Netherlands Enterprise Agency

# Hollandse Kust (noord) Wind Farm Zone

## Project and Site Description

October 2019

>> *Sustainable. Agricultural. Innovative. International.*

Version October 2019

# Contents

# Foreword

**Netherlands reaches major milestone in offshore wind history**

The Netherlands is fully committed to see 49 TWh (about 11 GW) of offshore wind energy per year by 2030. From the start, the Government understood it would take unparalleled dedication, cooperation, and ingenuity to get there. The strategic approach we - Government, industry, and other stakeholders - have taken is unique. Today, we know that approach was the right one.

The first tenders in the Borssele Wind Farm Zone proved successful, with bid prices at record lows, meaning the subsidies required were much lower than expected. The construction of those projects is now well underway. With the Hollandse Kust (Zuid) Wind Farm Zone (2017 and 2018) tenders, we entered a subsidy-free era for Dutch offshore wind energy.

This success stems from our strong market policy, providing clear, long-term project pipelines. Fully consented wind farm sites are handed over to the market. We have taken a hands-on approach whereby the Netherlands Enterprise Agency is responsible for producing high quality site studies and TenneT is responsible for the grid connection infrastructure. Rijkswaterstaat studies ecological impact on a national and international scale. For investors, this approach has reduced risk significantly and boosted confidence. And today, we see other countries around the world hoping to replicate our success.

Following our Roadmap Offshore Wind Energy, I invite the industry to participate in the next tender round for the 700 MW in the Hollandse Kust (noord) Wind Farm Zone. I am confident this wind farm can also be built without the need for subsidy. The recent successful delivery by TenneT of the Borssele Alpha grid connection adds to our confidence and the successful implementation of offshore wind energy in the Netherlands. I would like to thank everyone that is involved for their efforts and contribution.

Much hard work remains to be done. For now, I look to the industry to help us make the development of the Hollandse Kust (noord) Wind Farm Zone another success. I expect to publish the Ministerial Order for the tender of the 700 MW site in the fourth quarter of 2019. This updated project and site description document enables you to now fully optimise your project designs and prepare your bid(s) for the tender. I look forward to reaching a major milestone in our wind energy history with you.

E.D. Wiebes
Minister of Economic Affairs and Climate Policy

# 1.
# Objectives and reading guide

# 1.1 Objectives

This Project and Site Description (PSD) is for any party interested in participating in the planned permit tender for the Hollandse Kust (noord) Wind Farm Site (HKNWFS) in the Netherlands. Compared to previous PSDs, this PSD has been streamlined to provide a more direct focus on project specification and development requirements along with site data (including maps and tables) and site investigation results.

This PSD document therefore summarises:
- A description of the site, surroundings and characteristics of HKNWFS;
- All data collected by the Netherlands Enterprise Agency (RVO.nl) regarding the physical environment of the Hollandse Kust (noord) Wind Farm Zone (HKNWFZ);
- A selection of constraints, technical requirements, and grant related issues that are deemed to be most relevant for development of the Hollandse Kust (noord) area.

This document has been produced for information purposes only and is not intended to replace any legal or formally communicated rules, regulations, or requirements. More information on the site studies, including all reports and other deliverables mentioned in this PSD, can be found at ***offshorewind.rvo.nl.***

Readers should note that information relating to the tender and permit process itself, as well as to the overarching legal frameworks and regulatory decisions pertinent to development of offshore wind projects in the HKNWFZ, will be made available after official publication in the Netherlands Government Gazette. Furthermore, publication of relevant laws and related bid documents and information can be found for ***www.rvo.nl/windenergie-op-zee.*** When the tender is officially opened, the application forms and related bid documents will be available to download at ***www.mijnrvo.nl***

# 1.2 Reading guide

This PSD for HKNWFS presents an overview of all relevant project requirements and site information for parties interested in preparing a bid for a permit to build and operate a wind farm at this site. This PSD covers the following aspects in the different chapters:

Chapter 1: **Objectives and reading guide**

Chapter 2: **Offshore wind power development in the Netherlands.** Background information on Dutch offshore wind development to date, including progress on achieving the goals of the offshore wind energy roadmap 2030.

Chapter 3: **Hollandse Kust (noord) - site description**
General information on the HKNWFZ, the location, and surroundings. Information on the work on the offshore grid connection system by transmission system operator TenneT is included.

Chapter 4: **Site Studies and investigations**
An updated overview of all the studies, surveys, and measuring campaigns performed to date on the HKNWFZ, 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 desk study;
- Wind and Water: Wind Resource Assessment, Metocean desk study, Metocean measurement campaign.

Chapter 5: **Resources for further information**
Useful links for further information or help and a link to the magazine, Hollandse Kust: where wind and water works.

# 1.3 Site investigations quality and certification

### 1.3.1 Procedure

The Netherlands Enterprise Agency (RVO.nl), assisted by BLIX Consultancy, Arcadis, Fichtner, RHDHV and DNV GL, managed the process of site investigations for the HKNWFZ. RVO.nl maintained a quality assurance procedure to provide accurate, practical, high quality studies.
First, the scope of the different studies was determined using the following steps:
1. RVO.nl and the expert support determined the preliminary scope of the different studies. Lessons learned from the site investigations at the Borssele and Hollandse kust (zuid) Wind Farm Zones were taken into account;
2. Where applicable, input was provided on these scope descriptions by internal experts, other governmental departments, agencies, external experts, and the industry (Netherlands Wind Energy Association);
3. At market consultation sessions, the scope descriptions were discussed with market parties with input on completeness provided by the attendees at workshops;
4. The study deliverables were reviewed by internal experts from other governmental departments and external experts;
5. For studies with results becoming part of the design basis for the developer, the accredited certifying body DNV GL was contracted to confirm the completeness of the scope.

### 1.3.2 Procurement

The procurement of the different studies was carried out in compliance with the applicable procurement procedures within RVO.nl. The desk studies have been procured through a limited tender. The site investigations were procured through a public European tender. All proposals were assessed by internal experts, other governmental departments, agencies, and external experts. Contractors were selected on the basis of determining the most economic advantageous offer, with safety, quality, and track record as the primary award criteria.

### 1.3.3 Quality assurance

After procurement, whilst work was being conducted by the specific contractor, quality assurance was performed as follows:

1. A project team, from RVO.nl and external experts, was assigned for each study. The project team monitored that the execution of the scope was in compliance with the scope description;
2. Draft reports and other deliverables were reviewed by internal and independent, external experts;
3. Where applicable, accredited certifying body DNV GL reviewed reports and other deliverables and provided a 'Certification Report' to assure the results were acquired in compliance with DNVGL-SE-0190:2015-12 and other applicable industry standards. Certification reports are added to the published reports where applicable;
4. On a monthly basis a quality certificate by Ecofys/Navigant for metocean campaign HKN is provided.

DNV GL was assigned to ensure the overall quality, completeness, and the consistency between parameters found and used in the different studies.

An overall Statement of Compliance was issued for the complete set of site studies, allowing the studies to be used in the design basis of an offshore wind farm. The following was applied: DNVGL-SE-0190:2015-12 Project certification of wind power plants. By fulfilling the requirements in DNVGL-SE-0190, the Site Assessment Requirements listed in IEC 61400-22:2010-05 Wind turbines – Part 22: Conformity Testing and Certification are also fulfilled.

Based on the measurements and desk studies, DNV GL concluded the site conditions and site studies for HKNWFZ:

- have been established correctly;
- are complete and fulfil the requirements as given in the certification scheme;
- can be used directly as input for design;
- it also found that the risks and uncertainties have been minimised according to state-of-the-art methods.

### 1.3.4 Certification status

Several site studies and investigations for the HKNWFZ have been conducted. All studies and investigations are certified by DNVGL or quality approved. The overall certification has been issued by DNVGL.

**Table 1.1** *The Hollandse Kust (noord) Wind Farm Zone quality assurance*

| Site Studies | Site Study Certification | Overall Certificate |
|---|---|---|
| Archaeological Desk Study | Quality approved | DNV GL Certified |
| Archaeological Assessment | Quality approved | (Oct 2019 update expected) |
| Geophysical Survey | Certification received | |
| Geological Desk Study | Quality approved | |
| UXO Desk Study | Quality approved | |
| Geotechnical Survey | Certification received | |
| Morphodynamics and Scour Mitigation | Certification received | |
| Wind Resource Assessment | Certification received (updated October 2019) | |
| Metocean Desk Study | Certification received (updated October 2019) | |
| Metocean Measuring Campaign | Certification received | |

### 1.3.5 Experts

Experts that have provided input in the process include:

- Arcadis Nederland B.V. (Geotechnical site investigations)
- BLIX Consultancy (Geophysical site investigations, Morphodynamical study)
- DNV GL Denmark A/S (individual certification reports, overall certification)
- DNV GL (GIS)
- DNV GL & RHDHV (Metocean measurements, Metocean desk study)
- Ecofys WTTS/Navigant (Metocean measurements)
- Fichtner GmbH & Co (Wind Resource Assessment)
- Reynolds International Ltd (Geological desk study, Geophysical site investigations)
- RPS Energy Ltd (Geophysical and Geotechnical site investigations, Metocean measurements HSE)
- Ministry of Defence (UXO risk assessment)
- Rijkswaterstaat
- The Cultural Heritage Agency (Archaeological desk study and Archaeological assessment)

### 1.3.6 PSD development

This Project Site Description is developed and improved in cooperation with its users. Please send your feedback via **WOZ@rvo.nl**

### Change Log

Notable changes in comparison to version april 2019:

- Added overall certificate site conditions;
- Received all remaining individual certificates of site studies;
- Updated and Extended Results Geotechnical, Wind Resource Assessment & Metocean Desk studies.

### Archaeological assessment

In the final design of the wind farm, the site is positioned north of the paleo-river valley. In situ prehistoric sites will therefore not be affected by the wind farm installation and additional research is not considered necessary.
Therefore no archaeological research has been conducted on the geotechnical boreholes for this site.

### Scour study

The scour study is incorporated in the morphological desk study for HKNWFZ. This study was a separate technical note for the HKZWFZ.

DNV·GL

# STATEMENT OF COMPLIANCE

Statement No.: SC-DNVGL-SE-0190-04805-0

Issued 2019-07-22

Issued for:

## Site Conditions Assessment

of

## Wind Farm Zone Hollandse Kust (noord)

Comprising:

## Wind Turbines, Substation and Power Cables

Specified in Annex 1

Issued to:

## Netherlands Enterprise Agency

Croeselaan 15
3521 BJ Utrecht
The Netherlands

According to:

**DNVGL-SE-0190:2015-12**
**Project certification of wind power plants**

Based on the documents:

| | |
|---|---|
| CR-SC-DNVGL-SE-0190-04805-01 | Certification Report, dated 2019-07-15 |

Changes of the site conditions are to be approved by DNV GL.

**Hamburg, 2019-07-22**

**For DNV GL Renewables Certification**

Digitally signed by Argyriadis, Kimon
Date: 2019.07.22 17:31:28 +02'00'

in place of
**i.V. Fabio Pollicino**
Service Line Leader Project Certification

DAkkS
Deutsche Akkreditierungsstelle
D-ZE-11053-01-00

By DAkkS according DIN EN IEC/ISO 17065 accredited Certification Body for products. The accreditation is valid for the fields of certification listed in the certificate.

**Hellerup, 2019-07-22**

**For DNV GL Renewables Certification**

Digitally signed by Asp, Erik
Date: 2019.07.22 16:10:30 +02'00'

**Erik Asp**
Project Manager

The accredited certification body is Germanischer Lloyd Industrial Services GmbH, Brooktorkai 18, 20457 Hamburg.
DNV GL Renewables Certification is the trading name of DNV GL's certification business in the renewable energy industry.

# 2.
# Offshore wind power development in the Netherlands

**The Netherlands started developing wind energy technology in the mid 1970's and has been a key player ever since, both onshore and offshore, along the whole supply chain. In fact, the Netherlands was one of the first countries to install wind turbines offshore: in 1994 the Lely offshore wind farm was installed in the shallow waters of the 'IJsselmeer' and comprised four 0.5 MW NedWind 40/500 turbines which had a rotor diameter of 40 m. Two decades later we surpassed all earlier expectations, entering a period of zero-subsidy development for offshore wind in the Netherlands.**

## 2.1 Roadmap to 2030

In September 2014, the Government published its first roadmap towards 4,500 MW (4.5 GW) of offshore wind in the Netherlands. This sets out a schedule of tenders offering 700 MW of development each year in the period 2015 - 2019, with all wind farms to be fully operational by 2023. Borssele and Hollandse Kust (zuid) were allocated 1,400 MW each, with 700 MW allocated for Hollandse Kust (noord). This PSD for Hollandse Kust (noord) concerns the final 700 MW planned under the first offshore wind road map.

In light of the success of the first roadmap, the Dutch Ministry of Economic Affairs and Climate Policy announced a roadmap to 2030. This calls for the deployment of an additional 7 GW of offshore wind by 2030. This brings the Netherlands' total offshore wind capacity to 11,5 GW. RVO.nl and transmission system operator TenneT have already started preparations for the first Wind Farm Zone to be developed under the 2030 roadmap, Hollandse Kust (west). The Government foresees 1.4 GW in this zone.

The Dutch approach provides greater certainty for project developers, increases investor confidence, and drives down overall costs. RVO.nl has maintained its emphasis on providing more complete and high-quality site data. We have followed a thorough quality assurance procedure for the Holandse kust (noord) site investigations, including verification against applicable standards by accredited certification bodies. The next zone planned under the new roadmap is Ten Noorden van de Waddeneilanden, where 700 MW is planned. After this the third zone under the 2030 roadmap, IJmuiden Ver, is planned. Here around 4 GW is planned. The wind farms in the first two zones will most likely be connected to the grid in a similar way as prescribed under the current road map: using 700 MW platforms, infield voltage level 66 kV, exported to shore with 220 kV AC. RVO.nl will provide a set of site data comparable with those for HKZWFZ and HKNWFZ.

By 2022, the Netherlands is forecast to be one of the largest offshore wind market in terms of annual installations and offshore wind markets in terms of cumulative installed capacity. The Government conducts public consultations with stakeholders (e.g. environmental and nature conservation and other industries such as shipping, fishing and recreation as well as the wind industry) to further develop the 2030 roadmap and related legal frameworks, including where the final 0.9 GW should be allocated. The designation of (and corresponding assessment and decision regarding) the new wind farm zones will ultimately be implemented in an amendment to the National Water Plan or under the National Environmental Vision.

**Table 2.1 Roadmap 2030 schedule**

| Capacity (GW) | Wind farm zone | Shortest distance from the coast | Tender | Year of commissioning |
|---|---|---|---|---|
| **1.4** | Hollandse Kust (west) | 51 km from Petten | 2021 | 2024 to 2025 |
| **0.7** | Ten noorden van de Waddeneilanden | 56 km from Schiermonnikoog | 2022 | 2026 |
| **4.0** | IJmuiden Ver | 62 km from Den Helder; 80 km from IJmuiden | 2023 to 2025 | 2027 to 2030 |

*Please note: the schedule assumes the developments will fit within the ecological frameworks and that the permit procedures for the export and supply of electricity into the high-voltage grid will have been completed in a timely manner.*

## 2.2 Zero-subsidy breakthrough with Hollandse Kust (zuid)

For the HKZWFS I and II (2017), III and IV (2018) tenders the Government decided to invite companies to submit zero-subsidy bids. This decision was made in light of the decreasing bids in the Netherlands (for the Borssele wind farms) and in Denmark as well as companies submitting zero-subsidy bids for similar projects in Germany. The decision to see if companies could develop projects without the subsidies originally anticipated for the HKZWFZ proved right. Vattenfall was confirmed as the zero-subsidy winner for both tenders HKZWFS I, II and HKZWFS III, IV. These offshore wind farms will be the first built without state subsidy anywhere in the world. The first wind power is foreseen in 2022.

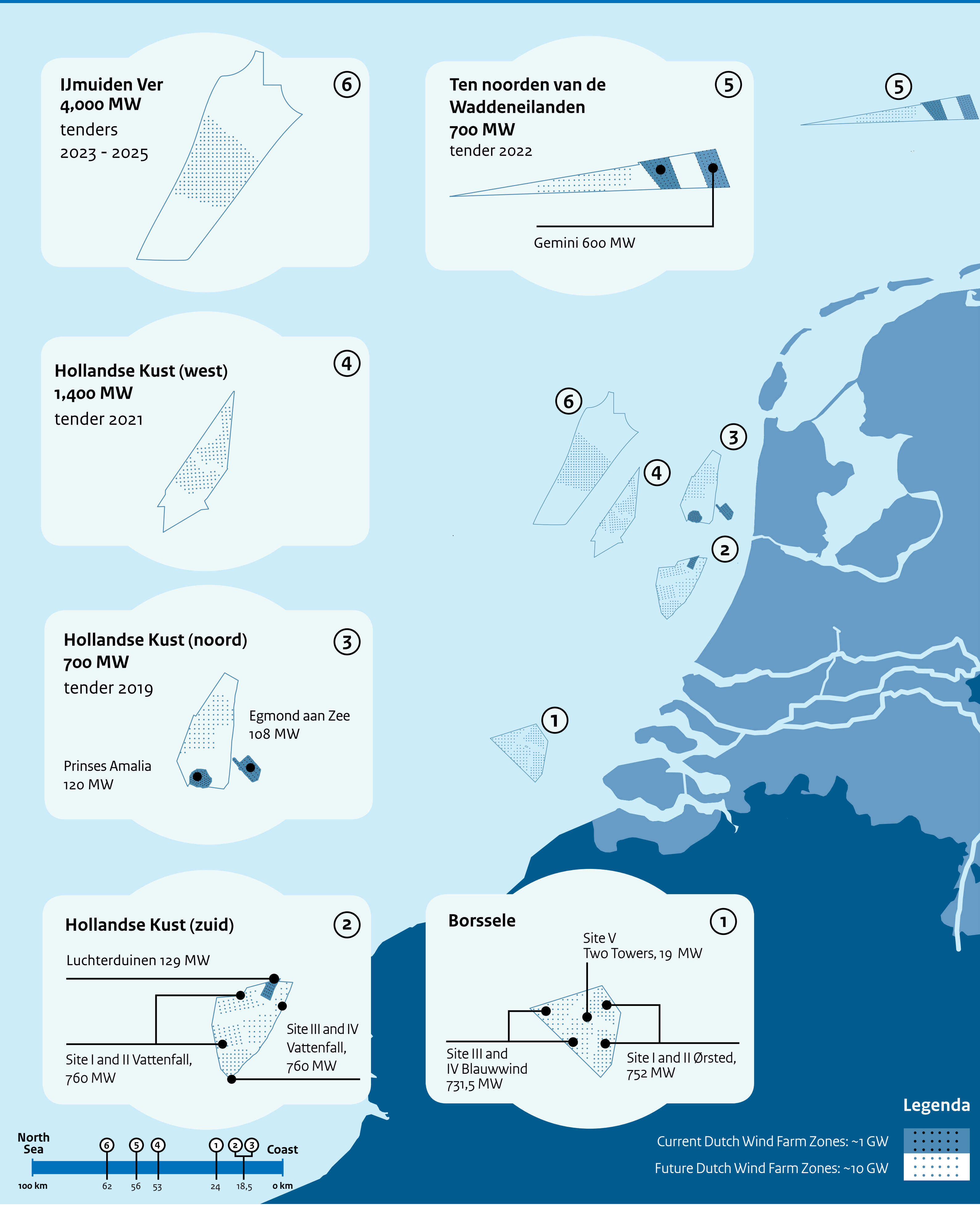
## 2.3 Wind and water works

The publication of the 2030 roadmap reconfirms the national commitment to providing a robust, cost-effective and sustainable offshore wind market. There will be trade opportunities related to the growth of offshore wind energy elsewhere in Europe, as well as in Asia and America. With all of this momentum, we work with the sector to expand the industry here in the Netherlands and across the globe.
Wind & water works (www.windandwaterworks.com) reflects the expertise and professional approach of Dutch companies and government in the field of offshore wind energy. The Dutch have centuries of experience working offshore. We are familiar with the specific conditions above and below sea level and have used that knowledge to create a successful Dutch offshore wind energy supply chain.
In this chain, small and large companies work with our world-leading knowledge institutions to constantly develop innovative solutions for offshore wind farms.

