Netherlands Enterprise Agency

Ten noorden van de Waddeneilanden Wind Farm Zone

Project and Site Description, Chapter 4: Site Characterisation

January 2022

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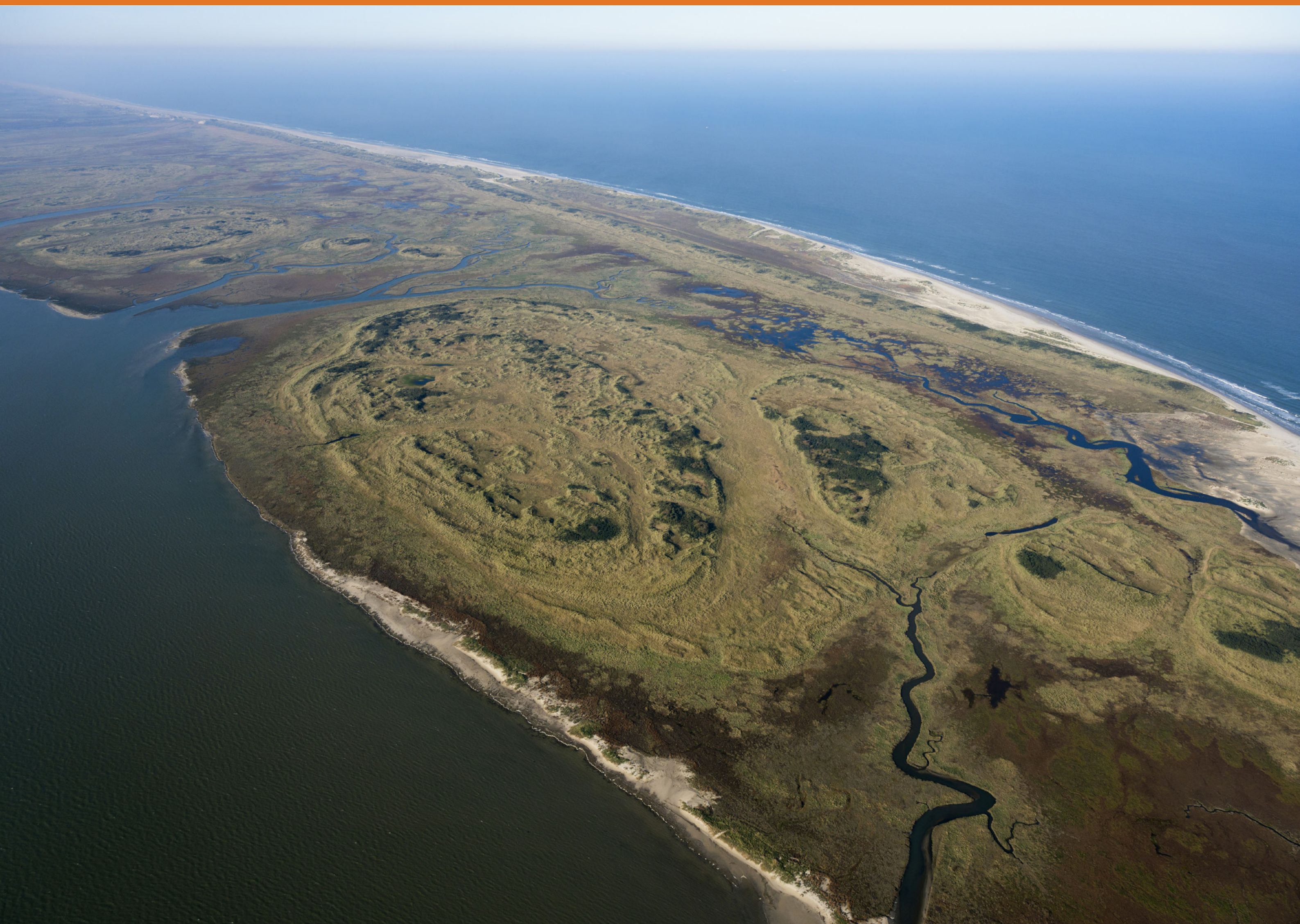

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Version January 2022

Contents

This document comprises the chapter on site characterisations only, i.e. chapter 4 in all previous Project and Site Descriptions (PSD). This is because plans for the grid connection in Ten noorden van de Waddeneilanden Wind Farm Zone (TNWWFZ) are yet to be determined. A complete and final PSD for TNWWFZ will be published in due course.

4. Site characterisation

The Netherlands Enterprise Agency (RVO) is responsible for publishing the site information companies require to prepare bids for the permit tender for the TNWWFZ. The site information package has sufficient detail and quality to be used as input for preliminary engineering design studies.

Results from previous tenders show this approach will provide the basis for an optimal tender result. In providing a more comprehensive data package, risk is significantly reduced for the developer, as is the need for conservatism in the assumptions of the tender design, while the business case for the project and the overall planning can be optimised.
In this chapter, the scope of work and results of the individual studies and investigations are summarised, covering the following:

- Obstructions: Archaeological desk study, Archaeological assessment of Geophysical survey results, UXO risk assessment desk study;
- Soil: Geological desk study, Geophysical survey, Geotechnical survey, Morphodynamical and Scour Mitigation desk study, Ground model;
- Wind and Water: Wind Resource Assessment, Metocean measurement campaign.

Figure 4.1 shows how the various studies and investigations relate to each other as well to which element of the wind farm design they feed into. The findings of the Archaeological, UXO and Geological desk studies were used to define the scope of work and basis of the Geophysical site investigation. The results of this comprehensive Geophysical site investigation refine and partly supersede those of the three earlier desk studies and further feeds into the main Archaeological assessment, the Geotechnical site investigation and the Morphodynamical study. Finally, one of the results of the soil investigation is the ground model which is accompanied by a visualization in this PSD.
This PSD includes a visualisation for the summary of the ground model.

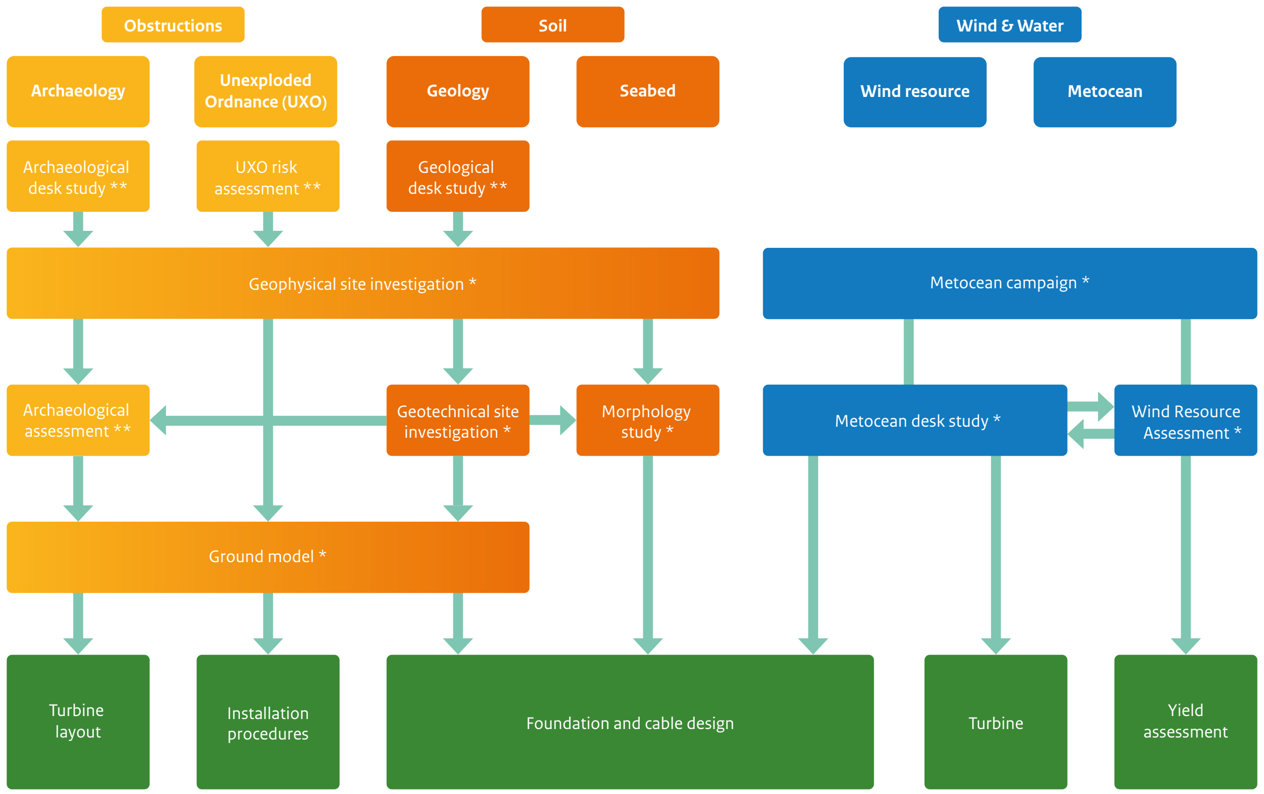

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Figure 4.1 *Site studies and investigations for Ten noorden van de Waddeneilanden Wind Farm Zone.*

4.1 Archaeological desk study

4.1.1 Overview - aims, objectives and approach

The purpose of this study was to provide insight into archaeological aspects that may have an impact on the development of the TNWWFZ. To meet this goal available geological, archaeological and historical sources have been studied, and information has been gathered on seabed disturbances induced by human activities in the past.

The main objectives of the study were to:
1. Assess whether archaeological remains (e.g. plane and ship wrecks or prehistoric remains) are (likely to be) present at the TNWWFZ;

And if present:
2. Describe the known information (location, size and dating) of these remains;
3. Assess the possible risks of the offshore wind farm development on these remains;
4. Assess options to mitigate disturbance on these remains;
5. Determine whether further archaeological assessments should be carried out and make a recommendation on the scope of future investigations;
6. Specify obligations and requirements for any activity carried out in the wind farm zone which may affect the archaeological aspects. These activities include (but are not limited to) site investigations, monitoring activities, installation activities and operational activities.

4.1.2 Supplier

Periplus Archeomare was assigned by RVO to conduct an archaeological desk study of the TNWWFZ. This company has a track record in maritime archaeological research, most notably the archaeological desk study and assessment of geophysical data for the Hollandse Kust (zuid), Hollandse Kust (noord) and Hollandse Kust (west) wind farm zones.

4.1.3 Results

According to the studied wreck databases nine known shipwrecks are present in the vicinity of the TNWWFZ (refer to figure 4.2). Apart from the known wrecks the area may contain remains of undiscovered shipwrecks or WWII aircraft.

The desk study further concludes that prehistoric landscapes and related archaeological remains may have been preserved intact. Late Paleolithic and Mesolithic camp sites and inhumations can occur in the coversand dunes and ridges (top of Wierden Member and embedded Usselo Bed), and along the valleys of small streams (Singraven Member). The covering Basal Peat Bed and Velsen Bed can contain well-preserved lost objects, intentional depots and dumps.

Remains of Neanderthal camp sites can be expected along the shores of fresh water lakes and beaches of lagoons which developed at the transition from Eemian to Weichselian. The sediments (clay and sand) are part of the Brown Bank Member.

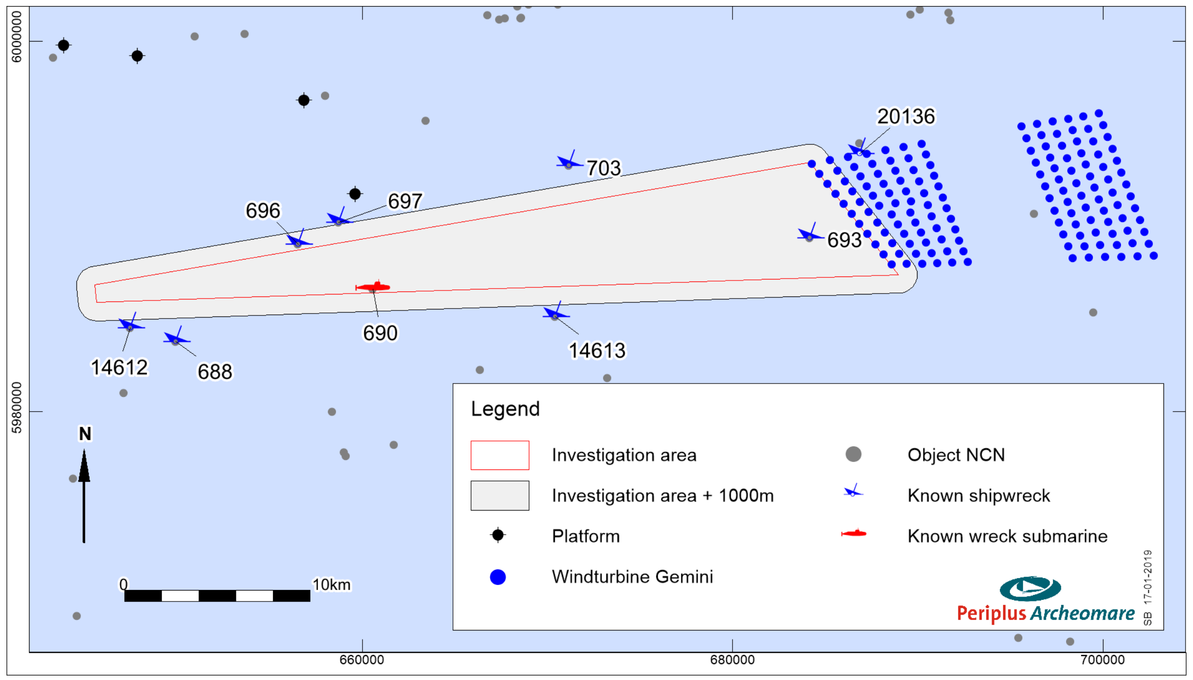

Figure 4.2 *Known objects in the TNWWFZ (source: NCN-database).*

Within peat deposits of the covering Woudenberg Formation well-preserved lost objects, intentional depots and dumps can be encountered.

Remains of Neanderthal camp sites can be expected at the moraine ridges and at the shores of melt water lakes which remained after retreat of the glaciers at the transition from Saalian to Eemian to Weichselian. The moraine ridges (boulder clay and sand) are part of the Gieten Member; the laminated lacustrine clays and sands are part of the Uitdam Member.

The archaeological desk study of the TNWWFZ indicates that nine shipwrecks are to be expected in the vicinity of the area. Two wrecks have been identified. One wreck is recent (1979) and does not represent an archaeological value. The second identified wreck is a German submarine from World War I which has an archaeological value. For the other seven wrecks, details like names, types and date of sinking are not known, nor are the exact locations. Further research is needed to determine the archaeological value of the wrecks and assess whether undiscovered shipwrecks are present.

4.1.4 Conclusions and recommendations

Within the investigated area of the wind farm zone there is a high probability for the presence of (remains of) ship wrecks and WWII aircraft.

Periplus Archeomare recommends to conduct a geophysical survey in order to:
- Map the locations of known and unknown wreck sites in detail and assess their potential archaeological value; and
- Obtain insight in the occurrence and integrity of prehistoric landscapes in order to further specify the predictive model and allocate areas where in situ prehistoric remains are to be expected.

The findings of this desk study serve as a starting point for subsequent investigations, most notably the archaeological assessment of the geophysical site investigation and, following that, an archaeological assessment of the geotechnical site investigation. The results of this desk study will to a large extent superseded by the findings of these reports.

4.1.5 Webinar

The results of the Archaeological Desk Study performed at the TNWWFZ will be presented and discussed at a webinar on February 8, 2022. Please refer to https://offshorewind.rvo.nl/cms/view/7a97c70f-38f1-4716-bc03-ce23d2c565ed/obstructions-tnw for details.

Figure 4.3 *Historical map (1777) of the investigation area and its surroundings.*

4.2 Unexploded ordnance (UXO) risk assessment desk study

4.2.1 Overview - aims, objectives, and approach

The UXO desk study, performed in Q2 of 2019, provides initial insight into the risk of encountering unexploded ordnances (UXOs). The main objectives of this study are to:

1. Identify risks and/or constraints for offshore wind farm related activities in the TNW WFZ as a result of the presence of UXOs;
2. Identify areas within the TNW WFZ where wind farm construction or cable installation should be avoided;
3. Identify requirements, from a UXO perspective, that should be taken into account for:
   - Determining the different sites in the WFZ;
   - Carrying out safe geophysical and geotechnical investigations;
   - Safe installation of wind turbine foundations;
   - Safe installation of cables.

4.2.2 Supplier

REASeuro performed the UXO desk study. The company is specialised in (offshore) UXO desk studies, risk assessments, and UXO clearance operations. Since 2012, REASeuro has been involved with several offshore projects in the North Sea, performing data analysis, project risk assessments, and coordination of UXO clearance activities. Moreover, the company has performed the UXO desk study for the Borssele and Hollandse Kust (south, west and north) Wind Farm Zones and export cable routes.

4.2.3 Results

The UXO risk assessment study consists of two sequential phases: historical research (1) and UXO risk assessment (2). The historical research delivers essential input for the risk assessment and subsequent mitigation strategies.

According to the historical research, the TNW WFZ and surrounding areas were the scene of war-related activities during World War I and World War II.

Historical research in The National Archives (London, United Kingdom) and Bundesarchiv-Militärarchiv (Freiburg, Germany) has shown that mining operations took place in and near the TNW WFZ in World War I and II (Figure 4.4), but the mines were only partially recovered after both wars. The types of mines which may be present are German moored contact mines and British contact and ground mines from both WW I and WWII. It must be taken into account that this overview is based on the minefields actually present in (the vicinity of) the TNW WFZ. Since the war, some ordnances are likely to have moved as a result of fishing, wave and current loads, and seabed dynamics. Other naval mines could be encountered, but is assessed as highly unlikely.

Furthermore, during the Allied bomber raids in World War II, a great many bombers flew towards targets in Germany or German occupied territory. In emergency situations or if finding the target failed, bomber crews often ditched remaining aerial bombs in the North Sea before returning to base. Furthermore, aerial attacks on ships, convoys and U-boats have likely left artillery shells from anti-aircraft guns and onboard aircraft cannons in the area.

Based upon this information the entire WFZ is considered an area where a UXO encounter is possible (Figure 4.4).

