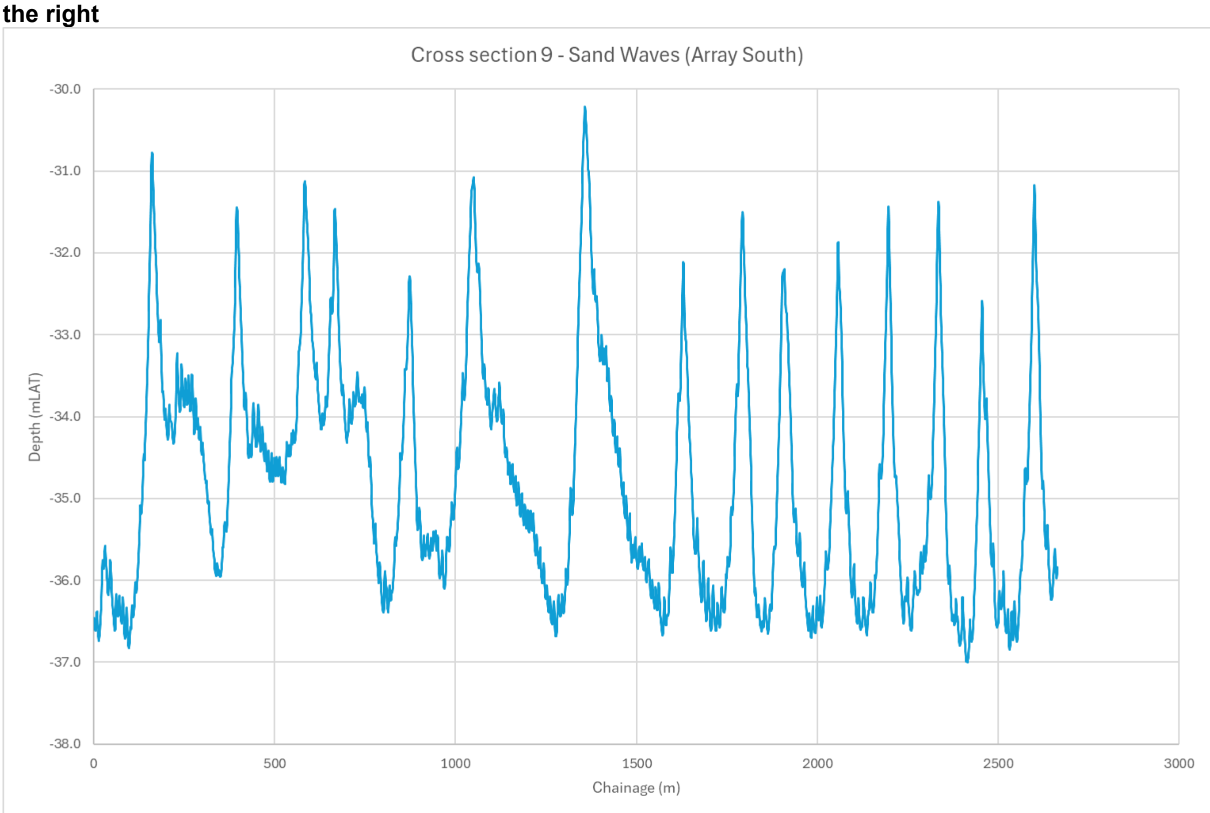

Figure 2.13 Cross-section 9 across sand waves (Array South). South is to the left and north is to the right

2.2.4 Array North

24. The location of sand waves (Array North) is shown on Figure 2.14 and a single section traversing perpendicular to the crests of the sand waves is shown in Figure 2.15. They are 5-7m high with wavelengths of 90-170m. Most of the sand waves have their steeper side facing north.