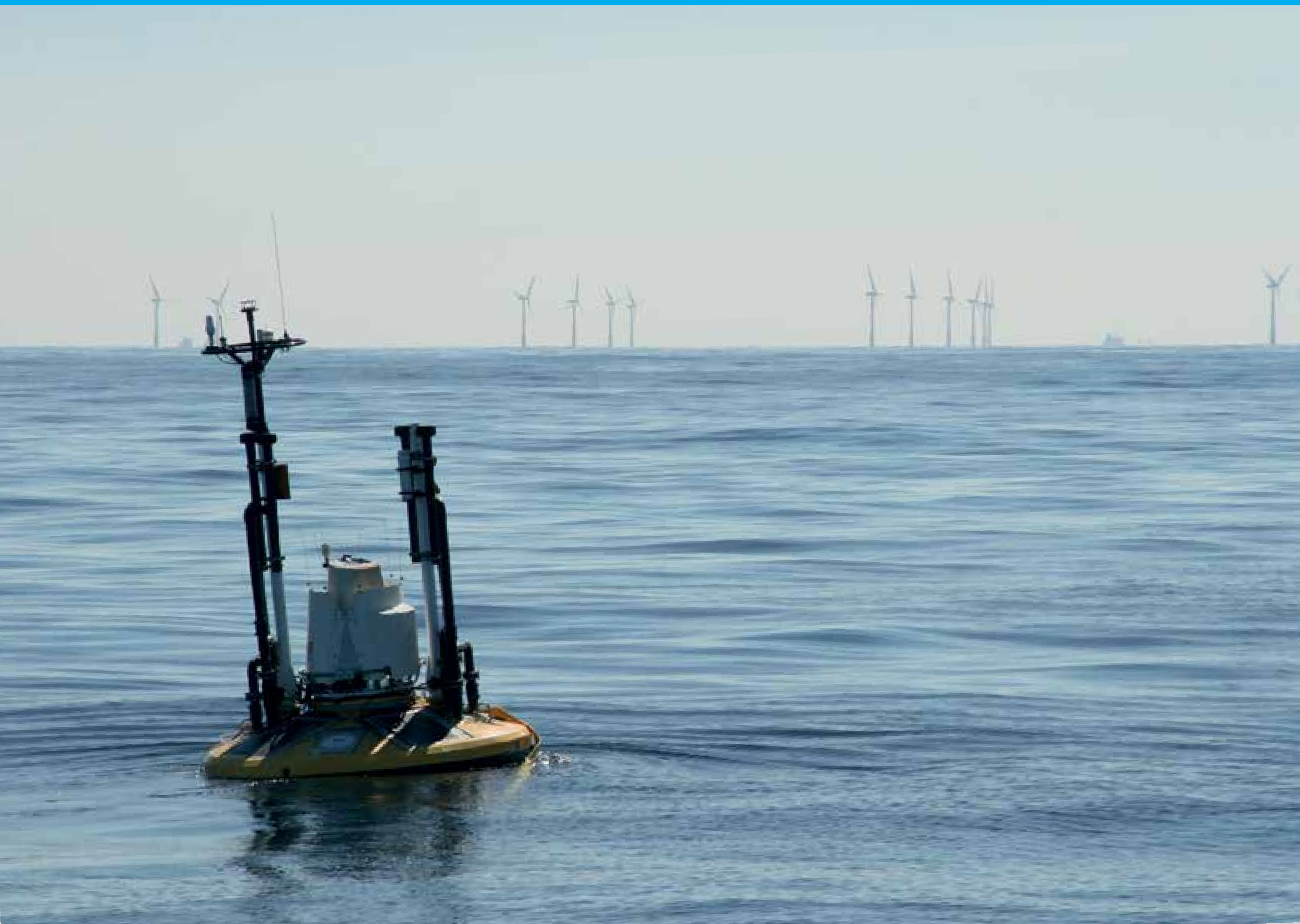
Together, we are proving that offshore wind is a powerful solution to achieve our climate goals cost effectively. Our approach provides greater certainty for project developers, increases investor confidence, and drives down overall costs. It requires dedicated teamwork, collaboration, and innovation across the board to ensure every wind farm has a safe and sustainable future. We are keen to share our knowledge with others.

wind & water works

# Dutch Offshore Wind Farm Zones



# 3.
# Site description and offshore grid



## 3.1 General description of the Hollandse Kust (noord) Wind Farm Zone

Covering an area of 290.1 km2, the Hollandse Kust (noord) Wind Farm Zone (HKNWFZ) shown below in Figure 3a is a designated wind farm zone located off the province of Noord-Holland. It is enclosed by the main shipping routes. There have been sand extraction areas in HKNWFZ, while others are in the vicinity of the HKNWFZ. The HKNWFZ encloses the Prinses Amalia Wind Farm, operational since 2008, in the south part of the zone. One wind farm is planned for the HKNWFZ in total.

## 3.2 Layout and coordinates of HKNWFS

The HKNWFS covers an area of 126.4 km2. The area includes the maintenance zones of infrastructure (active cables crossing the site). This reduces the effective area available for new wind farm construction. On this basis, the effective area available for HKNWFS is 93,7 km2. Part of the HKNWFS is located within the 12 nautical miles zone. The boundaries of HKNWFS, all coordinates tables for boundaries, maintenance zones, infield cable corridors and safety zones are published in appendix C, Memo Boundaries and Coordinates.

## 3.3 Existing infrastructure

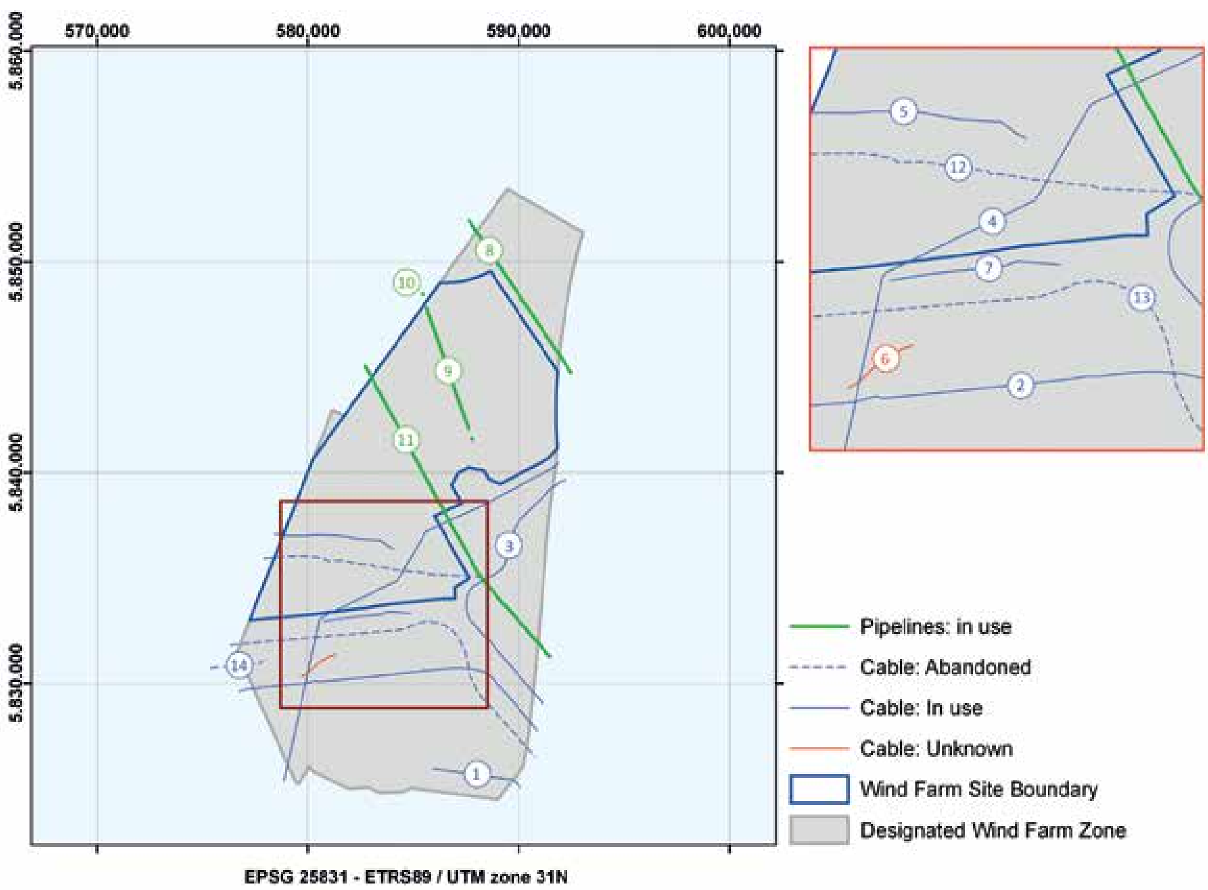
### 3.3.1 Cables and pipelines

There are planned cables, several active and inactive existing cables and existing pipelines crossing the Wind Farm Zone. These can be seen in Figure 3a. The description of pipelines and cables in HKNWFZ can be found in appendix C.

### 3.3.2 The nearby Amalia Wind Farm

The Amalia Wind Farm, commissioned in 2008 and operated by Dutch energy company Eneco, is located within the HKZWFZ. The coordinates of the windturbines can be found in appendix C.

**Figure 3a** *The Hollandse Kust (noord) Wind Farm Zone and surrounding areas*



### 3.3.3 Offshore platforms and other near by activities

There are several existing platforms and boreholes (both active and inactive) in or around the HKNWFZ.

### 3.3.4 Exclusion zones

A 500 m safety zone is defined around the HKNWFZ. No construction ships or building activities are allowed in this safety zone. Pipelines and cables, including their maintenance zones (500 m on both sides of the pipelines/cables), are also excluded from the site. The turbines need to be constructed and located in such a way that their blade tips are within the site boundaries and outside the maintenance zones. There are not any shipping corridors within the HKNWFZ. However, under the National Water Plan 2016-2021, vessels up to 24 m are allowed to cross the entire area (under conditions).

## 3.4 TenneT offshore grid connection system

The Ministry of Economic Affairs and Climate Policy formally designated TenneT as offshore grid operator in the Netherlands on September 6, 2016. The Electricity Act 1998 introduced a 'Development framework for the offshore grid', which provides a technical framework and outlines the future development of offshore wind energy in the Netherlands. The Development framework for the offshore grid was published by the Ministry of Economic Affairs and Climate Policy and amended in September 2018.
As prescribed in the Development framework and elaborated on in the offshore Quality and Capacity Document, published in December 2017, TenneT will build grid connections for the 3,500 MW new offshore wind capacity planned under the offshore wind roadmap 2023.

To create economies of scale, TenneT will construct five standardised substation platforms, each with a capacity of 700 MW. These platforms will be connected to the national extra-high voltage grid with two 220 kV export cables per platform. Output from HKNWFS will be connected to a single platform. The planned location of the platform is shown in Figure 3b, while Table 3.1 shows its coordinates.
Infield cables from the wind farm at HKNWFS will connect directly to this platform. Cable entry zones are designated as the area to place infield cables connecting the wind farm to the platform. This zone is confirmed for HKNWFS in the Wind Farm Site Decision. The Hollandse Kust (noord) platform will transform the power of HKNWFS from 66 kV to 220 kV and transport the electricity to shore through the two 220 kV export cables, which will connect to the planned onshore substation Beverwijk in the Development Framework, which will be made availabe in Appendix A. The contracts for platform and cables are currently (2019) being tendered by TenneT. A table in Appendix C shows the border coordinates of the export cable corridor.

## 3.5 Realisation Agreement and Connection and Transmission Agreement

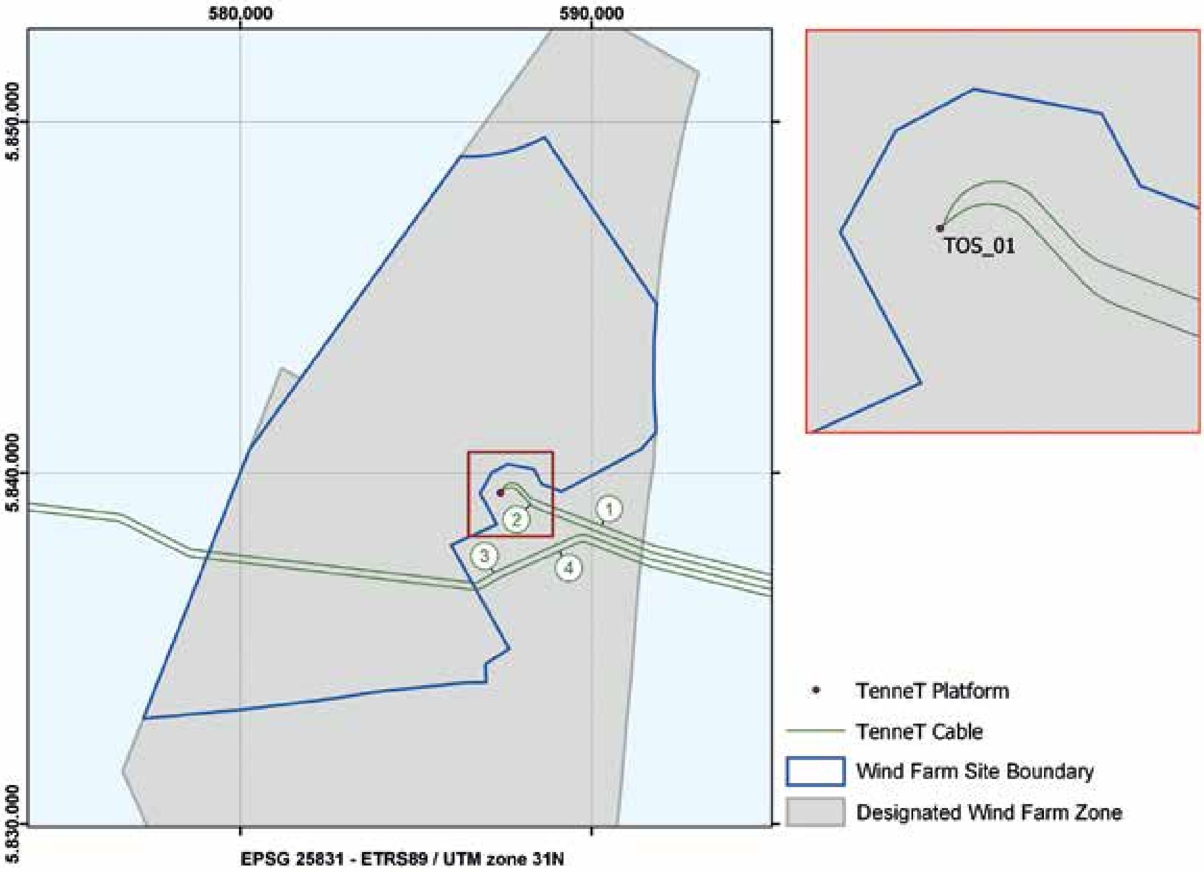
In close consultation with the offshore wind industry, the Ministry of Economic Affairs and Climate Policy, ACM, and representatives of the Dutch energy market, TenneT has developed an offshore legal framework consisting of so-called model agreements. Consultation sessions of these model agreements were open to all stakeholders of the offshore grid and this consultation was finalised ahead of the first subsidy tender process (2016). The model agreements consist of a Realisation Agreement and a Connection and Transmission Agreement supported by Offshore General Terms and Conditions, in line with onshore practice. All model agreements are available for parties to be connected to the offshore grid (see www.tennet.eu/netopzee). The model for these agreements will basically be the same for all winners of the tenders (past, present and future). All agreements will be entered into force according to the model agreements published by TenneT.

The agreements will be concluded on an equal basis with the parties concerned in accordance with the model which has been consulted. For the sake of completeness: the content of these agreements is non-negotiable. The missing data in these agreements will be completed in close consultation with the parties with whom TenneT enters into agreements.

**Table 3.1** *Planned TenneT Platform HKN*

| Planned TenneT Platform HKN ETRS 1989 UTM Zone 31N EPSG 25831 | | |
|---|---|---|
| Point No. | Easting | Northing |
| TOS_1 | 587,410.1 | 5,839,436.2 |

**Figure 3b** *The Hollandse Kust (noord) Wind Farm Zone TenneT Platform*




# 3.6 Applicable codes

The generic technical requirements for offshore wind farm connections are established as technical code requirements, and as such are based on public law. In December 2018, ACM concluded and published a major revision of codes, affecting both onshore and offshore technical regulations. Further generic technical requirements by TenneT can be found in the annexes to the model agreements.

# 3.7 Step-by-step process to connection

RVO.nl will, when requested, organise an introduction for the winner of the tender with RVO.nl, Ministry of Economic Affairs and Climate Policy, Rijkswaterstaat and TenneT. After this introduction, TenneT will invite the winner for bilateral meetings to start the connection process with the necessary steps for connecting a wind farm to the offshore grid:

- The winner of the tender will provide TenneT with the missing data as indicated by TenneT in the Realisation Agreement and the Connection and Transmission Agreement;
- TIn case TenneT's 220 kV export cables and the offshore wind farm 66 kV cables should cross or near each other, cable crossing and/or proximity agreements will need to be arranged between the tender winner and TenneT; TenneT will process the data received in the agreements and provide fully completed agreements to the winner;
- After the agreements have been signed by both parties, the parties will consult on the joint planning, and further information exchange and coordination will take place in the project working group (as referred to in Article 6 of the Realisation Agreement);
- Completion of the platform is scheduled in Q1 2023;
- Timely conclusion of the agreements is vital to effecting the connection to the offshore transmission grid according to the planning and to benefit from cost reduction opportunities during the construction of the offshore grid and especially the platform;
- RVO.nl will hand over all remaining samples of the geotechnical survey;
- Rijkswaterstaat will coordinate the Maritime Information Services. Several sensors for public use will be placed on the platform. The opportunity exists for the winner to add individual systems for its offshore wind farm operation.

# 4.
# Site Studies

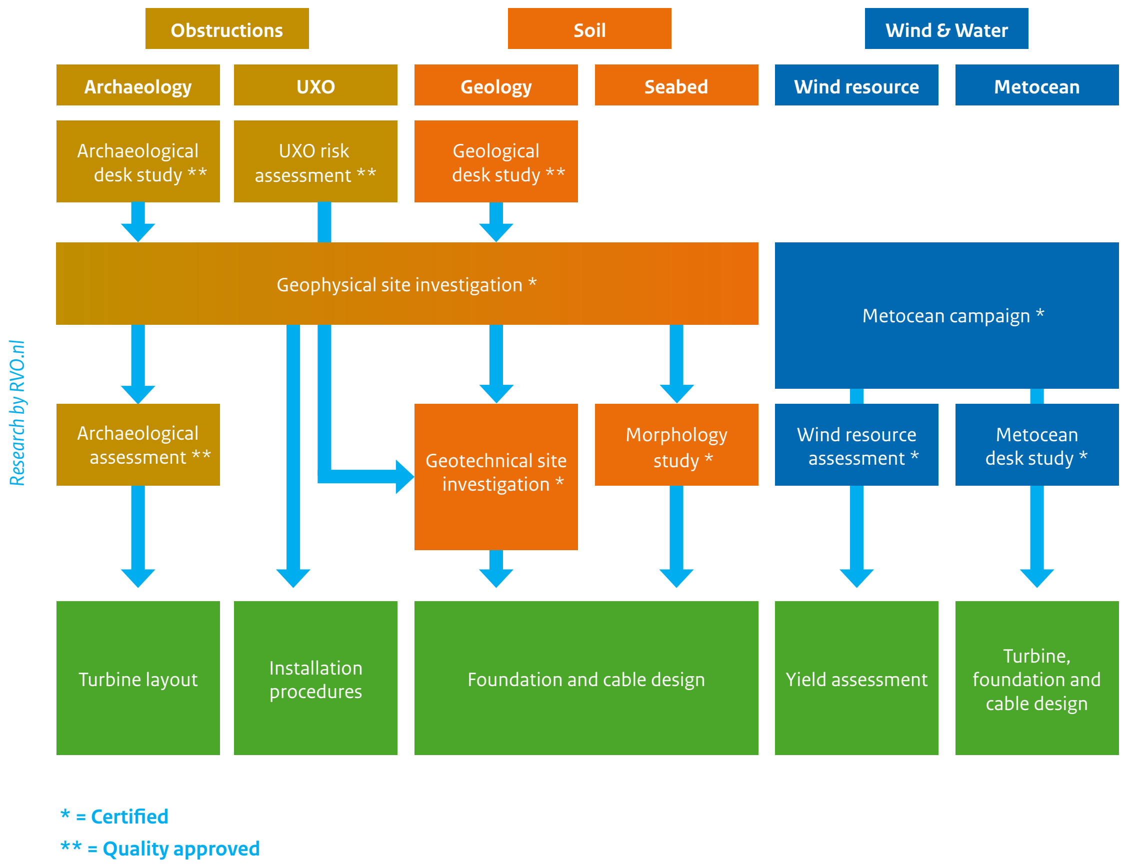
**The Netherlands Enterprise Agency (RVO.nl) is responsible for publishing the site information companies require to prepare bids for the permit tenders for the HKNWFZ. The site information package has sufficient detail and quality to be used as input for preliminary engineering design studies.**

Results from previous tenders show that 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 desk study;
- Wind and Water: Wind Resource Assessment, Metocean measurement campaign, Metocean desk study.

Figure 4a 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 study were used to define the scope of work and basis of the geophysical site investigation. The results of this more detailed 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. Meanwhile, the wind resource assessment takes into account the findings of the metocean measurement campaign. This PSD for HKNWFZ includes a summary of the results of all final studies and site investigations.

