Aramis Pipeline Routing Desktop Study - Expected Site Conditions

Consultancy Report | Dutch Sector of the North Sea

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TotalEnergies

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Nanterre, 10 February 2022

Dear [redacted],

Please find attached the final version of the Desktop Study performed as part of the ARAMIS Pipeline Routing project.

This report, referenced R201644 (03), was prepared by the joint efforts of [redacted], Engineering Geologist, [redacted] Geologist, [redacted], Principal Geologist. It was reviewed by [redacted], Principal Geologist, under the supervision of [redacted].

Thank you for giving us the opportunity to work for you.

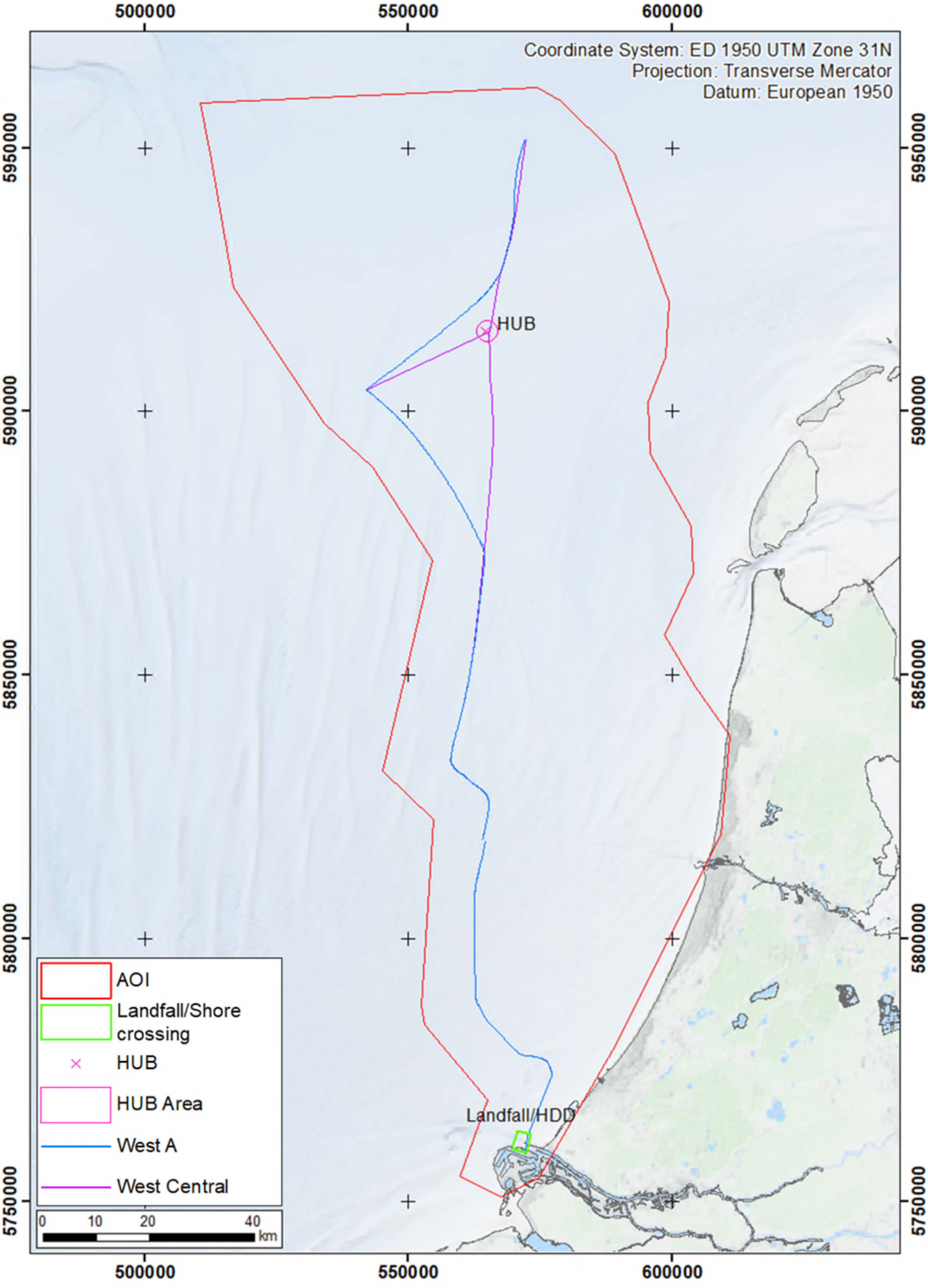
Please do not hesitate to contact us should you have any queries.

Yours faithfully,

[redacted]

[redacted]
Engineering Geologist

Frontispiece



Executive Summary

TotalEnergies requested Fugro to perform a desktop study (DTS) aimed at characterising soil conditions and site use based on publicly available data and Fugro experience over an area of 11,355 km^2 within the Dutch sector of the North Sea. Two areas of particular attention were differentiated within the general area of interest (AOI). These are the Landfall/Shore crossing Area and the Offshore Distribution HUB Area.

The main results of the DTS are summarised as follows:

- Information relating to site use, restricted areas, past or present activities, and any seafloor objects that may affect and constrain development of the proposed pipeline infrastructure was gathered and presented in the report in the form of text and maps;
- Water depths range from 0 m to a maximum of approximately 46 m relative to lowest astronomical tide (LAT). Seafloor gradients are generally less than 1°, but may be locally up to 30° and are related to anthropogenic features and crests of bedforms;
- Three zones with a distinct seafloor morphology were identified within the AOI: a coastal zone, a shallow continental shelf with low-angle topography covered by a complex compound of rhythmic bedforms, and a relatively deep low-energy zone with low-angle seafloor gradient;
- Three types of bedforms were observed within the AOI: sand banks, sand waves and megaripples;
- Sand waves are mobile over the lifetime of a pipeline and are considered to have a significant impact on pipeline foundation design and asset integrity;
- Six groups of surficial sediments were identified across the AOI: Sandy GRAVEL, (slightly) gravelly SAND, (slightly) gravelly muddy SAND, SAND, muddy SAND and sandy MUD. The main constituent is SAND;
- The AOI is characterised by variable soil conditions down to the depth of interest, which were grouped into geotechnical soil units based on the available data (geological, geophysical and geotechnical);
- Separate ground models are presented for the AOI, the Landfall/Shore crossing Area and the Offshore Distribution HUB Area. These ground models take into account the different depths of interest and site-specific site conditions;
- Eighteen soil profiles were generated to display the lateral and vertical variability across the AOI;
- In the Landfall/Shore crossing Area, the surficial sediments comprise predominantly sand to locally sandy gravel, and very soft clay in the Maasmond Kanaal. In the subsurface, the main units are the Naaldwijk Formation, comprising of interbedded sand and clay, with locally peat (laminae to thin beds), and the Kreftenheye, IJmuiden Ground and Winterton Shoal Formations, which comprise dense to very dense sand, with locally layers of silty sand and/or (laminated) clay in the lower part of the depth of interest.
- Three soil province maps were created to depict the spatial extent of each predicted soil profile within the AOI, Landfall/Shore crossing Area and Offshore Distribution HUB Area;
- A geohazards inventory list is provided, detailing (geo)hazards, soil and anthropogenic constraints and man-made obstructions identified across the AOI;

- Recommendations for site-specific geophysical and geotechnical surveys are detailed at the end of the report. These recommendations may aid in reducing uncertainties and aid decision making regarding the ARAMIS Pipeline routing.

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Abbreviations

AOI	Area of interest
BH	Borehole
bLAT	below Lowest Astronomical Tide
BP	Before Present
BSF	Below seafloor
CD	Chart datum
CM	Central meridian
CPT	Cone penetration test
DTM	Digital terrain model
DTS	Desktop study
ED	European Datum
Fm.	Geological formation
GIS	Geographic information system
ETRS	European terrestrial reference system
LAT	Lowest Astronomical Tide
ka	Period of thousand years
LGM	Last Glacial Maximum
Ma	Million years ago
Mb.	Geological formation member
MBES	Multibeam echosounder
MSL	Mean Sea Level
OWF	Offshore wind farm
SBP	Sub-bottom profiler
SHOM	Service Hydrographique et Océanographique de la Marine
SSS	Side Scan Sonar
UHR	Ultra High resolution
UTM	Universal Transverse Mercator
UXO	Unexploded ordnance
WFZ	Wind farm zone
WGS	World Geodetic System
WMS	Web Map Service

1. Introduction

1.1 Purpose

Fugro France SAS (Fugro) was contracted by TotalEnergies (client) to provide a desktop study to characterise the site conditions for the ARAMIS Pipeline Routing project.

This geological desktop study (DTS) aims to better understand the ground conditions along the future ARAMIS Pipeline located in the Dutch sector of the North Sea.

The final purpose is to provide the client with a geological and geotechnical model across area of interest (AOI), providing the necessary information to help decision making for the pipeline routing.

1.2 Study Areas

The AOI comprises an area of 11355 km² and is located in the southern North Sea, north-west off the coast of the Netherlands, within the Dutch administrative zone (Figure 1.1). Along the coastline, the AOI extends from Maasvlakte within the Port of Rotterdam in the south, to Egmond aan Zee in the north. The AOI extends over approximately 210 km in a north–south direction and 90 km in a west–east direction.

Within the AOI, two areas of particular attention were differentiated. These are:

- Landfall/Shore crossing Area: the first 3 km of the planned pipeline routing for horizontal directional drilling (HDD) and trenching at Maasvlakte;
- Offshore Distribution HUB Area: a 2 km radius area around the planned Offshore Distribution HUB location. This area is mentioned as HUB Area in maps throughout the report.

The depth of interest is 20 m below seafloor (BSF) for the entire AOI, except for the Landfall/Shore crossing Area, where it is 40 m to 50 m BSF and the Offshore Distribution HUB Area, where it is 100 m BSF.

Client provided preliminary offshore rigid pipeline routing (two options: West A and West Central). At this point the final pipeline routing is not defined.

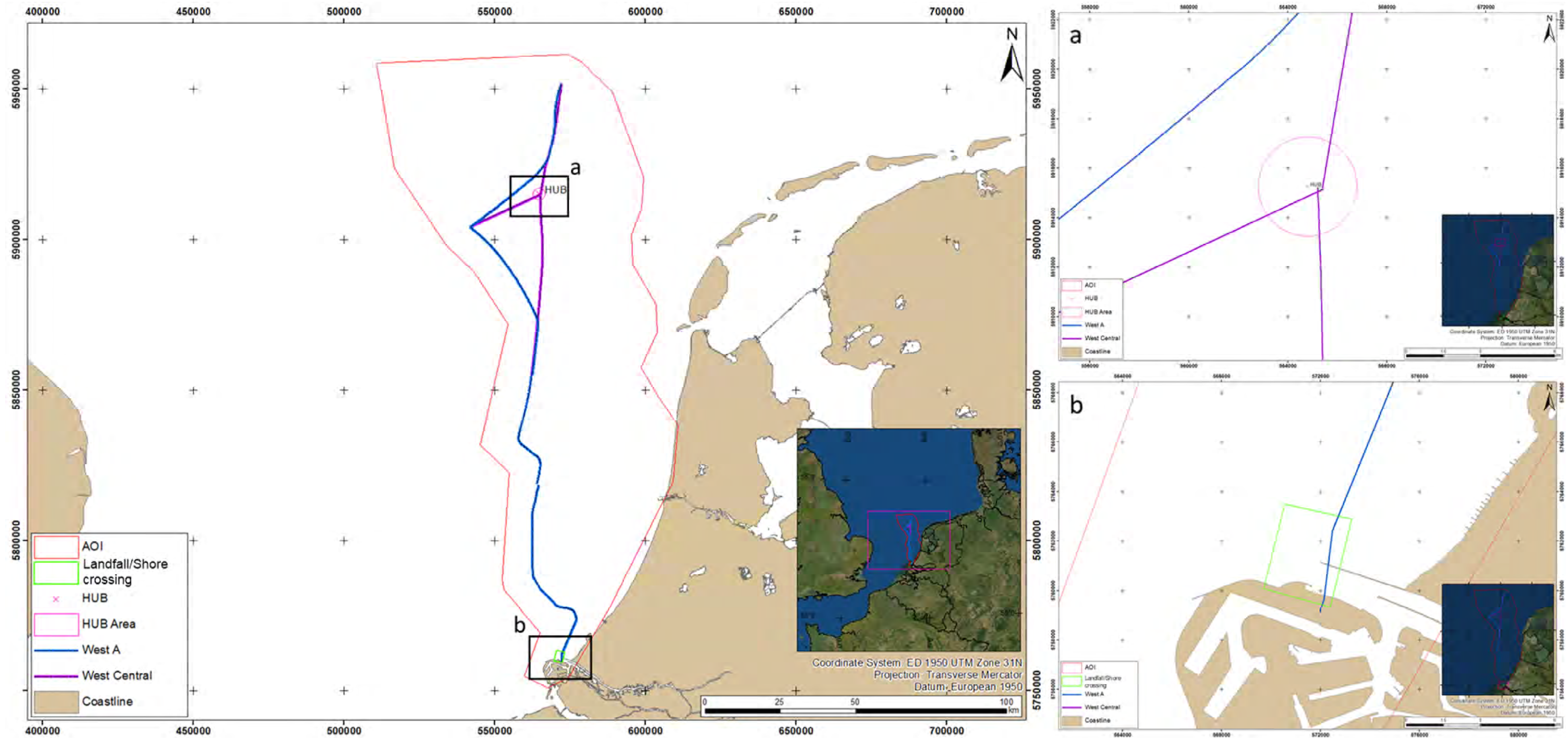

Figure 1.1: Extent of the AOI and definition of the Landfall/Shore crossing and Offshore Distribution HUB Areas

1.3 Scope of Work

The report presents the site-specific seafloor and sub-seafloor conditions derived from available data and the present understanding of the regional geology. These elements will be described across the AOI, Landfall/Shore crossing and Offshore Distribution HUB Areas.

This study includes comments on the site suitability considering a list of potential site-specific (geo)hazards, as well as soil and anthropogenic constraints across the AOI.

The UXO historical desktop study and archaeological desktop study were sub-contracted. Reports from sub-contractors are provided as Appendix B and Appendix C.

1.4 Study Limitations

This report does not cover the following topics:

- Metocean conditions;
- Environmental impact of foundations, if any;
- UXO risk assessment at the AOI.

The results of this study are dependent on the origin, quality, and quantity of available data. The presented ground model is preliminary and should only be used to help decision making during the bidding process.

Geotechnical parameters presented in this report are estimates, derived from Fugro experience over analogous representative areas within the AOI (e.g. planned wind farm sites). Future site-specific in situ measurements are required to confirm or adjust the presented geotechnical parameter ranges before any installation

1.5 Geodetic Parameters

Table 1.1 presents the coordinate reference system for this project. All illustrations in the report as well as the A3 maps are prepared using the ED50 datum and UTM Zone 31N projection.

Table 1.1: Geodetics parameters

Geodetic Datum	
Datum	International_1924
Spheroid	D_European_1950
Semi major axis	a = 6 378 137.0 m
Semi minor axis	b = 6 356 911.946127946 m
Inverse flattening	$^1/_f$ = 297.0
Map Projection	
Projection system	Transverse Mercator (UTM Zone 31N)
Central meridian	3°
Latitude of origin	0°

False easting	500 000 m
False northing	0 m
Linear unit	Metre

1.6 Data Use

Fugro understands that this report will be used for the purposes described in the 'Introduction' section. These purposes are a key factor in defining the scope and level of services offered.

It should also be noted that the geological and geotechnical data presented in this report are based on interpretations, correlations, and extrapolations, which implies a certain degree of uncertainty to be considered. This study will emphasise the level of confidence in the geological model and will detail the uncertainties related to stratigraphic conditions, the nature and thickness of the geological formations and geotechnical parameters.

However, the results of this report should not be used for purposes other than those for which this report was prepared, or if the original development or activity is modified by the client without prior control of their suitability.

1.7 Guidelines on Use of Report

Appendix A outlines the limitations of this report, in terms of a range of considerations including, but not limited to, its purpose, its scope, the data on which it is based, its use by third parties, possible future changes in design procedures and possible changes in the conditions at the site with time. It represents a clear description and explanation of the constraints which apply to all reports issued by Fugro. It should be noted that the Guidelines do not in any way supersede the terms and conditions of the contract between Fugro and TotalEnergies.

2. Approach and Data Review

2.1 Desktop Study Approach

The first step for the desktop study was to gather any relevant data, both public and internal, related to geological, geophysical and geotechnical features within the AOI but also covering a wider area. Based on these, the regional geological background was determined. This allowed for a better understanding and identification of potential or identified geological features or processes that may be expected across the AOI.

In addition, information relating to site use, restricted areas, past or present activities, and any seafloor objects that may affect and constrain development of the proposed pipeline infrastructure was gathered and presented in a number of maps.

These data were then reviewed and studied to characterise the different geological features, stratigraphic units, geotechnical parameters and constraints (geological and site-use) across the AOI, with a particular focus on the Landfall/Shore crossing Area and the Offshore Distribution HUB Area. Geotechnical parameters were derived mainly based on public information and Fugro experience. Note that no project names or locations are shared for confidentiality reasons. The data that were used are introduced in Section 2.2.

Attention is given to the identification of possible missing data or areas of uncertainties to establish recommendations for future geophysical and geotechnical site-specific surveys.

The ultimate result of the DTS is to provide a geotechnical ground model allowing to describe the soil variability, both vertically (soil profiles) and laterally (soil provinces), in the AOI (including Landfall/Shore crossing and Offshore Distribution HUB Areas).

The available data used for this study were compiled in a GIS (Geographic Information System) geodatabase. The maps were created using ArcGIS® software by Esri (version 10.8).

The final GIS project is delivered along with the final revision of the report.

2.2 Available Data

The main sources of information used in this study include:

- Client-supplied information (Table 2.1);
- Fugro internal databases;
- Digital public domain data (Table 2.2);
  - WMS
  - Freely downloadable GIS-compatible data
- Published literature.

For those sources that are not included in the GIS database deliverable, URL links are given to allow TotalEnergies to retrieve the relevant information.

2.2.1 Client-Supplied Information

Table 2.1: Project information

Data	Data Format	Date Provided
Boundaries of Area of Interest (AOI)	Shapefile	06 December 2021
WEST A and WEST CENTRAL Routings	Shapefile	07 December 2021
Offshore Distribution Area	Shapefile	04 November 2021
Outline of Landfall/Shore crossing Area	Coordinates	15 December 2021

2.2.2 Fugro Database

This report uses and summarises Fugro-held information:

- Information about regional geology;
- General geotechnical data;
- Previous geotechnical and geophysical investigation data applicable to development sites within the AOI.

2.2.3 Public Domain

Data from public sources have been gathered and reviewed. These data are accessible for consultation online, to download or using WMS servers. Table 2.2 presents the data sources used.

Table 2.2: Public domain data sources

Type	Source	Link
SITE USE		
Landing stations	EMODnet	https://www.emodnet-humanactivities.eu/view-data.php
Telecommunication cables	EMODnet, SHOM, Rijkswaterstaat	https://www.emodnet-humanactivities.eu/view-data.php https://www.rijkswaterstaat.nl/en
Power cables	Rijkswaterstaat	https://www.rijkswaterstaat.nl/en
Buoys	Rijkswaterstaat	https://www.rijkswaterstaat.nl/en
Offshore facilities	NLOG	https://www.nlog.nl/index.php/en/files-interactive-map
Wells	NLOG	https://www.nlog.nl/index.php/en/files-interactive-map
Pipelines	EMODnet	https://www.emodnet-humanactivities.eu/view-data.php
Active HC licenses	EMODnet	https://www.emodnet-humanactivities.eu/view-data.php
Navigation channels	Noordzeeloket	https://www.noordzeeloket.nl/en/up-date-atlas/

Type	Source	Link
Anchoring areas	Noordzeeloket	https://www.noordzeeloket.nl/en/up-date-atlas/
Harbour approach areas	Noordzeeloket	https://www.noordzeeloket.nl/en/up-date-atlas/
Wind farm active areas	Noordzeeloket	https://www.noordzeeloket.nl/en/up-date-atlas/
Wind farm development areas	Noordzeeloket	https://www.noordzeeloket.nl/en/up-date-atlas/
Dredging areas	EMODnet	https://www.emodnet-humanactivities.eu/view-data.php
Military areas	EMODnet	https://www.emodnet-humanactivities.eu/view-data.php
Environment Natura 2000 areas	EMODnet	https://www.emodnet-humanactivities.eu/view-data.php
Dredging areas	Rijkswaterstaat	https://geo.rijkswaterstaat.nl/services/ogc/gdr/stort_loswal/ows?
Fishing and shipping activities	EMODnet	https://www.emodnet-humanactivities.eu/view-data.php
BATHYMETRY		
AOI	EMODnet (2020)	https://portal.emodnet-bathymetry.eu/
Rotterdam approach area	EMODnet (2020)	https://portal.emodnet-bathymetry.eu/
Landfall/Shore crossing Area	EMODnet (2018)	https://portal.emodnet-bathymetry.eu/
Hollandse Kust WFZs	RVO	https://offshorewind.rvo.nl/
SOIL		
Substrate type	EMODnet	https://www.emodnet-geology.eu/map-viewer/?p=seabed_substrate
Grab samples, vibrocores and boreholes	DINOloket	https://www.dinoloket.nl/en/subsurface-data
Hollandse Kust WFZs	RVO	https://offshorewind.rvo.nl/
GEOLOGICAL INFORMATION		
Southern Bight Fm.	Balson et al. (1991), NITG–TNO (2004b)	-
Urania Fm.	NITG–TNO (2004b)	-
Naaldwijk Fm.	Cameron et al. (1984), Harrison et al. (1987), Balson et al. (1991)	-
Boxtel (Twente) Fm.	NITG–TNO (2004d)	-
Eem Fm / Brown Bank Mb.	NITG–TNO (2004d)	-
Kreftenheye Fm.	NITG–TNO (2004d)	-
Eem Fm.	Cameron et al. (1984, 1986)	-
Drente (Borkum Riff) Fm.	Laban (1995)	-
Drente (Cleaver Bank) Fm.	Laban (1995), NITG–TNO (2004d)	-
Tea Kettle Hole Fm.	Laban (1995)	-

Type	Source	Link
Egmond Ground Fm.	Cameron et al. (1984, 1986), Laban (1995)	-
Peelo (Swarte Bank) Fm.	Cameron et al. (1986), Laban (1995), Laban & van der Meer (2011)	-
Yarmouth Roads Fm.	Cameron et al. (1984, 1986)	-
Ice sheet extents	Laban (1995)	-
Notes: Data was accessed between December 2021 and January 2022		

3. Regional Geology

3.1 Regional Geodynamics and Geological History

The large-scale tectonic setting of the Netherlands and adjacent areas is driven by the north–south collision of Gondwana and Laurussia during the Late Carboniferous to form Pangaea, and the subsequent rifting during the Triassic in the Arctic–North Atlantic and western Tethys domains. This formed, in conjunction with the anisotropic and thickened crust of the Variscan fold belt, a complex system of basins and rifts in Northwest Europe (Geluk, 2005). Alpine inversion of these basins took place during the Late Cretaceous and early Paleogene as a result of the collision of Iberia and Europe. This was followed by multiple phases of subsidence from the Eocene up to recent times (Wong et al., 2007).

3.2 Pre-Quaternary Geology

From the late Miocene onwards, a complex fan delta system developed, which gradually evolved into an alluvial plain prograding from the east. Until the end of the Neogene, deposition in the North Sea was dominated by sediment input from the Eridanos (Baltic) river system (Overeem, 2002; Knox et al., 2010; Rasmussen & Dybkjaer, 2014; Thöle et al., 2014).

3.3 Quaternary Geology

During the Pleistocene, the depositional evolution of the North Sea basin was strongly influenced by climatic variations, glaciations and associated sea level fluctuations (Funnell, 1996; Overeem et al., 2001; Kuhlmann & Wong, 2008; Thöle et al., 2014). This resulted in a complex interplay of glacial, glaciolacustrine, glaciofluvial, fluvial, aeolian, deltaic and (shallow) marine environments and deposits (Laban, 1995; Laban & Rijswijk, 2002; Joon et al., 1990; Peeters et al., 2015).

By the mid-Pleistocene (~1 Ma), the Rhine, Meuse and Scheldt rivers had become important contributors of sediment influx to the North Sea basin, as a result of uplift of highland areas in Germany (Laban and Rijsdijk, 2002). Subsidence decreased during this time and the basin had become largely filled with deltaic deposits.

The AOI has been affected by an alternating series of glacial and interglacial periods that has occurred since the Pleistocene and continues to the present day. Below follows a more detailed description of the three glacial and three interglacial periods that took place.

3.3.1 Elsterian Glaciation (Middle Pleistocene)

During the Elsterian glaciation (475 ka to 410 ka BP), the Scandinavian and British ice masses coalesced and spread in southern direction to cover the northern part of the Netherlands and the southern North Sea (Ehlers, 1990; De Gans, 2007). The northern half of the AOI has been affected by the Elsterian ice sheet, while the southern half was influenced by the Rhine and Meuse river systems (Figure 3.1a). The Aramis area was also influenced by the Eridanos river system, which was deflected south of the ice limit. Deposition of predominantly low energy open marine deltaic sediments consisting of siliceous sands and clays ensued, which are thought to belong to the Yarmouth Roads Formation (Laban, 1995; Laban & Rijsdijk, 2002; Rijsdijk et al., 2005). Elsterian tunnel valleys occur within the Yarmouth Roads Formation. The infill of these tunnel valleys comprises glaciofluvial, glaciolacustrine and proglacial clays and sands of the former Swarte Bank Formation (now part of the Peelo Formation; Praeg, 1996; Rijsdijk et al., 2005; Graham et al., 2011; Moreau et al., 2012).

3.3.2 Holsteinian Interglacial (Middle Pleistocene)

During the subsequent Holsteinian interglacial (410 ka to 370 ka BP), sea level rose because of climate amelioration and melting ice masses. This resulted in a transgression phase in the AOI.

Fluvial and marine deposits were prevalent in this period. The fluvial deposits have been defined as the onshore Urk Formation (Bosch et al., 2003), while the offshore equivalent comprises marine deposits belonging to the Egmond Ground Formation (Bosch et al., 2003; Rijsdijk et al., 2005). Laterally, the Urk Formation grades into the Egmond Ground Formation (Bosch et al., 2003). The Urk Formation can contain clay interbeds, while the Egmond Ground Formation can contain marine shells. The Urk Formation and Egmond Ground Formation may locally incise into the underlying Yarmouth Roads Formation.

3.3.3 Saalian Glaciation (Middle to Late Pleistocene)

During the Saalian glaciation (370 ka to 130 ka BP), the eastern half of the AOI was probably covered by the Saalian ice sheet while the western half was located in close proximity to the Saalian Ice Margin (Figure 3.1b). However, the exact limit of the ice sheet advance offshore remains uncertain.

Ice masses formed glacially scoured basins and several ice-pushed ridges (moraines). The ice-pushed ridges were recognised directly south of the Hollandse Kust (noord) wind farm zone (WFZ) (Laban & van der Meer, 2011; Peeters et al., 2015; Cartelle et al., 2021).

Numerous tunnel valleys were created during the Saalian in subglacial and proglacial settings. A major tunnel valley is present in the centre of the site, and more tunnel valleys may be present near the north-eastern boundary of the Aramis area (Cameron et al., 1984a; Joon et al., 1990; Laban, 1995; Stouthamer et al., 2015).

Fluvial erosion of underlying formations occurred. During the Saalian glaciation, the Rhine–Meuse river system merged with a proglacial river system south of the ice margin (Peeters et al, 2015). This setting implies variable soil conditions dominated by extensive areas of glaciofluvial sands and gravels (outwash plains/sandurs) deposited in front of the ice sheet, with clays deposited in glaciolacustrine environments. Local aeolian deposition took place near the Saalian Ice Margin. The glaciofluvial and aeolian sediments belong to the Drachten Formation (formerly Tea Kettle Hole Formation), while the glaciolacustrine sediments belong to the Uitdam Member of the Drenthe Formation (formerly Cleaver Bank Formation). The latter is mainly confined to the Saalian tunnel valleys (Laban, 1995).

Between the coast of the island of Texel to a position about 14 km to the west, a till plateau is present.

TILL is unsorted glacial sediment. Within the AOI the TILL is expected to comprise silty, sandy CLAY, with matrix-supported gravel to boulder-sized grains. It is present in the north-east of the AOI and belongs to the Drenthe Formation (Gieten Member). Glacial TILL may pose a risk to the installation of offshore structures due to its heterogenic grain size composition and overconsolidated nature.

The Saalian glaciation is associated with widespread glacial deformation both onshore and offshore. Large deformation structures have been reported within the AOI (Joon et al., 1990; Laban, 1995). Some indications of glacial deformation have been identified in the Hollandse Kust WFZs.

Saalian sediments in the southern North Sea have been largely eroded by the subsequent Eemian transgression but are still present in Saalian channels and valleys.

3.3.4 Eemian Interglacial (Late Pleistocene)

A major marine transgression affected AOI during the Eemian interglacial (130 ka to 115 ka BP). The AOI became part of the delta plain of the river Rhine. Shallow marine sands (Eem Formation), lagoonal and estuarine clays and sands, and fluvial sands (Kreftenheye Formation) were laid down in a complex depositional setting (Peeters et al., 2015). Existing glacial valleys and channels were inundated by the marine transgression (Figure 3.1c).

With the onset of the marine regression at the end of the Eemian and beginning of the Weichselian glaciation, brackish marine clays and lagoonal or lacustrine silty laminated clays, identified as the Brown Bank Member (part of Eem Formation), were deposited in a low-energy environment in the (north-)western part of the AOI (Figure 3.1d; Cameron et al., 1984a; Peeters et al., 2015; GDN, 2018).

3.3.5 Weichselian Glaciation (Late Pleistocene)

During the youngest glacial period, the Weichselian (115 ka to 18 ka BP), the limit of the ice sheet extent was just north-west of the AOI. At the time, deposition in the southern North Sea was dominated by periglacial conditions with temporary fluvial influences of the Rhine–Meuse river system (Figure 3.1e).

The periglacial deposits comprise sand, sandy loam, peat, thaw-lake deposits and aeolian sediments belonging to the Boxtel Formation. The aeolian deposits are considered to have little preservation potential in a dominantly (glacio)fluvial environment (NITG–TNO, 2004). The glaciofluvial deposits comprise sand, gravelly sand and clay of the Kreftenheye Formation. Erosion of underlying formations probably occurred.

3.3.6 Holocene (Recent)

With the transition from late glacial to early Holocene (11.6 ka BP to present), climatic amelioration resulted in sea level rise, and the North Sea basin became flooded. Deposition took place in a terrestrial periglacial environment, transitioning into tidal and lagoonal as the sea level rose. Sediments from this period belong to the Naaldwijk Formation and are preserved as (scattered) sands and clays that often infill channels. Locally, peat beds were deposited in shallow marsh settings (Nieuwkoop Formation). As transgression progressed, the AOI was overlain by sands of the Southern Bight Formation and muddy sands of the Urania Formation.

The North Sea Basin has remained essentially sediment starved since the start of the Holocene (Jacobs & De Batist, 1996), and deposits occur mainly in the form of sand banks and sand waves (Liu et al., 1993). Surficial sediments in the AOI mainly consist of sand with shell and shell fragments typical of a high energy, open marine environment. These sands are partially derived from reworking of the sediments from the underlying fluvial deposits. Sands with a higher mud fraction are present in a bathymetric depression in the northern part of the AOI. These sediments belong to the Urania Formation and are indicative of a low energy open marine environment.

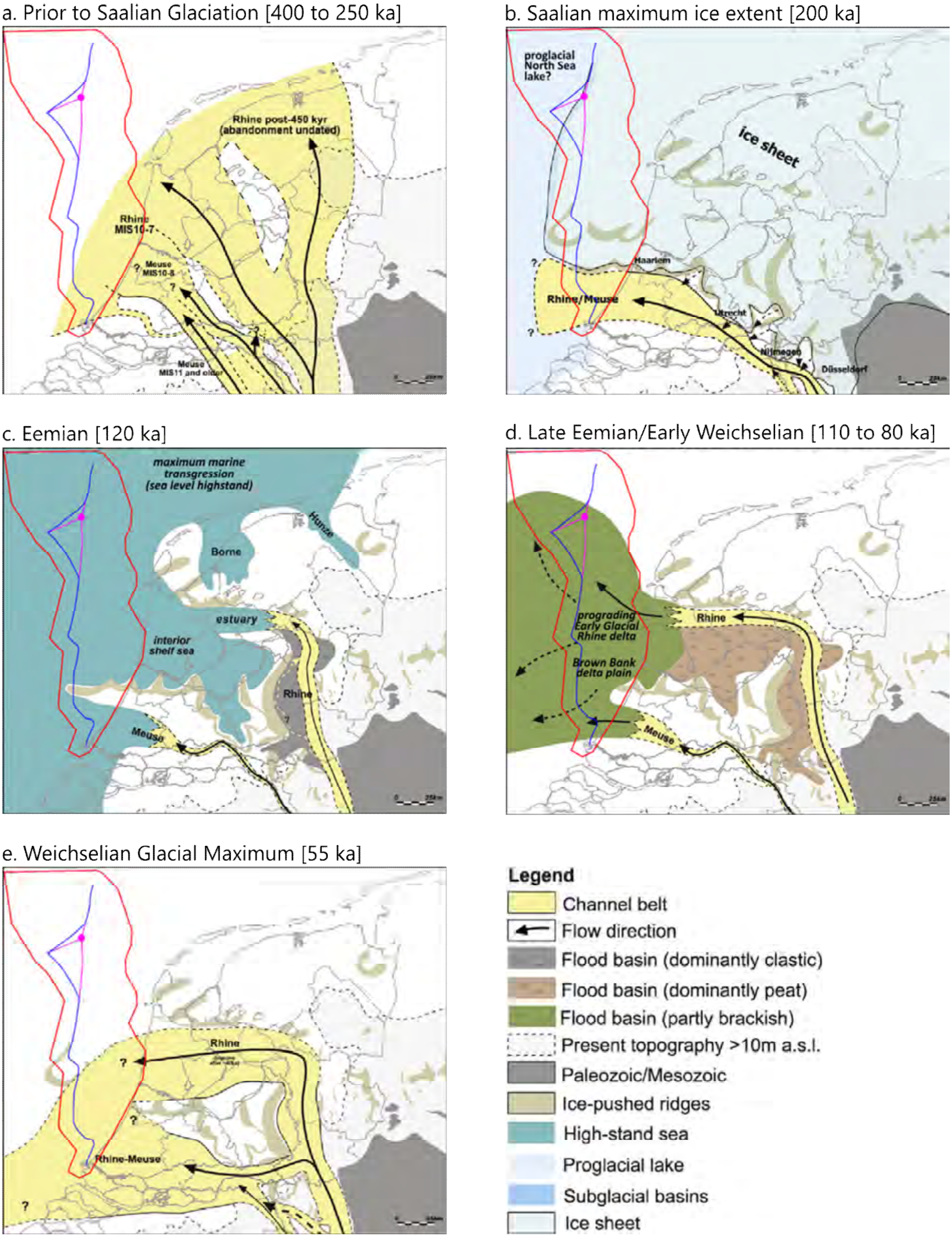

Figure 3.1: Paleo-geographical reconstructions of the Netherlands during the Middle to Late Pleistocene illustrated by five successive time frames. a) Rhine–Meuse drainage configuration prior to Saalian Glaciation. b) Maximum Saalian ice extent. c) Eemian interglacial maximum transgression during sea level highstand. d) Rhine delta prograding into lower-deltaic flood basin environment. e) Configuration of the Rhine and Meuse during the Weichselian glacial maximum (modified after Peeters et al., 2015).

3.4 Maximum Ice Sheet Extent and Subglacial Valleys

Three Pleistocene glaciations resulted in ice sheets covering large parts of the Dutch sector of the North Sea. From the oldest to the youngest, these glaciations are named Elsterian, Saalian and Weichselian. Figure 3.2 presents the maximum extent of the Pleistocene ice sheets and the location of the associated subglacial valleys.

The Elsterian valleys form a complex system of anastomosing, but mainly NNE–SSW trending, broad (approximately 1 km to 10 km wide) and deep (up to 400 m BSF) erosional features. They are present in the northern half of the AOI. These subglacial valleys were mainly filled with glaciofluvial SAND near the base and glaciolacustrine CLAY near the top, belonging to the Peelo Formation (Cameron et al., 1986; Laban, 1995).

A major Saalian subglacial valley runs in a N–S direction, along the margin of the maximum extent of the Saalian ice sheet, located in the centre of the AOI. It is approximately 10 km wide and up to 80 m deep. The infill consists locally of glaciolacustrine CLAY (Uitdam Member) near the base, covered with marine SAND of the Eem Formation (Laban, 1995, Fugro, 2020).

Weichselian subglacial valleys occur as close as 6 km north of the AOI (Laban, 1995).

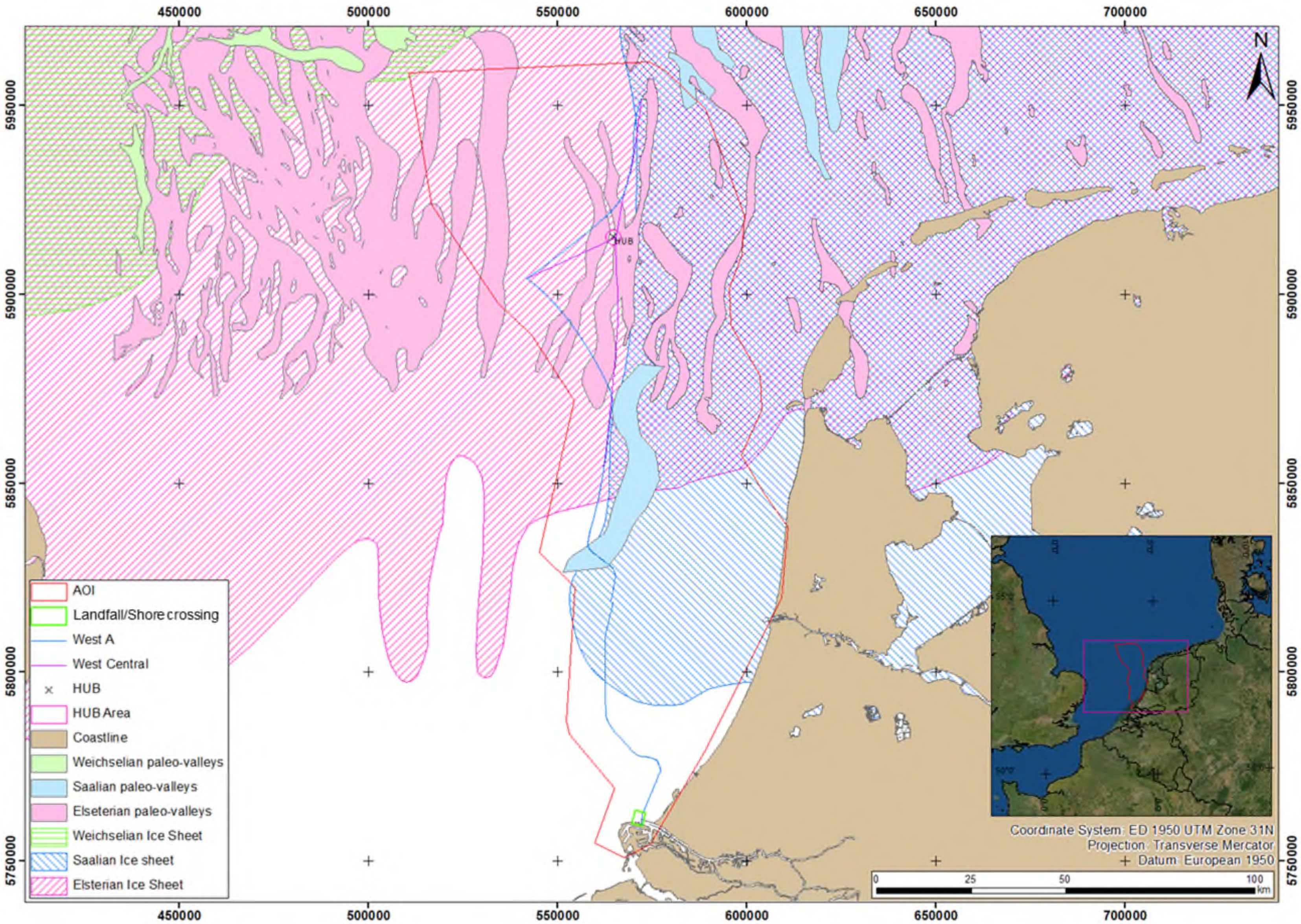

Figure 3.2: Maximum ice extent of the Pleistocene glaciations and associated paleo-valleys (Laban, 1995)

4. Site-Specific Conditions

4.1 Site Use

4.1.1 AOI

Past and/or present activities in the AOI can affect and constrain development of the pipeline infrastructure. Evidence of human activity and seafloor objects are documented in the Archaeological Desktop Study (Appendix B) and in the UXO Desktop Study (Appendix C).

Figure 4.1 presents navigation areas or infrastructure identified within the AOI:

- 197 navigation buoys;
- 7 navigation channels;
- 6 anchoring areas;
- 4 harbour approach areas.

Figure 4.2 presents restricted areas identified within the AOI:

- 7 navigation channels;
- 6 anchoring areas;
- 4 harbour approach areas;
- 3 wind farms in operation;
- 4 wind farms under development;
- 121 dredging areas;
- 11 dredge spoil areas;
- 4 military exercise areas;
- 7 natural protected areas.

Figure 4.3 presents seafloor oil and gas infrastructure identified within the AOI:

- 149 offshore facilities;
- 1153 wells;
- 227 pipelines.

Figure 4.4 presents seafloor cable and wind energy related infrastructure identified within the AOI:

- 1 cable landing station;
- 8 telecommunication cables;
- 139 wind turbine generators;
- 23 power cables.

Based on the currently available information, 36 cables and 35 pipeline crossings are to be expected in the AOI considering the current proposed pipeline routes.

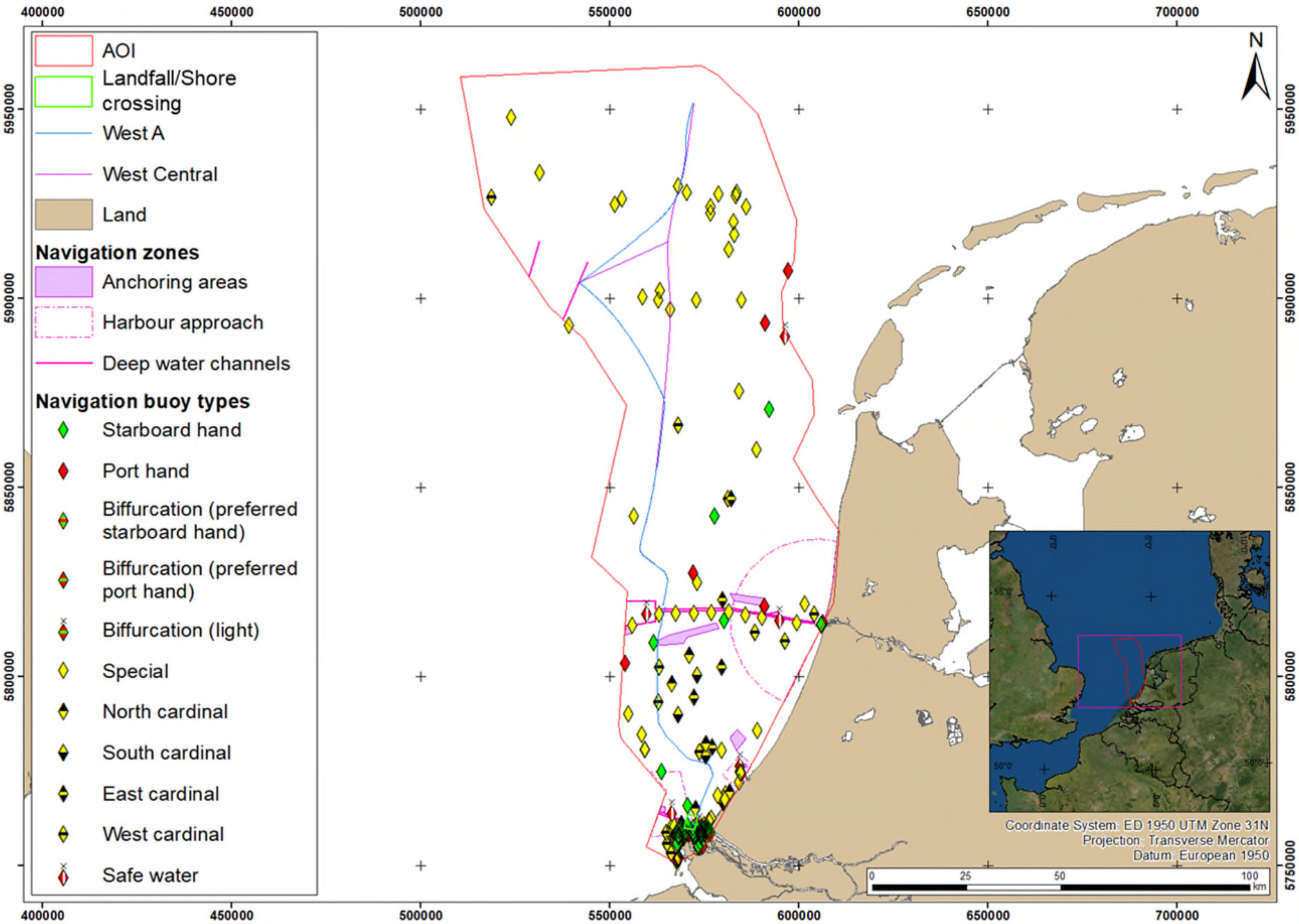

Figure 4.1: Navigation areas or infrastructures identified within the AOI

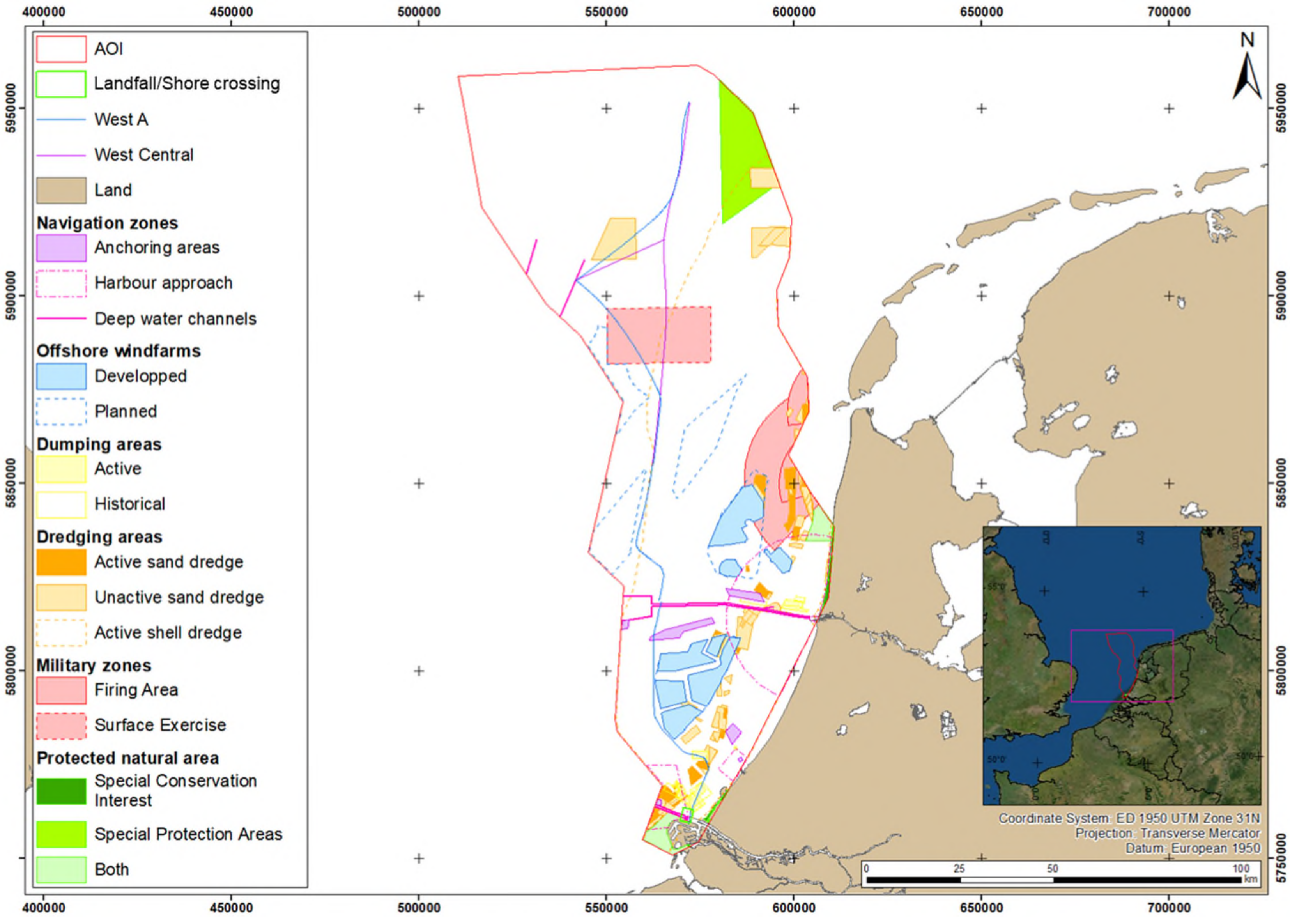

Figure 4.2: Restricted areas identified within the AOI

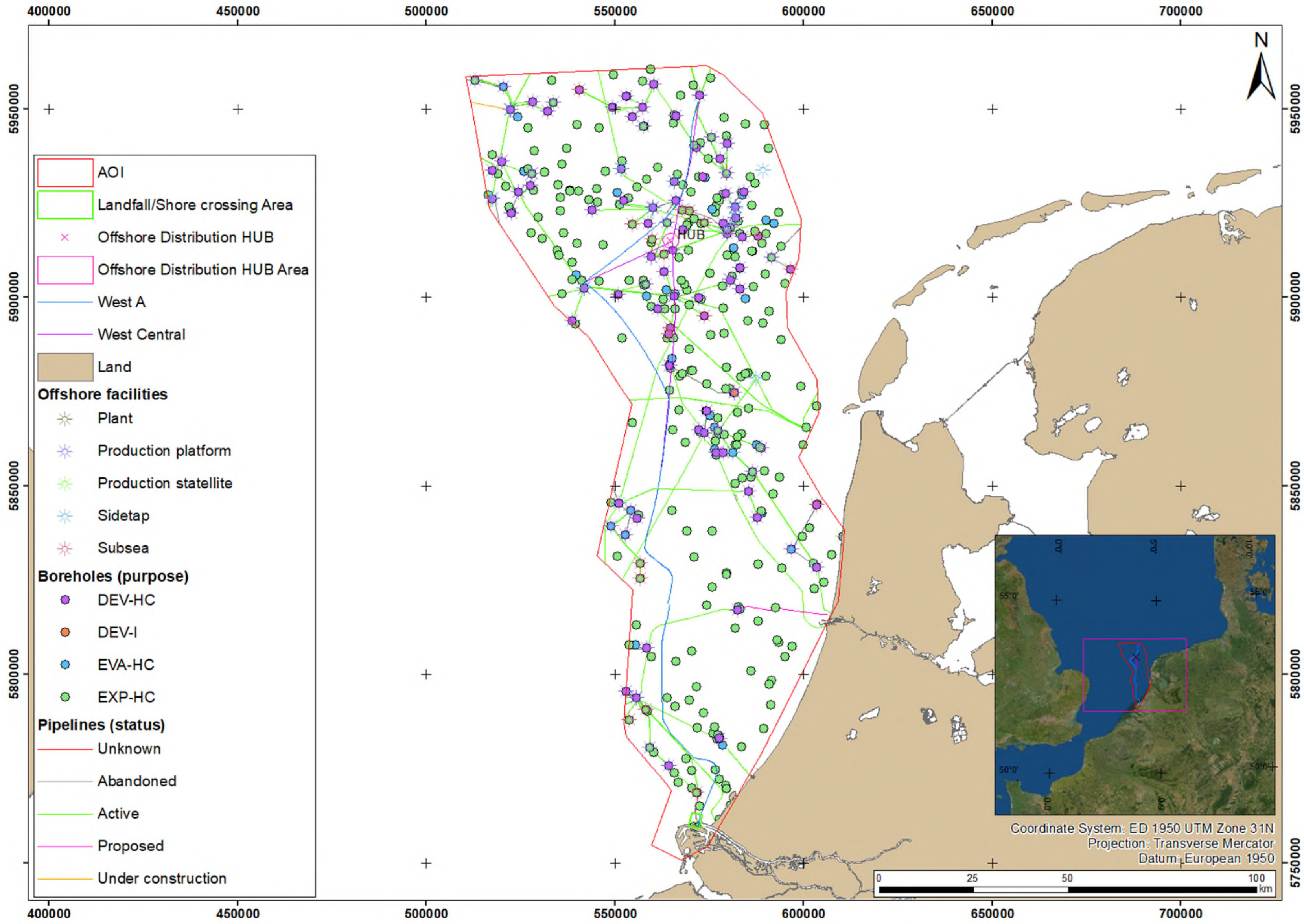

Figure 4.3: Oil and gas seafloor infrastructures identified within the AOI

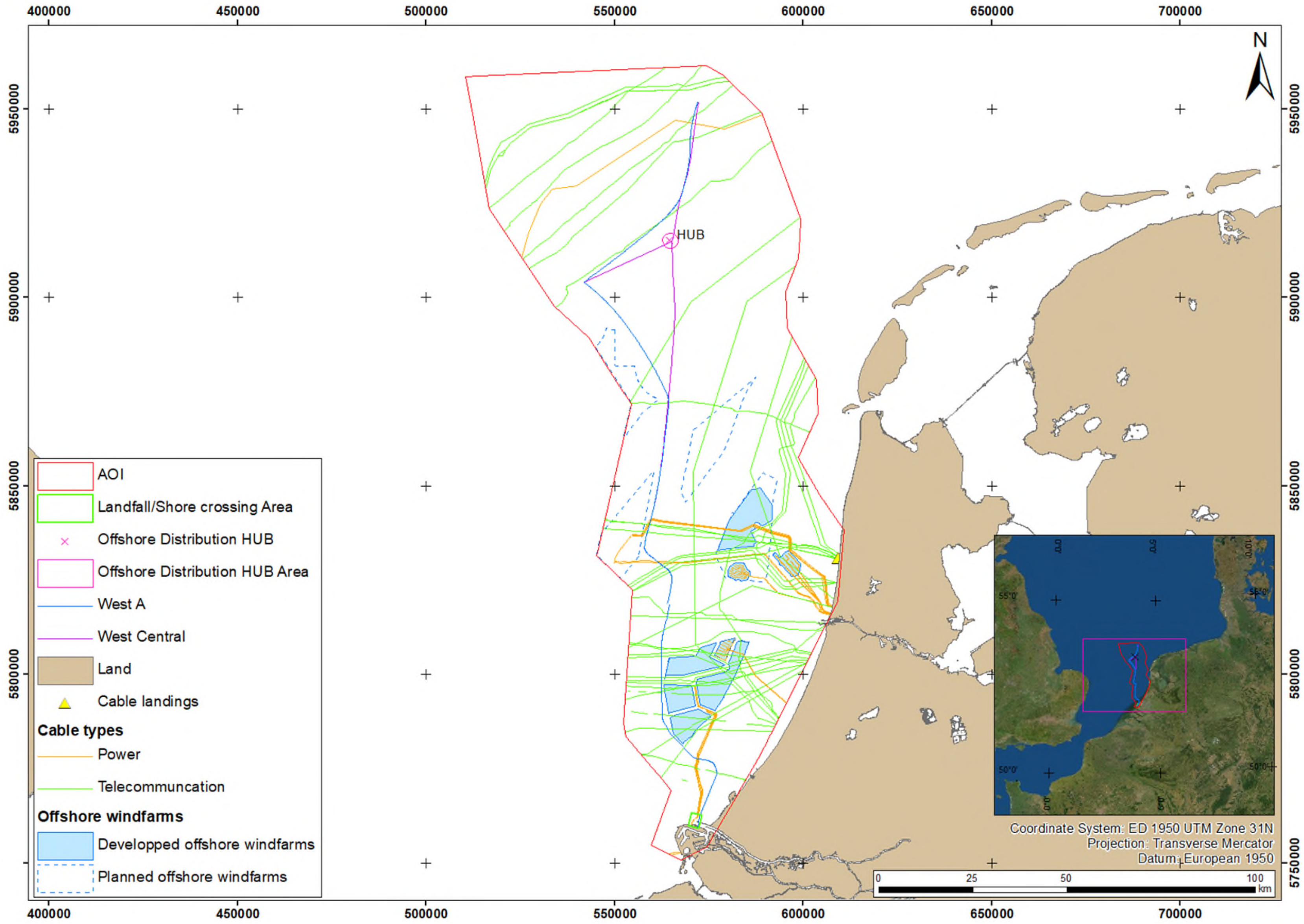

Figure 4.4: Cable and wind-energy related infrastructures identified within the AOI

Vessel route densities per type of vessels as well as vessel density per activity for 2020 were extracted from EMODnet.