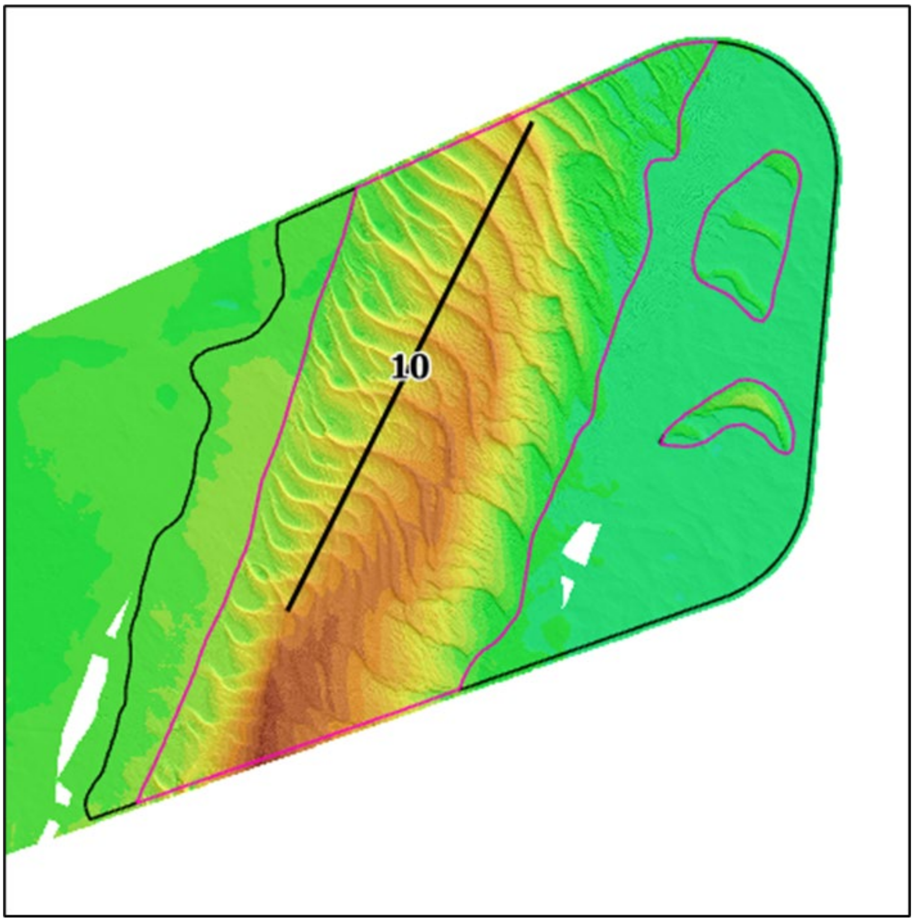

Figure 2.14 Location of sand waves in the Array Area (north) and a section through them

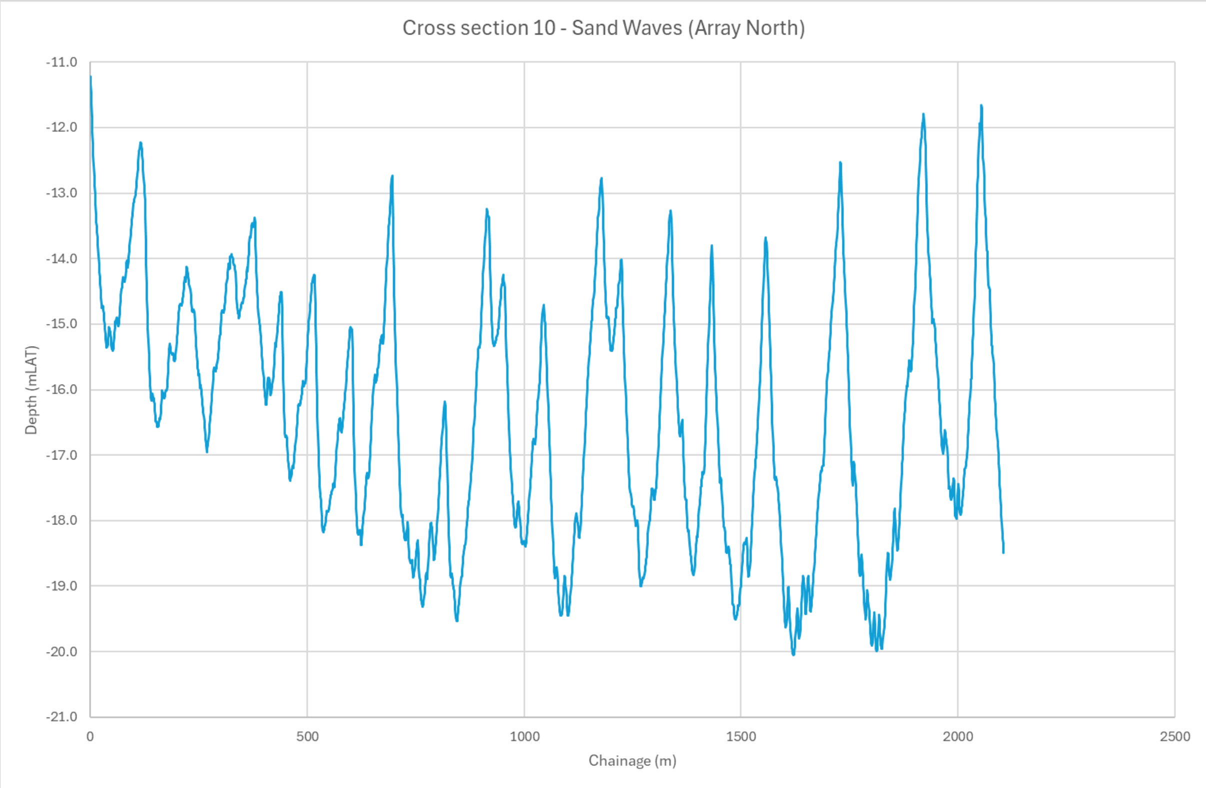

Figure 2.15 Cross-section 10 across sand waves (Array North). South is to the left and north is to the right

2.3 Particle Size

25. Particle size distributions across the sand wave fields are consistent (Figure 2.16). Fourteen seabed sediment samples show the sand waves can be classified as shown in Table 2.1. The sand waves are dominated by medium to coarse sand (87%) with a median diameter of between 0.3mm and 0.7mm.