After the historical research was performed, the risk assessment was conducted. A UXO can be sensitive to hard jolts, change in water pressure, and accelerations with an amplitude >1m/s². Detonation can lead to serious damage to equipment and injuries to crew members. The possible presence of UXOs in the area, however, is no constraint for offshore wind farm related activities. With proper UXO risk management strategies, risks can be reduced to a level that is As Low As Reasonably Practicable (ALARP).

The main challenge in UXO risk management at TNW WFZ is the dynamic character of the seabed. This may cause UXOs that were buried during preliminary scanning to resurface and become subject to migration. Also sand dune migration may have led to burial of UXOs. Furthermore, migration of UXOs may occur as a result of waves and currents or fishing activities. The possibility of UXO migration and burial needs to be considered in all development phases and closely integrated into the UXO risk management strategy.

4.2.4 Conclusions and recommendations

Based upon the analysis of historical sources, it is evident that different war related events took place within and nearby the area of investigation. Due to these events, the entire area of investigation is considered a UXO risk area. A variety of UXO are likely to be present which includes aerial bombs, naval mines and artillery shells. The likely presence of UXO in the area, however, is not a constraint for offshore wind farm development. By applying professional UXO risk management, these risks can be reduced to a level that is considered ALARP.

Within the proposed area, there are no UXO risk free areas identified. However, since the entire WFZ is to be considered a UXO risk area and the risks posed by the presence of UXO can be sufficiently mitigated to ALARP, the entire WFZ can be selected for the installation of offshore wind farms and/or cables.

The possible effects of a detonation to vessels, equipment, personnel, and surroundings may form an intolerable risk. This means mitigation measures are required to reduce the risks to ALARP. It is recommended to investigate the possible presence of UXO by performing a UXO geophysical survey prior to any intrusive works. The mitigation measures consist of UXO survey, identification of potential UXO objects, re-routing or re-location of cables and structure if possible, and disposal of UXO items if required.

Due to the highly dynamic soil morphology and possible associated migration and burial of UXOs, it is recommended that companies conduct UXO search (and removal) operations immediately prior to construction activities at the intended construction locations. The limited temporal validity of the collected survey data should be taken into account when planning survey and construction operations. According to the risk assessment, the 250 lbs Air Dropped Bomb is deemed the smallest ferrous threat item for an ALARP sign-off. The ferrous weight of these bombs can range from 50 kg to 83 kg dependent on the make, modification, and type of munition. Assuming these items can be successfully detected and identified within the geophysical datasets, larger objects will also be detectable. Magnetometry is generally considered the most reliable and common method of UXO geophysical survey. The provisional magnetometer (MAG) threshold is set on 50 kg ferrous mass. This threshold is also sufficient to detect ferrous naval mines which are likely to be present in the area. Artillery shells of the calibres expected in the WFZ fall below the threshold level of 50 kg ferrous mass and pose a negligible risk.

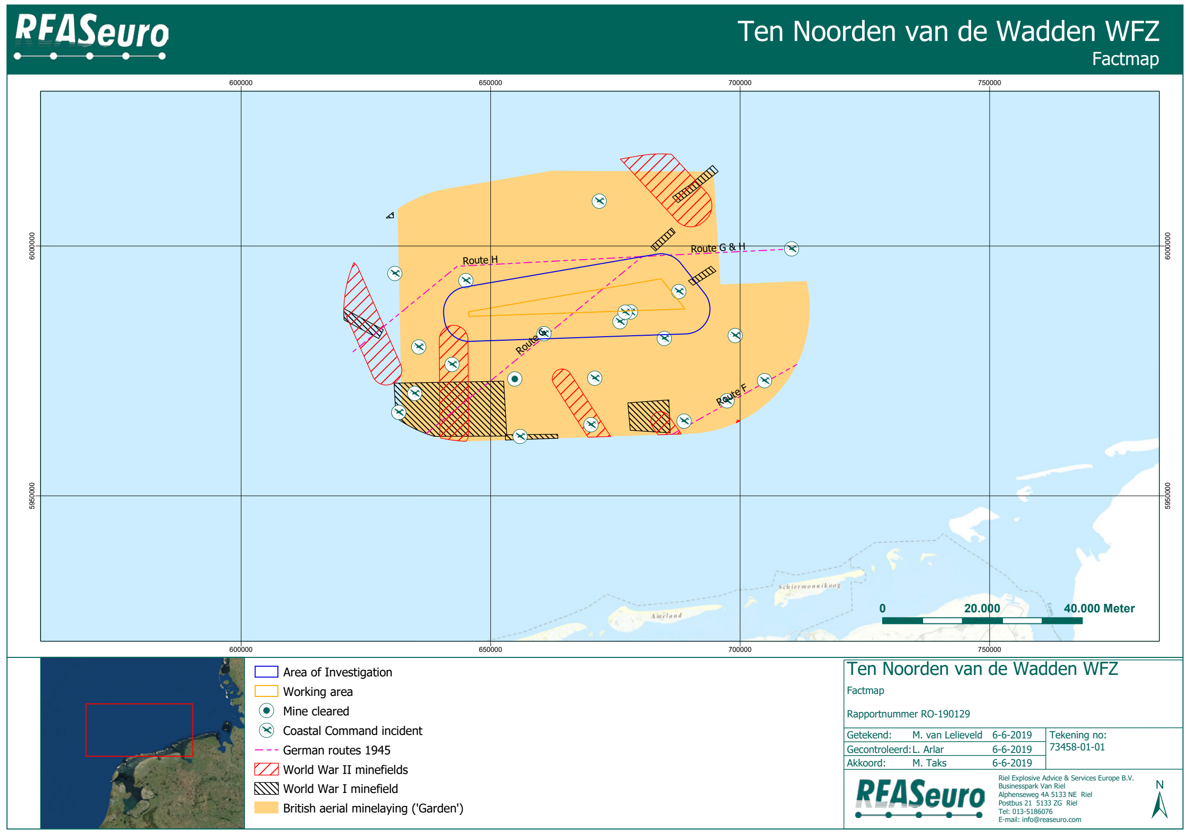

Figure 4.4 *Fact map of relevant UXO areas in the TNW WFZ.*

4.2.5 UXO removal procedure

Within the Dutch Exclusive Economic Zone (EEZ), the Netherlands Explosive Disposal Authority ("Explosieven Opruimingsdienst", EOD) is responsible for all maritime UXO disposal operations. If a wind farm developer identifies a UXO at a location where activities are planned, it needs to be removed. This should be reported to the Dutch Coastguard. The Royal Netherlands Navy will dispose of the UXO. No disposal costs will be charged to the wind farm developer.

4.2.6 Webinar

The results of the UXO Desk Study performed at the TNWWFZ will be presented and discussed at a webinar on February 15, 2022. Please refer to https://offshorewind.rvo. nl/cms/view/7a97c70f-38f1-4716-bc03-ce23d2c565ed/ obstructions-tnw for details.

4.3 Geological desk study

This study was the starting point for several other studies. However, more in-depth Geophysical and Geotechnical site investigations have since been conducted hence the desk study is not described further in this PSD.

4.4 Geophysical survey

4.4.1 Overview - aims, objectives, and approach

The geophysical site survey at the Ten noorden van de Waddeneilanden Wind Farm Zone (TNWWFZ) was designed to contribute to the bathymetric, morphological and geological understanding of the TNWWFZ by obtaining detailed seabed and sub seabed information. This information can then be used to aid geotechnical investigations and can also be integrated into a ground model used for the design and installation requirements for offshore wind farms at the site.

Specifically, the aim of the geophysical survey was to:

- Obtain an accurate bathymetric chart of the development area TNWWFZ;
- Identify or confirm the position of wrecks, pipelines, cables, and natural objects;
- Produce isopach charts showing the thickness of the main geological formations, including any mobile sediments, layers of potential archaeological significance and any other significant reflector levels which might impact on the engineering design;
- Locate and identify any structural complexities or geohazards within the shallow geological succession such as faulting, accumulations of shallow gas, peat, buried channels, structures associated with sub-glacial processes or glacio-tectonism, etc.;
- Provide detailed geological interpretation showing facies variations and structural feature changes via appropriate maps and sections;
- Provide proposed positions for a geotechnical sampling and testing programme following the completion of the geophysical survey;
- Prepare a comprehensive interpretative report on the survey results in order to assist design of the offshore foundations/structures and cable burial and assist in the preparation of the geotechnical investigation.

The geophysical site survey was carried out in two campaign phases using the survey vessel M/V Franklin. Main Geophysical and 2D UHRS site survey between 11 July to 26 August 2019 and a smaller site survey with 3D UHRS between 23 October and 08 November 2019.

Equipment used to carry out the investigation included Multibeam Echo Sounder (MBES), Side Scan Sonar (SSS), Magnetometer (MAG), Innomar Sub-Bottom Profiler (SBP), Sediment Grab Samples (GS), 2 Dimensional Ultra High Resolution Seismic (2D UHRS) and 3 Dimensional Ultra High Resolution Seismic (3D UHRS).

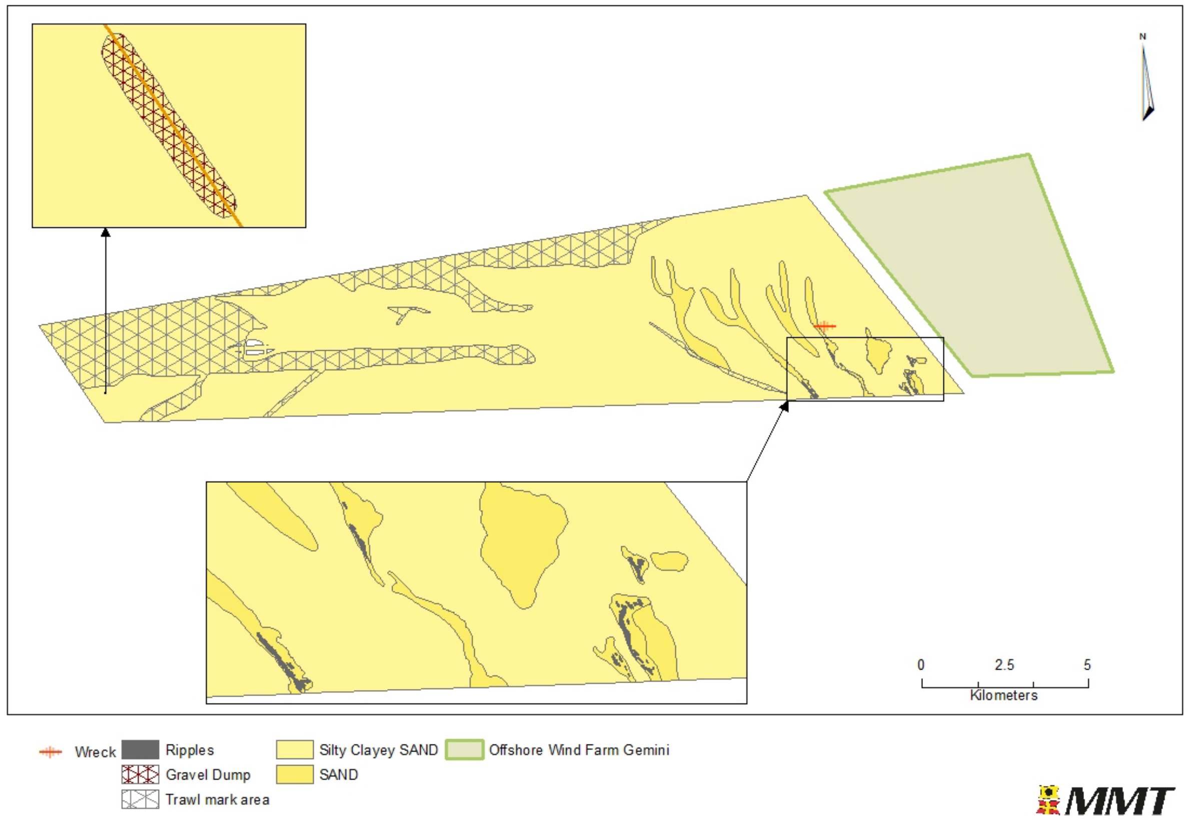

Figure 4.5 *Bedform distribution overview.*

4.4.2 Suppliers

MMT AB Sweden was contracted by RVO to conduct the geophysical survey of the TNWWFZ. MMT offers integrated geophysical and geotechnical packages with a complete set of marine surveys for the renewable energy industry. Geo Marine Survey Systems and GeoSurveys were subcontracted by MMT and conducted the 2D and 3D UHRS data acquisition, processing, Quality Control (QC) and interpretation.

MMT provides the Renewable Energy, Oil & Gas, and Interconnector industries with high-resolution marine surveys, asset integrity and construction support. The MMT team consist of highly skilled and experienced specialists determined to provide the most committed and best service on the market. MMT develop new processes and equipment based on the latest technology in order to meet and exceed every client's expectations.

GeoSurveys is an established company with more than 17 years of experience in the field and working for the industry, complying with client's needs and help them achieve their goal with excellence. GeoSurveys applies 'high end' processing (in addition to standard processing) to 2D & 3D marine Ultra High Resolution Seismic (UHRS) data. Specialized in broad band processing of UHRS, with in house developed advanced procedures for sparker source signature modeling and static corrections.

Geo Marine Surveys Systems (GMSS) is a worldwide leading designer and manufacturer of Ultra High-Resolution Seismic Solutions and geotechnical equipment. For 20 years, Geomarine has been developing the unique Negative Discharge Technology – patented in 1996 by Dr. Ivan De Jong, first director of Geo Marine. GMSS supplies equipment for over 150 Clients, Institutes and Survey companies from all over the world and is used by all the major survey companies for their challenging projects.

For the past 11 Years GeoSurveys and GMSS have been combining synergies to develop new 2D and 3D UHRS systems and to provide turnkey solutions to clients with equipment, operators, offline QC, data processing and interpretation.

The companies are familiar with the local conditions and technical requirements for a geophysical survey of the TNWWFZ. DNV was contracted to review the study results and provide certification of the results.

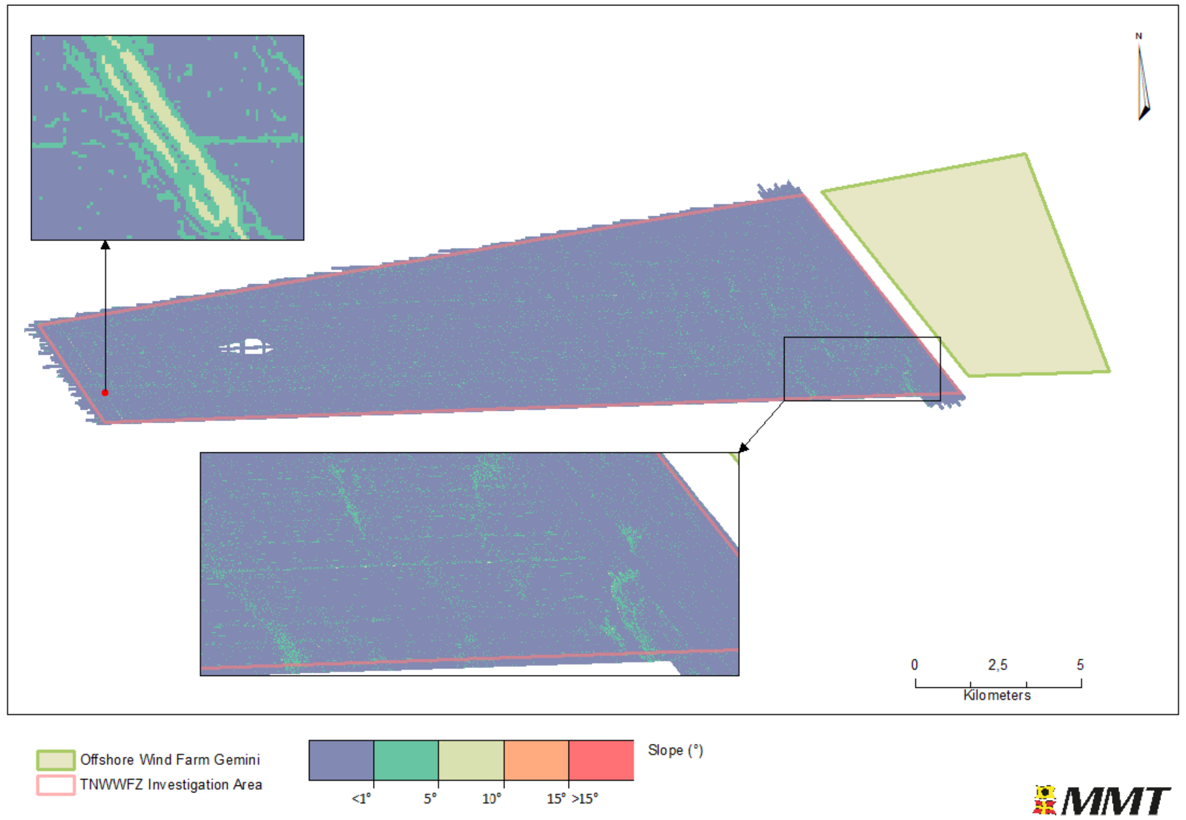

Figure 4.6 *Overview of slope angle surface.*

4.4.3 Results

4.4.3.1 Bathymetry and seabed features

The bathymetric survey recorded water depths across the TNWWFZ ranging between -32.77 m and 38.53 m Lowest Astronomical Tide (LAT) with depths generally increasing from east to west. The seabed is typically very smooth with greatest topographic variability occurring in the east of the TNWWFZ. Here there are widely-spaced, broad banks of sediment (up to 0.8 m high and approximately 400 m wide) with patches of ripple bedforms on their western flanks. The seabed is largely smooth and devoid of sedimentary bedforms across the western two-thirds of the TNWWFZ. Extensive trawl mark areas are present in the TNWWFZ. The bedform distribution across the site is displayed in Figure 4.5.

Across the TNWWFZ, contacts (boulders and debris) create localised depressions and mounds. Many of the contacts are associated with local maxima in slope angles compared to the surrounding seabed which typically has very gentle gradients (0° to 1°). Slope values associated with the wreck, pipeline and debris items range up to 37°. The greatest slope values not associated with contacts are located on the flanks of the ripple bedforms in the eastern third of the TNWWFZ recording slopes in the moderate range (5° to 10°), Figure 4.6.