Figure 4.5 present the total vessel route density for 2020 within and around the AOI, regardless of the types of boats. The main commercial routes are clearly visible as red lines, connecting the North Sea, Baltic Sea and English Channel as well as joining the main harbours (such as Rotterdam and IJmuiden). The present pipeline layout crosses three of the highest density routes. The Offshore Distribution HUB Area is within an area with medium density routes, probably corresponding mainly to small cargos, fishing, or leisure vessels.

Figure 4.6 presents the average fishing activity for 2020 within and around the AOI. Fishing activity is medium in the southern half of the AOI, and low within the northern half (and close to the Offshore Distribution HUB Area). Fishing activity is high within 20 km from the shore. However, within the Maasmond Kanaal, it is expected that fishing activity is low due to the presence of dense shipping traffic.

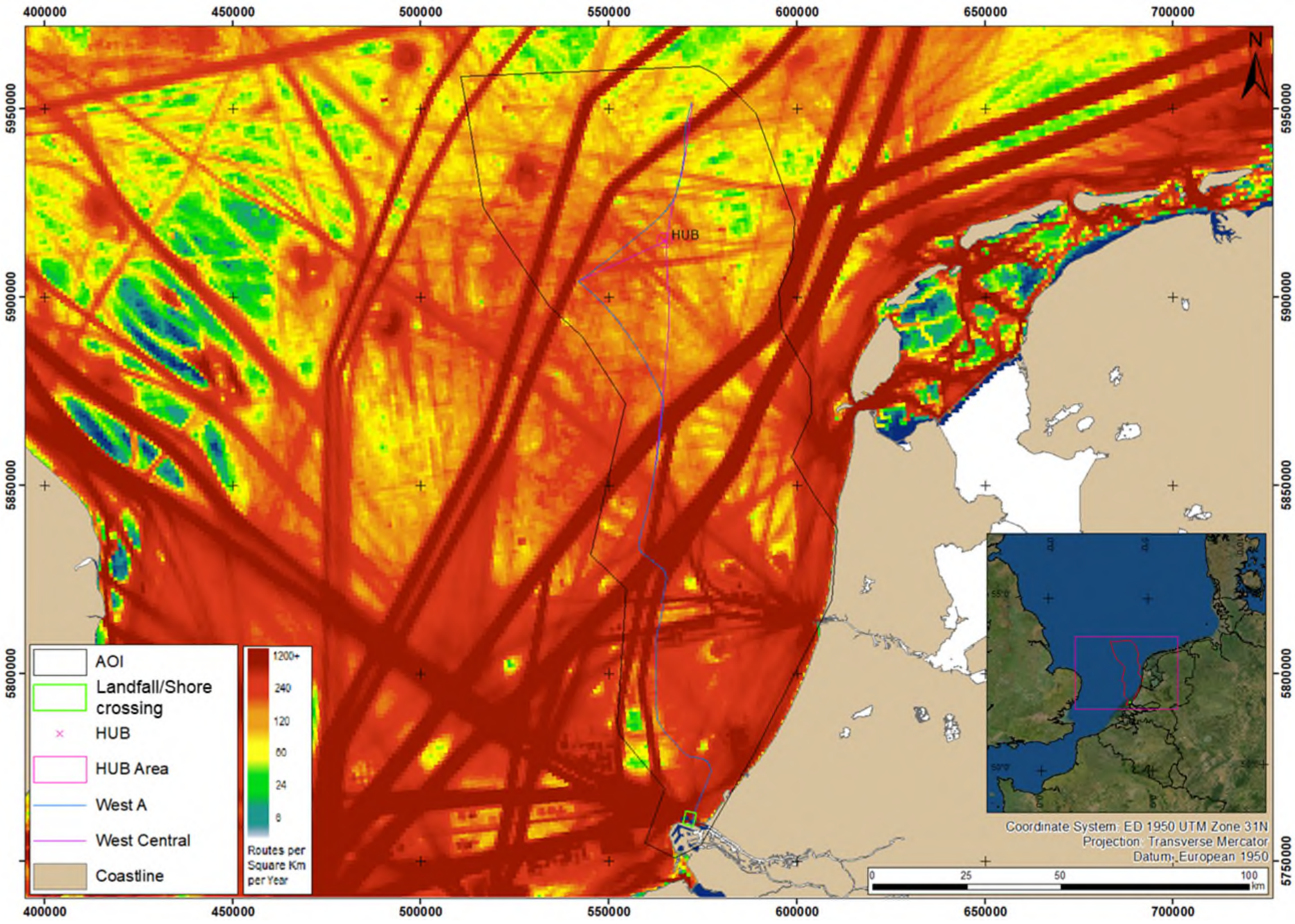

Figure 4.5: Total vessel routes density given as routes per km² per year for 2020 (EMODnet, 2022)

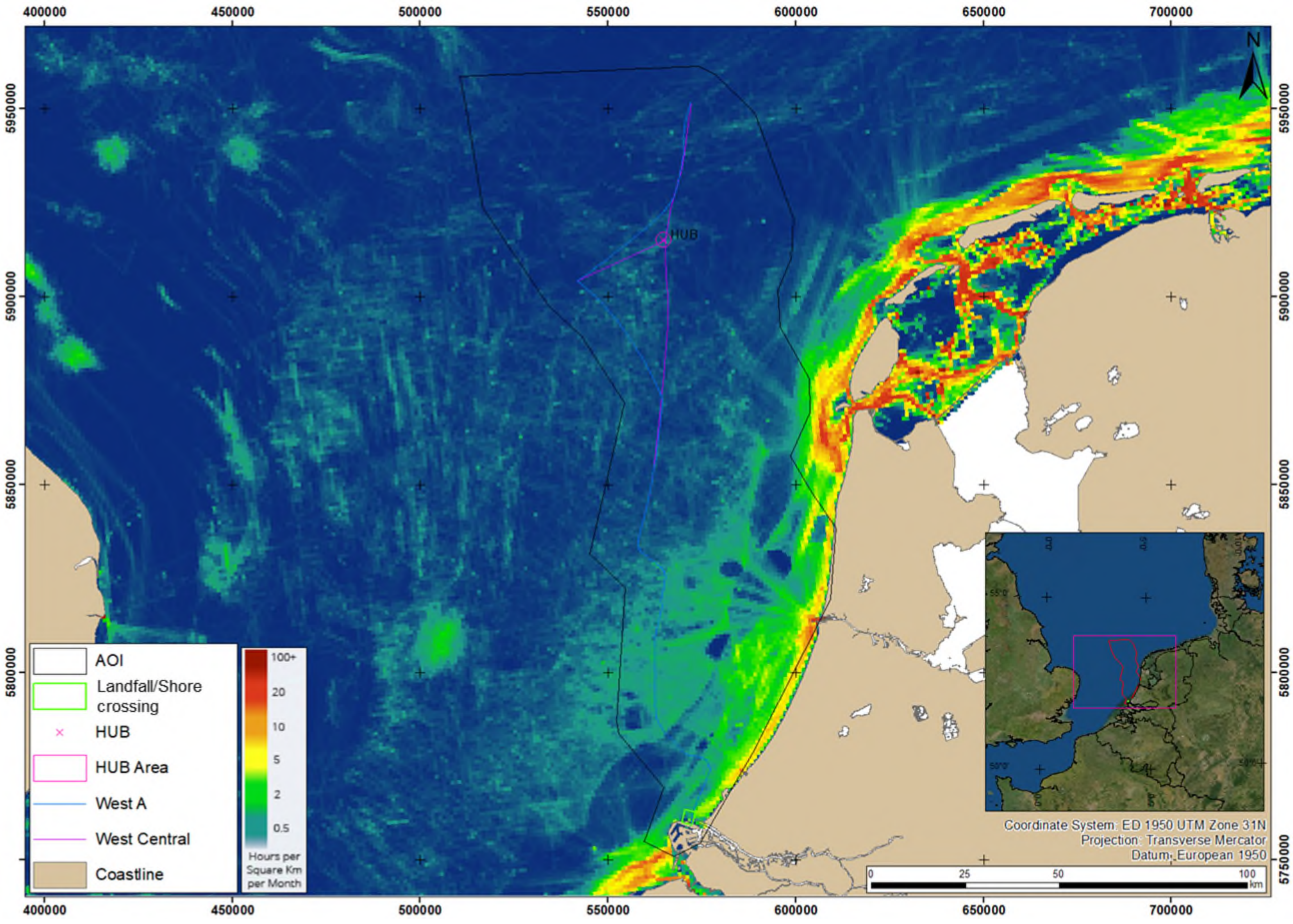

Figure 4.6: Average fishing activity density given in hours per km² per month for 2020 (EMODnet, 2022)

4.1.2 Landfall/Shore Crossing Area

Within the Landfall/Shore Crossing Area a number of restricted areas and infrastructure was identified.

Figure 4.7 presents the following:

- restricted areas and navigation infrastructures identified within the AOI:
  - 2 navigation buoys;
  - 1 (deep water) navigation channel;
  - 1 harbour approach area;
  - 1 dredge spoil area;
  - 1 natural protected area.
- seafloor oil and gas infrastructure identified within the AOI:
  - 1 production facility;
  - 4 wells;
  - 3 pipelines.
- power cables, related to wind energy infrastructure, identified within the AOI:
  - 4 power cables.

4.1.3 Offshore Distribution HUB Area

No specific site use or seafloor obstructions of any type are expected within the Offshore Distribution HUB Area, except for fishing activities and vessels crossing the area.

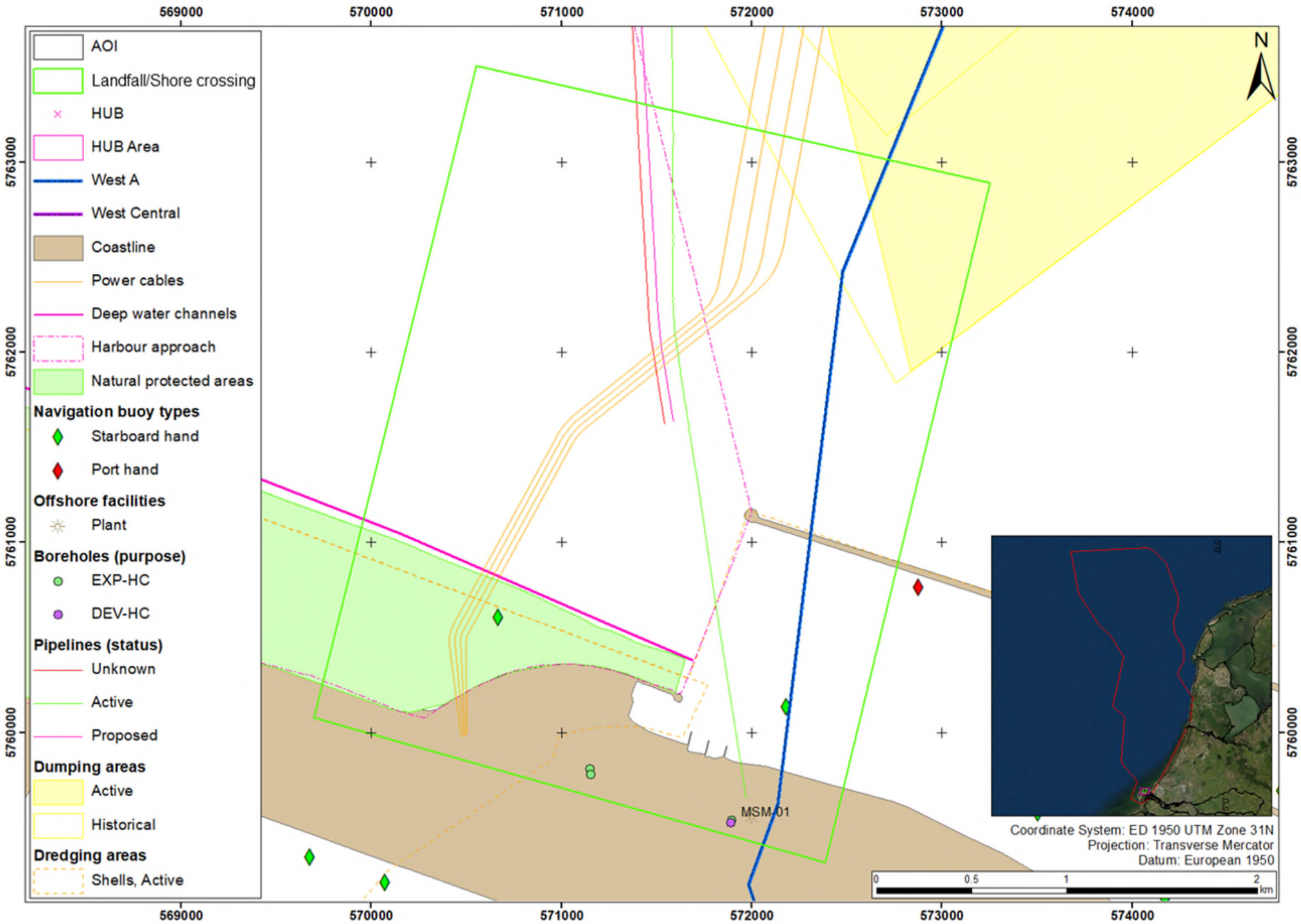

Figure 4.7: Site use across the Landfall/Shore crossing Area

4.2 Seafloor Conditions

4.2.1 Bathymetry and Seafloor Gradient

4.2.1.1 AOI

The Dutch offshore sector has been extensively surveyed by the Dutch Hydrographic Office, and historical data have been acquired and interpolated since 1979 (Deltares, 2016, 2020). This includes bathymetric data, which is publicly available on EMODnet.

Table 4.1 summarises the water depth and slope gradient values as observed in the individual bathymetry datasets available for the AOI. Included in the table is the resolution of the respective bathymetry datasets. Bathymetry and seafloor gradients of the AOI are presented in Figure 4.8. Close-ups for the Rotterdam approach, northern coastal, southern coastal, Hollandse Kust (noord), Hollandse Kust (west) and Hollandse Kust (zuid) WFZs are given in Figure 4.9 to Figure 4.14, respectively.

In general, the seafloor is gently dipping towards the west to west-north-west, perpendicular to the coast. The water depth in the AOI averages approximately 25 m below lowest astronomical tide (bLAT). Approximately 15 km north of the Offshore Distribution HUB Area, the seafloor deepens in a northern direction from approximately 20 m to 39 m bLAT over a distance of 20 km.

Most of the AOI is characterised by low seafloor gradients of less than 5°. Locally, higher seafloor gradients were observed and can have either a hydrodynamic (natural) or man-made origin.

The highest seafloor gradients associated with bedforms were observed on the lee side of sand waves (up to 30°). In the coastal area seafloor gradients up to approximately 19° were observed.

Man-made seafloor features resulting in higher seafloor gradients in the AOI include navigation channels, dredging areas, dumping areas, wrecks and other seafloor obstructions.

However, it should be noted that slope gradients are computed from bathymetry maps and therefore dependant on the data resolution. Where multibeam echosounder (MBES) data were acquired (WFZs), the calculated slope gradients are considered reliable and allow to visualise slope breaks linked to features as small as 2 m to 5 m. Outside of the wind farm sites, the grid resolution is either 30 m or 100 m and therefore smaller features cannot be imaged, and slope gradients are likely to be underestimated or overestimated locally.

Since the AOI covers a large area, Fugro does not recommend acquiring higher-resolution data at this stage. However, acquisition of MBES data along the final pipeline route will be paramount in order to assess and mitigate any seafloor hazards.

Table 4.1: Summary of water depths and seafloor gradients as observed in the different bathymetry datasets

Area	Maximum Water Depth [m LAT]	Minimum Water Depth [m LAT]	Average Slope Angle [°]	Maximum Slope Angle [°]	Minimum Slope Angle [°]	Bathymetry Grid Resolution [m]
AOI	-46.3	0	0.1	8	0	100
Hollandse Kust (noord) WFZ	-28.1	-14.9	1.7	29.9	0	2
Hollandse Kust (west) WFZ	-33.1	-22.5	2.2	20.6	0	2
Hollandse Kust (zuid) WFZ	-27.8	-16.1	0.6	14.9	0	5
Rotterdam approach area	-41.5	-13.5	0.3	9.5	0	30
Coastal area	-15.2	36.4	1.0	18.8	0	30

Notes:
m LAT = metres relative to Lowest Astronomical Tide

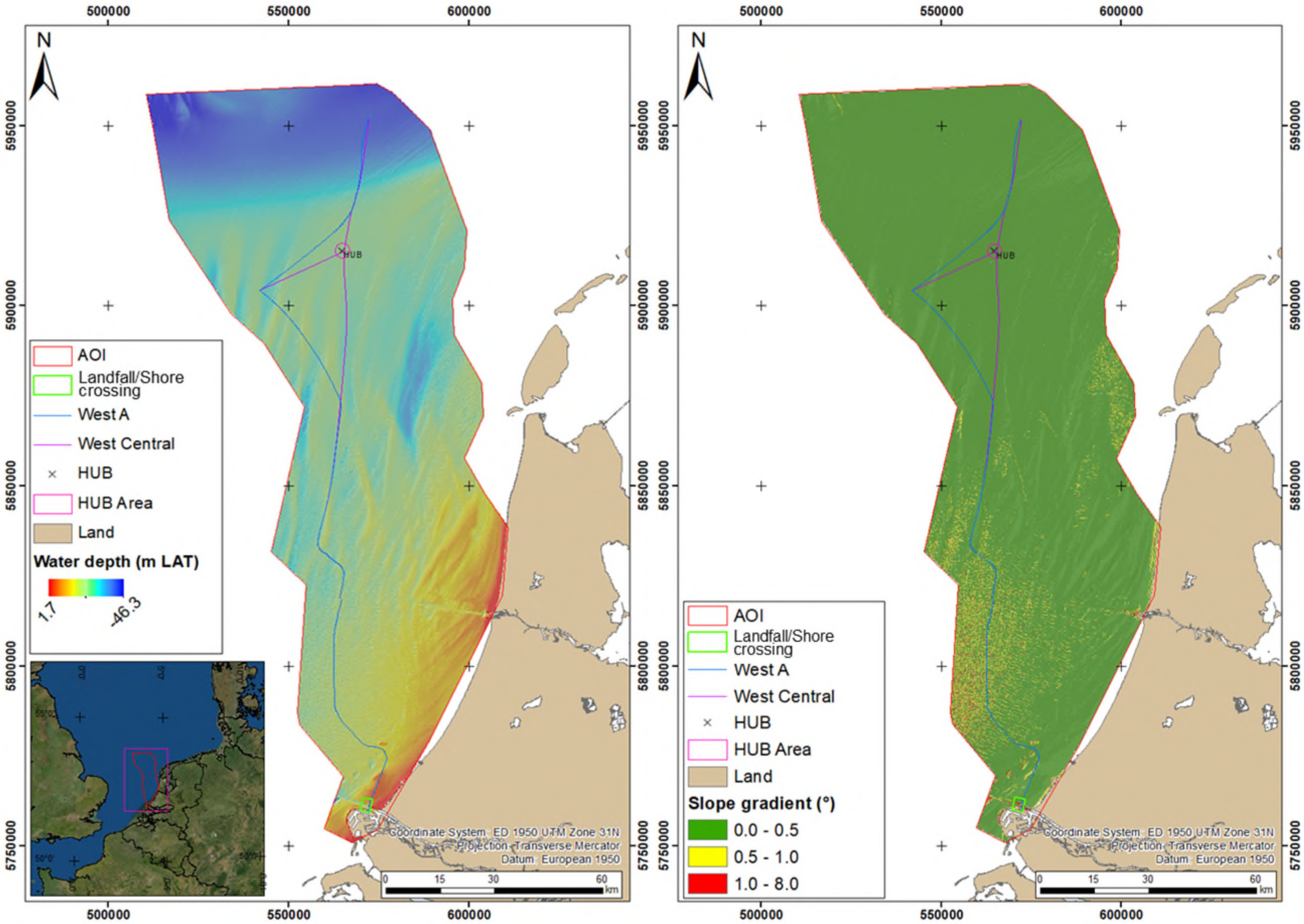

Figure 4.8: Left: bathymetric map and Right: slope gradient map of the entire AOI based on EMODnet 2020 data

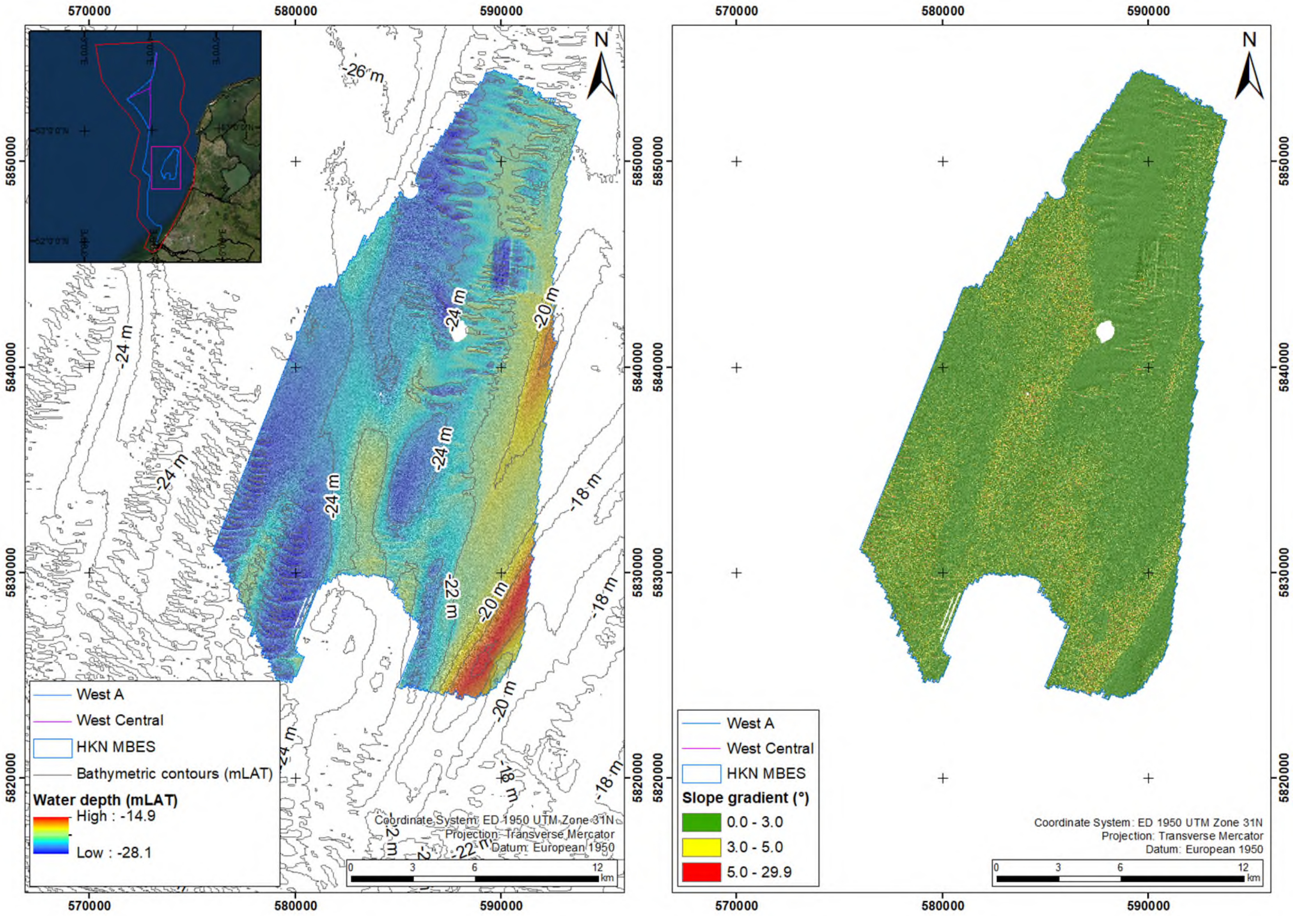

Figure 4.9: Left: bathymetric map and Right: slope gradient map of the Hollandse Kust (noord) WFZ area based on Fugro 2018 MBES data

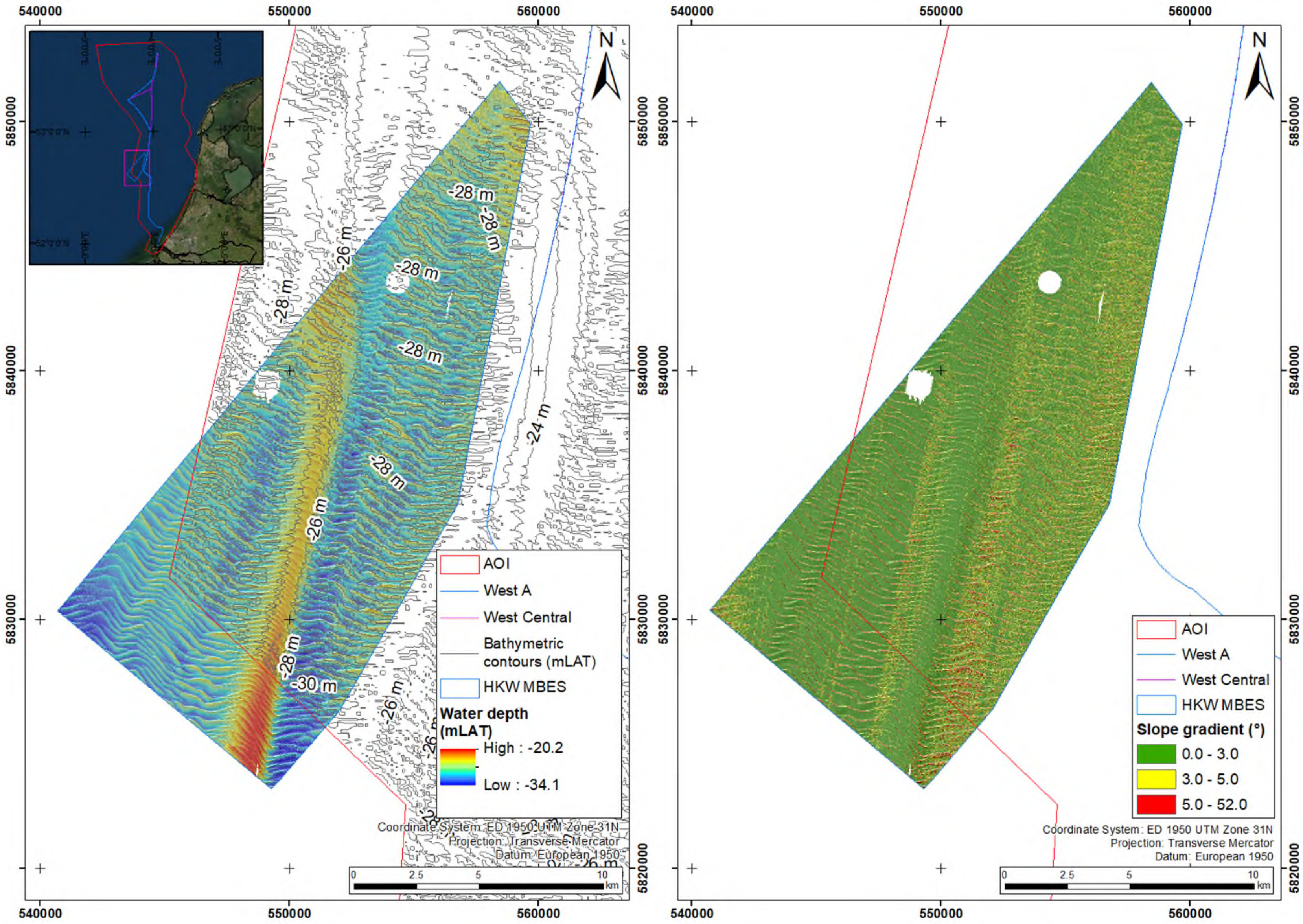

Figure 4.10: Left: bathymetric map and Right: slope gradient map of the Hollandse Kust (west) WFZ area based on Fugro 2019 MBES data

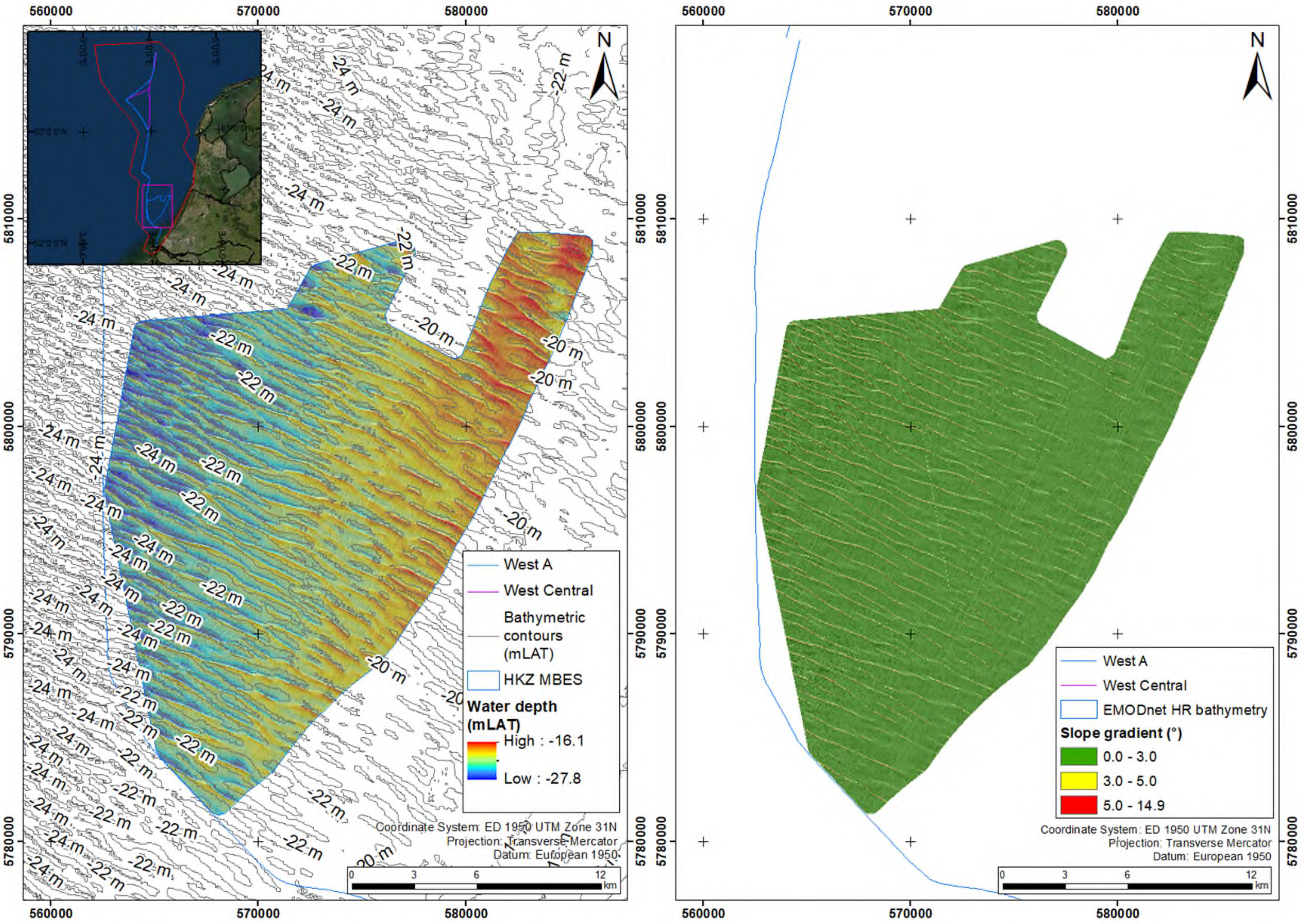

Figure 4.11: Left: bathymetric map and Right: slope gradient map of the Hollandse Kust (zuid) WFZ area based on Fugro 2016 MBES data

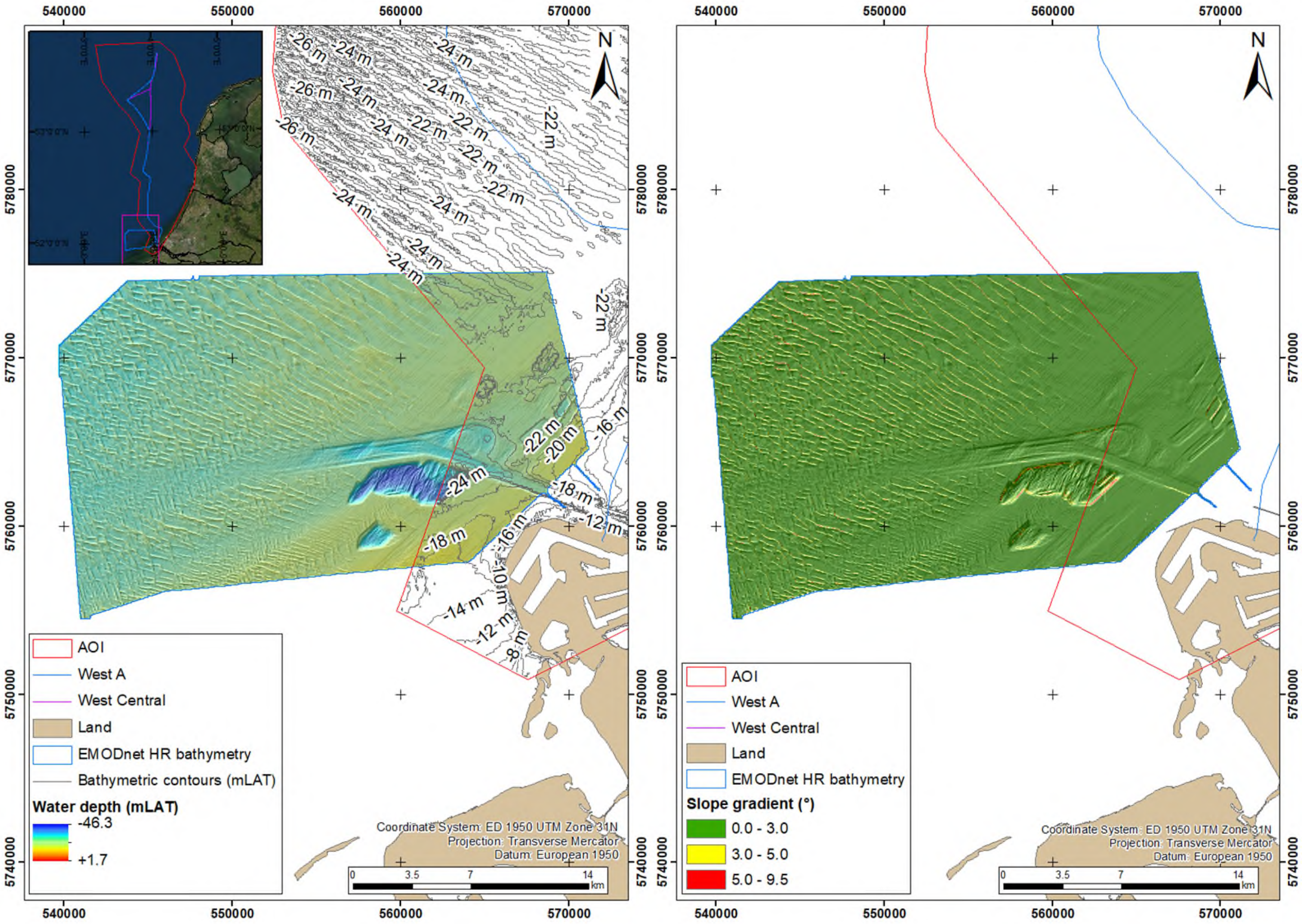

Figure 4.12: Left: bathymetric map and Right: slope gradient map of the Rotterdam approach area based on EMODnet 2020 high-resolution data

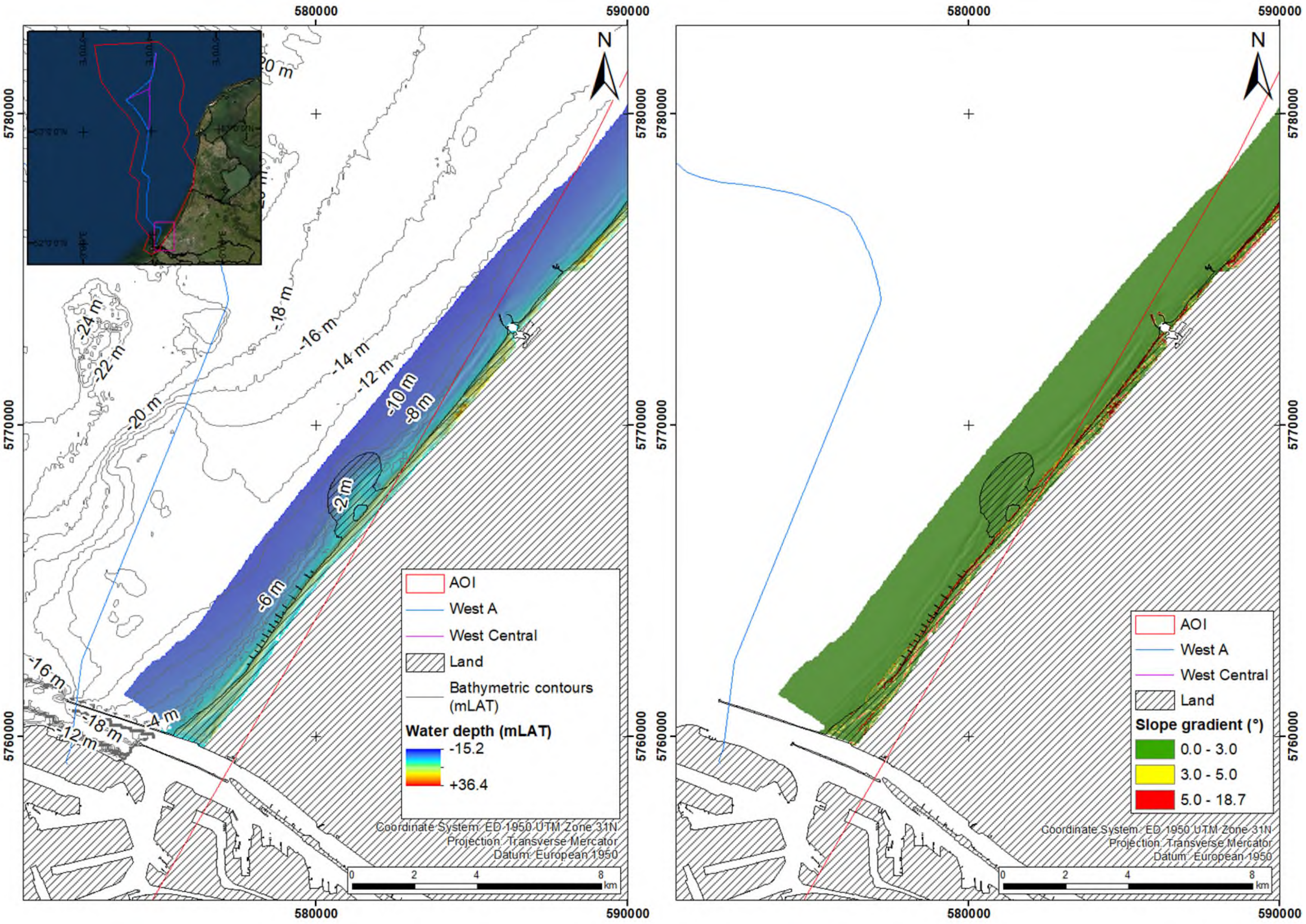

Figure 4.13: Left: bathymetric map and Right: slope gradient map of the southern coastal area based on EMODnet 2018 high-resolution data

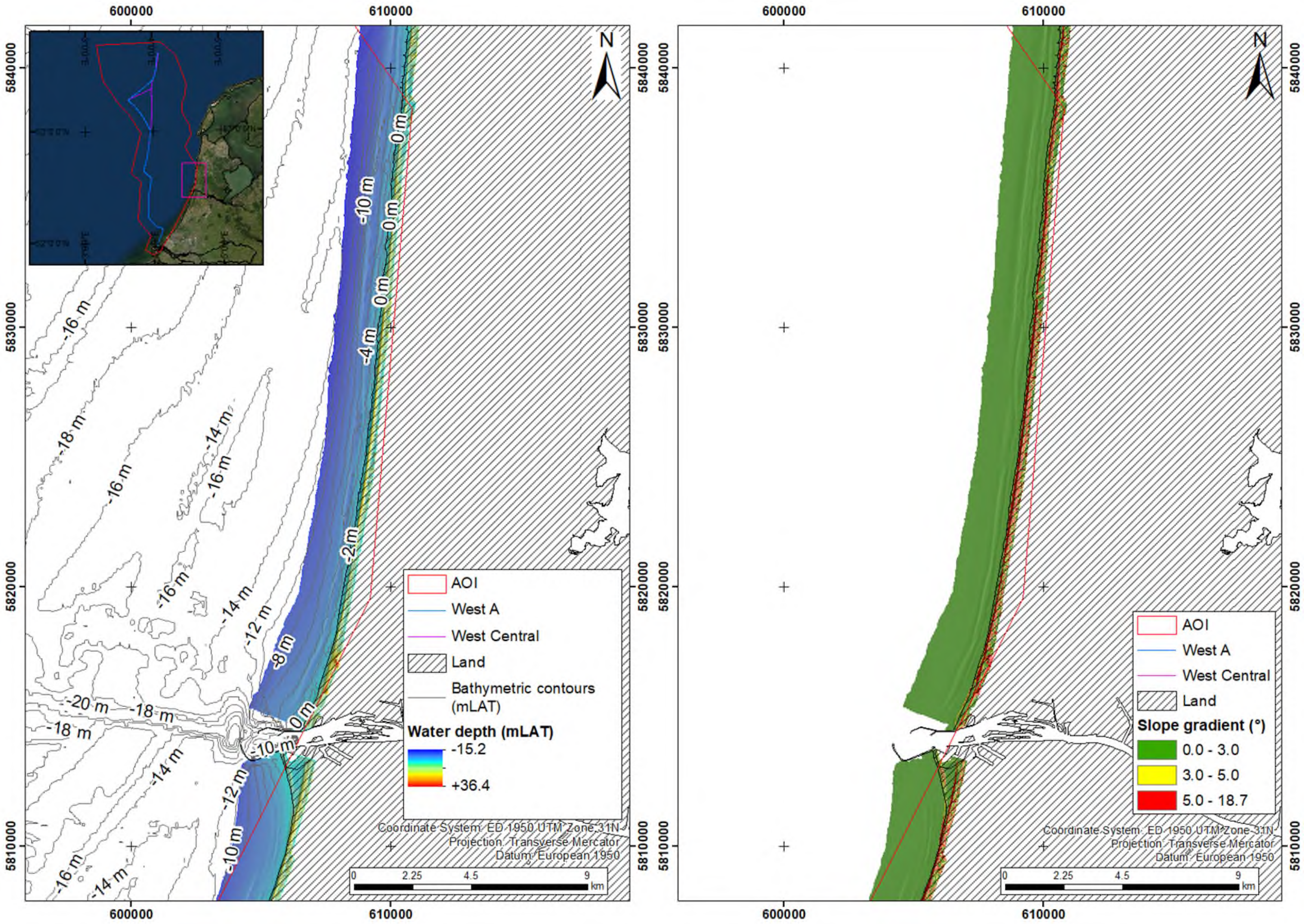

Figure 4.14: Left: bathymetric map and Right: slope gradient map of the northern coastal area based on EMODnet 2018 high-resolution data

4.2.1.2 Landfall/Shore Crossing Area

The Landfall/Shore crossing Area is covered by the EMODnet 2020 tile having a 100 m grid resolution.

Table 4.2 provides the water depth and slope gradient values for the Landfall/Shore crossing Area based on the available EMODnet data.

Table 4.2: Summary of water depths and seafloor gradients at the Landfall/Shore crossing Area

Area	Maximum Water Depth [m LAT]	Minimum Water Depth [m LAT]	Average Slope Angle [°]	Maximum Slope Angle [°]	Minimum Slope Angle [°]
Landfall/Shore crossing	-31.1	0	0.7	6.8	0

Notes:
m LAT = metres Lowest Astronomical Tide
Values derived from publicly available EMODnet (2020) bathymetry data, DTM with 100 m of grid resolution

The bathymetric map for the Landfall/Shore crossing Area is given in Figure 4.15.

Water depth within the Landfall/Shore crossing Area varies between 0 m and 31.1 m bLAT. The major bathymetric feature in this area is the relatively deep navigation channel (Maasmond Kanaal). The navigation channel is well imaged by the EMODnet bathymetry data, forming a WNW–ESE oriented depression. The water depth at the edges of the Maasmond Kanaal is approximately 15 m bLAT, whereas in the navigation channel it is ranging between approximately 20 m 25 m bLAT. In local depressions within the Maasmond Kanaal water depths may exceed 30 m bLAT.

North of the navigation channel, no seafloor features are visible, and the seafloor gently dips from SE to NW ranging between 11 m to 18 m bLAT.

The slope gradients range from 0° to 7° with an average value of 0.7°. Slope gradients up to 20° are expected at the flanks of the navigation channel.

The southern flank of the Maasmond Kanaal appears regular, steep and narrow in the south-east and widens towards the south-west. The northern flank of the Maasmond Kanaal has locally an irregular shape, possibly as a result of slumping observed in this area. Seafloor gradients of up to 34° are related to these slumped areas (Fugro database).

A site-specific MBES survey across the entire Landfall/Shore crossing Area would allow to increase the resolution of these maps and highlight any features smaller than 100 m (which cannot be imaged based on the present data resolution).

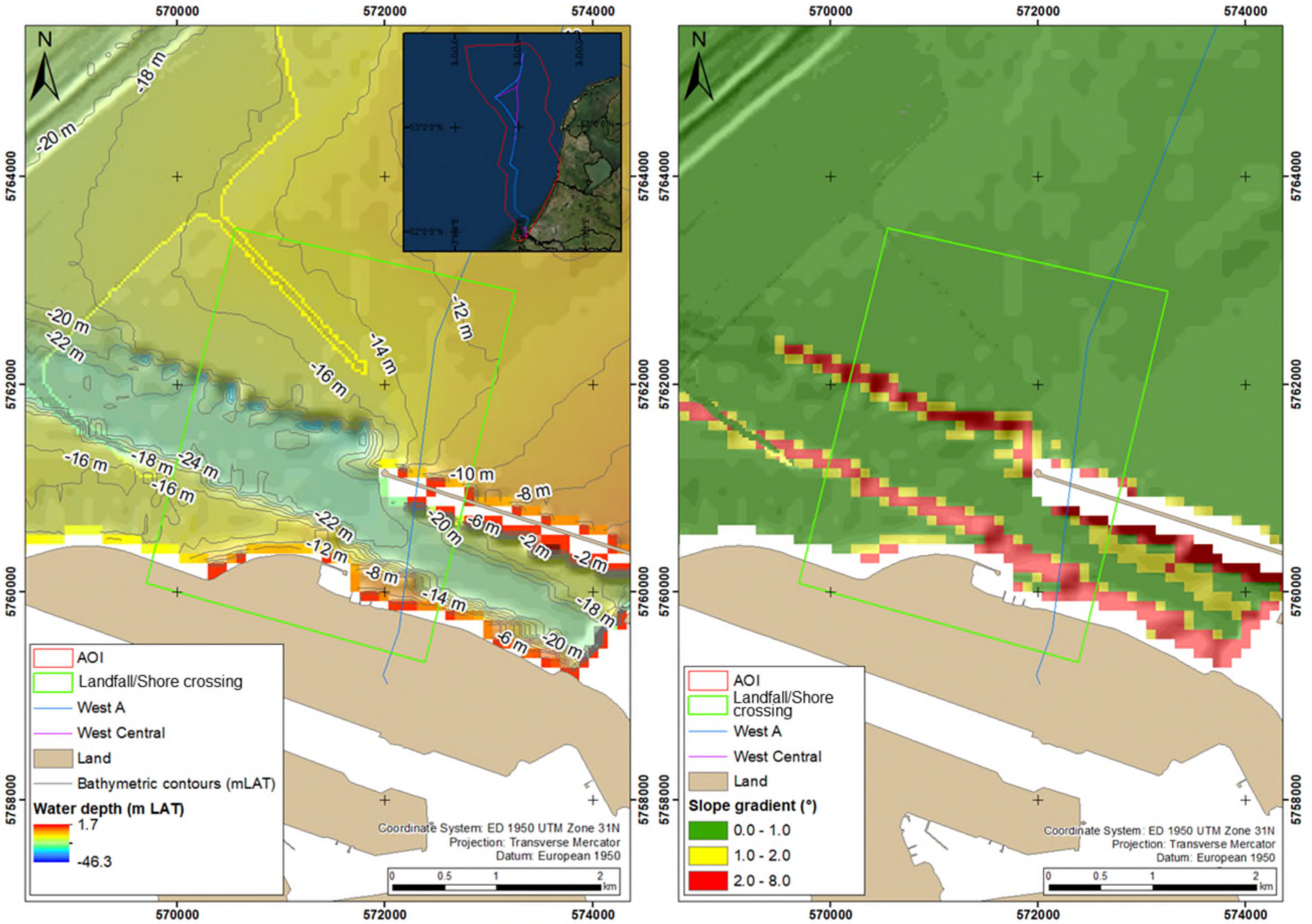

Figure 4.15: Left: bathymetric map and Right: Slope gradient map of the Landfall/Shore crossing Area based on the EMODnet 2020 data

4.2.1.3 Offshore Distribution HUB Area

The Offshore Distribution HUB Area is covered by the EMODnet 2020 tile having a 100 m grid resolution.

Table 4.3 provides the water depth and slope gradients values for the Offshore Distribution HUB Area based on the available EMODnet data.

Table 4.3: Summary of water depths and seafloor gradients at the Offshore Distribution HUB Area

Area	Maximum Water Depth [m LAT]	Minimum Water Depth [m LAT]	Average Slope Angle [°]	Maximum Slope Angle [°]	Minimum Slope Angle [°]
Offshore Distribution HUB Area	-26.2	-25.2	0.05	0.1	0

Notes:
m LAT = metres Lowest Astronomical Tide
Values derived from publicly available EMODnet (2020) bathymetry data, DTM with 100 m of grid resolution

Water depth within the Offshore Distribution HUB Area varies between 25.2 m and 26.2 m bLAT.

The bathymetric map for the Offshore Distribution HUB Area is given in Figure 4.16. The seafloor appears smooth, with a maximum water depth to the west of the Offshore Distribution HUB Area and minimum values to the north-east. No clear dipping trends can be noticed, except with bathymetric contours that tend to show that the Offshore Distribution HUB Area is crossed by a NE–SW oriented trough of less than 1 m deep (probably linked to a small seafloor bedform).

The slope gradients range from 0° to 0.1° confirming the presence of a flat and smooth seafloor. However, it has to be noted that slope gradients were computed based on the 100 m grid resolution bathymetry and that local features presenting higher seafloor gradients may occur.

A site-specific MBES survey across the entire Offshore Distribution HUB area would allow to increase the resolution of these maps and highlight any feature smaller than 100 m such as sand waves, megaripples and any other types of bedforms and seafloor obstructions that may occur.

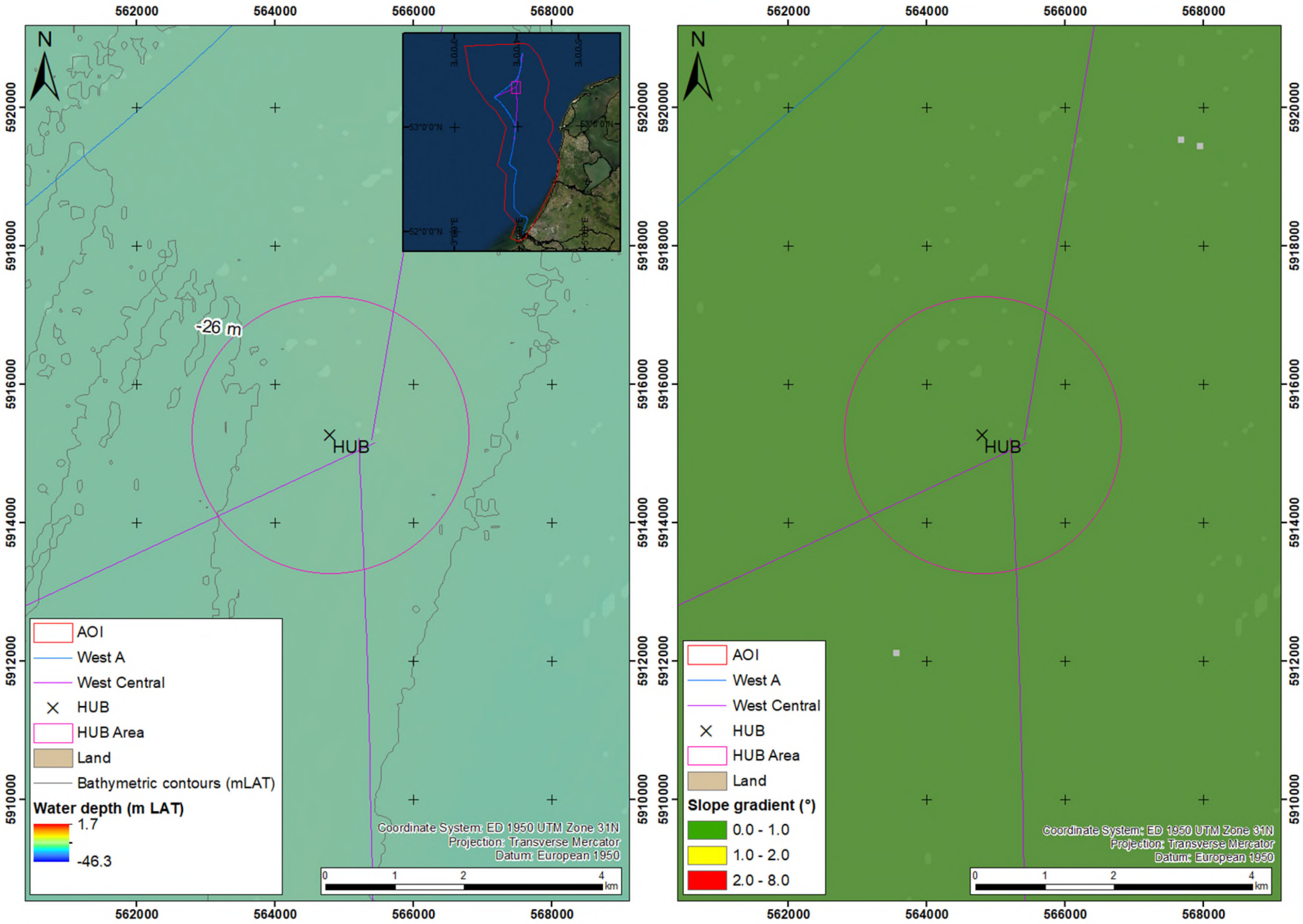

Figure 4.16: Left: bathymetric map and Right: slope gradient map of the Offshore Distribution HUB Area based on the EMODnet 2020 data

4.2.2 Seafloor Morphology

4.2.2.1 AOI

The seafloor morphology within the AOI can be divided into three distinct zones as illustrated in Figure 4.17: 1) a coastal zone covered by a complex compound of rhythmic bedforms, 2) a shallow continental shelf with low-angle topography covered by a complex compound of rhythmic bedforms, and 3) a relatively deep low-energy zone with low-angle topography (Figure 4.8).

The bedforms observed in Zones 1 and 2 include sand banks, sand waves, megaripples and ripples. These bedforms have been classified by Deltares (2016, 2019 and 2020), as part of morphodynamic desktop studies to aid development of the wind farms. The classification considers different parameters such as wavelength, wave height and mobility, which are the result of the complex interaction between hydrodynamics, sediment grain-size and character, sediment transport and morphology.

Below follows a more detailed description of the bedforms observed in the AOI. Table 4.4 summarises the characteristics of the different bedform types observed in the AOI.

Table 4.4: Bedform characteristics in the AOI

Type	Wavelength [m]	Wave Height [m]	Orientation
Sand bank	3000 to 10000	2.5 to 8	N–S to NNE–SSW
Sand wave	120 to 1750	0.5 to 6	NW–SE to WNW–ESE
Megaripple	4 to 20	0.1 to 0.4	NW–SE to WNW–ESE
Notes: N: North E: East		S: South W: West	

Bedforms across the AOI were mapped based on what is imaged on the EMODnet 100 m grid resolution data. Elements that were identified include sand banks, areas with sand waves as well as troughs and other depression features. Megaripples are below resolution of the EMODnet data. The resulting map is presented in Figure 4.8. The identified and expected bedforms across the AOI are further detailed hereafter.