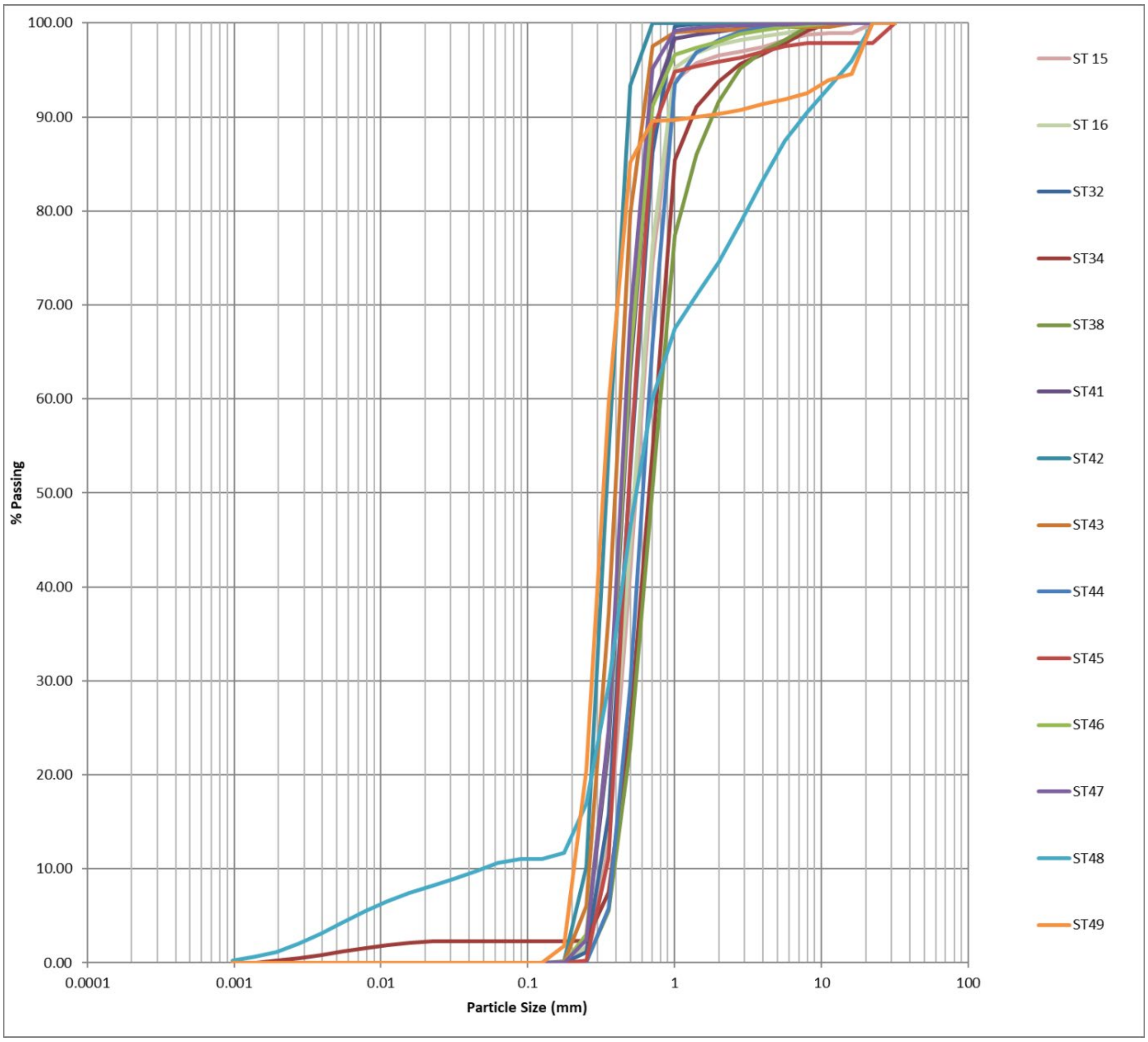

Figure 2.16 Cumulative particle size distributions of seabed sediment samples collected within the sand wave fields