4.4.3.2 Sub-surface interpretation

The seismic interpretation of the sub-surface sedimentary and structural architecture was based on 2D and 3D multichannel UHRS and SBP data. The composition of the units mapped was inferred based on seismic interpretation techniques and on the Desktop Study provided by Arcadis, no geotechnical sampling was available at the time of interpretation.

A total of 198 individual 2D seismic sections adding up to around 2200 km and a 4150x1500 m 3D seismic block imaged the geology down to a depth of more than 100 m below the seabed. The seismic data was considered fit for purpose, meeting the projects data quality and interpretation requirements.

Generally, the sediments within the site are heterogeneous, ranging from clays, fine to coarse sands and gravel; deposited under a wide variety of environments, such as glacial, subglacial, subaerial, shallow marine, deltaic, estuarine and open marine. Six seismic units (U10 to U60) were identified and mapped in the TNWWFZ, these have a geological significance and spatial continuity across the site. The younger seismic units, U10 (Figure 4.8) and U20 were deposited in a shallow marine to coastal plain environment (marine, estuarine, deltaic systems). Seismic units U30 and U40 represent marine sediments from an interglacial period. Seismic unit U50 correspond to a periglacial deposit. Lastly, seismic unit U60 consists of fine layered sediments settled in a glaciolacustrine environment. Older sequences consist of a mixture of different soils generated under varying environments. Seismic unit bases are all erosive in nature and internal erosive surfaces occur inside most of the mapped seismic units. A summary of the mapped units is provided within Table 4.1, the complexity of the site is illustrated in the 2D and 3D UHRS sections within Figure 4.7.

Note: following completion of the geophysical site survey at TNWWFZ a ground model has been developed which incorporates geotechnical sampling results. The interpretations above and within Table 4.1 were derived prior to geotechnical sampling and are superseded by the updated ground model.

4.4.3.3 Wrecks, cables and pipelines

To confirm and/or identify the presence of wrecks, cables and pipelines in the investigated area, MMT was provided with a database listing all known obstructions, objects and wrecks in the Dutch inland waters and North Sea.

Three cables and one pipeline were detected in the TNWWFZ which represent all the cables and pipelines in the provided database. In addition, two linear features interpreted as possible cables, which were not listed in the background data, were observed within the MAG data. The first found in the northwest corner of the TNWWFZ, trending in a southwest-northeast direction. The second crossing the entire site in a west-south-west to east-north-east direction.

One wreck was identified in the TNWWFZ, which correlated to a wreck position in the provided archaeological study and Nationaal Contactnummer Nederland (NCN) database.

One rock dump is located within the TNWWFZ. It is observed on top of the Noordgastransport B.V. PL0154_PR pipeline in the west of the TNWWFZ.

4.4.3.4 Surface contacts and magnetic anomalies

Surface contacts were interpreted from SSS and MBES data within the TNWWFZ. A total of the 231 contacts were interpreted classified as: one wreck, 112 debris, 95 boulders and 23 "other" contacts.

Table 4.1 *Summary of the mapped units, their most relevant characteristics and correlation with sediment type, geological formations and age.*

Seismic units	Acoustic facies and internal configuration	Lower bounding surface		Expected composition	Tentative litho stratigraphic correspondence and age
		Morphology	Nature		
U10	Mostly transparent; poorly organised reflections	Mostly flat, irregular in some places	Erosive, wave cut ravinement surface	Sands, silts, shell fragments, gravelly sands	Southern Bight Formation and Urania Formation. Holocene
U20	Low to high amplitude reflectors; transparent, (sub) parallel fine-layering, negative impedance features	Irregular	Erosive, delineating small channels/basins	Mud to gravel	Holocene/ Upper Pleistocene
U30	Low to high amplitude; seismic facies transparent and chaotic; internal erosive surfaces, negative impedance features	Mostly flat and in some places very undulated	Erosive, subaerial exposure surface, Lowstand System Tract	Sands, silts, clays, gravels	Eem Formation. Upper Pleistocene
U40	Moderate to high amplitude (sub) parallel reflections, transparent; internal erosive surfaces; small basin infill accommodated in deformed areas, negative impedance features	Base is flat and irregular outside the channels where it is deeper	Erosive	Muds and sands	Upper/Middle Pleistocene
U50	Low to high amplitudes; poorly-organised, (sub) parallel, divergent, transparent, chaotic reflections; internal erosive surfaces	Irregular, undulated base relatively well depictable	Erosive, Glacial surface of erosion	Fine to medium sands, local silt and clay laminae	Boxtel Formation Middle Pleistocene
U60	Moderate amplitude reflectors; well-organised, parallel to subparallel and continuous reflectors transparent; internal erosive surfaces	Irregular	Erosive	Very fine to medium sands, locally, gravelly or layers of silty, sandy and stiff clay	Egmond Ground Formation Middle Pleistocene
Base Unit (older deposits)	Reflectors of low to medium amplitude contrasts; chaotic and transparent facies; internal erosive surfaces	-	-	Undifferentiated	Yarmouth Roads, Peelo Formation and older. Middle Pleistocene

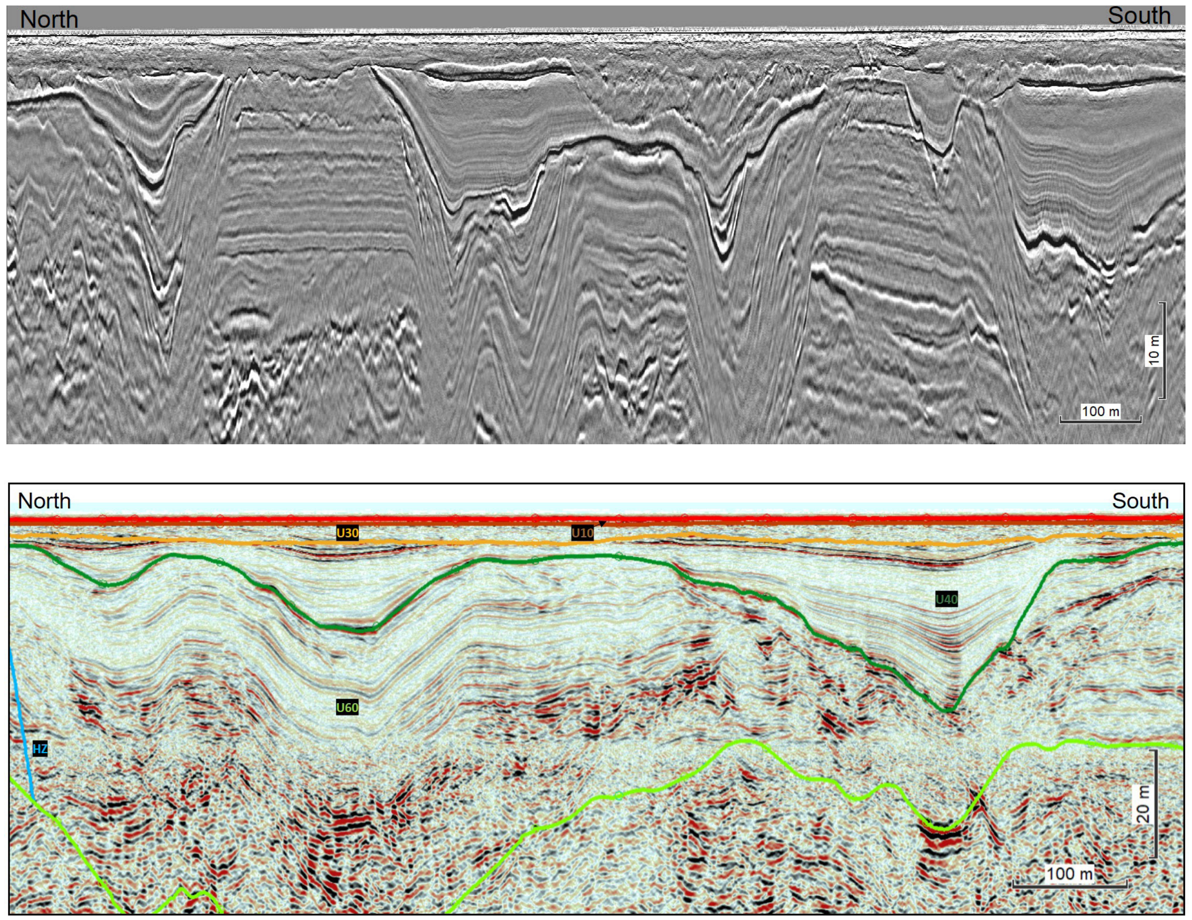

Figure 4.7 *Portion of seismic section of UHRS data, 3D (upper), 2D (lower), imaging the complex geology of the site.*

Magnetic anomalies were interpreted from the MAG data within the TNWWFZ. A total of 1758 anomalies were interpreted. 275 of the anomalies were associated to known cable and pipeline infrastructure and 113 associated with the two unknown linear features (possible cables). The number of anomalies detected was high compared to the observed number of SSS contacts. The anomaly detection threshold (5 nT) was low which resulted in a large number of anomalies (1000 of the 1371 discrete anomalies have a peak to peak amplitude less than 15 nT). The high proportion of low amplitude anomalies (5 to 15 nT), is interpreted to be associated with increased background noise originating from sub-surface geology, predominantly in the eastern half of the TNWWFZ.

4.4.3.5 Sub surface constrains

The geophysical survey displays evidence of several potential constrains to engineering structures, located at the sub-surface and seabed, commonly known as geohazards. The geohazards identified in the seismic data include point diffractors (sub-surface boulders and coarse sediment/gravel layers), deformation (glaciotectonic features and faults), channel/tunnel valleys, fine materials, organic-rich deposits and shallow gas.

Within the sub-surface potential boulders and coarse sediment/gravel layers were identified within all units, except for the uppermost seismic unit U10. Usually, these point diffractors constitutes a constraint in drilling and other operations as they can cause damage to equipment, affect equipment installation and ultimately cause foundation failure. Evidence of tectonisation/deformation in sediments of seismic units U30, U40 and U60 result in a high lateral and vertical variability in soil properties. Palaeochannel infills were identified at the base of seismic units U20, U40 and U60 (Figure 4.9). The sediment infill is heterogeneous and the sharp contrasts in physical properties can result in different responses when subjected to loading, which may pose a hazard to engineering operations and installations. Peat layers may be present in all units, except for the uppermost seismic unit U10.

The geophysical data and seismic interpretation were used to plan a geotechnical campaign. The results from the ground truthing will be integrated with further geological interpretation in order to produce a ground model with soil types to better plan the future development of the wind farm site.

4.4.4 Webinar

The results of the Geophysical Survey performed at the TNWWFZ will be presented and discussed at a webinar on February 3, 2022. Please refer to https://offshorewind.rvo.nl/cms/view/be898bea-672f-464c-bfaf-74666cb8c489/soil-tnw for details.

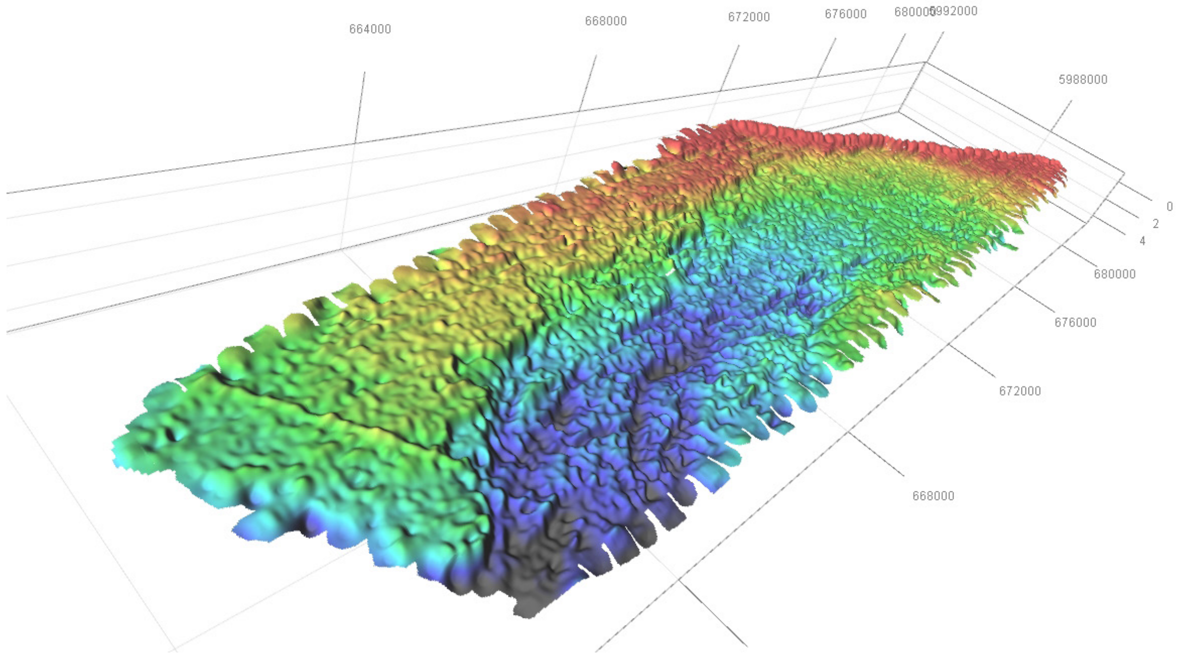

Figure 4.8 *3D view of the uppermost mapped horizon (H10) evidencing the subaerial exposure drainage pattern it delineates at the site scale.*

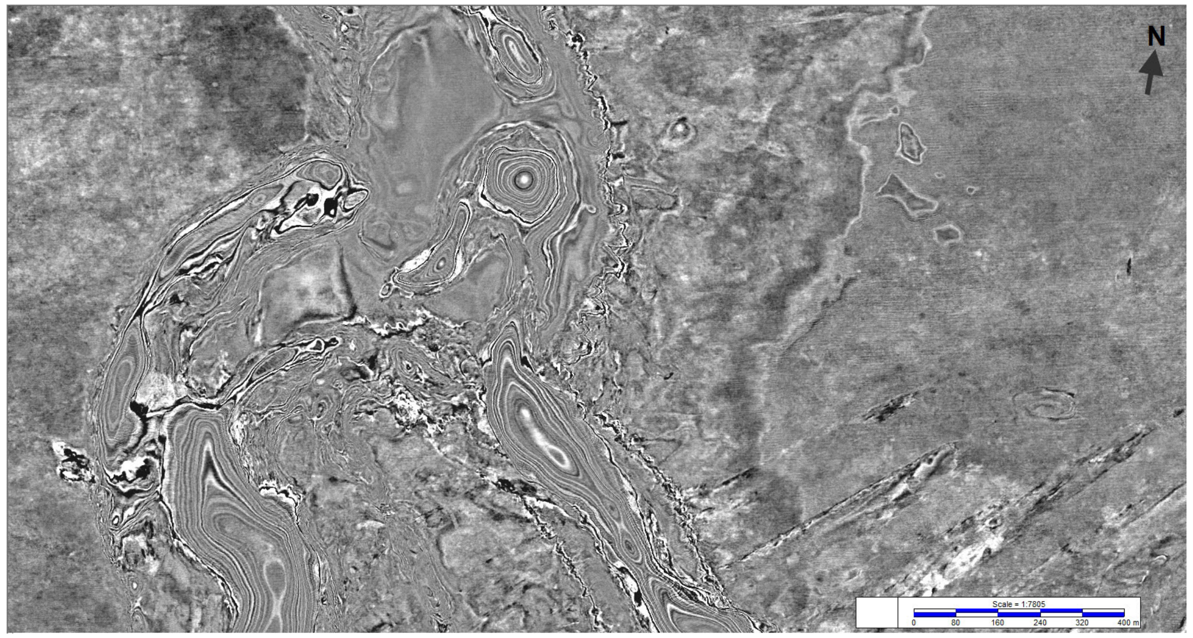

Figure 4.9 *Depth slice (54.5 m, LAT) taken from the 3D seismic block imaging deformed sediments and a fine-layered sequence that infills a channel/trough that cuts through the surrounding sediments.*

4.5 Archaeological assessment of geophysical survey results

4.5.1 Overview - aims, objectives and approach

Following on from its initial work on the archaeological desk study, Periplus Archeomare conducted an archaeological assessment of the geophysical survey results to further investigate the presence of archaeological remains in the TNWWFZ.

The goals set for this assessment were:
1. To determine the historical or archaeological value of contacts found in the geophysical survey;
2. To validate the locations of known wrecks; and
3. Assess the prehistoric landscape based on the seismic data.

4.5.2 Supplier

Periplus Archeomare was contracted by RVO to conduct an archaeological assessment of the geophysical survey data acquired by MMT.

4.5.3 Results

From the assessment of the geophysical survey data it is concluded that none of the man-made objects which were found exposed at the seabed are of archaeological value. One known ship wreck (NCN 693; 'Insulaner') was found. This ship sunk in 1979 and is not of archaeological value.

The assessment of magnetometer data has resulted in the identification of 1350 magnetic anomalies which could not be correlated with pipelines and cables, or exposed objects at the seabed surface. The anomalies are related to unknown ferrous objects which are either too small to be traced with side scan sonar or covered by sediments. 35 of these anomalies have peak-to-peak values of 50 nT and more.

The character of the 35 objects with magnetic anomalies of 50nT and more is, other than that they are iron-bearing, not known. These objects could be of archaeological value. Apart from archaeological objects, pieces of cable, chains, UXO, lost anchors and debris could have induced the measured magnetic anomalies. As long as the character of these objects has not been determined, the objects are considered to be of potential archaeological interest.

In accordance with Dutch Law and Legislation no seabed disturbances shall be carried out within 100 meters of each of the 35 locations where magnetic anomalies of 50 nT or more have been measured. This also applies to cable trenching and anchorages of work vessels.

The extent of the buffer zone might be reduced if it can be substantiated that the activity will not affect the potential archaeological object. For example, when no anchoring is used during cable lay operations the buffer zone may be decreased.