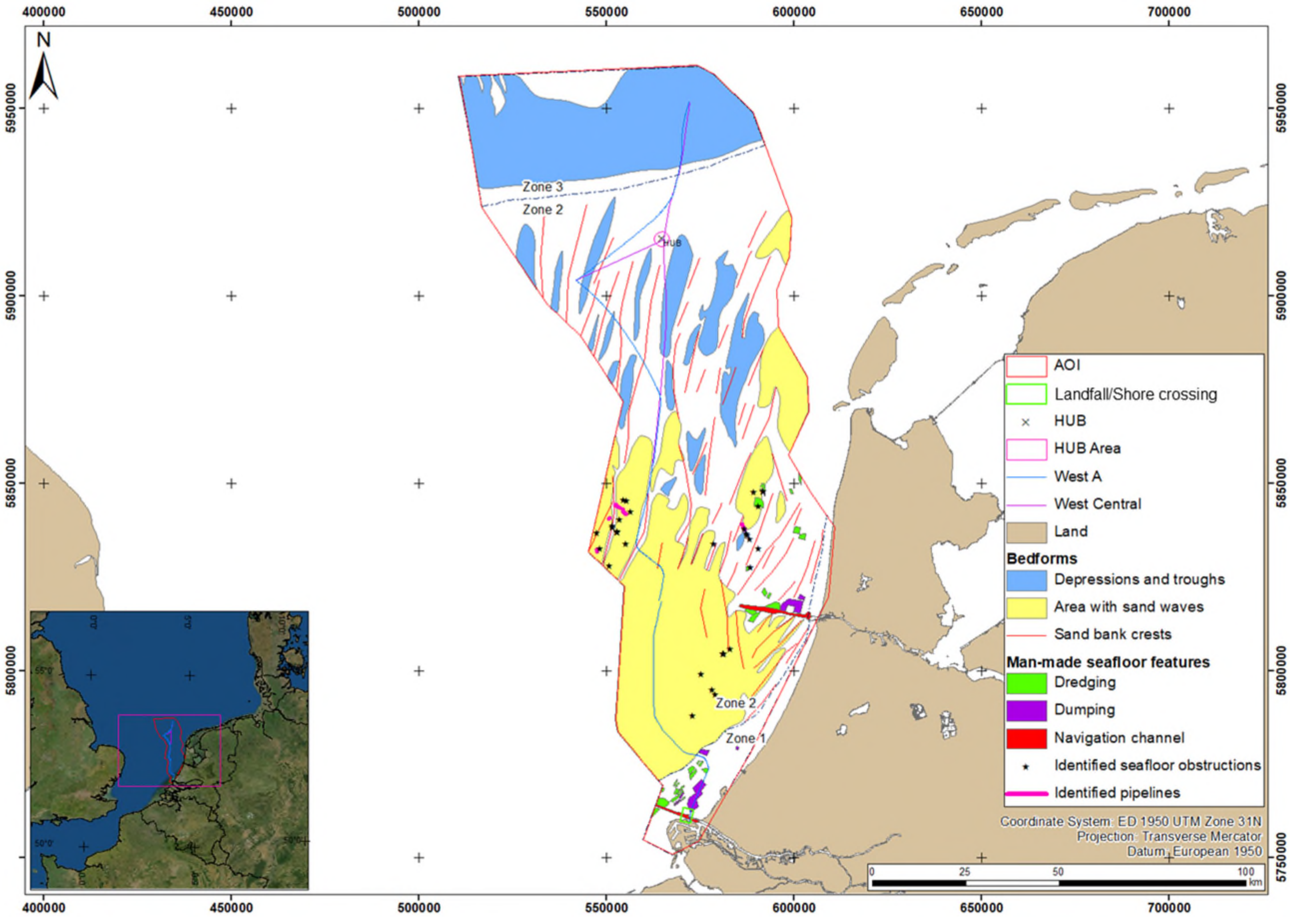

Figure 4.17: Map of the identified bedform and man-made seafloor features across the AOI

Sand Banks

The largest bedforms within the AOI are sand banks. They are present only in Zones 1 and 2 of the AOI (Figure 4.17). They form elongated ridges (sub-)parallel to the coast with a N–S to NNE–SSW orientation. The ridges are tens of kilometres long with a symmetric cross profile and lie several kilometres apart. They are on average 10 m high. An example of sand banks as imaged in Hollandse Kust (west) MBES data is given in Figure 4.18, with a bathymetric section perpendicular to the sand bank crest allowing to illustrate the morphology, height, and wavelength of sand banks in the AOI.

The sand banks are orientated roughly parallel to the main current direction (Hulscher et al., 1993). Near the coast they may be orientated more obliquely to the tidal current (Calvete et al., 2001). The sand banks closer to the shore are classified as tidal ridges (van Dijk et al., 2012). The formation of sand banks can broadly be divided into two categories (Dyer and Huntley, 1999):

- relict features, remaining after postglacial sea level rise;
- newly formed, in the present hydrodynamic regime.

The offshore sand banks may have formed during the early Holocene and the tidal ridges have been possibly formed more recently. Formation of tidal ridges is related to tidal currents in a tide-dominated coastal embayment (Ashley, 1990).

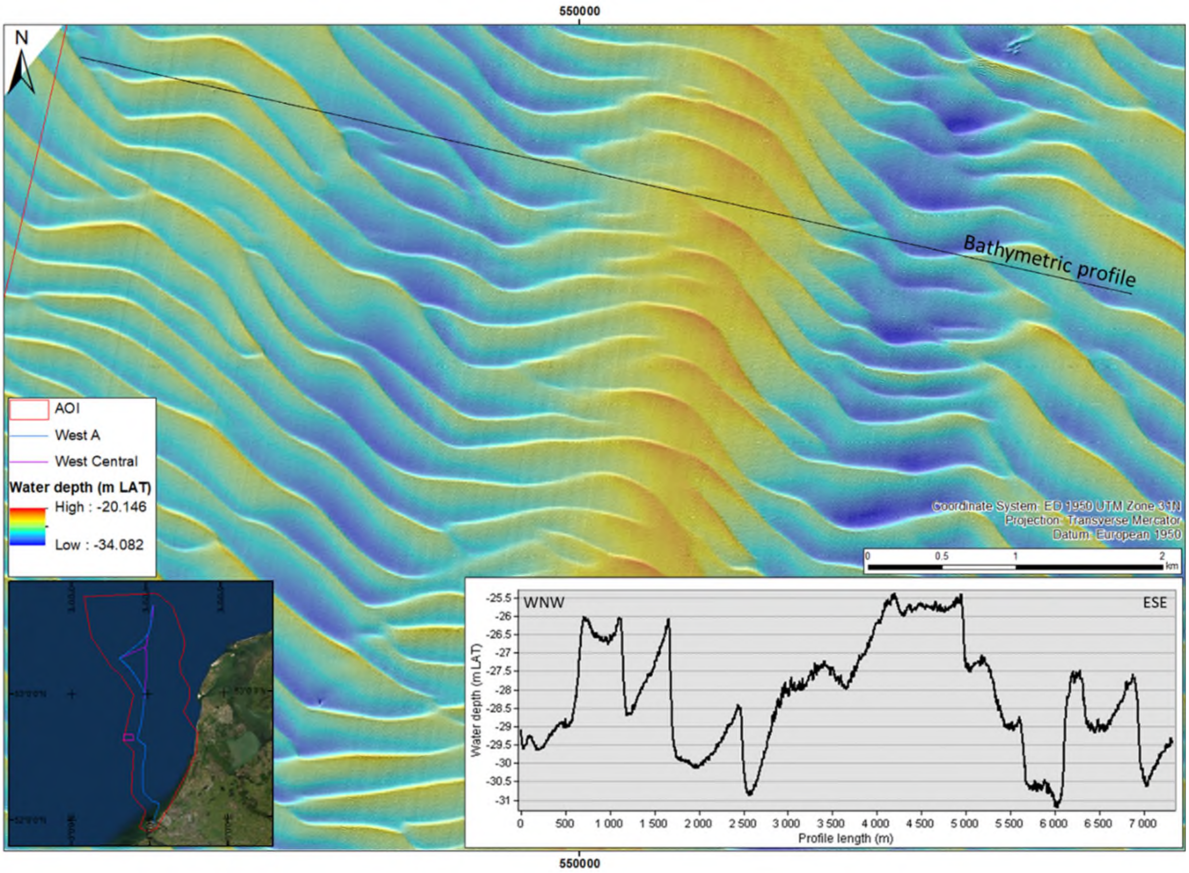

Figure 4.18: Example of sand banks with superimposed sand waves in the Hollandse Kust (west) WFZ as imaged on MBES bathymetry data. A bathymetric profile is given in a perpendicular direction to the sand banks.

Sand Waves

Sand waves are superimposed on the sand banks. They are observed in water depths of approximately 20 m to 28 m bLAT within Zones 1 and 2 of the AOI (Figure 4.17). The crests of the sand waves are orientated NW–SE to WNW–ESE, roughly perpendicular to the sand banks (see Figure 4.18). Their wavelength ranges between approximately 120 m and 1750 m, while wave height varies between 0.5 m and 4 m. The sand waves typically have an asymmetric profile with a lower angle stoss side and a steep lee side facing the direction of propagation. This morphology implies that the dominant migration direction is north to north-north-east (for sediment mobility refer to Section 4.3).

Sand waves are created due to tidal flow and may be as high as 25% of the water depth (McCave, 1971), and have wavelengths in the order of hundreds of metres (Ashley, 1990; van Dijk & Kleinhans, 2005; Deltares, 2016).

An example of sand waves as imaged in Hollandse Kust (west) MBES data is given in Figure 4.19, with a bathymetric section perpendicular to their direction, allowing to illustrate the morphology, height, and wavelength of sand waves in the AOI. Sand waves are also visible in Figure 4.18, perpendicular to the sand banks.

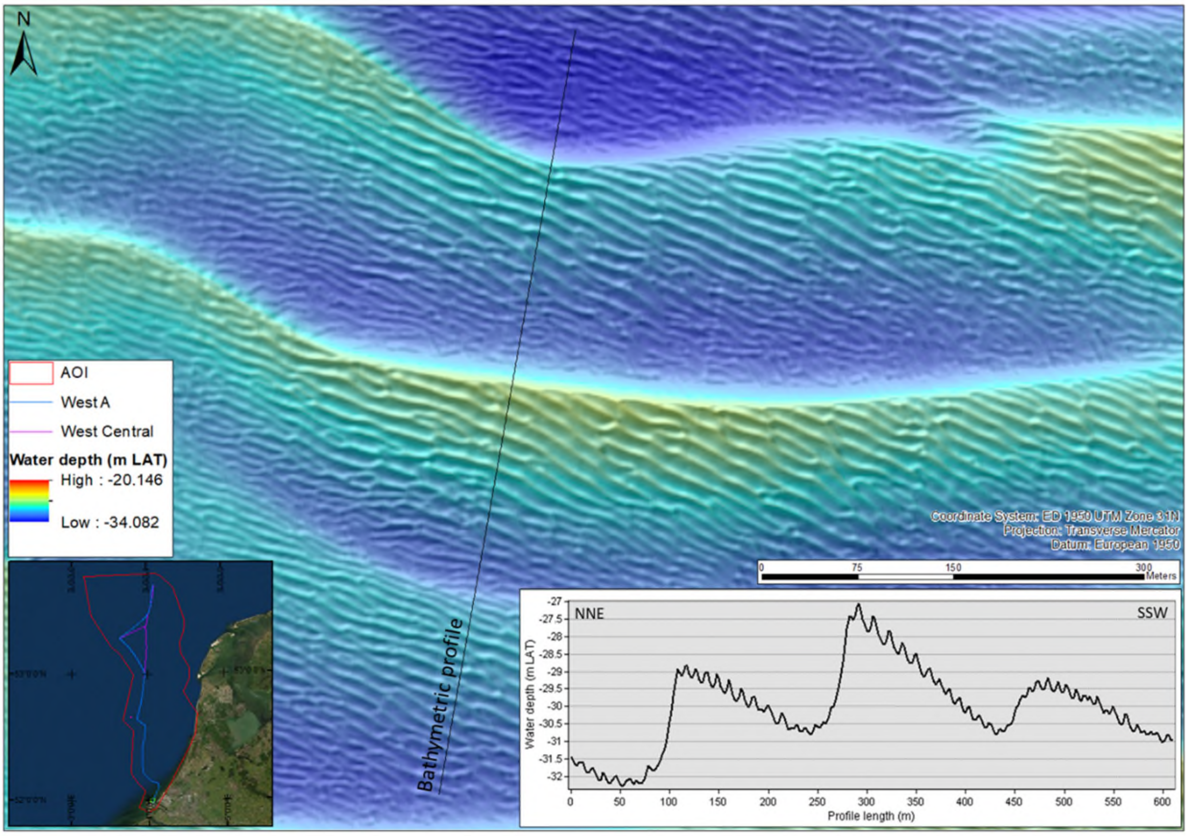

Figure 4.19: Example of sand waves with superimposed megaripples in the Hollandse Kust (west) WFZ as imaged on MBES bathymetry data. A bathymetric profile is given in a perpendicular direction to the sand waves.

Megaripples

High resolution bathymetry datasets for the wind farm sites located within the AOI allowed to capture the presence of megaripples. Megaripples are ubiquitous, superimposed on the stoss side of sand waves and are similarly orientated (Figure 4.19). They have wavelengths of approximately 4 m to 20 m, with heights between 0.1 m and 0.4 m.

An example of megaripples as imaged in Hollandse Kust (west) MBES data is given in Figure 4.19, with a bathymetric section perpendicular to their direction allowing to illustrate their morphology, height, and wavelength in the AOI.

Ripples

Ripples are the smallest bedforms, with dimensions in the order of centimetres. Because of their limited size, they cannot be observed in bathymetry data. They are superimposed on the megaripples and are similarly orientated. Because of their small size, ripples are not a concern for offshore pipeline design. They are, however, relevant for the seafloor roughness and sediment transport in the area (Deltares, 2020).

Troughs and Depressions

Troughs are linked to the presence of the sand banks in areas that are not affected by sand waves (deeper than 28 m bLAT). These troughs can be 4 m to 6 m deep and are elongated in a N–S direction (parallel to the sand banks). Where sand waves are present, these troughs were probably subsequently filled by sediments through the formation and evolution of the sand waves. Seafloor within the troughs appears to be smooth and regular on the EMODnet bathymetry. Troughs are only found in Zone 2 of the AOI as mapped in Figure 4.17.

Moreover, the northern depression (Zone 3) is characterised by a smooth seafloor and no bedform is imaged at the resolution of the EMODnet bathymetry. This is probably linked to the sudden increase of water depth (from 30 m bLAT to 42 m bLAT).

4.2.2.2 Landfall/Shore crossing Area

No bedforms were imaged at the EMODnet 2020 grid resolution of 100 m in the Landfall/Shore crossing Area. A site-specific MBES survey will provide a higher resolution, potentially imaging small-scale bedforms such as megaripples or ripples.

4.2.2.3 Offshore Distribution HUB Area

No bedforms were imaged at the EMODnet 2020 grid resolution of 100 m in the Offshore Distribution HUB Area. However, the Offshore Distribution HUB Area is located within an area containing sand banks (Zone 2), to the north of a trough (Figure 4.17). As the sand banks are the largest expected bedforms in the AOI (Table 4.4), it is likely that the Offshore Distribution HUB Area is too small to capture the typical sand bank morphology entirely. A site-specific MBES survey will provide a higher resolution, potentially imaging small-scale bedforms such as sand waves and/or megaripples.

4.2.3 Seafloor Sediments

4.2.3.1 AOI

An overview of the substrate type classification (Folk, 1954) is presented in Figure 4.20 (EMODnet). The seafloor sediments map is corroborated by information contained in the DINOloket (2021) database, which includes grab sample data, vibrocore data and sampling borehole data. In addition, seafloor sediments were mapped in high detail at the Hollandse Kust (noord), Hollandse kust (west) and Hollandse Kust (zuid) WFZs.

The following seafloor sediments are present in the AOI:

- Sandy GRAVEL
- (Slightly) gravelly SAND
- (Slightly) gravelly muddy SAND
- SAND
- Muddy SAND
- Sandy MUD

MUD is defined in the geological maps as the fraction composed of clay-sized to silt-sized sediments.

The AOI is covered by predominantly SAND with numerous patches of (slightly) gravelly SAND. North of the Offshore Distribution HUB Area, the seafloor comprises mainly muddy SAND with some patches of (slightly) gravelly muddy SAND and sandy MUD. This area with a higher MUD fraction coincides with the deeper low-energy marine environment as described in Section 4.2.2.1. Areas of (slightly) gravelly SAND correspond to areas where sand banks and sand waves are expected based on Figure 4.17 and Figure 4.20.

In terms of expected stratigraphy at the seafloor, three main Holocene units were mapped (Figure 4.21):

- Southern Bight Formation, deposited in a high-energy open-marine environment, mainly composed of SAND to (slightly) gravelly SAND, distributed in Zone 2 of the AOI;
- Urania Formation, deposited in a low-energy open-marine environment mainly composed of sandy MUD to muddy SAND, covering Zone 3 entirely;
- Naaldwijk Formation, deposited in a coastal to tidal-dominated environment and is mainly composed of (slightly) gravelly SAND, covering Zone 1 (not completely mapped).

Fugro recommends acquiring site-specific geotechnical data along the final pipeline layout prior to pipe installation in order to verify and refine the seafloor sediment types.

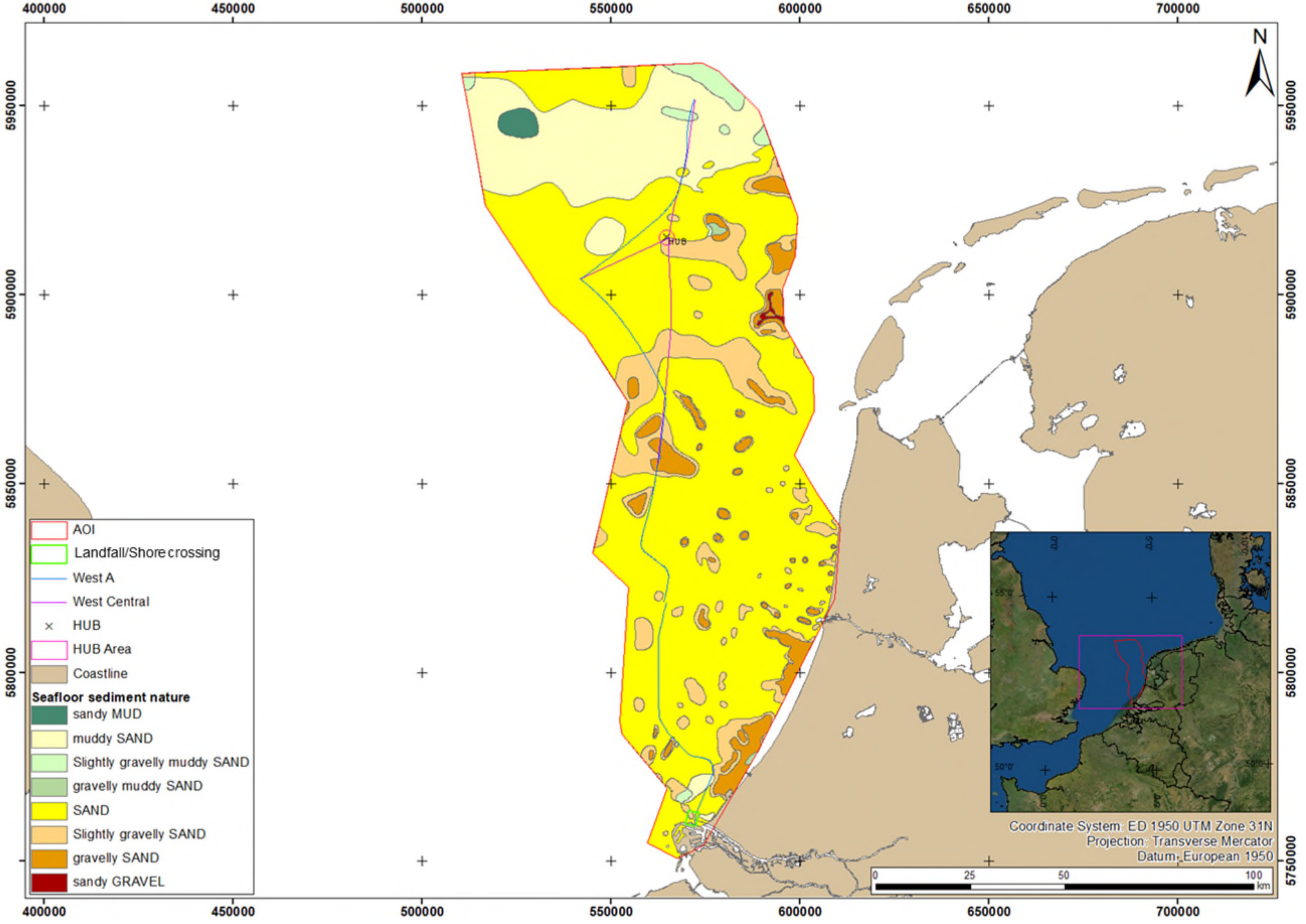

Figure 4.20: Surficial sediments across the AOI

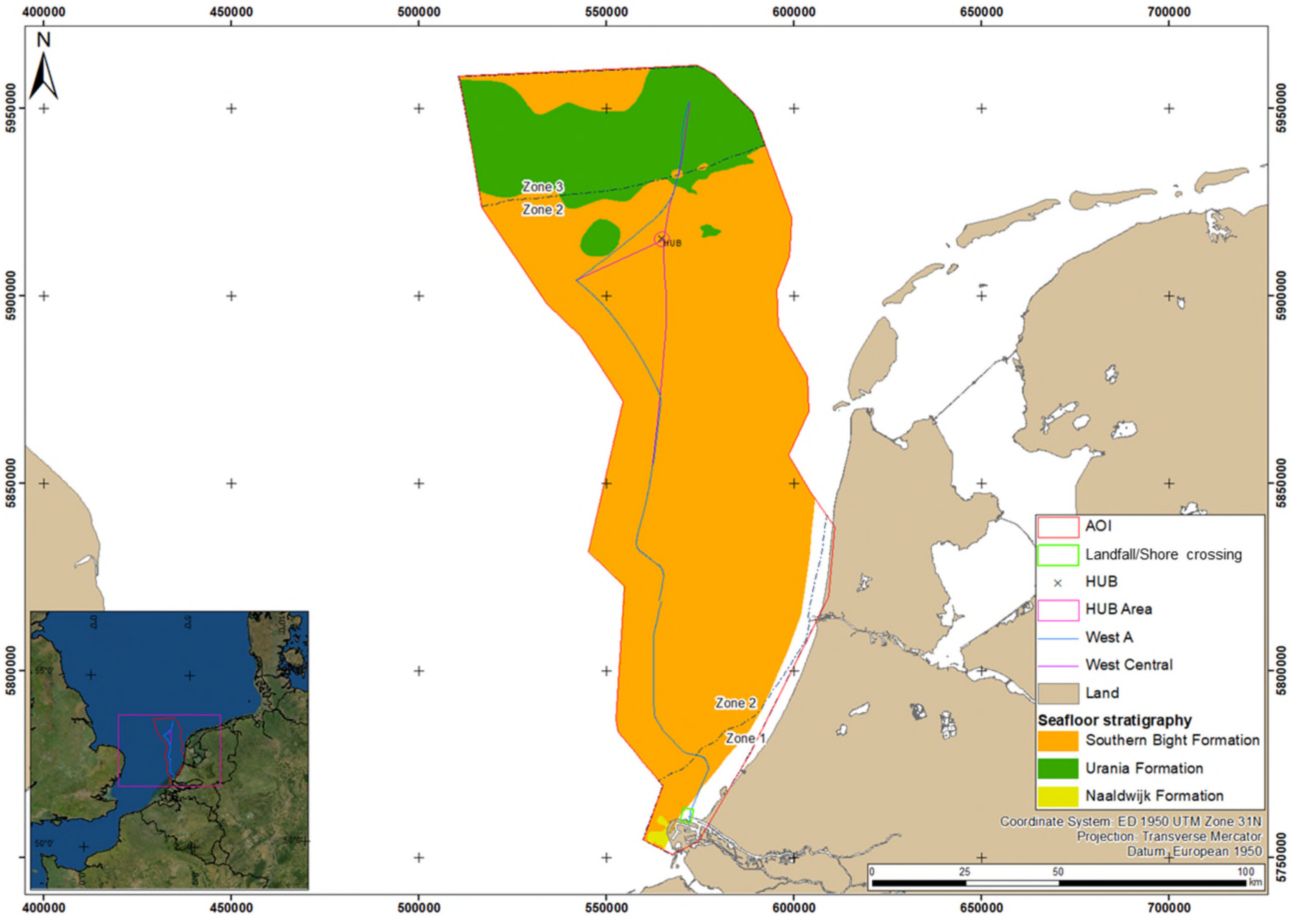

Figure 4.21: Surficial sediment stratigraphy across the AOI. Coverage is missing along the coastal area. In this area the Naaldwijk Formation is expected

4.2.3.2 Landfall/Shore Crossing Area

Two main seafloor sediment types are to be expected in the Landfall/Shore crossing Area (Figure 4.22):

- SAND;
- Slightly gravelly SAND, in the north-west corner.

Based on Fugro experience, clayey or silty SAND, locally slightly gravelly dominates at seafloor in areas outside the Maasmond Kanaal. In the Maasmond Kanaal very soft to soft CLAY dominates, with localised patches of clayey SAND.

Site-specific geotechnical surveys would allow to refine the sediment nature within the Landfall/Shore crossing Area.

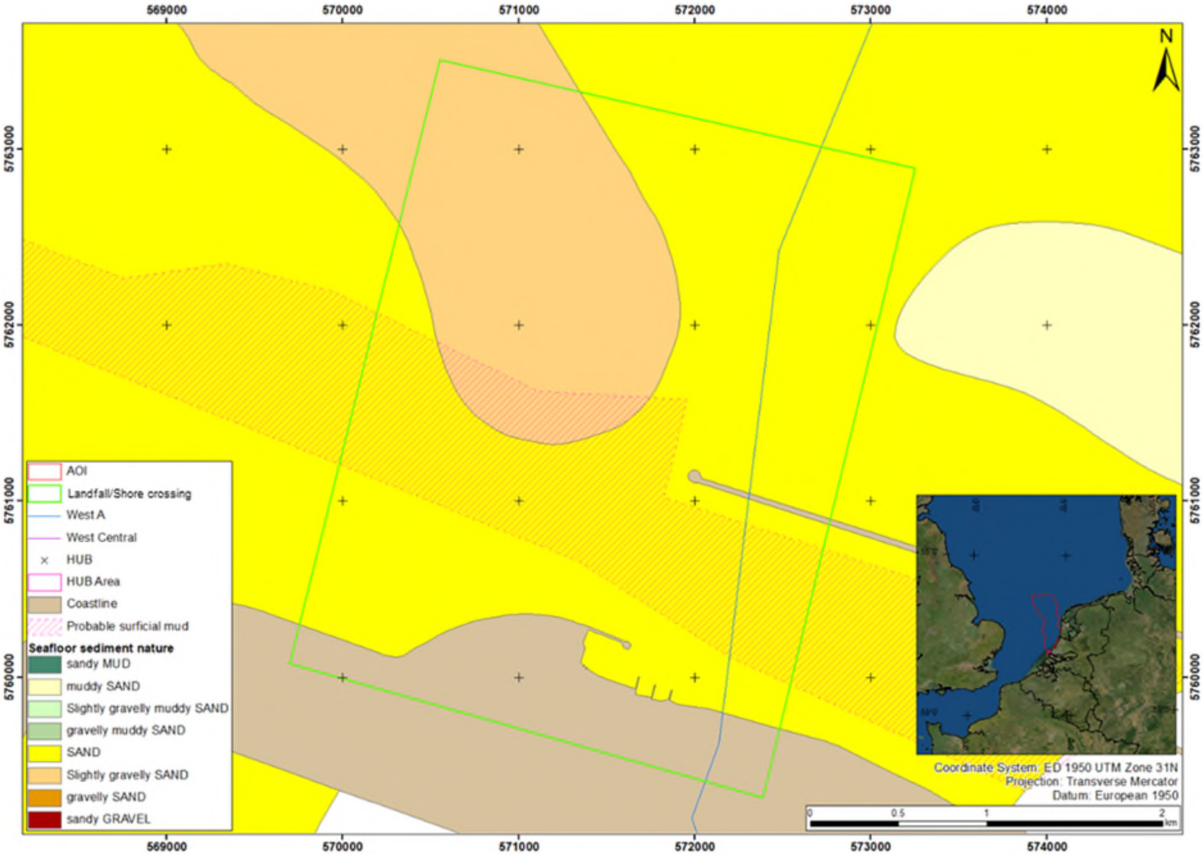

Figure 4.22: Surficial sediment nature across the Landfall/Shore crossing Area

4.2.3.3 Offshore Distribution HUB Area

The Offshore Distribution HUB Area comprises two main seafloor sediment types that are presented in Figure 4.23:

- SAND;
- Slightly gravelly SAND, in the south.

Site-specific geotechnical surveys would allow to refine the sediment nature within the Offshore Distribution HUB Area.

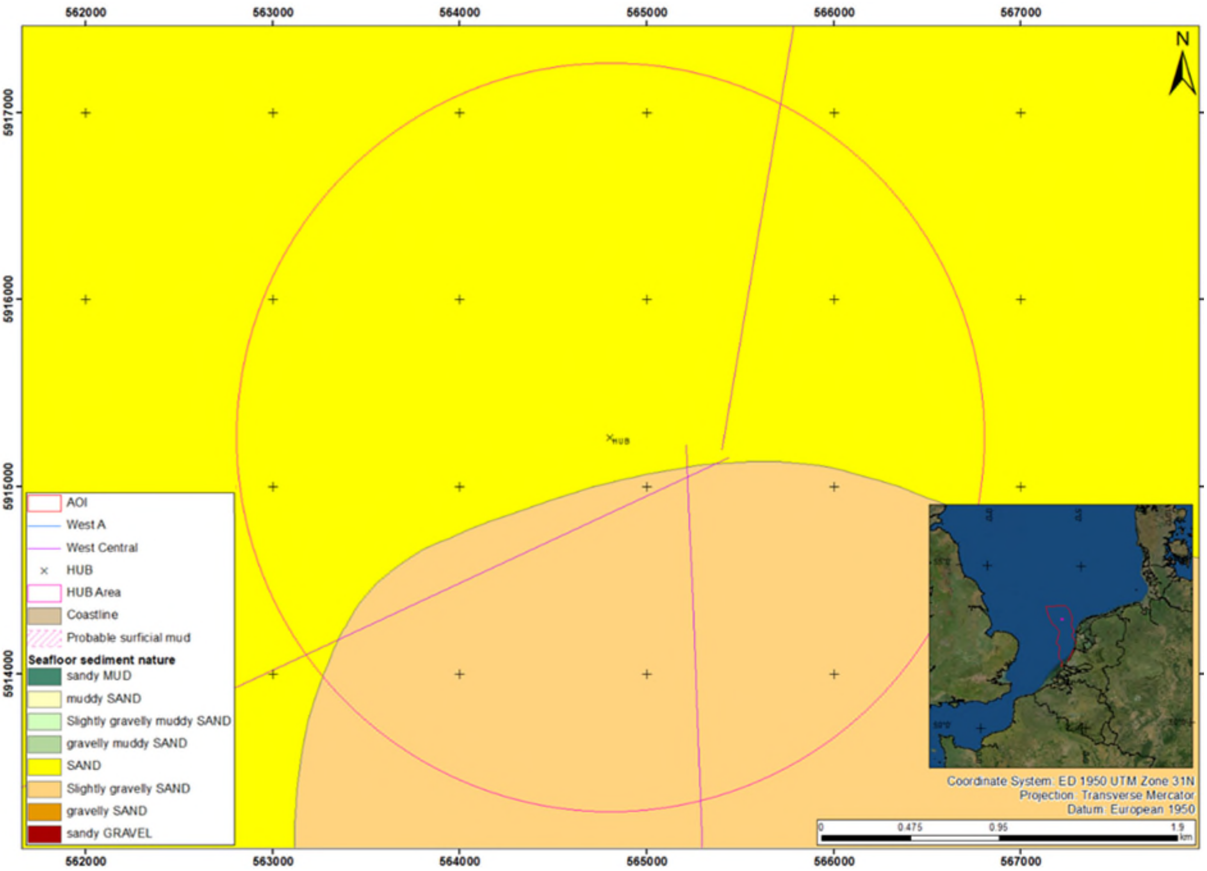

Figure 4.23: Surficial sediment nature across the Offshore Distribution HUB Area

4.2.4 Man-Made Seafloor Features

4.2.4.1 AOI

Man-made seafloor features were identified in the different bathymetric data. These features include:

- Unidentified seafloor obstructions (including probably several wrecks and wellheads);
- Pipelines;
- Dredged areas;
- Dumped material;
- Navigation channels.

These elements were mapped and are displayed in Figure 4.17. The man-made obstructions could only be mapped on the high-resolution MBES data. More details on the man-made obstructions are provided in the UXO and Archaeological DTS reports (Appendix C and Appendix B).

4.2.4.2 Landfall/Shore Crossing Area

The Maasmond Kanaal navigation channel and a dumping area were recognised within the Landfall/Shore crossing Area as mapped in Figure 4.24. In addition, ROCK dumps related to coastal defence structures are present on the shores of the Maasmond Kanaal as well as numerous seafloor scars related to dredging operations (Fugro database).

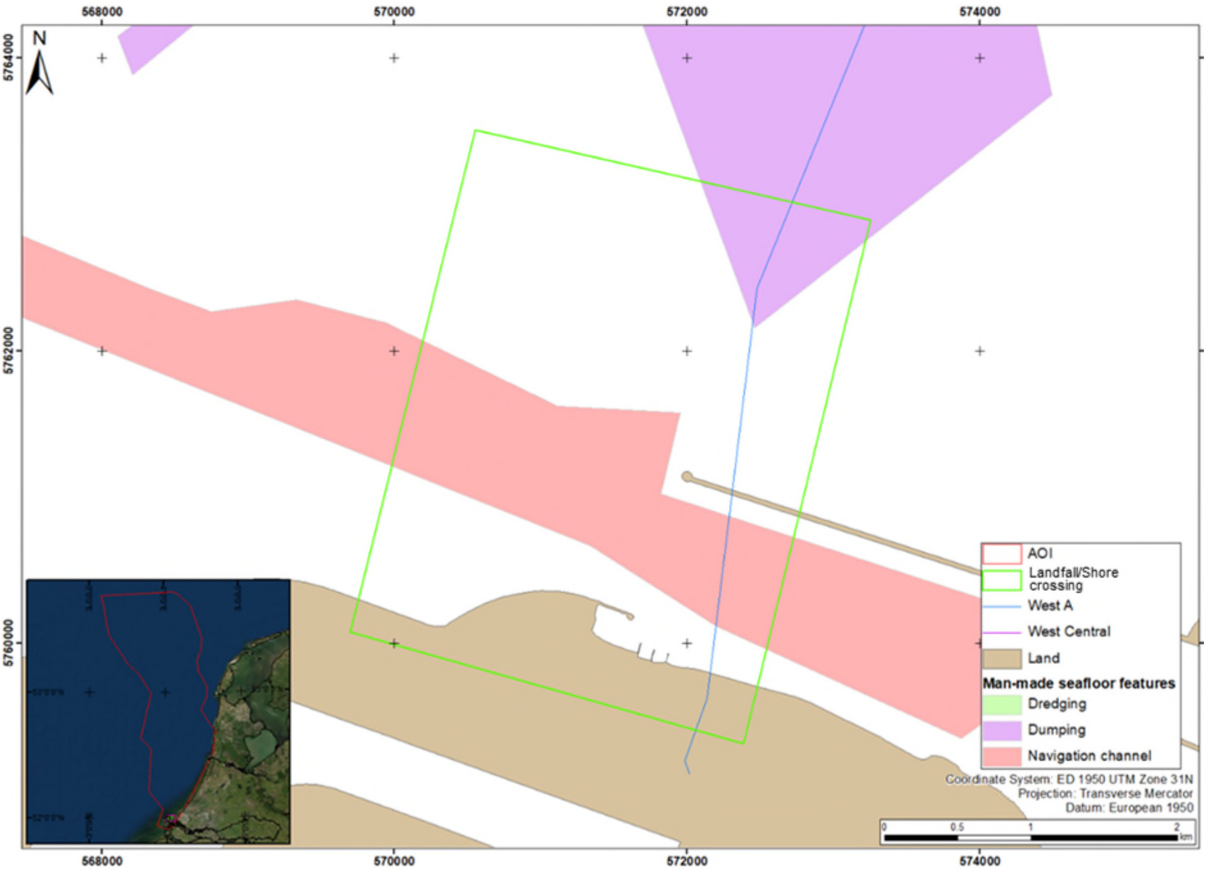

Figure 4.24: Surficial sediment nature across the Landfall/Shore crossing Area

4.2.4.3 Offshore Distribution HUB Area

No man-made seafloor features were recognised within the Offshore Distribution HUB Area.

4.3 Seafloor Mobility

The high availability of sand at seafloor facilitates the formation of dynamic bedforms (refer to Section 4.2.2 for description of bedforms), which are mobile in response to (tidal) currents.

Sand waves and sand banks have dimensions that are significant for pipeline foundation design, while megaripples and ripples are perceived as not having a significant impact. The sand banks are considered stationary over the lifetime of a pipeline, whereas the sand waves may migrate at a speed up to tens of metres per year (van Dijk & Kleinhans, 2005; Dorst et al., 2009; van Santen et al., 2011) and cause metres-scale vertical seafloor variations over the lifetime of a pipeline.

If sand waves are removed by dredging, they may regenerate within a period of years (Knaapen and Hulscher, 2002). This is illustrated in Figure 4.25, where sand waves appear to be building back within a former dredging area.

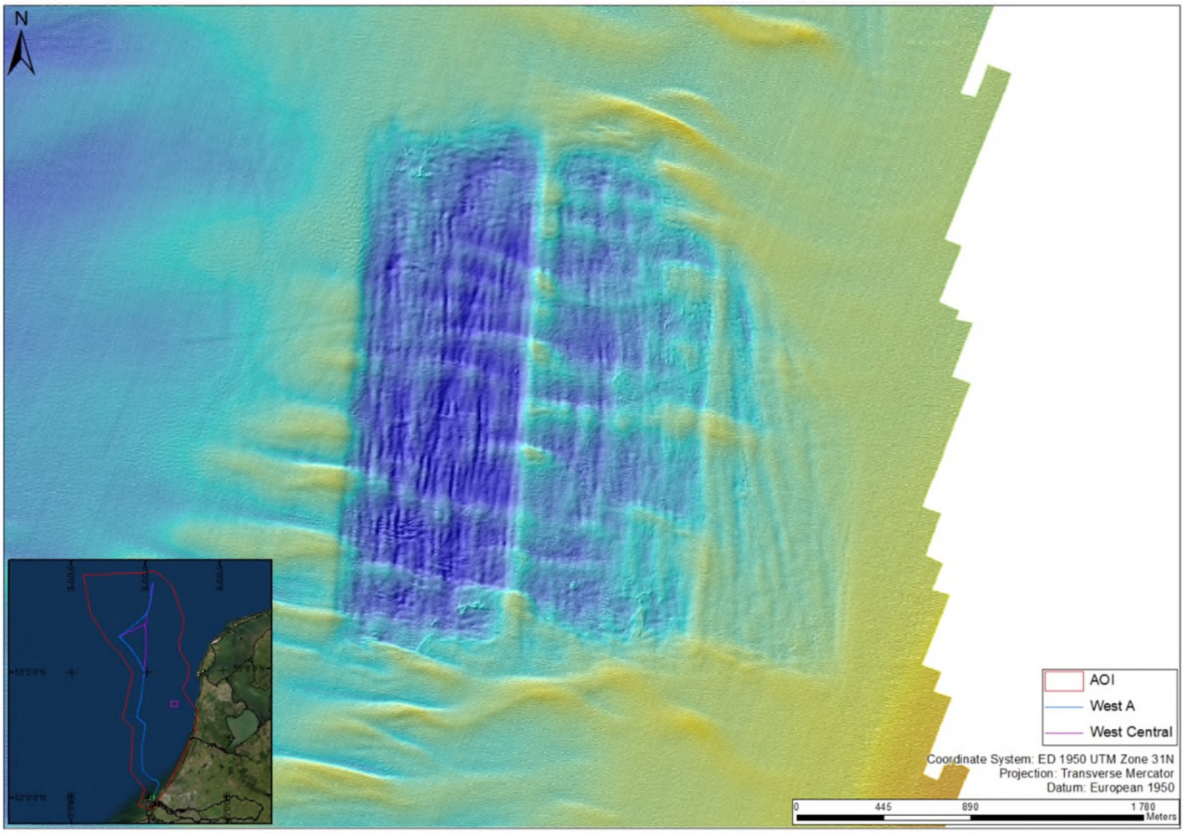

Figure 4.25: Former dredging area where sand waves are building back , as imaged in Hollandse Kust (noord) MBES bathymetry

Table 4.5 provides a summary of sand wave migration rates based on a selection of studies performed in the southern North Sea.

Table 4.5: Sand wave migration rates in the southern North Sea

Location	Average Migration Rate [m/year]	Source
Hollandse Kust (noord) WFZ	1.9 to 5.4	Deltares (2019)
Hollandse Kust (west) WFZ	1 to 3.9	Deltares (2020)
Hollandse Kust (zuid) WFZ	1 to 2.6	Deltares (2016)
Prinses Amalia OWF	4	Deltares (2017)
Luchterduinen OWF	2 to 3	Deltares (2017)
Texel	> 20	Van der Meulen et al. (2004)
Rotterdam Harbour	0	Van der Meulen et al. (2004)
Belgian Sector	1 to 4	Fugro database
UK Sector – east of Norfolk Banks	0 to 4	Fugro database

Typical sand wave migration rates in the southern North Sea are between 1 m/year to 10 m/year and in exceptional cases, as for example coastal zones, up to 20 m/year (Deltares, 2020). The sand wave morphology indicates that the dominant migration direction in the North Sea is to the north-north-east.

The migration rates of sand waves vary spatially and over time. In general sand waves in shallower water depths, e.g., on top of the sand banks migrate faster than in the deeper parts and locally migration speeds as high as 9.0 m/year are observed (Deltares, 2019).

The migration distance may increase in the event of storms or exceptional weather surge. Winter storm events can change the morphology of sand waves. For example, sediment can be transported from crest to trough, decreasing the height of bedforms. Additionally, megaripples and ripples may be smoothened. These small-scale bedforms will reappear once the rhythmic currents' regime is re-established (Deltares, 2016).

Van der Meulen et al. (2004) reported a migration rate of over 20 m/year near the island of Texel, with typical migration rates decreasing southwards to a stationary (0 m/year) field near the Rotterdam harbour. Migration rates in the Prinses Amalia offshore wind farm (OWF) and Luchterduinen OWF, located in the centre of the AOI, were assessed to be in the order of 4 m/year and 2 m to 3 m per year, respectively.

Fugro performed several seafloor mobility studies in the North Sea, which included comparison of MBES data between different years. For example, in the Belgian sector, MBES data acquired 3 years apart revealed sand wave migration rates in the order of 1 m to 4 m per year. In the UK sector, east of Norfolk Banks, the MBES data between consecutive years revealed sand waves migration rates from 0 m to 4 m per year.

4.4 Sub-seafloor Conditions

Section 3 provides background information on the regional geological setting. The following sections provide project-specific results on sub-seafloor conditions. The Stratigraphic

Nomenclature by TNO – the Geological Survey of the Netherlands is used and is available on the DINOloket website (TNO-GDN, 2022).

4.4.1 AOI

The expected geological formations that occur in the AOI and description of the lithologies associated with these formations are summarised in Table 4.6. Included are the expected thickness ranges and distribution of the formations across the AOI. The expected thickness values are based on Cameron et al. (1984; 1986), Laban et al. (1992), Laban (1995), Fugro (2019a, 2020) and DINOloket (2022). The distribution of the geological formations was compiled from maps by Cameron et al. (1984, 1986), Harrison et al. (1987), Balson et al. (1991), Laban (1995), NITG–TNO (2004b, 2004d) and Laban & van der Meer (2011), which are stored in the GIS database for easy access.

To illustrate the subsurface stratigraphy a schematic profile from northern part of the AOI is provided on Figure 4.27. Figure 4.26 shows a detailed interpreted seismic profile taken from the Hollandse Kust (west) WFZ (Fugro, 2020) situated in the central-west part of the AOI.

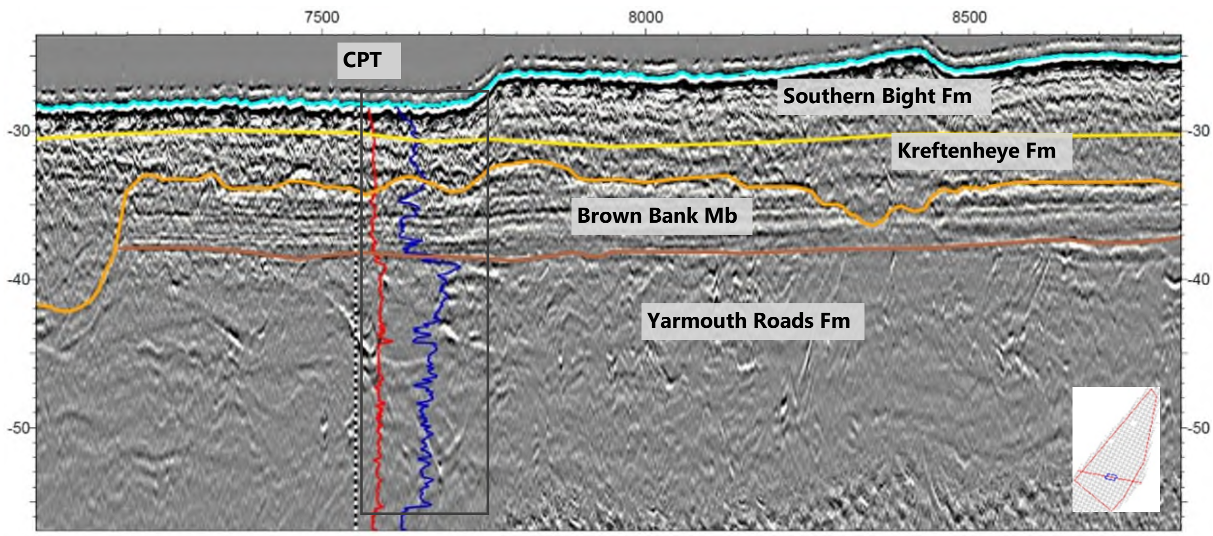

Figure 4.26: Example seismic reflection (2DUHR) cross section within the Hollandse Kust (west) WFZ (modified from Fugro, 2020). *Vertical scale is in metres reduced to LAT. The horizontal scale shows relative distance in metres along the seismic line. Width of the Cone Penetration Test (CPT) box shows cone resistance values (blue curve) within range of 0 to 60 MPa and sleeve friction values (red curve) from 0 to 1 MPa*

Maps showing distribution of the geological formations are provided in the following figures:

- Figure 4.21 shows the geological formations occurring at the seafloor;
- Figure 4.28 shows the thickness of the Holocene;
- Figure 4.29 shows distribution of the Late Pleistocene formations (directly below Holocene sediments);
- Figure 4.30 shows distribution of the Early to Middle Pleistocene formations, from the Drente Formation (Gieten Member) down to the Yarmouth Roads Formation;
- Figure 4.31 shows the distribution of the Early Pleistocene formations, comprising the Peelo Formation and the Yarmouth Roads Formation.

Note that the formations may have a larger extent than indicated on these figures (display effect—younger formation may partially cover the older formation). Refer to the GIS database for their full extents.

Table 4.6: Overview of the stratigraphy in the AOI specifying the geological units present

Age	Geological Formation / *Member**	Expected Thickness Range [m]	Soil Type†	Depositional Environment	Distribution and Comments
Holocene	Southern Bight	0 to 25	Very loose to very dense, fine to coarse SAND with shells and shell fragments, locally silty	High energy open marine	Present across the entire AOI, except the depression in the north and locally in the south The unit is thicker at the crests of the sand waves and thinner in the troughs between them. The maximum thickness is approximately 10 m. The extreme values are reached locally in the coastal area
Holocene	Urania	0 to 7	Very soft to soft (sandy) CLAY or very loose to medium dense (clayey) SAND	Low energy open marine	Present in the depression in the north
Early Holocene	Naaldwijk	0 to 15	Medium dense to very dense fine to medium (clayey) SAND and/or loose to medium dense (sandy) SILT or soft (low strength) CLAY, locally with beds of PEAT, locally thin beds of gravelly sand	Coastal to tidal	Present locally across the entire AOI, mostly as infill in shallow paleo-channels, which are highly variable in lateral and vertical extent. In general, the unit is more extensive and increase in thickness towards the coastline.
Weichselian	Boxtel (Twente)	0 to 5	Medium dense to very dense fine SAND, with minor intercalations of clay, silt, gravel and/or peat	Periglacial, aeolian	Patchy distribution across the AOI
Weichselian	Kreftenheye	0 to 25	Dense to very dense fine to medium SAND, with locally beds of gravelly sand, silty clay, clayey peat	Glaciofluvial to fluvial	Mainly present in the southern half of the AOI. Reaches maximum thickness in the southern part (Landfall/Shore crossing Area) and is absent in the northern part of the AOI
Late Eemian to Early Weichselian	Eem / *Brown Bank* (Brown Bank)	0 to 20	Firm to very stiff calcareous CLAY or SILT, with extremely closely to very closely spaced laminae to thick beds of sand	Brackish marine lagoonal to lacustrine	Present in the north-western part of the AOI. The unit reaches largest thickness (>10 m) very locally, where it forms infill of channelling features
Eemian	Eem	0 to 15	Medium dense to very dense fine SAND with shells and shell fragments; locally clay and silt beds	Shallow to open marine, locally glaciofluvial	Present in the most of the AOI, can be locally absent. Absent in the southernmost part of the AOI
Saalian	Drente / *Gieten* (Borkum Riff)[2)]	0 to 5	Very stiff to hard silty sandy gravelly CLAY (glacial TILL)	Glacial	Locally present only in the north-eastern part of the AOI
Saalian	Drente / *Uitdam* (Cleaver Bank)[2)]	0 to 25	Stiff to hard CLAY, locally with silt, sand, and gravel beds	Periglacial, glaciolacustrine	Mainly confined to Saalian tunnel valleys in the northern half of the AOI. The unit thickness is typically <10 m, larger thickness observed only very locally
Saalian	Drachten (Tea Kettle Hole)	0 to 10	Medium dense to dense, fine to medium SAND, with locally laminae of silt or/and clay	Periglacial, glaciofluvial, aeolian	Present locally in the northern half of the AOI
Holsteinian	Egmond Ground	0 to 40	Medium dense to very dense fine SAND with shells and shell fragments, with thin clay and silt interbeds	Open marine	Present across the northern half of the AOI
Elsterian	Peelo (Swarte Bank)	0 to > 100	Interbedded medium dense to very dense (silty) SAND and very stiff to hard (sandy) CLAY	Glacial, glaciofluvial (infill of valleys) to glaciolacustrine	Present across northern half of AOI, thickness significantly increases in (deep) tunnel valleys
Early to Middle Pleistocene	Yarmouth Roads	0 to > 100	Interbedded medium dense to very dense, slightly silty to very silty, fine to medium SAND, and stiff to very stiff CLAY or SILT with laminae of sand; locally laminae to thin beds of PEAT	Fluvio-deltaic to marine	Present across the AOI, except in the most south-eastern part
Early Pleistocene	Winterton Shoal / IJmuiden Ground	0 to > 100	Interbedded medium dense to very dense, silty, fine to medium SAND, with laminae to thick beds of (organic) clay and stiff to hard CLAY or SILT with laminae of sand; locally laminae of PEAT	Fluvio-deltaic to marine	Present in the south-eastern part of the AOI (Landfall/Shore crossing Area)

Notes:

Information is presented for depth range of interest (to 100 m BSF)
'Greater than' sign ('>') indicates minimum observed thickness

* = BGS naming convention between brackets
† = May contain boulders

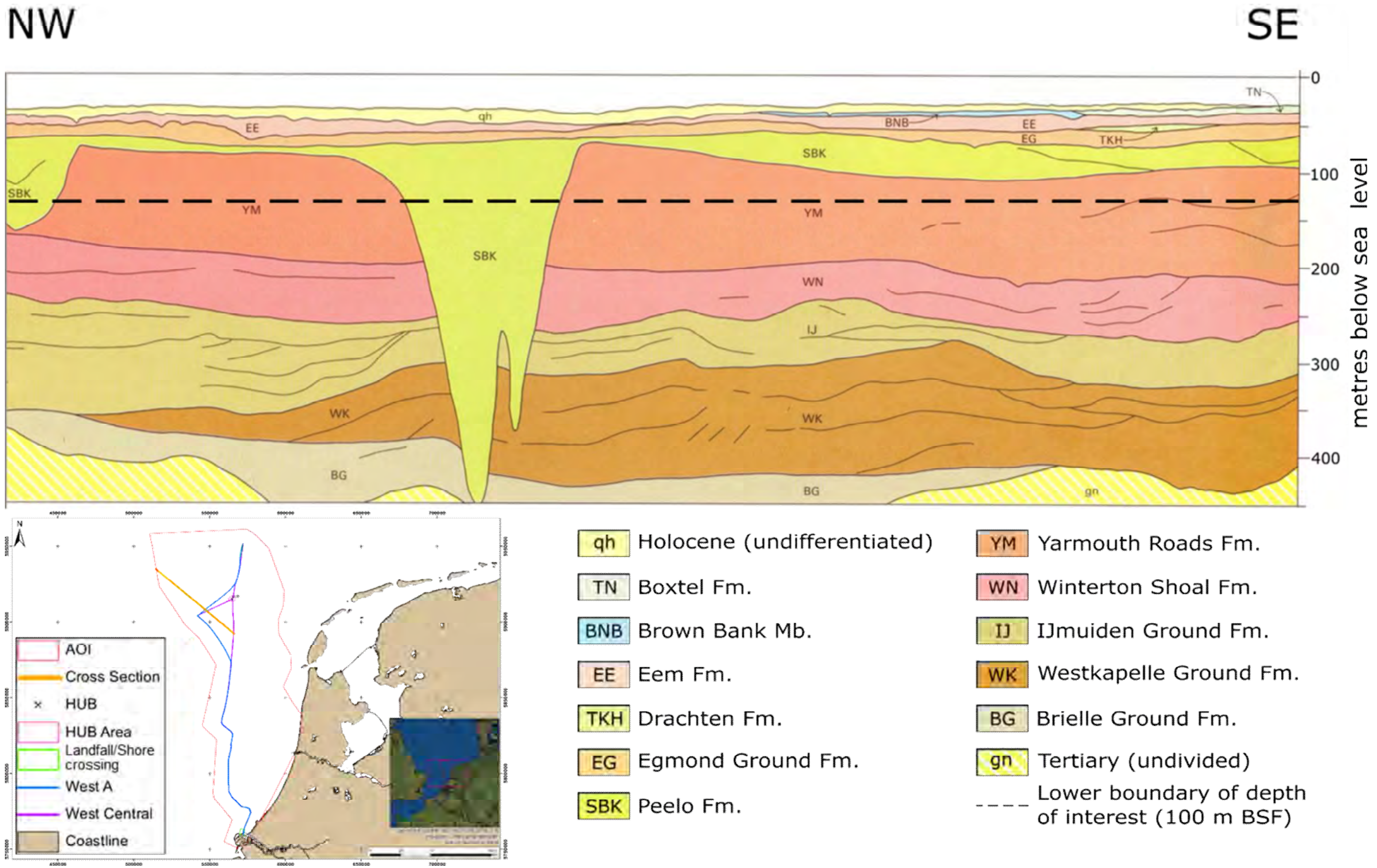

Figure 4.27: Schematic profile (with 50x vertical exaggeration) of the north-west part of the AOI. See the inset in the bottom left-hand corner for the location of the cross section (in orange). Modified after Cameron et al. (1986)