**Figure 4a** *Site studies and investigations for the Hollandse kust (noord) Wind Farm Zone*



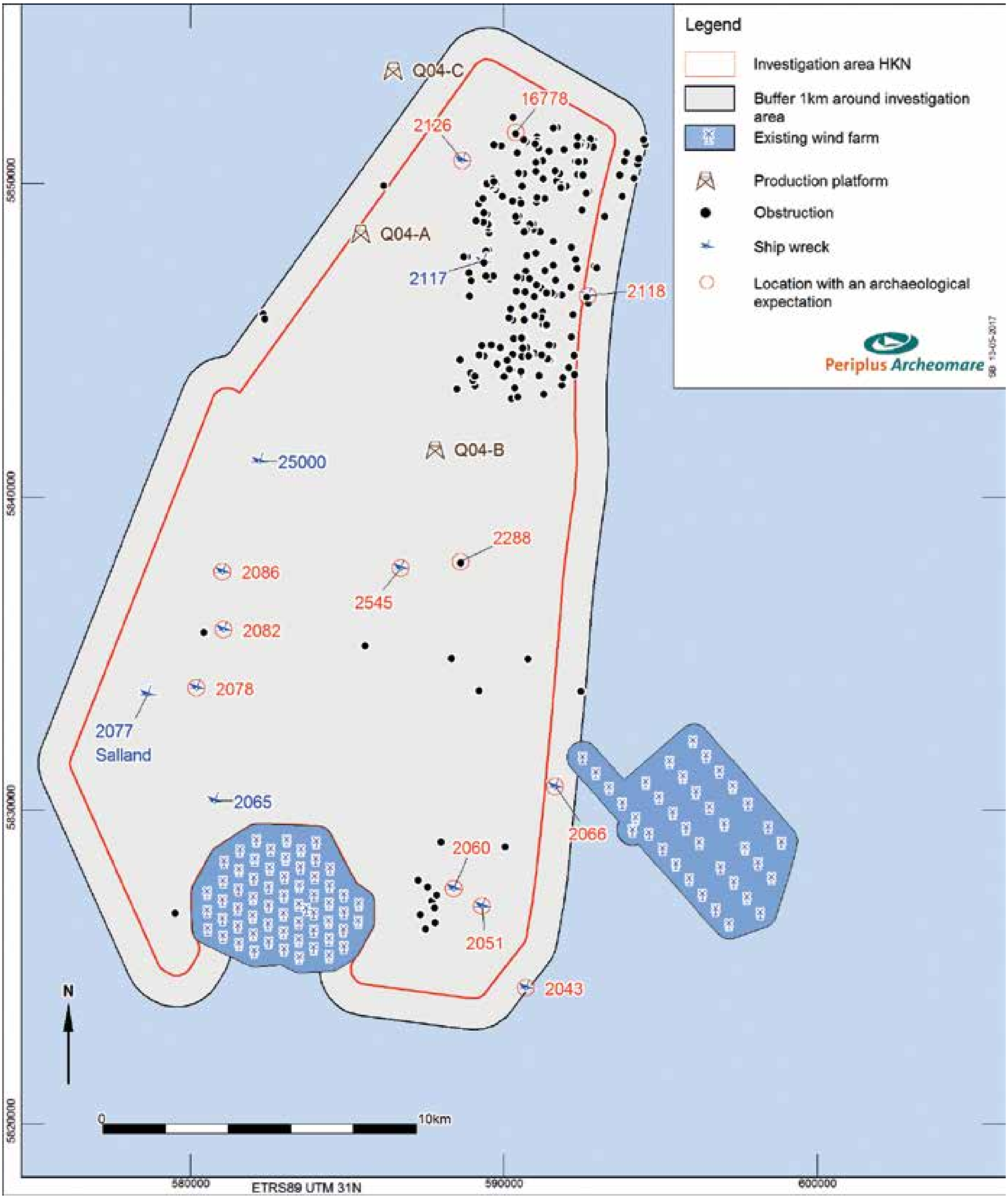



**Figure 4b** *The maritime archaeological desk study of the Hollandse Kust (noord) Wind Farm Zone indicates that 14 shipwrecks are to be expected in the area. Four wrecks have been identified and are not considered to be of archaeological value. The other registered wrecks (10) lack detailed information. The exact location, ship name, ship type, date of sinking, and the archaeological value is unknown. Additional information on these wrecks can be obtained by the execution of a geophysical site survey.*

# 4.1 Archaeological desk study

### 4.1.1 Overview - aims, objectives and approach

The purpose of this study was to provide insight into any archaeological aspects that may have an impact on the development of the HKNWFZ. To meet this goal (For example figure 4c), 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:

- Assess whether archaeological remains (e.g. plane and ship wrecks or prehistoric remains) are present, or likely to be, at the HKNWFZ.

If present:

- Describe the known information (location, size and dating) of these remains;
- Assess the possible risks of the offshore wind farm development on these remains;
- Assess options to mitigate disturbance on these remains;
- Determine whether further archaeological assessments should be carried out and make a recommendation on the scope of future investigations;
- 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

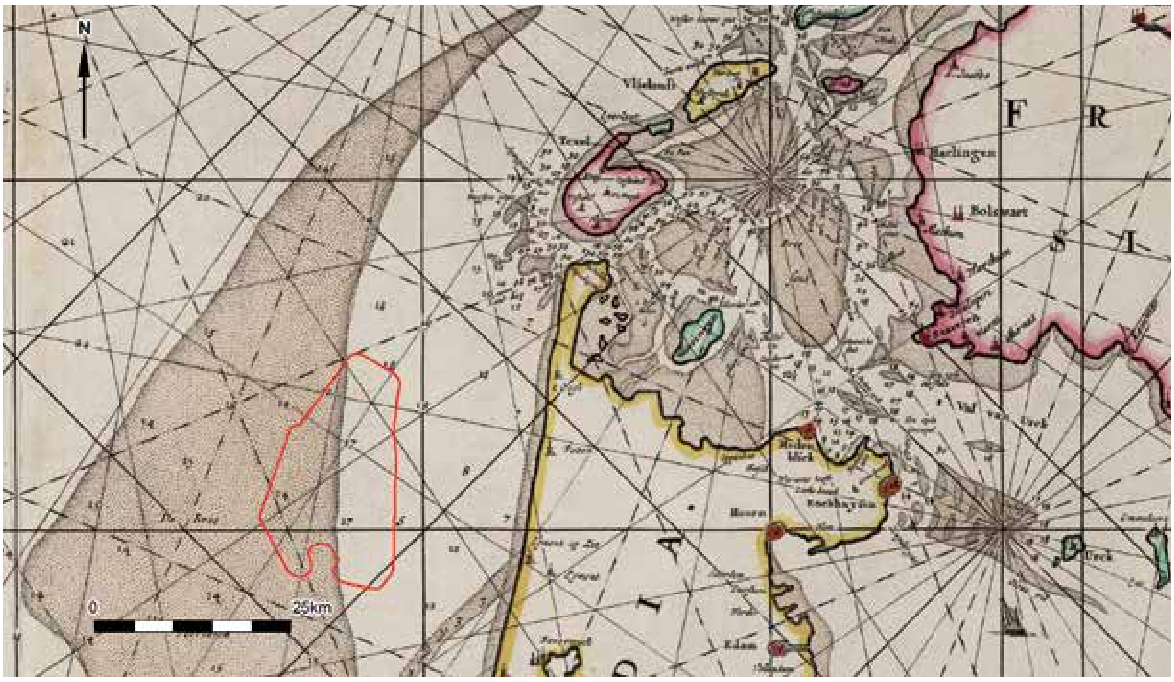
Periplus Archeomare was assigned by RVO.nl to conduct a maritime archaeological assessment of the HKNWFZ. This company has a track record in maritime archaeological preparatory research, most notably the archaeological desk study and assessment of geophysical data for the Q5 and Q7A sand extraction areas, both of which are located within HKNWFZ.

### 4.1.3 Results

The studied wreck databases indicate that 14 known shipwrecks are present in the HKNWFZ (Figure 4b). In addition to known wrecks, the area may contain remains of undiscovered shipwrecks or WWII aircraft.
The desk study also concluded that in situ remains of prehistoric sites may be present. Prehistoric camp sites are to be expected in situ in Pleistocene cover sand dunes and ridges (Wierden Member) and river dunes (Delwijnen Member), provided these units are un-eroded. The Pleistocene landscape is covered by Holocene deposits of which the Basal Peat Bed and Velsen Bed might contain well-preserved lost objects and dumps. The archaeological levels of interest are located under a cover of the Bligh Bank Member.

Parts of the research area have been investigated in previous geophysical surveys. During the geophysical survey for sand extraction area Q05, two locations were classified with a possible archaeological expectation. Over 90% of HKNWFZ has not, however, been investigated by detailed geophysical surveys previously.

**Figure 4c** *Historic chart of the Hollandse Kust (noord) Wind Farm Zone and its surroundings*



### 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 and plane wrecks, mostly resulting from WWII.
Periplus Archeomare recommends further exploratory field investigation should be conducted in order to:

- Map the location of known and unknown wreck sites in detail to be able to assess their archaeological value; and
- Create an inventory of the parts of the HKNWFZ that have not been investigated in previous surveys.

The findings of this desk study have served as a starting point for subsequent investigation, most notably the geophysical site investigation (section 4.4) and, following that, an archaeological assessment of the geotechnical site investigation (section 4.6). The results of this desk study are now to a large extent superseded by the findings of these reports.

## 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 2017, provides the 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 HKNWFZ as a result of the presence of UXOs;
2. Identify areas within the HKNWFZ where wind farmcon-struction 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 Wind Farm Zone
   - 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 and Persian Gulf, performing data analysis, project risk assessment, and coordination of UXO clearance activities. Moreover, the company has performed the UXO desk study for the Borssele and Hollandse Kust (zuid) Wind Farm Zones and export cable routes.

### 4.2.3 Results

The UXO risk assessment study consists out of two sequent phases: historical research (1) and UXO risk assessment (2). The historical research delivers essential input for the risk assessment. According to the historical research, the HKNWFZ and surrounding areas were the scene of many war-related activities during World War I and World War II. Historical research in The National Archives (Kew, London) and Bundesarchiv-Militärarchiv (Freiburg, Germany) has shown mining operations took place in and near the HKNWFZ in World War II, but the mines were only partially recovered after the war (Figure 4d).

Furthermore, during the Allied bomber raids in World War II, a great many bombers flew towards targets in Germany or German occupied territory. On their way back, bomber crews often ditched remaining aerial bombs in the North Sea. Attacks on convoys off the Dutch coast were also executed by Allied planes armed with bombs, rockets and torpedoes. At least two German convoy routes passed through the area where the HKNWFZ is located.

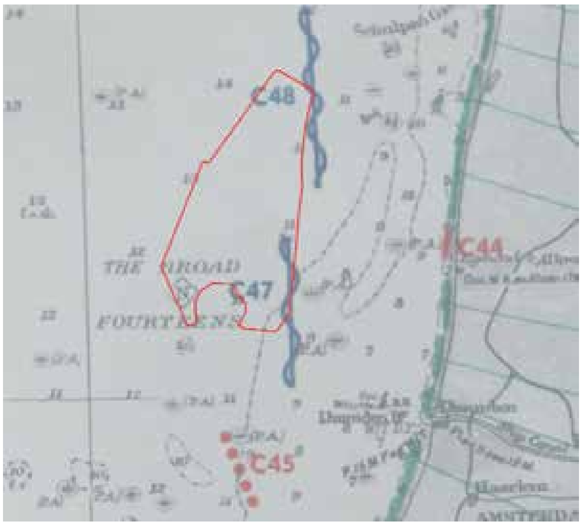



**Figure 4d** *The HKNWFZ site and the overlap with two German mine fields (Source: annex 6, BAMA, ZA 5/50).*

The outcome of the historical research points towards a presence of aerial bombs in the HKNWFZ. This is also true for artillery shells in the part of the HKNWFZ that overlaps with an army shooting range. According to the consulted historical sources, types of mines which may be present are German moored mines and sweep obstructers, along with British moored contact mines and moored acoustic mines.
It must be taken into account that this overview is based on the minefields actually present in (the vicinity of) the HKNWFZ. Since the war, some ordnances are likely to have moved as a result of fishing, wave and current loads and seabed dynamics. The entire Wind Farm Zone is considered a UXO risk area. This conclusion is supported by the fact that, since 2005 fishermen have found three UXOs within the HKNWFZ and

eleven in its vicinity. However, the types of mines mentioned in the additional research are considered the most plausible types of mines to be present.

Once the historical research is completed, the risk assessment starts. 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).

A main challenge in UXO risk management at HKNWFZ 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 Conclusion and recommendations

UXOs, mainly World War II, are likely to be present at the site, which is therefore considered a UXO risk area. Due to the types and sizes of UXO likely to be present, there is no 'silver bullet solution' for the UXO geophysical survey (Figure 4e). The provisional thresholds in the geophysical survey needed to mitigate the risk to a level that is considered ALARP. Due to the highly dynamic soil morphology and possible associated migration and burial of UXOs, it is recommended 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. Due to the time-limited nature of findings and the required survey demands (dense grid spacing), a dense magnetometer survey to detect UXOs was not part of the geophysical survey performed by RVO.nl. However, the survey does include a magnetometer survey on a grid spacing of 100 m.

### 4.2.5 UXO removal procedure

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 Risk Assessment desk study for HKNWFZ were presented and discussed at a webinar in May 2019. Please refer to the website, offshorewind.rvo.nl/obstructionsnh.

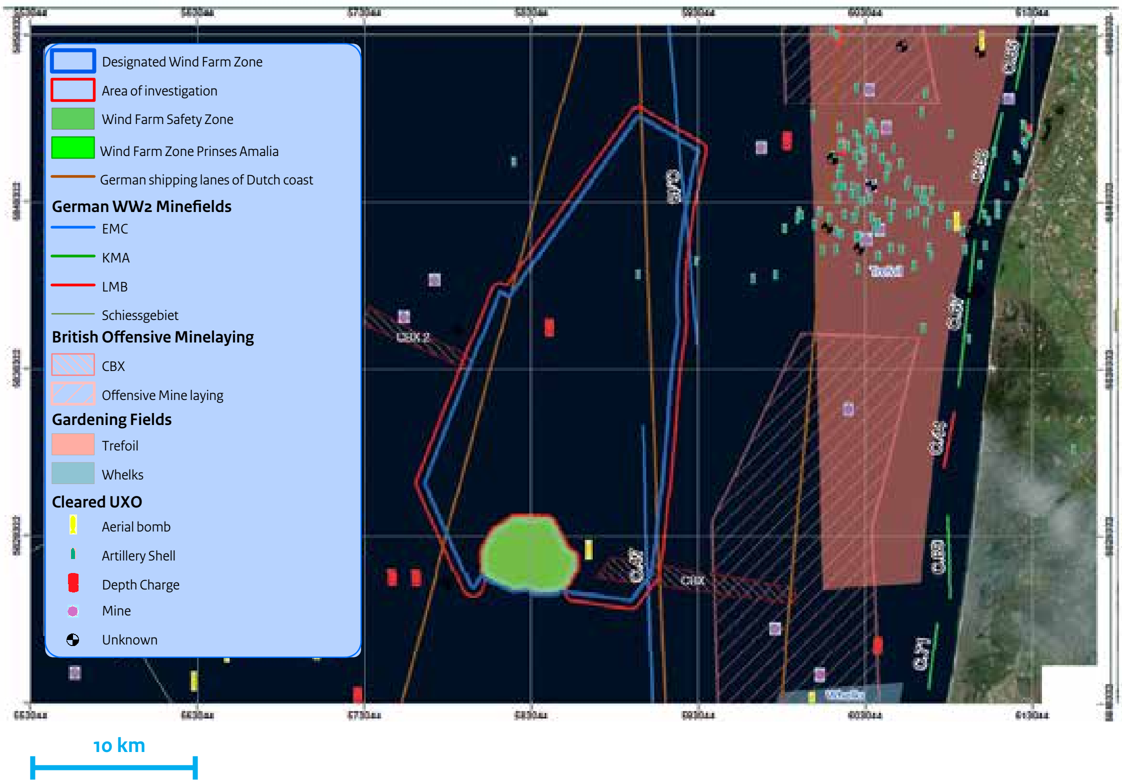



**Figure 4e** *The HKNWFZ site and the overlap with two German mine fields (Source: annex 6, BAMA, ZA 5/50).*

# 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 Hollandse Kust (noord) Wind Farm Zone (HKNWFZ) was designed to improve the bathymetrical, morphological and geological understanding of the area. The results were then used for planning a geotechnical campaign, whilst the geological interpretation from the geophysical survey was integrated with the results of the geotechnical assessment of the geophysical survey results campaign to produce a ground model for the wind farm site. The ground model will serve as the base for the design and installation of support structures and bases.

Specifically, the aim of the geophysical survey was to:

1. Obtain an accurate bathymetric chart of the development area HKNWFZ;
2. Identify or confirm the position of wrecks, pipelines, possible electrical cables, and natural objects;
3. Produce isopach charts showing the thickness of the main geological formations, including any mobile sediments and any other significant reflector levels which might impact on the engineering design;
4. Locate and identify any structural complexities or geo-hazards within the shallow geological succession such as faulting, accumulations of shallow gas, buried cables, etc;
5. Provide detailed geological interpretation showing facies variations and structural feature changes via appropriate maps and sections;
6. List the exact position of existing (active & inactive) cables and pipelines;
7. Provide proposed positions for a geotechnical sampling and testing programme following the completion of the geophysical survey;
8. 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: the first, from 30 July to 01 September 2017, used survey vessel MV Fugro Gauss, whilst MV Fugro Meridian was used in the second period from 12 September to 03 November 2017. Equipment used to carry out the investigation included single beam echo sounder (SBES), multibeam echo sounder (MBES), sidescan sonar (SSS), magnetometer (MAG), sub-bottom profiler (SBP), single channel ultra-high resolution sparker (SC-UHRS) and multichannel ultra-high resolution sparker (MC-2DUHRS).

### 4.4.2 Supplier

Fugro was contracted by RVO.nl to conduct the geophysical survey of the HKNWFZ. Fugro is an integrator of geotechnical, survey, subsea and geosciences services.

Services are designed to support engineering design and large structure building projects. The company has previously performed investigations for offshore wind farm projects in The Netherlands, Belgium, United Kingdom, Denmark and Germany. The company is familiar with the local conditions and technical requirements for a geophysical survey of the HKNWFZ. DNV GL was contracted to review the study results and provide certification of the results.

### 4.4.3 Results

#### *4.4.3a Bathymetry and seabed features*

The water depth varies across the site from a minimum of 14.9 m LAT in the south-easternmost part of the HKNWFZ to a maximum of 28.1 m LAT in the central part of the HKNWFZ. The bathymetry shows a dynamic morphology characterised by a complex pattern of bedforms. The seabed is homogeneously covered by megaripples, generally WNW-ESE orientated crests. Occasionally, WNW-ESE orientated sand waves are present, superposed by megaripples. Sand waves occur in the SW, central and N half of the site, exhibiting seabed gradients of up to 14.1°. The lee side of the sand waves is orientated toward the north, indicating a predominant current direction from south to north. Additional to these bedforms, transverse to the general flow direction, the HKNWFZ is characterised by large NNE-SSW orientated tidal sand ridges. The crests of the sand waves and megaripples run approximately perpendicular to the trending of the tidal sand ridges (Figure 4f).

The interpretation of the sub-surface was based on multi-channel ultra high resolution seismic (MC-2DUHRS), single channel ultra high resolution seismic (SC-UHRS) and sub-bottom profiler (SBP) data, to a depth of 100 m below seabed. Five units were identified and interpreted in the HKNWFZ. Generally, the sediments within this area are heterogeneous, from fine to coarse sands and gravel, with minor clay and possible presence of peats, but they were deposited in different environments. Unit A and B were deposited in a shallow marine to coastal plain environment. Unit C was deposited in an intermixed environment from fluvial to glacial. Unit D and Unit E in a fluvial/tidal environment.