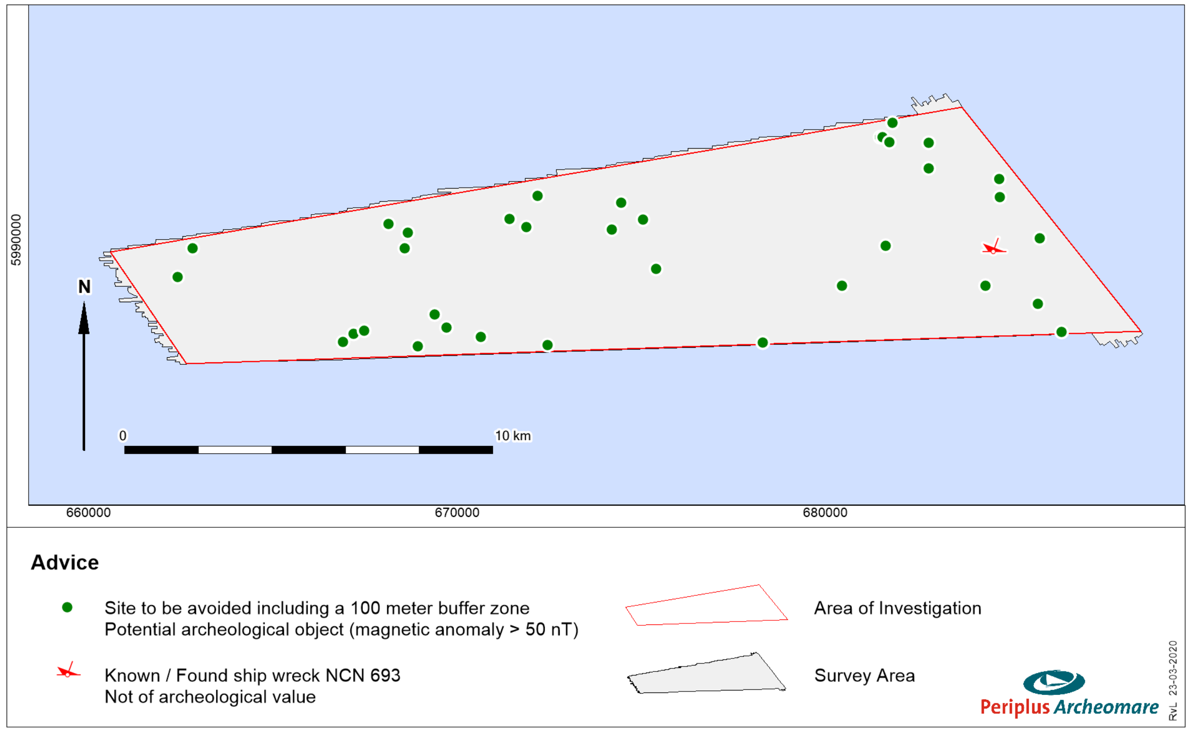

Figure 4.10 *Areas to be avoided: potential archaeological objects including 100 m buffer zone.*

The reduction of a buffer zone shall only be applied after consent of Rijkswaterstaat on behalf of the Ministry of EZK and its advisor, the Cultural Heritage Agency (RCE). If it is not feasible to avoid the designated sites of potential archaeological value, additional research shall be conducted to determine the actual archaeological value of the reported locations.
It is suggested that any UXO research conducted within 100 m of magnetic anomalies with peak-to-peak values of 50 nT or more is carried out under archaeological supervision. Depending on the outcome of the UXO research, it can be decided if additional research (for instance by means of ROV or dive investigations) is needed.

4.5.4 Prehistoric remains

The acquired seismic data have been used to assess the evolution of prehistoric landscapes in the TNWWFZ. The results are as follows.

Prior to the Early Holocene marine ingression the landscape was shaped by vegetated outcrops of marine sediments of the Eem Formation and (presumably) terrestrial deposits of the Boxtel Formation. A major part of this Pleistocene landscape has been eroded. Two separate phases of erosion can be distinguished:

Phase 1 - 12.000 to 10.000 years ago
The development of an estuarine or deltaic environment with a discreet channel in the eastern part of the area and a network of interconnected channels and flood plains in the western part of the area (refer to figure 4.11). The development of tidal creeks is possibly preceded by small-scale fresh or brackish water fluvial systems in a predominantly terrestrial environment.

Phase 2 - around 10.000 years ago
Rapid sea level rise due to the Early Holocene climate warming leads to a marine ingression and the development of a wave cut refinement surface in the western and central part of the area. The sand banks in the eastern part of the area may be relic beach barriers left behind after continuous transgression. Mesolithic hunter-gatherer communities were able to adapt to the rapidly changing landscape in Early Holocene times. The evolving wetlands are characterized by a rich flora and fauna offering ample food sources including both animals (mammals, birds, fish and amphibians) and plants (roots, tubers, nutshells and seeds). Higher parts of the landscape could have been used for the installation of camp sites.

A geotechnical campaign is to be carried out to test and refine the geological model of the subsurface and to determine the physical properties of the sediment layers present. Based on this 'better' geological model it will be possible to refine the archaeological potential of prehistoric landscapes in the TNWWFZ.

It is advised to use designated subbottom samples and CPT-graphs for geo-archaeological research into the genesis and integrity of both terrestrial and aquatic paleolandscapes. The research includes the analysis of macro-plant remains, pollen, diatoms, ostracods, formaminifera and mollusks, which are obtained from specifically targeted sediment sample intervals. The samples will be collected from eight vibrocores. The proposed vibrocore locations are shown in figure 4.11.

The geo-archaeological research shall be carried out in accordance with the Dutch Quality Standard for Archaeology (KNA Waterbodems 4.1).

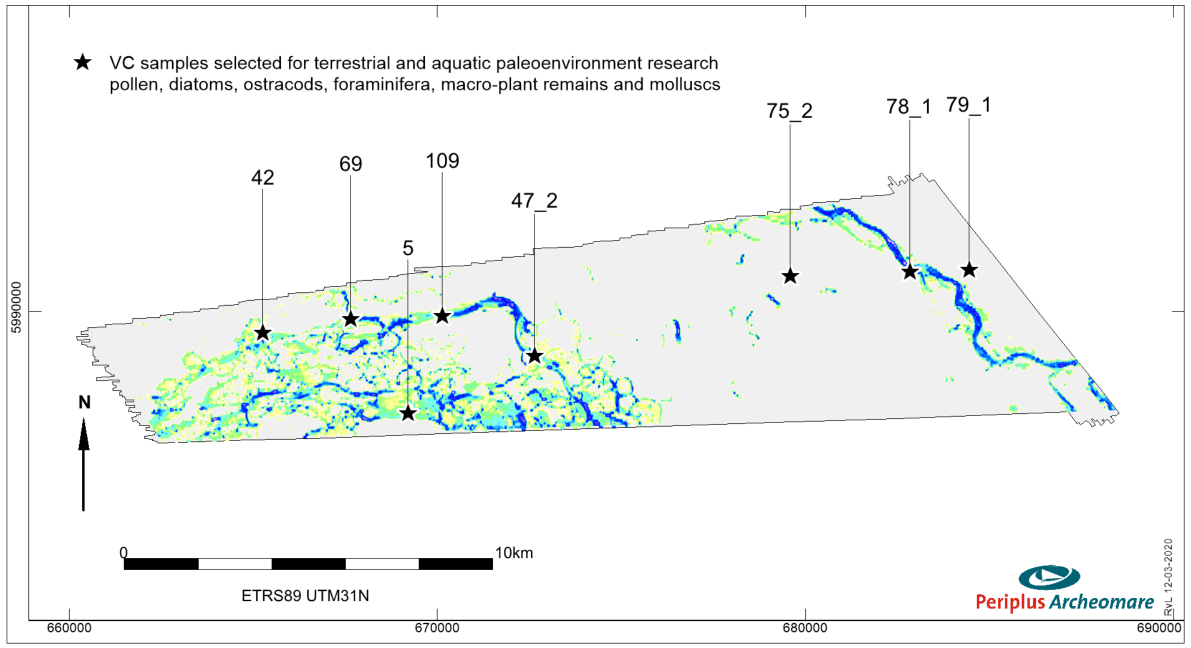

Figure 4.11 *Proposed vibrocore sample locations for geo-archaeological research.*

During the construction of the wind farm, data can be collected that - from an archaeological point of view - provide valuable information at a detailed level. It can be very useful to investigate this information further from an archaeological point of view in consultation with the RCE.

Finally, during the installation of the wind turbines and cable lay operations, archaeological objects may be discovered which were completely buried or not recognized as an archaeological object during the geophysical survey. Periplus Archeomare recommends archaeological supervision based on an approved Program of Requirements. Following this recommendation would prevent delays during the work when unexpected archaeological remains are found. In accordance with the law on cultural heritage (Erfgoedwet), those findings must be reported to the competent authority. This notification must also be included in the scope of work.

4.5.5 Webinar
The results of the Archaeological Assessment performed at the TNWWFZ will be presented and discussed at a webinar on February 8, 2022. Please refer to https://offshorewind.rvo.nl/cms/view/7a97c70f-38f1-4716-bc03-ce23d2c565ed/obstructions-tnw for details.

4.6 Geotechnical survey

4.6.1 Overview - Aims, Objectives, Approach
The aim of the geotechnical campaign is to provide relevant geotechnical data which is suitable to improve the geological and geotechnical understanding of the Ten noorden van de Waddeneilanden Wind Farm Zone (TNW WFZ) and to progress the design and installation requirements for offshore wind farms, including, but not limited to, foundations and cables.

The geotechnical campaign for the TNW WFZ used intrusive techniques to gain insight into the characteristics of the subsoil. Three types of investigation techniques were used: (1) in situ testing from seafloor, consisting of (standard, seismic, and temperature) cone penetration testing and pore pressure dissipation testing, (2) sampling from seafloor using a High Performance Corer (HPCTM) sampling device, (3) geotechnical borehole drilling with downhole sampling, in situ testing consisting of (standard and seismic) cone penetration testing and pore pressure dissipation testing, and borehole geophysical logging (caliper, natural gamma radiation, spectral gamma radiation, P and S logging, and dual laterolog). Onsite geotechnical laboratory testing was performed on recovered samples. An office programme of geotechnical laboratory testing and reporting of results followed the site phase.

The geotechnical site investigation included investigations at the location of a future TenneT substation. Quantities for this location are considered in the overviews of locations and laboratory test quantities which are presented in Table 4.2.

The site investigation at the TNW WFZ comprised the following:
- One hundred (100) seafloor piezocone penetration tests (PCPT) at 85 locations to depths ranging from 0.1 m to 49.6 m below seafloor (BSF);
- Sixteen (16) seafloor seismic cone penetration tests (SCPT) at 15 locations to depths ranging from 2.8 m to 37.8 m BSF. Fifteen (15) test points include seismic velocity tests (SVT);
- Twenty-seven (27) seafloor temperature cone penetration tests (TCPT), including temperature equilibrium tests (TET) at 25 locations to depths ranging from 2.5 m to 6.6 m BSF;
- Thirty-eight (38) pore pressure dissipation tests (PPDT) at 24 locations. PPDT tests were performed at selected depths within a PCPT stroke or at selected depths as part of downhole in situ cone penetration testing;
- Fifty-one (51) vibrocores at 50 locations to depths ranging from 2.9 m to 6.2 m BSF;
- Sixty (60) boreholes at 34 locations to depths ranging from 8.0 m to 78.5 m BSF. These boreholes include downhole in situ testing, -sampling, or alternating downhole in situ testing and (over)sampling to depths ranging from 8.0 to 62.0 m BSF. One (1) borehole was performed reaching a depth of 78.5 m BSF. In 18 boreholes at 17 target locations a drill out was performed followed by downhole in situ testing, -sampling, or alternating downhole in situ testing and (over-) sampling. Of these 60 boreholes, five (5) boreholes at five (5) target locations also included borehole geophysical logging;
- Five (5) boreholes at five target locations to depth ranging from 80.2 to 81.0 m BSF.
- One (1) borehole with downhole sampling (centre location TenneT substation) and four (4) boreholes with downhole cone penetration testing and (over)sampling (corner points of TenneT substation);
- Four (4) seafloor cone penetration tests at four target locations to depths ranging from 14.5 m to 30.2 m BSF (corner points of TenneT substation).

The term ‘location’ used in this document refers to a specified target location. The activities at any given location can consist of a single borehole or multiple boreholes (for example in case of ‘re-drills’) and test(sample-) points whereby the term ‘borehole’ is defined as a geotechnical borehole with associated downhole sampling, downhole in situ testing, and borehole geophysical logging, and ‘test point’ as an individual seafloor in situ testing operation.

An overview of the standard and advanced laboratory test programmes can be found in Table 4.2 titled ‘Overview of Standard Laboratory Test Programme’ and Table 4.3 titled ‘Overview of Advanced Laboratory Test Programme’. Note that determinations of water content, unit weight, torvane, and pocket penetrometer tests are not presented in these tables.

4.6.2 Supplier
Fugro was contracted to perform this geotechnical site investigation. The site investigation was performed according to ISO 19901-8 (2014). The investigation was conducted in two campaigns using geotechnical vessels MV Despina and MV Normand Flower, between 14 February and 13 June 2020.

A SEACALF® 20 tons MkV Constant Drive System (CDS) with a coiled rod system and friction reducer was used for seafloor in situ testing. The unit was fitted with piezocone penetrometers, seismic cone penetrometers, and temperature cone penetrometers. The SEACALF® CDS provided a reliable, safe, and efficient test unit for high quality data acquisition. Sampling from seafloor was performed using a High Performance Corer (HPCTM) sampling device equipped with a 6.4 m core barrel and an inner PVC liner to contain the sample.

The geotechnical boreholes were performed using open-hole rotary drilling in combination with Pure-Bore® and/or sea water as drill fluids. Borehole drilling included the use of a seabed frame equipped with a SEACLAM system, for re-entry and for axial and lateral support of the drill string at seafloor. Downhole push sampling and in situ testing employed WIPSAMPLER® and WISON® downhole tools. Downhole cone penetration tests (CPT) were performed using piezocone penetrometers.

Table 4.2 *Overview of Standard Laboratory Test Programme.*

Test Type	Test Quantity
Geotechnical Index	
Density of solid particles	219
Particle size distribution – sieving and sedimentation	517
Particle size distribution – dynamic image analysis	14
Minimum and maximum index dry unit weight - DGF method	111
Minimum and maximum index dry unit weight - shaker method	TBC
Atterberg limits	101
Microscopic photography	69
Geochemical Index	
Carbonate content	144
Total and organic carbon content	188
Organic matter content	25
Mass loss on ignition	3
Pore water salinity	10
Strength and Stiffness	
Unconsolidated undrained triaxial compression - undisturbed	60
Unconsolidated undrained triaxial compression - remoulded	45
Isotropically consolidated undrained triaxial in compression (CIUc)	7
Isotropically consolidated undrained triaxial in extension (CIUe)	3
(An)isotropically consolidated undrained triaxial in compression (CAUc)	24
(An)isotropically consolidated undrained triaxial in extension (CAUe)	7
Bender element measurements (as part of CIU/CAUe/CAUc)	6
Isotropically consolidated drained (CID) - three stages	79
Isotropically consolidated drained (CID) - single stage	TBC
Bender element measurements (as part of CID)	24
Direct simple shear (constant volume)	15
One-dimensional Consolidation	
Constant rate of strain	22
Constant rate of strain - reconstituted	3
Oedometer incremental load	1
Oedometer incremental load - reconstituted	1
Permeability	
Permeability tests - permeameter	47
Permeability tests – triaxial cell	41
Shear	
Direct shear	59
Ring shear	20
Interface ring shear (soil-steel)	100
Other	
Thermal conductivity and heat capacity	36
Electrical resistivity	10
Transient plane source	5
Geological dating analyses	-
Microbiological analyses	39

Table 4.3 *Overview of Advanced Laboratory Test Programme.*

Test Type	Test Quantity
Geotechnical Index	
Density of solid particles	5
Particle size distribution	25
Minimum and maximum index dry density – DGF method	10
Minimum and maximum index dry density – shaker method	10
Atterberg limits	15
Sample microscopic photography	10
Geochemical Index	
Carbonate content	5
Organic content	5
Strength and Stiffness	
Anisotropically consolidated undrained triaxial in compression (CAUc) with cyclic pre-shear	5
Anisotropically consolidated undrained triaxial in compression (CAUc)	6
Anisotropically consolidated undrained triaxial in extension (CAUe) with cyclic pre-shear	5
Anisotropically consolidated undrained triaxial in extension (CAUe)	2
Anisotropically consolidated drained in compression (CAD) with cyclic pre-shear	13
Anisotropically consolidated drained in compression (CAD)	25
Bender element measurements (as part of CAD)	10
Direct simple shear (constant volume)	13
Direct simple shear (constant vertical stress)	20
Direct simple shear (constant volume) with cyclic pre-shear	33
Direct simple shear (constant vertical stress) with cyclic pre-shear	25

Test Type	Test Quantity
Shear	
Interface ring shear (soil-steel)	5
One-dimensional Consolidation	
Constant rate of strain - reconstituted	15
Permeability	
Permeability - permeameter	6
Permeability - triaxial cell	9
Cyclic and Dynamic	
Cyclic direct simple shear (constant volume) with cyclic pre-shear	45
Cyclic direct simple shear (constant vertical stress) with cyclic pre-shear	5
Cyclic direct simple shear (constant volume)	41
Cyclic direct simple shear (constant vertical stress)	30
Undrained cyclic triaxial with cyclic pre-shear	40
Undrained cyclic triaxial	25
Cyclic triaxial with drainage, with cyclic pre-shearing	5
Cyclic triaxial with drainage	40
Resonant column - single stage	30
Resonant column - multi-stage	15

Upon completion of downhole sampling and/or in situ testing and after reaching the required depth for borehole geophysical logging, the drill bit was pulled up to a minimum safe depth with respect to the risk of borehole collapse. This allowed open-hole acquisition of borehole geophysical data by lowering the downhole geophysical tools through the bit into the open-hole. At each location multiple runs were executed, employing a suite of wireline conveyed Antares (Caliper, Natural- and Spectral Gamma Ray, and Resistivity) and Geovista (P and S suspension logger) downhole geophysical tools.

4.6.3 Results

Results of the geotechnical site investigation are presented in the following reports:

A geotechnical report containing interpreted CPT logs and results from seafloor in situ testing, including:
- Interpretation of soil profile, strata descriptions and CPT-derived relative density and undrained shear strength;
- Cone resistance (net/total), sleeve friction, pore pressure or temperature, friction ratio and pore pressure ratio, where applicable;
- Results of seismic velocity tests, i.e. recorded seismic traces (X and Y channel), and derived shear wave velocity and low-strain shear modulus;
- Results of temperature equilibrium tests, i.e. temperature versus time;
- Results of pore pressure dissipation tests, i.e. cone resistance and pore pressure versus time.