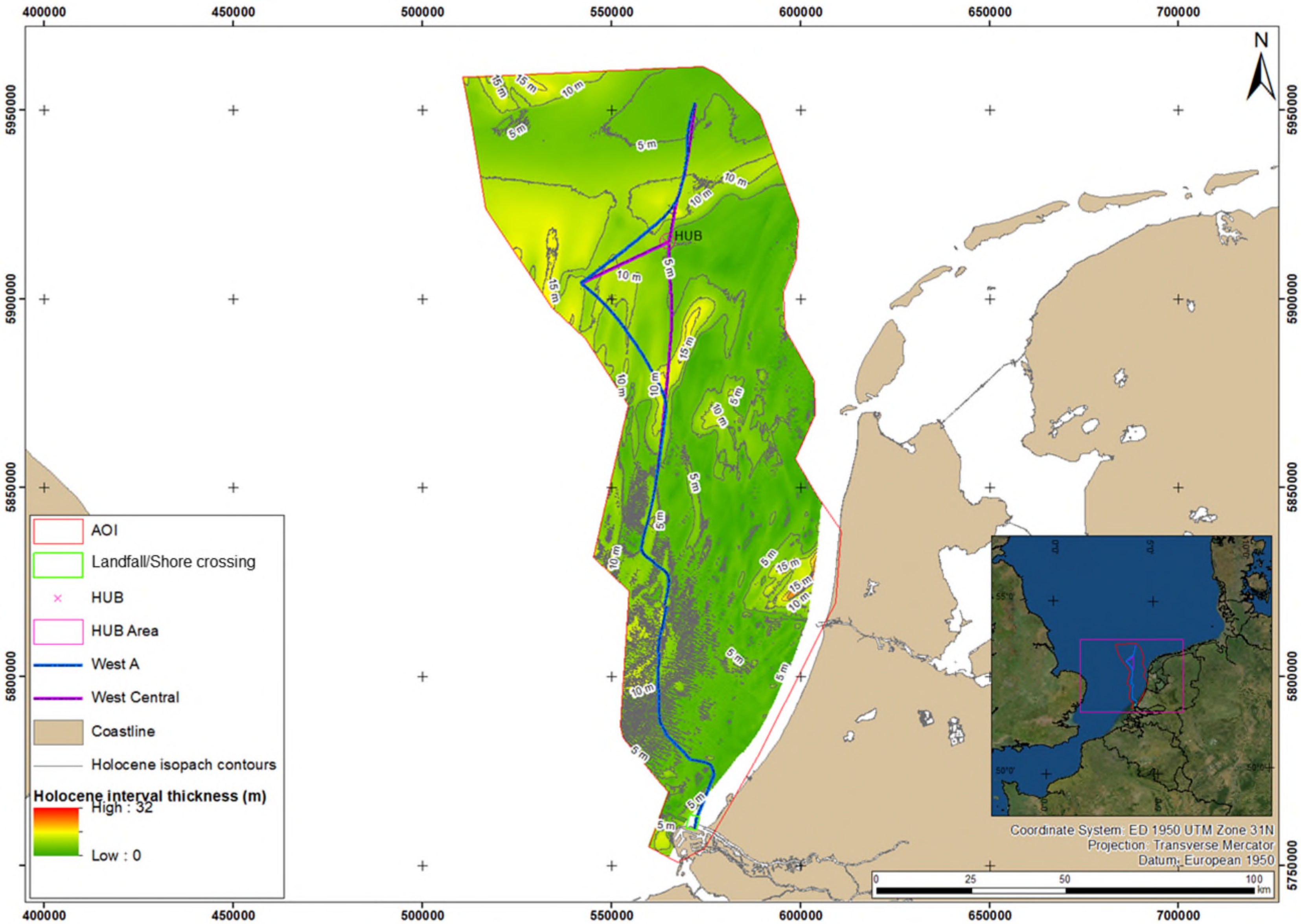

Figure 4.28: Expected thickness of the Holocene in the AOI

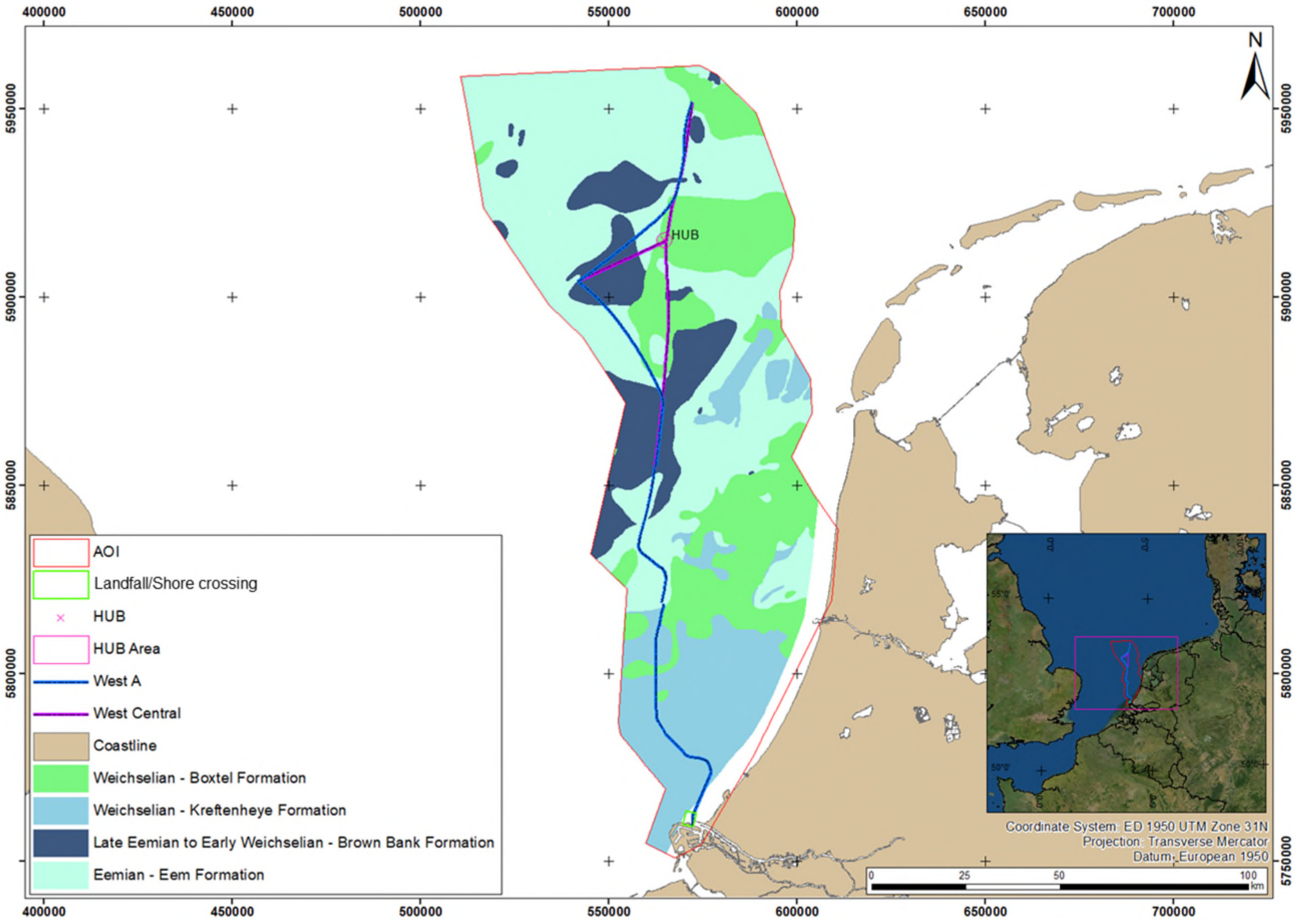

Figure 4.29: Distribution of the Late Pleistocene formations and members

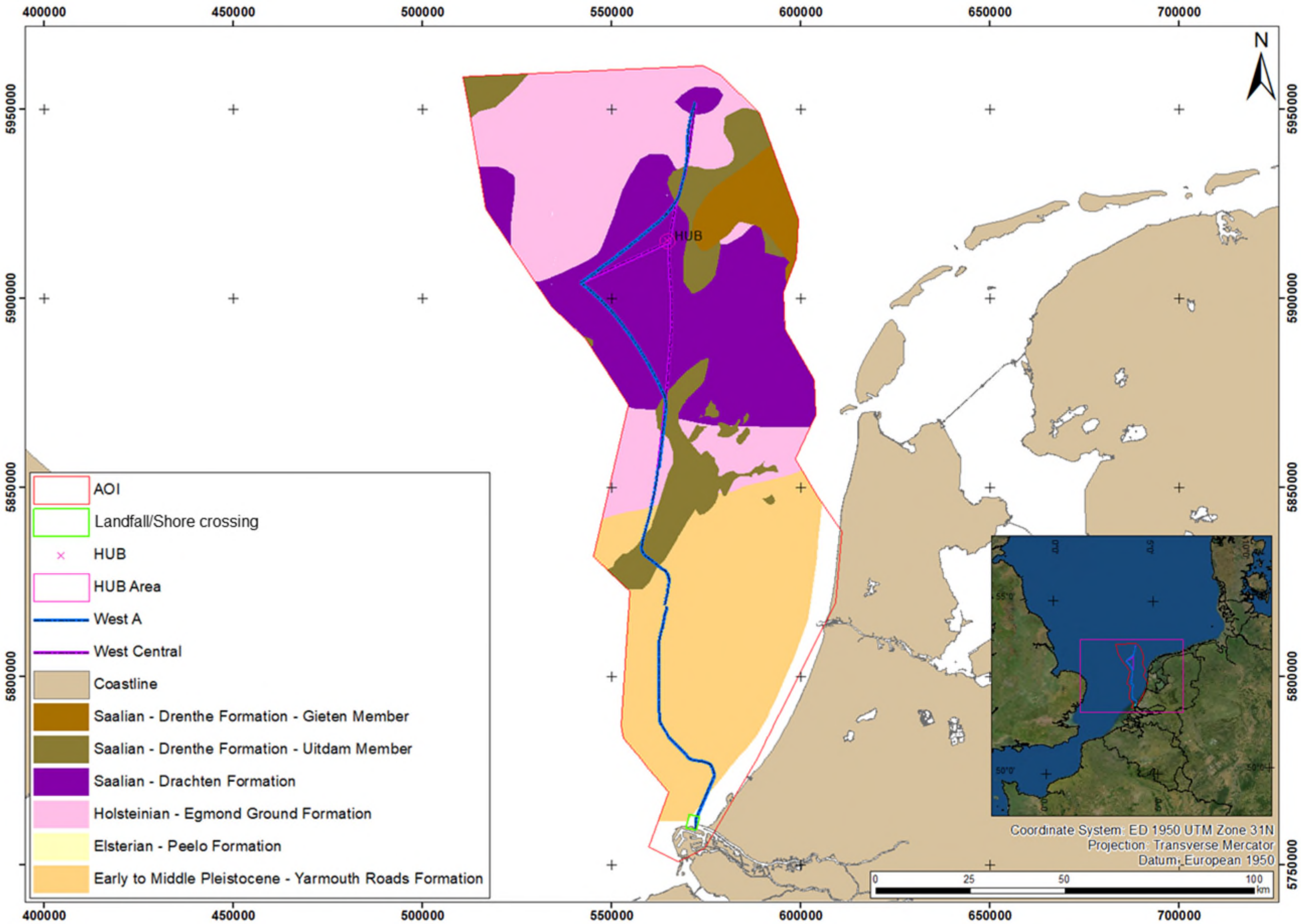

Figure 4.30: Distribution of the Early to Middle Pleistocene formations and members

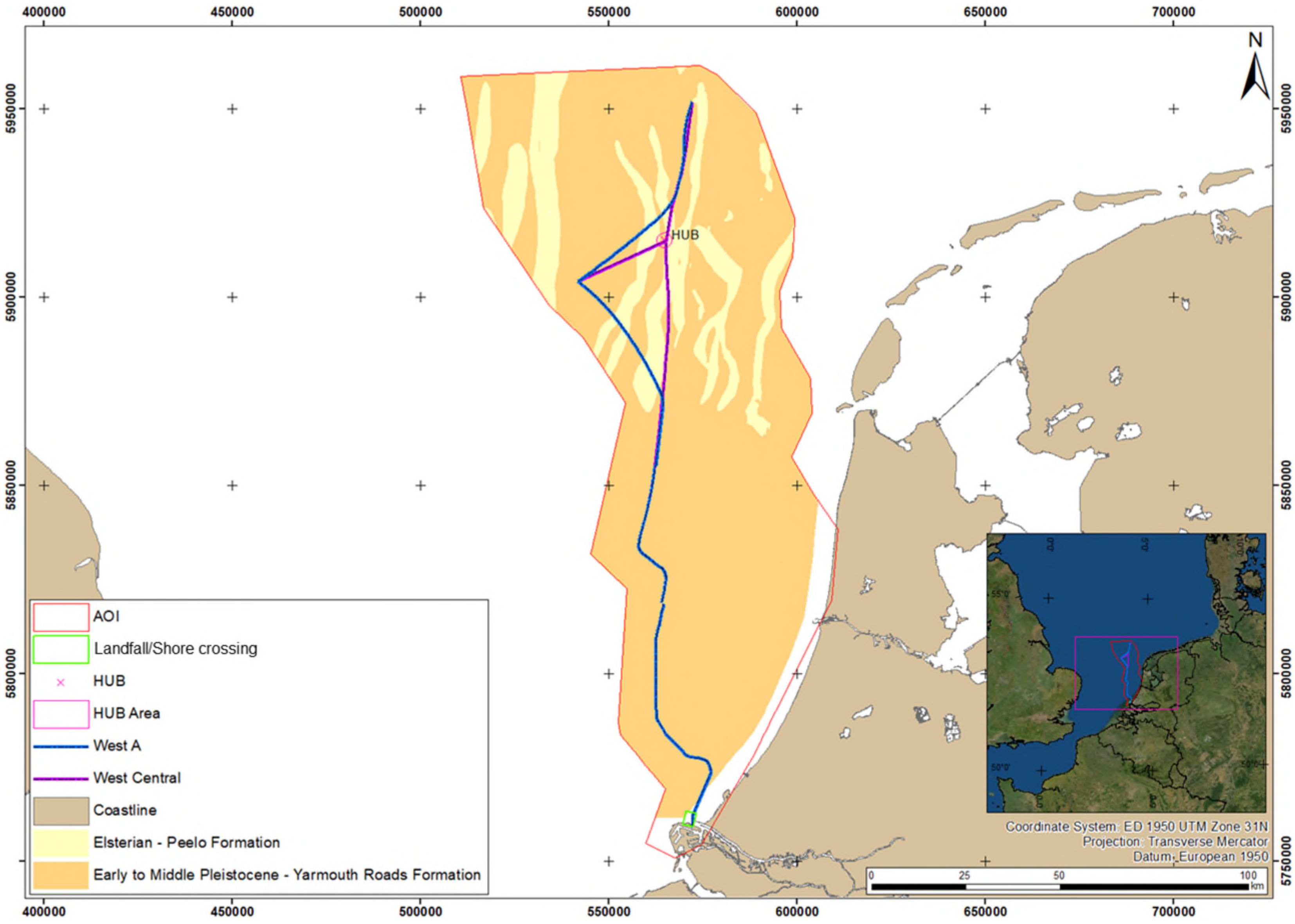

Figure 4.31: Distribution of the Early Pleistocene formations

4.4.2 Landfall/Shore Crossing Area

The expected stratigraphy and lithologies in the Landfall/Shore crossing Area, based on the information from DINOloket is presented in Figure 4.32.

There are three main units/geological formations to be expected, from top: Naaldwijk, Kreftenheye and Early Pleistocene formations, which comprise the Winterton Shoal and/or IJmuiden Ground Formations. The Naaldwijk Formation is internally very variable with dominant clay and locally some inclusions of peat. Kreftenhaye Formation is dominated by SAND and the Early Pleistocene deposits by SAND mixed with CLAY.

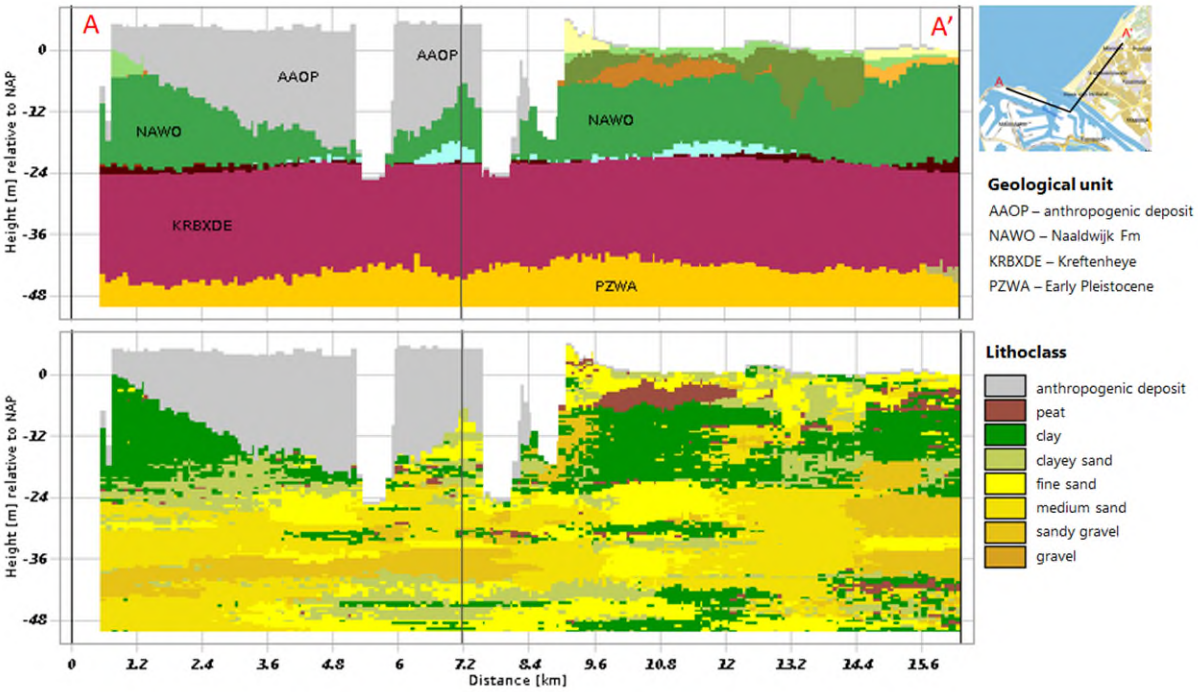

Figure 4.32: Synthetic ground models showing geological units (top image) and most probable lithologies (bottom image) in the vicinity of the Landfall/Shore crossing Area (source: DINOloket)

Table 4.7 presents the expected stratigraphy and spatial soil variability at the Landfall/Shore crossing Area. The information presented is based on (1) three geotechnical boreholes with penetration depth from approximately 17 m to 35 m BSF (Fugro, 2019c); (2) numerous geotechnical sampling and CPT testing locations from Fugro database, with various penetration depths from a few metres to approximately 40 m BSF. The geotechnical borehole data are within the boundaries of the Landfall/Shore crossing Area, located mainly in the western part.

Particularly, the presented depth and thickness values for the identified stratigraphic units/geological formations, as well as the spatial soil variability are based on previous geotechnical and geophysical investigation data performed by Fugro in the area. Figure 4.33 presents a schematic cross section along the first 3 km of the proposed pipeline route based on the interpretation of these data.

Table 4.7: Expected stratigraphy for the Landfall/Shore crossing Area

Geological Formation	Depositional Environment	Expected Thickness [m]	Soil Type	Distribution and Spatial Variability*
Disturbed Soil (DS)	Recent accumulation	0 to 5	Very soft to soft CLAY, locally sandy, locally gravelly	Present in the Maasmond Kanaal
Southern Bight	Marine	0 to 1	Very loose to dense, medium SAND with frequent shells and shell fragments	Locally present as a thin cover or in form of possible localised small-scale bedforms; can be present especially in the northern part of the area
Naaldwijk	Coastal, tidal channel and tidal flat	0 to 13	Medium dense to very dense, fine and medium SAND and soft to firm (sandy) CLAY, locally PEAT interlayers	Present across the entire area. Locally this unit might be removed due to dredging activities (i.e., in the Maasmond Kanaal) The unit is characterised by very high spatial soil variability. The unit locally forms infill of paleo-channels, where it reaches maximum thickness. More extensive paleo-channels are expected in the northern part of the area (Figure 4.34)
Kreftenheye	Fluvial	10 to 25	Very dense fine to medium SAND, locally slightly gravelly to gravelly, locally with traces to few gravels; locally with laminae to thin beds of clay	Present across the entire area. Relatively homogenous unit, with minor localised laminae to thin beds of clay
IJmuiden Ground/ Winterton Shoal	Deltaic to fluvial	> 20	Medium dense to very dense (slightly) silty SAND, locally beds of laminated CLAY, locally with thin to thick beds of very stiff to hard CLAY	The entire area; high variability in relative density of sand or an alternation of sand and clay; beds of laminated sandy clay can be (locally) present

Notes:
Information is presented for depth range of interest (to 40 m BSF)
'Greater than' sign ('>') indicates minimum observed thickness
* = refer to Figure 4.33 for schematic cross section

Comments are as follows:

- The base of the Maasmond Kanaal has been dredged up to 10 m depth. As a result, the upper strata (i.e., the Naaldwijk Formation) were likely removed or reduced to thickness of occasionally less than 1 m.
- In the Maasmond Kanaal the top comprises very soft to soft clay or medium dense (clayey or silty) sand laminated with clay. This top relatively weak layer can be a recent deposit in the channel and/or partly a remnant or of the Naaldwijk Formation. Thickness of this layer is on average between 1 m and 3 m, but locally can be up to 6 m.

- Peat/organic clay layers (laminae to thin beds) can be present locally within the Naaldwijk Formation outside of the Maasmond Kanaal, and within the top layer in the Maasmond Kanaal. On seismic reflection data, localised areas of acoustic blanking were observed in and outside of the Maasmond Kanaal, which can be related to the peat and/or possible accumulations of gas as a result of decomposition of the organic material.
- Localised gravel beds may be present in the subsurface. A thick bed of very sandy gravel was encountered at a depth of approximately 5 m BSF at a single location south of the Maasmond Kanaal.
- Rock dumps made of gravel, cobbles and boulders (as part of the flood-defence structure) are present in the coastal zones. Side scan sonar (SSS) data indicated that submerged rock dump extent from several metres to tens of metres from the shoreline. No information on the thickness of this layer is available. In boreholes located onshore 2 m to 6 m-thick layers of gravel/cobbles were encountered.
- Seafloor depressions associated with objects interpreted as possible boulders were observed sporadically on the MBES data in the Landfall/Shore crossing Area. Boulders were not encountered or reported in the subsurface, based on the available information.

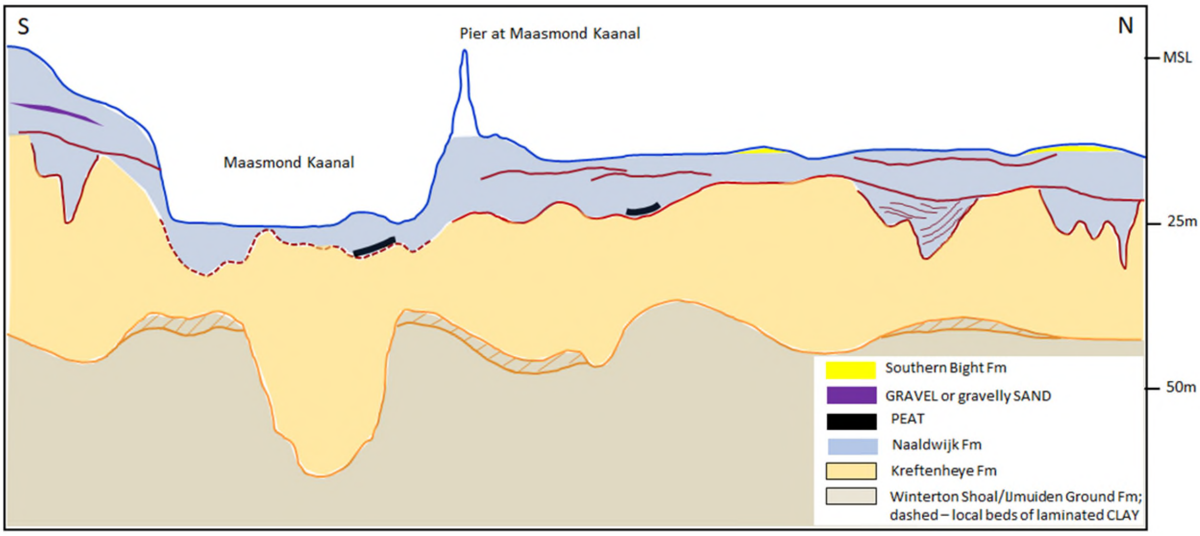

Figure 4.33: Schematic simplified cross section across the Maasmond Kanaal (based on geotechnical Fugro experience). Refer to Table 4.7 for detailed description of the units/geological formations

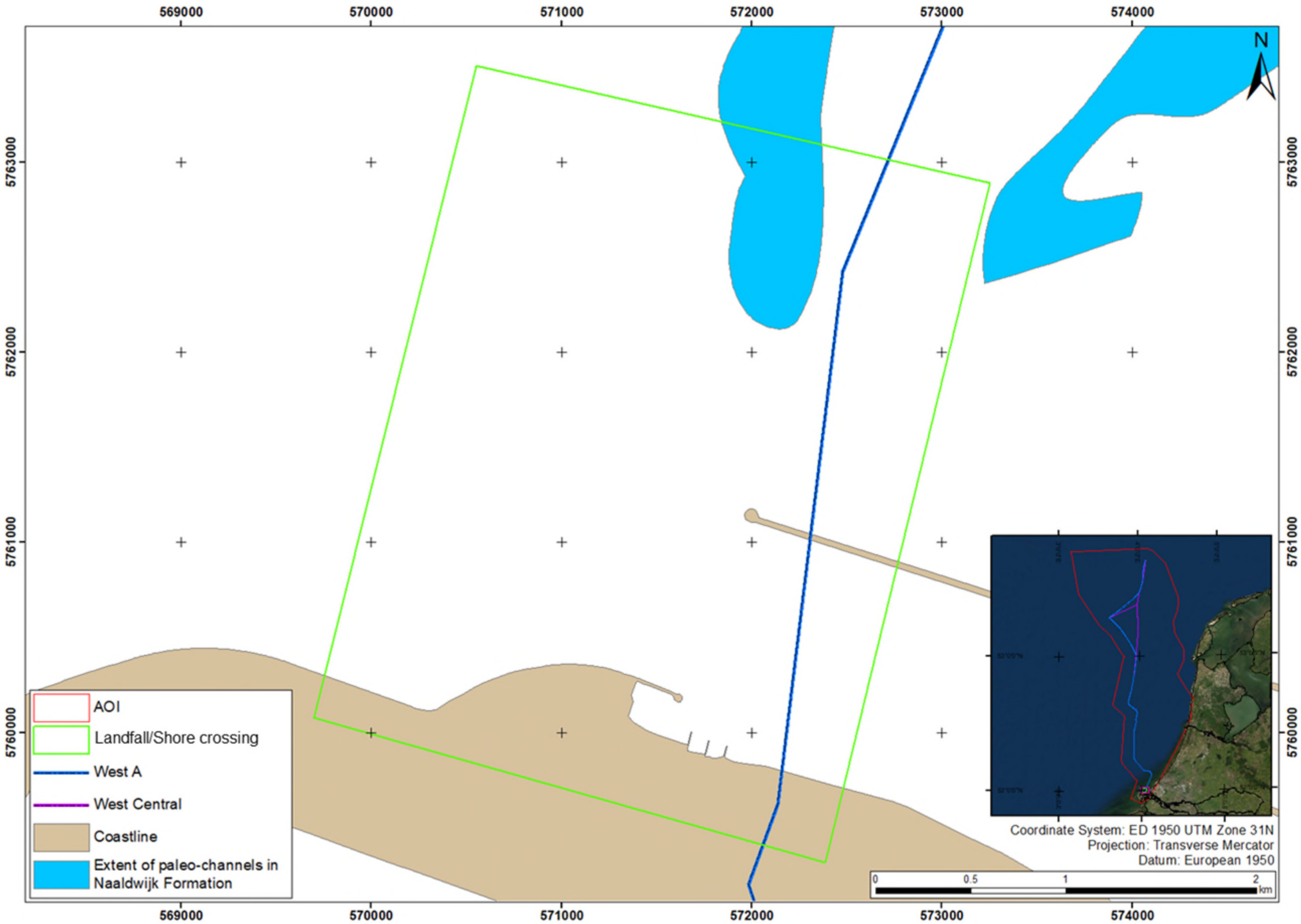

Figure 4.34: Distribution of the early Holocene (Naaldwijk Formation) paleo-channels in the Landfall/Shore crossing Area

4.4.3 Offshore Distribution HUB Area

Table 4.8 presents the general stratigraphy and spatial soil variability at the Offshore Distribution HUB Area. The information presented is based on geological maps and three geotechnical boreholes located approximately 3 km from the Offshore Distribution HUB Area boundary (Fugro confidential experience). No borehole information is available within the Offshore Distribution HUB Area.

Table 4.8: Expected stratigraphy for the Offshore Distribution HUB Area

Geological Formation / *Member*	Depositional Environment	Expected Thickness [m]	Soil Type	Distribution and Spatial Variability
Southern Bight	Marine	2 to 10	Very loose to very dense SAND with shells and shell fragments, locally silty	Present across the entire area
Naaldwijk	Coastal to tidal	0 to 5	Highly variable; generally soft CLAY, with silt, sand and peat beds	May be present (locally)
Boxtel	Periglacial, aeolian	0 to 5	Medium dense to very dense fine SAND	May be present (locally)
Eem / *Brown Bank*	Brackish marine lagoonal to lacustrine	0 to 10	Firm to very stiff calcareous CLAY or SILT, with extremely closely to very closely spaced laminae to thick beds of sand	May be present (locally)
Eem	Marine	5 to 15	Medium dense to very dense SAND with shells and shell fragments, locally silty and with peat beds	Expected to be present
Drente / *Uitdam*	Periglacial, glaciolacustrine	0 to 5	Stiff to hard CLAY, locally with silt, sand, and gravel beds	May be present (locally)
Drachten	Periglacial, aeolian	0 to 5	Medium dense to dense, fine to medium silty SAND	Expected to be present
Egmond Ground	Marine	10 to 40	Medium dense to very dense SAND with shells and shell fragments and beds of clay and silt	Expected to be present
Peelo	Glacial, glaciofluvial to glaciolacustrine	> 20	Interbedded medium dense to very dense SAND and very stiff to hard sandy CLAY	Expected to be present, although thickness may vary within the area
Yarmouth Roads	Fluvio-deltaic to marine	> 40	Dense to very dense SAND with shells and shell fragments, locally slightly silty	Expected to be present, although thickness may vary within the area

Notes:
Information is presented for depth range of interest (to 100 m BSF)
'Greater than' sign ('>') indicates minimum observed thickness

Comments are as follows:

- Based on the available geological maps, the Naaldwijk Formation and the Brown Bank Member may be (partly) present in the Offshore Distribution HUB Area. Based on

information from the nearby boreholes it is not possible to distinguish between these formations and member. However, CLAY with a thickness of 0.5 m to 5 m between the Southern Bight Formation and the Eem Formation was observed. Therefore, either Naaldwijk or Brown Bank is expected to be (locally) present.
- Beds of PEAT may be present locally and belong to either the Naaldwijk, or the Brown Bank Member.
- Stratigraphy descriptions for the nearby geotechnical boreholes incorporated the Drachten Formation and Uitdam Member into the Eem Formation and/or Egmond Ground Formation. Therefore, it is not possible to confirm the presence of these strata. The geological maps suggest that the Drachten Formation should be present, while the Uitdam Member might be (locally) present. The expected thickness of each of these formations is up to 5 m.
- The thickness of the Peelo Formation as observed in the nearby boreholes is approximately 22 m and 29 m. Regional geophysical and geotechnical information suggests that the formation is present throughout the area (Figure 4.27; Cameron et al., 1986; Laban, 1995).
- The base of the Yarmouth Roads Formation was not encountered in the nearby geotechnical boreholes. However, regional geophysical and geotechnical information suggests the formation is present throughout the wider area and has a thickness of at least 40 m (Figure 4.27; Cameron et al., 1986; Laban, 1995).

4.5 Ground Models

One ground model per study area is presented in this report, allowing to capture site-specific details and the different depth of interest for each site.

4.5.1 AOI

4.5.1.1 Predicted Soil Units and Geotechnical Parameters

To predict soil units across the AOI, the seafloor and sub-seafloor features identified in the available geological, geophysical and geotechnical data and literature were reviewed and summarised (Sections 4.2 and 4.4). Predicting soil units enables soil profiles and associated soil province map(s) to be generated.

Soil units were defined by grouping together stratigraphic formations expected to have similar lithologies (e.g., principal soil type). A geotechnical description is given allowing to encompass the possible variability and change in lithology within each of the soil units.

Eight soil units were predicted to be present across the AOI and within the depth of interest. Table 4.9 presents the predicted soil units and the associated preliminary geotechnical parameters defined for each unit.

The geotechnical description of soil units, detailed below, are applicable for the complete AOI as well as on the specific Landfall/Shore crossing and Offshore Distribution HUB Areas:

- Soil unit i, comprising the Holocene surficial sediments:
  - ia: sandy very soft MUD to muddy loose SAND;
  - ib: very loose to very dense SAND;
  - ic: slightly gravelly loose SAND to sandy GRAVEL;
- Soil unit ii, comprising tidal and coastal deposits of Early Holocene: interbedded very thin to thick beds of CLAY and SAND;
- Soil unit iii, grouping the Pleistocene formations dominated by SAND: SAND, locally (slightly) silty, with locally (and minor) beds of CLAY, SILT, GRAVEL and PEAT;
- Soil unit iv, grouping the Pleistocene formations dominated by CLAY, subdivided based on age (strength):
  - iva: overconsolidated (firm to stiff) CLAY with SAND laminae/thin beds;
  - ivb: overconsolidated (stiff to hard) CLAY, with beds of SILT to SAND;
- Soil unit v, corresponding to glacial TILL: very stiff to hard silty sandy gravelly CLAY.

Geotechnical parameters are derived from Fugro experience comprising numerous geotechnical sampling and CPT boreholes across the AOI. Thicknesses given are based on the same experience as well as on geological maps used in this report. The AOI being very large, the geotechnical parameters values cannot be detailed precisely, and ranges given in Table 4.9 allow to encompass potential range of values across the AOI.

Fugro recommends geotechnical sample data and CPTs along the final pipeline route to refine parameter ranges, and precise the expected thicknesses of the different units along the pipeline route. It is also recommended that the siting of the sampling and CPT locations is performed once geophysical data has been acquired to ensure areas of variability are sufficiently characterised and consistent areas only collect the required information. Based on these future geophysical and geotechnical surveys, the soil units may be discriminated further along the pipeline route.

Table 4.9: Predicted preliminary geotechnical parameters for the AOI

Stratigraphic Unit (Geological Formation)	Soil Unit	Description	Soil Type	Thickness [m]	γ′ [kN/m³]	D_r [%]	s_u [kPa]	S_t [-]	Φ′ [°]	q_c [MPa]
Surficial Sediments (Southern Bight and Urania)	**ia**	sandy very soft MUD to muddy loose SAND	CLAY	0 to 5	18 to 19	N/A	5 to 50	-	N/A	<2
	ib	very loose to very dense SAND	SAND	0 to 10	18 to 19.5	<35 to >100		N/A	25 to 45	2 to 20
	ic	slightly gravelly loose SAND to sandy GRAVEL	SAND	0 to 5	19 to 20	<35		N/A	25 to 30	4 to 20
Naaldwijk	**ii**	interbedded very thin to thick beds of CLAY and SAND	CLAY	0 to 15	18 to 19.5	N/A	20 to 100	1 to 3	N/A	1 to 3
			SAND			25 to 85		N/A	25 to 35	2 to 10
Boxtel (Twente) Kreftenheye, Eem Drachten (Tea Kettle Hole) Egmond Ground Yarmouth Roads	**iii**	SAND, locally slightly silty, with locally beds of CLAY, SILT, GRAVEL and PEAT	CLAY	0 to >20	18.5 to 20.5	N/A	100 to 200	~1 to 3	N/A	2 to 4
			SAND			65 to >100		N/A	30 to 45	15 to 90
Brown Bank	**iva**	overconsolidated firm to stiff CLAY with SAND laminae/thin beds	CLAY	0 to 10	18.5 to 19.5	N/A	50 to 200	1 to 3	N/A	1 to 4
			SAND			25 to 75		N/A	30 to 40	2 to 10
Drenthe (Cleaver Bank) Peelo (Swarte Bank)	**ivb**	overconsolidated stiff to hard CLAY, with beds of SILT to SAND	CLAY	0 to >20	19.5 to 21	N/A	200 to 400	~1 to 2	N/A	4 to 8
			SAND			65 to >100		N/A	35 to 45	15 to 90
Drenthe (Borkum Riff)	**v**	sandy, gravelly CLAY (glacial TILL)	CLAY	0 to 5	20 to 22	N/A	200 to 600	~1 to 2	N/A	4 to 12

Notes:
N/A = not applicable
- = no information available
γ′ = total unit weight
s_u = undrained shear strength
S_t = sensitivity
Dr = relative density
Φ′ = drained peak effective friction angle
q_c = CPT cone resistance

4.5.1.2 Geotechnical Profiles

Nine soil profiles were generated for the AOI based on available data. These soil profiles describe the possible lateral and vertical variability of soil units predicted to be present to 20 m BSF across the AOI. Soil profiles are presented in Figure 4.35. They were designed to discriminate areas with presence of:

- glacial TILL (profiles numbered 2);
- firm to stiff CLAY from the Brown Bank Formation (profiles numbered 3);
- neither glacial TILL or Brown Bank CLAY (soil profiles numbered 1).

The other criteria differentiating between the soil profiles are the types of surficial sediments: (a) mud-rich, (b) sand and (c) gravel-rich.

Bedforms were considered as positive features relatively to the mean seafloor level and are shown as positive triangles at the top of the profiles.

4.5.1.3 Soil Provinces

A soil province map, presented in Figure 4.36, was generated for entire AOI to depict the spatial extent of each predicted soil profile (Figure 4.35). The soil province map allows the lateral variability in soil units to be better understood and pictured.

Areas covered by each soil province are given in Table 4.10 along with the percentage of the total AOI surface area they represent. From this table, it appears that over 84 % of the AOI is characterised by the normal soil profiles (profiles numbered 1 in Figure 4.35). Less than 4% of the AOI is likely to present glacial TILL (unit v) within the depth of interest (profiles numbered 2), while 12% of the AOI present firm to stiff CLAY of the Brown Bank Formation (unit iva) within the depth of interest (profiles numbered 3). 65% of the area is covered by SAND rich surficial sediments (profiles numbered 'b'), less than 19% is covered by MUD-rich sediments (profiles numbered 'a') and 16% is covered by GRAVEL-rich surficial sediments (profiles numbered 'c').

Table 4.10: Area covered by each soil province

Soil Province	Area (km^2)	% of AOI
AOI - 1a	1920.2	16
AOI - 1b	6455.9	56
AOI - 1c	1395.2	12
AOI - 2a	18.6	<1
AOI - 2b	321.7	2
AOI - 2c	123.8	1
AOI - 3a	235.3	2
AOI - 3b	807.3	7
AOI - 3c	347.1	3

Figure 4.36 presents the maximum extent of units consisting of stiff to hard CLAY (unit ivb) as hatched areas. However, the stiff to hard CLAY is in general likely to occur below the depth of interest of the AOI.

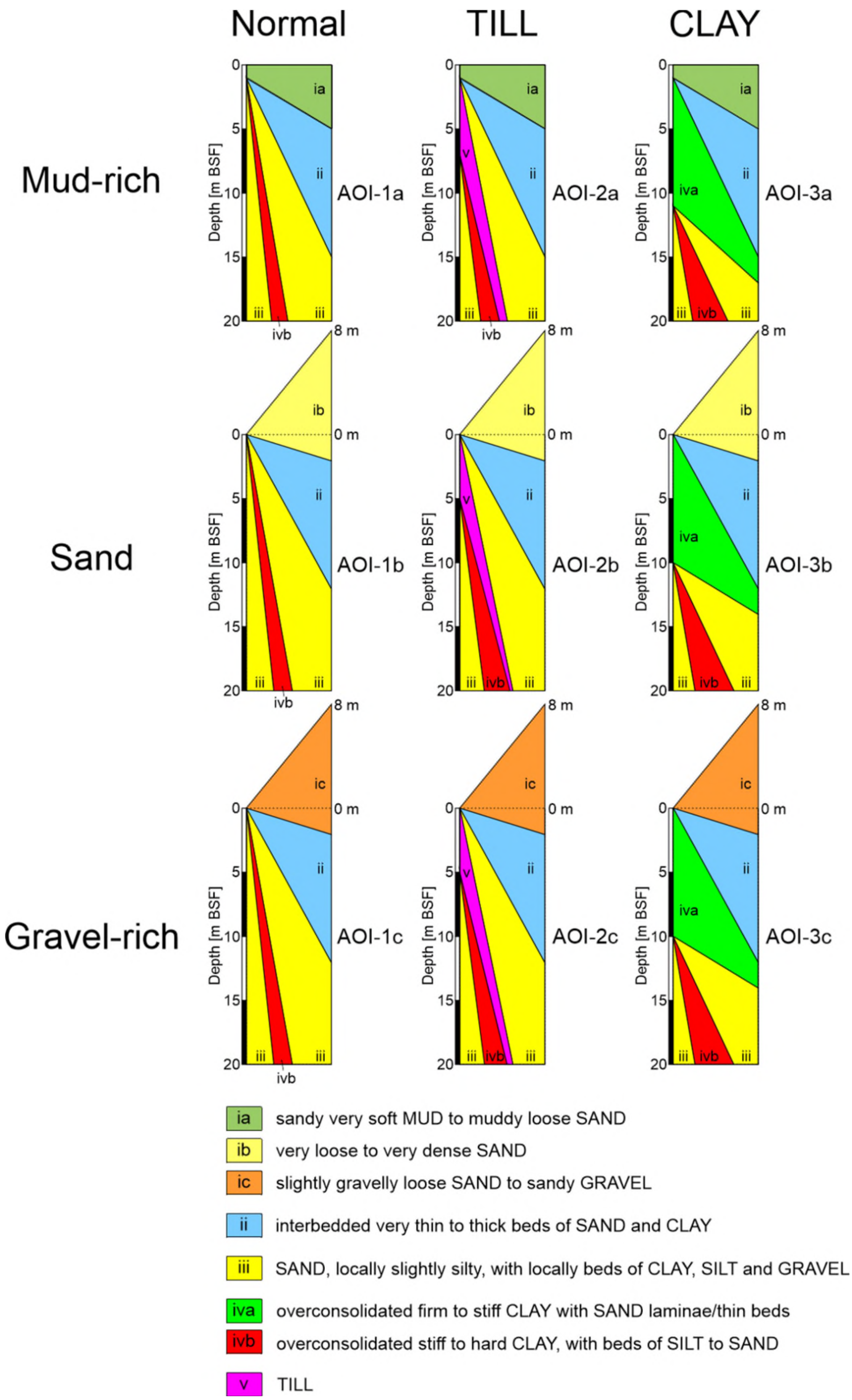

Figure 4.35: Predicted soil profiles across the AOI

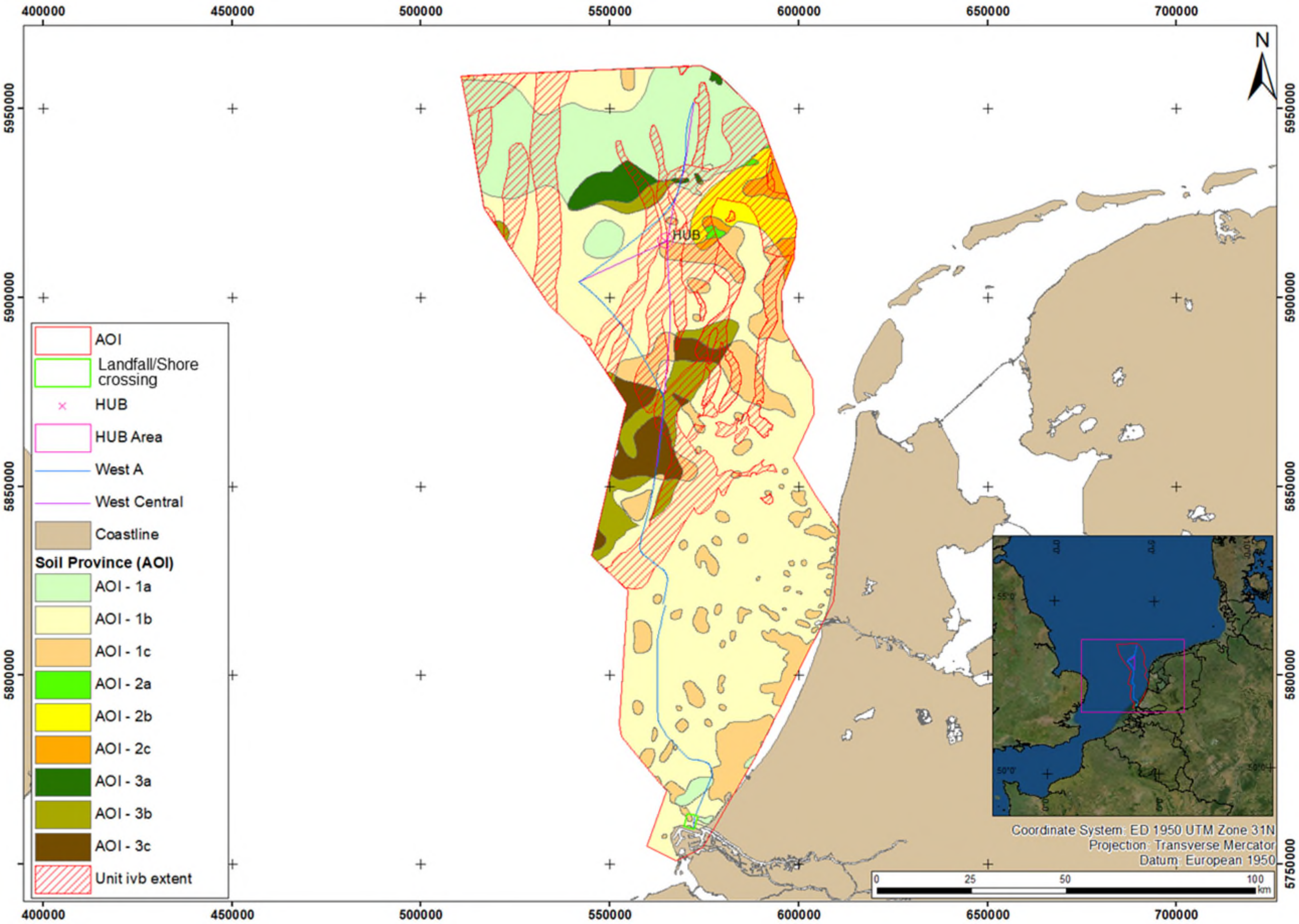

Figure 4.36: Soil province map across the AOI

4.5.2 Landfall/Shore Crossing Area

4.5.2.1 Predicted Soil Units and Geotechnical Parameters

Five soil units were predicted to be present in the Landfall/Shore crossing Area and within the depth of interest (40 m to 50 m BSF). Table 4.11 presents the predicted soil units and the associated preliminary geotechnical parameters defined for each unit.

Geotechnical descriptions and soil units are the same as those defined for the AOI (Section 4.5.1.1), with the addition of unit 'ds' corresponding to disturbed soil/recent accumulation consisting of very soft CLAY or very loose to medium dense SAND. This unit is limited to the Maasmond Kanaal and probably comprises residues of dredging operations.

Unit iii also includes the Early Pleistocene Winterton Shoal/IJmuiden Ground Formations, which are lateral equivalents of the Yarmouth Road Formation.

GRAVEL beds may be present locally in the subsurface. In the coastal zones there are gravel/cobbles/boulders accumulations (as part of rock dumps of the flood-defence structure). These deposits extent laterally from metres to several tens of metres from the shoreline. The thickness is unknown but may be up to several metres. No boulders were encountered in the subsurface, however presence of boulders cannot be entirely excluded (see also Section 4.4.2).

Geotechnical parameter values and thickness ranges are specific to the Landfall/Shore crossing Area and were derived from geotechnical Fugro experience in the Landfall/Shore crossing Area.

Fugro recommends acquisition and interpretation of site-specific geophysical data (sub-bottom profiler (SBP), MBES and SSS) across the Landfall/Shore crossing Area in order to confirm or refine the pipeline routing. Once the final routing is agreed, a site-specific survey should be planned depending on the expected soil variability. This would then allow to confirm and further refine geotechnical parameters and soil unit vertical and lateral variability. An update of the ground model may be subsequently considered based on any new findings.

Table 4.11: Predicted preliminary geotechnical parameters for the Landfall/Shore crossing Area

Stratigraphic Unit (Geological Formation)	Soil Unit	Description	Soil Type	Thickness [m]	γ' [kN/m^3]	D_r [%]	s_u [kPa]	S_t [-]	Φ' [°]	q_c [MPa]
Disturbed Soil	**ds**	very soft CLAY	CLAY	0 to 5	15 to 19	N/A	< 2	-	N/A	< 2
		very loose to medium dense SAND	SAND			<35 to 65		N/A	25 to 35	2 to 10
Surficial Sediments (Southern Bight and Urania)	**ib**	very loose to very dense SAND	SAND	0 to 5	18 to 19.5	<35 to 100		N/A	25 to 35	2 to 20
	ic	slightly gravelly loose SAND to sandy GRAVEL	SAND	0 to 5	18 to 19	<35		N/A	25 to 35	4 to 10
Naaldwijk	**ii**	interbedded very thin to thick beds of CLAY, SAND and locally PEAT	CLAY	0 to 13	18 to 19.5	N/A	2 to 100	1 to 3	N/A	1 to 4
			SAND			25 to 100		N/A	25 to 45	2 to 20
Kreftenheye,	**iii**	Dense to very dense SAND	SAND	10-25	18.5 to 20.5	80 to >100		N/A	25 to 45	20 to 60
Winterton Shoal / IJmuiden Ver		SAND, silty, with locally beds of CLAY and/or SILT	CLAY	>40		N/A	100 to 300	~1 to 3	N/A	2 to 6
			SAND			35 to >100		N/A	25 to 45	15 to 90

Notes:
N/A = not applicable
- = no information available
γ' = total unit weight
s_u = undrained shear strength
S_t = sensitivity
Dr = relative density
Φ' = drained peak effective friction angle
q_c = CPT cone resistance

4.5.2.2 Geotechnical Profiles

Four soil profiles were drawn for the Landfall/Shore crossing Area based on available data. These soil profiles describe the possible lateral and vertical variability of soil units predicted to be present to 40 m BSF across the Landfall/Shore crossing Area.

Soil profiles are presented in Figure 4.37. They were designed to discriminate areas with different surficial sediment types (GRAVEL and MUD above SAND), as well as areas with anthropogenic reworked material. Profile 1 was subdivided to discriminate areas where unit ii may be thicker (up to 14 m) due to the presence of paleo-channels from the Early Holocene.

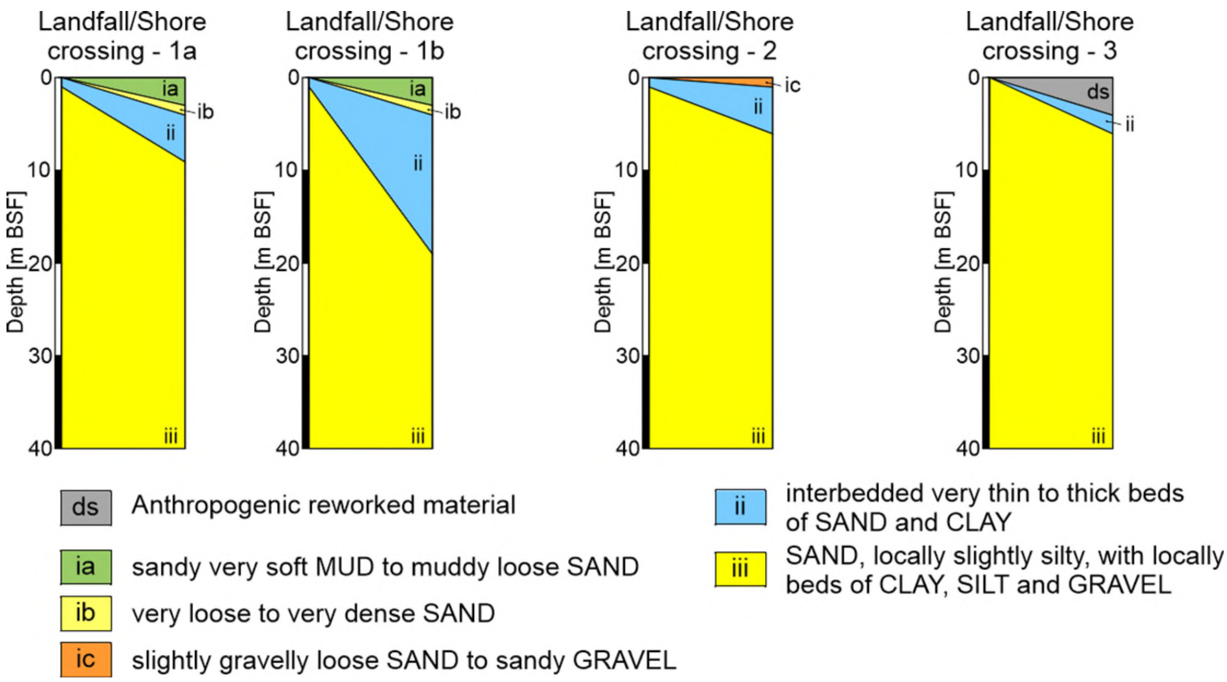

Figure 4.37: Predicted soil profiles across the Landfall/Shore crossing Area

4.5.2.3 Soil Provinces

A soil province map presented in Figure 4.38 was generated for the entire Landfall/Shore crossing Area to depict the spatial extent of each predicted soil profile (Figure 4.37). The soil province map allows the lateral variability in soil units to be better understood and pictured.

Areas covered by each soil province are given in Table 4.12 along with the percentage of the total Landfall/Shore crossing Area they represent. From this table, it appears that 38% of the area is characterised by mud-rich and muddy SAND surficial sediments (units ia and ib) with thin unit ii. 25% of the area, to the north-eastern corner, is expected to be covered by GRAVEL-rich sediments (unit ic). 21% of the area corresponds to the Maasmond Kanaal, potentially covered by disturbed/reworked deposits. Finally, only 4% of the area corresponds to the potential extent of paleo-channels (Naaldwijk Formation) based on geological maps (Figure 4.34).

About 12% of the Landfall/Shore crossing Area is covered by land and is not covered by any soil province.