*4.4.3b Wrecks, cables and pipelines*

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

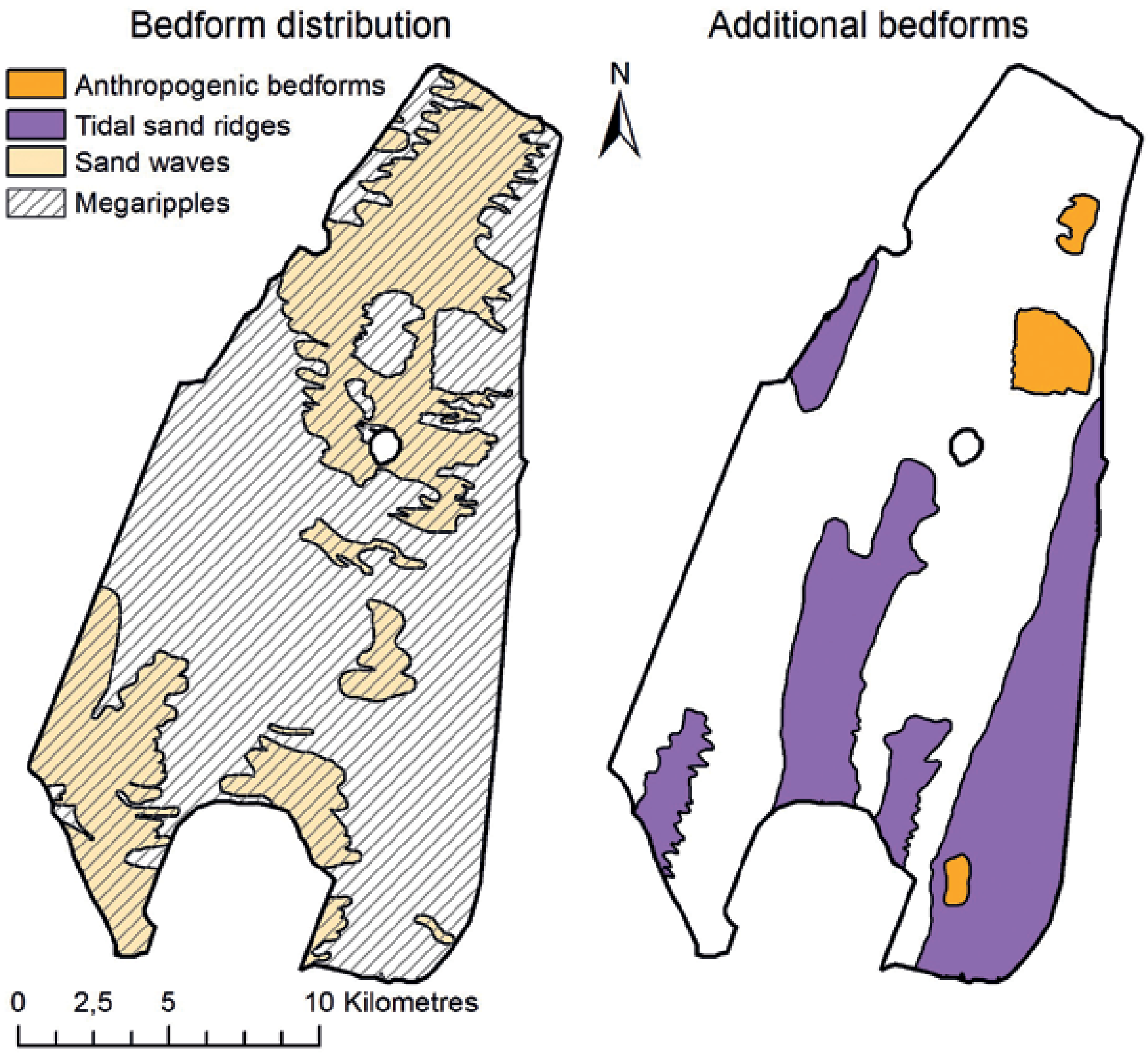
Nine cables and four pipelines were detected in the HKNWFZ, which represent all the cables and pipelines in the provided database. In addition, several aligned magnetometer targets were observed in the south-west of the wind farm zone, which may represent a potential unknown cable.

Six wrecks were identified in the HKNWFZ, all of which can be correlated to wreck positions in the provided archaeological desk study. Seven additional wrecks listed in the database were not, however, detected during the survey.

A previous jack-up drilling location was identified by three spud-can impressions in the north-east of the HKNWFZ Three dredged zones were observed in the HKNWFZ: two in the NE and one in the SE. The dredged areas are classified as anthropogenic bedforms.

Four rock dumps are located within the HKNWFZ. One is located at the TAT 14 Seg J crossing with the Helm to IJmuiden pipeline. Another rock dump is located at the Atlantic Crossing 1 Seg B2/Helm to IJmuiden 20-inch Oil Pipeline. The third one is located at the Q4-B to Q4A 12-inch gas flexible whilst the fourth rock dump is at the Q4-C to Wijk aan Zee 10.7-inch gas pipeline.

**Fig 4f** *Bedform distribution overview and additional bedforms.*



The following structures are located within the HKNWFZ: The Q-4B platform is in the central part, the Q4-A platform is on the north-eastern boundary and the Prinses Amalia Wind Farm is in the south. Debris and boulders were observed within the HKNWFZ: as well as 136 SSS contacts, which one debris field, 27x significant debris objects and 11x significant boulders, either 5 m and more in length or 0.5 m and more in height.

1713 magnetometer contacts were detected with magnetic anomalies ranging from 2.7 nT to 11,417 nT. Most of the stronger anomalies are associated with cable and pipeline crossings, especially the Helm to IJmuiden 20-inch oil pipeline. A large number of the smaller anomalies are scattered throughout the HKNWFZ. Furthermore, it should be noted that few high amplitude magnetic anomalies were observed across the HKNWFZ. However, they cannot be correlated to any pipeline or cable.

The geophysical survey identified several sub-seabed geohazards in the survey area. Palaeochannel infills were identified across the base of Unit B and Unit C. Channelling and palaeochannel infills are heterogeneous and indicate high spatial soil variability. They can pose an engineering hazard due to abrupt (lateral and vertical) changes in mechanical soil properties within short distances. Moreover, coarser and glacio tectonised sediments could be present within the HKNWFZ throughout the Pleistocene units (C, D and E), resulting in a high lateral variability in soil properties.
Possible boulders were identified within Unit C and the uppermost part of Unit D. Peat layers were identified at the base of Unit B, and within Unit C and Unit D/E. Seismic indications of possible fluid pressure (liquid or gas) within surficial sediments were observed within Unit A (figure 4g/4h/4i).

The geophysical results were used for planning a geotechnical campaign. The geological interpretation from the geophysical survey was integrated with the results of the geotechnical assessment of the geophysical survey results campaign to produce a ground model for the wind farm site.

**Figure 4g** *Seismic anomalies and possible gas charged sediments (left). Palaeochannel on H05 and H10 (right)*

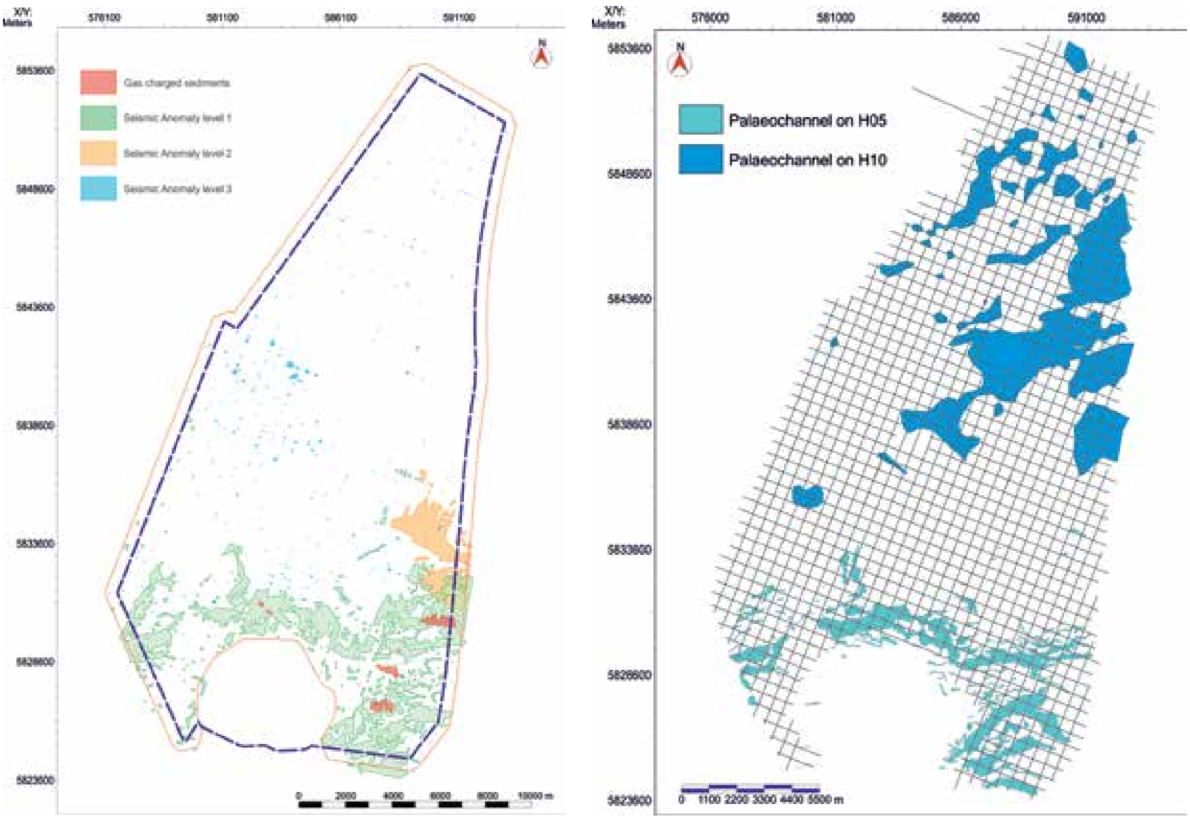


**Figure 4h** *Overview of units A to E' and Local stratigraphy (MC-2DUHRS Line V5-X-S6500A)*

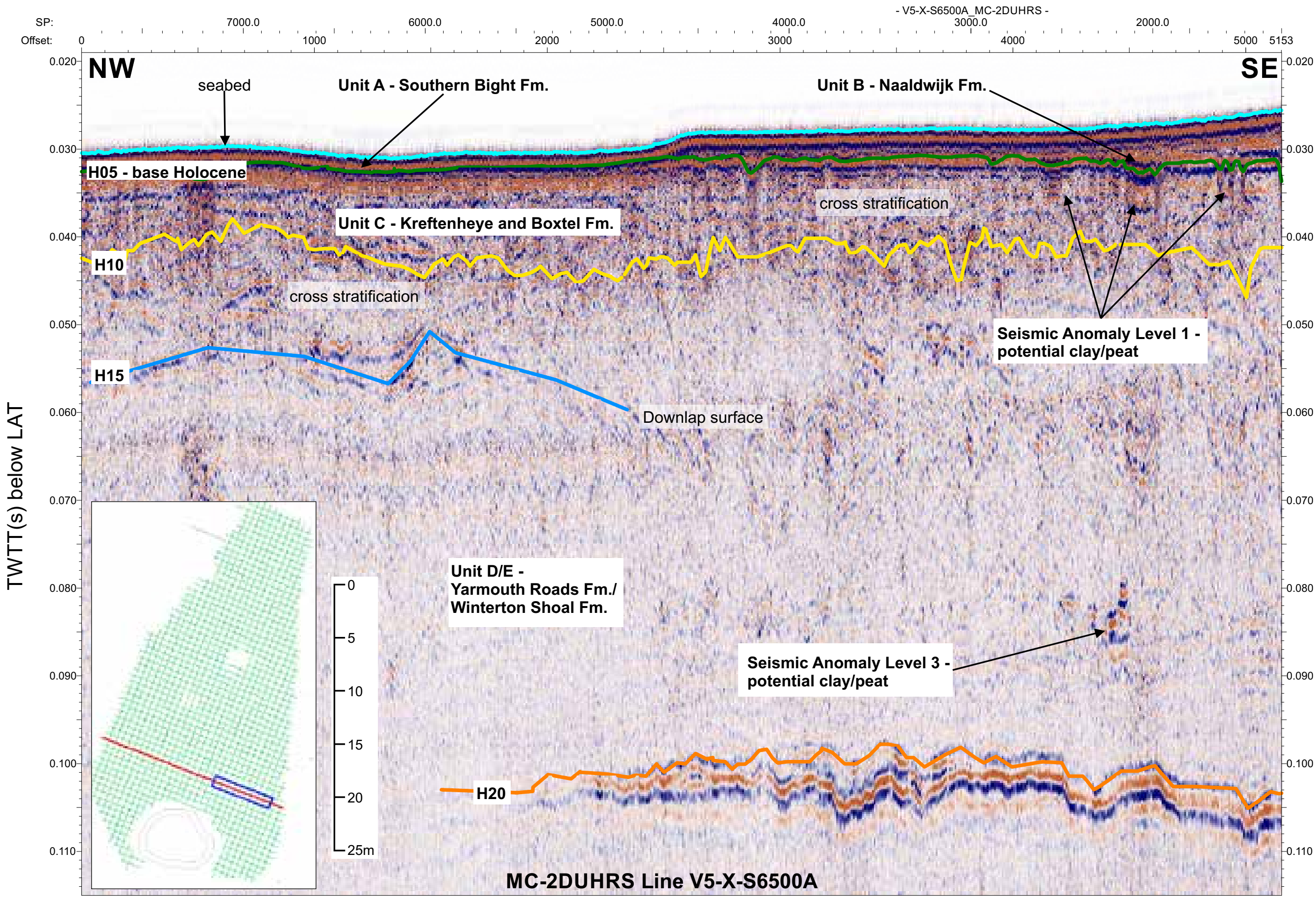
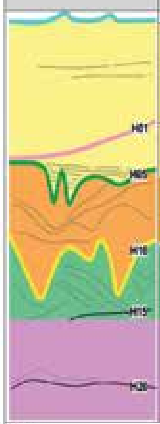



**Figure 4i** *Local stratigraphy (MC-2DUHRS Line V5-X-S6500A)*

| Schematic Log | Seismic units | Reflectors | | Base of unit min/max depth in m LAT [1] | Base of unit min/max depth in m below seabed [1] | Geometry of the base of the unit | Seismic signature | Amplitude Distribution | Continuity of internal reflectors | Internal structure of the unit | Indicative lithology [2] | Depositional Environment | Formation | Age |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Top | Base | | | | | | | | | | | |
|  | A | Seabed | H01 or H05 | -20 to -29 | 0 to 12 | Uneven surface | Transparent to semi-transparent, locally some weak reflectors | Generally low | Low | Controlled at the top by sand dune morphology | Fine to coarse SAND with CLAY and SILT laminae, locally GRAVEL, sparse boulders | Shallow marine | Southern Bight (Bligh Bank Member) | Holocene |
| | B | H01 | H05 | -20 to -29 | 0 to 12 | Erosional surface | Discontinuous internal reflectors | Variable from low to high | Medium to low | Sheet-like deposit channelled at the base | Very fine to medium SAND, locally CLAY levels and PEAT, possible boulders | Coastal plain | Naaldwijk (Wormer Member, Velsen Bed) | Holocene |
| | C | H05 | H10 | -23 to -64 | 4 to 38 | Erosional surface | Discontinuous internal reflectors | Variable from low to medium | Discontinuous to transparent | Complex configuration channelled at the base | Fine to coarse SAND; GRAVEL and minor CLAY, possible boulders | Fluvio – peri-glacial environment | Kreftenheye and Boxtel | Upper Pleistocene |
| | D | H10 | Not interpreted | Approx. -60 to -70 | N/A | Not detectable | Highly discontinuous | Variable from low to high | Low | Complex configuration | Fine to coarse SAND with local CLAY and SILT, possible boulders and occasional clay/peat beds | Fluvial | Yarmouth Roads | Lower to Middle Pleistocene |
| | E | Not interpreted | N/A | N/A | N/A | Not visible | Discontinuous to transparent, some continuous reflectors | Variable from low to high | Generally Low, some continuous internal reflectors | Sheet-like deposit | Fine to coarse SAND with CLAY intercalation | Fluvio - deltaic | Winterton Shoal | Lower to Middle Pleistocene |

Notes:
1. Derived from Ref. 2., Fugro Reports (Ref 14 to 19) and public domain data
2. Lithology tied to available borehole data (Table 3.1)
3. N/A = Not Applicable

# 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 (section 4.1), Periplus Archeomare was to conduct an archaeological assessment of the geophysical survey results to further investigate the presence of archaeological remains in the HKNWFZ.

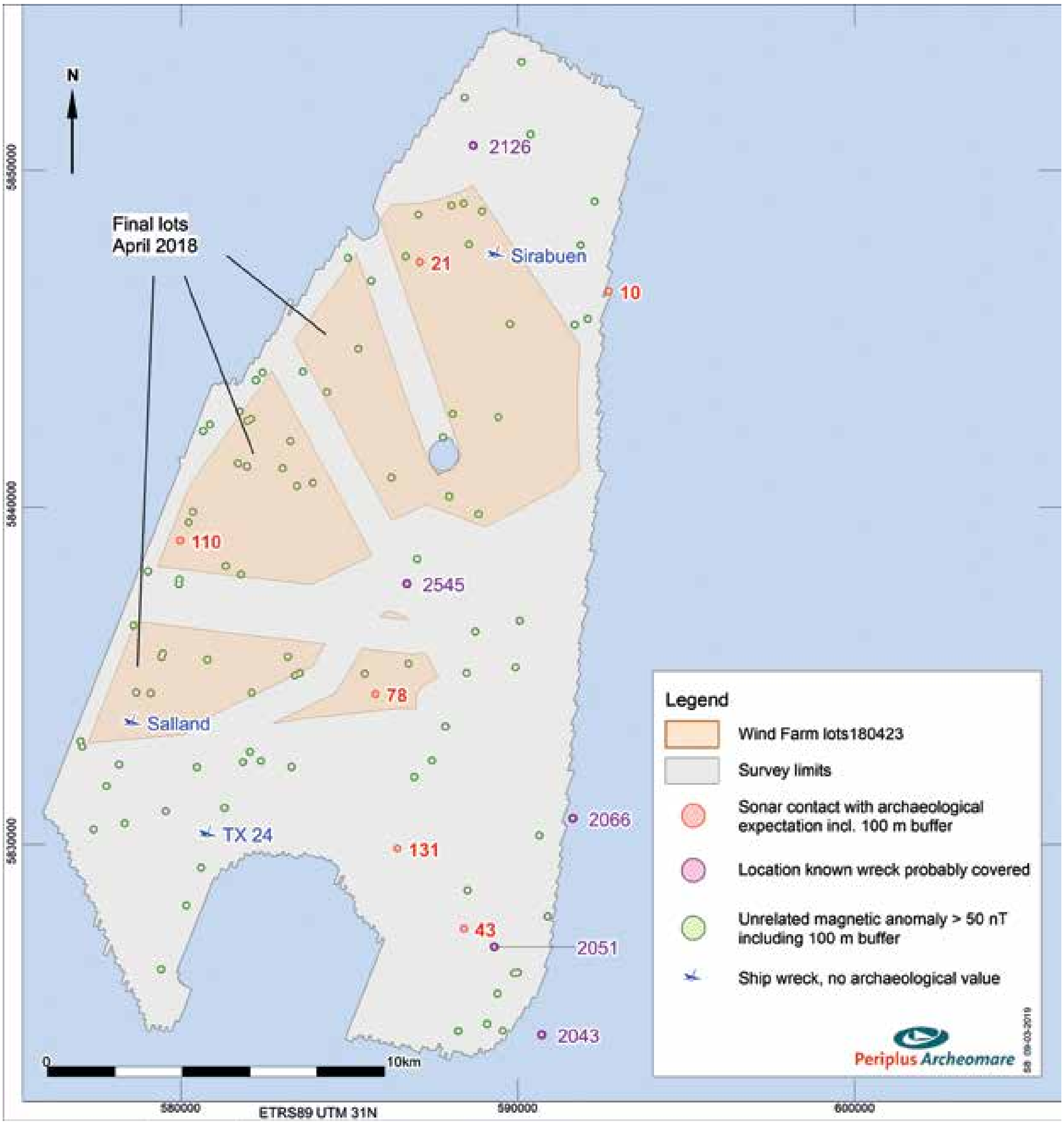
The goals set for this assessment were:

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.nl to conduct an archaeological assessment of the geophysical survey by Fugro Survey B.V.

**Figure 4j** *Map with 100 m zones around contacts found with respect to the final wind farm lots.*



### 4.5.3 Results

Periplus Archeomare's further analysis of the geophysical survey concluded that at HKNWFS there are six visible objects at the surface and five covered known objects with a possible archaeological expectation.
The company's report suggests a buffer zone of 100 m should be applied around the objects found which have yet to be determined to have no archaeological value (Figure 4j). This also applies to cable trenching and anchorages of work vessels. The buffer zone may be reduced if it can be substantiated that the applied activity and disturbance has no effect on the archaeological object. For example, when no anchoring is used during cable lay operations the buffer zone can be decreased. Reduction of the distance may be obtained after consultation with Rijkswaterstaat on behalf of the Ministry of EZK and its advisor, the Cultural Heritage Agency.

Meanwhile, a number of magnetic anomalies have also been observed that cannot conclusively be related to known pipelines and cables, or visible objects at the seabed surface. They are related to unknown ferrous objects buried in the seabed, covered by sediments and some have an amplitude of 50 nT and more. Whilst installing wind turbines and the various inner field and export cables, the report advises developers to avoid areas where these buried ferrous objects have been identified, again by implementing a 100 m buffer zone. If it is not feasible to avoid the reported magnetometer locations with such a buffer zone, additional research should be conducted to determine the actual archaeological value of the reported locations, the report says.
It also suggests any UXO research conducted within 100 m of magnetometer anomalies with an amplitude of 50 nT or more is carried out under onboard 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. If the UXO research indicates the object has no UXO risk, the location can be omitted.