A geotechnical report containing geotechnical logs and results from seafloor sampling and laboratory testing, including:
- Interpretation of soil profile and strata descriptions based on available data sources, including sample descriptions and laboratory tests;
- Results of laboratory tests.

A geotechnical report containing geotechnical logs and results from borehole sampling and in situ testing and standard laboratory testing, including:
- Interpretation of soil profile, strata descriptions, and CPT-derived relative density and undrained shear strength;
- Where applicable, cone resistance (net/total), sleeve friction, pore pressure, friction ratio and pore pressure ratio;
- Results of seismic velocity tests, i.e. recorded seismic traces (X and Y channel), and derived shear wave velocity and low-strain shear modulus;
- Results of pore pressure dissipation tests, i.e. cone resistance and pore pressure versus time;
- Results of borehole geophysical logging including (derived) values for natural gamma radiation measurements, caliper logging, P- and S-wave velocities, spectral gamma radiation measurements, and resistivity, porosity, and bulk density measurements;
- Results of laboratory tests;
- An overview of (remaining) sample material.

A geotechnical report containing results of the advanced laboratory testing programme, including:
- Results of geotechnical index tests;
- Results of microscopic photography;
- Results of static triaxial tests;
- Results of monotonic direct simple shear tests;
- Results of interface ring shear tests;
- Results of one-dimensional consolidation tests;
- Results of permeability tests;
- Results of cyclic triaxial tests;
- Results of cyclic direct simple shear tests;
- Results of resonant column tests.

A geotechnical report containing geotechnical logs and results from seafloor in situ testing, borehole sampling and in situ testing, and standard laboratory testing at the location of a future TenneT substation, including:
- Interpretation of soil profile, strata descriptions, and CPT-derived relative density and undrained shear strength;
- Where applicable, cone resistance (net/total), sleeve friction, pore pressure, friction ratio and pore pressure ratio;
- Results of laboratory tests.

In addition to the reports, digital data files accompanying the various reports are also issued. These data files comprise the following data types:
- AGS 4.0: seafloor CPT data, downhole CPT data, borehole data;
- ASCII: seafloor CPT data, PPDT data, TET data;
- LAS: borehole geophysical logging data;
- Excel: shear wave velocity test data, list of remaining sample material, overview of advanced laboratory test results, and individual laboratory test results.

4.6.4 Conclusion

Significant effort was taken to maximise data quality and suitability of geotechnical data for the TNW WFZ. The reports were certified by DNV. The samples remaining after the laboratory testing phase will be available to the winning developers, e.g. to perform additional testing.

4.6.5 Webinar

The results of the geotechnical site investigations performed at the TNW WFZ are presented and discussed during our webinar on 10 March 2022. Please refer to https://offshorewind.rvo.nl/cms/view/be898bea-672f-464c-bfaf-74666cb8c489/soil-tnw for details.

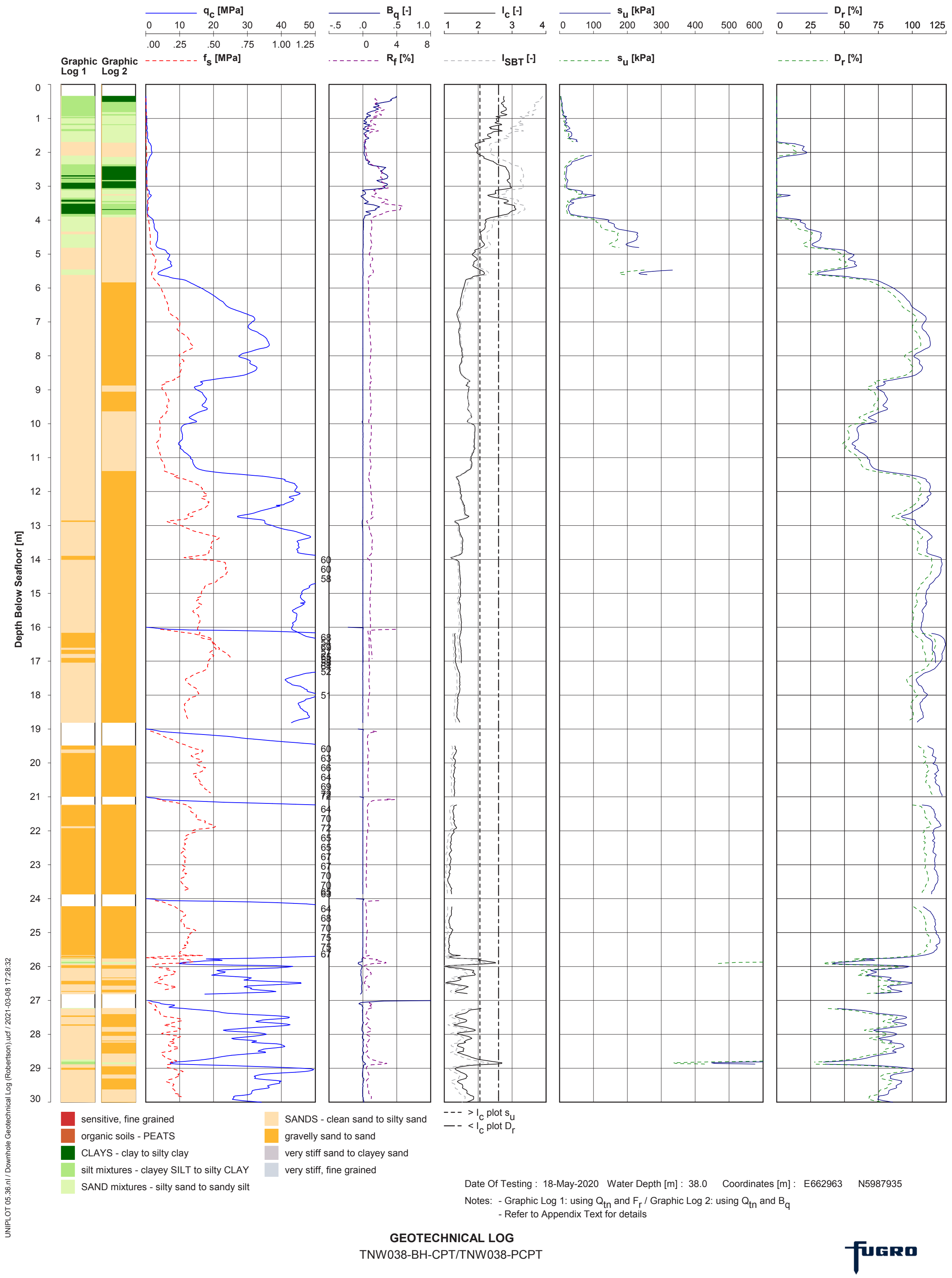

Figure 4.12 *Geotechnical log presenting interpretation of soil profile, strata descriptions, and derived parameters based on CPT data.*

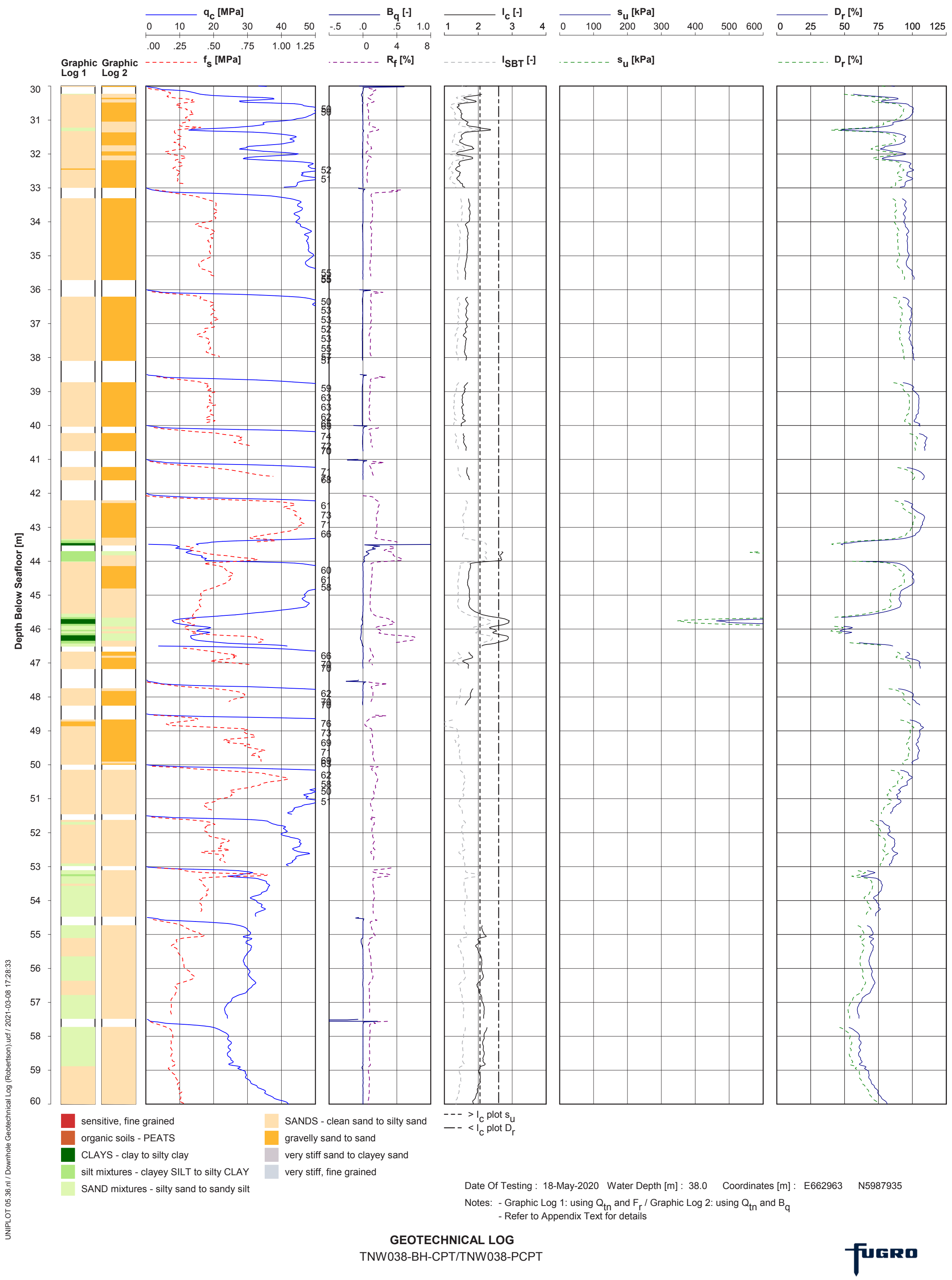

Figure 4.12 *Geotechnical log presenting interpretation of soil profile, strata descriptions, and derived parameters based on CPT data.*

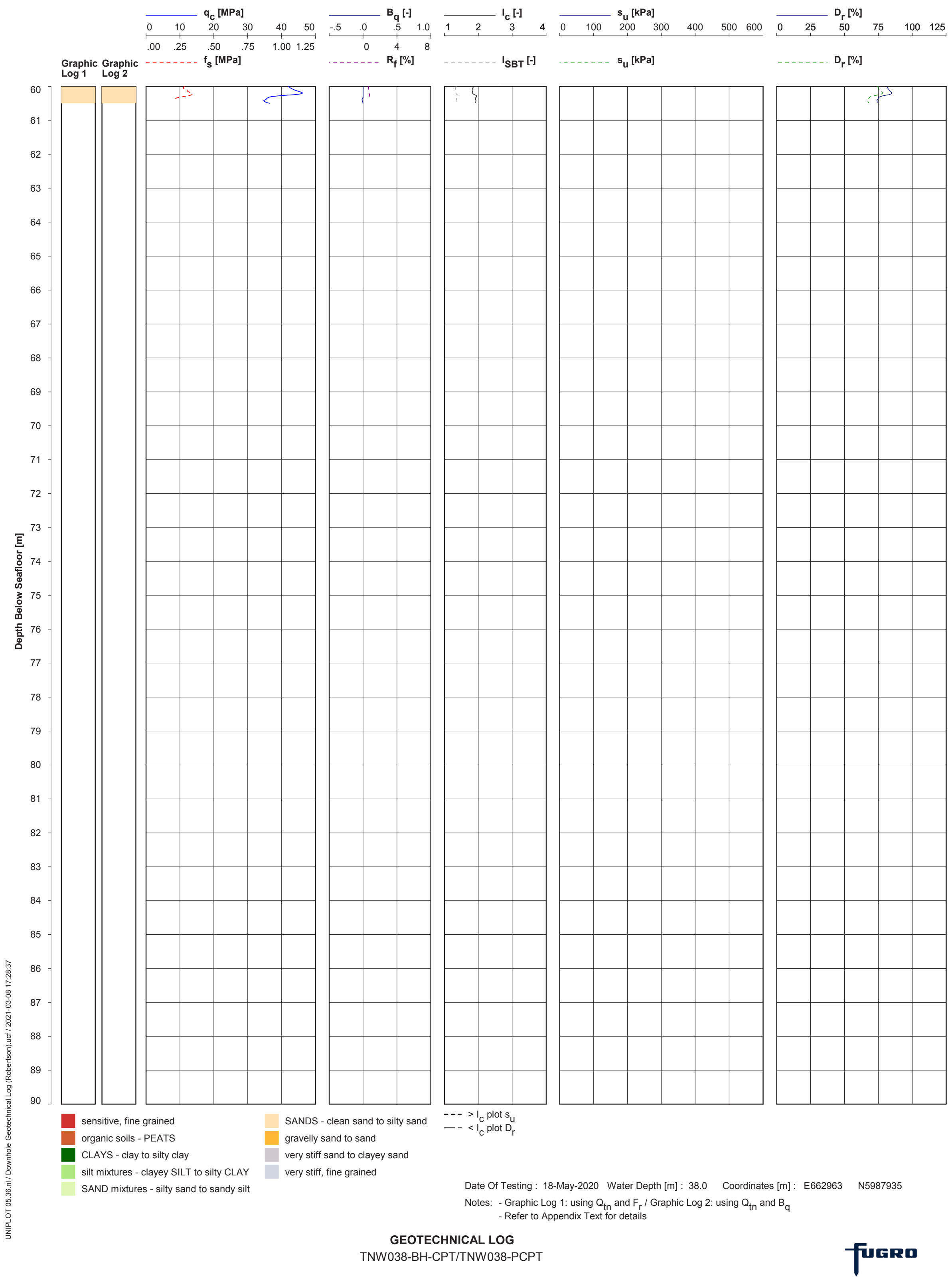

Figure 4.12 *Geotechnical log presenting interpretation of soil profile, strata descriptions, and derived parameters based on CPT data.*

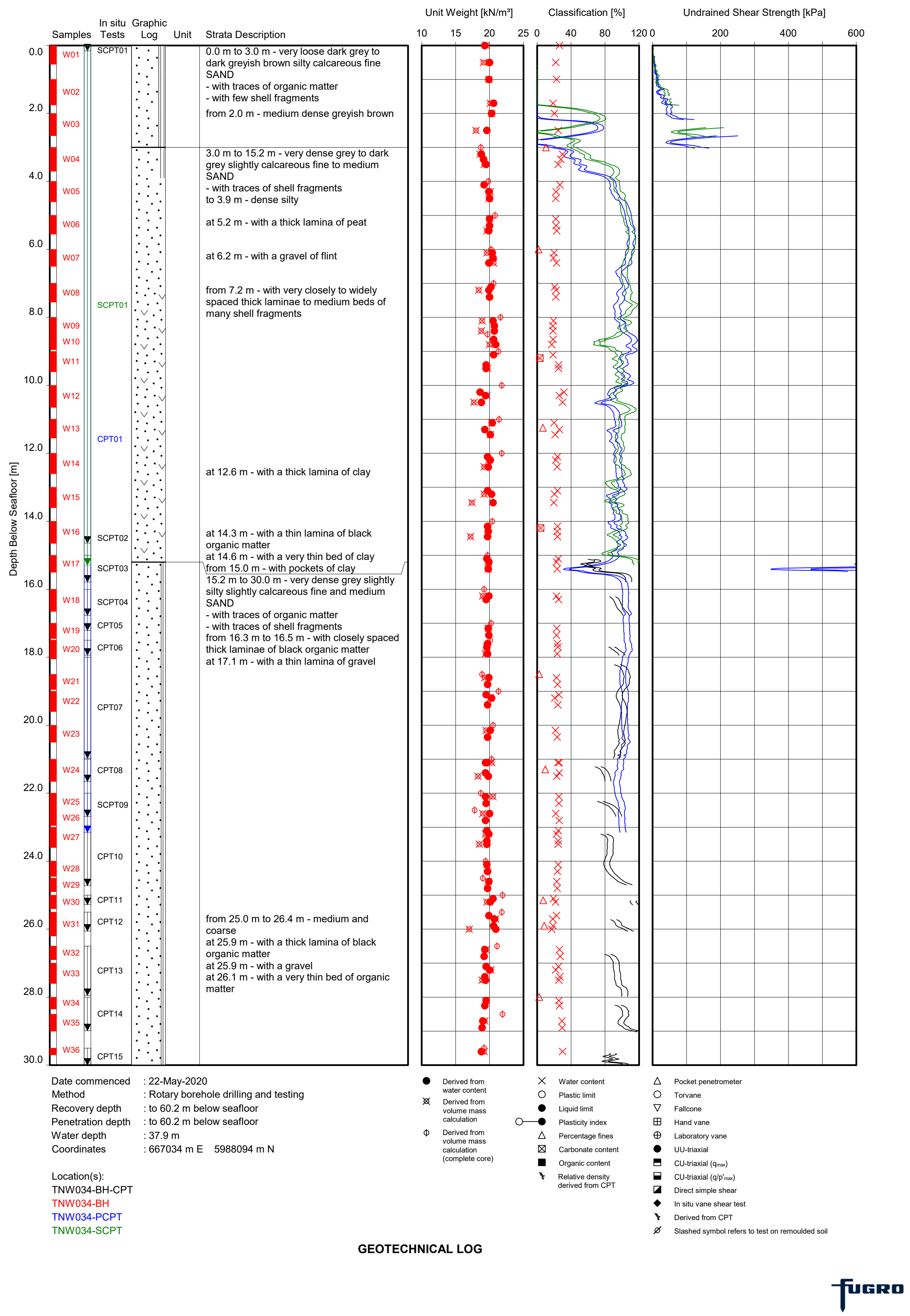

Figure 4.13 *Geotechnical log presenting interpretation of soil profile, strata descriptions, and derived parameters based on sampling and in situ testing data.*