Table 4.12: Area covered by each soil province across the Landfall/Shore crossing Area

Soil Province	Area (km^2)	% of AOI
Landfall/Shore crossing - 1a	3.8	38.3
Landfall/Shore crossing - 1b	0.4	4.4
Landfall/Shore crossing - 2	2.5	24.9
Landfall/Shore crossing - 3	2.1	20.8
Notes: 11.6% of the Landfall/Shore crossing Area is covered by land		

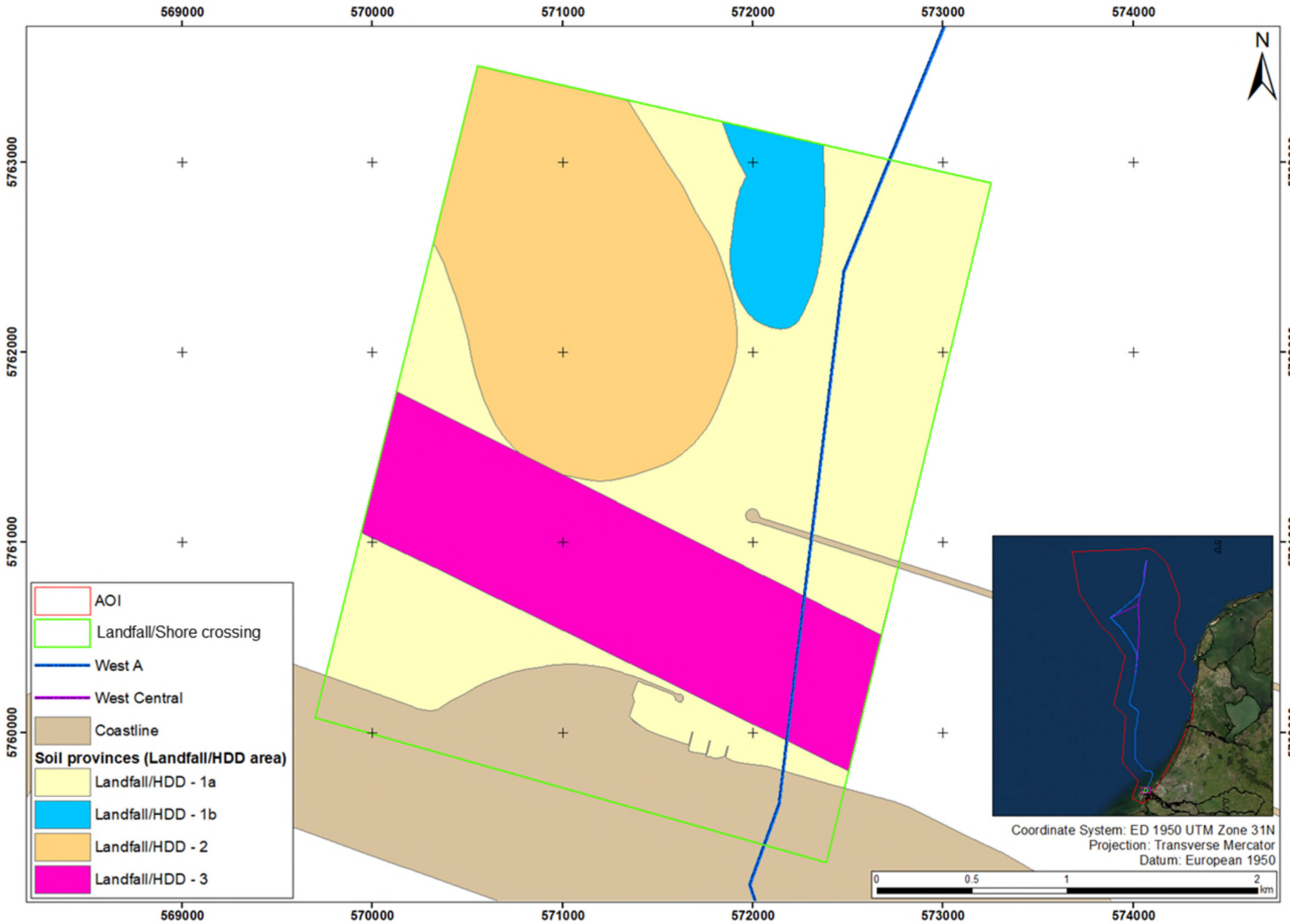

Figure 4.38: Soil province map across the Landfall/Shore crossing Area

4.5.3 Offshore Distribution HUB Area

4.5.3.1 Predicted Soil Units and Geotechnical Parameters

Five soil units were predicted to be present across the Offshore Distribution HUB Area and within the depth of interest (e.g., 100 m BSF). Table 4.13 presents the predicted soil units and the associated preliminary geotechnical parameters defined for each unit.

Geotechnical descriptions and soil units are the same as those defined for the AOI (Section 4.5.1.1).

Geotechnical parameters are the same as those presented for the entire AOI (Section 4.5.1.1). Fugro experience does not cover the Offshore Distribution HUB Area specifically, but the geotechnical parameter ranges for the AOI are likely to apply for the Offshore Distribution HUB Area to a depth of 100 m BSF. Expected thicknesses were adapted based on information from publicly available data and three geotechnical boreholes (Fugro experience) within 3 km of the Offshore Distribution HUB Area boundary.

Fugro recommends acquisition and interpretation of site-specific geophysical data (SBP, MBES and SSS) across the Offshore Distribution HUB Area to confirm or refine the pipeline routing. Once the final routing is agreed, a site-specific survey should be planned depending on the expected soil variability. This would then allow to confirm and further refine geotechnical parameters and soil unit vertical and lateral variability. An update of the ground model may be subsequently considered based on any new findings.

Table 4.13: Predicted preliminary geotechnical parameters for the Offshore Distribution HUB Area

Stratigraphic Unit (Geological Formation)	Soil Unit	Description	Soil Type	Thickness [m]	γ' [kN/m^3]	D_r [%]	s_u [kPa]	S_t [-]	Φ' [°]	q_c [MPa]
Surficial Sediments (Southern Bight and Urania)	**ib**	very loose to very dense SAND	SAND	4 to 9	18 to 19.5	<35 to >100		N/A	25 to 45	2 to 20
	ic	slightly gravelly loose SAND to sandy GRAVEL	SAND	4 to 9	19 to 20	<35		N/A	25 to 30	4 to 20
Naaldwijk	**ii**	interbedded very thin to thick beds of CLAY and SAND	CLAY	0 to 1	18 to 19.5	N/A	20 to 100	1 to 3	N/A	1 to 3
			SAND			25 to 85		N/A	25 to 35	2 to 10
Boxtel (Twente) Kreftenheye, Eem Drachten (Tea Kettle Hole) Egmond Ground Yarmouth Roads	**iii**	SAND, locally slightly silty, with locally beds of CLAY, SILT, GRAVEL and PEAT	CLAY	40 to >100	18.5 to 20.5	N/A	100 to 200	~1 to 3	N/A	2 to 4
			SAND			65 to >100		N/A	30 to 45	15 to 90
Drenthe (Cleaver Bank) Peelo (Swarte Bank)	**ivb**	overconsolidated stiff to hard CLAY, with beds of SILT to SAND	CLAY	0 to 30	19.5 to 21	N/A	200 to 400	~1 to 2	N/A	4 to 8
			SAND			65 to >100		N/A	35 to 45	15 to 90

Notes:
N/A = not applicable
\- = no information available
γ' = total unit weight
s_u = undrained shear strength
S_t = sensitivity
Dr = relative density
Φ' = drained peak effective friction angle
q_c = CPT cone resistance

4.5.3.2 Geotechnical Profiles

Four soil profiles were drawn for the Offshore Distribution HUB Area based on available data. These soil profiles describe the possible lateral and vertical variability of soil units predicted to be present to 100 m BSF across the Offshore Distribution HUB Area.

Soil profiles are presented in Figure 4.39. They were designed to discriminate areas with overconsolidated stiff to hard CLAY (unit ivb) at depth from the Peelo Formation. A subdivision was made to differentiate areas where SAND (ib) is expected at the seafloor from areas where GRAVEL-rich sediments (unit ic) are mapped.

The Offshore Distribution HUB Area is localised in-between two sand banks and therefore positive features of 1 m have been drawn to encompass the presence of the flanks of these bedforms.

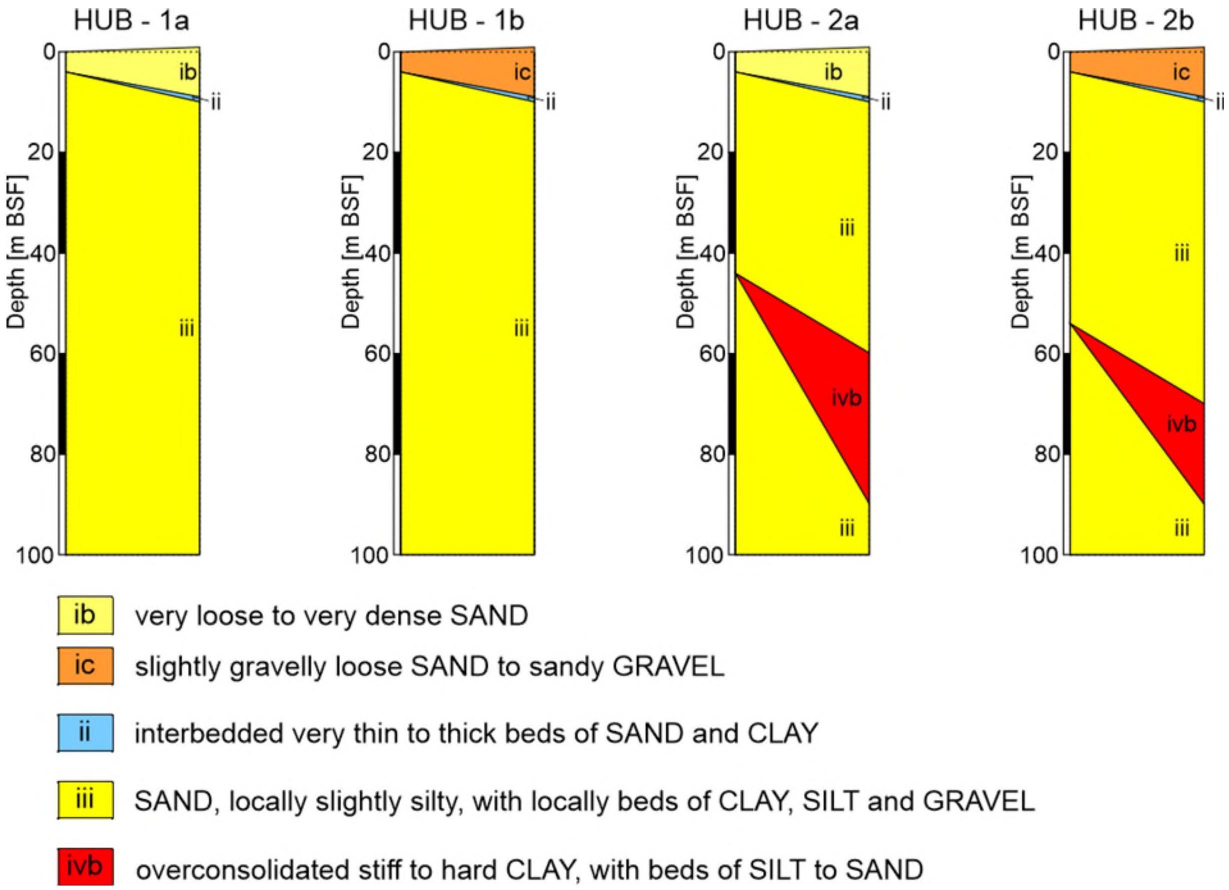

Figure 4.39: Predicted soil profiles across the Offshore Distribution HUB Area

4.5.3.3 Soil Provinces

A soil province map presented in Figure 4.40 was generated for the entire Offshore Distribution HUB Area to depict the spatial extent of each predicted soil profiles (Figure 4.37). The soil province map allows the lateral variability in soil units to be better understood and pictured.

Areas covered by each soil province are given in Table 4.14 along with the percentage of the total Offshore Distribution HUB Area they represent. From this table, it appears that 54% of the area is characterised by the potential presence of stiff to hard CLAY (unit ivb) within the depth of interest. This surface is divided within two distinct areas covering the western and eastern sides of the Offshore Distribution HUB Area. The areas correspond to two distinct paleo-channels from the Peelo Formation orientated north–south. More than 60% of the area is expected to be covered by SAND, while the southern part (40%) is expected to be composed of GRAVEL-rich material.

Table 4.14: Area covered by each soil province across the Offshore Distribution HUB Area

Soil Province	Area (km^2)	% of AOI
HUB - 1a	3.6	28
HUB - 1b	2.3	18
HUB – 2a	4.4	35
HUB – 2b	2.3	19

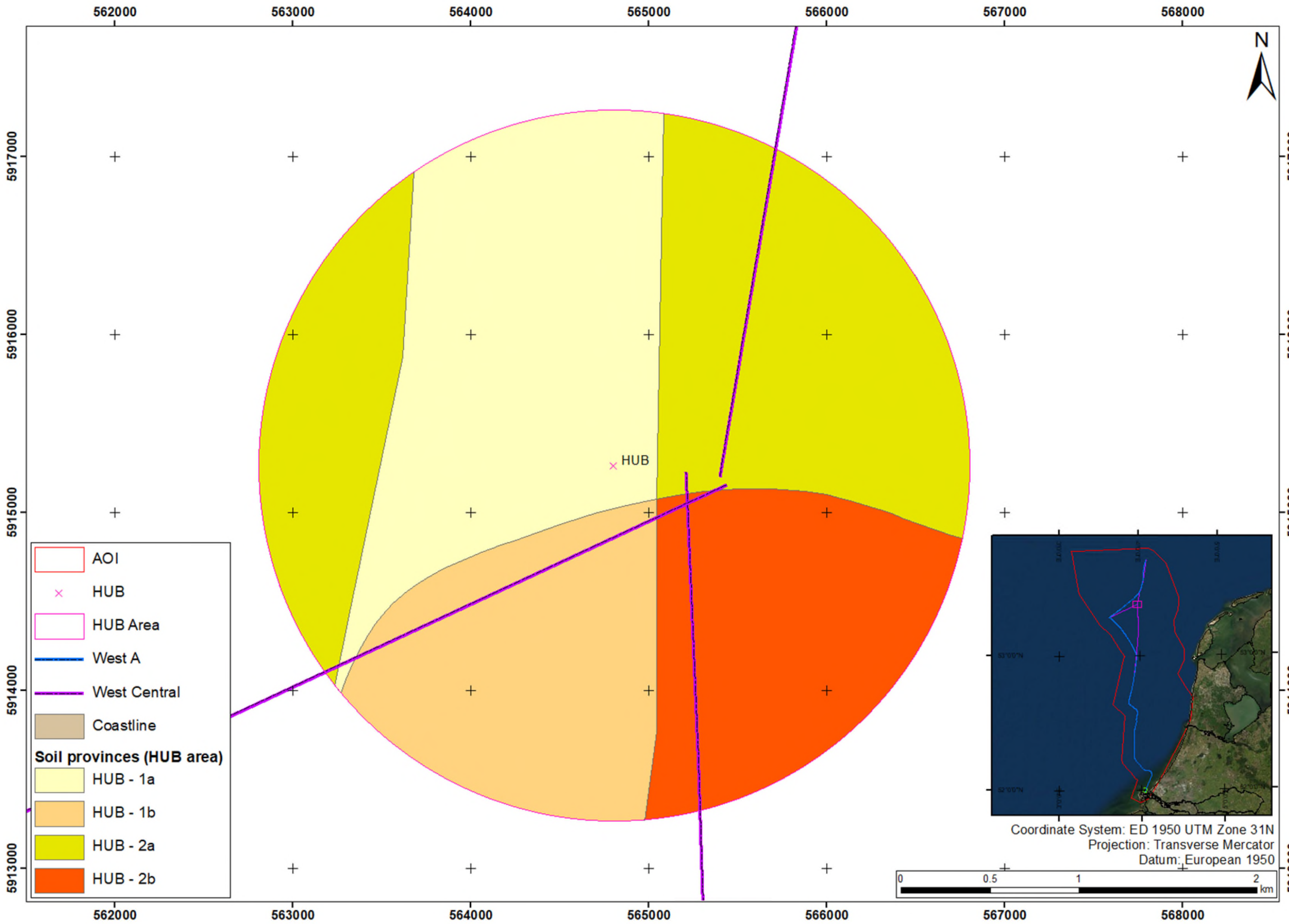

Figure 4.40: Soil province map across the Offshore Distribution HUB Area

5. Geohazards, Hazards and Site Constraints

5.1 General

Table 5.1 presents potential and identified geohazards and soil constraints for pipeline and other offshore infrastructures as well as for their installation. The information provides screening-level hazard characterisation (i.e. indicative) and may not be complete or comprehensive. Mitigation measures are proposed to reduce associated risks.

Table 5.2 presents potential and identified man-made related hazards, obstructions and site constraints for a pipeline and other offshore infrastructures. The information provides screening-level hazard characterisation (i.e. indicative) and may not be complete or comprehensive. Mitigation measures are proposed to reduce associated risks.

Table 5.1: Summary of potential and identified geohazards and soil constraints across the AOI

Constraint / Geohazard	Location / Distribution	Impact on Structure	Possible Mitigation
(Migrating) bedforms	Entire AOI, except northern part (Zone 3)	• Exposure or burial of structure; leading to snagging from trawling or anchoring, scour affecting structure stability • Spanning leading to uneven support of structure, critical stresses on structure • Temperature variations may lead to expansion / contraction of pipeline (increased susceptibility to walking in areas of exposure)	• Detailed mapping of bedforms through MBES data acquisition along pipeline route and within specific areas (Landfall/Shore crossing, Offshore Distribution HUB Areas) • Sediment mobility assessment, morphodynamic assessment and specific site survey works in areas of high risk • Meteocean site-specific desktop study to precisely assess migration/stability of bedforms • Avoid where possible areas with sand waves • Trenching to a certain depth (depending on bedform amplitude)
Storm events / wave action	Entire AOI. Probably lower impact within the areas deeper than 30 m LAT (northern AOI)	• Dynamic and cyclic loading • Burial or exposure, leading to loss of support, instability and damage	• Meteocean site-specific desktop study • Scouring site-specific study • Trenching to a certain depth (depending on estimated wave action depth)
Steep slopes / irregular topography	Flanks of Maasmond Kanaal Steep slopes also associated with bedforms, seafloor objects and dredging areas	• Uneven support of structure • Critical stresses on structure • Non-uniform penetration	• Avoidance • Trenching within bedforms

Constraint / Geohazard	Location / Distribution	Impact on Structure	Possible Mitigation
		• Slope failure • Lateral displacement of structure • Trenching difficulties	
Slumping	Northern flank of Maasmond Kanaal	• Slope instability and failure • Critical stresses • Scour and spanning or burial and loading • Rupture or failure of pipeline	HDD solution
Very soft clays	In Maasmond Kanaal and locally across the entire AOI, especially in paleo-channels	• Potential plough sinkage • Non-uniform penetration	• Jetting to install pipeline in soft sediments • Geophysical survey data to perform precise mapping of paleo-channels using UHR seismic or SBP data
Interbedded sand and clay sediments	Offshore Distribution HUB Area	Punch-through risk for foundation	Geotechnical survey at Offshore Distribution HUB location to refine geotechnical unitisation and parameters
Very dense sand	Entire AOI	• Trenching difficulties • Early refusal/limited penetration with plough	Selection of tools for pipeline emplacement suitable to deal with geotechnical properties
Gravel, cobbles and / or boulders	Localised areas across the AOI, particularly close to shore in the Landfall/Shore Crossing Area (in rock dumps of the flood-defence structure) and in deposits of Drente Formation	• Obstruction, trenching difficulties, possible early refusal or damage to structure • Gravel layers may impact HDD operations	• Detailed mapping of seafloor sediments along pipeline routing and across Offshore Distribution HUB area (MBES, SSS) • Detailed mapping of boulders expected at depth in UHR seismic and SBP data • Avoid areas with boulders
Peat / organic material	Locally present across AOI	• High compressibility, non-uniform support • chemical reaction between soil and steel • shallow gas	Geophysical and geotechnical survey in order to map and avoid areas where peat is expected
Pockmarks / shallow gas (peat)	Locally present in the Landfall/Shore crossing Area. Can be locally present in the AOI	• Laterally variable soil strength, steel corrosion, spanning of pipeline • Masking of acoustic signal • Risk of blowout and gas release during drilling and piling operations	• Geophysical survey data to detect shallow gas accumulations within seismic data • Map related seafloor features (pockmarks) • Avoid areas with shallow gas or identified markers (pockmarks)

Constraint / Geohazard	Location / Distribution	Impact on Structure	Possible Mitigation
Glacial TILL / boulder clay	Present locally in NE of AOI (Gieten Member)	• Spatially variable soil conditions • Heterogenous soil • Cobbles and boulders leading to challenging installation conditions	• Geophysical survey data to perform precise mapping and identification of these type of deposits using UHR seismic or SBP data • Geotechnical data collection to characterise conditions • Selection of pipeline emplacement method that can cope with variable soil conditions
Glaciotectonic deformation features	Present locally in NE and centre of AOI, related to the Gieten Member and Drachten Formation	• Variable soil conditions • Lower lateral resistance	• Geophysical survey data to perform precise mapping and identification of these type of deposits using UHR seismic or SBP data • Geotechnical data collection to characterise conditions
Regional subsidence / (historic) oil and gas extraction	Entire AOI	• Time-dependent reduction of freeboard of pipeline • Damage to structure	Monitoring during ongoing pipeline inspection surveys

Table 5.2: Summary of identified man-made obstructions and constraints across the AOI

Constraint / hazard	Location / Distribution	Impact on Structure	Possible Mitigation
Existing and planned future structures	Across AOI	• Obstruction • Potentially disturbed ground • Potential interruption in hydraulic flow regime affecting scour and soil deposition processes	• Relocation • Design pipeline/cable crossing • Collection of specific geophysical survey data at crossing locations
Rock dump / fill	Shorelines in the Landfall/Shore crossing Area related to coastal defence structures	• Disturbed soil / variable soil conditions • Potential interruption in hydraulic flow regime affecting scour and soil deposition processes • Pipeline abrasion • Installation problems	• Identify and map • Avoidance and relocation
Artificial soil / contaminated soil	Landfall/Shore crossing Area and dumping areas	• Variable soil conditions • Contamination	Avoidance and relocation
Wellheads	Across AOI	• Obstruction • Potentially pressurised shallow gas in soil	Avoidance and relocation

Unexploded ordnance (UXO)	See Appendix C	• Obstruction • Damage to structures • Uneven seafloor, disturbed soil	• UXO precise identification along pipeline route via magnetometer survey • UXO hazard risk assessment • Relocation • UXO clearance processes
Shipwrecks / dropped objects	See Appendix B and Appendix C	Obstruction	• Archaeological study and identification along pipeline route • Relocation • Investigate and remove if required
Potential archaeological targets	See Appendix B	• No / limited access • Project delay	• Archaeological study and identification along pipeline route • Relocation • Investigate and remove if required
Restricted areas (nature reserve, military exercise)	Across AOI	No / limited access	• Relocation • Permission requirements
Dredging and dumping areas	Across AOI	• Uneven seafloor • Disturbed soil • Variable soil conditions • Lateral displacement • No / limited access	• Damage to structures • Relocation • Permission requirements
Fishing activity (anchor and / or trawl scars)	Throughout most of AOI	• Disturbed soil / variable soil conditions • Entanglement of fishing gear • Damage to structure and offshore equipment • Lateral displacement	• Clearance operations before any site surveys, fishing liaison officer during survey works • Trenching to avoid damage from anchors or trawls
High level of shipping activity and anchorage areas	• Near Rotterdam and IJmuiden harbours • Navigation Channels	• Entanglement of anchor(line) • Damage to structure • Lateral displacement	• Clearance operations before any site surveys • Trenching to avoid damage from anchors or trawls

Figure 5.1 displays the extent of some mapped and identified soil constraints and geohazards. These includes:

- Glacial TILL;
- Areas with expected boulders;
- Areas with very soft surficial sediments;
- Expected paleo-channels;
- Extent of unit ivb, composed of stiff to hard CLAY.

Bedforms are mapped and highlighted as part of Figure 4.17, while steep slopes are highlighted in Figure 4.8 to Figure 4.16.

Most of the identified man-made seafloor obstructions and constraints are listed and mapped within Sections 4.1 and 4.2.4 of the report. More details on UXO and archaeological related features are provided within specific reports (see Appendix B and Appendix C).

Soils containing the mineral glauconite and/or carbonate soils are not expected to be present in the AOI (including the Landfall/Shore crossing Area) within the depth of interest based on available data.

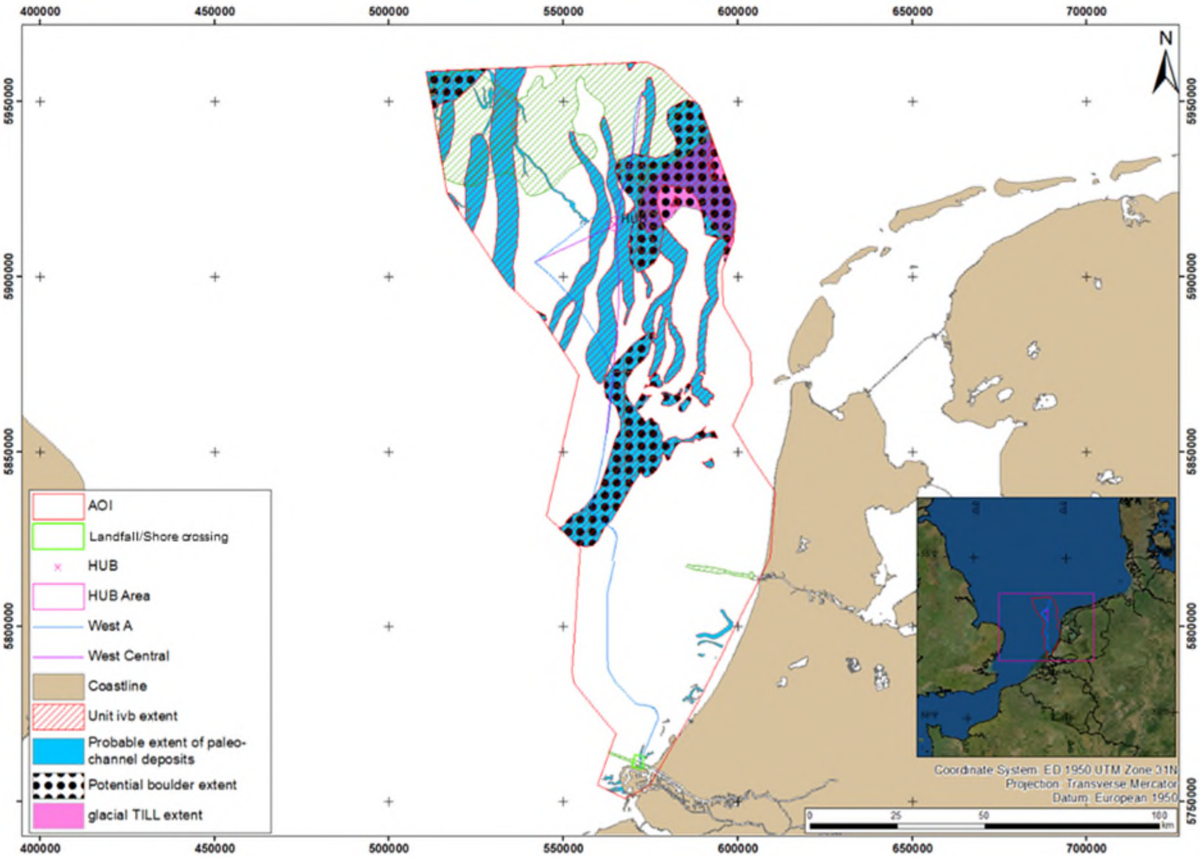

Figure 5.1: Map of identified soil constraints and potential geohazards across the AOI

5.2 Seismicity

Natural seismicity is mainly restricted to the southern (onshore) part of the Netherlands, where earthquakes with magnitudes of 2.5 to 6.0 are possible. The AOI lies within a tectonic region known as the West Netherlands Basin, which has been seismically quiet since the Neogene (Deltares, 2017).

The extraction of natural gas is known to produce induced seismicity. A total of 186 oil and gas fields are located in the AOI. Several induced seismic events related to these fields were recorded. These earthquakes had a magnitude between 2 and 4 (Deltares, 2017; Arcadis, 2018).

It is recommended that a probabilistic seismic hazard assessment is performed for the gas fields that are within a 5 km radius of the Landfall/Shore crossing Area and Offshore Distribution HUB Area to confirm the actual seismic hazard.

6. Conclusions and Recommendations

6.1 Conclusions

This desktop study aimed at characterising the soil conditions based on available public data and Fugro experience over an area of 11355 km² within the southern North Sea, Dutch sector. The ultimate purpose of the report is to provide information to help TotalEnergies in decision making regarding the ARAMIS Pipeline routing and provide recommendations regarding future site-specific surveys.

Based on available data, three preliminary geotechnical ground models focusing on three different areas are provided. These allow to picture the soil conditions and vertical and lateral variability to depth of interest. Geotechnical parameters were derived based on Fugro experience across the southern North Sea. The data review and analysis also allowed to list potential (geo)hazards, soil and anthropogenic constraints and man-made obstructions within the AOI.

The results provided within this desktop study are dependent on the available data and on data quality. Due to the large surface covered by the AOI, approximations and simplifications were made to create a comprehensive ground model allowing to capture the expected range of soil conditions. Variability within the defined soil units is expected, arising from varying depositional environments captured within independent units.

Site-specific data acquisition should be considered to refine and confirm the findings of the present study, once a more precise pipeline routing has been decided. Some recommendations are provided hereafter to help reducing uncertainties and mitigate identified (geo)hazards in the AOI.

6.2 Recommendations

Possible mitigation of identified or potential (geo)hazards and anthropogenic or soil constraints, including relocation of pipeline, engineering solutions or avoidance of certain features are already detailed in Table 5.1 and Table 5.2. These elements should help TotalEnergies in the decision making for the final pipeline route.

To better capture site conditions and soil variability along the future pipeline route and at specific areas (Offshore Distribution HUB and Landfall/Shore crossing Areas), several recommendations on further specific studies, geophysical and geotechnical site surveys are listed in this section. Most of these recommendations, in particular geophysical and geotechnical surveys will have to be considered once the pipeline route is decided.

6.2.1 Further Specific Studies

To better characterise some elements that are highlighted or identified within the present DTS, Fugro recommends performing specific studies including, but not limited to:

- Metocean site-specific desktop study to better understand mobility of bedforms and sediments due to currents, waves and tides;
- A sediment mobility assessment and study based on bathymetric data acquired at different dates across the area. This could be accompanied by specific site surveys in areas of identified high risks;
- UXO risk assessment study as defined in the conclusions of the UXO historical DTS (Appendix C) allowing to set fitting mitigation strategies.

6.2.2 Geophysical Site Surveys

Once the pipeline route corridor is agreed on, a number of geophysical methods should be considered to refine the mapping and identification of seafloor features and better define the variability of sub-seafloor soil units. They will in turn allow to better mitigate soil constraints and (geo)hazard-relatedrisks. Data acquired during these geophysical site surveys may include:

- MBES data to be acquired along the pipeline route with a typical corridor of 2 km allowing any re-routing if avoidance of any identified feature is required. MBES data will provide a high-resolution bathymetry along the route allowing to compute precise slope maps. Reflectivity may also be acquired during MBES operations giving a detailed representation of the seafloor rugosity. MBES should also be acquired around the planned Offshore Distribution HUB Area;
- SSS data to be acquired along the pipeline corridor with a typical corridor of 2 km and around the Offshore Distribution HUB location. SSS data helps identifying seafloor features and sediment types;
- SBP data to be acquired along the pipeline corridor. This will better characterise the sub-seafloor variability at the pipeline location, helping in the planning of the geotechnical site survey. At the Offshore Distribution HUB location and along the planned Landfall/Shore crossing Area, SBP grids should be acquired before any operations to identify potential sub-seafloor soil constraints and estimate soil variability. SBP can also provide valuable information when identifying preserved paleo-landscapes and potential prehistorical archaeological sites (Appendix B);
- UHR seismic data can be planned locally where specific designs are needed (such as HDD, piling at the Offshore Distribution HUB Area, trenching, tunnelling). UHR seismic data will provide a better penetration within deeper dense/hard units;
- A magnetometer survey must be performed along the entire pipeline corridor to identify any wrecks and UXOs at or close to the seafloor.

6.2.3 Geotechnical Site Surveys

Soil sampling and in situ testing (CPTs) are paramount to refine the geotechnical soil conditions and variability with depth. A geotechnical survey should be designed after geophysical data are acquired and interpreted to optimise the sampling and locations (both distribution and quantities). Where variable conditions or specific risks are identified, more locations may be required to better constrain them. Where more homogeneous conditions are expected, less locations could be planned. Geotechnical surveys should include:

- Sediment sampling to identify, log and test soil types. Sampling methods include gravity corers, box corers, grab samples and vibrocorers. A variety of laboratory testing can be considered, including geological testing (Multi-Sensor Core Logging, mineralogy, or dating) or geotechnical testing (water content, P-wave velocity, electrical resistivity, thermal conductivity, shear vane and oedometer tests). Specific geotechnical testing could be considered in order to measure the clay sensitivity;
- CPT allows to capture the site-specific soil conditions through a variety of measurements such as cone resistance and sleeve friction. It allows to identify soil units at depth and measure in situ mechanical properties such as sediment undrained shear strength (s_u) for clay or relative density for sand.

Along the pipeline route the depth of geotechnical locations can be limited to the first 5 m to 6 m BSF, while geotechnical locations within the Landfall/Shore crossing Area and at the Offshore Distribution HUB location should have greater penetration depths. For these deeper locations Fugro recommends downhole sampling and testing from a dedicated drilling platform (e.g. geotechnical drilling vessel or jack-up platform).

7. References

Arcadis (2018). *Geological Desk Study, Hollandse Kust (west) Wind Farm Zone* (Document No. WOZ2180087, dated 6 June 2018 to RVO). Arcadis Germany GmbH.

Ashley, G. M. (1990). Classification of large-scale subaqueous bedforms; a new look at an old problem. *Journal of Sedimentary Research, 60*(1), 160–172. https://doi.org/10.2110/jsr.60.160

Bosch, J.H.A., Weerts, H.J.T. & Busschers, F.S. (2003). Formatie van Urk. In *Lithostratigrafische Nomenclator van de Ondiepe Ondergrond*. Retrieved 18 October 2016 from https://www.dinoloket.nl/formatie-van-urk

Calvete, D., Walgreen, M., De Swart, H. E., & Falqués, A. (2001). A model for sand ridges on the shelf: Effect of tidal and steady currents. *Journal of Geophysical Research: Oceans*, *106*(C5), 9311–9325. https://doi.org/10.1029/2001JC900001

Cameron, T.D.J., Laban, C. & Schüttenhelm, R.T.E. (1984). *Flemish Bight, Sheet 52˚N–02˚E, Quaternary Geology (1:250.000 Series).* British Geological Survey & Rijks Geologische Dienst.

Cameron, T.D.J., Laban, C., Mesdag, C.S. & Schüttenhelm, R.T.E. (1986). *Indefatigable, Sheet 53˚N–02˚E, Quaternary Geology (1:250.000 Series).* British Geological & Survey Rijks Geologische Dienst.

Deltares (2016). *Morphodynamics of Hollandse Kust (zuid) Wind Farm Zone* (Document No. CR-SC-DNVGL-SE-0190-02453-2_Morphodynamics, issue 2, dated 24 December 2016 to RVO).

Deltares (2017). *Geological Study Hollandse Kust (noord) Wind Farm Zone* (Document No. 11200513-002-BGS-0001, issue 2, dated 23 March 2017 to RVO).

Deltares (2019). *Morphodynamics and Scour Mitigations for Hollandse Kust (noord) Wind Farm Zone* (Document No. 11202796-000-HYE-0002, issue 1, dated 15 March 2019 to RVO).

Deltares (2020). *Morphodynamics of Hollandse Kust (west) Wind Farm Zone* (Document No. 11204811-002-HYE-0001, issue 1, dated 6 July 2020 to RVO).

DINOloket, Data and Information of the Dutch Subsurface. (offshore dataset received on 29 December 2021). TNO, Geological Survey of the Netherlands. https://www.dinoloket.nl/en

Dorst, L. L., Roos, P. C., Hulscher, S. J., & Lindenbergh, R. C. (2009). The estimation of sea floor dynamics from bathymetric surveys of a sand wave area. *De Gruyter, 3*(2), 97–120. https://doi.org/10.1515/JAG.2009.011

Dyer, K. R., & Huntley, D. A. (1999). The origin, classification and modelling of sand banks and ridges. *Continental Shelf Research*, *19*(10), 1285–1330. https://doi.org/10.1016/S0278-4343(99)00028-X

Ehlers, J. (1990). Reconstructing the dynamics of the north-west European Pleistocene ice sheets. *Quaternary Science Reviews, 9*(1), 71–83. https://doi.org/10.1016/0277-3791(90)90005-U

Folk, R. L. (1954). The distinction between grain size and mineral composition in sedimentary-rock nomenclature. *The Journal of Geology*, 62(4), 344-359. https://doi.org/10.1086/626171

Fugro (2018). *Geophysical Site Investigation Survey, Dutch Continental Shelf, North Sea, Hollandse Kust (noord) Wind Farm Zone Survey 2017* (Document No. GH216-R3, issue 3, dated 18 May 2018 to RVO).

Fugro (2019a). *Geological Ground Model, Hollandse Kust (noord) Wind Farm Zone, Dutch Sector, North Sea* (Document No. P903749(03), issue 5, dated 1 May 2019 to RVO).

Fugro (2019b). *Geophysical Results Report, Hollandse Kust (west) Wind Farm Zone Survey 2018, Dutch Continental Shelf, North Sea* (Document No. P904162(03), issue 4, dated 19 August 2019 to RVO).

Fugro (2019c). *Project Porthos Maasgeul Crossing Dutch Sector North Sea* Investigation Results Geotecnics (Document No. P905721/01, issue 2, dated 4 September 2019 to Port of Rotterdam).

Fugro (2020). Geological Ground Model, Hollandse Kust (west) Wind Farm Zone, Dutch Sector, North Sea (Document No. P904711(06), issue 3, dated 12 May 2020 to RVO).

Funnell, B.M. (1996). Plio-Pleistocene palaeogeography of the southern North Sea basin (3.75–0.60 Ma). *Quaternary Science Reviews, 15*(5–6), 391–405. https://doi.org/10.1016/0277-3791(96)00022-4

De Gans, W. 2007. Quaternary. In Wong, T.E., Batjes, D.A.J. & De Jager, J. (Eds.) *Geology of the Netherlands* (pp. 173–195). Royal Netherlands Academy of Arts and Sciences.

GDN (2018). *Geological Overview Map of the Kingdom of the Netherlands 1:600,000 (centennial edition)*, Utrecht: TNO–Geological Survey of the Netherlands, 1 map sheet.

Geluk, M. C (2005). *Stratigraphy and tectonics of Permo–Triassic basins in the Netherlands and surrounding areas*. [PhD Thesis, Utrecht University].

Graham, A. G., Stoker, M. S., Lonergan, L., Bradwell, T., & Stewart, M. A. (2011). The Pleistocene glaciations of the North Sea basin. In Ehlers J., Gibbard, P.L. & Hughes, P.D. (Eds.) *Developments in Quaternary Sciences* (Vol. 15, pp. 261–278). Elsevier. https://doi.org/10.1016/B978-0-444-53447-7.00021-0

Hulscher, S. J., de Swart, H. E., & de Vriend, H. J. (1993). The generation of offshore tidal sand banks and sand waves. *Continental Shelf Research*, *13*(11), 1183–1204. https://doi.org/10.1016/0278-4343(93)90048-3

Jacobs, P. & De Batist, N. (1996). Sequence stratigraphy and architecture on a ramp-type continental shelf: the Belgian Palaeogene. In De Batist, N. & Jacobs, P. (Eds.) *Geology of Siliciclastic Shelf Seas* (pp. 23–48). Geological Society Special Publications, 117. https://doi.org/10.1144/GSL.SP.1996.117.01.03

Joon, B., Laban, C. & Van der Meer, J.J.M. (1990). The Saalian Glaciation in the Dutch part of the North Sea. *Geologie en Mijnbouw, 69*(2), 151–158.

Knaapen, M. A. F., & Hulscher, S. J. (2002). Regeneration of sand waves after dredging. *Coastal Engineering*, *46*(4), 277–289. https://doi.org/10.1016/S0378-3839(02)00090-X

Knox, R.W.O'B., Bosch, J.H.A., Rasmussen, E.S., Heilmann-Clausen, C., Hiss, M., De Lugt, I.R., Kasińksi, J., King, C., Köthe, A., Słodkowska, B., Standke, G. & Vandenberghe, N. (2010). Cenozoic. In Doornenbal, J.C. & Stevenson, A.G. (Eds.) *Petroleum geological atlas of the Southern Permian Basin area* (pp. 211–223). EAGE Publications B.V., Houten.

Kuhlmann, G. & Wong, T.E. (2008). Pliocene paleoenvironment evolution as interpreted from 3D-seismic data in the southern North Sea, Dutch offshore sector. *Marine and Petroleum Geology, 25*(2), 173–189. https://doi.org/10.1016/j.marpetgeo.2007.05.009

Laban, C., Schüttenhelm, R.T.E., Balson, P.S., Baeteman, C. & Paepe, R. (1992). *Ostend, Sheet 51˚N–02˚E, Quaternary Geology (1:250.000 Series).* British Geological & Survey Rijks Geologische Dienst & Belgische Geologische Dienst.

Laban, C. (1995). *The Pleistocene glaciations in the Dutch sector of the North Sea: a synthesis of sedimentary and seismic data*. [PhD Thesis, University of Amsterdam].

Laban, C. & Rijsdijk, K.F. (2002). De Rijn–Maasdelta's in de Noordzee. *Grondboor & Hamer 56*(3/4), 60–65.

Laban, C., & van der Meer, J. J. (2011). Pleistocene glaciation in the Netherlands. In Ehlers J., Gibbard, P.L. & Hughes, P.D. (Eds.) *Developments in Quaternary Sciences* (Vol. 15, pp. 247–260). Elsevier. https://doi.org/10.1016/B978-0-444-53447-7.00020-9

Liu, A. C., De Batist, M., Henriet, J. P., & Missiaen, T. (1993). Plio–Pleistocene scour hollows in the Southern Bight of the North Sea. *Geologie en Mijnbouw, 71*(3), 195–204.

McCave, I. N. (1971). Sand waves in the North Sea off the coast of Holland. *Marine geology, 10*(3), 199–225. https://doi.org/10.1016/0025-3227(71)90063-6

Moreau, J., Huuse, M., Janszen, A., van der Vegt, P., Gibbard, P. L., & Moscariello, A. (2012). The glaciogenic unconformity of the southern North Sea. *Geological Society, London, Special Publications, 368*(1), 99–110. https://doi.org/10.1144/SP368.5

NITG–TNO (2004d). *Top Pleistocene Formations*. Scale 1:750.000.

NITG–TNO (2004b). *Distribution of Holocene Formations at Seafloor*. Scale 1:750.000.

Overeem, I., Weltje, G.J., Bishop-Kay, C. & Kroonenberg, S.B. (2001). The Late Cenozoic Eridanos delta system in the southern North Sea basin: a climate signal in sediment supply? *Basin Research,13*(3), 293–312. https://doi.org/10.1046/j.1365-2117.2001.00151.x

Overeem, I. (2002). *Process–response simulation of fluvio–deltaic stratigraphy*. [PhD Thesis, Delft University of Technology, Department of Applied Earth Sciences].

Peeters, J., Busschers, F.S. & Stouthamer, E. (2015). Fluvial evolution of the Rhine during the last interglacial–glacial cycle in southern North Sea basin: a review and look forward. *Quaternary International, 357*, 176–188. https://doi.org/10.1016/j.quaint.2014.03.024

Praeg, D. (1996). *Morphology, stratigraphy and genesis of buried Mid-Pleistocene tunnel-valleys in the southern North Sea basin*. [PhD Thesis, University of Edinburgh]. http://hdl.handle.net/1842/15659

Rasmussen, E.S. & Dybkjær, K. (2014). Patterns of Cenozoic sediment flux from western Scandinavia: discussion. *Basin Research, 26*(2), 338–346. https://doi.org/10.1111/bre.12024

Rijsdijk, K.F., Passchier, S., Weerts, H.J.T., Laban, C., Van Leeuwen, R.J.W. & Ebbing, J.H.J. (2005). Revised Upper Cenozoic stratigraphy of the Dutch sector of the North Sea basin: towards an integrated lithostratigraphic, seismostratigraphic and allostratigraphic approach. *Netherlands Journal of Geosciences, 84*(2), 129–146. https://doi.org/10.1017/S0016774600023015

Stouthamer, E., Cohen, K., & Hoek, W. (2015). De vorming van het land. *Geologie en geomorfologie*. Perspectief Uitgevers, ISBN 978 94 91269 11 0.

Thöle, H., Gaedicke, C., Kuhlmann, G. & Reinhardt, L. (2014). Late Cenozoic sedimentary evolution of the German North Sea – a seismic stratigraphic approach. *Newsletters on Stratigraphy, 47*, 299–329. https://doi.org/10.1127/0078-0421/2014/0049

TNO-GDN (2022). Upper North Sea Group. In: *Stratigraphic Nomenclature of the Netherlands*, TNO – Geological Survey of the Netherlands. Accessed during December 2021 and January 2022 from https://www.dinoloket.nl/en/stratigraphic-nomenclature.

Van der Meulen, M.J., van Gessel, S.F., Tiemersma, J.J. & van Dijk, T.A. (2004). Grind en stenen voor de kust van Texel en de winbare voorraad suppletiezand (Document No. NITG 04-236-B1299). TNO–NITG.

Van Dijk, T. A., & Kleinhans, M. G. (2005). Processes controlling the dynamics of compound sand waves in the North Sea, Netherlands. *Journal of Geophysical Research: Earth Surface, 110*(F4). https://doi.org/10.1029/2004JF000173

Van Dijk, T. A., van Dalfsen, J. A., Van Lancker, V., van Overmeeren, R. A., van Heteren, S., & Doornenbal, P. J. (2012). Benthic habitat variations over tidal ridges, North Sea, the Netherlands. In *Seafloor geomorphology as benthic habitat* (pp. 241–249). Elsevier. https://doi.org/10.1016/B978-0-12-385140-6.00013-X

Van Heteren, S (2010). *Analyses of seabed and soil quality required for wind farms*. Final report We@Sea Project 2005-005, dated April 2010.

Van Santen, R. B., De Swart, H. E., & van Dijk, T. A. G. P. (2011). Sensitivity of tidal sand wavelength to environmental parameters: A combined data analysis and modelling approach. *Continental Shelf Research*, *31*(9), 966–978. https://doi.org/10.1016/j.csr.2011.03.003

Wong, T.E., Batjes, D.A. & de Jager, J. (2007). *Geology of the Netherlands*. Royal Netherlands Academy of Arts and Sciences, Amsterdam.

Appendix A

Guidelines on Use of Report

A.1 Guidelines on Use of Report

This report (the “Report”) was prepared as part of the services (the “Services”) provided by Fugro France SAS (“Fugro”) for its client (the “Client”) under the terms of the relevant contract between the two parties (the “Contract”). The Services were performed by Fugro based on requirements of the Client set out in the Contract or otherwise made known by the Client to Fugro at the time. Fugro’s obligations and liabilities to the Client or any other party in respect of the Services and this Report are limited in time and value as defined in Contract (or in the absence of any express provision in the Contract as implied by the law of the Contract) and Fugro provides no other representation or warranty whether express or implied, in relation to the Services or for the use of this Report for any other purpose. Furthermore, Fugro has no obligation to update or revise this Report based on changes in conditions or information which emerge following issue of this Report unless expressly required by the Contract.
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Appendix B

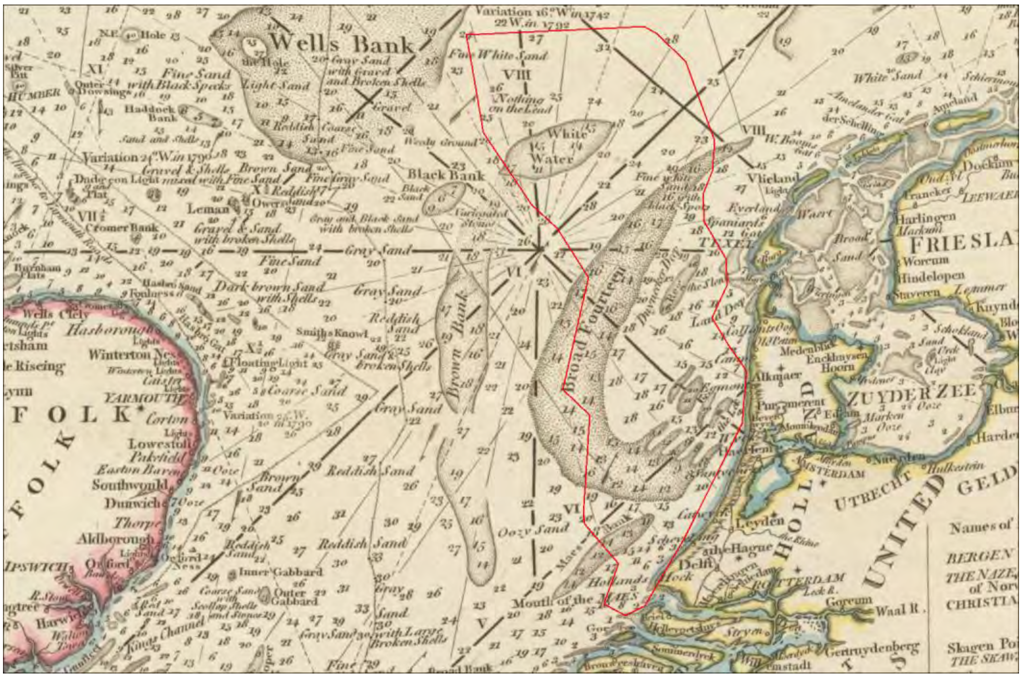
Archaeological Desktop Study

Periplus Archeomare

Archaeological Desk Study

Area of interests

Aramis pipelines



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Contents

Table 1. Dutch archaeological periods

Period	Time in Years				
Post-medieval / Modern Times	1500	A.D.	-	Present	
Late medieval period	1050	A.D.	-	1500	A.D.
Early medieval period	450	A.D.	-	1050	A.D.
Roman Times	12	B.C.	-	450	A.D.
Iron Age	800	B.C.	-	12	B.C.
Bronze Age	2000	B.C.	-	800	B.C.
Neolithic (New Stone Age)	5300	B.C.	-	2000	B.C.
Mesolithic (Stone Age)	8800	B.C.	-	4900	B.C.
Palaeolithic (Early Stone Age)	300.000	B.C.	-	8800	B.C.

Table 2. Administrative details

Location:	North Sea		
Toponym:	Aramis pipelines		
Chart:	1801-01		
Coordinates Geodetic datum: ED50 Projection: UTM31N	Centre:	E 560722	N 5856233
	NW	E 510577	N 5961562
	NE	E 610866	N 5961562
	SW	E 510577	N 5750904
	SE	E 610866	N 5750904
Depth (LAT):	0 to 46.1 meter, average 26.7 meter		
Surface investigation area	11,355 km^2		
Environment:	Tidal currents, salt water		
Area use:	Shipping , fishing, wind farm zones		
Area administrator:	Rijkswaterstaat Zee en Delta Municipality of Rotterdam		
ARCHIS number:	5144645100		
Periplus-project reference:	21A036-01		
Period of execution	January 2022		

Samenvatting (in Dutch)

Periplus Archeomare heeft in opdracht van Fugro een archeologisch bureauonderzoek uitgevoerd naar het plangebied voor de Aramis-leidingroutes. Het gebied van 11.355 km2 ligt in de Noordzee, voor de kust van Nederland.

Door de aanleg van de leidingen kunnen eventueel aanwezige archeologische resten in het gebied worden bedreigd. Volgens de Erfgoedwet (2016) is een wettelijke verplichting om archeologisch onderzoek te doen om archeologische resten te beschermen. Dit archeologische bureauonderzoek is de eerste stap in het archeologisch proces om vast te stellen of archeologische resten aanwezig zijn en of deze resten kunnen worden aangetast door de aanleg van de geplande pijpleidingen. De resultaten zijn hieronder samengevat.

Het gebied heeft hoge verwachtingen voor de aanwezigheid van (overblijfselen van) scheepswrakken en vliegtuigwrakken uit de Tweede Wereldoorlog. Intacte prehistorische landschappen en verwante in situ overblijfselen van paleolithische en vroeg-mesolithische campings en opgravingen kunnen op bepaalde plaatsen bewaard zijn gebleven. De voorlopige pijpleidingroutes zijn nog niet onderzocht door gedetailleerde geofysische onderzoeken. Deze gebieden bevatten mogelijk meer onontdekte scheepswrakken of overblijfselen van scheepswrakken dan nu bekend is.

Op dit moment is er nog weinig bekend over de integriteit van het Pleistoceen landschap. Door middel van seismiek kunnen hierin de voorkomende geologische eenheden (zowel horizontaal als verticaal) en archeologische niveaus in kaart worden gebracht. Het karakter van laaggrenzen (erosief of niet-erosief) kan worden geïnterpreteerd. Het is echter onwaarschijnlijk dat archeologische overblijfselen van paleolithische en mesolithische nederzettingsresten op basis van geofysisch en geotechnisch onderzoek met voldoende zekerheid kunnen worden geïdentificeerd om beperkingen op te leggen aan de aanleg van pijpleidingen. In dit stadium moet daarom niet worden geconcentreerd op het opsporen van prehistorische nederzettingsresten, maar op een pragmatische inzet geofysische technieken inzetten om een beter inzicht te krijgen in (de integriteit van) het Pleistoceen landschap. De verkregen inzichten zullen worden gebruikt om a) het archeologische verwachtingsmodel te verfijnen en b) gebieden met een hoge verwachting voor in situ prehistorische overblijfselen toe te wijzen.

Conform de AMZ-cyclus wordt geadviseerd om een inventariserend veldonderzoek uit te voeren om de archeologische verwachting. In het algemeen bestaan vergelijkbare onderzoeken uit een geofysisch onderzoek met side scan sonar, magnetometer en subbottom profiler en een geotechnisch onderzoek. De resulterende gegevens moeten worden geanalyseerd nadat de algemene verwerking, interpretatie en rapportage door de onderzoeksaannemer is uitgevoerd.

De archeologische beoordeling van de gegevens dient te worden uitgevoerd door een geofysisch specialist (KNA prospector Waterbodems). De datakwaliteit van de onderzoeken moet aansluiten bij de eisen voor deze archeologische beoordeling. Om de afstemming tussen het geofysisch onderzoek en de vereiste kwaliteit voor deze beoordeling te waarborgen, dient een Programma van Eisen opgesteld te worden conform de KNA (Kwaliteitsnorm Nederlandse Archeologie 4.1) dat door de bevoegde autoriteit wordt beoordeeld en goedgekeurd.

Summary

Periplus Archeomare was assigned by Fugro to conduct an archaeological desk study of the area of interest for the Aramis pipeline routes. The area of interest of 11.355 km^2 is located in the North Sea, off the coast of the Netherlands.

The installation of the pipelines may affect archaeological remains in the area, if present. According to the Law on Archaeological Heritage (Dutch: Erfgoedwet 2016) there is a statutory obligation to conduct archaeological research in order to protect the remains. This archaeological desk study is the first step in the archaeological process aiming to establish whether archaeological remains are, or are likely to be, present, and whether these remains could be effected by the development of the planned pipelines. The results are summarized below.

The area of interest has a high expectation for the presence of (remains of) ship wrecks and WWII plane wrecks. Intact prehistoric landscapes and related *in situ* remains of Palaeolithic and Early Mesolithic camp sites and inhumations are expected to have been preserved in places.

The proposed pipeline routes have not been investigated by detailed geophysical surveys yet. These areas may contain more undiscovered shipwrecks or remains of shipwrecks than currently known.

At this stage little is known about the integrity of the *Pleistocene* landscape. By means of subbottom profiling the occurrence geological units (both horizontal as vertical) and archaeological levels herein can be mapped. The character of layer boundaries (erosive or non-erosive) can be interpreted. It is unlikely however that archaeological remains of Palaeolithic and Mesolithic camp sites can be identified with sufficient certainty (based on the geophysical and geotechnical surveys) to impose restrictions on pipeline development. At this stage focus should therefore not be put on tracing prehistoric camp sites but on a pragmatic employment of geophysical techniques in order to obtain a better insight in (the integrity of) the *Pleistocene* landscape. The insights gained shall be used to a) refine the archaeological expectancy model and b) allocate areas with a high expectancy for *in situ* prehistoric remains.

In accordance with the AMZ cycle it is advised to conduct a field investigation (in Dutch '*Inventariserend veldonderzoek opwaterfase*') in order to test the archaeological predictive model and further specify the type, vertical and lateral extent, age, integrity and preservation of ship wrecks, prehistoric landscapes and potential archaeological levels.

Archaeological Expectancy	**Method**		**Goal**	**Remarks**
Ship and aircraft wrecks	Geophysical	Side Scan Sonar	detect and map wreck sites	wrecks exposed at, or protruding from the seabed
		Multibeam	characterize wreck sites morphologically; detect (partially) buried wrecks by the occurrence of scours	in addition to side scan sonar
		Sub-bottom Profiler	detect buried objects including possible ship wrecks and remains of aircraft	nature of the buried object cannot be determined directly
		Magnetometer		
Prehistoric settlements		Sub-bottom Profiler	map the Pleistocene landscape; specify expectancy	supported by, and validated with drill data

Archaeological Expectancy	Method		Goal	Remarks
(camp sites)	Geotechnical	Geological Sampling	determine lithostratigraphy, soil layer boundaries (erosive or gradual) and characteristics of soil formation and maturation; specify expectancy	designation of borehole and/or vibrocore locations for geo-archaeological research based on SBP data
		Cone Penetration Test	determine lithostratigraphy	correlate with drilling data

In general, similar investigations carried out in the past consist of a geophysical survey with *side scan sonar*, *magnetometer* and *subbottom profiler* and a geotechnical survey. The resulting data should be assessed after the general processing, interpretation and reporting has been performed by the survey contractor.

The archaeological assessment of the data shall to be conducted by a geophysical specialist (KNA prospector Waterbodems). The data quality from the surveys needs to match the demands for this archaeological assessment. To ensure compatibility between the site investigation and the required quality for this assessment it is recommended to define a Program of Requirements (In Dutch: 'Programma van Eisen') in accordance with the 'KNA' (the Dutch quality standards for archaeological research), to be authorized by the competent authority.