*Pre-historic remains*

The seismic data reveals a submerged prehistoric river valley in the southern part of the HKNWFZ. The river valley provided fresh water and a rich flora and fauna and therefore fit conditions for hunting and gathering. Remains of intact and well-preserved Late Paleolithic and Mesolithic camp sites and inhumations are expected within the river valley and at the cover sand landscape along the valley edges; especially in areas where archaeological remains have been covered with peat and clay.
It is concluded that archaeological levels in the central and northern part of the area have been subjected to erosion. Although no borehole data was available to test this conclusion, the seismic data provided sufficient information to support the conclusion that the probability of prehistoric camp sites having been preserved intact outside the clay and peat covered river valley is small.
In the final design of the wind farm, the site is positioned north of the paleo-river valley. In situ prehistoric sites will therefore not be affected by the wind farm installation and additional research is not considered necessary. Finally, the report notes that 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 passive archaeological supervision based on an approved Program of Requirements. Passive archaeological supervision means that an archaeologist is not present during the execution of the work but always available on call. 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. The recommendations are incorporated in the Wind Farm Site Decision.

### 4.5.4 Webinar

The results of the Archaeological Assessment for HKNWFZ were presented and discussed at a webinar in May 2019. Please refer to the website, offshorewind.rvo.nl/obstructionsnh.

# 4.6 Geotechnical survey

### 4.6.1 Overview - Aims, Objectives, Approach

The primary aim of the geotechnical campaign is to validate the geological model resulting from the geophysical investigation and to confirm the soil engineering properties at HKNWFZ required by developers to progress their geotechnical foundation designs and other general design and installation requirements for the wind farm, as well as those relating to cable installation.
The investigation strategy adopted for this project consists of the following elements:

- Building on the available geophysical ground model to enhance understanding of site conditions. Individual target locations intend to confirm and enhance understanding of the stratigraphy and alignment with the identified geophysical horizons, confirm uniformity or variability within the geophysical horizons, and allow identification of specific geophysical features;
- Determine the vertical and lateral variation in seabed conditions;
- Capturing the predominant soil conditions across the site to depths relevant for future wind farm development and acquire sufficient information to minimise requirements for future developers to perform additional geotechnical investigation, primarily requirements for drilling mode type of investigations;
- Combining different investigation techniques at specific locations to allow correlation of geological and geophysical features with a range of geotechnical parameters. The intent was to reduce uncertainty when extrapolating soil properties across the investigation area.

The geotechnical campaign for HKNWFZ is completed and used intrusive techniques to gain an insight into the characteristics of the subsoil. Two types of investigation techniques were used: (1) in situ testing from the seafloor, consisting of (standard/seismic/temperature) cone penetration testing and pore pressure dissipation testing; and (2) geotechnical borehole drilling with downhole sampling and (standard/seismic) cone penetration testing (Table 4.1 p33/34). An office programme of geotechnical laboratory testing and reporting of results followed the site phase. The geotechnical laboratory testing was done on recovered samples.

The geotechnical site investigation included investigation points for a planned TenneT substation. These locations are considered in the overview of locations and laboratory test quantities given below as these tests may provide additional information to support site characterisation.

Measurement locations at HKNWFZ were as follows:

- Eighty-five (85) seafloor CPTs at 78 locations to depths ranging from 2.1 m to 53.0 m below seafloor (BSF);
- Twenty-eight (28) seafloor seismic CPTs (SCPT) at 21 locations to depths ranging between 2.9 m and 52.9 m BSF;
- Twenty-four (24) seafloor temperature CPTs (TCPT) at 23 locations to depths ranging between 3.0 m and 7.5 m BSF;
- Seventy-two (72) pore pressure dissipation tests (PPDT) at 38 locations at selected depths within a CPT stroke.
- Thirty-one (31) boreholes (including 3 re-drills) at 28 target locations. The boreholes included downhole sampling and (at selected locations) seismic cone penetration testing, to depths approximately equal to the deepest penetration depth of the performed seafloor in situ test(s) at that location, followed by cone penetration testing with over-sampling to a target depth of 60 m BSF. Various locations were continued to 65 m BSF (one borehole) or 80 m BSF (3 boreholes) to investigate specific geophysical features at these locations;
- Four (4) boreholes at 4 target locations included a drill-out to 52 m BSF followed by cone penetration testing and selected over-sampling to a target depth of 60 m BSF;
- One (1) borehole included downhole seismic cone penetration testing and selected over-sampling to a target depth of 60 m BSF;
- One (1) borehole included downhole sampling to a target depth of 100 m BSF (centre location TenneT substation);
- Five (5) boreholes (including 1 re-drill) at 4 target locations (corner points TenneT substation) included downhole cone penetration testing to a target depth of 100 m BSF.

**Table 4.1** *An overview of the basic laboratory test programme*

| Test Type | Test Quantity |
|---|---|
| **Index tests** | |
| Density of solid particles (small pycnometer) | 235 |
| Particle size analysis (sieving and pipette) | 570 |
| Minimum and maximum index dry unit weight | 123 |
| Atterberg limits | 95 |
| Carbonate content | 192 |
| Organic content (dichromate oxidation) | 198 |
| Organic content (mass loss on ignition) | 61 |
| Pore water salinity | 27 |
| **Triaxial tests** | |
| Unconsolidated undrained triaxial compression - undisturbed | 3 |
| Unconsolidated undrained triaxial compression - remoulded | 2 |
| (An)isotropically consolidated undrained triaxial in compression | 9 |
| (An)isotropically consolidated undrained triaxial in compression with bender element testing | 5 |
| Isotropically consolidated drained triaxial in compression | 63 |
| Isotropically consolidated drained triaxial in compression with bender element testing | 40 |
| **Ring Shear Tests** | |
| Ring shear (soil-soil interface) | 57 |
| Ring shear (soil-steel interface) | 105 |
| **Compressibility Tests** | |
| Incremental loading | 4 |
| Constant rate of strain | 17 |
| **Other Tests** | |
| Permeability tests | 69 |
| Thermal conductivity | 28 |
| Electrical resistivity | 27 |
| Transient plane heat source | 22 |
| Microscopic photography | 109 |
| Geological dating analyses (suite of tests) | 115 |
| Biogeochemical analyses for microbially induced corrosion (MIC) risk assessment | 22 |

*Note that determinations of water content, unit weight, torvane, and pocket penetrometer tests are not presented in this table.*

**Table 4.1** *(continued) An overview of the basic laboratory test programme*

| Test Type | Test Quantity |
|---|---|
| **Index tests** | |
| Particle size analysis (sieving and pipette) | 9 |
| **Strength (Static)** | |
| Isotropically consolidated undrained triaxial in compression | 9 |
| Isotropically consolidated drained triaxial in compression | 9 |
| Direct simple shear - constant volume | 10 |
| Direct simple shear - constant vertical stress | 9 |
| **Strength (Cyclic)** | |
| Stress-controlled (an)isotropically consolidated undrained cyclic triaxial | 32 |
| Stress-controlled isotropically consolidated drained cyclic triaxial | 20 |
| Stress-controlled cyclic direct simple shear - constant volume | 56 |
| Stress-controlled cyclic direct simple shear - constant vertical stress | 18 |
| **Dynamic** | |
| Resonant column - multi-stage | 10 |
| Resonant column - drained/undrained | 2 |
| **Other** | |
| Microscopic photography | 9 |

### 4.6.2 Supplier

Fugro was contracted to perform this geotechnical campaign. The campaign was performed according to ISO 19901-8 (2014) Marine Soil Investigations. The investigation was conducted in two campaigns with geotechnical vessels MV Despina and Fugro Synergy, between 19 April and 2 July 2018.

Fugro's state of the art seafloor in situ test unit, the SEACALF® 20 tons MkIV Constant Drive System (CDS) with a coiled rod system was used for the seafloor in situ testing. The unit was fitted with piezo-cone penetrometers, seismic cone penetrometers, and temperature cone penetrometers. The SEACALF® CDS provided a notifiable safe and efficient test unit for high quality data acquisition.

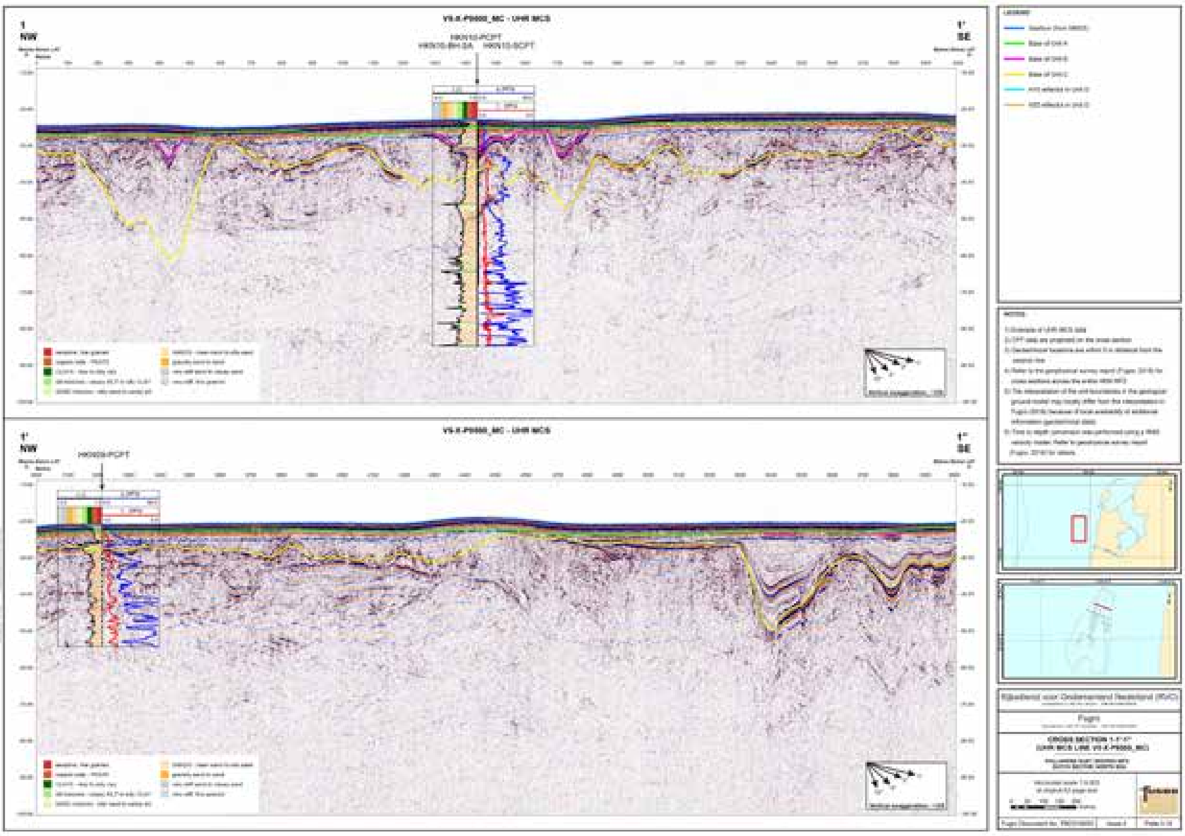
The geotechnical boreholes were performed using open-hole rotary drilling in combination with water and/or guar gum or bentonite as drill fluids. Borehole drilling included the use of a seabed frame equipped with a SEADEVIL™ system to facilitate accurate depth control whilst drilling, re-entry, and for axial and lateral support of the drill string at seafloor. Downhole push sampling and in situ testing employed a WIPSAMPLER® and WISON® downhole tools. Downhole (seismic) CPTs were performed using piezo-cone penetrometers.

### 4.6.3 Results

The geophysical, geotechnical, and geological data were integrated to build a geological ground model. Four main soil units were defined within the HKNWFZ. The top two soil units (A and B) were deposited in shallow marine to coastal plain environments during the Holocene. The soil units below (C and D) were deposited during a number of glacial and interglacial stages of the Pleistocene. During the interglacial stages, fluvial to fluvio-deltaic sediments were deposited, whereas during glacial stages, fluvio-glacial sedimentation prevailed, interrupted by episodes of subaerial exposure and extensive erosion.

Two main palaeochannel systems/levels were identified across the HKNWFZ. The upper system at the base of soil unit B is related to meltwater channels incised at the end of the last glaciation and filled with clay-rich, early Holocene deposits. The lower palaeochannel system, at the base of

**Figure 4k** *Seismic UHR MCS cross section with CPT data projected*



soil unit C, is of post-Saalian glaciation and exhibits high variability in terms of shape, depth, and infill (predominantly sand). Further, internal channelling features were observed occasionally within the Pleistocene units (especially in soil unit D), which are typically related to fluvial and fluvio-deltaic settings and therefore can be expected within these units.

Soil conditions across the HKNWFZ are predominantly characterised by sand deposits, with minor clays and intermediate soils. There is a limited lateral correlation of geotechnical soil properties across the site, as expected for a complex continental shelf setting. Spatial soil variability particularly applies to units that were influenced by fluvial processes (Figure 4k).

The results of the geotechnical investigation and the basic laboratory test programme can be found in three reports:

1) A geotechnical report containing interpreted CPT logs (Figure 4k, p37) and results from in situ testing, including:
  - Interpretation of soil profile, strata description, 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 (SVT), i.e. recorded seismic traces (X and Y channel), shear wave velocity, and low-strain shear modulus (Figure 4m, p38);
  - Results of temperature equilibrium tests (TET), i.e. temperature versus time;
  - Results of PPDTs, i.e. cone resistance and pore pressure versus time.

2) A geotechnical report containing geotechnical logs and results from in situ testing and laboratory testing, including:
  - Interpretation of soil profile, strata description, 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 SVTs, i.e. recorded seismic traces (X and Y channel), shear wave velocity, and low-strain shear modulus;
  - Selected results of laboratory tests;
  - An overview of (remaining) sample material.

3) A geological ground model report containing a geological ground model, including:
- Geological setting, stratigraphy, lateral variability, cross sections, depth to top of soil unit maps and contours, and thickness of soil unit maps and contours;
- Geotechnical parameter values per borehole location and soil unit;
- Geohazards and assessment of suitability of selected types of structures;
- Results of geological dating analyses;
- Results of a microbially-induced corrosion (MIC) risk assessment, including recommendations for corrosion rates.

In addition to the reports mentioned above, the following documents have also been issued as part of the deliverables for the geotechnical survey:

4) A geotechnical report containing results of the advanced laboratory testing programme, including:
- Results of geotechnical index tests;
- Results of microscopic description and photography;
- Results of static triaxial tests and direct simple shear tests;
- Results of cyclic triaxial tests and cyclic direct simple shear tests;
- Results of resonant column tests;
- Cyclic test results plotted in S-N graphs including (background) degradation curves;
- Cyclic test results plotted with Drammen Clay model contours as background.

5) A geotechnical parameter report containing results of a geotechnical parameter study, including:
- A geotechnical ground model comprising a CPT grouping approach and estimated proportioning of the CPT groups to the HKNWFZ;
- Derived values of geotechnical parameters;
- Indicative values of selected geotechnical parameters which account for transformation of derived values to in situ values;
- Guidance on selection of characteristic values of geotechnical parameters based on indicative value ranges and qualitative commentary;
- Data gap analysis considering data requirements for detailed design of monopiles.

In order to provide further insight which may help for tendering or preliminary design purposes, a report containing results of a 3D geotechnical ground model considering a layering approach will be provided in Q4/2019.

In addition to the geotechnical reports, data packs containing digital data files accompanying the various reports have also been issued. These data packs include the following data types:

- AGS 4.0 format: seafloor CPT data, downhole CPT data, sample data;
- ASCII format: seafloor CPT data, PPDT data, TET data;
- Excel format: SVT data, list of remaining sample material, overview/summary of advanced laboratory test results;
- IHS Kingdom format: geological ground model data files;
- ArcGIS format: geological ground model GIS data files.

Additional data in digital format are under preparation and will be available during Q4/2019. These data will include detailed results of advanced laboratory tests in Excel format.

### 4.6.4 Conclusion

Significant effort was taken to maximise the data quality and suitability of the geotechnical data for HKNWFZ. The reports were certified by DNV GL. Noticeable difference compared to previous geotechnical investigation campaigns at Borssele and HKZWFZ were:

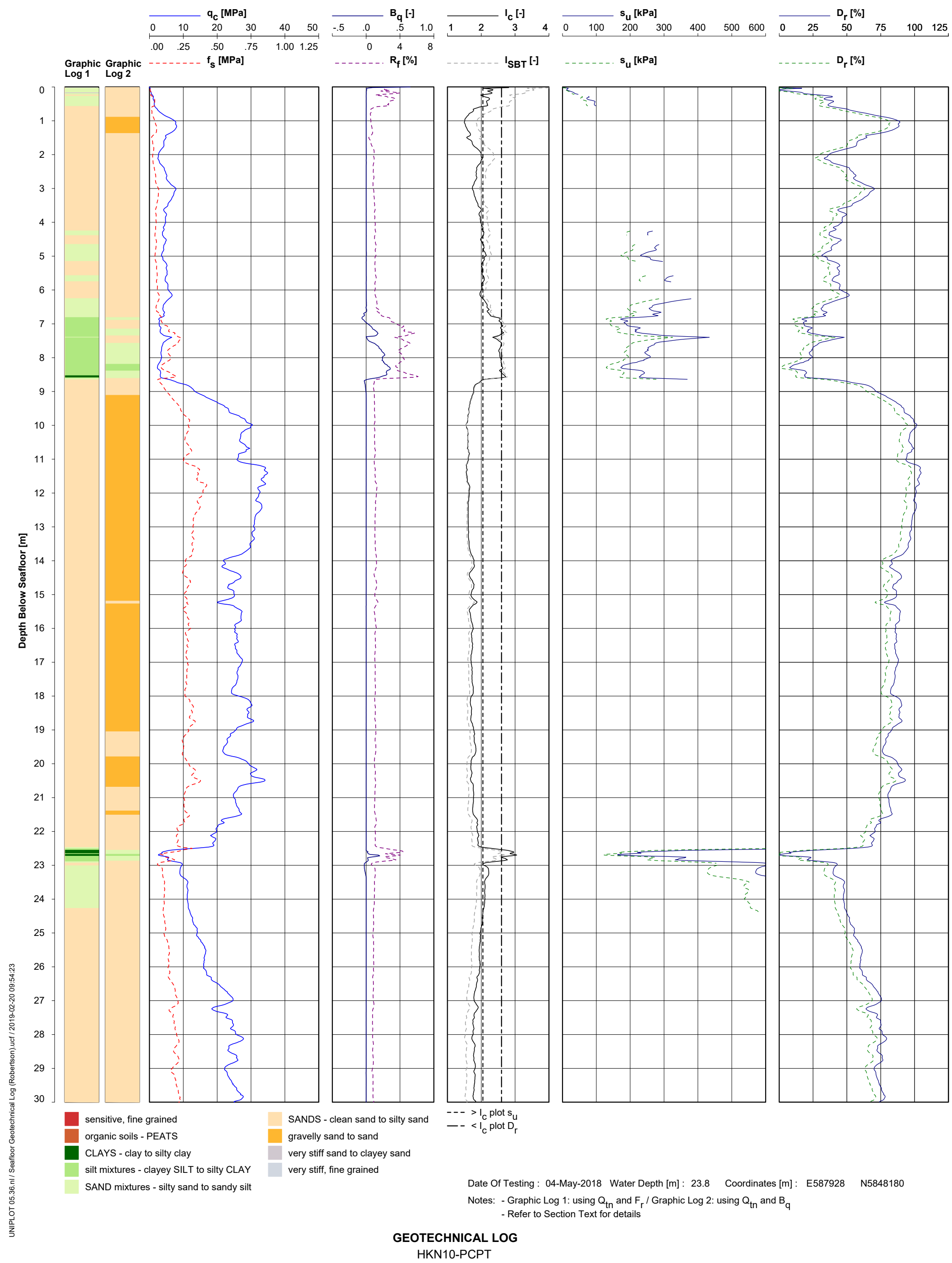
- The addition of seismic testing from seafloor providing a higher quality seismic data set;
- Extensive in situ and laboratory test programmes to support assessment of thermal conductivity and heat capacity;
- Inclusion of recommendation for corrosion rates, seismicity assessment, and assessment of geotechnical parameter indicative values for pile design.

These additions are believed to further increase the value of the provided information packages and allow for further optimisation of future foundation and cable designs in terms of time, costs, and risk.

The geotechnical data was used to ground truth the geological ground model resulting from the geophysical campaign and to laterally correlate soil layers and geological features.
The unit boundaries derived from geophysical data interpretation generally correlate with those identified in the geotechnical data. The data further enhances and refines the understanding of the identified units and their spatial variability. Interpretation of geological features (e.g. buried channels, organic clay/peat accumulation) was based on seismic reflection data and geotechnical data. The results are anticipated to form a solid basis for geotechnical designs at HKNWFZ.

Additional sampling boreholes may not be needed in further stages of the development, if a reliable correlation between CPT data and laboratory test data can be made.