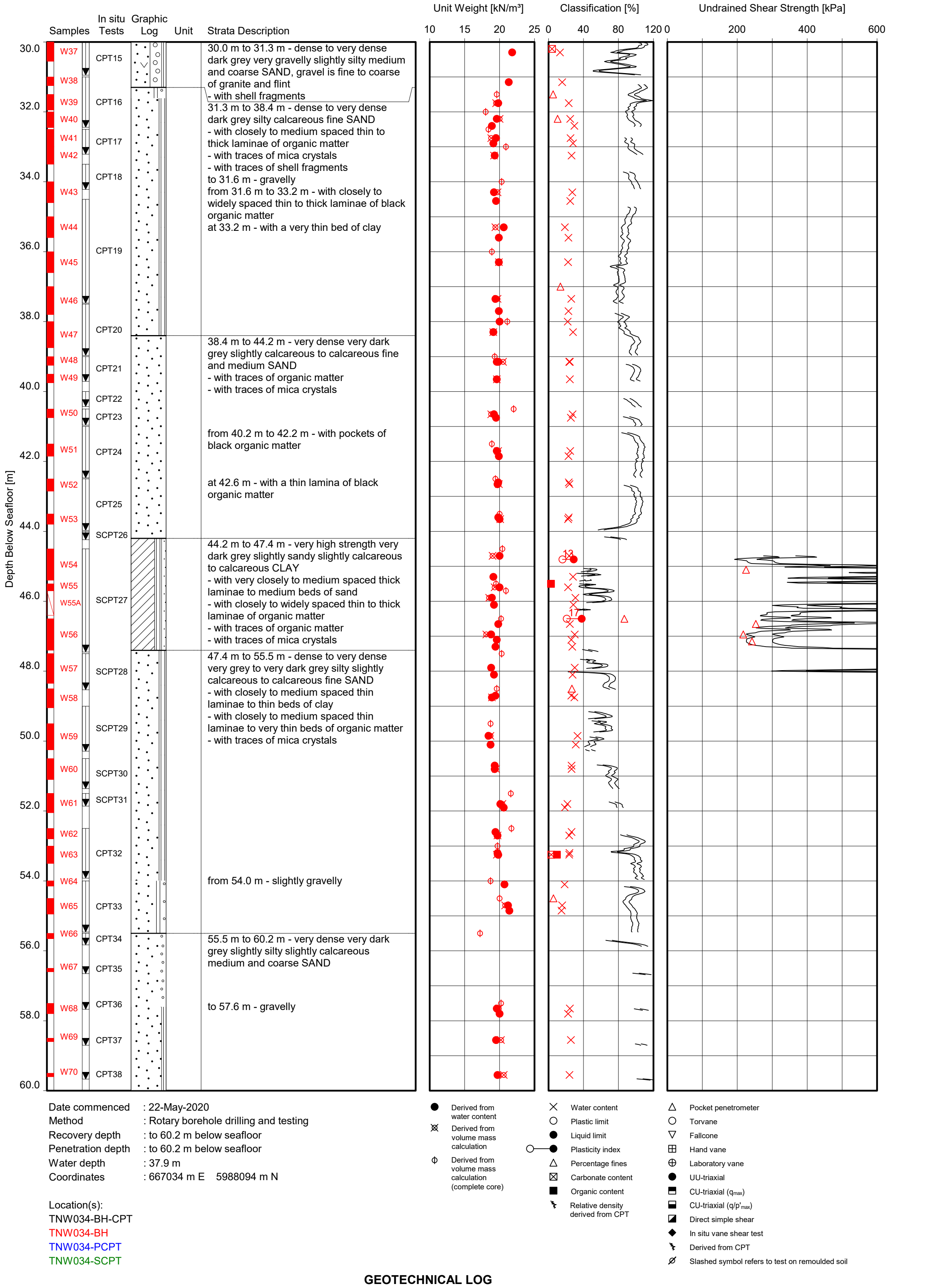

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Plate B.1-37

Figure 4.13 *Geotechnical log presenting interpretation of soil profile, strata descriptions, and derived parameters based on sampling and in situ testing data.*

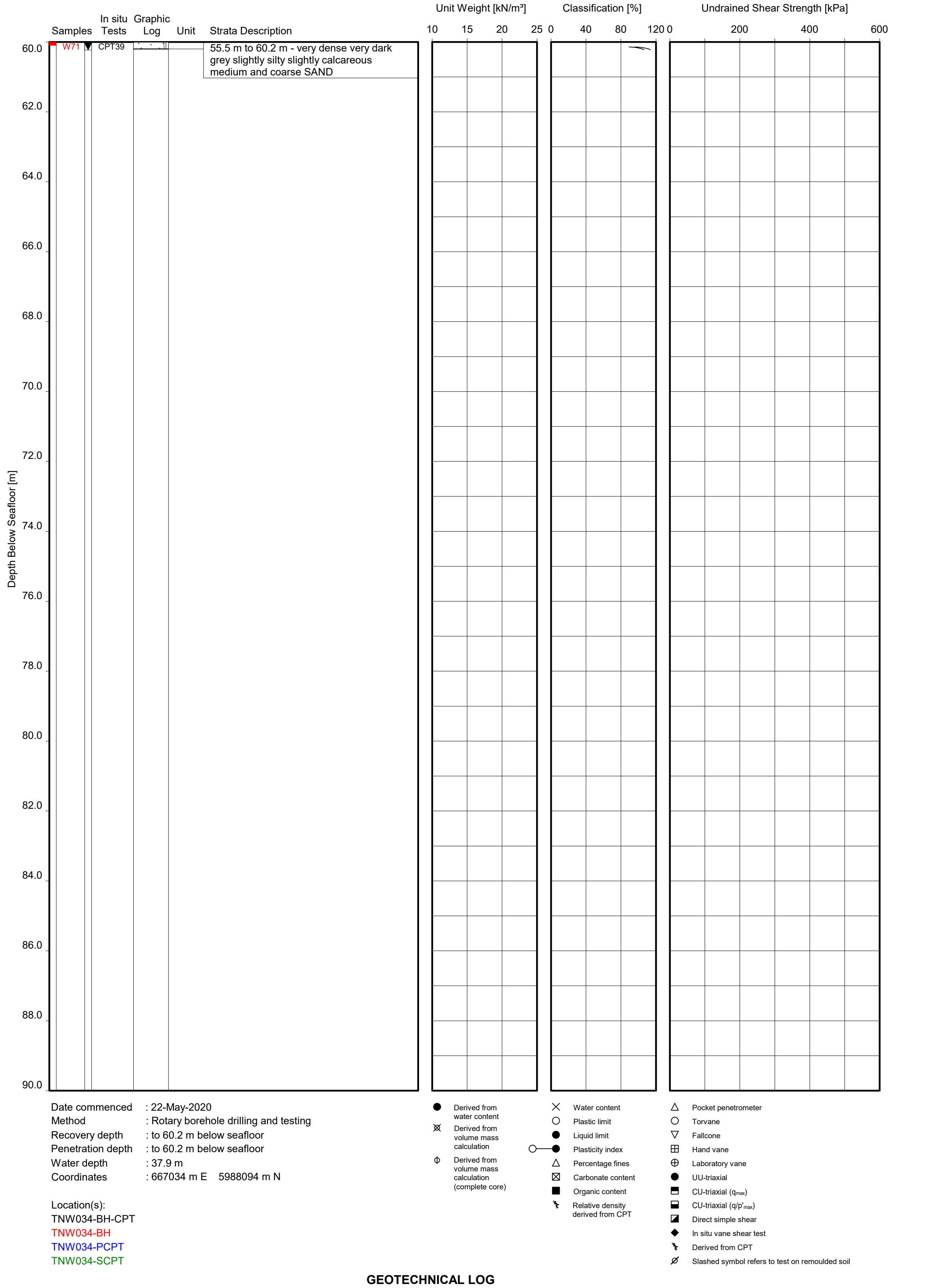

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Plate B.1-38

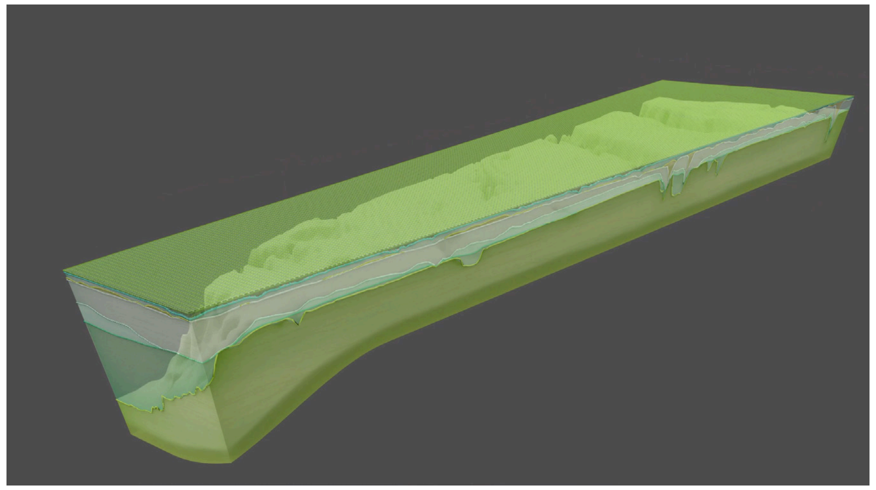
Figure 4.13 *Geotechnical log presenting interpretation of soil profile, strata descriptions, and derived parameters based on sampling and in situ testing data.*

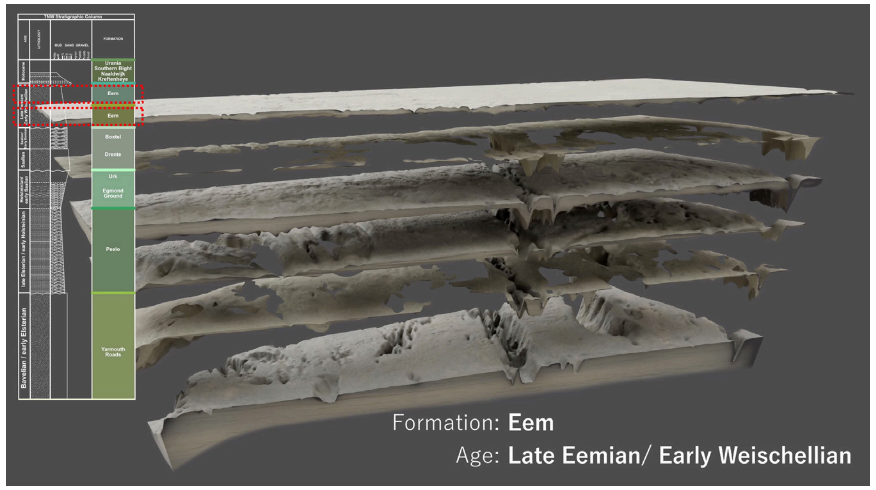
4.7 Integrated Ground Model

Norwegian Geotechnical Institute (NGI) is, together with Sand Geophysics, contracted by the Netherlands Enterprise Agency to provide an Integrated Ground Model (IGM).

This IGM provides geotechnical parameters for Ten noorden van de Waddeneilanden Wind Farm Zone (TNW WFZ).

NGI has developed a visualisation, which you can start via **this link**, to provide insight in the soil characterisation of the TNW WFZ. Further information will be provided in the webinars on March 10th, 2022 and April 5th, 2022, which are referred to in this visualisation.





Stills from the video.

4.8 Morphodynamics and Scour Mitigation desk study

4.8.1 Overview - aims, objectives, and approach

This desk study is comprised of two main elements. Firstly the (autonomous) seabed dynamics in the Ten noorden van de Waddeneilanden Wind Farm Zone (TNW) are addressed, and secondly the report on scour and scour mitigation provides general considerations on how to deal with scour development and scour mitigation at TNW, taking into account the morphodynamics of the area and a range of potential foundation types. In addition, general considerations for cable routing in a morphodynamic environment are provided. The analysis is based on existing historical survey data and the survey results obtained during the TNW geophysical campaign, together with survey data from the neighbouring Gemini wind farm.

The aim of this combined study is to:

1. Characterise the seabed and associated morphodynamics at TNW;
2. Characterise the shallow geological and sedimentological site conditions, to a depth of 20 m below the measured seabed level, as well as the seabed features at TNW;
3. Provide a prediction of the change in seabed level at TNW over the lifetime of a wind farm development (considered period: 2019 – 2065) to support the design; installation; operation and maintenance of wind turbines; inter array cables; platforms; and their support structures;
4. Provide guidance on the depths at which UXO may be encountered, based on a hindcast of historic seabed levels (1945-2019);
5. Describe the scour conditions to be expected at TNW for typical wind farm-related infrastructure;
6. Provide a state-of-the-art overview of scour mitigation measures and their applicability for wind farm-related infrastructure at TNW ;
7. Provide guidance on how the morphodynamics should be accounted for in the selection of the structures; cable route locations; and any scour mitigation strategy.

Overall, the information collated and interpreted in this desk study provides detailed information to assist potential developers with the design, installation and maintenance of wind turbines, inter-array cables, substations and their support structures at TNW.

Compared to the study previously undertaken at the Borssele wind farm zone, the morphodynamic study for TNW was extended with a geological analysis of the uppermost strata (mostly unconsolidated material); hydrodynamic modelling to assess and validate the migration directions of seabed features; and best-estimate seabed levels for 5-year periods. In comparison with the study that was conducted for Hollandse Kust (zuid), additionally the most probable depths at which UXO may be encountered were also computed. Also maps of expected scour depths; rock gradings; and of scour protection volumes, for various monopile diameters are added. In comparison with the study that was conducted for Hollandse Kust (noord) new methods for determining seabed dynamics; an improved numerical model using a flexible mesh; and maximum seabed slopes were introduced. Compared to the Hollandse Kust (west) study the analysis was extended, with new methods for extrapolation of seabed levels, including probabilistic ranges in historic trends; updated cable routing methodology; and the inclusion of measurement data for a neighbouring wind farm (Gemini).

4.8.2 Supplier

Research institute Deltares was awarded the contract by RVO to conduct the desk study for TNW. Deltares has previously conducted morphodynamic studies for other offshore wind farms, including Hollandse Kust (west, noord and zuid); Borssele. Additionally, Deltares has also performed many scour assessments; developed scour mitigation strategies; and physical model testing for a number of offshore wind farms, including Hollandse Kust (west, noord and zuid); Borssele. The studies have involved many different scour protection systems and foundation types (e.g. monopiles; jackets; suction buckets; and gravity bases).

4.8.3 Results morphodynamics

The bathymetry at TNW is considered to be relatively static because of limited presence of bedforms and seabed dynamics. The uppermost sediment layer below the seabed is partly mobile with a few bedforms oriented towards the east with small megaripples also present (Figure 4.14). Based upon the analyses that have been conducted the few bedforms that are present within the TNW zone have wavelengths in the range of 710 to 1170 m; heights of 0.4 to 0.8 m; and migration speeds up to 0.6 m/year (Figure 4.15). An analysis of the large-scale seabed level variation indicates that the underlying seabed may be considered generally static and stable over the lifetime of the proposed wind farm development.

Review of the geotechnical data indicate that the present non-erodible layers, below the seabed surface, are not likely to affect the seabed morphodynamics, because they are too deep (based on observed and expected seabed dynamics) to be exposed by the seabed dynamics. A numerical analysis of the hydrodynamics and sediment transport in the area indicates that the net sediment transport is aligned with the residual tidal flow direction, which is towards the north-northeast.