1 Introduction

Periplus Archeomare was assigned by Fugro to conduct an archaeological desk study of the area of interest for the proposed Aramis pipeline routes. The area of interest of 11.355 km^2 is located in the North Sea off the coast of the Netherlands.

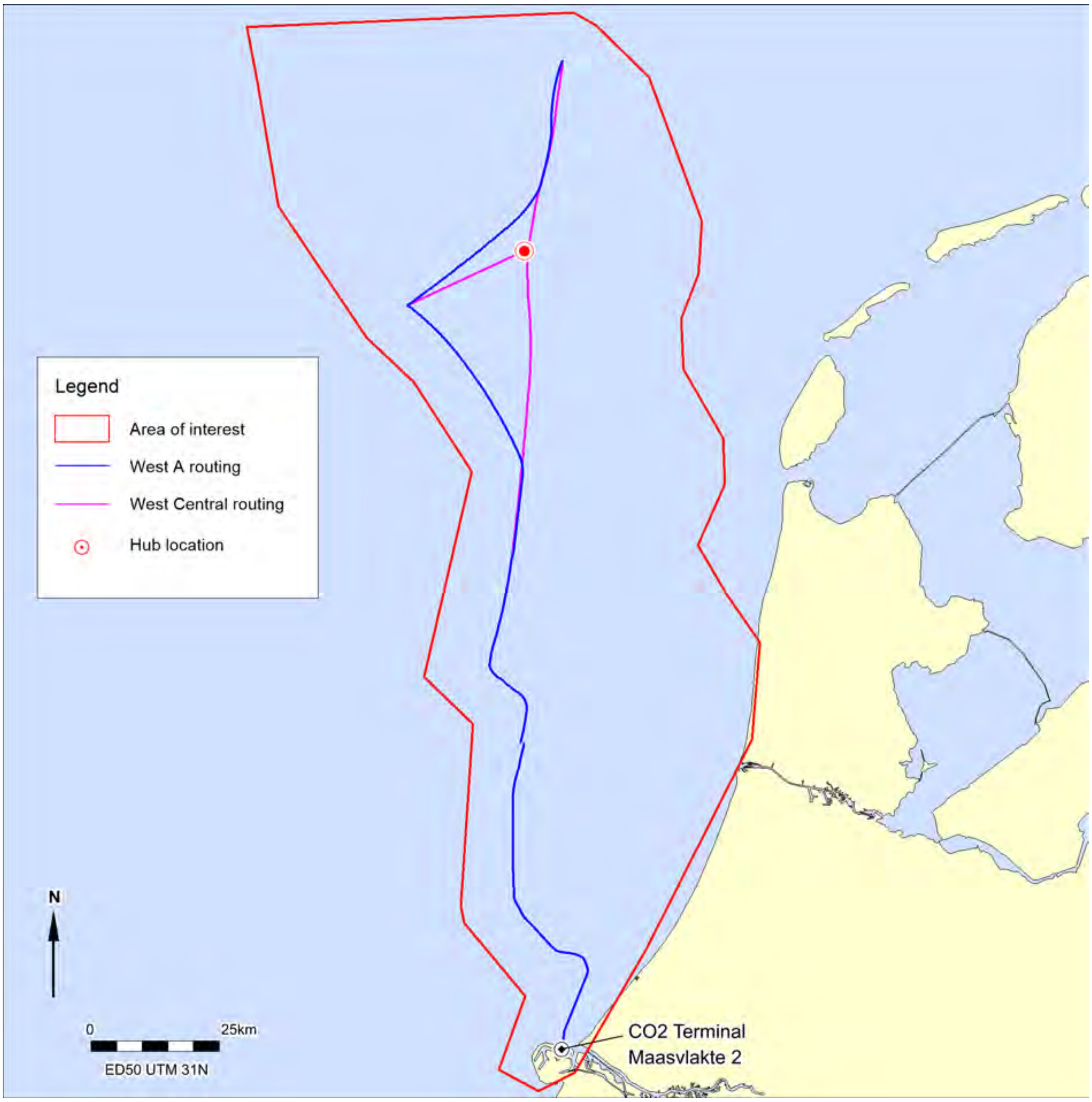

Figure 1. Location map of the area of interest

The desk study and reporting were carried out in accordance with the Dutch Quality Standard for archaeological research[1].

[1] Kwaliteitsnorm Nederlandse Archeologie (KNA waterbodems 4.1).

1.1 Background

TotalEnergies plans to build a new pipeline from Maasvlakte 2 to offshore blocks L4/K6 as part of the CCS Aramis project. The area to be investigated encompasses:

(1) the shore approach/Landfall pipeline routing for HDD and dredging part at Maasvlakte
(2) the offshore rigid pipeline routing from Maasvlakte to blocks L4/K6
(3) the offshore distribution hub.

As a preparation phase of the future surveys to be performed, TotalEnergies intends to conduct desktop studies of the area of interest. The final routing and the location of the distribution hub are not defined yet.

In the Law on Archaeological Heritage (Erfgoedwet 2016), emerged from the Malta Convention (1992), incorporated in the Monuments Act through the Archaeological Heritage Act, the protection of the archaeological heritage is regulated. Planned activities, such as the installation of pipelines in the North Sea, may affect the archaeological values if present. If effects on possible remains are expected, there is a statutory obligation to conduct archaeological research. This process is also outlined in the Water Decree (Dutch: Waterbesluit).

This archaeological desk study for the proposed Aramis pipeline is the first step in the archaeological process as part of the so-called *AMZ* cycle.

1.2 Objective

The purpose of an archaeological desk study in general is to specify the archaeological expectancy for a certain area. More in detail, the purpose of this desk study is to establish whether archaeological remains are, or are likely to be, present along the pipeline route, and whether these (possible) remains could be affected by the installation of the pipeline. Where possible, the desk study aims to give insight into the (possible) archaeological value of these remains in terms of their physical or scientific value, such as the overall quality of preservation and the rarity of the remains. Furthermore, this report aims to make recommendations regarding subsequent steps in dealing with known and expected archaeological remains along the pipeline route.

The archaeological management procedure ('AMZ-cycle') is a defined sequence of steps and decisions within archaeological heritage management in the Netherlands. The procedure is embedded in the Dutch Quality Standard for Archaeology (KNA Waterbodems 4.1) as the mandatory workflow for archaeologists. A detailed description of the different phases of archaeological research is included in appendix 1.

1.3 Research questions

For an archaeological desk study, the following research questions are applicable:

- Are there any known archaeological values present within the area of interest? If so, what is the nature, extent (depth) location and dating of these sites?
- Are there, in addition to any known values, archaeological remains to be expected? If so, what are the nature, extent (depth) location and date of the expected archaeological remains?
- Can the proposed activities affect known or expected archaeological values? If so, can an impact on archaeological assets be prevented or restricted by planning adaptation?
- If the archaeological values cannot be saved: What kind of further research is needed to determine the presence of archaeological values and their size, location, type and date to be determined enough to come to a selection decision?
- What are the possible effects of the installation of the pipeline on the areas with specific archaeological interest?
- What are the possibilities to mitigate the disturbance of areas with specific archaeological interests?
- Should further investigations be carried out from archaeological point of view and what are the recommendations on the scope and specifications of these investigations?

If, on the basis of this desk study, a connection can be made with other questions from the *NoaA* 2.0, then these must be answered. Given the nature of the research and the often limited possibilities for the identification of archaeological object, it is not possible to select all the questions in advance. As far as the possible find categories are concerned, there are also various ongoing research programs at universities, with which a relationship can be established.

1.4 Research and management framework

Our knowledge of the development of *Pleistocene* and Early *Holocene* landscapes and the plants, animals and humans who lived in the North Sea area is limited. This gap in geo-archaeological knowledge was recognized by the Dutch Cultural Heritage Agency (Rijksdienst voor het Cultureel Erfgoed). To provide tools to fill this gap the ‘North Sea Prehistory Research and management Framework (NSPRMF)’ was published, in which the foundation was laid for future research and management of the prehistoric heritage. The themes and topics of the NSPRMF are listed in table 3.

Theme	Topics
A. Stratigraphic and chronological frameworks	A.1: Lithostratigraphic classification and chronological anchoring A.2: Sea level change and glacio-isostacy A.3: Survival of deposits of archaeological significance A.4: Biostratigraphies and absolute dating
B. Palaeogeography and environment	B.1: Middle/Late Pleistocene reshaping of topography and river drainage B.2: Development of the Weichselian/Devensian landscape B.3: Palaeogeographic evolution after the Last Glacial Maximum (LGM) B.4: Quaternary palaeoecology
C. Global perspectives on intercontinental hominin dispersals	C.1: North Sea coastal dynamics and human uses of the coastal zone C.2: Pleistocene North Sea level oscillations and population of islands
D. Pleistocene hominin colonisations of northern Europe	D.1: Early human exploitation strategies in changing environments D.2: Natural barriers for hominin expansion
E. Reoccupation of northern Europe after the Last Glacial Maximum (LGM)	E.1: Post-LGM occupation flux E.2: Occupation strategies
F. Post-glacial land use dynamics in the context of a changing landscape	F.1: Changing landscape structure F.2: Behavioural diversity among hunter-gatherers F.3: Maritime archaeologies of the North Sea
G. Representation of prehistoric hunter-gatherer communities and lifeways	G.1: Spatial perspectives on North Sea palaeolandscapes G.2: The distributional nature of early hominin communities G.3: Enculturated hunter-gatherer landscapes

* Despite the fact that theme G primarily focusses on post-LGM hunter-gatherers, topic G.2 was broadly defined, and of equal relevance to theme D.

Table 3. NSPRMF - research themes and topics (Peeters 2009)

In 2019 the NSPRMF agenda was retuned based on the developments in the previous decade. This report contains the basis for policy in the years to come. The archaeological studies currently conducted in the context of wind farm development, pipeline and cable installation, sand extraction and exploration for oil and gas in the North Sea area, are conducted in accordance to the AMZ-cycle. These studies shall contribute to the goals set in the NSPRMF.

As described above little is known about the early *Holocene* inhabitants of the North Sea region, their settlements and the way in which they maintained themselves in the rapidly changing landscape. The information value of the expected settlements is therefore large. This is also stated in the National Research Agenda for Early Prehistory: *Locations and any surrounding phenomena that are located in paleo-landscape contexts that have not or have hardly been investigated have by definition a large information value.* For future investigations, reference shall therefor be made to the framework and the research questions in the *NOaA* in addition to the NSPRMF.

2 Methodology

The desk study was conducted in accordance with the Dutch Quality Standard for Archaeology (KNA Waterbodems 4.1, Protocol 4002). This concerns in particular the specifications LS01, LS02, LS03, LS04 and LS05. The study is reported in accordance with specification LS06.

In order to comply with the main objectives and answer the research questions, the archaeological desk study is carried out according to the scope of Work as described in the following steps:

- Description of the Area of Interest and determination of the consequences for future use (LS01);
- Description of the current usage of the area of Interest (LS02);
- Description of the historical situation and possible disturbances (LS03);
- Description of the geological setting within which the archaeological objects are to be found (LS04);
- Description of the known archaeological features and objects (LS04);
- Definition of a specified archaeological expectation (LS05).

Based on these components a specified archaeological expectation is defined. It is expressed whether, and if so, which archaeological values can be expected. The properties of these values will be indicated in as much detail as possible. The results of the study are summarized in chapter 3. Based on the results the research questions are answered in chapter 4. The study concludes with a summary and recommendation in chapter 5.

The research and reporting were conducted by S. van den Brenk (senior marine archaeologist) and R. van Lil (senior marine prospector). The results were approved and authorized by B. van Mierlo (Senior marine prospector).

2.1 Sources

The following sources were consulted for the study:

- Archis III, archaeological database of the Dutch Cultural Heritage Agency
- Databases of Periplus Archeomare
- Dutch Federation for Aviation Archaeology (NFLA)
- Geological maps
- Geological publications
- Scope of Work NL DTS Aramis (Memo TotalEnergies)
- National Contact Number (NCN) database Rijkswaterstaat
- Rijkswaterstaat Zee en Delta
- The Hydrographic Service of the Royal Netherlands Navy
- *TNO-NITG*; geological borehole data and maps
- Various results from previous investigations in the area of interest
- Various sources from the Internet

For a complete overview of the sources and literature see references on page 51. Words in *italics* and abbreviations are explained in the glossary on page 50.

3 Results

3.1 Definition of the area of interest and consequences of future use (LS01)

The area of interest is located off the west coast of the Netherlands and stretches from Maasvlakte 2 to mining block L4, 75 km northwest of the island of Texel.

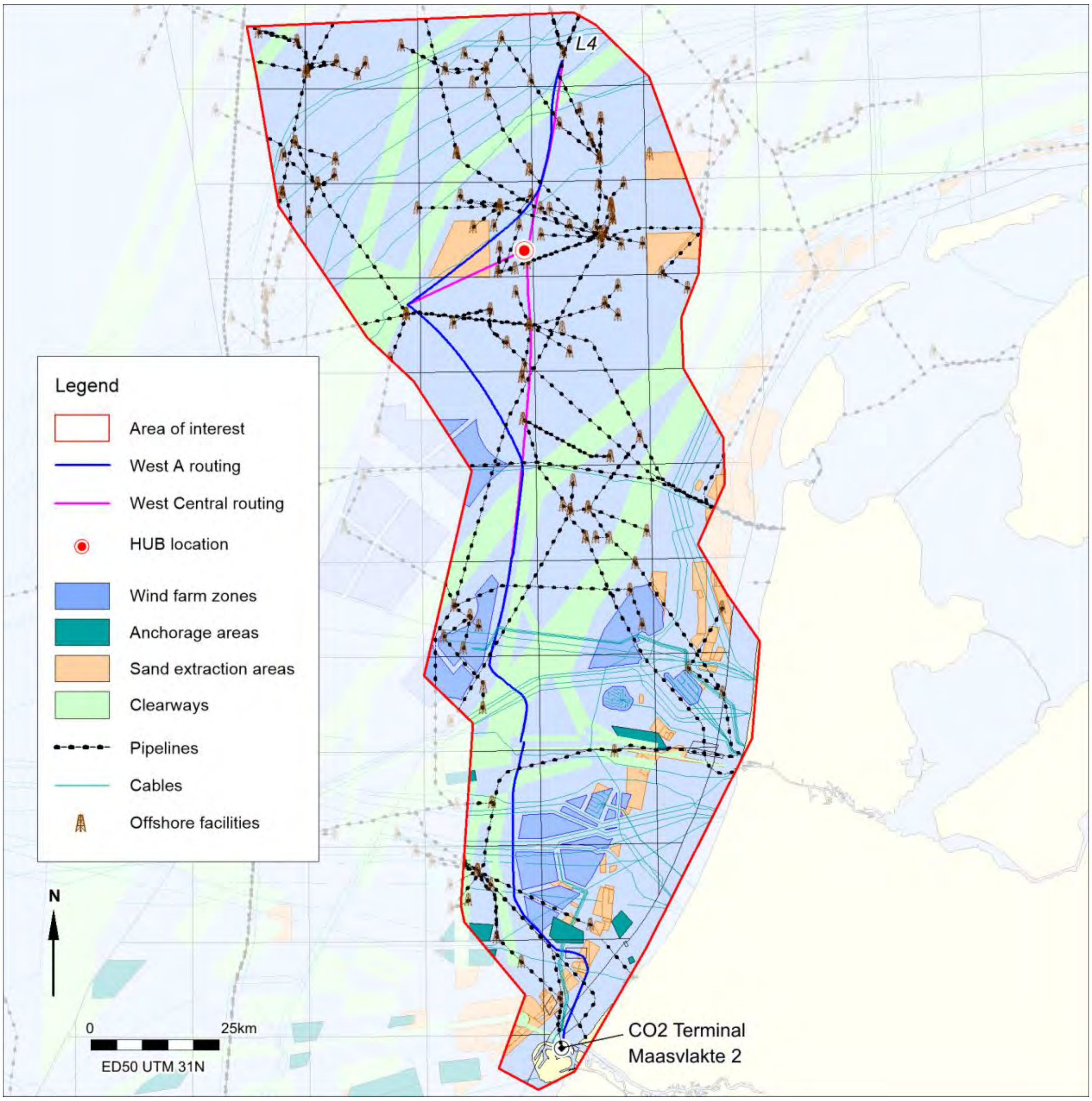

Figure 2. Overview of the area of interest in relation to other areas of use

The trenching of the pipelines has a direct impact on the seafloor, which might have an effect on the possible presence of cultural heritage. In the longer term, exposed pipelines can cause a change in seafloor morphology due to change of tidal currents. This may cause, in turn buried ship wrecks to emerge at the surface, exposing them to erosion.

Previous research

Parts of the area of interest have been investigated in the past for archaeological purposes:

- Several offshore drill locations
- Wind farm zones Hollandse Kust North, South and West
- Cable and pipeline corridors

The outlines of the investigated areas are shown in the figure below.

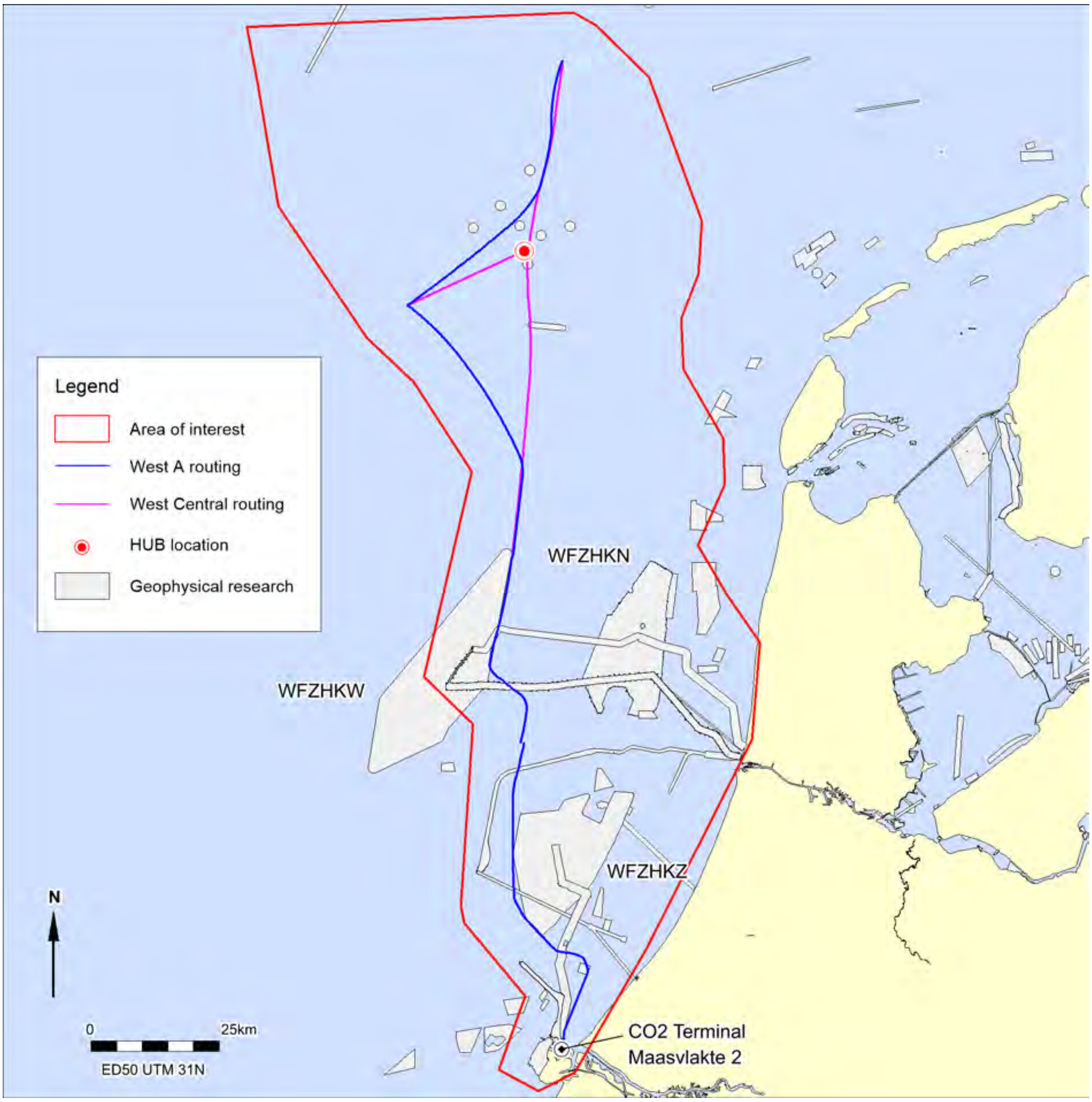

Figure 3 Previous conducted archaeological investigations in the area

The results of these investigations have been incorporated in paragraph 3.5, description of known archaeological values.

3.2 Description of the current situation (LS02)

The figure below shows a colour depth map based on composite data from the Hydrographic Service (25m grid, 2009) and data from various wind farm zones (5m, 2026-2020).

The water depth within the area of interest varies from 0 to 46.1 meter (LAT), with an average of 26.7 meter (LAT).

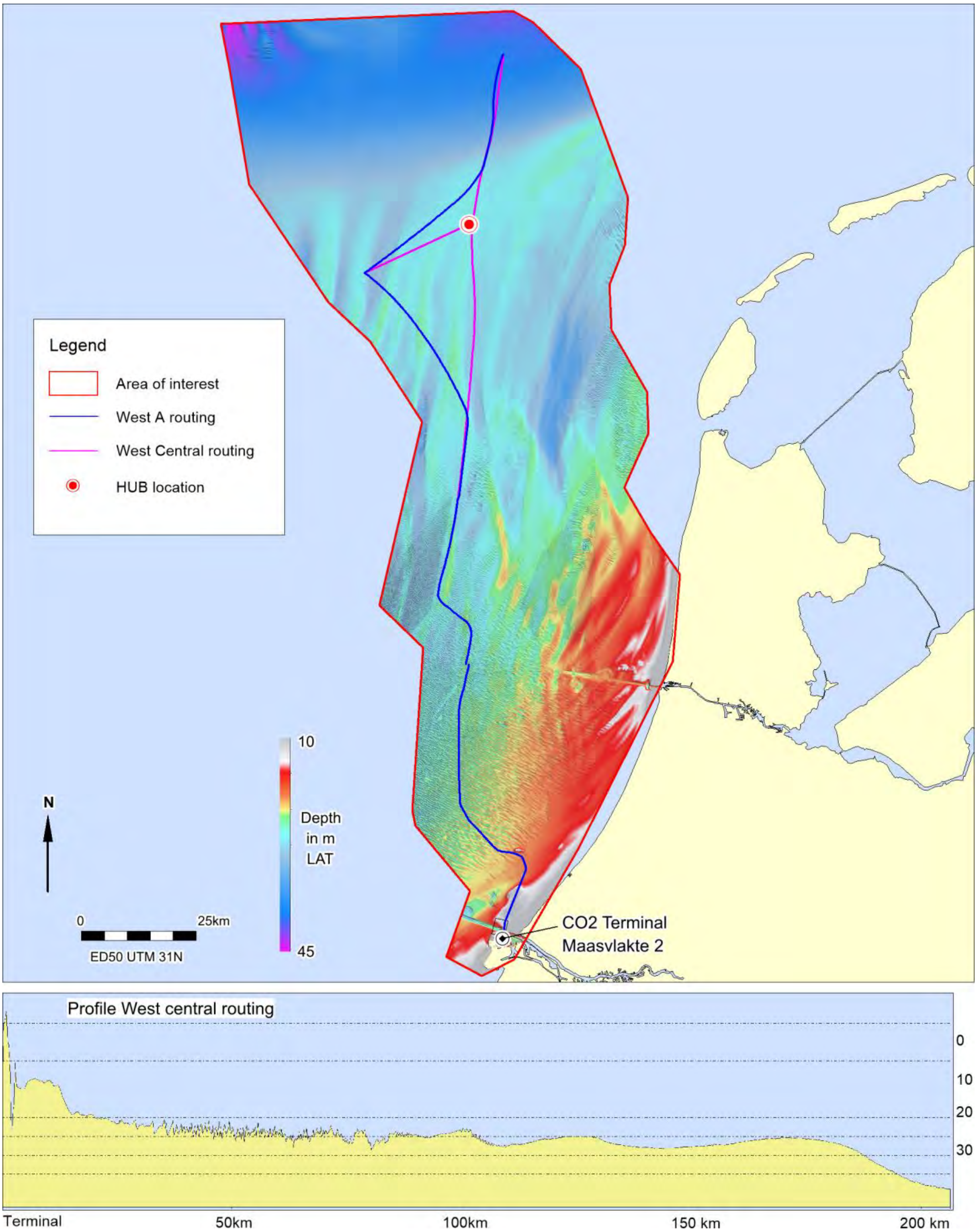

Figure 4. General bathymetry of the seabed and profile along the West central routing

The seabed is characterized by three types of morphological structures. The largest structures are north-south orientated ridges. The ridges vary in width from 1km to 4km and are generally up to 10m in height.
Superposed on the ridges sand waves have developed. The occurrence of sand waves is confined to the southwestern and central part of the area. The sand waves are up to 4m in height; the average distance between the crests is 300m. The crest heights tend to diminish towards the north. The sand wave crest orientation changes from west-east to northwest-southeast at the intersections with the large north-south orientated ridges.

Mega-current ripples which developed on top of the sand waves cannot be distinguished due to the grid-scale available (25m), but are nonetheless expected to be present. The ripple height is often less than a few dm; the distance between the current ripple crests is up to 10m.

The large ridges, sand dunes and current ripples have formed in the top layer of mobile sand. The ripples migrate along with tidal currents; the sand dunes typically migrate with a speed of 1 to 10 m/year. The migration rate of sand dunes in the Princes Amalia Wind Farm Zone was assessed to be in the order of 4 m/year[2].

[2] Laban 2004.

Landfall area

An overview of the recent bathymetry in the landfall area is constructed based on composite data from various surveys (Hydrographic service, Rijkswaterstaat and Tennet, with permission).

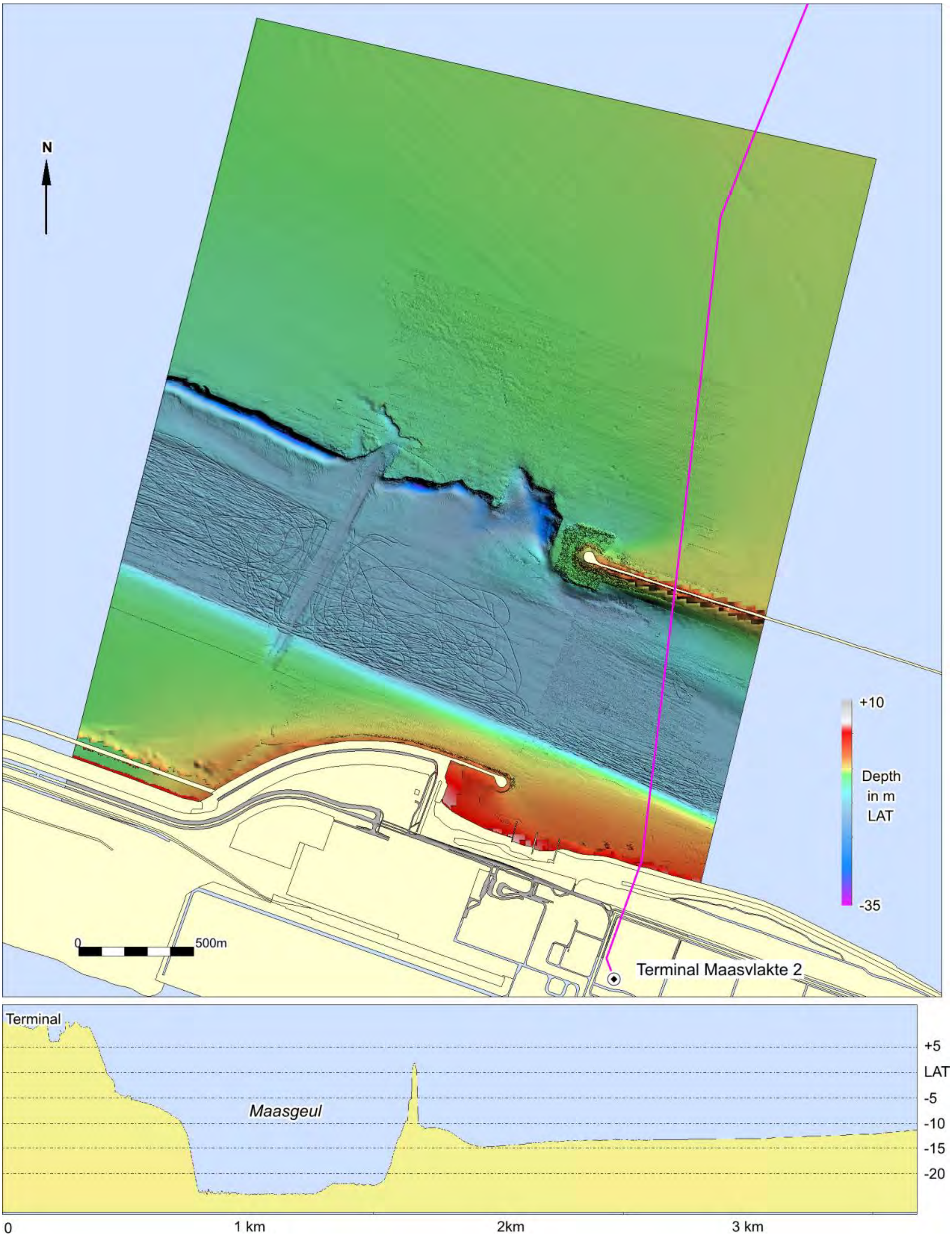

Figure 5. Bathymetry of the seabed in the landfall area

Seabed morphology

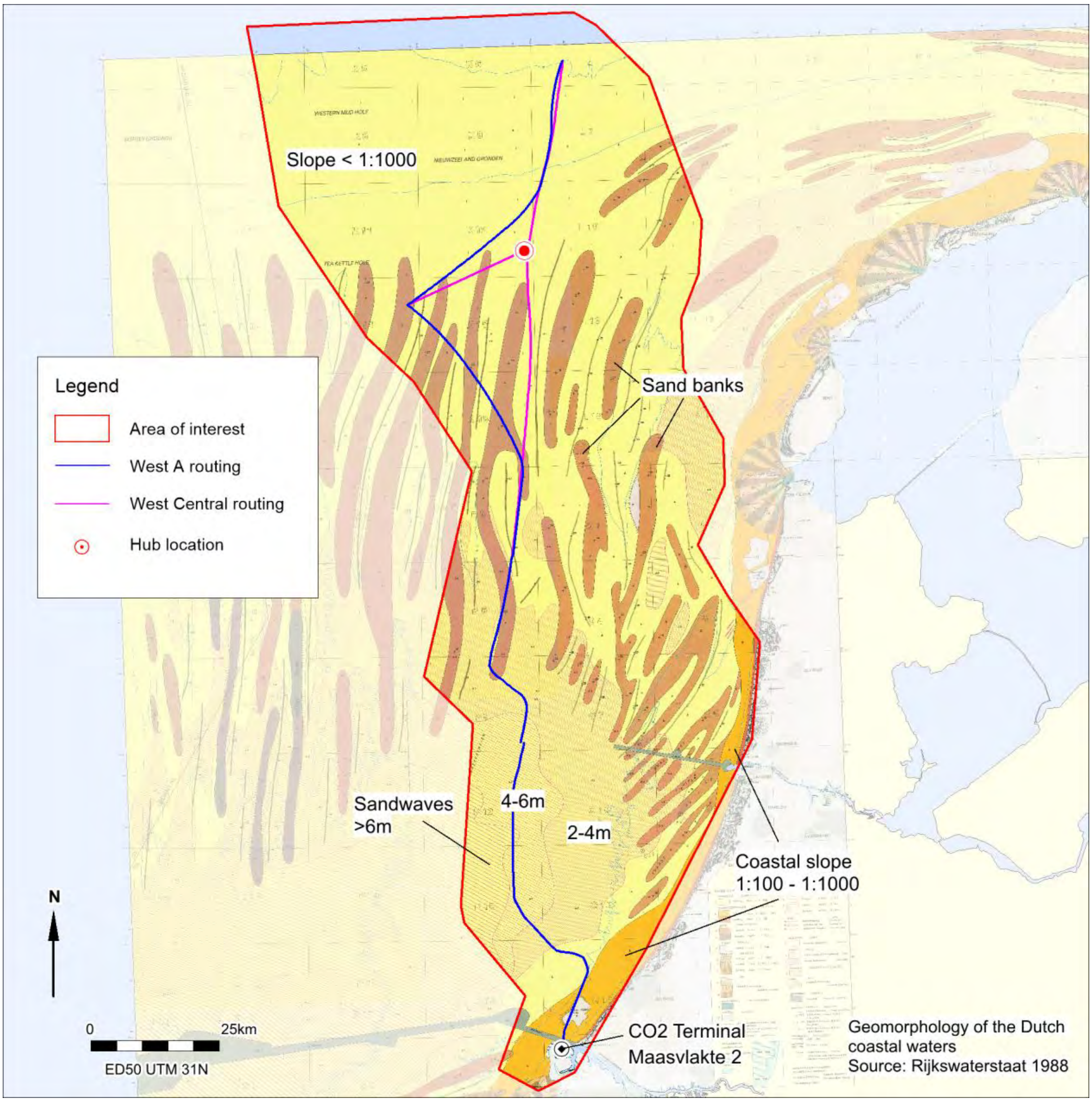

Figure 6. Geomorphology of the seabed

The southern part of the area of interest is dominated by sand waves with a northwest-southeast orientation and a height of 4 to 6 meters. The central area is dominated by large north-south oriented sand banks, superimposed by sand waves. The northern part is predominantly flat and featureless.

3.3 Historical situation and possible disturbances (LS03)

The North Sea basin formed about 12000 years ago as an extensive aeolian sand landscape with a tundra climate. At the end of the last Ice Age (ca 11500 years ago), the temperature rose as a result, the northern glaciers melted. The sea level rose and the North Sea basin was gradually filled. The filling of the North sea plains did occur over a period of 3500-5000 years. During this time the landscape changed, from freezing tundra to woodland where birch dominated the region, with some alder, hazel, juniper, and pine[3]. During this time, the North sea rose more rapidly than it does today, therefore, the residents of the area had to leave eventually for higher ground.[4]

Figure 7. Reconstruction of the historical coast lines in the North Sea basin (map by: McNulty, W.E. and J.N. Cookson in National Geographic Magazine)

The Dogger Bank in the North of the Dutch Continental Shelf is an example of an elevated area. Remnants of the tundra landscape and its inhabitants are regularly found in the nets of fishermen. However, all over the North Sea, remnants are found of hominin occupation of the region. For example, the only known Neanderthal from the Netherlands was found in the North sea. Moreover, multiple Palaeolithic and Mesolithic artefacts and even human remains have been found within the remains of the North Sea[12]. A number of artefacts have been found within the area of interest [5]. By 6000 years ago, the North sea plains were fully submerged, and the North sea looked very much as it does today.

[3] Van de Noort, 2011

[4] Gaffney e.a. 2005.

[5] Louwe Kooijmans 1970.

Due to the sea level rise the ancient landscapes drowned. These landscapes are depicted through geophysical and geotechnical engineering. Recently, for example, on the basis of seismic data from the oil industry a prehistoric landscape was reconstructed near the east coast of England[6]. Authors concluded that a large part of the Southern North Sea contains an in-situ prehistoric landscape.

Figure 8 shows the remains of mammal bones, among which many remains of mammoths which have been found in the nets of fishermen in the North Sea area. Among the finds is a well-preserved prehistoric human skull. Possibly the skull has been found near the Brown Bank area, but unfortunately the location of these finds is not known [7].

The finds are done by different fishermen, but given to fisherman Kommer Tanis who preserves and collects the finds. Tanis reports important finds, such as the human skull shown in figure 8 to scientists. In close cooperation with the scientists he makes the finds available for further analysis, such as DNA research.

Figure 8. Human skull found in the nets of fishermen in 'North sea/Doggerland' in November 2019

[6] Project 'North sea paleo-landscapes' of the University of Birmingham

[7] Pers. Comm. Fisherman and collector Kommer Tanis.

Figure 9. Prehistoric artefacts collected by fishermen and found at the beach (after Kooijmans 1970 en Armkreutz 2018).

Shipping

The earliest evidence of shipping in the North Sea dates from the Neolithic. For example, evidence of this can be found in prehistoric Rhineland burials. In this region the access of tin was limited and was therefore considered a luxury good. It had to be imported from other regions. One of such regions is South-West Britain[8]. It can be seen the other way around as well, Alpine jade axe heads have been sporadically found across the British Isles. Since this age, there is an increase of shipping in the North Sea with a few well-documented historical peaks. During Roman times, the North Sea and in particular the Channel served as connecting bridge for the empire. From the Early and High Middle Ages new centres of power arose along the North Sea coast. Furthermore, the raids of the Vikings should also be mentioned in this context. From the late Middle Ages, the international trade and the shipbuilding industry developed so that the North Sea was a stepping stone for global shipping routes. In all periods, ships were lost at sea. Ship wrecks are

[8] Van de Noort 2011.

the traces of the maritime past and this can be preserved under favourable storage conditions in sediment. Obviously, the possible existing wreck sites only occupy a very small area of the total area of interest.

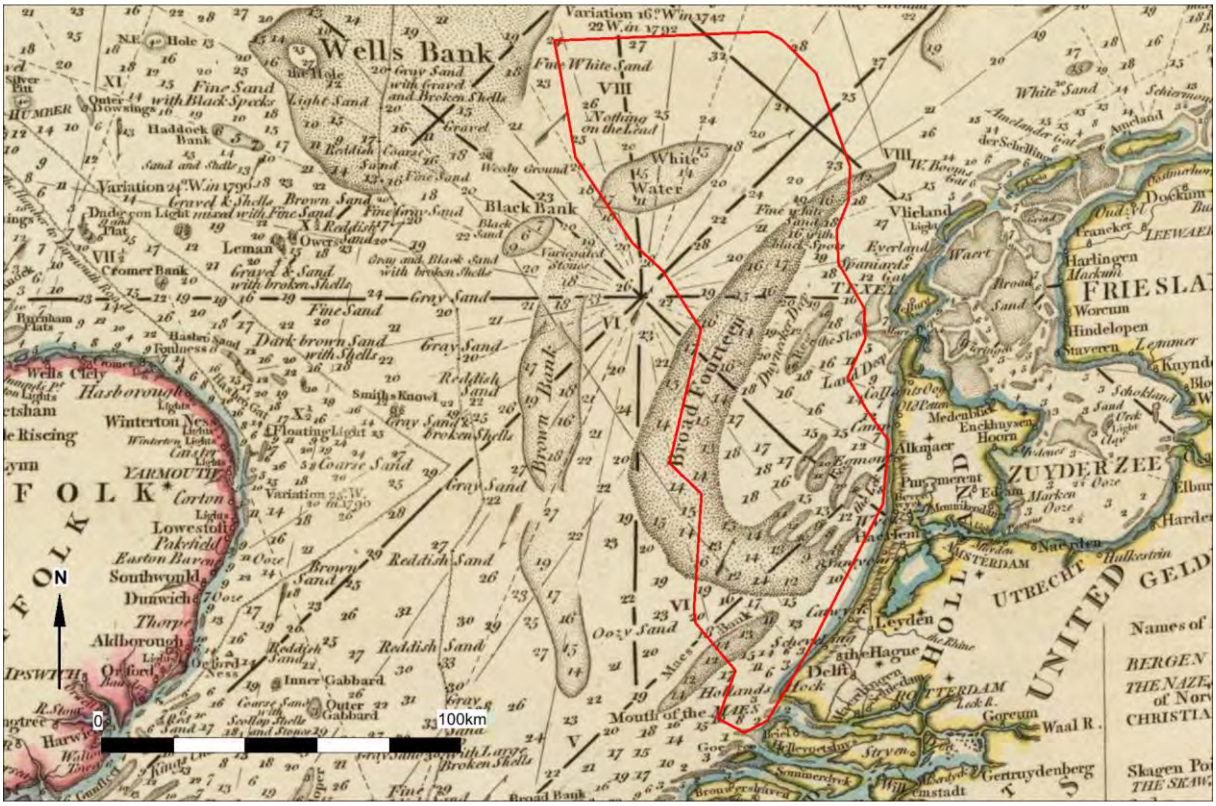

Figure 10. The area of interest on the historical map of 1777 (Faden)

Known disturbances of the seabed

In the past, parts of the seabed within the area of interest have been disturbed by trenches for cables and pipelines. The initial depth of burial of the cables is unknown, but should be a minimum of 1 meter according to the environmental permits. It is however expected that the cables are laid at a depth of 2 meters up to a maximum of 5 meters below the seabed. This also applies to the pipelines in the area.

Within the area of interest, more than 100 areas are known where sand is extracted, generally to a depth of 2 meters in relation to the seabed.

In general, large parts of the seabed have been disturbed by trawl nets of fishermen.

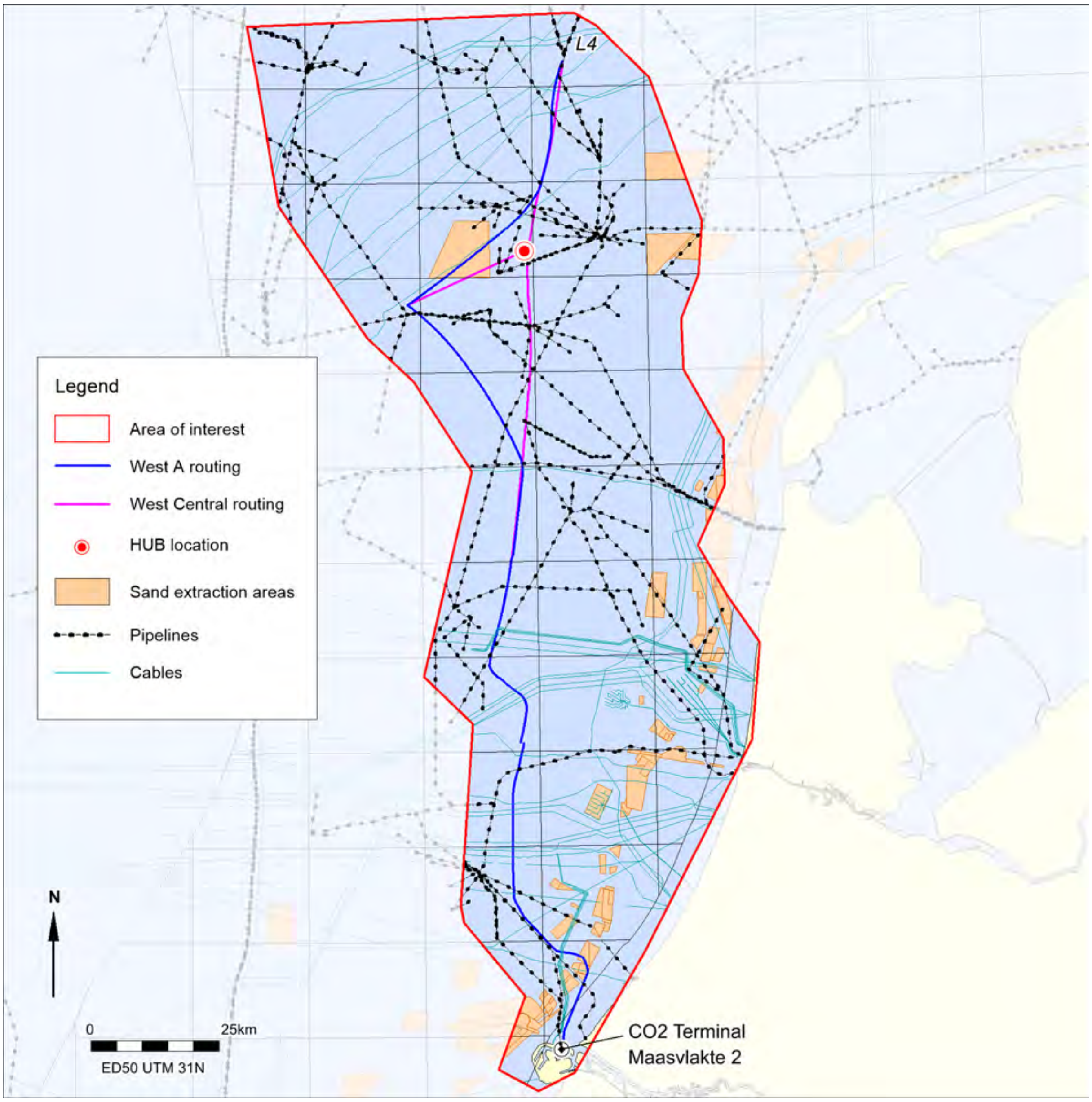

Figure 11. Pipelines, cables and sand extraction areas in the area

Locations and status of cables, pipeline and sand extraction areas are based on the database of Rijkswaterstaat (November 2021). This may differ from the as-built data from the operators.

3.4 Geological setting within which the archaeological objects are to be found (LS04)

The archaeological prospect for (pre)historic settlements is strongly related to the geogenesis of the plan area. The geogenesis is reflected by the lithostratigraphic units present, the character of layer boundaries (erosive vs non-erosive) and indications for the development of soils within the sediments in prehistoric times. Therefore geophysical and geological data are an important source to answer questions with respect to the nature, age, depth and location of occurrence, integrity and preservation of the archaeological remains which are to be expected within the area of interest.

Seabed sediments

The seabed sediments in the area of interest consist mainly of sand, with patches of gravelly sand in the southern and central area. In the northern part the sediments become finer (muddy sand).

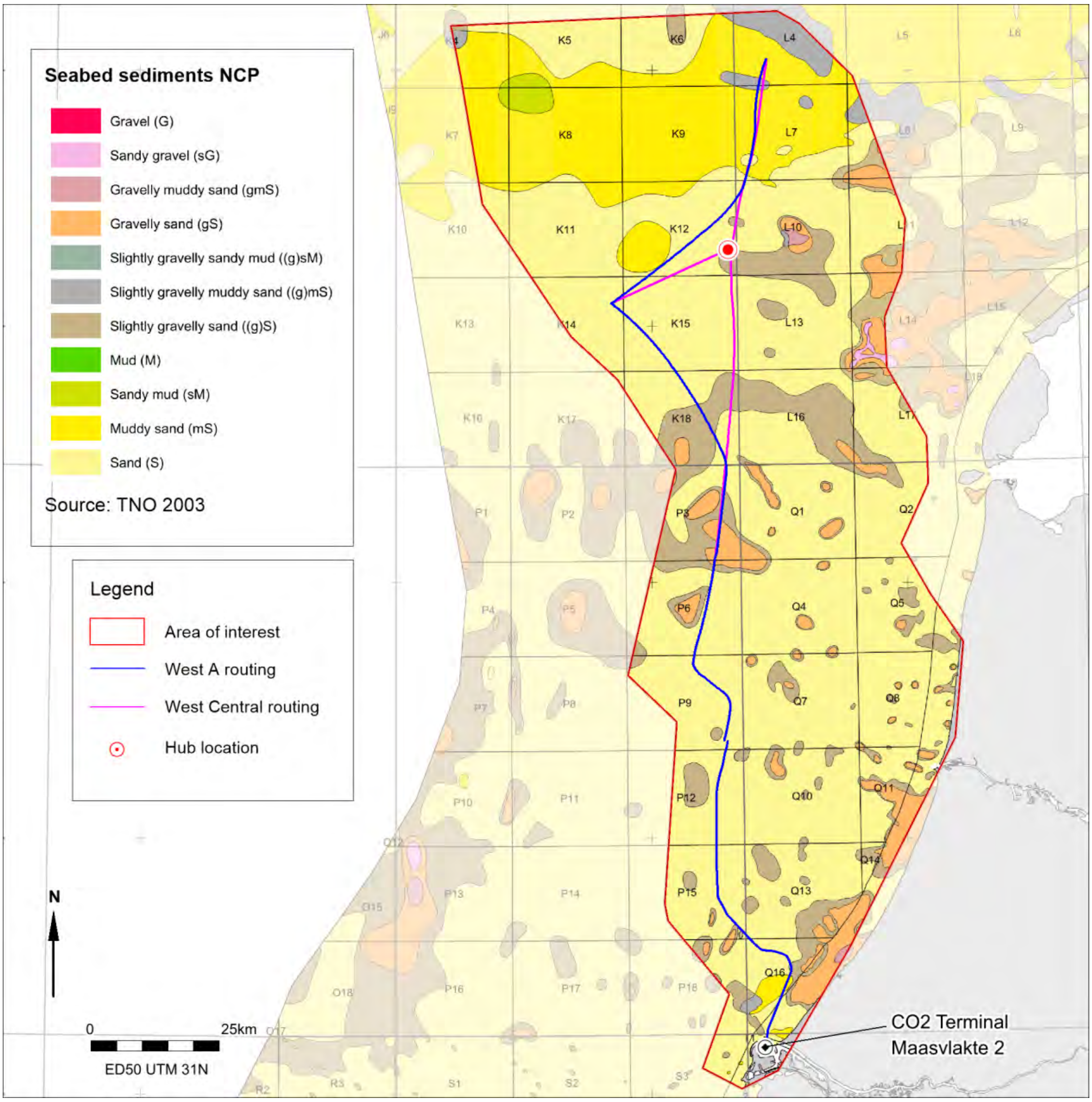

Figure 12. Seabed Sediments (Laban 2003)

Pleistocene Units

Figure 13 shows the different subcropping *Pleistocene* units in the area of interest[9].

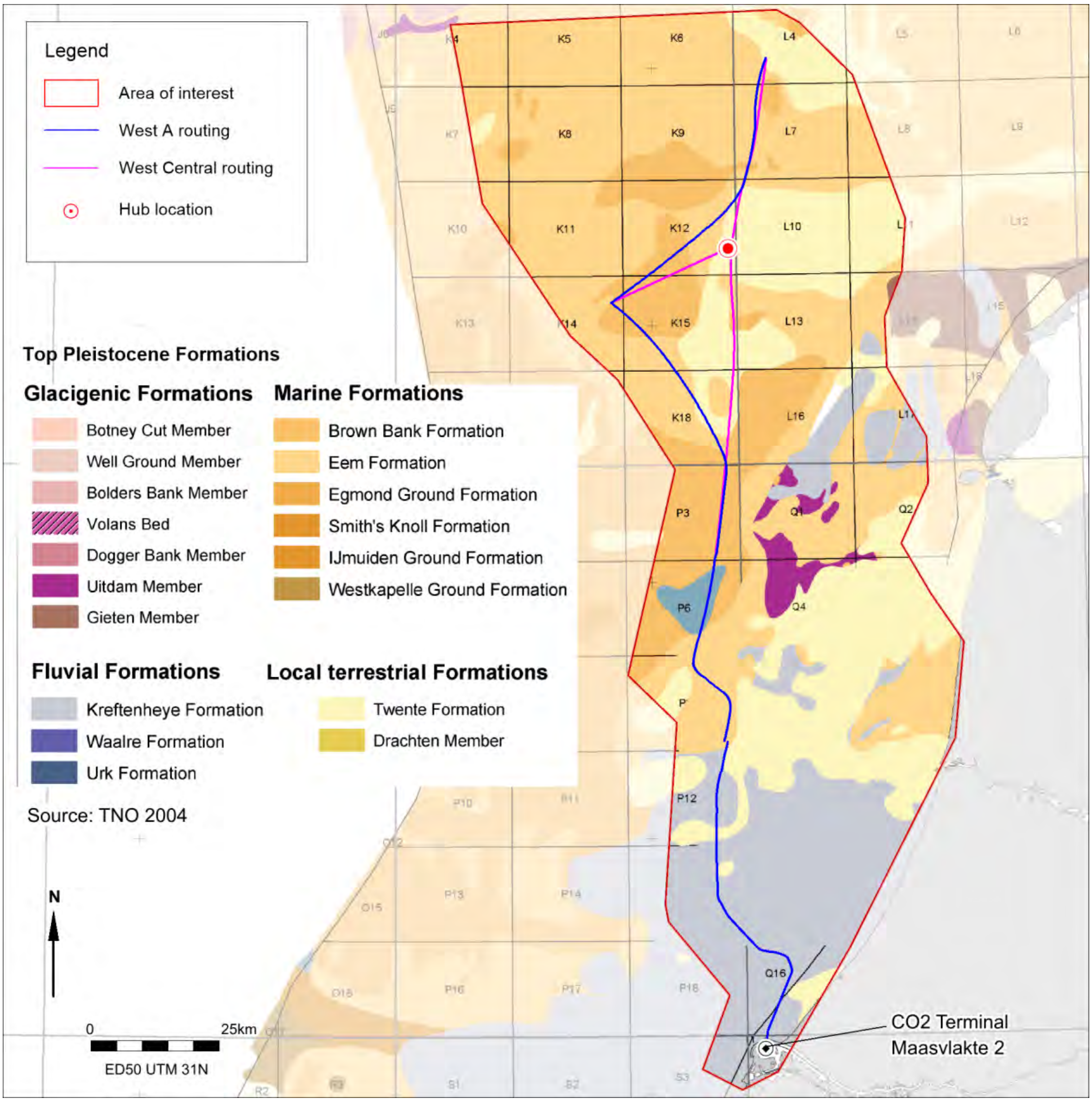

Figure 13. Subcropping Pleistocene formations

Within the boundaries of the area of interest several subcropping *Pleistocene* units have been mapped. The most relevant are described below.

<u>Yarmouth Roads Formation</u>

The Yarmouth Roads Formation consists of fine or medium-grained grey-green sands, typically non-calcareous, with variable clay lamination and local intercalations of reworked peat. According to the Lexicon of Named Rock Units of the British Geological Survey the depositional environment of the Yarmouth Roads Formation is interpreted to be 'mainly fluviatile, with possible shallow marine incursions'.[10]

[9] Laban 2004.

[10] https://webapps.bgs.ac.uk/lexicon/lexicon.cfm?pub=YM.

In the DINO nomenclature the depositional setting is described as 'predominantly low energy open-marine deltaic, delta top and fluvial'.[11] The Yarmouth Roads Formation is older than 500 kyr. The unit has been glacially deformed into ice-pushed ridges in the section that is crossed by the current Aramis route trajectory.

Egmond Ground Formation
The Egmond Ground Formation consists of fine-grained, sparsely shelly marine sands with clay interbeds. The amount of shells and shell fragments is markedly less than the overlying younger sands of the Eem Formation.[12] The marine deposits date from the Holsteinian interglacial period. The exact age of the deposit is uncertain, including both Marine Isotope Stage 11 (424 kyr – 374 kyr ago) and Marine Isotope Stage 11 (424 kyr – 374 kyr ago) and Marine Isotope Stage 9 (300 kyr – 337 kyr years ago). The deposits of the Egmond Ground Formation predate the Saalian glacial period and can therefore be part of the ice-pushed ridges.

Eem Formation
The Eem Formation predominantly consists of shell bearing fine sands deposited in an open marine environment during the Remain interglacial (warm) period.[13]

Brown Bank Member (Eem Formation)
At the end of the Eemian period brackish and fresh water clays were deposited in lagoons and lakes which remained in the glacial basins during regression of the Eemian Sea. These lake and lagoonal deposits have separately been classified as the Brown Bank Member within the Eem Formation. The Brown Bank Member was previously referred to as Brown Bank Bed or Brown Bank Formation.

Woudenberg Formation
In the Early Weichselian cooling climate peat was locally deposited on top of the clayey Brown Bank Member. At its base the peat is often rich in wood remains; at the top moss is a major constituent. The unit consists of firm, amorphous, clayey, non-calcareous, brown to black peat or gyttja. The peat has been deposited in a nutrient-poor (moss peat) to nutrient-rich (reed, sedge and woody peat) marsh or swamp. Occurrences of the Woudenberg Formation have been described in the Amersfoort Basin, not in the North Sea area. Formerly, this unit was part of the Eem Formation. As the Saalian glacial basins are present in the North Sea area which is crossed by the proposed Aramis pipeline routes, local occurrences of this unit could be crossed.

Kreftenheye Formation (Weichselian)
The Kreftenheye Formation consists of sands of the Rhine | Meuse fluvial system. The depositional environment includes braided and meandering stream, and braidplain and floodplain. The deposits consist of yellowish grey to greyish brown medium to very coarse sand. The sands are moderately to very gravelly. Locally, fine to coarse gravel lags occur. Occasional thin clay laminae and clay pebbles can be present intercalations in the predominantly sandy sequence. Characteristic of the Kreftenhye river deposits is a parallel layering on mm- to cm-scale which is related to small variations in grain size and composition. Offshore the coast of South Holland, small shallow channel incisions are observed in subbottom profiler data. These incisions occur in the top of the Kreftenheye Formation which is truncated by the Bligh Bank

[11] In accordance with Rijsdijk 2005.

[12] British Geological Survey: Lexicon of Named Rock Units.