**Figure 4l** *Example of CPT data interpretation*

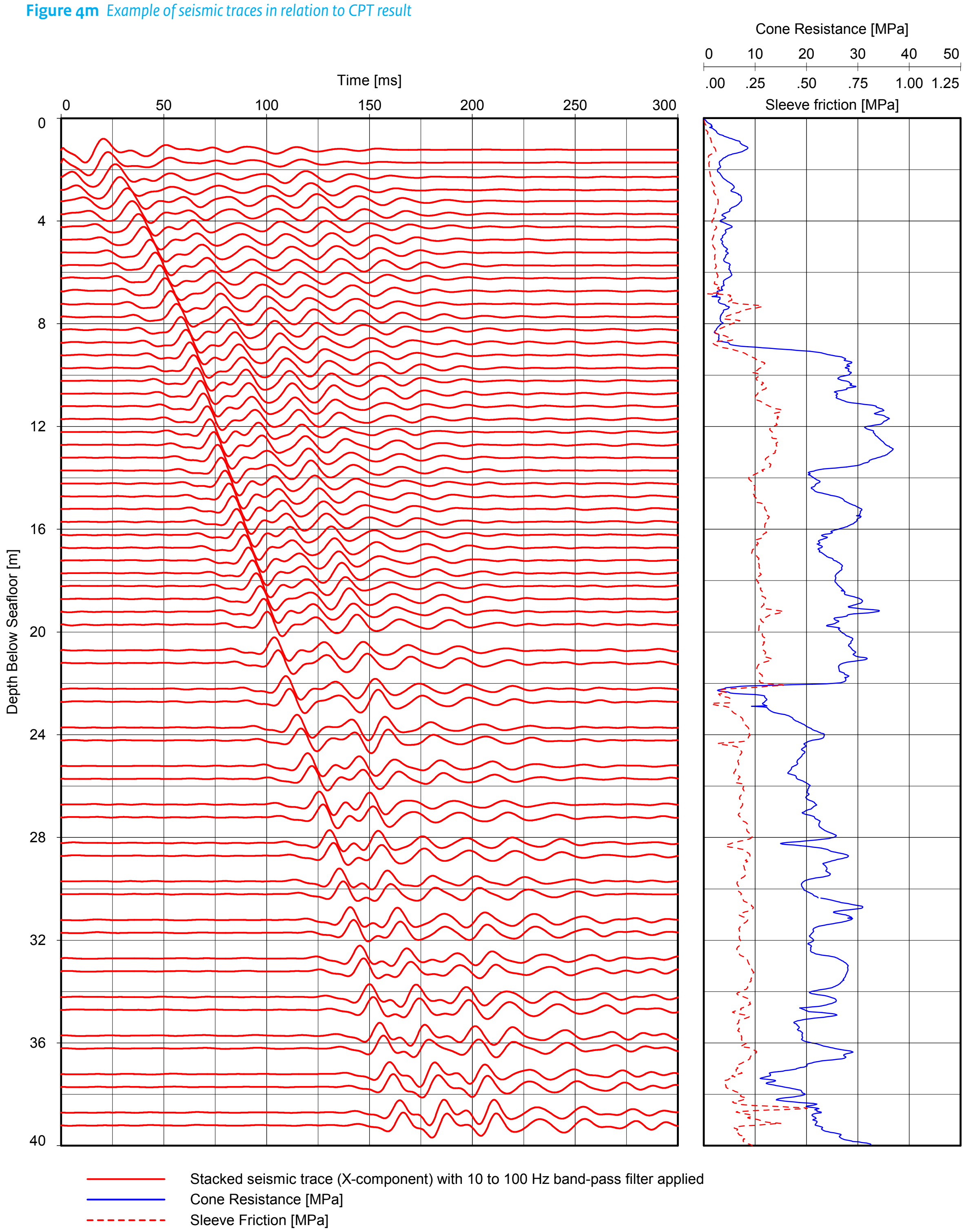



However, this remains the final responsibility of the developers. The remaining samples after the laboratory testing phase will be available to the winning developers, e.g. to perform additional testing.

### 4.6.5 Webinar

The results of the geophysical and geotechnical surveys for HKNWFZ were presented and discussed at a webinar in June 2019. Please refer to the website, offshorewind.rvo.nl/soilnh.

**Figure 4m** *Example of seismic traces in relation to CPT result*




**RECORDED SHEAR WAVE TRACES VERSUS DEPTH (X-COMPONENT) AND CONE RESISTANCE**

LOCATION HKN10-SCPT (1/2)

Photo: Assembly of the Coiled Rod System SEACALF®
on board of the Despina

## 4.7 Morphodynamical desk study

### 4.7.1 Overview - aims, objectives and approach

This desk study comprises two main elements. The first part addresses the (autonomous) seabed dynamics in HKNWFZ, whereas the second part on scour and scour mitigation provides general considerations on how to deal with scour development and scour mitigation in the HKNWFZ taking into account the morphodynamics of the area and a range of potential types of foundations. General considerations for cable routing in a morphodynamic environment are also provided.

The aim of this combined study is to:

1. 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 the HKNWFZ;
2. Assess the morphodynamics at the HKNWFZ;
3. Predict the change in seabed levels at the HKNWFZ over the lifetime of a wind farm (considered period: 2018 – 2058) to support the design, installation, and maintenance of wind turbines, inter array cables, platforms, and their support structures;
4. Provide guidance on the depths at which Unexploded Ordnances (UXOs) can be encountered based on a hindcast of historic seabed levels (1945-2021);
5. Describe scour conditions to be expected at HKNWFZ for typical wind farm-related structures;
6. Provide a state-of-the-art overview of scour mitigation measures and their applicability at these structures in the HKNWFZ;
7. Provide guidance on how the morphodynamics should be taken into account for the selection of locations for structures and cables and scour mitigation strategy.

Overall, the information gathered in this desk study should provide detailed information to help developers with the design, installation, and maintenance of wind turbines, inter-array cables, substations, and their support structures, e.g. by choosing smart locations for the wind farm infrastructure.

Compared to Borssele, the morphodynamic study of HKN was extended with a geological analysis of the top layers, hydrodynamic modelling to assess and validate the migration directions of the bed features, and best-estimate seabed levels for 5-year periods. Compared to Hollandse Kust (zuid), the most probable depths at which UXOs may be encountered were computed and the morphology within the sand mining areas was investigated in detail.

### 4.7.2 Supplier

Research institute Deltares was awarded the contract to conduct this desk study for HKNWFZ. Deltares previously conducted morphodynamic studies for other offshore wind farms, including Hollandse Kust (zuid), Borssele, Prinses Amalia, Luchterduinen, Nordergründe, Vesterhav Nord and Syd, Belwind, and Yunlin.

In addition, Deltares has performed many scour assessments, developed scour mitigation strategies and physical model testing for many offshore wind farms, including Borssele, Egmond aan Zee, GEMINI, Luchterduinen, Nordergründe, Butendiek, Norther, Merkur, Mermaid Seastar, DanTysk, and Formosa offshore wind farms.

### 4.7.3 Results - morphodynamics

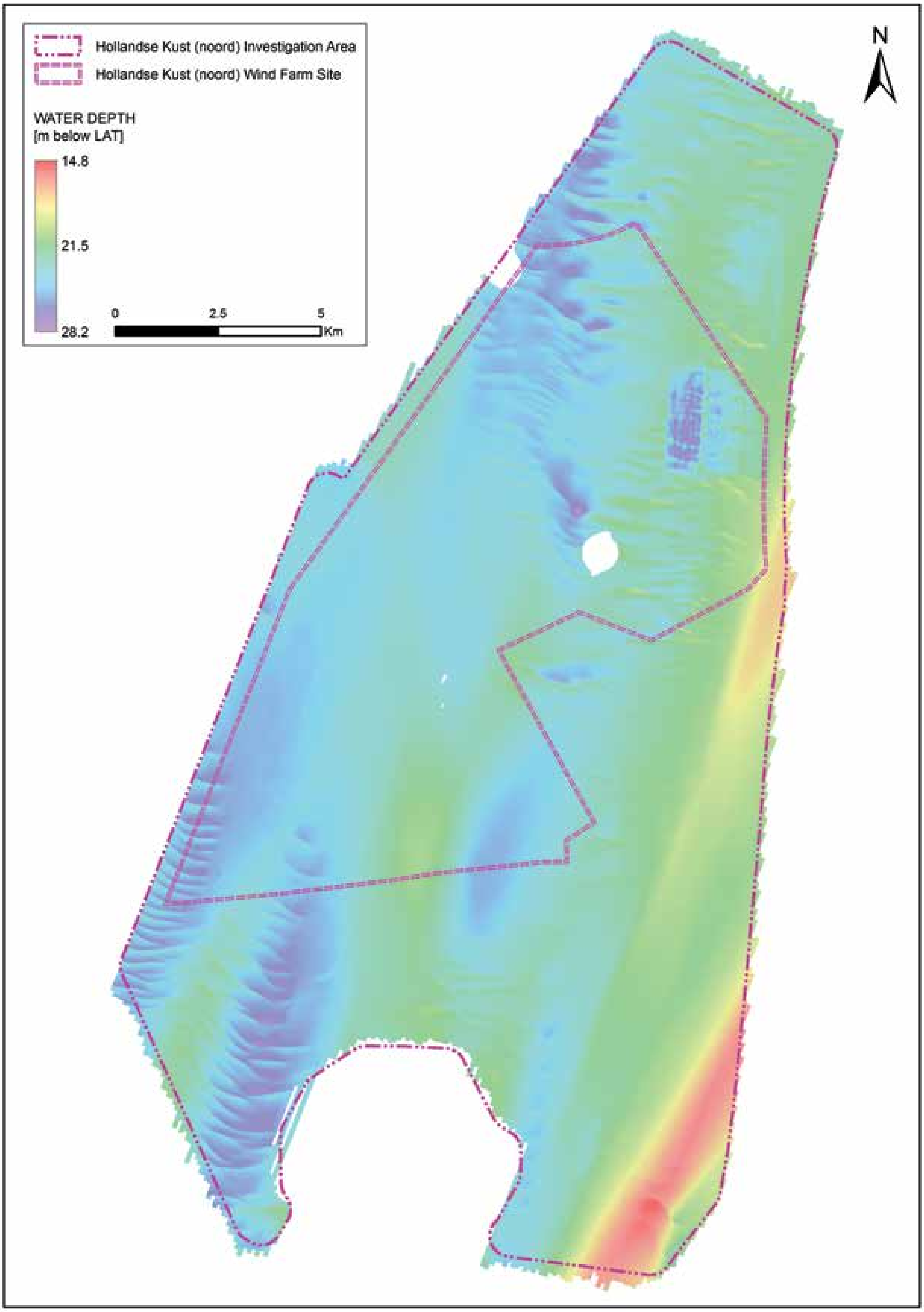
The bathymetry in the HKNWFZ has a non-uniform morphology including a number of prominent sand banks and a partial cover of sand waves, which are migrating towards the north-northeast (Figure 4n). The top sediment layer is mobile and covered with sand waves migrating towards the north-northeast with megaripples on top. Considering the entire HKNWFZ, the sand waves have wavelengths in the range of 190 to 500 m, heights of 0.8 to 2.8 m and migration speeds up to 5.4 m/year with a median speed of 3.2 m/year. An analysis of the large-scale seabed variations shows the underlying seabed may be considered static over the lifetime of the wind farm.

A review of available geological and geophysical data indicates non-erodible layers exist, but they are located too deep to influence the sand wave migration. A numerical analysis of the hydrodynamics and sediment transport in the area indicates the net sediment transport is aligned with the residual tidal flow and towards the north-northeast.

The sand mining pit present in the HKNWFZ is subject to an infill process with a relatively slow time scale of backfilling. A data analysis on the sand mining pit in the HKNWFZ and on a nearby sand mining pit indicated no significant infill or migration, when considering a relatively short. Based on longer term simulations using the SEDTUBE model for a representative hydrodynamic time series and varying soil conditions, a significant northward migration of the sand mining pit is observed extending over 2 km downstream from the present location of the pit.

Based on the morphodynamic analysis Best Estimate Bathymetries (BEB), a lowest seabed level (LSBL) and a highest seabed level (HSBL) were determined. The LSBL and HSBL indicate the lowest and highest seabed levels that are expected during the lifetime of the wind farm (2018-2058), including

**Figure 4n** *Map view of the bathymetry*



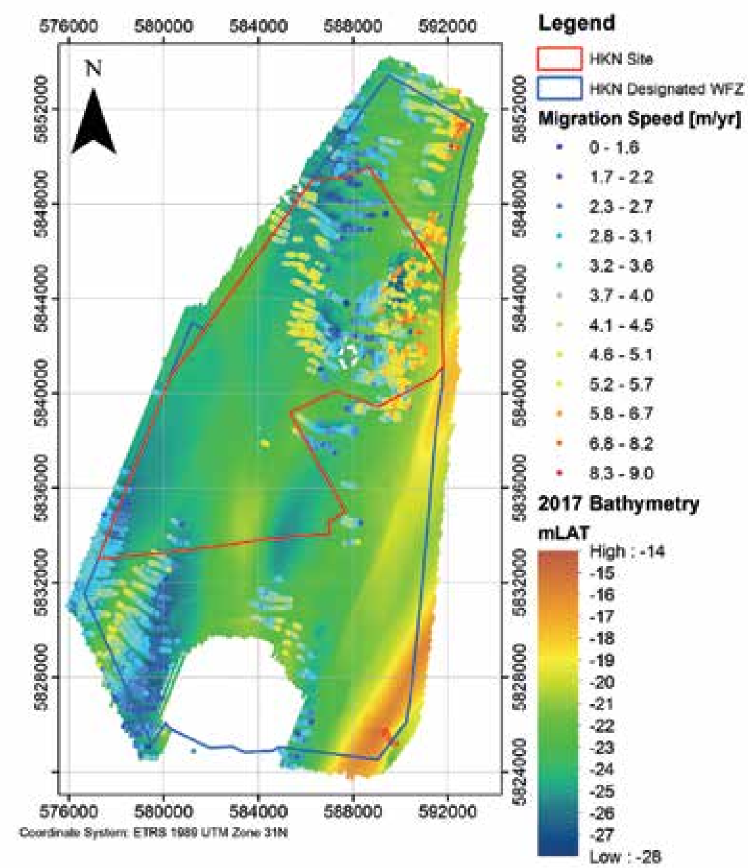



**Figure 40** *Map view of the measured bathymetry in 2017 and the mean estimated sand wave migration speed over the period 1996 – 2017; note that dots are only present at locations where sand waves are present.*

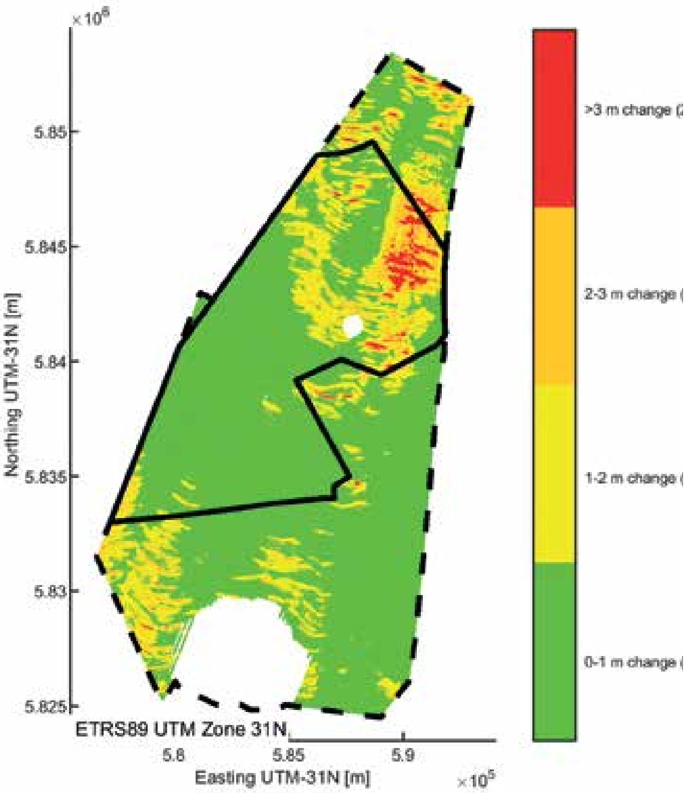



**Figure 4p** *Overview map of classification zones including classification for both highest and lowest seabed levels*

uncertainty bands. The BEB 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. Comparison of the LSBL with the most recent measured bathymetry from 2017 shows a predicted maximum local seabed level lowering of approximately 5.7 m (with -2.6 m as the 99%-non exceedance value). As expected, the largest lowering is found at the location of the existing sand wave crests and north of the sand mining pit, while minimal lowering is found at the location of the sand wave troughs. Comparison of the HSBL with the most recent measured bathymetry from 2017 shows a predicted maximum local seabed level lowering of a few meters, but locally in the sand mining pit as much as 7.0m (with +3.2 m as the 99%-non exceedance value).

A hindcast of seabed levels is made to assess the possible levels at which UXOs are located. An important assumption in this method is that an UXO will never travel upwards and a typical UXO will self-bury to about half its height. To consider 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 1945-2021 are calculated.

The predicted seabed level changes presented in this study follow from the applied morphological analysis techniques, describing the physics and the natural variability of the analysed morphological system. No additional safety margins for design purposes have been applied. Finally, classification zones were provided to assist developers in determining the locations of their cables and foundations (see Figure 4o/4p).

#### 4.7.4 Results – scour mitigation

In most situations, offshore structures can either be protected against scour or be designed such that scour development can be allowed. To decide which strategy can best be 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, taking into account the morphodynamic scenarios of stable, lowering, and rising seabeds.
It can be concluded that for monopiles an easy-applicable, well-proven solution is to place the monopiles 1) in areas with limited seabed dynamics; 2) just north-east of the sand wave crests; or 3) 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 is needed, while, in the third case, a longer or thicker scour protection is recommended to cater for the lowering seabed. Other solutions are also possible though, such as leaving out the scour protection completely at locations with a rising seabed, when scour protection costs outweigh the costs for additional steel consumption.

To illustrate the choice for a proper scour mitigation strategy for monopiles, dynamic equilibrium scour depths, stable rock gradings, and required scour protection volumes were computed for the entire HKNWFZ. 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 when the pile is protected or left unprotected. In case of protection, the map provides an indication which scour protection is required at different locations. 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 (Figures 4q/4r/4s p44). This report also discusses general considerations for cable routing in a morphodynamic area such as HKNWFZ. It is expected that cables can be buried sufficiently deep to avoid cable exposure, when smart cable routing techniques are adopted. Areas with the largest morphodynamic seabed lowering or other “expensive” areas with higher risks should be avoided.