Table 2.1 Sediment characteristics of the sand wave fields

Sediment type	Minimum (%)	Maximum (%)	Average (%)
Gravel (>2mm)	0.00	25.44	4.67
Very Coarse Sand (1-2mm)	0.01	14.21	3.18
Coarse Sand (0.5-1mm)	4.46	64.06	37.24
Medium Sand (0.25-0.5mm)	22.71	83.13	50.02
Fine Sand (0.125-0.25mm)	0.05	20.52	3.95
Very Fine Sand (0.063-0.125mm)	0.00	0.37	0.03
Mud	0.00	10.66	0.92

2.4 Sand Wave Recovery

26. The Applicant disagrees that removal or modification of sand waves could potentially interfere with sediment transport pathways across the North Falls Offshore Project Area due to failure of the sand waves to recover after levelling. The dynamic nature of the sand waves across the offshore project area means that any direct changes to the seabed associated with sand wave levelling are likely to recover over a short period of time due to natural sand transport pathways. Also, given the large size of the sand waves, the ability to recover quickly is improved because they are stable and have had significant longevity in the past, which would be translated into successful future recovery. Therefore, despite the disturbance to sand waves intersecting the offshore cable corridor or array area, the wider sediment transport system would remain undisturbed as new sand waves will form.

27. This assessment is supported by the findings of a review of the evidence base into the recovery of sand waves at the similarly dynamic areas of Race Bank and Haisborough, Hammond and Winterton (HHW) Special Area of Conservation (SAC) (ABPmer, 2018).

28. To install parts of the array and export cables for Race Bank Offshore Wind Farm, the crests of sand waves were reduced in elevation. Multibeam echosounder monitoring was completed pre- (2015/2016), during (2017) and post- (2018) sand wave levelling to assess the level of disturbance and the rate of natural recovery (restoration) of seabed morphology. Nine areas were chosen (seven array cables routes and two areas along the offshore cable corridors) where significant sediment mobility was expected. The results showed that along most of the nine study areas, the seabed had completely or nearly completely recovered to pre-construction levels (greater than 75% recovery of sand waves in all areas).

29. Work done by ABPmer (2018) to predict effects on HHW SAC for Norfolk Vanguard / Boreas Offshore Wind Farms provides another suitable analogy. ABPmer investigated sand wave properties (height, wavelength, asymmetry, mobility and migration characteristics) and the sediment transport potential. The results showed that the sand wave area is in an active and highly dynamic environment, governed by flow speeds, water depth and sediment supply, all of which are conducive to the development and maintenance of sandbanks. Therefore, despite the disturbance to sand waves intersecting the cable corridor, the HHW SAC sandbank system would remain undisturbed as new sand waves will continue to be formed. They concluded that the overall form and functioning of any sand wave, or the SAC sandbank system, would not be disrupted by levelling of the sand waves.

30. Similar physical and sedimentary processes apply to the areas of sand waves across the North Falls Offshore Project Area. The driving forces (tidal currents) and sediment supply regime will be like the sand waves in Race Bank and HHW SAC (as it is for all areas with sand waves). Hence, the same principles of recovery would apply. ABPmer concluded that the estimated time for the cable trenches and the seabed levelling to be naturally infilled, and for sand waves to recovery would be in the order of a few days to a year.

31. Also, they showed that the governing sediment transport processes within the HHW SAC occur at a much larger scale than the proposed bed levelling works. Therefore, these processes will not be disrupted by the localised bed levelling. The same can be said for the sand waves in the North Falls Offshore Project Area, and so there is no reason to believe that the sand waves would not recover in a similar fashion and at a similar rate, without upsetting the bigger landscape scale processes across the sand waves.

2.5 Susceptibility to Scour

32. With respect to susceptibility to scour, the sand wave areas are loaded with sediment and dynamic. The bedforms are mobile and so the seabed will rise as a crest migrates from one location to another whilst the seabed will lower (i.e. appear to scour/erode) as the trailing trough moves with the wave. This is all part of the natural process of seabed mobility.

3 References

ABPmer (2018). Norfolk Vanguard and Norfolk Boreas Export Cable Route Sandwave bed levelling.
Fugro (2021a). WPM1 Main Array Seafloor and Shallow Geological Results Report: Offshore Site Investigation, North Falls Offshore Windfarm. UK, North Sea.
Fugro (2021b). WPM2 and WPM3 ECR Seafloor and Shallow Geological Results Report. Offshore Site Investigation, North Falls Offshore Windfarm. UK, North Sea.

HARNESSING THE POWER OF NORTH SEA WIND

North Falls Offshore Wind Farm Ltd

A joint venture company owned equally by SSE Renewables and RWE.

To contact please email contact@northfallsoffshore.com