Utilising the morphodynamic analysis conducted within the study Best Estimate Bathymetries (BEB); a lowest seabed level (LSBL); and a highest seabed level (HSBL) were determined. The LSBL and HSBL are the lowest and highest seabed levels that are expected to occur during the lifetime of the

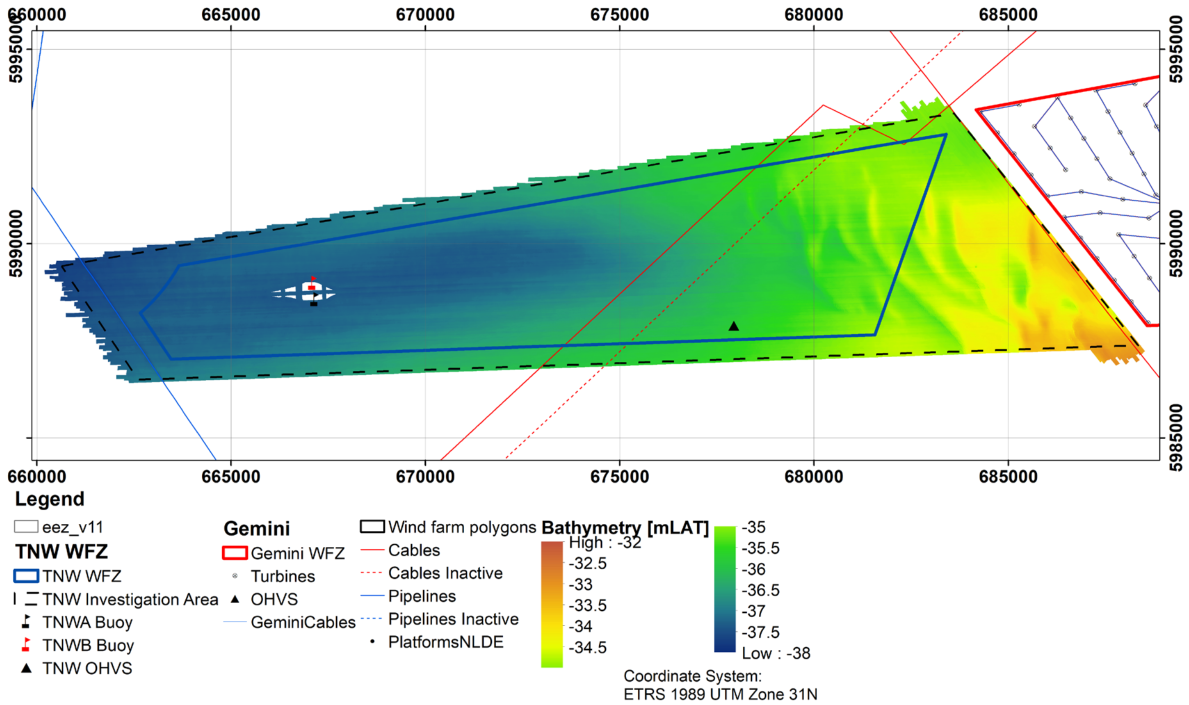


Figure 4.14 *Map view of the bathymetry as measured in 2019.*

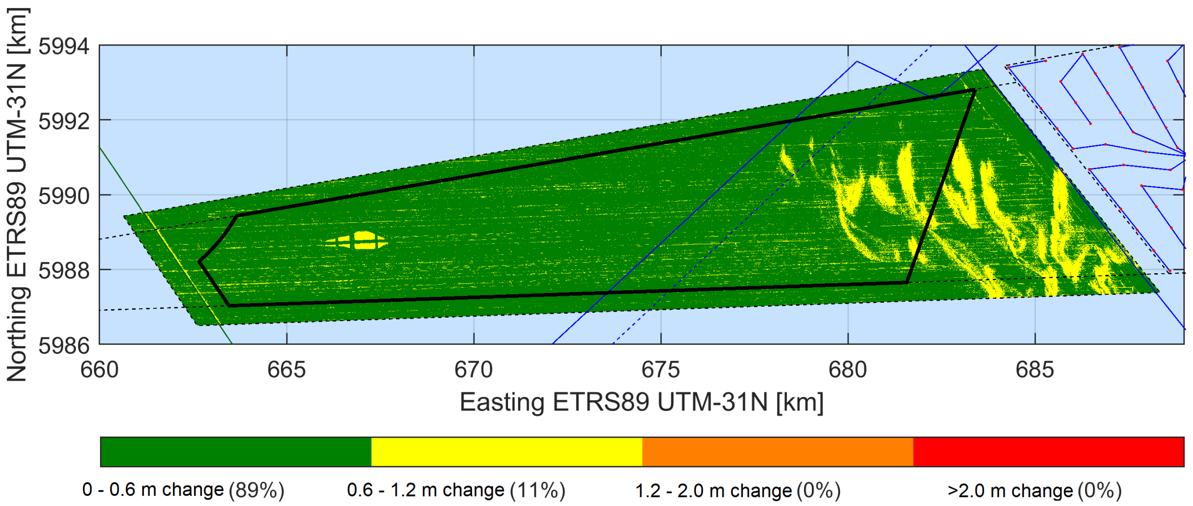


Figure 4.15 *Classification of seabed changes to be expected.*

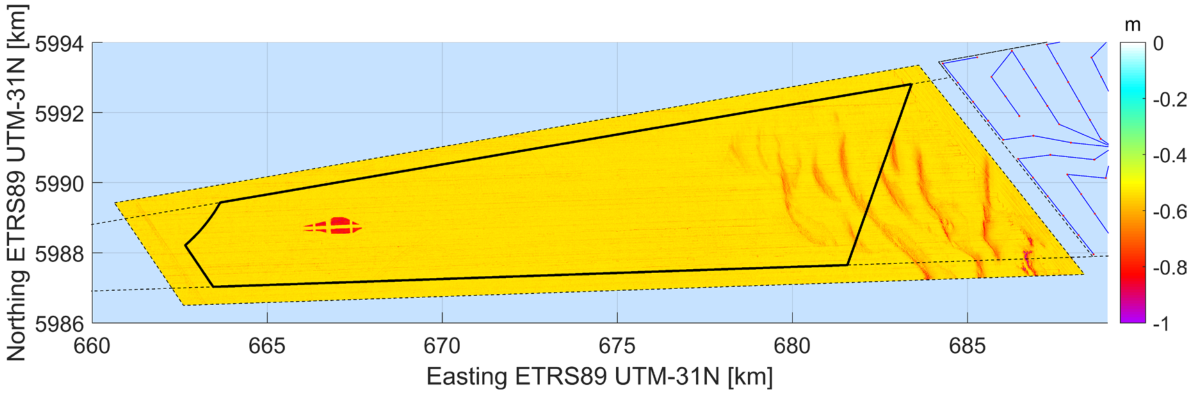


Figure 4.16 *Expected seabed lowering over the period 2019 to 2065.*

wind farm (2019-2065). These levels also include uncertainty bands (Figure 4.16). The Best Estimate Bathymetry for a certain year within this period is expected to have the smallest area-averaged total difference with the actual bathymetry measured in that year.

The overall bathymetry of the LSBL looks very similar to the 2019 bathymetry, but it is typically a few decimetres deeper with slightly less pronounced sand waves. The apparent "sand wave" crests shown in the 2019 bathymetry have the largest expected lowering in seabed level, of up to -0.83 m (as the 99.9%-non exceedance value). The areas with limited seabed mobility have a zero expected lowering when excluding the uncertainty band. The maximum lowering is found at the location of the TNW FLiDAR buoy deployments, though this is likely to be related to higher uncertainties in available bathymetry data for that location.

The overall bathymetry of the HSBL looks very similar to the 2019 bathymetry, but it is typically a few decimetres shallower with more pronounced sand waves. The sand wave troughs of the 2019 bathymetry have the largest expected rise in seabed level, up to 0.69 m (as the 99.9%-non exceedance value). The crests of the sand waves and areas with limited seabed mobility have a zero expected rise when excluding the uncertainty band.

A hindcast of seabed levels has also been made to assess the possible levels at which Unexploded Ordnance (UXO) may be located. An important assumption in this methodology is that an UXO will never travel upwards and a typical UXO will self-bury to about half of its height. To take into account the full range of possible object levels, the Lowest Object Level (LOL), the Highest Object Level (HOL) and the Best-Estimate Object Level (BEOL) over the period 1945-2020 are calculated.

The predicted seabed level changes presented in this study follow from the applied morphological analysis techniques, describing the (uncertainty of the) physics and the natural variability of the analysed morphological system. No additional safety margins for design purposes have been applied. Results of the morphodynamic study are comparable to findings for the neighbouring Gemini wind farm. Finally, classification zones were provided to assist developers in determining the locations of inter array cables and foundations of WTGs and OSPs.

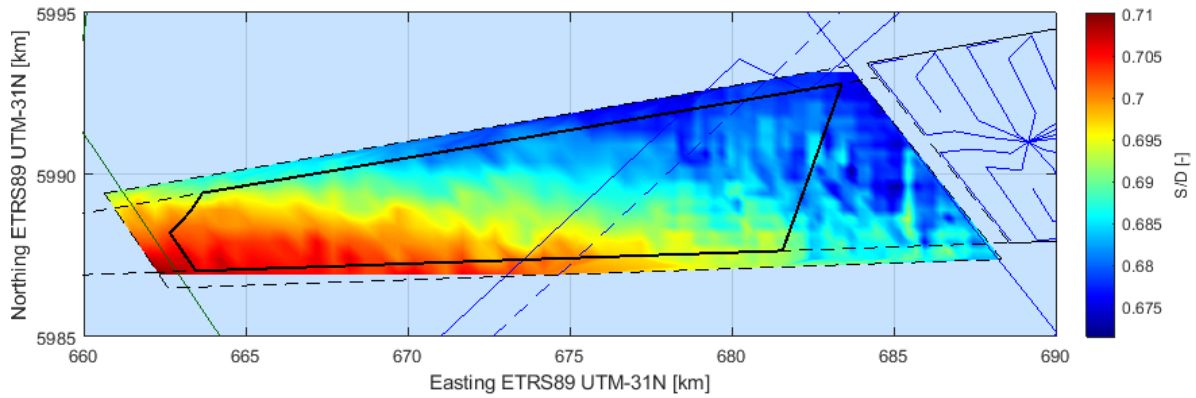


Figure 4.17 *Estimated scour depth/monopile diameter of 10 m in case monopiles are used as foundation concept.*

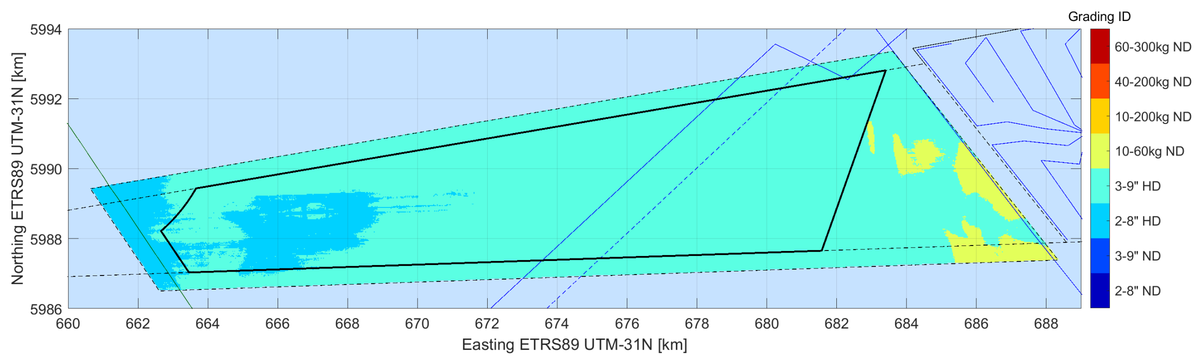


Figure 4.18 *Indicative rock gradings in case of using scour protection consisting of rock.*

4.8.4 Results Scour and scour mitigation

In most situations, offshore structures can either be protected against scour or be designed such that the development of any is tolerable to the design. To decide which strategy is best adopted for a certain foundation type and specific location, information was presented on how to predict the scour depth (when not protected) and how to protect against scour, both taking into account the morphodynamic scenarios of stable, lowering and rising seabeds.

It can be concluded that for monopile foundations an easy-applicable, well-proven solution is to site the monopiles: 1) in areas with limited seabed dynamics; or 2) on top of the sand wave crests and to apply a scour protection to maintain a more or less fixed seabed level around the foundation. In the second case a slightly longer pile or thicker scour protection is recommended to cater for the lowering seabed. Other solutions are also possible, such as leaving out the scour protection completely at locations with a rising seabed, and when scour protection costs exceed the cost of additional steel for the monopile (i.e. a longer foundation). In terms of other typical WTG foundation types:

- Gravity-Based-Structures if used at TNW will most likely require scour protection due to too severe scour development and the low tolerance for scour of this foundation type due to undermining risks. Locations with a significantly lowering seabed are best avoided altogether, however these are in the most part not present within at TNW.
- Jacket structures are also expected to experience significant scour development, but as long as they are not located in areas with lowering seabeds and cable free spanning risks are mitigated by proper cable protection measures (such as application of cable stiffeners) they can be designed for free scour development.
- This does not hold for Suction Bucket Jackets: due to the limited penetration depth of the suction cans and the large scour potential at TNW, scour protection for these foundations is always recommended at TNW. Self-installable systems look promising here.

To illustrate the choice for a proper scour mitigation strategy, for monopiles dynamic equilibrium scour depths (Figure 4.17), stable rock gradings (Figure 4.18) and required scour protection volumes were computed for the entire TNW zone. Additional analyses of the manifestation and measurement of edge scour around the scour protection of the WTG structures at the neighbouring Gemini OWF, which was limited to a maximum of 0.7 m, provided significant insight into expected edge scour dimensions for structures at TNW.

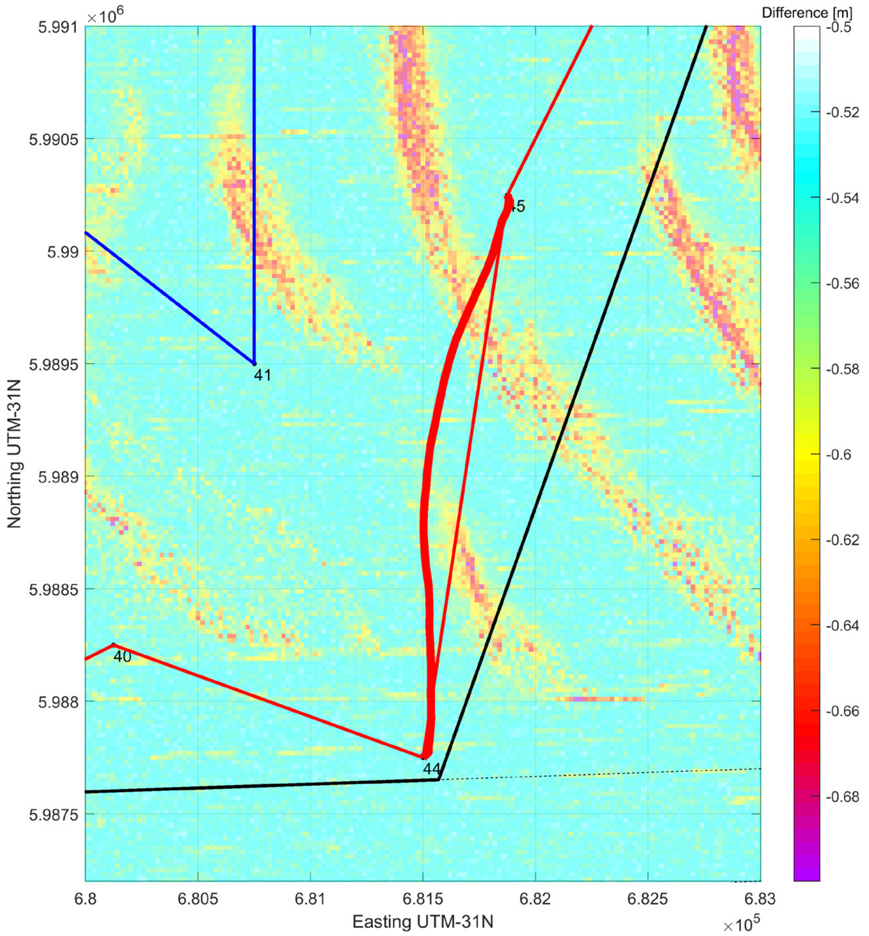


Figure 4.19 *Example of cable route optimisation taking into account seabed dynamics.*

With the provided maps for water depth, maximum seabed lowering, predicted scour depth, stable rock gradings and required scour protection volumes for each location it can be computed which pile length is required, both for the situation that the pile will be protected and for the situation that the pile will be left unprotected. In case of protection, the map plots provide an indication which scour protection is required. With the provided information the wind farm designer can determine the optimum locations for the wind turbine foundations and select a cost-efficient and safe scour mitigation strategy for each foundation. Further optimization for scour predictions and/or scour protection designs can, if warranted, be achieved by means of physical model testing.

In addition to foundations, this report also discusses general considerations for cable routing in a morphodynamic area such as TNW. It is expected that cables can be buried sufficiently deep to avoid cable exposure (Figure 4.19) when smart cable routing techniques are adopted with actual foundation locations and additional constraints added to the routing routines. Although for TNW the expected morphodynamic activity is very limited and the effect of including seabed dynamics in the cable routing is considered to be small, it is strongly recommended that predicted seabed level changes are taken into account.

4.8.5 Deliverables

The results of the morphodynamics and scour mitigation study are summarised in a desk study report and a GIS archive and xyz data. The associated deliverables include:

- General background information regarding morphodynamic seabed features and the seabed characterisation at TNW;
- Geological and geophysical characterisation of the site relevant to the dynamics of the seabed;
- Analysis regarding bed form migration speed and direction, including storm effects;
- Summary of performed numerical modelling for tides and sediment transport;
- Predicted future seabed levels (LSBL, HSBL, BEB);
- Predicted levels where UXO can be expected (LOL, HOL, BEOL);
- Predicted maximum seabed slopes;
- Classification zones and considerations for cables and foundations;
- Recommendations regarding possible scour mitigation strategies for TNW;
- Scour predictions for selected foundations, e.g. monopiles, jacket structures and Gravity Based Structures;
- Map-based estimates for scour depths around monopiles, taking into account spatially varying hydrodynamics and water depth;
- Scour predictions for selected jack-up platforms (for installation purposes);
- Implications of edge scour around scour protections;
- Design requirements for a scour protection;
- Description of scour protection methods, e.g. rock, mattresses, gabions, artificial vegetation, filter units etc.;
- Map-based estimates for required rock gradings and rock volumes, taking into account spatially varying hydrodynamic design conditions, water depth and seabed variations;
- Recommendations for eco-friendly scour protection designs;
- Description of how to deal with cable routing in morphodynamic environments.

4.8.6 Webinar

The study will be presented and discussed during a webinar on 17 February 2022. Please refer to https://offshorewind.rvo.nl/cms/view/be898bea-672f-464c-bfaf-74666cb8c489/soil-tnw for details.

4.9 Metocean measurement campaign

4.9.1 Overview - aims, objectives, and approach

The metocean measurement campaign at the TNWWFZ aims to provide two sets of continuous meteorological and oceanographic (metocean) data including wind profiles with excellent quality and high availability.

It is expected that the data will allow stakeholders to carry out more accurate calculations of the annual energy yield and improve/validate metocean models that have been made as input for the overall wind farm design. Furthermore, it is expected that the resulting accurate wind and metocean data will lead to a lower uncertainty. And, therefore, lower cost of capital in the business case for an offshore wind farm.

Two measurement stations (and alternates) in 36 – 38 m water depth were established at the TNWWFZ (Table 1). Fugro Seawatch Wind LiDAR Buoys (SWLB) were initially deployed at TNWA and TNWB in June 2019.

The SWLB is a compact multiparameter platform to measure wind profile (speed and direction) from 4m to a maximum of 250 m height, air pressure, air temperature and humidity, waves, current velocities profile, and sea surface temperature simultaneously on a single point oceanographic mooring system. The LiDAR wind measurement system is an OWA Carbon Trust stage 2 pre-commercial floating LiDAR system validated by DNV GL.

The buoys are independent of each other but located close to each other to create a redundant system to achieve a full representative overview over wind, currents, waves and atmospheric data in the whole TNWWFZ.

For this campaign, the measurement suite includes:
- wind speed and direction, including turbulence intensity, inflow angles and wind shear and veer at 11 heights in the range of 30 – 250 m above MSL with ZephIR ZX300 LiDARs;
- wind speed and direction at 4 m above MSL (top of buoy mast);
- air temperature and humidity at 4 m level (top of buoy mast);
- air pressure at sea water level;
- significant wave height, mean and peak wave periods, wave direction, and wave spectra;
- current speed and direction at evenly spread depths over the water depth;
- sea surface temperature; and
- water level.