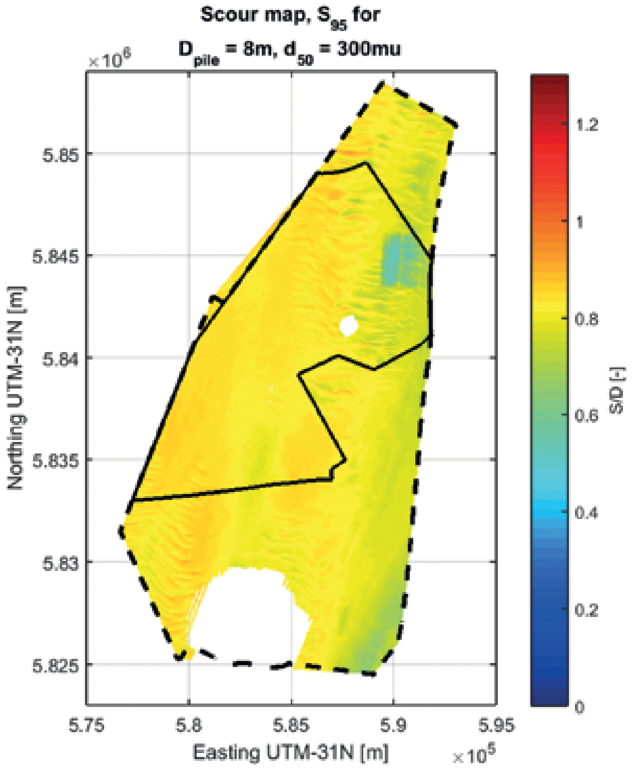



**Figure 4q** *Map showing the 95%-non-exceedance value for the dynamic equilibrium scour depth (S95/Dpile) in the HKNWFZ, for one simulation with Dpile = 8 m, d50 = 300 µm and spatially varying hydrodynamics*

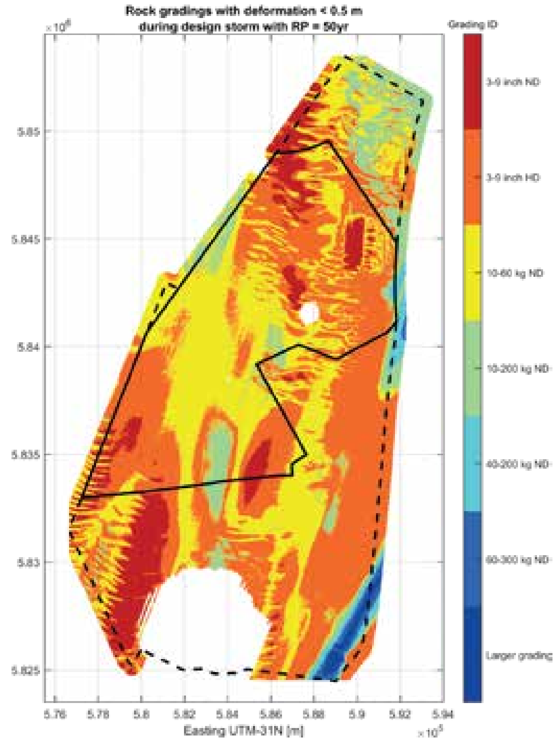
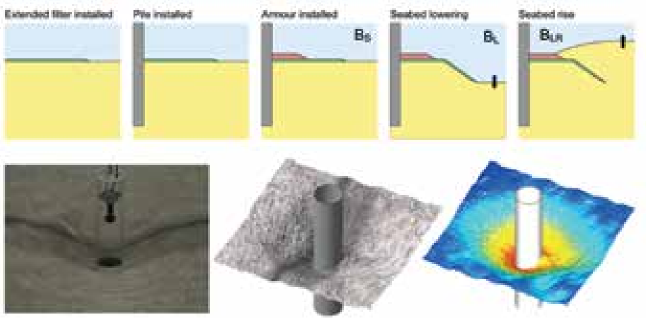
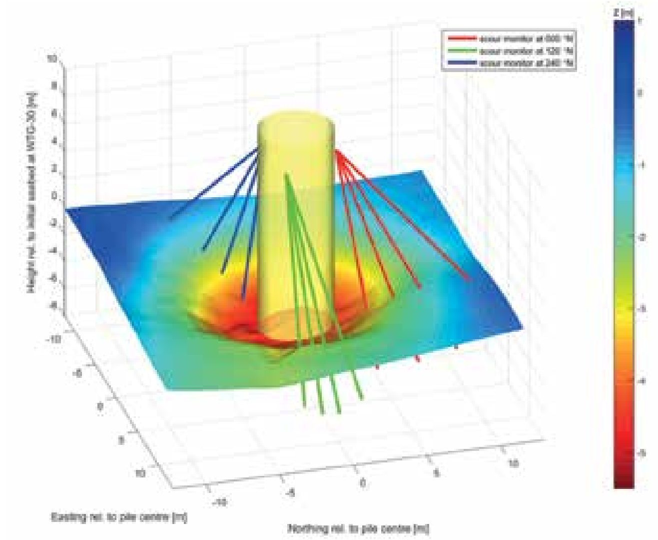



**Figure 4r** *Spatial distribution of rock gradings that are expected to show less deformation than 0.5 m during the design storm with a return period of 50 years.*

**Figure 4s** *1,2 + 3/ X*



#### 4.7.5 Deliverables
The results of the morphodynamics and scour mitigation study are summarised in a desk study report. This report includes:

- General background information regarding morpho-dynamic seabed features of which sand waves are the most prominent in HKNWFZ;
- Geological and geophysical characterisation of the site to a depth of 20 m below the measured seabed level;
- 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 UXOs can be expected (LOL, HOL, BEOL);
- Classification zones and considerations for cables and foundations;
- Recommendations regarding possible scour mitigation strategies for the HKNWFZ;
- 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. rocks, mattresses, gabions, artificial vegetation, filter units, etc.;
- Map-based estimates for required rock gradings and rock volumes, taking into account spatially varying hydro-dynamic design conditions, water depth and seabed variations;
- Recommendations for eco-friendly scour protection designs;
- Description of how to deal with cable routing in morpho-dynamic environments.

#### 4.7.6 Webinar
The study was presented and discussed during a webinar in May 2019. Please refer to the website, offshorewind.rvo.nl/soilnh.

# 4.8 Metocean measurement campaign

### 4.8.1 Overview - aims, objectives and approach
Two Seawatch Wind LiDAR Buoys (SWLB) were deployed at the HKNWFZ site in April 2017. The SWLB are equipped with an integrated system of instruments to measure wind, waves, currents, water levels, air pressure, and air temperature simultaneously.

### 4.8.2 Supplier
The metocean measurement campaign is being conducted jointly by Fugro. 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.

### 4.8.3 Results
The SWLB including the wave sensors are validated for use by clients requiring high quality wave measurements. The LiDAR wind measurement system is an OWA Carbon Trust stage 2 pre-commercial floating LiDAR system validated by DNV GL.

Data from all sensors are transmitted to shore in real time and quality checked monthly. The measurements are validated, on an ongoing monthly basis, by Deltares against several surrounding measurement stations in the North Sea. Monthly results are available on offshorewind.rvo.nl. Offshore operations are being performed to service the buoys and instruments at regular intervals. Raw wind and wave data are then downloaded. The buoys are independent of each other but located close to each other to create a redundant system.

For this campaign, the measurement suite includes:

- Wind speed and direction, turbulence intensity, and inflow angles at 10 heights in the range of 30 – 200 m above MSL with ZephIR 300 LiDARs, including wind shear and veer;
- Air temperature, pressure, and humidity at LiDAR level;
- Significant wave height, mean and peak wave periods, wave direction, and wave spectra;
- Current speed and direction at 10 evenly spread depths over the water depth;
- Sea surface temperature;
- Water level.

The SWLB is robust and has carried out excellent measurements under harsh environmental conditions, including strong winds, high waves, and strong currents. Throughout the two-year campaign, the systems have performed well and delivered high data availability for all parameters. Precise measurements record events like storms (e.g. in October 2018, (Figures 4t and 4u) both above and below the sea surface. 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 wind direction as expected.

### 4.8.4 Deliverables
The results of the metocean campaign are published on a monthly basis on offshorewind.rvo.nl/windwaternh.
The data package includes raw data, a data report, a data validation report and a Statement of Compliance.
The packages become available about two months after completion of a month of measurements.

In addition, raw wind and wave data is provided after each service of the SWLB. The final report over 24 months (April 2017 – April 2019) of data including all processed and raw wind and wave data including a Statement of Compliance by Navigant is also available on offshorewind.rvo.nl/windwaternh.

### 4.8.5 Webinar
The setup of the metocean measurement campaign was presented and discussed at a webinar in May 2019.
The webinar will be available on offshorewind.rvo.nl/windwaternh.

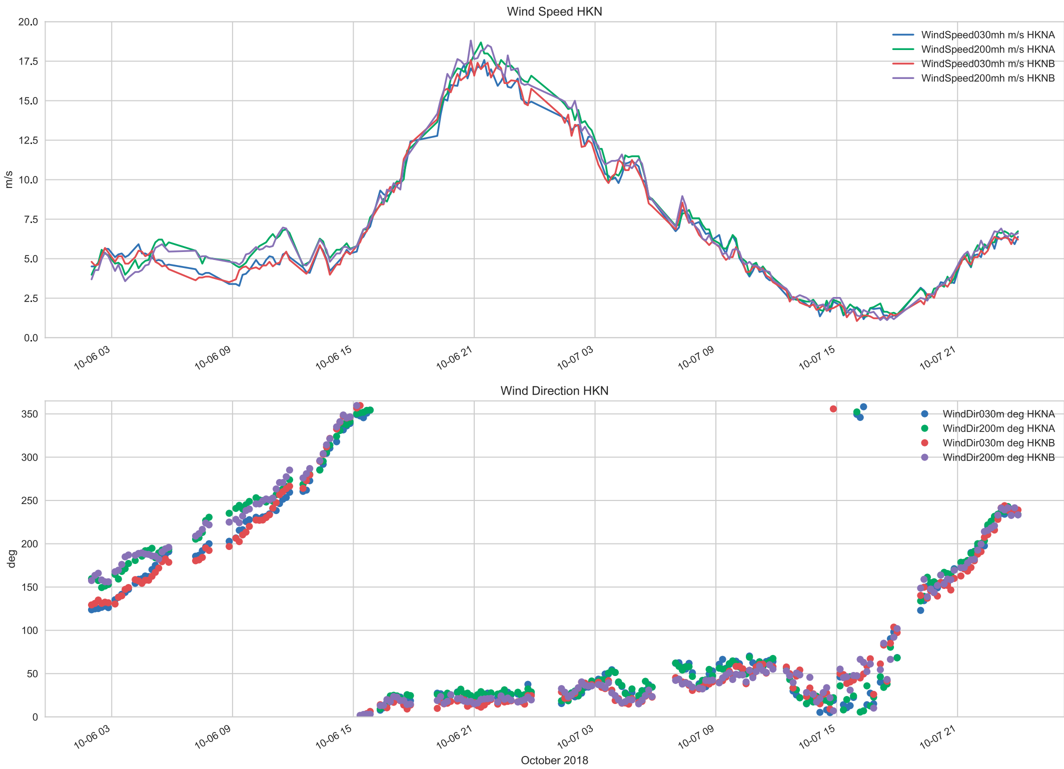



**Figure 4t** *Wind speed and direction measured by the SWLB LiDAR at the highest and lowest heights for both buoys during a storm event in October 2018. The measurements correspond well.*

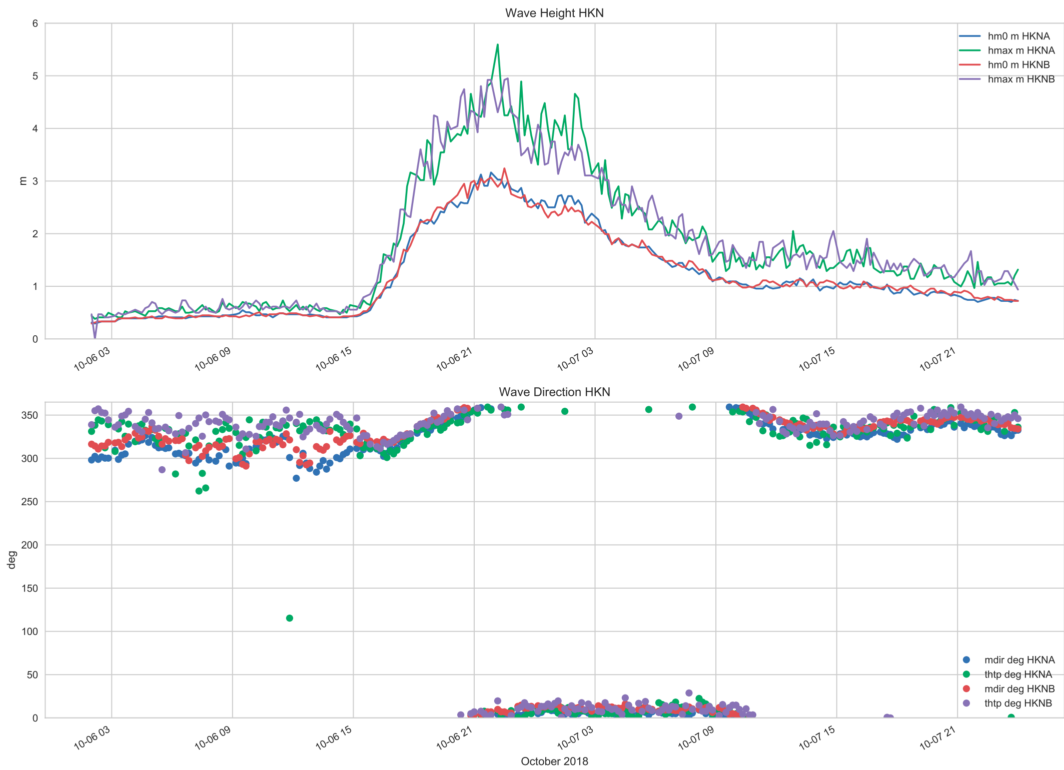



**Figure 4u** *Wave height and direction from both buoys during the storm event in October 2018 correspond well.*

## 4.9 Wind resource assessment

### 4.9.1 Overview - aims, objectives and approach

The goal of this study is to provide a wind resource assessment (WRA) for the HKNWFZ. The results can be used as input for wind farm modelling, yield assessments and business case calculations for the offshore wind farm to be developed at HKN. The analysis is based on the best possible data and state-of-the-art methods and models and is designed to be in accordance with applicable offshore standards. For calculation of wake effects, an innovative LES-model has been used and compared with industry standard models. The study consists of an elaborated wind resource assessment using on-site metocean campaign data and off-site met mast data. The study concludes with a discussion and the combined findings from both elements for a final wind climate assessment. Wind measurement data from the metocean measurement campaign (see 4.8) has been used as the basis for the wind resource assessment study. An initial study based on the first year of metocean measurement campaign data was issued in March 2019 and was updated in the second half of 2019. The update includes the measurement results of the full two-year campaign.
For the updated WRA, the metocean measurement campaign data from April 2017 to April 2019 have been used. The campaign comprises two Fugro Sea Watch LiDAR buoys (HKNA and HKNB), each with a Zephir Z300 wind LiDAR installed. The wind speed measurements of the HKNB floating LiDAR campaign (no gap filling applied) were the primary source for the initial and updated assessment.
Wind data from the mesoscale model ERA5 were selected as the long-term reference, based on a validation using multiple mesoscale wind datasets against available offshore measurement data sets. Based on this reference dataset, a translation to the long-term wind speed was performed, using the so-called MCP-method.

As an additional calculation, to help reduce uncertainty in the first estimate presented above, the Oldbaum consortium performed a second analysis based on the Offshore Wind farm Egmond aan Zee (OWEZ) 70 m met mast data.
This source was selected because of its proximity to the site and the overall low uncertainty of the wind measurements plus the fact that it gathered data in using a different technology. The long-term wind climate was also calculated based on ERA5 mesoscale model data.
For the initial WRA only, the results of both calculations (the one based on the first year of the HKNB floating LiDAR campaign as well as the OWEZ met mast), were compared to the KNMI North-Sea Wind (atlas) and found to match very closely (within 1%). Based on this atlas, subsequently a horizontal scaling to the various nodes within and directly around the site was performed.
At these nodes, wind speed and direction time series were created and analysed. The analysis included variations with height, time and distance, as well as a comprehensive uncertainty assessment. An extensive modelling of the possible effects of the existing nearby wind farms of OWEZ and Offshore Wind Farm Prinses Amalia (OWFPA) was also included. The resulting wind climate was compared with various other studies and wind atlases.

Detailed analyses of the calculated wind climate were carried out across the modelled heights, showing good comparisons of the analysed trends with measurements at other offshore sites in the Dutch North Sea.

The WRA and metocean desk study (see 4.10) were carried out in parallel. Both the WRA and the metocean desk study analyse the ambient wind climate at the HKNWFZ. However, they do so for different application and with different outcomes in mind - the metocean study is to be used for wind farm design purposes whilst the WRAs are used to calculate energy yield.
RVO.nl and the contractors responsible for the WRA and metocean desk study have ensured that the basic boundary conditions (e.g. wind speeds and directions, vertical/ horizontal bins and assumed vertical wind profiles) were compared and aligned as much as possible to achieve consistency or a motivated deviation between both studies.

### 4.9.2 Supplier

Oldbaum Services Ltd together with its partners Pondera Consult, Whiffle, and Deltares, were contracted by RVO.nl to conduct the wind resource assessment. The consortium members have ample experience in offshore wind resource assessments, having performed multiple similar offshore measurement campaigns, prepared bankable reports, and detailed high resolution wake calculations previously. Moreover, the consortium is skilled in the validation and application of mesoscale model data, including detailed uncertainty assessments.

### 4.9.3 Results

The results of the two approaches (1) HKNB + ERA5 and 2) OWEZ + ERA5) of the WRAs differ only slightly, within 0.05 m/s difference in the mean wind speeds at 100 m MSL.
Also, the uncertainty of both assessments is largely comparable. Since the calculations are partly independent, the two results may be combined based on inverse-variance weighting, to result in long-term mean wind speed at 100 m MSL at the centre of the HKNWFZ of 9.53 ± 0.38 m/s (± standard deviation). The initial WRA based on the first year of metocean measurement campaign data came to a result of 9.56 ± 0.39 m/s, which is considered to be very close to the new results. The spatial variation from the wind farm zone's centre is about ±0.1m/s, as seen in Figure 4v. The wind speeds

found within the WRA, based on the first year of the HKNB floating LiDAR campaign, are closely comparable with the wind speeds found within the metocean desk study (within 0.1 m/s). Please note this final WRA is for reference only.

### 4.9.4 Deliverables

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

- Annual mean wind speeds at elevations of 10 to 300 m;
- Annual mean wind speeds at various probability levels (P05 – P95);
- Wind roses (mean wind speed vs. direction) and wind shear (vertical distribution);
- Omni and directional mean wind speed distributions including Weibull parameters;
- Diurnal, monthly, seasonal and year to year variations of mean wind speed;
- Anticipated wake losses due to the existing wind farms;
- A comprehensive uncertainty assessment.

In addition, the spatial distribution of the mean wind speed from the resulting wind resource is provided as a GIS file. Time series are provided at eight output locations in and around the current site for the period 2003-2018.

Due to the small difference between the results of the initial WRA and the updated WRA, the report was revised. The above listed deliverables, however, were not updated.

For information regarding wind turbulence, please refer to the metocean desk study report. Turbulence is considered applicable for design and was not considered as part of the wind resource assessment.

### 4.9.5 Webinar

The initial study based on the 1st year of measurements was presented and discussed at a webinar in May 2019. The webinars are available on offshorewind.rvo.nl/windwaternh.

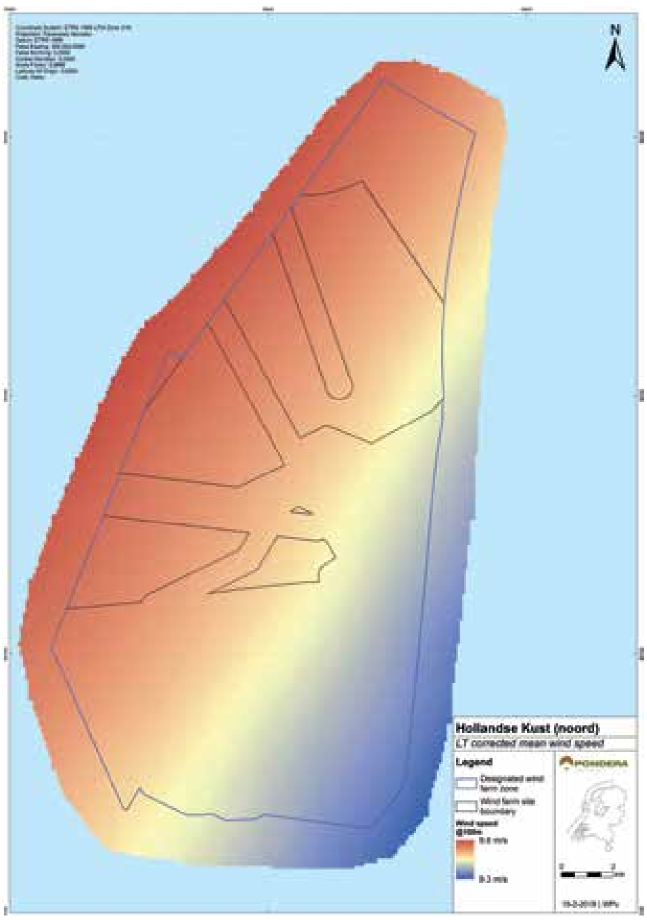



**Figure 4v** *Long term corrected mean wind speed Hollandse Kust (noord) at 100 metres above mean sea level.*

# 4.10 Metocean desk study

### 4.10.1 Overview - aims, objectives and approach

The metocean desk study provides information on the meteorological and oceanographic (metocean) conditions in the HKNWFZ. This will serve as input for the design, installation, and maintenance of wind turbines, inter array cables, substations, and support structures, for companies submitting bids to develop projects at Hollandse Kust (noord). Both the metocean study report and the metocean database have been certified by DNV GL for the HKNWFZ, certifying that the design conditions provided can be used for the design and development of an offshore wind farm at this location.

A feasibility level report has also been provided for Hollandse Kust (west), IJmuiden-Ver, and Ten noorden van de Wadden-eilanden offshore wind farms. This report defines the metocean conditions at these locations. This report and the conditions provided are not certified; the modelling and analysis at these wind farms has been done in the same manner as for HKNWFZ, but the detail on bathymetry is less. Also, no measurements were available at the location to validate the modelling results. Overall calibration of the models, however, show that modelling results may be expected to be accurate and the derived extreme conditions are reliable estimates for these locations.

The metocean desk study includes the following:

1) A general characterisation of the metocean climate at the sites (e.g. operational conditions, dominant tides, storm severity, spatial uniformity of conditions);
2) Analysis of normal and extreme metocean conditions for winds, waves, currents, water levels, and their joint probability;
3) A comprehensive report for Hollandse Kust (noord);
4) A web-based digital metocean database that enables users (e.g. project developers) to obtain output (time series, tables, and graphs, for both normal and extreme conditions) at any requested location within the site boundaries of the HKNWFZ, as well as the surrounding areas and other wind farms such as Hollandse Kust (west), IJmuiden Ver, and Ten noorden van de Waddeneilanden;
5) An application program interface (API) to extract the above data directly from the online metocean database.