[13] Eemien: interglacial period between 128.000 and 115.000 years ago.

Member. The channels are filled with fine sand. An impression of the stratigraphy that is to be expected in the southern part of the current Aramis route trajectory in the vicinity of sand extraction areas Q16H and Q16H is illustrated in figure 14 below.

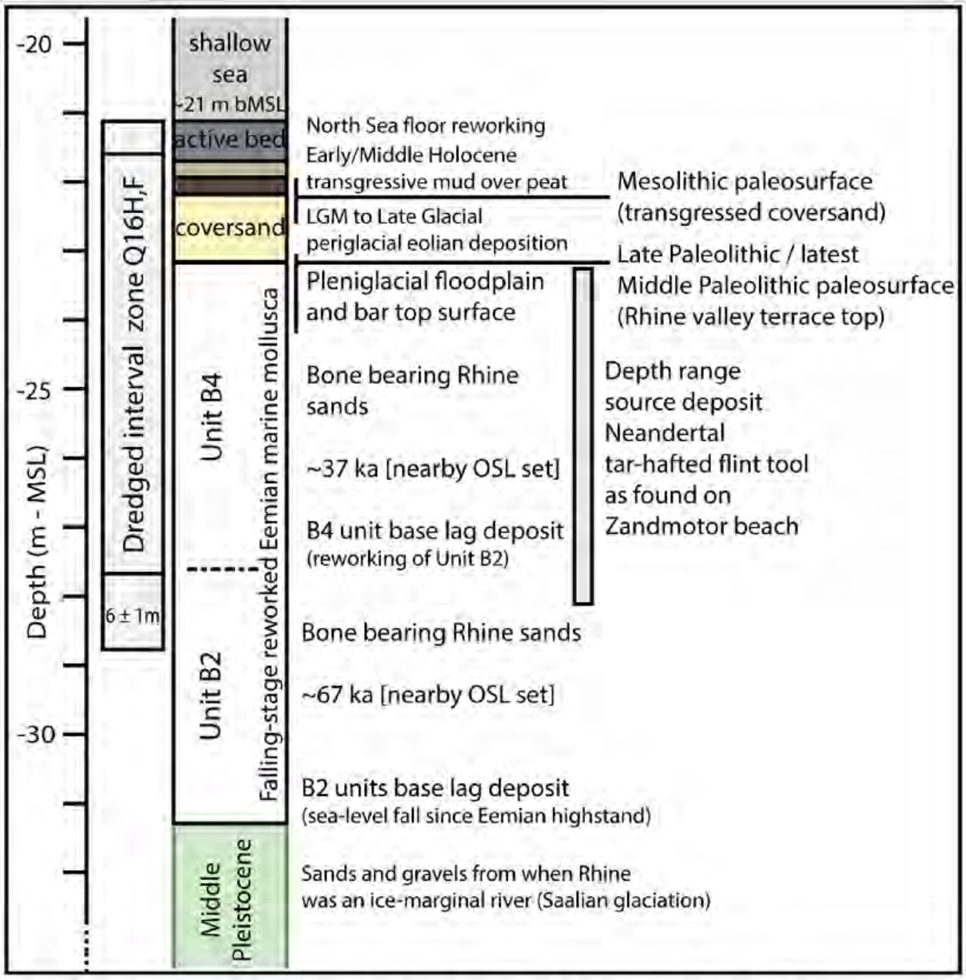

Fig. S2. Stratigraphy of the dredging area Q16. The upper 6-8 meters of the sedimentary column consist of: 1) a dynamic sheet of shelly sand of the active sea bed, 2) beds of Early-Middle Holocene transgressive tidal muds on basal peat, 3) Late Glacial eolian coversands containing Mesolithic materials (27, 28), and 4) medium to coarse grained fluvial sands of the Rhine-Meuse valley, Units B2 and B4, dating to 70-30 ka.

Figure 14. Stratigrafie van het zandwingebied Q16 (Niekus 2019).

During the installation of the Hollandse Kust (zuid) export cables mammoth bones were found on the trencher when the trencher emerged above water (see for site location figure 1). The very well preserved mammoth bones probably originate from an infilled channel.

The course of the river Rhine changed during the Weichselian. The extent and distribution of the Rhine - Meuse channel belts is shown in figure 15, below.

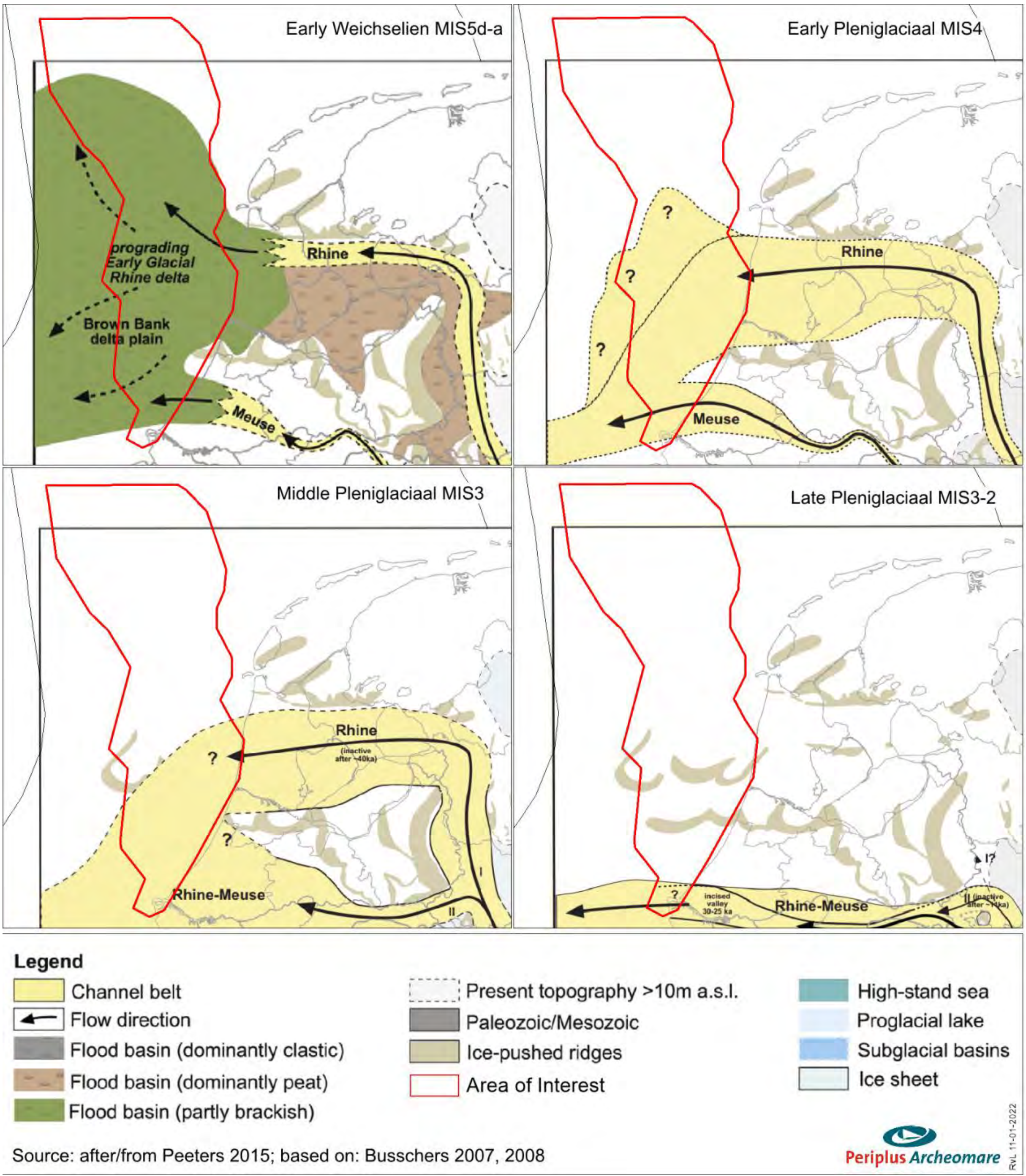

Figure 15. Paleogeographic maps of the Weichselian.

North and south of Maasgeul firm beds of clay and loam occur at the top of the Kreftenheye Formation. The firm clay dates from the Late Weichselian (Allerød interstadial) and Early *Holocene* and is separately classified as the Wijchen Bed. The Wijchen Bed has been deposited in meandering floodplain of the Rhine which is subject to frequent overbank flow.[14] The deposition of the Wijchen Bed is related to the evolution of the Rhine – Meuse river pattern from braided to meandering. The change to a meandering river pattern is triggered by a warming of the climate, which resulted in the development of a vegetation cover. The landscape morphology is more or less fixed by the vegetation, thus promoting incision of the river. This

[14] Törnqvist 1994; Makaske 1995; Busschers 2008.

also explains why the overbank clay of the Wijchen Bed is characterized as 'humic and non-calcareous, especially at the organic-rich top, which may be marked by a palaeosol'.[15]

The Late Glacial fluvial evolution of the Niers–Rhine and Maas in relation to climate and vegetation changes is nicely illustrated by Kasse (see, below).[16]

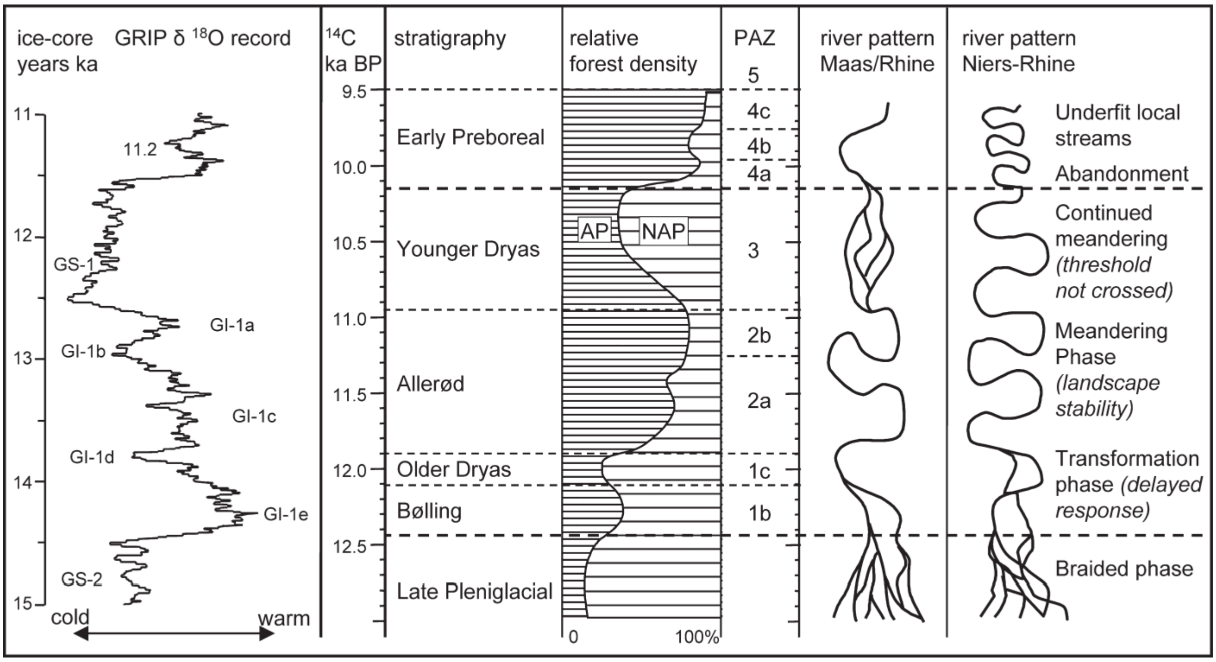

Figure 16. Late Glacial fluvial evolution of the Niers–Rhine and Maas in relation to climate and vegetation changes (from: Kasse 2005).

In the Yangtze area two separate beds are distinguished in the Wijchen Bed:[17] a lower bed that is described as 'grey loam, sandy clay and clayey sand, and is internally stratified', and an upper bed that is described as 'moderately silty to strongly silty and humic (often humically stratified), and at the base sandy and mostly sandy-stratified.' The lower bed was found between 23m and 22m – asl; the upper bed between 22m and 19m – asl. In the upper bed charcoal is found which is related to the archaeological sites that were found on the nearby river dunes.

Boxtel Formation (Weichselian and Early *Holocene*)

The Boxtel Formation consists of terrestrial deposits. The upper part of the unit subcrops below a cover of *Holocene* deposits in parts of the area of interest (figure 13). The subcrops of the Boxtel Formation shown in figure 13 date from the latest ice age, the Weichselian, and Early *Holocene*. This upper part of the unit most probably consists of aeolian deposits of the Wierden Member (cover sands) and loamy stream deposits of the Singraven Member. Apart from loam (=silt) the Singraven Member can contain sand, clay and peat. The Boxtel Formation overlies brackish to fresh water lagoonal and deposits or laminated fresh water lacustrine clays of the Brown Bank Member and peat of the Woudenberg Formation. The thickness of the Boxtel Formation is unknown.

[15] TNO-GDN (2022). Wijchen Bed. In: Stratigraphic Nomenclature of the Netherlands, TNO – Geological Survey of the Netherlands. Accessed on 13-01-2022 from http://www.dinoloket.nl/en/stratigraphic-nomenclature/wijchen-bed-0.

[16] Kasse 2005.

[17] Moree and Sier 2015; The Wijchen Bed is refered to as Wijchen Member.

During the Early *Holocene* aeolian sands were deposited within the floodplain bordering the dry bed of the river Rhine (these river deposits themselves are part of the Kreftenheye Formation; see above). The so-called river dunes are found in the subsurface of the route trajectory north and south of the Maasgeul. The river dune deposits are described as grey to brown, fine to medium, moderately sorted sand, mostly non-calcareous but calcareous near base, with sporadic silt layers or granule laminae. The river dune deposits are separately classified as the Delwijnen Member within the Boxtel Formation.

Drachten Formation

Terrestrial deposits can also occur at a deeper stratigraphic level. The Drachten Formation is located in between the Egmond Ground Formation and the Eem Formation. Formerly the Drachten Formation was onshore classified as the Eindhoven Formation and later as a member of the Boxtel Formation. Offshore the Drachten Formation was referred to as the Tea Kettle Hole Formation. The local terrestrial deposits date from the Saalian ice age and consist of fine grained periglacial aeolian, fluvial and lacustrine sands. The Drachten Formation predates the Saalian glaciation and is often deformed due to the overriding ice-sheet. Deposition took place during the Hoogeveen and Bantega interstadials (227 – 180 ka. ago), when the landscape was covered by temperate zone forests. In the 1980s, Neanderthal camps related to the Hoogeveen or Bantega interstadials were excavated in the Maastricht-Belvédère quarry in Limburg. Therefore, remains of Neanderthal camps may exist *in situ* if intact palaeosol are present.

Holocene Units
The *Pleistocene* units are - except from some local outcrops - covered in by a sequence of *Holocene* deposits. The overall thickness of the *Holocene* sediments ranges from 0m to 37m. The differences in thickness are for a major part related to the present-day seabed morphology, which is characterized by sand dunes, ridges and valleys. The occurrence of *Holocene* units which are exposed at the seabed is shown in figure 17. Because this map displays the exposed lithostratigraphic units, under these units older *Holocene* deposits can occur.

Nieuwkoop Formation (*Holocene*)
Fluvial deposits of the Kreftenheye Formation and terrestrial deposits of the Boxtel Formation are in places covered by peat. This Early *Holocene* peat layer is classified as the Basal Peat Bed within the Nieuwkoop Formation. Occurrences of the Basal Peat Bed could indicate that the underlying *Pleistocene* landscape has been preserved intact, provided that no erosion as taken place prior to the deposition of the peat. If the Basal Peat Bed is found in borehole or vibrocore samples, signs that the top of the underlying unit is intact can be found in the occurrence of palaeosol horizons. Known are the podzol soils which developed at the higher parts of the cover sand landscape during the Early *Holocene*. These cover sands are classified as the Wierden Member within Boxtel Formation (see text above).

Echteld Formation (*Holocene*)
Both north and south of the Maasgeul a bed of silty humic clay with silty laminae occurs. The presence of washed-in wood remains is characteristic.[18] The clay is deposited in a freshwater environment, with slight tidal influence. Presumably, sedimentation took place under water (subaquatic, subtidal). The bed of humic clay is classified by Hijma as Terbregge Member | Echteld Formation. The classification as a separate member has not been formalized in the DINO nomenclature, yet. The Terbregge Member covers the Early *Holocene* Basal Peat Bed and is itself covered by the Wormer Member | Naaldwijk Formation.

Naaldwijk Formation (*Holocene*)
Pleistocene units and the Early *Holocene* Basal Peat Bed are in places covered by *Holocene* tidal deposits (clay and fine sand). These layered and laminated tidal deposits are part of the Wormer Member within the Naaldwijk Formation. The earliest clastic deposits are those of the Velsen Bed. The Velsen Bed consists of firm to stiff humic clay, sometimes containing considerable amounts of Hydrobia shells. The lower boundary can be present as a gradual transition from peat deposits of the Basal Peat Bed to clastic lagoonal deposits of the Velsen Bed.

Southern Bight Formation (*Holocene*)
The Southern Bight Formation consists of reworked sediments. The Southern Bight Formation is exposed at the seabed surface in major part of the Aramis route trajectory (see figure 17). Along the route, three members of this formation have been mapped. The Bligh Bank Member is a mobile sand layer in which sand ridges, dunes and mega-ripples have developed. This unit predominantly consists of marine sands with variable admixtures of gravel. The formation often has a more gravelly structure towards the base. It should be noted that shell fragments over 4 mm are considered to be 'gravel'.

In the northern part of route, the Bligh Bank Member changes into the Terschellingerbank Member, which consists of reworked (peri-)glacial sand with a small amount (< 10%) of mud.[19]

[18] Moree and Sier 2015.

[19] Mud = clay (< 2µm) + silt (>2µm and <63µm)

<u>Urania Formation (*Holocene*)</u>

The Urania Formation is found in the northernmost of the route, where the Western Mudhole Member is mapped. Alike the Terschellingerbank Member, the Western Mudhole Member consists of reworked (peri-)glacial material, but the grain size of the sediments is smaller. The unit is described as very fine sand with a considerable admixture (> 10%) of mud.

Figure 17. Geological overview map (De Mulder 2003).

Only the total thickness of the *Holocene* sequence including the Basal Peat Bed, the Naaldwijk Formation, the Southern Bight Formation and Urania Formation is known. The total thickness of the *Holocene* layer ranges from less than 1 to over 10 meters in the area of interest (see figure below).

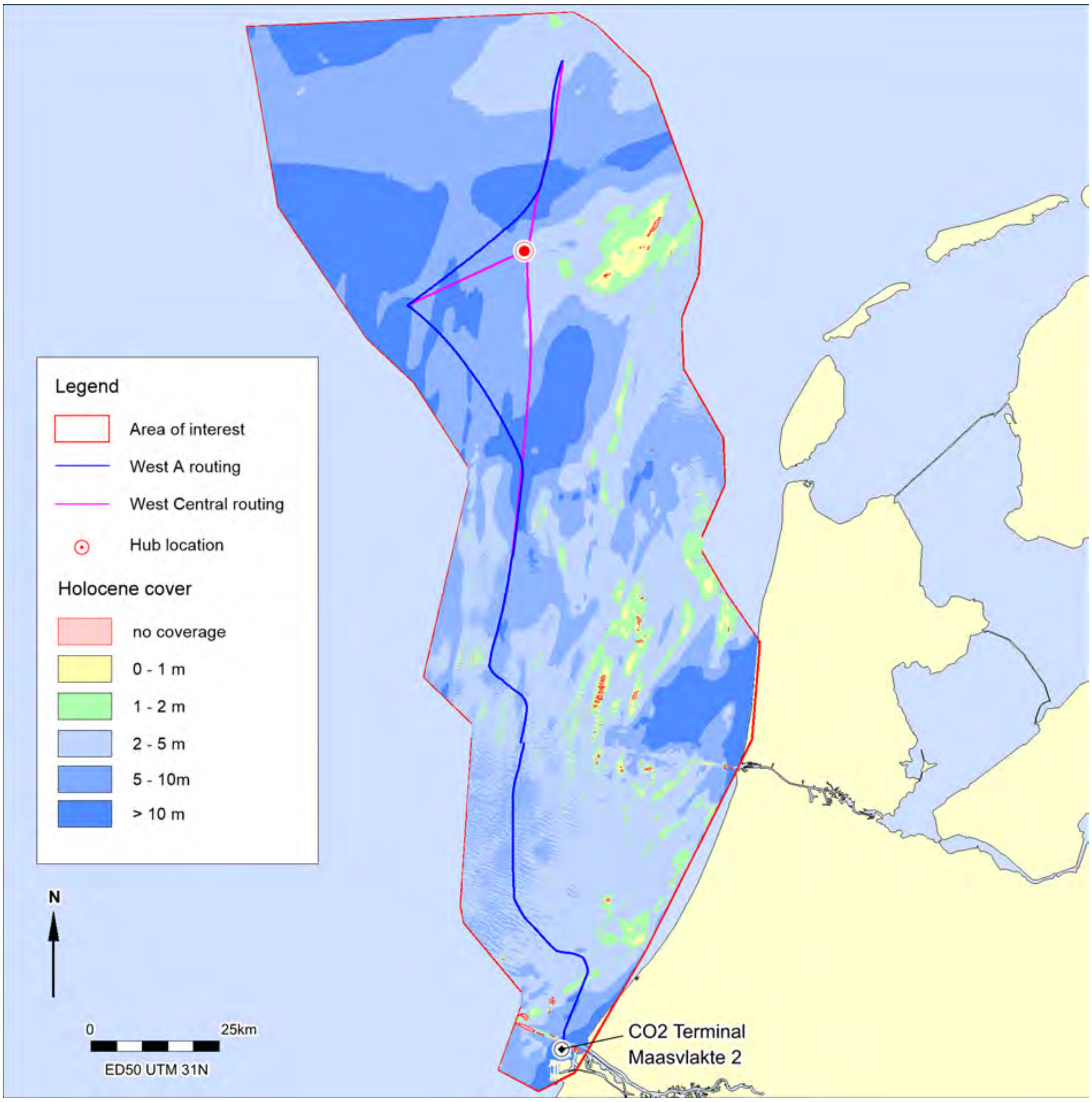

Figure 18. Thickness of Holocene cover

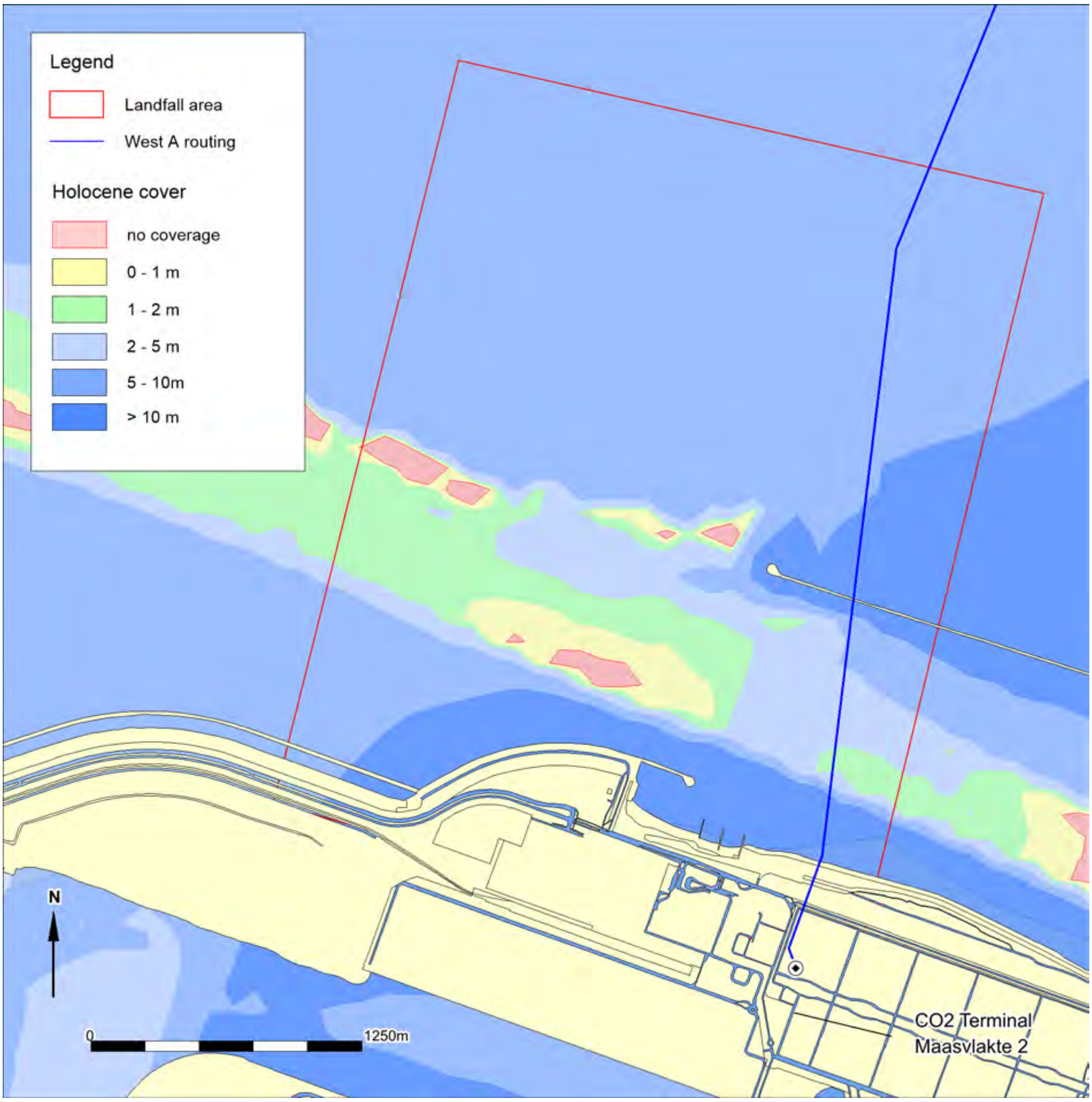

Figure 19. Holocene cover within the landfall area

3.5 Known archaeological values and other objects (LS04)

The former National Service for Archaeological Heritage (ROB, now Dutch Cultural Heritage Agency or RCE) in collaboration with Rijkswaterstaat and TNO NITG has developed a comprehensive archaeological map of the continental shelf based on geological and archaeological observations (see figure below)[20].

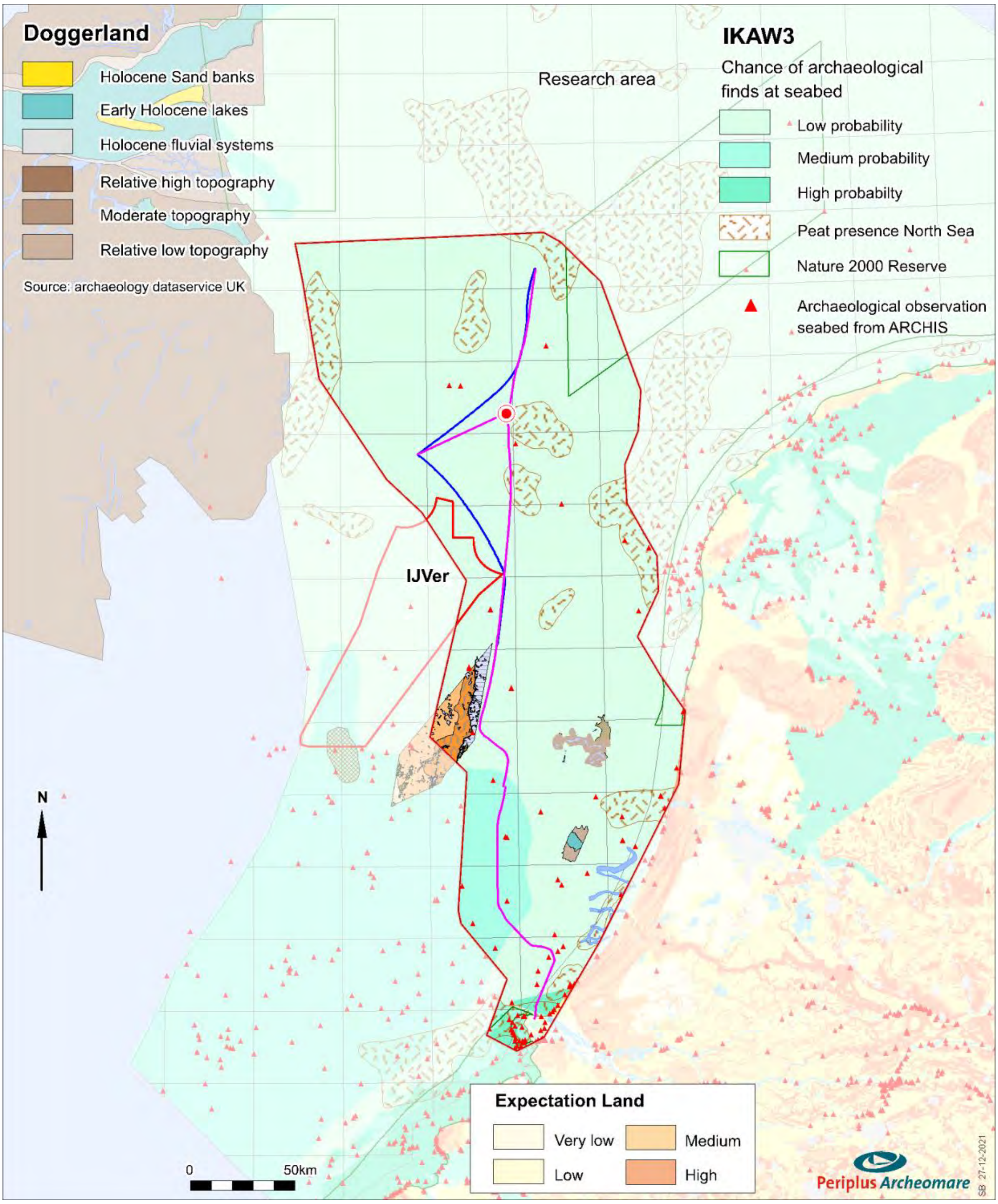

Figure 20. Overview indicative map of archaeological values (IKAW)

[20] IKAW 3e generatie, RCE 2008.

This global map presents the probability of well-preserved shipwrecks to be encountered (and often a ship's discovery of high archaeological value) in the Dutch part of the Continental Shelf, expanded with available palaeogeographic reconstructions.

However, this map is of very limited use. This is partly due to the large scale (1: 500,000). Further the map has become outdated, because it shows the state of knowledge 25 years ago. The degree of conservation of wreck remains is closely related to geology and morphology which has not been taking into account in the IKAW3 map. The idea here is that in channel deposits or regions with soft sediment, a wreck quickly sinks into the seabed and therefore remains in good condition. In other areas with harder top sediments the chance of a find is not necessarily lower, but the chance to find a well-preserved ship with the cargo and equipment still intact is considerably less.

Figure 20 also indicates areas where peat and clay have been preserved. This cover with clay / peat only refers to the possible location of *Pleistocene* deposits on / near the seabed. Where *Holocene* clay or peat is eroded *Pleistocene* layers with artefacts and fauna fossils may be present. The presence of early *Holocene* sediments could indicate the presence of a well preserved prehistoric landscape. West of the area of interest lies the nature reserve Brown Bank, a shoal known for its paleontological and prehistorical finds. At this archaeological hotspot rigid *Pleistocene* clays and silts of the Brown Bank Member are exposed at the seabed. These sediments contain the prehistoric remains which are found in the nets of fishermen.

Research in the last decade has shown that the probability of encountering prehistoric residues in the North Sea is much greater than originally thought. The archaeological map for the Dutch continental shelf is therefore being revised. In 2016, an indicative model of the archaeological potential of the North Sea was published by Deltares[21]. A detail of this map is shown in figure 21. The potential for prehistoric remains is closely related to the lithostratigraphic units which have been discussed and outlined in previous paragraphs. For instance the potential for Middle Palaeolithic remains indicated in red coincides with the occurrence of the Kreftenhye Formation and Brown Bank Member, the potential for residual Mesolithic and Late Palaeolithic remains indicated in beige coincides with the occurrence of the Boxtel Formation and the limited potential for prehistoric remains in areas indicated in grey relates to the occurrence of the marine deposits of the Egmond Ground Formation and the Eem Formation[22].

It should however be stressed that figure 21 offers a two dimensional view. The occurrences of the Eem Formation (grey), the Kreftenheye Formation and the Brown Bank Member (red) are not limited to the mapped areas but extend underneath the Boxtel Formation (beige). This means that Middle Palaeolithic remains are also to be expected in those areas.

It is important to bear in mind that the occurrences and boundaries of the lithostratigraphic units mapped are based on a limited amount of geological data. The occurrences and boundaries should therefore not be considered definite, but an indication of what is to be expected in the area and a framework for further research. Also morphological phenomena like the ice-pushed ridges have not been taken into account in this map.

[21] Vonhögen et al, 2016.

[22] Occurrence Naaldwijk Fm according to Deltares grids (2004).

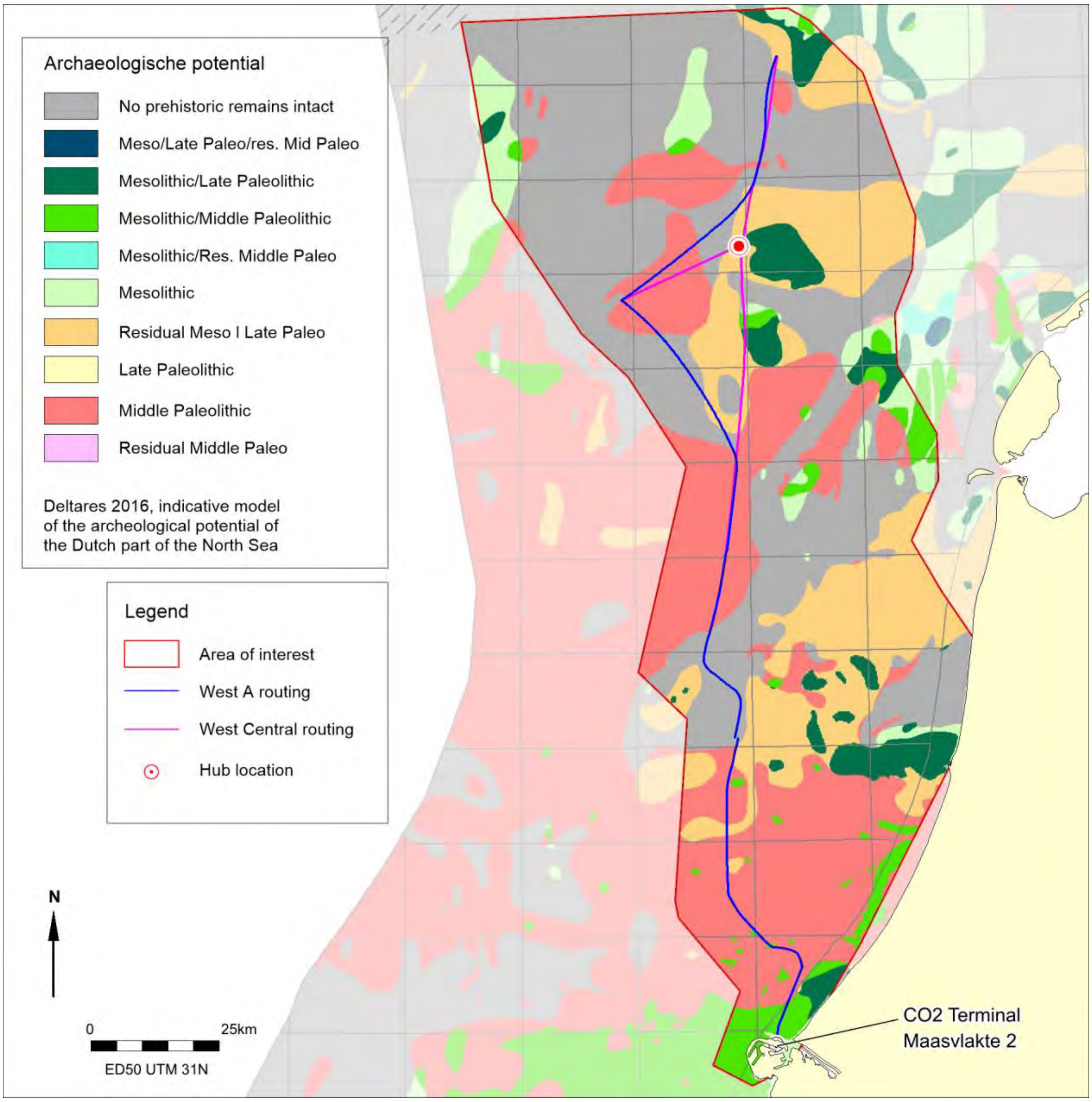

Figure 21. Archeological potential for prehistoric remains

Ice-pushed ridges

The ice-pushed ridges have been formed by Saadian glaciers which stretched into the North Sea area. pre-dates the Eemian, Weichselian and Early *Holocene* deposits. The ice-pushed river sands of the Yarmouth Roads Formation can contain reworked flint artefacts from Lower and Middle Palaeolithic times. At the top of the ice-pushed ridge in situ remains of camp sites and inhumations of Neanderthal and Late Palaeolithic and Mesolithic hunters and gatherers can be expected.

Open sea (Eemian)

The Eem Formation consists predominantly of marine sand deposited in the Eem Sea during the Eemian interglacial (warm) period.[23] Within the sandy marine deposits no *in situ* archaeological remains are expected.

[23] Eemien: interglacial which lasted from 130.000 till 115.000 years ago.

Lagoons, lakes and fens (Eemian to Early Weichselian)

The Brown Bank Member at the top of the Eem Formation consists of lacustrine fresh water and coastal marine brackish water deposits of silty clay. At the end of the Eemian the sea regressed and the Brown Bank clays were deposited. This layer can contain Middle Palaeolithic artefacts from, or remains of Neanderthals who in this period populated the Netherlands and the North Sea area. Little archaeological research has been done into this often deep-seated stratigraphical unit. Camp sites are expected to be intact and well preserved, especially when the remains are contained in a clayey context and covered by peat of the Woudenberg Formation and/or cover sands of the Wierden Member | Boxtel Formation. The Woudenberg Formation can contain dumps from close-by camps, lost hunting gear and intended depositions. The available geological information does not suffice to assess whether the Late Eemian to Early Weichselian facies of sandy lagoonal beaches and/or clayey shores of lakes and fens is present.

The top of the Brown Bank Member is expected at depths varying from 0m to 30m below the seabed.

River valley (Weichselian)

The Kreftenheye Formation consists of fluvial deposits of the Rhine and Rhine - Meuse system. The extent and distribution of the channel belts during the Pleniglacial (74 ka – 15 ka ago) is illustrated in Figure 15. Well-preserved finds prove that Neanderthal occupied the Rhine valley. Melt water discharged through the braided channels of the Rhine. Peak discharge occurred during the summer months, when temperatures rose above freezing point in the hinterland. Large mammals including woolly mammoths, woolly rhinoceros, musk ox and steppe wisent migrated over the steppe-tundra landscape. This landscape was vegetated with grasses, herbs and occasional dwarf birches. The water-intake of mammoths was immense, so the fresh-water-filled channels must have had a large attraction to these animals, thus offering Neanderthal the opportunity to hunt them. The change of encountering *in situ* remains in the residual infilled channels of the Kreftenheye Formation is considered to be relatively large. It is believed that the Neanderthal became extinct some 40 kyr to 35 kyr ago, prior to the Late Glacial Maximum, some 27 kyr to 19 kyr ago.

The Wijchen Bed at the top of the Kreftenheye Formation consists of firm, matured humic clays in which locally palaeosol developed. In the clayey context of this bed well-preserved Late Palaeolithic and Mesolithic remains could be encountered. These remains include lost hunting gear and waste of camp sites which are found on nearby river dunes. Also the presence of camp site relics on the overbanks deposits cannot fully be excluded.

Cover sand landscape (Late Weichselian and Early *Holocene*)

The camp sites of Late Palaeolithic and Mesolithic hunters and gatherers are found in a cover sand landscape with ridges and dunes and valleys formed by small streams. Stream valleys offered fresh water, a large variety of plant species and ample opportunities for hunting. Camps were installed along the borders of those valleys. The remains of sites can be encountered in the context of sandy, loamy, clayey or peaty beak deposits of the Singraven Member. The lithological context of settlements found at the dunes and ridges comprises well sorted non-calcareous fine cover sand of the Wierden Member. Both Singraven and Wierden Member are part of the Boxtel Formation.

Late Palaeolithic and Mesolithic remains are expected at two distinct levels within the cover sand sequence. The first is a palaeosol found in between two cover sand layers Late Palaeolithic remains of camp sites of reindeer hunters are to be expected. The palaeosol is a charcoal rich layer called the Usselo Bed, which has been formed during the Bølling and Allerød interstadials. The second level is the top of the cover sand sequence. The sandy dunes and ridges often display a well-developed podzol, if not eroded. Due to the low carbonate content presence of oxygen in the pores of the sand the preservation conditions for organic remains (wood, bone, et cetera) is a priori not so good in cover sands. The preservation of organic remains is therefore highly dependent on the timing of the water table rising above the archaeological level.

If the Boxtel Formation is covered by the Basal Peat Bed or the Velsen Bed the integrity and conservation of archaeological remains is expected to be high. Considering our limited knowledge of prehistoric sites in the North Sea area such well-preserved finds would *a priori* be worth preserving. Archaeological markers consist of flint and bone artefacts, burnt nuts and seeds and charcoal. Zones of interest are locations where the top of the cover sands and river dunes (if present) are not eroded. The presence of the Basal Peat Bed and Velsen Bed indicate that underlying Boxtel Formation and possible archaeological remains herein could be intact.

Peat and humic clays

The Basal Peat Bed and Velsen Bed themselves can also contain archaeological remains. These remains include dumped waste from nearby camp sites, lost hunting gear or intentional (e.g. ritual) depositions. Due to the low levels of oxygen and wet conditions both organic and inorganic remains might be very well preserved.

Site characteristics

The expected camp sites of hunters and gatherers are generally small (a few sqm), although larger settlements (up to approximately 2000 sqm) can occur in case the site repeatedly or for prolonged period of time was occupied. Sites are characterized by the presence of concentrations of charcoal, flint artefacts, bone remains, burnt seeds and nuts, natural stones and artefacts of bone or horn. Inhumations can occur. The density of finds (debris of flint processing) can vary from low to high.

Physical Quality

It is not known to what extent erosion has affected the integrity of the *Pleistocene* landscape and embedded remains of prehistoric settlements. The presence of the Basal Peat Bed, the Terbregge Member (Maasgeul area) and/or Velsen Bed provides an indication for an intact *Pleistocene* landscape, although it should be noted that erosion could have taken place prior to the deposition of peat and clay, leading to degradation or even annihilation of prehistoric remains. If the *in situ* prehistoric remains did not suffer from erosion, the very rapid Early *Holocene* ‘drowning’ of the *Pleistocene* landscape and local deposition of a peat and/or clay cover offered perfect conditions for the conservation of both organic and inorganic remains. In this situation well-preserved sites of high physical quality can occur.

Occurrence and spacial distribution

The occurrence and spacial distribution of Late Saalian ice pushed-ridges, Early Weichselian lagoons, lakes and fens, Pleniglacial river deposits and the Late Weichselian wind-blown dunes and stream valleys in the area of interest is not known in detail. Surely the available geological maps of the Flemish Bight Map (1984), the Indefatigable Map (1986), the Top *Pleistocene* Formation map and Deltares’ grid data (2004) and palaeogeographic maps (2015) provide an indication, but the actual situation can only be established through subbottom profiling in combination with borehole sample analysis. The depth below the seabed of the *Pleistocene* landscape ranges from 0m (*Pleistocene* exposed) to nearly 30m.

Known objects and shipwrecks

For a listing of known objects and shipwrecks within the area of interest, the united NCN database is consulted[24].

The National Contact Number (NCN)

The NCN database combines the data from three governmental databases:

- The Dutch Continental Shelf and Westerschelde wrecks register from The Hydrographic Service of the Royal Netherlands Navy.
- The SonarReg92 object database of Rijkswaterstaat
- The ARCHIS database (the official archaeological database of the Ministry of Cultural Heritage)

The permission for the use of the NCN database was granted by the owner (Rijkswaterstaat Sea and Delta)

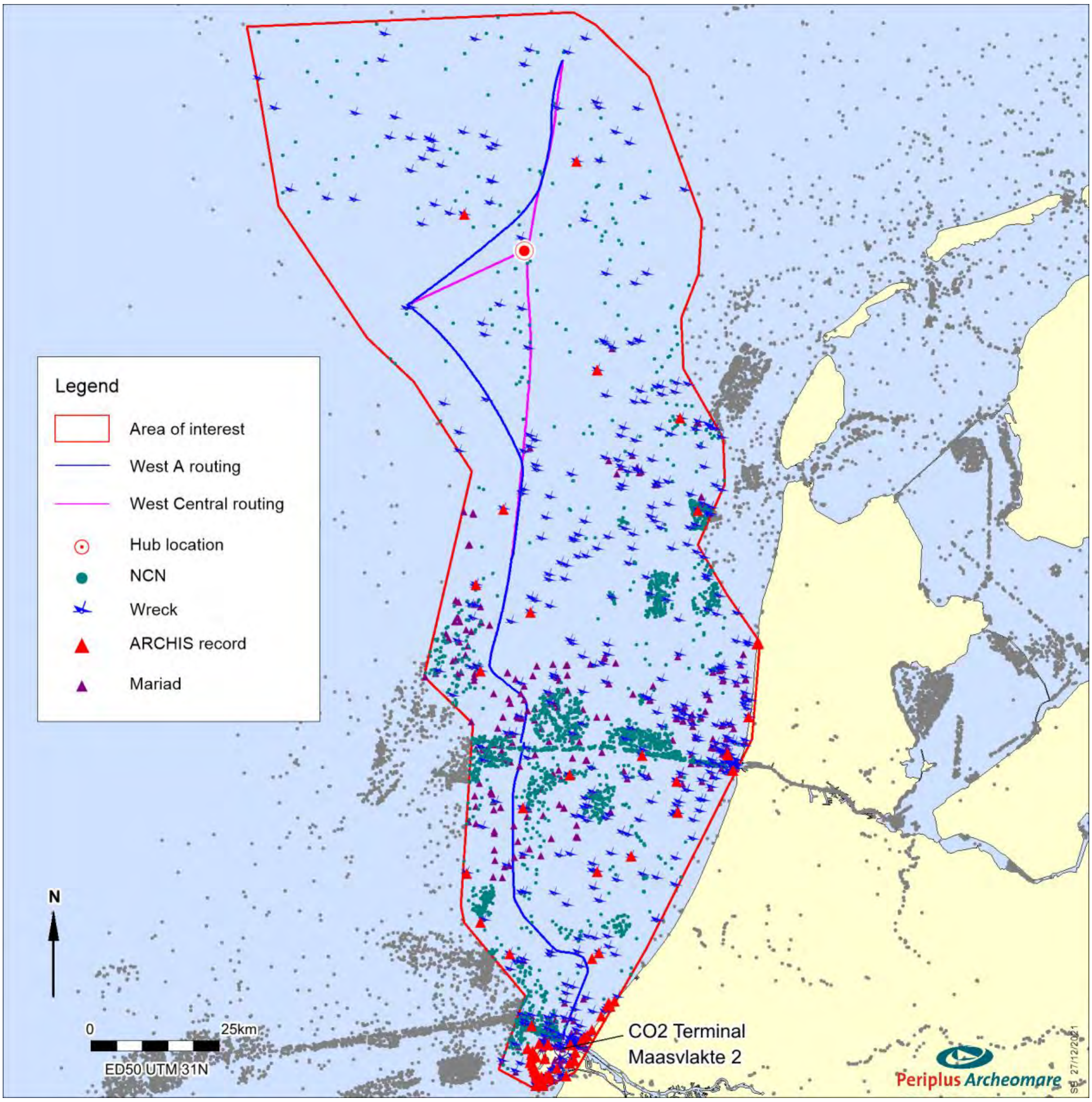

Figure 22. Overview of known objects and contacts in the area of interest

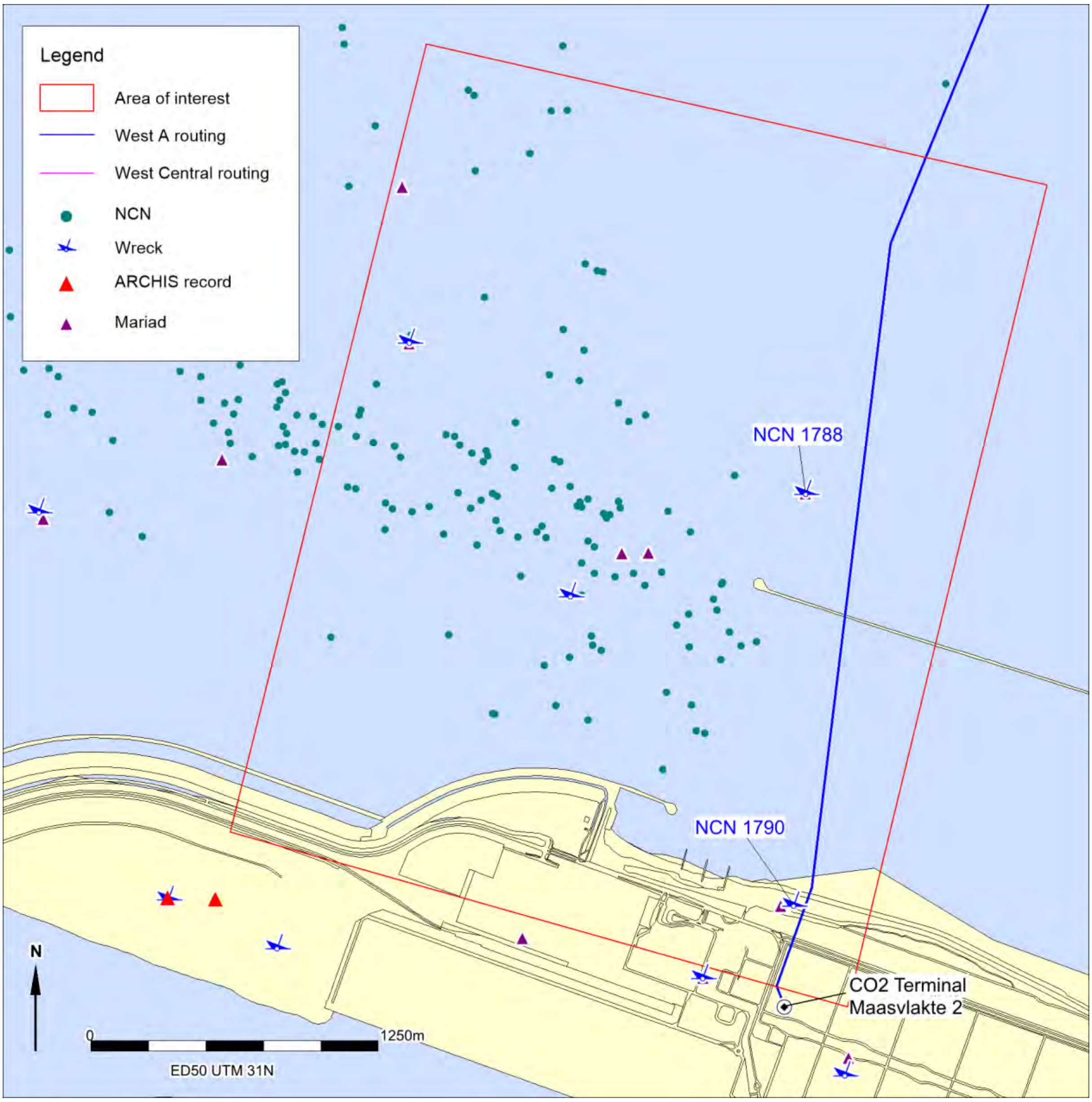

Figure 23. Overview of known objects and contacts in the landfall area

Archaeological records.

Within the area of interest, 316 records of archaeological finds are known with the ARCHIS 3 database. These vary from prehistoric artefacts (mainly concentrated around Maasvlakte 2) to remains of shipwrecks, (see next paragraph).

Shipwrecks

There are 458 known shipwrecks within the area of interest of which 38 are officially recorded in the ARCHIS database. 307 wrecks are identified and date from the 16th to the 21st century. The remaining 151 wrecks have not been identified and dated yet. Additional research is needed to determine the cultural-historical value.

Within the landfall area, two records of ship wrecks are known in the vicinity of the proposed route. NCN 1788 was the wreck of the *SS Ceres*, sunk in 1934, and was cleared away to a depth 0f 75 dm. Remains may still be present. NCN 1790 was the wreck of the *Hertha Engelina Frit, sunk in 1941.* It is now covered by sand in reclaimed area.

In general, when a sinking ship ends up on the seabed, the tidal currents will create scouring around the wreck, and bury it down to a level of a harder surface within the sedimentary sequence. The thicker the layer of loose material, the more the ship will be packaged therein and will be retained. Especially in areas where the sediments have high clay content the wreck remains will be sealed and well preserved. In more sandy areas this effect is much smaller. Uncovered wooden parts may be affected by a naval shipworm (Teredo Navalis).

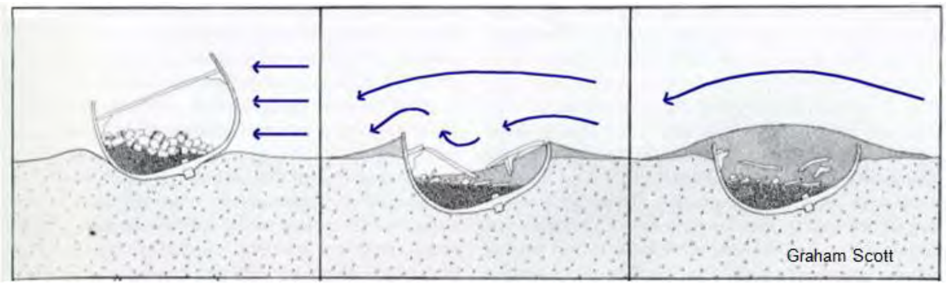

Figure 24. Example of wreck site formation (Graham Scott)

Other know objects

Besides wrecks, the SonarReg database contains records of 3494 other known objects within the area of interest. A summary is listed below.

Classification	**Amount**
Anchors	121
Boulders	77
Cables/Chains	304
Man-made objects	193
Natural phenomena	10
Seabed disturbances	226
Unidentified objects	2563
Total	**3494**

Table 4. Observations of known objects

Among the man-made objects and unidentified objects archaeological artefacts may be present.

Airplane wrecks

During World War II, many airplanes crashed into the North Sea. Several sources are ambiguous about the number of aircraft still missing. It is at least hundreds[25]. Remains are found on a regular basis by fishermen or during sand extraction or and beach protection projects. Within the area of interest, five locations with remains of aircrafts are known.