Data measured at each buoy is packed into a digital package that is simultaneously stored on the buoy and transmitted via satellite in near real-time to allow for near real-time operations checks, maintenance scheduling and quality control and reporting. Offshore operations are performed to service the buoys and instruments at regular intervals. Raw wind, wave and current data are then recovered.

4.9.2 Supplier

The metocean measurement campaign is conducted by the SEAWATCH Centre of Excellence of Fugro Norway. With more than 30 years' experience, Fugro is a global leader in design, manufacturing, installation and support services for environmental monitoring, metocean observation and forecasting systems.

4.9.3 Results

The SWLB are robust and have carried out excellent measurements under harsh environmental conditions, including strong winds, high waves, and strong currents. Throughout the campaign, the systems have performed well and delivered high data availability for all parameters.
Precise measurements record events like storms both above and below the sea surface. Figures 4.20 – 4.22 show an example of a high wind period with corresponding wave and current measurements. Changes in wind speed and direction correspond well between the buoys at all heights. Wind sea wave height and wave direction match well between the buoys and can be seen to trail the changes in wind direction as expected. The current velocity data show a consistent semi-diurnal tidal current pattern.
The measurements are validated on a monthly basis by Deltares against several surrounding measurement stations in the North Sea and numerical models. The validation confirms the high quality of the collected data.

Table 4.4 *Positions (ETRS89/UTM zone 31N) of the LiDAR buoys at TNW.*

Station	Longitude (E ETRS89)	Latitude (N ETRS89)	Easting (m UTM zone 31N)	Northing (m UTM zone 31N)	Water depth (m MSL)
TNWA	5° 33.014'	54° 01.089'	667077	5988551	36
TNWA-2	5° 33.8302'	54° 01.0932'	667968	5988591	38
TNWB	5° 32.988'	54° 01.306'	667034	5988952	36
TNWB-2	5° 33.1098'	54° 01. 3044'	667167	5988954	37

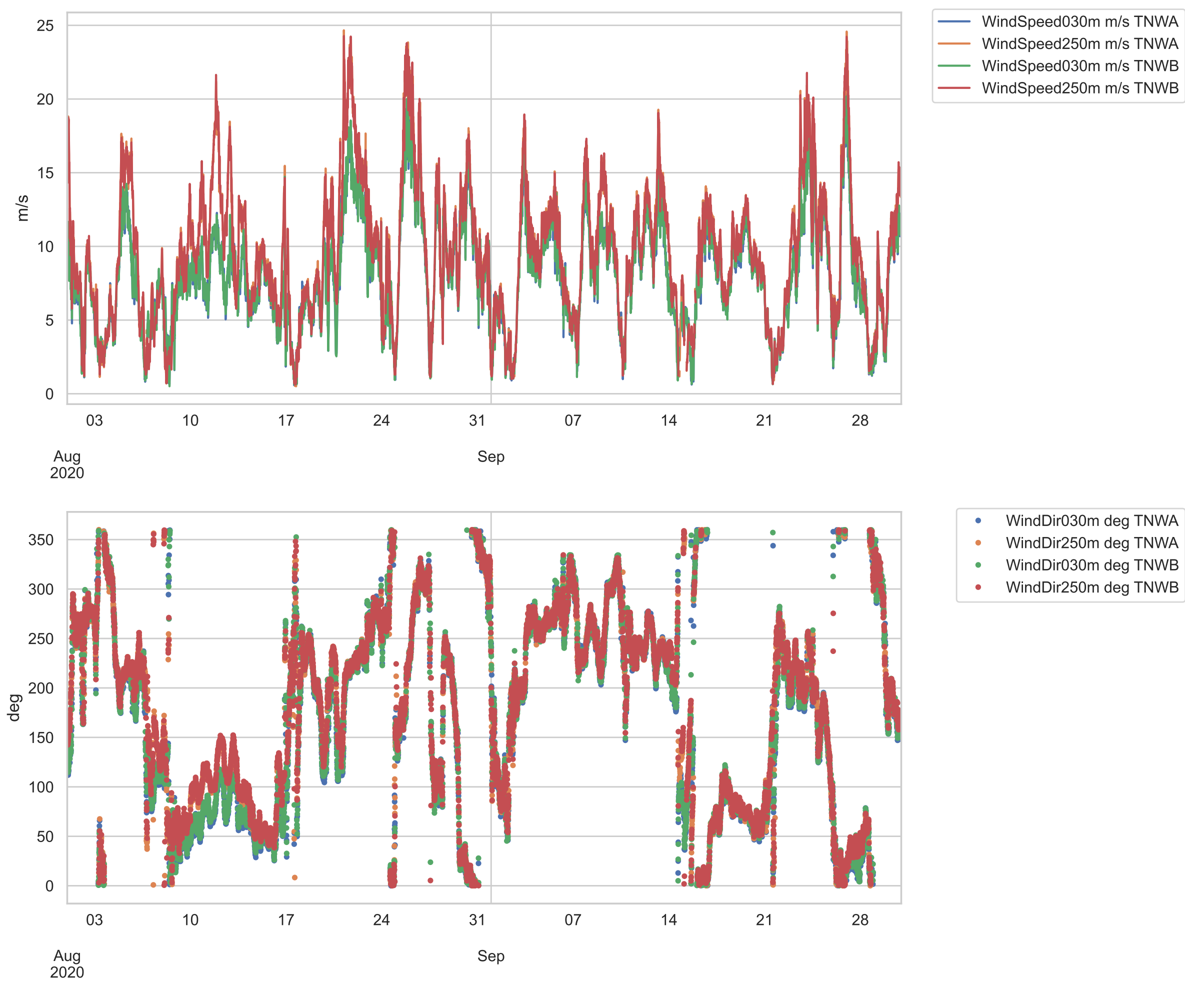


Figure 4.20 *Wind speed and direction measured by the SWLB LiDAR at the highest and lowest heights from stations TNWA and TNWB during August and September 2020. The measurements correspond well.*

4.9.4 Deliverables

The results of the metocean campaign are published on https://offshorewind.rvo.nl/cms/view/c26468f2-f44e-4d01-81c1-bocc3de8787d/wind-en-water-tnw. The data package includes data, a data report and a data validation report. This strict quality assurance procedure assures that the results serve as a high-quality reference for wind climate and metocean studies. In addition, raw wind, wave and current data is provided after each service of the SWLB.

Separate data and reports are available for each month within the 24 month measurement period.For the first full year of the measurement campaign (June 2019 – June 2020), the data are summarized in a 12-month comprehensive dataset. A final dataset and campaign report over all 24 months of data (June 2019 – June 2021) summarizing all processed wind, wave and current data accompanied by a comprehensive validation report has been made available on https://offshorewind.rvo.nl/cms/view/c26468f2-f44e-4d01-81c1-bocc3de8787d/wind-en-water-tnw in January 2022.

4.9.5 Webinar

The setup of the metocean measurement campaign will be presented and discussed at a webinar on 01 February 2022. The webinar will be available on https://offshorewind.rvo.nl/cms/view/c26468f2-f44e-4d01-81c1-bocc3de8787d/wind-en-water-tnw.

Figure 4.21 *Wave height and direction from stations TNWA and TNWB during August and September 2020 correspond well.*

Figure 4.22 *Current speed and direction from stations TNWA and TNWB during August and September 2020.*

4.10 Wind Resource Assessment

4.10.1 Overview - aims, objectives and approach

TNWWFZ has been identified by RVO as an area of potential wind energy development. The site is located in the Dutch Exclusive Economic Zone in the Dutch shelf in the North Sea. It lies approximately 56 km off the north coast of the Netherlands, located in water depths ranging from 29 m to 45 m. The operational offshore wind farms Gemini 1 and Gemini 2 lie to the east of the TNWWFZ.

The study aimed to assess the wind resource across the TNWWFZ to inform possible future investment in offshore wind development. The long-term ambient wind conditions for the development area were analysed on behalf of RVO. The assessment was conducted using state-of-the-art procedures and software, according to industry best practices.

The wind resource assessment was based on a combination of onsite and off-site wind measured data. Measurements were gathered onsite by two floating lidar systems (FLS) labelled TNWA and TNWB. The data collected by the TNW FLS were corrected to remove wakes from the neighbouring Gemini wind farms and were aggregated to compile a wake-free single data-set, called TNW. The aggregated TNW dataset is representative of the measurements gathered within TNWWFZ. These data were supported by the FINO 1 met mast measurements gathered in the North Sea, approximately 61 km east from TNWWFZ.

The TNW dataset was corrected to the long-term by means of an MCP procedure. The ERA5 reanalysis data was applied as the long-term reference dataset. Following the long-term correction, the wind potential across the whole TNWWFZ was determined. This was done with a tailor-made mesoscale model, based on the ERA5 reference data. The mesoscale model was fine-tuned with the short-term measurements and long-term statistics at TNW and FINO 1. As a result, the long-term wind speed and wind direction time-series at the TNWWFZ corner locations and central nodes were derived and analysed.

These long-term results were compared to multiple other mesoscale modelled sources, and wind resource assessments commissioned by RVO at other Dutch North Sea sites.

4.10.2 Supplier

Guidehouse WTTS B.V. (Guidehouse), in cooperation with ProPlanEn GmbH, Arcvera and OWC (Aqualis) GmbH (Consortium referred to as Guidehouse Project Consortium, GHPC) was contracted by RVO to conduct the wind resource assessment. The consortium members were able to utilise their extensive experience in offshore wind resource assessments for this Project, from completing several bank-grade wind resource and energy yield assignments in the Dutch and German North Sea; performing and validating CFD wake modelling for offshore projects. These unique strengths of the consortium members were tailored for the Project by the strong focus on wake effect and blockage experiments and design of a tailored mesoscale model and its validation.

4.10.3 Results

The long-term wind speed at TNW at the height of 140 m was found to be 10.36 m/s with a total associated uncertainty of 4.6%. Meanwhile, the long-term wind speed at FINO 1 was found to be 9.94 m/s at the height of 102.5 m, with a total associated uncertainty of 4.0%.

Based on the calibrated mesoscale model, the short-term calibrated model output was post-processed to obtain synthetic long-term time-series at five (5) selected nodes to describe the spatial variation across the TNWWFZ. The long-term wind speed at the central node (Node 5) within the TNWWFZ was found to be 10.37 m/s at the height of 140 m, with prevailing direction in the southwest (240°) and west directions (270°). The vertical and horizontal variation in long-term wind speed at the TWNWFZ is shown in table 4.5, and the wind frequency rose is shown in Figure 4.23.

The results from the mesoscale model show reasonable agreement with all the different sources.

Table 4.5 *Long-term mean wind speeds within TNWWFZ at various heights.*

Height above LAT [m]	Mean Wind Speed [m/s]				
	Node 1	Node 2	Node 3	Node 4	Node 5
10	8.11	8.10	8.07	8.12	8.12
60	9.60	9.59	9.55	9.60	9.60
100	10.03	10.03	9.99	10.04	10.04
120	10.20	10.20	10.16	10.21	10.22
140	10.35	10.35	10.31	10.36	10.37
200	10.69	10.70	10.67	10.71	10.71
250	10.90	10.91	10.88	10.92	10.92
300	11.02	11.03	11.01	11.04	11.04

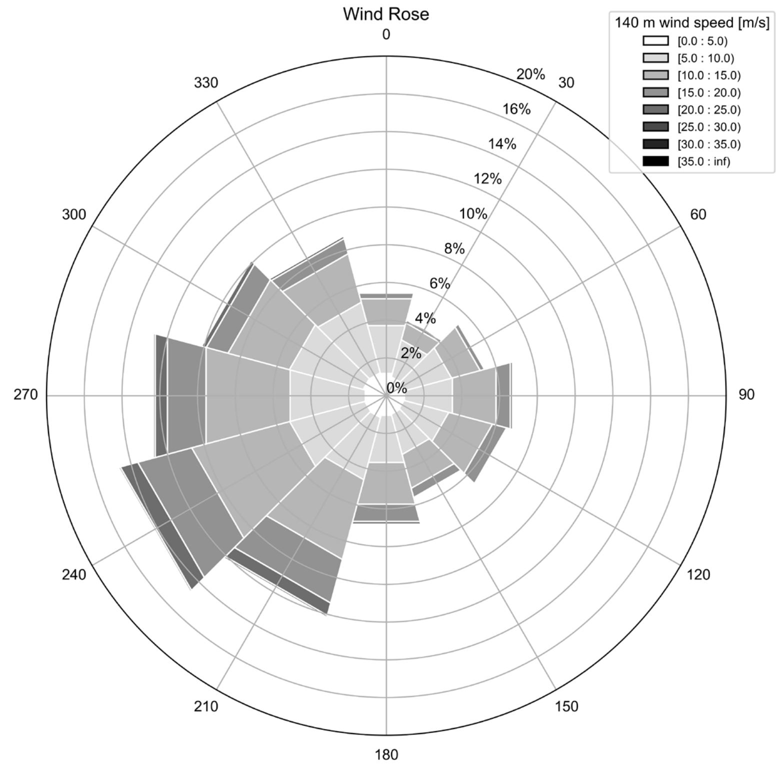


Figure 4.23 *Synthetic long-term Node 5 frequency wind rose at 140 m.*

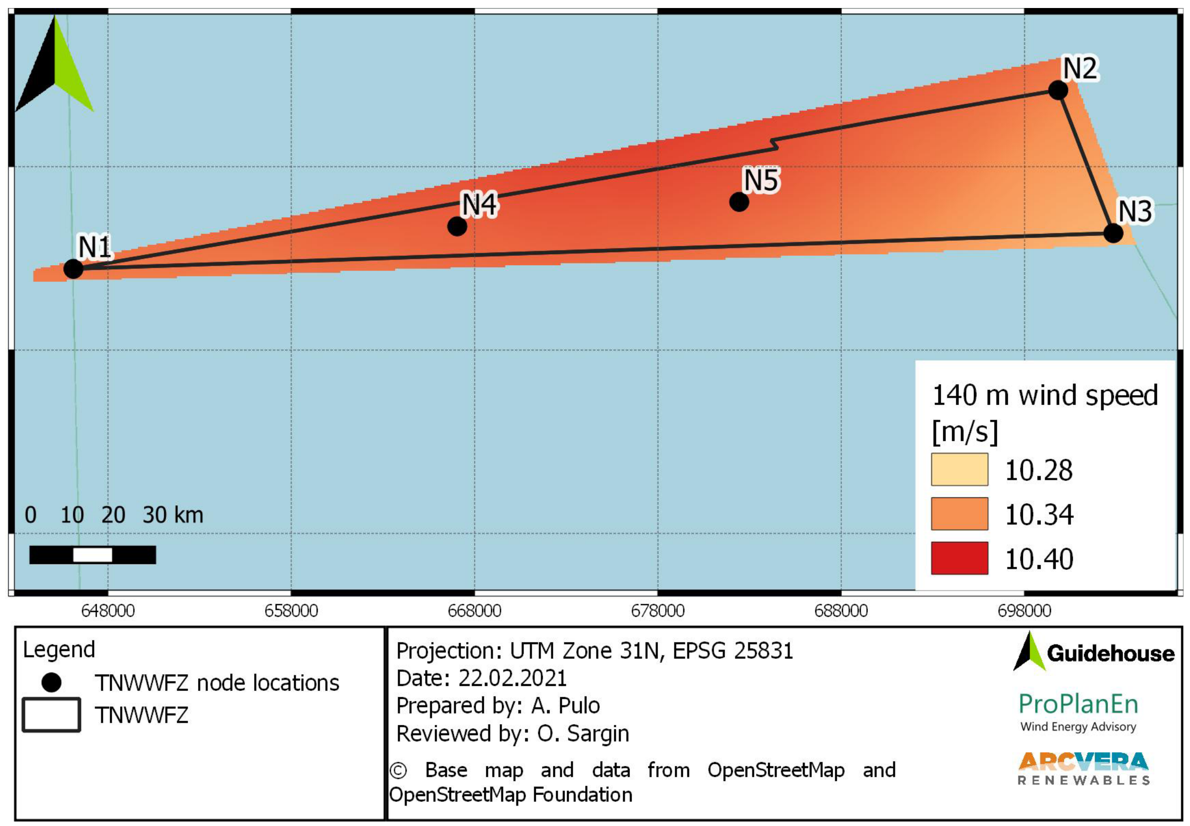


Figure 4.24 *Horizontal modelled long-term wind speed gradient at 140 m at TWNWFZ.*

The spatial variation of wind speed across TNWWFZ is around 0.06 m/s shown in Figure 4.24 and presented in above Table 4.5.

4.10.4 Deliverables

The results of the WRA are summarised in a desk study report. The report includes results for the following:

- Long-term mean wind speeds at heights from 10 m to 300 m
- Long-term mean wind speeds at the height of 140 m at various probability levels (P10 – P90)
- Long-term direction frequency wind rose, and long-term wind shear
- Omni and directional mean wind speed distributions, including Weibull parameters
- Long-term diurnal, monthly, and year to year variations of mean wind speed
- Estimated wake loss and blockage effect due to existing wind farms
- Comprehensive uncertainty assessment

In addition, the spatial distribution of the long-term mean wind speed from the wind resource study conducted is provided as a GIS file. Timeseries are provided at five output locations in and around the TNWWFZ defined for the period of 01 November 2005 to 31 October 2020. Further, a wind resource grid (WRG) output was provided, which is representative of the long-term wind climate, both in terms of wind distribution and magnitude of resource with a spatial resolution of 100 m.

4.10.5 Webinar

The results of the Wind Resource Assessment performed at the TNWWFZ will be presented and discussed at a webinar on February 10, 2022. Please refer to https://offshorewind.rvo.nl/cms/view/c26468f2-f44e-4d01-81c1-bocc3de8787d/wind-en-water-tnw for details.

4.11 Metocean Desk Study

At the time of publication, the final results of the Metocean Desk study were unavailable. Therefore, the desk study is not discussed further in this PSD. Final results will be presented at a webinar in April 2022. Please refer to https://offshorewind.rvo.nl/cms/view/c26468f2-f44e-4d01-81c1-bocc3de8787d/wind-en-water-tnw for the final results when available.

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