The metocean conditions vary across the zone, mainly due to variations of the local bathymetry and tide. With the metocean database, developers will be able to optimise their designs - i.e. for wind turbines, inter array cables, substations, and support structures - based on the conditions at their actual location, rather than using a single conservatively chosen reference point in each zone.
The database is available through https://www.metocean-on-demand.com/. The API is available via https://api.metocean-on-demand.com/. The development of the online metocean database is one of the main improvements compared to the metocean desk study performed for Hollandse Kust (zuid) Wind Farm Zone. This online service will allow developers to access all the metocean information through a user-friendly and easily accessible platform and optimise their preliminary design when preparing the tender bid. The results (Table 4.2) can also be used for detailed design of the offshore wind farms. In addition, this study uses DHI's most advanced statistical analysis tools (based on new advances in non-stationary extreme value statistics) which has resulted in less uncertainty in the extreme values and will lead to more optimised design. The new tool is superior to traditional methods, especially in the Dutch North Sea, where there are large variations in available fetch and storm systems.

### 4.10.2 Supplier

RVO.nl assigned DHI to perform the metocean study. DHI is a renowned hydraulic institute with significant experience with the provision of metocean conditions and databases all around the world. DHI has contributed to most of the existing offshore wind farms in Europe.

### 4.10.3 Results

Work started on the metocean desk study in August 2018. The metocean conditions were established using a dedicated high-resolution model covering the period from 1979 to 2018 (39+ years). The modelling procedure comprised a wave model to simulate wave generation and propagation and a hydrodynamic model to simulate currents and water levels. Both featured an unstructured grid with respective grid resolutions of about 400 m and 200 m at the wind farm site in the HKNWFZ. The atmospheric forcing for both wave and hydrodynamic model was taken from the wind and pressure field data in the Climate Forecast System Reanalysis (CFSR) dataset provided by the National Centers for Environmental Prediction (NCEP).

DHI carried out an extensive analysis on the CFSR wind data and performed bias corrections, which lead to more accurate wind and wave results. The local hydrodynamic model was forced by a regional DHI model covering the North-Atlantic and optimised with data assimilation techniques. The local wave model was forced by DHI's regional North Sea wave model. An extensive validation of the modelling results was conducted using available satellite and local measurements.

The local measurements included wind data from met masts at IJmuiden and Egmond aan Zee, LiDAR wind measurements at K13, Europlatform, and MMIJmuiden, Rijkswaterstaat wave measurements at platforms K13, K14, Euro platform, Lichteiland Goeree, F3, F16, J6, L9, Eierlandse Gat, and IJmuiden Stroommeetpaal, in addition to measurements

**Table 4.2** *Results of the metocean desk study*

| Subjects | Results of the metocean desk study include: |
|---|---|
| **Wind** | |
| | Wind velocity roses |
| | Joint occurrence tables |
| | Weibull parameters |
| | Persistence of wind speed |
| | Extreme wind speeds |
| | Wind profiles |
| | Wind energy spectra |
| | Wind turbulence intensity and spatial variations |
| **Wave** | |
| | Roses of significant wave height and peak wave period |
| | Joint occurrence tables |
| | Persistence of wave height |
| | Extreme wave conditions |
| | Partitioning wind sea and swell |
| | Mean storm durations |
| | Spatial variations |
| | Breaking wave effects |
| | Normal sea states (according to DNV-GL-0437) |
| **Currents** | |
| | Current roses |
| | Velocity profiles |
| | Occurrence tables of current velocity and direction |
| | Extreme currents |
| | Separation tides and residual currents |
| | Spatial variations |
| **Water levels** | |
| | Astronomical tide levels |
| | Extreme water levels |
| | Assessment of sea level rise |
| | Spatial variations of water levels |
| **Joint probabilities** | |
| | Joint occurrence tables of wind and waves |
| | Current and waves |
| | Water levels and current |
| **Other metocean parameters** | |
| | Snow and ice accretion |
| | Salinity |
| | Air and sea temperature |
| | Atmospheric and seawater density |
| | Marine growth |
| | Lightening |
| | Visibility |

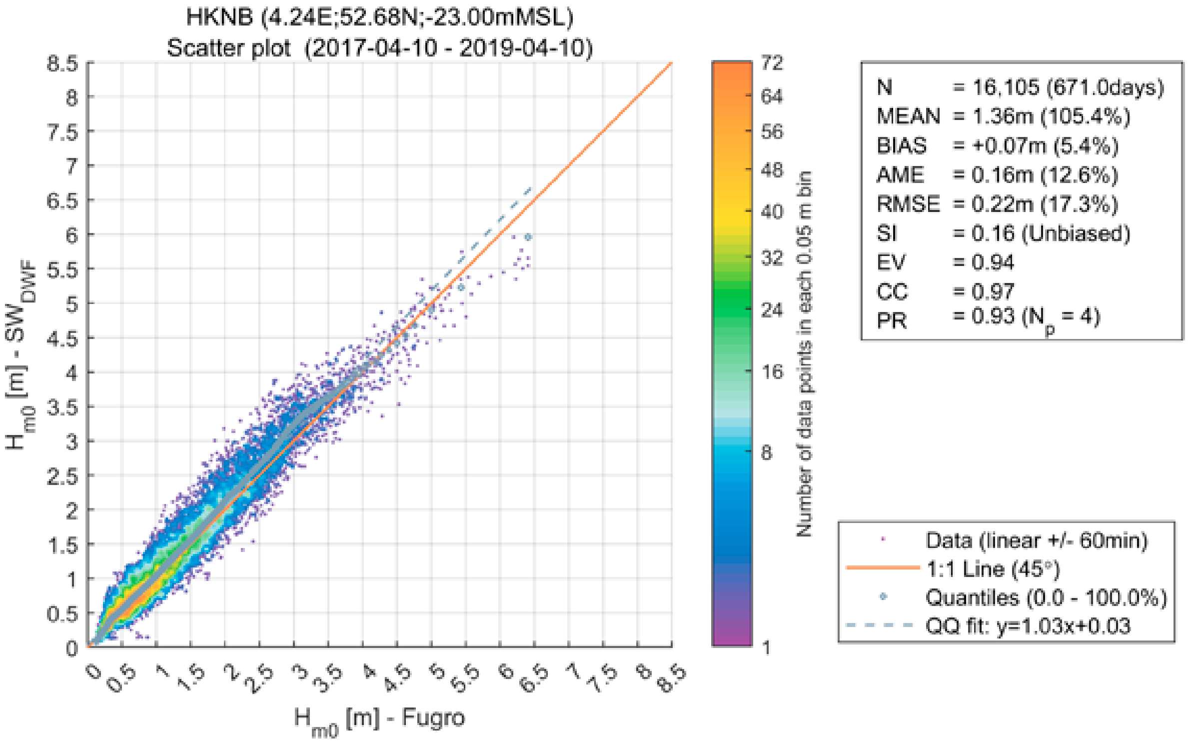



**Figure 4w** *Scatter comparison plot of significant wave heights between the model and measurements at location HKNB.*

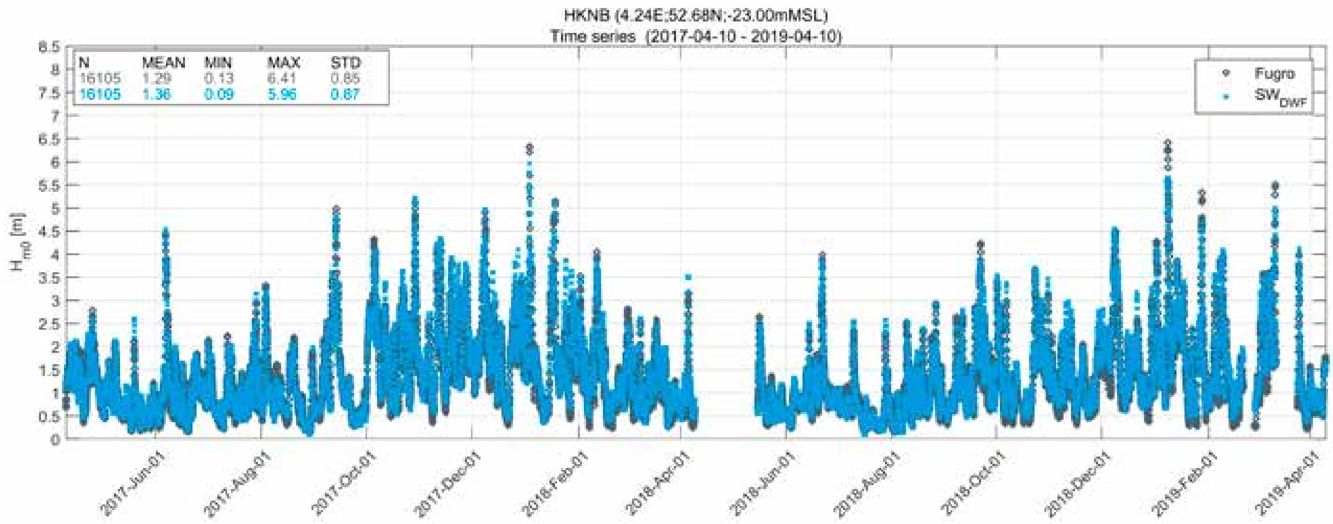



**Figure 4x** *Time series comparison of significant wave height between model and measurements at location HKNB.*

performed by RVO.nl at Borssele, HKZWFZ, and HKNWFZ (15 months of available measurements). The resulting validation showed very good model performance and demonstrated accurate and high-quality metocean conditions at the wind farm areas (see e.g. Figure 4w and Figure 4x).

The metocean analysis covered winds, waves, currents, and water levels, both under normal (ambient) conditions and extreme storm conditions. The analysis included persistence tables, scatter tables, rose plots, spatial variations, spectral analyses, joint occurrence tables, occurrence of individual wave heights and periods, and misalignment of wind and waves. Particular attention was paid to the extreme value analyses, since the resulting values are critical for design. Extreme conditions were established based on DHI's J-EVA tool for winds, currents, and water levels for return periods up to 1,000 years and for waves (significant wave height, maximum individual wave height, and maximum crest heights) for return periods up to 10,000 years. Extreme conditions were provided on a directional and monthly basis. In addition, the joint probability of various parameters and the likelihood of breaking waves were assessed.

The report includes results of metocean analysis at five output locations for Hollandse Kust (noord). The output locations were selected at a location with maximum extreme significant wave height (HKN2018) and the corner points within HKNWFZ to show spatial variations of the metocean conditions (see Figure 4y).

Typical design values with a 50-year return period at the output location of HKN2018 include 10-minute wind speed (at 100 m elevation relative to MSL) of 41 m/s, a significant wave height of 7.3 m, an associated peak wave period of 11.5 s (to the 50-year significant wave height) and a depth-averaged total current velocity of 1.1 m/s at a water depth of about 24 m MSL (23 m LAT).

The extreme sea states show spatial variability of a few decimetres across the HKNWFZ. Due to using more advanced extreme value analysis methods, the extreme values have been reduced compared to previous studies. Extreme values at other locations can be accessed through the metocean database, which enables users to access the modelling data and the analysis results through a user-friendly web interface.

In August-September 2019, the metocean database was verified against the full 24 months time series for wind, wave, current, and water level recordings as collected at HKNB. Also measurements up to July 2019 for Europlatform, K13, and Lichteiland Goeree (only wave recordings) were collected and compared to the model results. The comparison of the modelled wind, wave, current, and water level parameters against the measurements confirmed the accuracy of the model results and therefore further validated the metocean database, especially for HKNWFZ.

### 4.10.4 Deliverables

The state-of-the-art metocean database is an online application that can be accessed via https://www.metocean-on-demand.com (Figure 4z). The user-friendly database provides users with many ways to view and access the data. A summary of the functionalities is given below:

1) A graphical user interface with capability to contain user-defined shapefiles and coordinates with the option to convert UTM coordinates to Long/Lat (see Figure 4r);
2) Access to modelling results (winds, waves, currents, water levels, and other meteorological parameters) at about 56,000 grid points within a large area covering Hollandse Kust (noord), Hollandse Kust (west), IJmuiden Ver, and Ten noorden van den Waddeneilanden, for the period from 1979 to 2018 (39+ years) at high resolution;
3) Functionality to perform analyses: plot time series, rose plots, scatter diagrams, persistence tables, distribution tables, extreme conditions and NSS tables and surface maps, all with user-defined settings;
4) Functionality to export time series, data, and plots at selected location(s); Outputs can be provided in ASCII, NetCDF, Mat and DFS format;
5) Functionality to download full directional-frequency spectrum on a 1 km grid within the wind farm zones and 5 km grid at offshore locations;
6) Option to validate the offshore wave results to altimeter data;
7) A tutorial video;
8) Make cross scatter tables/plots between two datasets (for example waves against currents).

The metocean database can also directly be approached by a cURL, matlab, or Python script using an API. This API helps the user to download the selected datasets in https://www.metocean-on-demand.com without going through the website. The API downloader can be found on https://api.metocean-on-demand.com. The link directs you to a tutorial in which an API key can be generated and examples are given to use the key in several scripts.

### 4.10.5 Webinar

The study was presented and discussed at a webinar in May 2019. The approach towards the metocean study and the performed analyses are presented in the first part of the webinar. In the second part of the webinar, the metocean database is demonstrated. The webinar is available on offshorewind.rvo.nl/windwaternh.

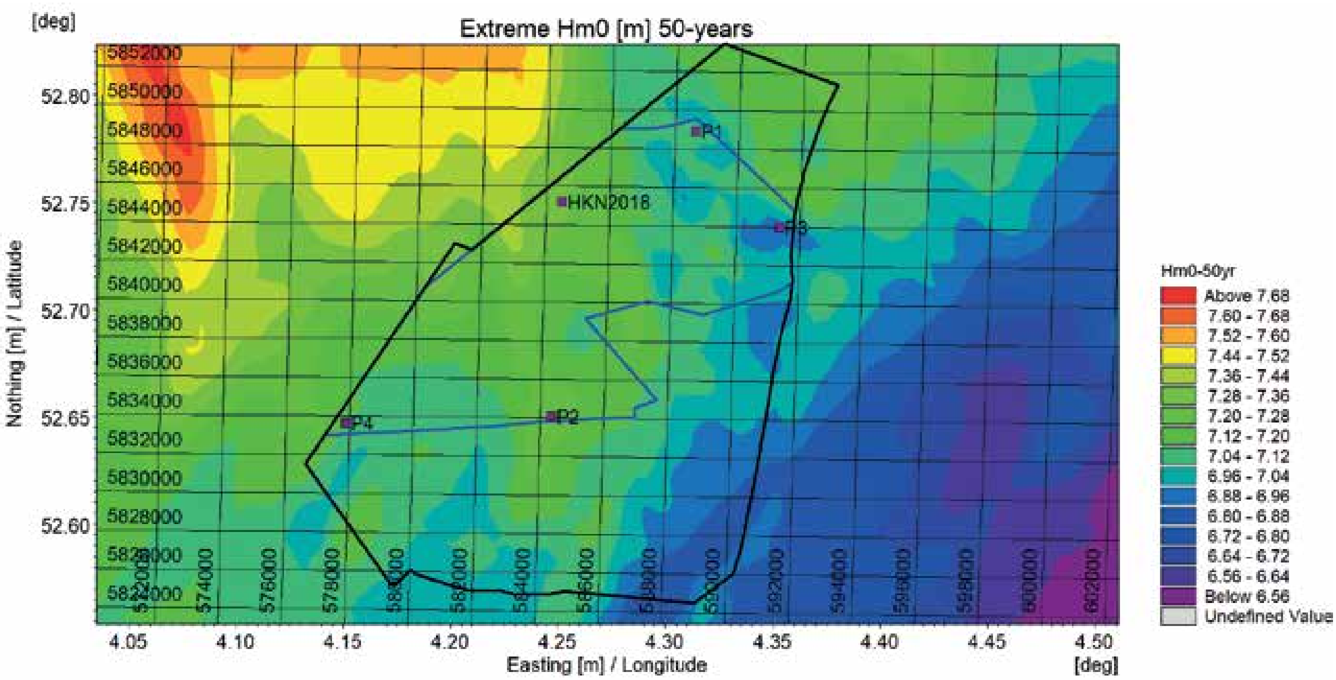



**Figure 4y** *Scatter comparison plot of significant wave heights between the model and measurements at location HKNB.*

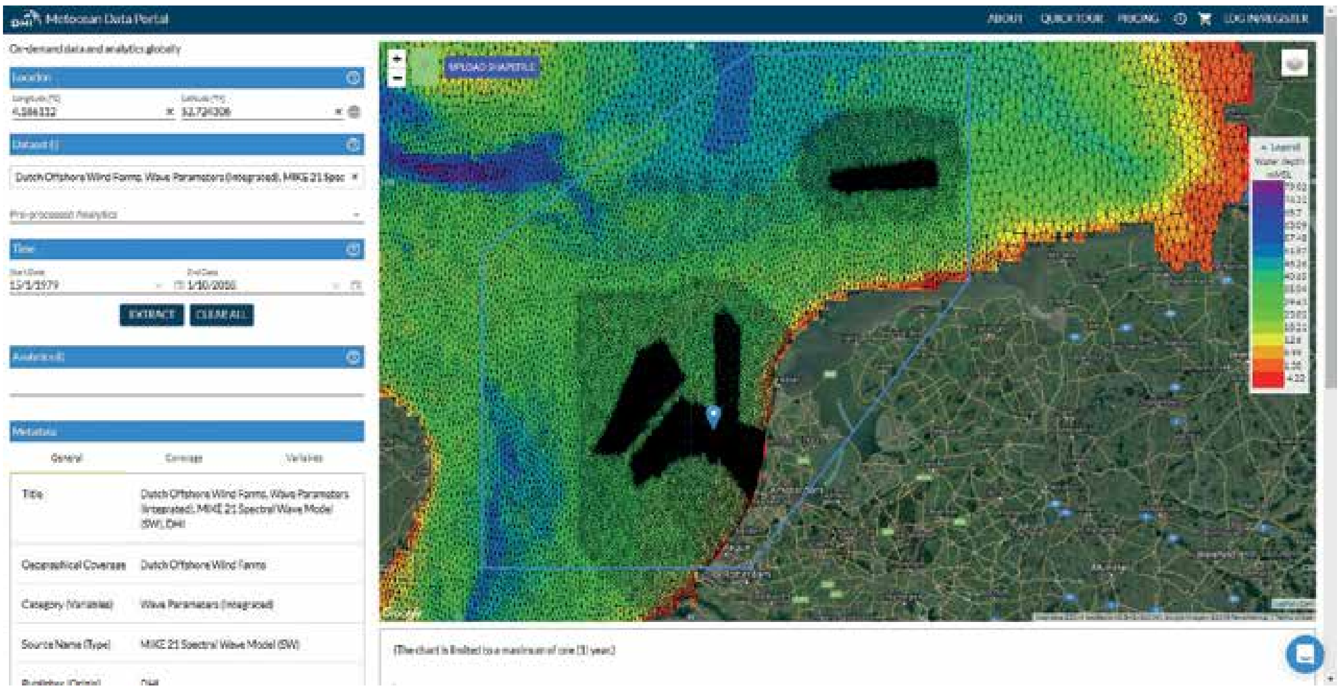



**Figure 4z** *Example of graphical user interface of metocean database.*

# 5.
# Resources for further information

**Preparations by the Government for the tender Hollandse kust (noord) are being finalised. This Project and Site Description (PSD, version October 2019) is the first version, which contains available site data and requirements to start preparing for a tender. In this Chapter, you will find the following information (and web links) to help you.**

## 5.1 Useful websites to help keep track

Several websites provide the most up-to-date information and status of all relevant studies, legal framework and the application process for a subsidy and permit. The most important of these are listed below:

- The most up-to-date information on site data, including the results of the HKNWFZ metocean campaign, can be found at ***https://offshorewind.rvo.nl/***. The site also contains maps, minutes of workshops, and a Q&A and revision log;
- More information on the permit, the Wind Farm Site Decisions and the FAQ can be found at ***https://english.rvo.nl/subsidies-programmes/sde/offshore-wind-energy*** and ***www.rvo.nl/windenergie-op-zee***
- Information from Holland Trade and Invest on opportunities in the Netherlands for offshore wind: ***www.hollandtradeandinvest.com/key-sectors/energy/***
- “Noordzeeloket” provides information on several spatial topics concerning the North Sea, including offshore wind ***www.windopzee.nl*** and ***https://www.noordzeeloket.nl/en/functions-and-use/***
- Information by TenneT, related to Grid Connection System Hollandse Kust (noord): ***https://www.netopzee.eu/hollandsekustnoord/***

## 5.2 Hollandse Kust: where wind & water works

The magazine, 'Hollandse Kust: where wind & water works' published November 2017, includes and expands on information published in the PSDs for HKZWFS I and II. This includes, amongst other things, the following:

- Useful websites that provide the most up-to-date information, e.g. for all relevant site studies;
- Information and contact details of key stakeholders relating to the Hollandse Kust region;
- A detailed overview of all the major Dutch ports that can service the offshore wind sector, both locally and in a European context;
- An overview of TenneT's work relating to the offshore grid for the Netherlands.

# Appendices

| | |
|---|---|
| **Appendix A:** | **Applicable Law** |
| **Appendix B:** | **Summary of Environmental Impact Assessment** |
| **Appendix C:** | **Boundaries and Coordinates HKNWFS** |

**All appendices available on offshorewind.rvo.nl/generalnh**

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