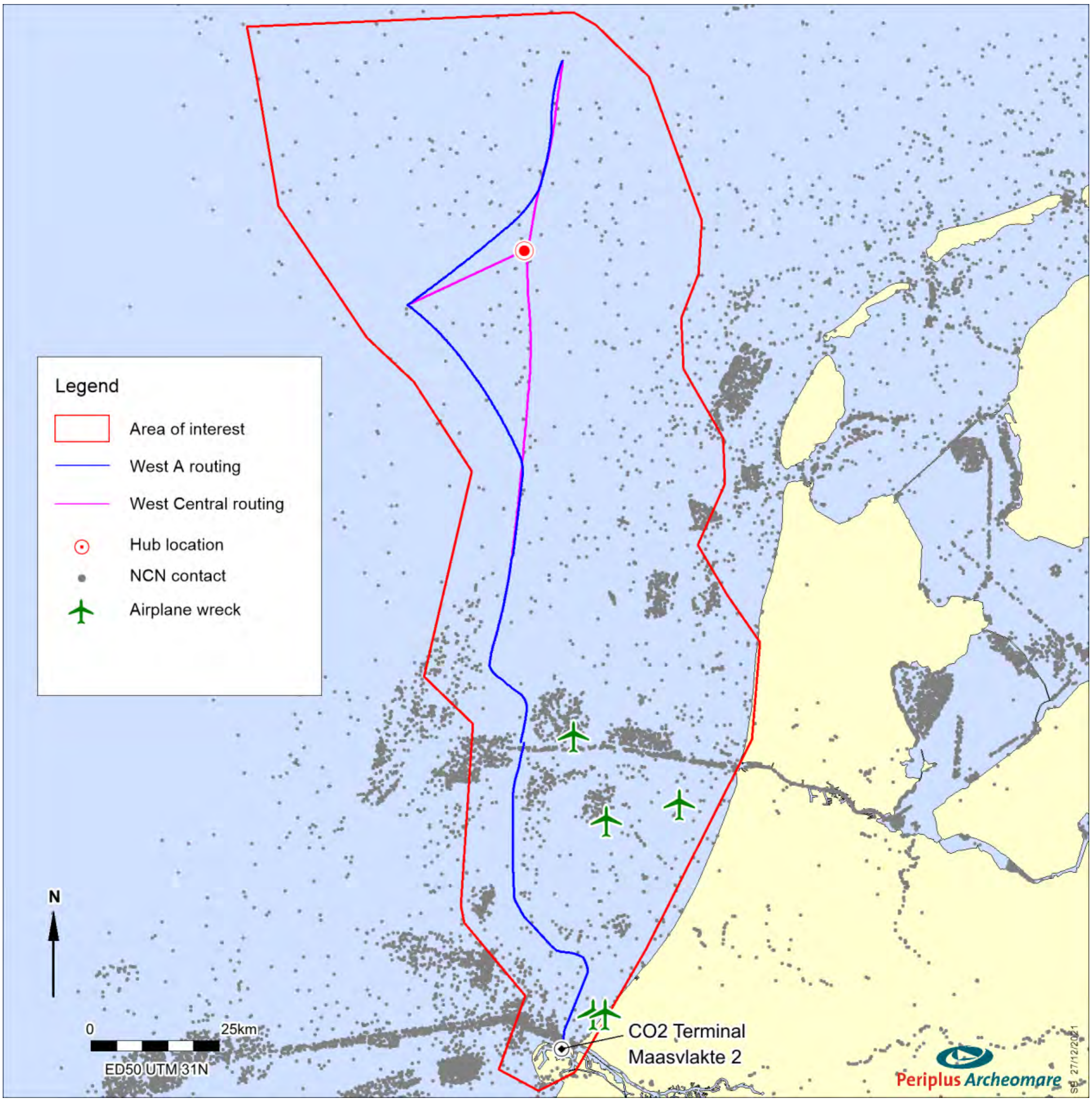

Figure 25. Known airplane wrecks within the area of interest

A complete listing of all known wrecks and objects within the area of interest can be made digitally available in consult with the administrator, Rijkswaterstaat Zee en Delta.

[25] Dutch Federation of Aviation Archaeology

3.6 Specified archaeological expectancy (LS05)

Shipwrecks

The area has a high expectation for shipwrecks from all periods. A total of 458 shipwrecks are known in the area, and more undiscovered wrecks can be expected. For some of the wrecks details like names, types and date of sinking are not known. Further research is needed to determine the cultural-historical value of these wrecks.

Plane wrecks

The area has a high expectation for plane wrecks from the Second World War. Several sources are ambiguous about the number of aircraft still missing. It is at least hundreds [26]. Within the area of interest, five locations with remains of aircrafts are known.

> **Current theme : wrecks from the First and Second World Wars**
> In addition to archaeological and cultural-historical value, ship and aircraft wrecks can also have a, memorial or emotional value. The commotion that arose as a result of the clearing of WWII wrecks in the Java Sea can be mentioned as an example. With regard to wrecks from the World Wars in Dutch waters, more and more voices are coming from society to deal with this respectfully.

Prehistory

During the last ice ages the area of interest was exposed due to very low sea levels. In those times the landscape was occupied by hunters and gatherers. Therefore camps sites are to be expected in the top of *Pleistocene* formations. The archaeological expectancy is discussed below by means of the geogenesis of the area and lithostratigraphic units present. As discussed in the section on ship wrecks, also for the *Pleistocene* landscape applies that our specific knowledge is limited, because a major part of the area has not been investigated by detailed geophysical surveys or the analysis of high quality borehole samples. As part of the Aramis pipeline development shall therefore be strived to gather additional information to broaden and deepen our geo-archaeological knowledge of the area, as outlined in the NSPRMF report.

[26] Dutch Federation of Aviation Archaeology.

Formation	Member / Bed		Lithology	Environment	Age	Arch. Potential*	Period
Southern Bight	Bligh bank		sand	open marine	Holocene	I, IV	Historical periods
Naaldwijk	Wormer		clay and sand	tidal		I	
		Velsen	humic clay	lagoon	Early Holocene	II	Meso
Echteld	Terbregge		humic clay with plant remains	freshwater tidal		II	
Nieuwkoop	Basal Peat		Peat	coast marsh		II	
Boxtel	Singraven		sand, loam, clay and peat	small-scale fluvial	Weichselian and Early Holocene	II and III	LPaleo + Meso
	Delwijnen		sand	river dune		III	
	Wierden		fine sand	cover sand		III	
Kreftenheye		Wijchen	clay and loam	overbank	Weichselian and Early Holocene	II and III	
			sand	bedding sand		II and III	MPaleo
Woudenberg			Peat	lakes	Eemian and Early Weichselian	II	
Eem	Brown Bank		humic clay and silt	lagoons and lakes	Eemian and Early Weichselian	II and III	
			sand and clay	open marine	Eemian	IV	
Boxtel | Drachten			gravel, sand, loam, peat	terrestrial	Late Saalian to Early Eemian	II and III	
Egmond Ground (ice-pushed)			sand with clay beds	open marine	Pre-Saalian deposition; Saalian (ice-push event)	II, III and IV	MPaleo - Meso
Yarmouth Roads (ice-pushed)			sand and clay	open-marine deltaic, delta top and fluvial	Pre-Saalian deposition; Elsterian/Saalian (ice-push event)	II, III and IV	Paleo - Meso

Table 5. Relation between lithostratigraphy and archaeological potential

*

Archaeological Expectancy	
I	Ship wrecks and shipping related objects; air planes from World War I and II
II	Lost or dumped objects including flint and bone hunting gear, fish weir, fish traps and dugout boats
III	Camp sites and inhumations
IV	Artefacts in reworked context

Archaeological levels are contained in the stacked sequence of *Pleistocene* and *Holocene* units. The relationship between the lithostratigraphic units and archaeological levels contained herein is summarized in table 5.

4 Synthesis

Based on the results of de data analysis the research questions are answered.

Are there any known archaeological values present within the area of interest? If so, what is the nature, extent (depth) location and dating of these sites?
Yes, within the area of interest, 316 records of archaeological finds are known with the ARCHIS 3 database. These vary from prehistoric artefacts (mainly concentrated around Maasvlakte 2) to remains of shipwrecks.

Are there, in addition to any known values, archaeological remains to be expected? If so, what are the nature, extent (depth) location and date of the expected archaeological remains?
Yes. There are 458 known shipwrecks within the area of interest of which only 38 are officially recorded in the ARCHIS database. 307 wrecks are identified and date from the 16th to the 21st century. The remaining 151 wrecks have not been identified and dated yet. Additional research is needed to determine the cultural-historical value.

The area may contain shipwrecks, remains of shipwrecks or remains of airplanes from the Second World War which have not been discovered to date. Apart from undiscovered ship and plane wrecks it is expected that locally prehistoric landscapes have been preserved intact. Related to these intact landscapes *in situ* prehistoric remains left behind by Palaeolithic and Mesolithic hunters and gatherers can be encountered.

Those *in situ* prehistoric remains include camp sites, burials, lost hunting gear, et cetera. Remains of camp sites are characterized by the presence of flint and bone artefacts, burnt nuts and seeds, charcoal and hunting gear.

Can the proposed activities affect known or expected archaeological values? If so, can an impact on archaeological assets be prevented or restricted by planning adaptation?
This question can only be answered once the area has been geophysically investigated and when the cultural historic value of the objects in the area has been determined.

If the archaeological values cannot be saved: What kind of further research is needed to determine the presence of archaeological values and their size, location, type and date to be determined enough to come to a selection decision?

Further research is to be performed within the framework of the standardized sequence of phases of maritime archaeological research as defined in the Dutch archaeological management procedure (Dutch: 'AMZ Cycle'). The research strategy is further determined by the type of archaeological remains which, based on the archaeological expectancy outlined in section 3.6 of this report, are to be expected. In summary the expectancy is two-fold comprising plane and ship wrecks on one hand and prehistoric remains on the other. The first phase after the archaeological desk study is an inventory field research. This field research comprises a geophysical survey. The methods employed include multibeam echo sounder, side scan sonar and magnetometer to trace and map wrecks and shipping related objects. A subbottom profiler is used to assess the potential for prehistoric remains by mapping the top of the buried *Pleistocene* landscape, identify seismostratigraphic units and correlate those units with the expected lithostratigraphic units (and potential archaeological remains herein), and determine the locations at which archaeological levels have been affected by erosion.

What are the possible effects of the installation of the pipeline on the areas with specific archaeological interest?

Archaeological values can be affected by human activities which result in a disturbance of the seabed. Direct disturbances are caused by trenching operations. Scouring adjacent to the pipeline is considered to be an indirect disturbance which might lead to the exposure of wrecks and erosion of the prehistoric landscape.

What are the possibilities to mitigate the disturbance of areas with specific archaeological interests?

In general, a buffer or safety zone of 100 meters around an archaeological object or an object with an archaeological expectation is to be defined in which seabed disturbing activities are not allowed[27]. If additional research shows that the object has no archaeological value, the location and the buffer zone can be omitted. The identification and mapping of camp sites from the Palaeolithic and Mesolithic is, due to their limited size and depth of burial, in practice troublesome. Mitigating measures to preserve those sites can therefore only be effected by excluding areas in which prehistoric landscapes have been preserved intact and which are considered to have a high probability for containing those sites.

Should further investigations be carried out from archaeological point of view and what are the recommendations on the scope and specifications of these investigations?

Additional research in the form of a geophysical survey is standard in the process of archaeological investigations. (in Dutch: *Inventariserend veldonderzoek opwaterfase*). The scope and specifications for this geophysical survey are to be recorded in a mandatory Program of Requirements (PvE). Typical requirements include restrictions about the maximum range and minimum frequency of the side scan sonar, survey speed and line spacing.

[27] Beleidsregels ontgrondingen in Rijkswateren, see http://wetten.overheid.nl/BWBR0028498/

5 Summary and recommendations

The installation of the pipelines may affect archaeological remains in the area, if present. According to the Law on Archaeological Heritage (Dutch: Erfgoedwet 2016) there is a statutory obligation to conduct archaeological research in order to protect the remains. This archaeological desk study is the first step in the archaeological process aiming to establish whether archaeological remains are, or are likely to be, present, and whether these remains could be effected by the development of the planned pipelines. The results are summarized below.

The area of interest has a high expectation for the presence of (remains of) ship wrecks and WWII plane wrecks. Intact prehistoric landscapes and related *in situ* remains of Palaeolithic and Early Mesolithic camp sites and inhumations are expected to have been preserved in places.

The proposed pipeline routes have not been investigated by detailed geophysical surveys yet. These areas may contain more undiscovered shipwrecks or remains of shipwrecks than currently known.

At this stage little is known about the integrity of the *Pleistocene* and Early *Holocene* landscapes. By means of subbottom profiling the occurrence geological units (both horizontal as vertical) and archaeological levels herein can be mapped. The character of layer boundaries (erosive or non-erosive) can be interpreted. It is unlikely however that archaeological remains of Palaeolithic and Mesolithic camp sites can be identified with sufficient certainty (based on the geophysical and geotechnical surveys) to impose restrictions on pipeline development. At this stage focus should therefore not be put on tracing prehistoric camp sites but on a pragmatic employment of geophysical techniques in order to obtain a better insight in (the integrity of) the *Pleistocene* landscape. The insights gained shall be used to a) refine the archaeological expectancy model and b) allocate areas with a high expectancy for *in situ* prehistoric remains.

In accordance with the AMZ cycle it is advised to conduct a field investigation (in Dutch '*Inventariserend veldonderzoek opwaterfase*') in order to test the archaeological predictive model and further specify the type, vertical and lateral extent, age, integrity and preservation of ship wrecks, prehistoric landscapes and potential archaeological levels.

Archaeological Expectancy	**Method**		**Goal**	**Remarks**
Ship and aircraft wrecks	Geophysical	Side Scan Sonar	detect and map wreck sites	wrecks exposed at, or protruding from the seabed
		Multibeam	characterize wreck sites morphologically; detect (partially) buried wrecks by the occurrence of scours	in addition to side scan sonar
		Sub-bottom Profiler	detect buried objects including possible ship wrecks and remains of aircraft	nature of the buried object cannot be determined directly
		Magnetometer		
Prehistoric settlements (camp sites)		Sub-bottom Profiler	map the Pleistocene landscape; specify expectancy	supported by, and validated with drill data
	Geotechnical	Geological Drilling	determine lithostratigraphy, soil layer boundaries (erosive or gradual) and characteristics of soil formation and maturation; specify expectancy	designation of borehole and/or vibrocore locations for geo-archaeological research based on SBP data
		Cone Penetration Test	determine lithostratigraphy	correlate with drilling data

Table 6. Testing of archaeological expectation with geophysical and geotechnical methods

In general, similar investigations carried out in the past consist of a geophysical survey with *side scan sonar*, *magnetometer* and *subbottom profiler* and a geotechnical survey. The resulting data should be assessed after the general processing, interpretation and reporting has been performed by the survey contractor.

The archaeological assessment of the data shall to be conducted by a geophysical specialist (KNA prospector Waterbodems). The data quality from the surveys needs to match the demands for this archaeological assessment. To ensure compatibility between the site investigation and the required quality for this assessment it is recommended to define a Program of Requirements (In Dutch: ‘Programma van Eisen’) in accordance with the ‘KNA’ (the Dutch quality standards for archaeological research), to be authorized by the competent authority.

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Glossary and abbreviations

Terminology	**Description**
AMZ	Archeologische Monumenten Zorg
CPT	Cone penetration test
Ferrous	Material which is magnetic or can be magnetized, and well known types are iron and nickel
Holocene	Youngest geological epoch (from the last Ice Age, around 10,000 BC. To the present)
In situ	At the original location in the original condition
KNA	Kwaliteitsnorm Nederlandse Archeologie
Magnetometer	Methodology to measure deviations from the earth's magnetic field (caused by the presence of ferro-magnetic = ferrous objects)
Multibeam	Acoustic instrument that uses different bundles or beams to measure the depth in order to create a detailed topographic model
NoaA	Nationale Onderzoeksagenda Archeologie
NSPRMF	North Sea Prehistory Research and management Framework
Pleistocene	Geological era that began about 2 million years ago. The era of the ice ages but also moderately warm periods. The *Pleistocene* ends with the beginning of the *Holocene*
PvE	Program of Requirements (Programma van Eisen)
RCE	Rijksdienst voor het Cultureel Erfgoed
ROV	Remotely Operated Vehicle
Side scan sonar	Acoustic instrument that registers the strength of reflections of the seabed. The resulting images are similar to a black / white photograph. The technique is used to detect objects and to classify the morphology and type of soil
Current ripples	Asymmetrical wave pattern at the seabed caused by currents. The steep sides of the ripples are always on the downstream side.
Subbottom profiler	Acoustic system used to create seismic profiles of the sub surface.
Trenching	Construction of a trench for the purpose of burying a cable or pipeline
Vibrocore	A special drilling technique where a core tube is driven by means of vibration energy in the seabed. In addition, the core tube is provided with a piston so that the bottom material in the core tube remains in place.

References

Literature

- Busschers, F.S. 2008. Unravelling the Rhine. Response of a fluvial system to climate change, sea-level oscillation and glaciation. PhD Thesis, Vrije Universiteit Amsterdam, 184 p.
- Busschers, F.S., C.W. Dubelaar, J. Stafleu en D. Maljers, 2010: Lithological and sand grain-size variability in the three-dimensional GeoTOP model of Zuid-Holland, Delft.
- De Mulder, E. e.a., 2003: *De ondergrond van Nederland*, Groningen.
- Deeben, J., D.P. Hallewas & Th.J. Maarleveld, 2002: Predictive modelling in Archaeological Heritage Management of the Netherlands: the Indicative Map of Archaeological Values (2nd Generation), Berichten van de Rijksdienst voor het Oudheidkundig Bodemonderzoek 45, 9-56.
- Forzoni, A., Vermaas, T., Mesdag, C., Hijma, M., de Lange, G. and de Kleine, M., 2017. Geological study Hollandse Kust (West) Wind Farm Zone).
- Gaffney, V.L., K. Thomson en S. Fitch, 2005: The Archaeology and geomorphology of the North Sea, Kirkwall.
- Hessing, W.A.M., 2005: Het Nederlandse kustgebied, in: Bechert, T en W.J.H. Willems (red.), De Romeinse rijksgrens tussen Moezel en Noordzeekust, 89-102.
- Hijma, M., 2009: From river valley to estuary, The early-mid holocene transgression of the Rhine-Meuse valley, The Netherlands, Netherlands Geographical Studies 389, Utrecht.
- Huizer, J. en H.J.T. Weerts, 2003: Formatie van Maassluis, In: Lithostratigrafische Nomenclator van de Ondiepe Ondergrond, Geologische Dienst Nederland (DINOloket).
- IMAGO projectgroep, 2003: Eindrapportage IMAGO: Samenvatting en conclusies, RDIJ rapport 2003-13a.
- Kasse, C., W.Z. Hoek, S.J.P. Bohncke, M. Konert, J.W.H. Weijers, M.L. Cassee and R.M. van der Zee, 2005. Late Glacial fluvial response of the Niers-Rhine (western Germany) to climate and vegetation change. Journal of Quaternary Science 20 (4): 377-394.
- Kramer, E. e.a., 2003 (red.): Koningen van de Noordzee, 250-850, Leeuwarden / Nijmegen.
- Laban, C. 2004: Top Pleistocene Formations map. Netherlands Institute of Applied Geoscience TNO. Department of Geo Marine and Coast. Utrecht.
- Louwe Kooijmans, L.P., 1970-1971. *Mesolithic Bone and Antler Implements from the North Sea and from the Netherlands*.- Berichten van de Rijksdienst voor het Oudheidkundig Bodemonderzoek, 20-21: 69-70.
- Maarleveld, Th. J. en E.J. van Ginkel, 1990: Archeologie onder water, het verleden van een varend volk, Amsterdam.
- Maarleveld, TH.J. , Almere 1998: Archaeological heritage management in Dutch waters: exploratory studies.
- Makaske, B., NAP, R.L. 1995. A transition from a braided to a meandering channel facies, showing inclined heterolithic statification (Late Weichselian, central Netherlands). Geologie en Mijnbouw, 74, 1-8.
- Niekus, Marcel J. L. Th., Paul R. B. Kozowyk, Geeske H. J. Langejans, Dominique Ngan-Tillard, Henk van Keulen, Johannes van der Plicht, Kim M. Cohen, Willy van Wingerden, Bertil van Os, Bjørn I. Smit, Luc W. S. W. Amkreutz, Lykke Johansen, Annemieke Verbaas, Gerrit L. Dusseldorp, 2019: Middle Paleolithic complex technology and a Neandertal tar-backed tool from the Dutch North Sea. Proceedings of the National Academy of Sciences 116(44).
- Peeters J.H.M., L.W.S.W. Amkreutz, K.M. Cohen and M.P. Hijma, 2019. North Sea Prehistory Research and Management Framework (NSPRMF) 2019. Retuning the research and management agenda for prehistoric landscapes and archaeology in the Dutch sector of the continental shelf. Nederlandse Archeologische Rapporten (NAR) 63
- Rieu, R., van Heteren, S., van der Spek, J.F., and de Boer, P.L., 2005: Development and preservation of a Mid-holocene Tidal-Channel Network Offshore the Western Netherlands. Journal of Sedimentary Research, 75-3, p 409-419.

- Rijsdijk, K.F, S. Passchier, H.J.T. Weerts, C. Laban, R.J.W. van Leeuwen & J.H.J. Ebbing, 2005: Revised Upper Cenozoic stratigraphy of the Dutch sector of the North Sea Basin: towards an integrated lithostratigraphic, seismostratigraphic and allostratigraphic approach. Netherlands Journal of Geoscience 84-2, p 129-146
- Schüttenhelm, R.T.E.and Laban, C. 2005. Heavy minerals, provenance and large scale dynamics of seabed sands in the Southern North Sea.
- Thal, J., Socko, L., Feldmann, S, Brock, J. P. (2018). Geological Desk Study for the Hollandse Kust (west) Wind Farm Zone. Arcadis Nederland B.V. and Geo-Engineering.org GmbH, 180017. Netherlands Enterprise Agency. (RVO).
- Thal, J., Feldmann, S., Brock, J. P. (2019). Geological Desk Study for the IJmuiden Ver Wind Farm Zone. Arcadis Nederland B.V. and Geo-Engineering.org GmbH, 180017. Netherlands Enterprise Agency. (RVO).
- Törnqvist, T.E., Weerts, H.J.T., Berendsen, H.J.A. 1994. Definition of two new members in the upper Kreftenheye and Twente Formations (Quaternary, the Netherlands): a final solution to persistent confusion? Geologie en Mijnbouw, 72, 251-264.
- Van de Noort, R., 2011. North sea archeaeologies: A maritime biograph, 10,000 BC to AD1500. Oxford university press
- Van den Brenk, S., B.E.J.M. van Mierlo en W.B.Waldus, 2008. Archeologisch bureauonderzoek aanleg windturbinepark Tromp-Binnen en kabelroutes naar de Nederlandse kust. Periplus Archeomare rapport 08A014
- Van Lil, R. en van den Brenk, S., 2014. Windturbinepark Q4 en kabelroute naar de Nederlandse kust. Periplus Archeomare rapport 14A021
- Van Lil, R. en van den Brenk, S., 2018. Net op Zee Hollandse kust (Noord) and (west Alpha), offshore export cable routes. Periplus Archeomare report 18A013-01 (English)
- Verhart, L., 2005: Een verdronken land. Mesolithische vondsten uit de Noordzee, in: Louwe Kooijmans, L.P. e.a. (red.), de Prehistorie van Nederland, 157-160.
- Vonhögen-Peeters, L.M., S. van Heteren and J.H.M. Peeters, 2016. Indicatief model van het archeologische potentieel van de Noordzeebodem. Deltares rapport 209133-000
- Waasdorp, J.A., 1999: Van Romeinse soldaten en Cananefaten, Den Haag.
- Zijverden, W.K. van, 2017: After the deluge, a palaeogeographical reconstruction of bronze age West-Frisia (2000-800 BC), Leiden University dissertation, Leiden.

Atlases and Maps

- GeoTOP-model Laag van Wijchen en Hollandveen Laagpakket
- Globale Archeologische Kaart van het Continentale Plat

Sources from the Internet

- Dienst der Hydrografie (www.hydro.nl)
- Geologische Dienst Nederland - Data Informatie Nederlandse Ondergrond (www.dinoloket.nl)
- Noordzeeloket (www.noordzeeloket.nl)
- North sea paleolandscapes, University of Birmingham (http://www.iaa.bham.ac.uk)
- Olie en Gasportaal (www.nlog.nl)
- Stichting Aircraft recovery Group 40-45 (http://www.arg1940-1945.nl)
- Stichting Infrastructuur Kwaliteitsborging Bodembeheer (SIKB.nl)
- Stichting Maritiem Historische Databank (http://www.marhisdata.nl/)

Various sources

- Archis III, archeologische database Rijksdienst voor het Cultureel Erfgoed
- Databases Periplus Archeomare
- KNA Waterbodems 4.1
- Nationaal Contactnummer Nederland (NCN)
- SonarReg92, objectendatabase Rijkswaterstaat Zee en Delta

Appendix 1. Phases of maritime archaeological research

The Dutch Quality Standard for Archaeology (KNA waterbodems, version 4.1) describes all procedures and requirements for the archaeological research process. Below a brief description of the steps involved:

Desk study

The purpose of a desk study is to collect and report all available historical data, geological information and information about disturbances in the past. The result is an archaeological expectation map or model.
The desk study may be expanded with an analysis of sonar and multibeam data, if available.

IF the outcome of the desk study shows that there is a risk of occurrence of archaeology, then the next phase must be carried out:

Exploratory geophysical field research (opwaterfase)

In order to test the archaeological expectation, a geophysical survey is carried out. The type of survey depends on the type of expected objects, local geology and expected depth of the objects below the seafloor. In practice, the research usually consists of a side scan sonar survey, if necessary, supplemented with multibeam echo sounder recordings, subbottom profiling and magnetometer measurements. The requirements of the survey are based on the desk study and should be included in a program of requirements which must be approved by the competent authorities.

IF potential archaeological objects are found, then the next phase must be carried out:

Exploratory field research under water (onderwaterfase verkennend)

The suspected sites are investigated by specialized divers in order to identify the objects. The requirements of the underwater research are included in a program of requirements which must be approved by the competent authorities.

IF as site is identified as an archaeological object or structure then the next phase must be carried out:

Validating field research (onderwaterfase waarderend)

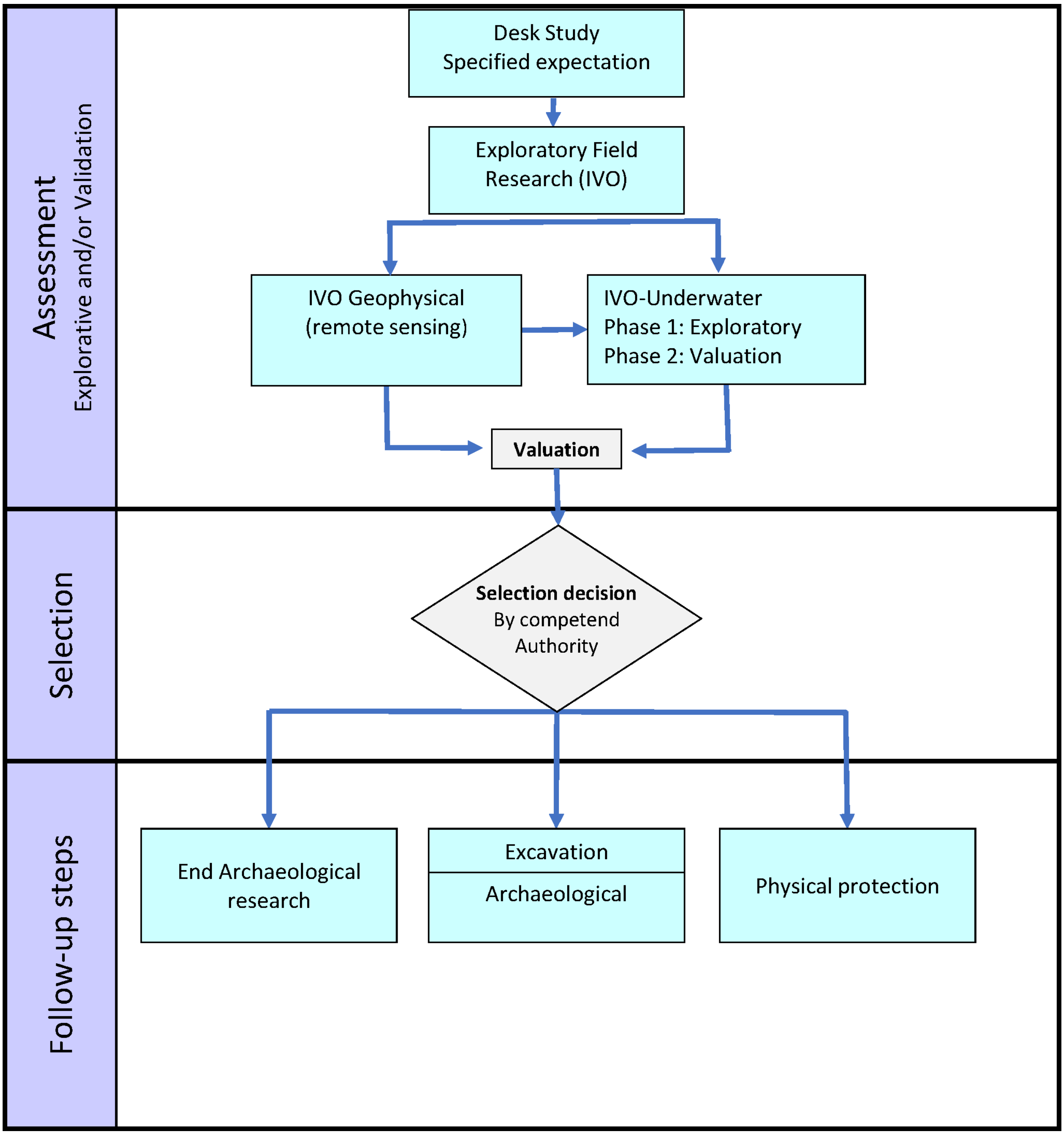
The archaeological remains at the site are thoroughly investigated and mapped by a specialized archaeological diving team and samples are collected for additional research. Then a decision will be made whether the archaeological remains are worth preserving. If the latter is the case, then there are two possibilities: either the remains can be preserved in situ (adjustment of plans) or the next phase will be conducted:

Archaeological excavation

The archaeological remains are excavated under supervision of a senior maritime archaeologist. All remains need to be documented, registered and conserved. The requirements of the underwater research are included in a program of requirements which must be approved by the competent authorities.

The phases described above contain a number of decision points that are dependent on the detected archaeological objects and structures. The figure on the next page shows these moments schematically.

Schematic overview KNA Waterbodems version 4.1



Appendix 2. Archaeological and geological periods and time scale

Chronostratigrafie

Serie	Etage - Chronozone			Tijd
Holoceen	**Laat Subatlanticum**			**1150 n. Chr**
Holoceen	Vroeg Subatlanticum			0
Holoceen	Vroeg Subatlanticum			450 v. Chr
Holoceen	Subboreaal			3700
Holoceen	Atlanticum			7300
Holoceen	Boreaal			8700
Holoceen	Preboreaal			9700
Pleistoceen	Weichselien	Laat Glaciaal	Jonge Dryas	11.000
Pleistoceen	Weichselien	Laat Glaciaal	Allerød	12.000
Pleistoceen	Weichselien	Laat Glaciaal	Oude Dryas	12.100
Pleistoceen	Weichselien	Laat Glaciaal	Bølling	13.000
Pleistoceen	Weichselien	Pleniglaciaal L		17.000
Pleistoceen	Weichselien	Pleniglaciaal L	Late Glacial Max	20.000
Pleistoceen	Weichselien	Pleniglaciaal L		31.500
Pleistoceen	Weichselien	Pleniglaciaal L	Denekamp	34.000
Pleistoceen	Weichselien	Pleniglaciaal M		40.000
Pleistoceen	Weichselien	Pleniglaciaal M	Hengelo	41.500
Pleistoceen	Weichselien	Pleniglaciaal M		45.000
Pleistoceen	Weichselien	Pleniglaciaal V	Moershoofd	50.000
Pleistoceen	Weichselien	Pleniglaciaal V		71.000
Pleistoceen	Weichselien	Vroeg Glaciaal	Odderade	74.000
Pleistoceen	Weichselien	Vroeg Glaciaal		
Pleistoceen	Weichselien	Vroeg Glaciaal	Brørup	
Pleistoceen	Weichselien	Vroeg Glaciaal		
Pleistoceen	Weichselien	Vroeg Glaciaal	Amersfoort	
Pleistoceen	Weichselien	Vroeg Glaciaal		114.000
Pleistoceen	Eemien			126.000
Pleistoceen	Saalien			236.000
Pleistoceen	Oostermeer			241.000
Pleistoceen	onbenoemd			322.000
Pleistoceen	Belvédère			336.000
Pleistoceen	onbenoemd			384.000
Pleistoceen	Holsteinien			416.000
Pleistoceen	Elsterien			463.000

Archeologische periode

Tijdperk					Datering
Nieuwe tijd			C		1850
Nieuwe tijd			B		1650
Nieuwe tijd			A		1500
Middeleeuwen			Laat	B	1250
Middeleeuwen			Laat	A	1050
Middeleeuwen			Vroeg	D	900
Middeleeuwen			Vroeg	C	725
Middeleeuwen			Vroeg	B	525
Middeleeuwen			Vroeg	A	450
Romeinse tijd			Laat		270
Romeinse tijd			Midden		70 n. Chr.
Romeinse tijd			Vroeg		15 v. Chr.
Prehistorie	Metaaltijden	IJzertijd	Laat		250
Prehistorie	Metaaltijden	IJzertijd	Midden		500
Prehistorie	Metaaltijden	IJzertijd	Vroeg		800
Prehistorie	Metaaltijden	Bronstijd	Laat		1100
Prehistorie	Metaaltijden	Bronstijd	Midden		1800
Prehistorie	Metaaltijden	Bronstijd	Vroeg		2000
Prehistorie	Steentijd	Neolithicum	Laat		2850
Prehistorie	Steentijd	Neolithicum	Midden		4200
Prehistorie	Steentijd	Neolithicum	Vroeg		4900/5300
Prehistorie	Steentijd	Mesolithicum	Laat		6450
Prehistorie	Steentijd	Mesolithicum	Midden		8640
Prehistorie	Steentijd	Mesolithicum	Vroeg		9700
Prehistorie	Steentijd	Paleolithicum	Laat	B	12.500
Prehistorie	Steentijd	Paleolithicum	Jong	B	16.000
Prehistorie	Steentijd	Paleolithicum	Jong	A	35.000
Prehistorie	Steentijd	Paleolithicum	Midden		250.000
Prehistorie	Steentijd	Paleolithicum	Oud		

Appendix C

UXO desktop Study

Historical Desktop Study

Unexploded Ordnance (UXO)

Maasvlakte Aramis CCS Project

RO-220005 Report version 1.0 (final)
9th February 2022

Riel Explosive Advice & Services Europe B.V. • Vijfhuizenbaan 1b 5133 NH Riel Nederland
Postbus 21 5133 ZG Riel Nederland • T +31 (0) 13 518 6076 • www.reaseuro.com • info@reaseuro.com

Historical Desktop Study

Unexploded Ordnance (UXO)

Maasvlakte Aramis CCS Project

Client	:	Fugro GB Marine Limited
Label	:	74497 / RO-220005 version 1.0 (final)
Place, Date	:	Riel, 9th February 2022

REASeuro			
	Name/Function	Signature	Date
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	[redacted] Senior UXO expert	[redacted]	19th January 2022
Approved by	[redacted] Head of the Advice Department	[redacted]	9th February 2022
Fugro			
Accepted	[redacted] Manager Marine Geotechnics		

Front page image: Fragment of oblique aerial photograph showing Bristol Beaufighter's of the North Coates Strike Wing attacking a small enemy convoy off Terschelling, Holland. The nearest trawler is being attacked with cannon gunfire, and also with rocket projectiles fired by the aircraft from which the photograph was taken. Source: Imperial War Museum.

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SUMMARY

Historical research

The Central North Sea was the scene of several war related events during World War I and II. Among these are the sinking of a large amount of vessels and aircraft, bombing by planes, naval battles and the presence of minefields, military exercise zones and munition dumping grounds. Due to these events UXO may be located within the area of interest. The UXO items considered most likely to be present within the investigation area are shown in the overview below. Note that the overview shows the likelihood of presence of generic UXO types within the site based on the evidence available in the REASeuro GIS-Database at the time of writing this report.

UXO type	Likelihood of presence	Subtype / calibre	Remarks
Naval mines (WWII)	Feasible Probable	German E-Mine moored contact mines British Vickers / British Elia and H Mark II moored contact mines	The area of interest was situated between the British coast and Germany. During the First World War this area was a theatre of mine warfare. Multiple German and British minefields were laid within the area of investigation. This evidence supports a strong likelihood that naval mines are present within the boundaries of the known minefields. Outside these boundaries likelihood of presence is determined to be feasible.
Naval mines (WWII)	Probable Certain	British Mk I-IV ground mines and British Mk VII- VIII and Mk XIV German EMB, EMC, EMD, UMA, RMA, KMA contact mines German LMB Ground mines German Exploding Floats (and also non explosive sweep obstructors) Dutch Model 1921 ‘2e soort’	During the Second World War the area of interest was situated between the British oast and the German occupied coasts of Europe. During the Second World War this area was once again a theatre of mine warfare. Multiple German and British minefields (filled with mines and sweeping obstructers) were laid within the area of investigation. Primary sources lead to the conclusion that within the boundaries of the known minefields, the likeliness of presence of naval mines is certain. Outside these boundaries likelihood of presence is determined to be probable.
Aerial bombs	Certain Probable	4 lbs, 25 lbs, 30 lbs, 100 lbs, 250 lbs, 260 lbs, 300 lbs, 500 lbs, 1.000 lbs, 4.000 lbs	During the Second World War, aerial warfare played a huge factor. Research shows that a large amount of allied airstrikes took place in the area of investigation. Depending on the target bombs, rockets, torpedoes and depth charges could be deployed. Besides airstrikes, allied aircraft often jettisoned bombs over the North Sea. At least one direct indication of jettisoning in the area of investigation has been derived from the historical sources. Indirect indications are plentiful. Due to the large amount of sources stating attacks near the convoy routes it is deemed certain that UXO as a result of aerial warfare might still be present near these convoy routes. In the rest of the area of investigation the likelihood of presence of UXO is deemed probable due to the large amount of jettisons in the North Sea.
Rockets	Certain Probable	3 inch rocket with 25 lbs or 60 lbs (SAP) warhead	
Under water ammunition	Certain Probable	18 inch torpedo Mk XV Depth charge	

UXO type	Likelihood of presence	Subtype / calibre	Remarks
Artillery Shells Small calibre ammunition (Naval weaponry)	Probable Remote	Small Calibre Ammunition .303 .50 13,2 mm 15 mm Artillery Shells 2 cm/20 mm 2 pr. pompom 3.7 cm 6 pr. 8.8 cm	As mentioned, German shipping was attacked regularly by Allied aircraft. As a countermeasure German ships were equipped with anti-air (machine)guns. Due to the deployment of these guns, UXO might be present near the commonly used German convoy routes. Outside of these convoy routes the likelihood of presence of UXO is deemed remote. This statement is further enhanced by the fact that British surface craft tried to infiltrate the German convoy routes and, in some instances, fought small scale naval battles with German ships.
Artillery Shells	Probable Negligible	Coastal guns: 5 cm 7,5 cm 9,4 cm 10,5 cm 12 cm 14,91 cm 15 cm 15,2 cm 24 cm 28 cm	After the German occupation coastal guns were installed along the Dutch coast as part of the *Atlanikwall*. The coastal guns covered the whole coast in order to repel a possible Allied attack. Due to exercises and combat UXO of artillery shells could be present within the area of investigation. However, UXO could only have reached as far as the range of the coastal guns. Within range of the coastal guns the likelihood of presence is deemed to be probable, outside of this range the likelihood of presence is deemed negligible.
Unknown (exercise) munition	Certain Negligible	Each military exercise zones had it's own purpose, it is outside the scope if this research to determine the munition used in each zone.	Within the area of investigation there were several military exercise zones. Some were already in use by German troops during the Second World War, others taken into use by the Dutch military after the war. It is deemed certain that UXO of (exercise) munition is still present within the boundaries of the military exercise zones, outside these zones the presence of UXO of (exercise) munition is deemed negligible.
Unknown dumped munition	Certain Probable Negligible	-	A total of three known munition dumping grounds overlap with the area of investigation. Sources state that fishermen found munition outside of the dumping grounds, therefore a buffer of three nautical miles was projected around dumping grounds. 'Fishing, intrusive, and seismographic activities' were deemed dangerous within this buffer. The presence of munition dumping grounds lead to the determination of a UXO Risk Area at the location of the dumping ground. The likelihood presence of UXO at this location is deemed certain. Within the buffer of three nautical miles this likelihood presence is deemed probable, in the rest of the area of investigation the likelihood presence is set to negligible.

Table 1: UXO items likely to be encountered in the area of interest.

1 GENERAL INFORMATION

This chapter describes the context and goal for the Historical Desktop Study–Unexploded Ordnance (HDTS-UXO). Furthermore the area of investigation, the area of interest, the purpose and methodology are described. The chapter concludes with a general structure of the report.

2.1 INTRODUCTION

Fugro has invited REASeuro to conduct an HDTS-UXO for the CCS Aramis project. The plans are to build a new pipeline from Maasvlakte (man-made westward extension of the Europoort port and industrial facility within the Port of Rotterdam) to offshore blocks L4/K6. To obtain insight in the possible chance of encountering UXO during this project, Fugro Survey B.V. has requested REASeuro to provide a HDST-UXO.

2.2 AREA OF INTEREST AND AREA OF INVESTIGATION

The area of interest is located off the Maasvlakte, Netherlands to offshore blocks L4/K6, located within the northwestern part of the North Sea. The area of investigation is the given radius, based on the inaccuracies inherent to conducting offshore desk research. The positions of naval minefields, air strikes, crashes and convoy routes in historical sources are given approximately only, since navigation equipment was not nearly as accurate as it is in modern systems. The most common method of marking locations during the World Wars was based on decimal degrees, which were accurate down to 1 naval mile (1,852 meters). Another way of positioning is found in German sources, which are based on the German Naval Grid (*Kriegsmarine Quadranten*), with a grid size of 6x6 nautical miles. Historical sources based on this grid thus position war related events in an area of 123 square kilometres.

Besides these inherent inaccuracies from historical sources, one must take into account the displacement of UXO on the seabed. Bottom trawling, tides and currents, and recent developmental activities may have caused this displacement. The area of interest and research area are shown in Figure 1.

Figure 1: Area of interest and area of investigation (Source of base map: ESRI).

2.3 PURPOSE AND MAIN OBJECTIVES

The HDTS-UXO will be performed with sources which are currently in the REASeuro-database and open sources in a short amount of time. Therefore, it provides an indication if UXO might be present in the Area of interest. By conducting the sources which are mentioned above, historical research will be conducted on the war-related events that took place within the Area of Interest. More specifically, the HDTS-UXO will provide historical research on:

- Aerial attacks on ships
- Airplane crashes
- Shipwrecks
- Laying of minefields (WWI, WWII)
- Dumping of UXO
- Military zones

The starting point of REASeuro is, that the presence of UXO cannot be excluded. In the HDTS-UXO REASeuro will examine whether this premise is true and if there are areas with an increased risk of UXO. Based on the historical sources, the possible calibres and type of UXO are determined which could be present within the Area of Interest.

The HDTS-UXO will provide historical research on:

1. The military events, battle activities, aerial attacks on ships, airplane crashes, shipwrecks, laying of minefields (WWI, WWII), dumping and submarine activities.
2. The possible calibres and type of expected UXO.

3 APPRAISAL OF HISTORICAL SOURCES

This chapter describes the consulted sources. Detailed information extracted from each source is included within the annexes. Information extracted from the sources, results in an overview of relevant war events. These events are the starting point for the review and analysis of sources in chapter 4 of this historical research.

3.1 METHODOLOGY OF HISTORICAL RESEARCH

This research report is conducted in accordance with the Dutch CS-OOO regulations for UXO research and REASeuro's internal standards for offshore desk top studies. War related events that took place in the area of investigation are derived from historical sources, and subsequently analysed. Based on this analysis a UXO risk area may be demarcated.

Due to several years of experience with offshore research, REASeuro has built up a substantial database regarding war related events in the North Sea. A multitude of sources are consulted for this report. All consulted sources are listed and explained in paragraph 2.2.

The research has been conducted by an historian. Page 1 of this report mentions the involved experts. ArcGIS Pro version 2.9.0[1] has been used as a tool to conduct this research. Historical maps and other information have been gathered and projected in this geographical information system for analysis[2]. GIS is also used to position and clarify the relevant war related events mentioned in the list of war related events in chapter 3.

3.2 SOURCES

For more than twenty years, REASeuro has collected historical sources regarding war-related events within the North Sea. Many of these sources have been made available for historical research through an internal database in our own Geographical Information System (GIS). This database contains a wide variety of sources. The following sources will be consulted for the HDTS-UXO:

Sources
Literature • Maps and charts regarding minefields
Nationaal Archief, The Hague, The Netherlands • Coastal guns
Noorzeeloket, The Netherlands • Military zones
Dienst der Hydrografie, Koninklijke Marine, The Netherlands • Wrecks • Military zones
Nederlands Instituut voor Militaire Historie, The Hague, The Netherlands • Minefields
Marinemuseum, Den Helder, The Netherlands • Coastal guns
Bundesarchiv-Militärarchiv, Freiburg, Germany • ZA 5 Deutscher Minenräumdienst (German Minesweeping Administration) – mine-clearance operations
The National Archives, Richmond, United Kingdom • Bomber Command: aerial attacks and minelaying within the North Sea

[1] Mentioned as 'GIS' throughout this report.
[2] Historical charts are "georeferenced" in GIS and used for this report. Georeferencing is the name given to the process of transforming a scanned map or aerial photograph so it appears "in place" in GIS. By associating features on the scanned image with real world x and y coordinates, the software can progressively warp the image so it fits to other spatial datasets. For this research, historical charts have been georeferenced by distinguishing points of recognition on both the historical and present maps and placing 'those points together' so that both maps align. Since several of these charts are hand-drawn or lack exact coastlines, inaccuracies may occur and exact inaccuracies in meters could not be given.

• Coastal Command: aerial attacks and minelaying within the North Sea • Squadrons: Loss charts
National Archives and Records Administration, College Park (MD), United States • Documents from the US Army Air Forces (USAAF)
Beneficial Cooperation - The Royal Netherlands Navy and the Belgian Navy • UXO-clearance operations • Military zones
OSPAR-convention • UXO-clearance operations
Wrecksite • Locations of wrecks (airplanes/ships etc.) within the North Sea
UK Hydrographic Office • Charts regarding minefields • Charts regarding naval routes
Library of Congress • Charts regarding minefields

Literature
An overview of used literature can be found in Annex 2. Literature is consulted in order to get a general depiction of the war related events (especially the laying of minefields) within the area of investigation. The resulting events are shown in chronological order in tables. The references (book and page) for each event are included in the tables.

Nationaal Archief, The Hague, The Netherlands
The Dutch National Archives have been consulted for more information on the coastal guns on the Dutch Coast.

Noordzeeloket, The Netherlands
The Noordzeeloket is a comprehensive website, covering relevant Dutch maritime policy related North Sea information. On the website relevant information about the locations of Voormalige munitiestortplaatsen (Former munitions dump locations), Oefengebieden Mijnenruimen (Mine clearance training areas), (Laag)vlieggebieden ((Low) flying areas) and Schietterrein / onveilige zone (Shooting site / unsafe area) is available.

Dienst der Hydrografie, Koninklijke Marine, The Netherlands
Naval charts of the area of analysis have been acquired through the Hydrographic Service. Besides naval charts regarding military usage the HP39 (wreck registry) publication has been consulted to gain information on possible wrecks in the area of investigation.

Nederlands Instituut voor Militaire Historie, The Hague, The Netherlands
The 'Nederlands Instituut voor Militaire Historie' has been consulted on information about Dutch naval minefields.

Marinemuseum, Den Helder, The Netherlands
The map collection of the Marinemuseum (Navy Museum) in Den Helder has been consulted. NEMEDRI-maps were found in this collection. These maps offer information on minesweeping after the Second World War. The NEMEDRI maps show some information about mine clearance shortly after the war.

Bundesarchiv-Abteilung Militärarchiv (BAMA) in Freiburg
The German military archives were severely damaged during World War II. The remains of the archives are kept and maintained in the Bundesarchiv in Freiburg. The archives of the German navy (*Kriegsmarine*) survived the war relatively well compared to the other service branches. These have been consulted for this

desktop study, as well as the German Air Force (*Luftwaffe*) archives, of which only 2% of the documents survived the war. Annex 4 contains the relevant information from the BAMA.

The National Archives (TNA) in Londen

The National Archives have been consulted for information on naval minefields, air strikes, naval combat, bomb jettisoning and other relevant war related events. The Admiralty, War Cabinet and Air Ministry archives have been consulted for this information. Annex 4 contains relevant results from TNA.

National Archives and Records Administration (NARA) in College Park (MD)

Research has been conducted in the US National Archives and Records Administration. The NARA has been consulted for documents from the US Army Air Forces (USAAF) and for the collection of captured German records. Annex 4 contains the relevant information from the NARA.

Beneficial Cooperation - The Royal Netherlands Navy and the Belgian Navy

The Dutch navy is working with the Belgian navy to keep the sea, coastal waters and harbour mouths free of mines. Therefore, the UXO-related interventions in the database of the Beneficial Cooperation is consulted.

Post-war UXO clearance: OSPAR

The area of interest is situated in the North Sea. Therefore, the UXO-related interventions in the database of the OSPAR Commission[3] were consulted. The results are shown in Annex 4.

Wrecksite

The wreck site is the world's largest online wreck database. The website has information about 205.740 wrecks around the world. When information about the reason for the sinking of a ship is known, it is mentioned on the website.

UK Hydrographic Office

The UK hydrographical office maintains a collection of historical naval charts, including charts that contain minefields and convoy routes. Naval charts showing the area of investigation have been consulted, but no map has been found with information regarding the area of interest.

Library of Congress

On the website of the Library of Congress, which is known as the national library of the United States, a chart has been consulted regarding minefields in the First World War. This chart is shown in Annex 5.

[3] The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR-convention) provides a framework for reporting encounters with conventional and chemical munitions in the OSPAR maritime area.

4 ANALYSIS OF WAR RELATED EVENTS

The consulted historical sources (see annexes) indicate several war related events within the area of interest. The war related events derived from the historical sources that are relevant for the area of interest are listed categorically in the tables underneath. The events are grouped into four categories: war at sea, the air war, naval mines, and other UXO-related events. Following these tables per category, the UXO type and likeliness of presence within the area of interest is determined. Before each category is analysed below, the method of defining UXO risk areas is explained.

Defining the UXO risk area

The UXO items considered most likely to be present within the area of interest are shown in each specified category. Note that the table at the end of each paragraph shows the probable presence of generic UXO types within the site based on the evidence gathered about potential UXO sources. It's important to recognise that the presence of a UXO type does not necessarily mean that it will be encountered. The likelihood of encounter (i.e. a positive interaction with the UXO during a specific project activity), will generally be less than the probability of items of that particular UXO type being present across the whole area of interest; given that the actual footprint of the anchor locations will be less than the total investigation area volume. In the following table the terminology used for the likely presence of UXO is shown.

"Presence" Term	Meaning
Negligible	No evidence pointing to the presence of this type of UXO within an area but it cannot be discounted completely.
Remote	Some evidence of this type of UXO in the wider region but it would be unusual for it to be present within the area of study.
Feasible	Evidence suggests that this type of UXO could be present within the area.
Probable	Strong evidence that this type of UXO is likely to be present within the area.
Certain	Indisputable evidence that this type of UXO is present within the area.

Table 2: Definitions of terminology used for the likely presence of UXO.

Condition of expected UXO

The majority of the expected UXO are likely to be in an armed condition. This means that the safety devices preventing the UXO from premature detonation, e.g. during handling, have been removed. Therefore, the explosive train, is in line.

The explosive train is a sequence of events that culminates in the detonation of explosives and can be different for each type of UXO:

- In the case of aerial bombs which were dropped by aircraft in distress situations, the bombs could have been dropped with safety features still in place, however they still present an explosive risk, e.g. as a result of corrosion of vital safety features.
- Some of the expected UXO, e.g. naval munitions, contain a large quantity of explosives and may be encountered in very poor condition as the thin metal casings may have severely eroded. In many cases, the explosive capability could remain more or less undiminished. Some explosive charges neither absorb nor dissolve in water, and some charges do. However, stability of the explosive charge may have deteriorated with age.
- Naval contact mines from the period of interest typically contained a dry cell battery with an electrical detonating circuit which was connected to external conventional switch horns. These batteries will have now deteriorated and no longer have the ability to supply sufficient power to function. However, the condition of the explosives can be unstable.
- Contact mines with Hertz Horns were also common from World War I and onwards. Each horn contains a container of acid. Heavy contact with the horn can brake the acid container within, which

subsequently energizes a battery and detonates the main charge. Therefore, this type of mine (like all other UXO) must be handled with extreme caution.

Although corrosion can make a UXO more sensitive, it can also make it less likely to detonate, as i.e. electrical wiring may have corroded resulting in a break in the explosive train. As a wide range of UXO can be expected, all UXO must be handled with extreme caution until the exact state is determined after positive identification by an EOD-expert.

4.1 NAVAL MINES

Naval mines were laid in the North Sea during the First and Second World War. The purpose was twofold. Mines were used in a defensive way to protect own waters and ports and to hold off enemy ships. At the same time, mines could be used to harass enemy shipping and obstruct military movements. Mines could be laid by surface ships, submarines and aircraft. During the First World War moored contact mines were used almost uniquely. Moored mines float beneath the water surface and are kept in position with an anchor and anchor cable. This technique was also used during the Second World War. Next to contact mines, the belligerent parties developed influence mines. These mines were laid on the sea bottom and would detonate if sensors in the mine detect a difference in pressure, sound, or magnetism caused by a passing ship.

The area of investigation has overlap with a suspected British minefield from the First World War and several German minefields from the Second World War. These minefields, the post-war clearance and UXO encounters are discussed in the next paragraphs. A conclusion is added in paragraph 4.1.4.

4.1.1 First World War

A map from the Library of Congress (see Annex 3) shows two minefields on relatively large distance from the area of investigation. It was a large German minefield (red, marked with a '3') lying along the Dutch coast. The map title (see subscript of Figure 2) explains that only the approximate position of the minefield is showed. The presence of the minefield is confirmed in the book *The Hidden Threat* (see Annex 2). According to this book 664 mines were laid in the field. No information about the exact type of mines was found, but the belligerent parties during the First World War used almost uniquely moored contact mines.

The second Minefield was British (bordered in red, northeast of the area of investigation). The border indicates an area in which multiple smaller minefields were laid. The mined area, the German Bight, was a major theatre of naval warfare during World War I. British forces laid 42.899 naval mines in the Bight. Only few German minefields can be found in the German Bight.

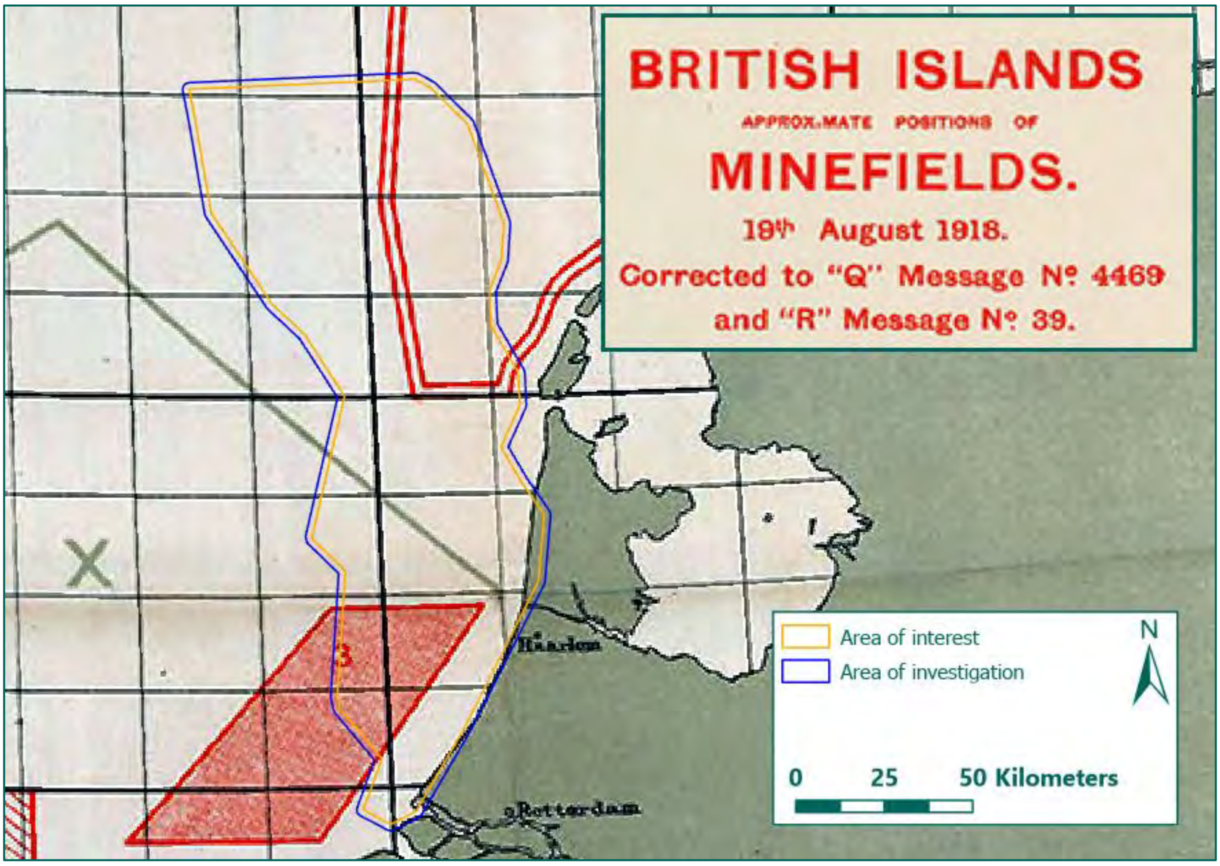


Figure 2: Cutout of the map *British Islands. Approximate position of minefields*, *19th August 1918,* showing minefields around the British Islands (Source: Library of Congress).

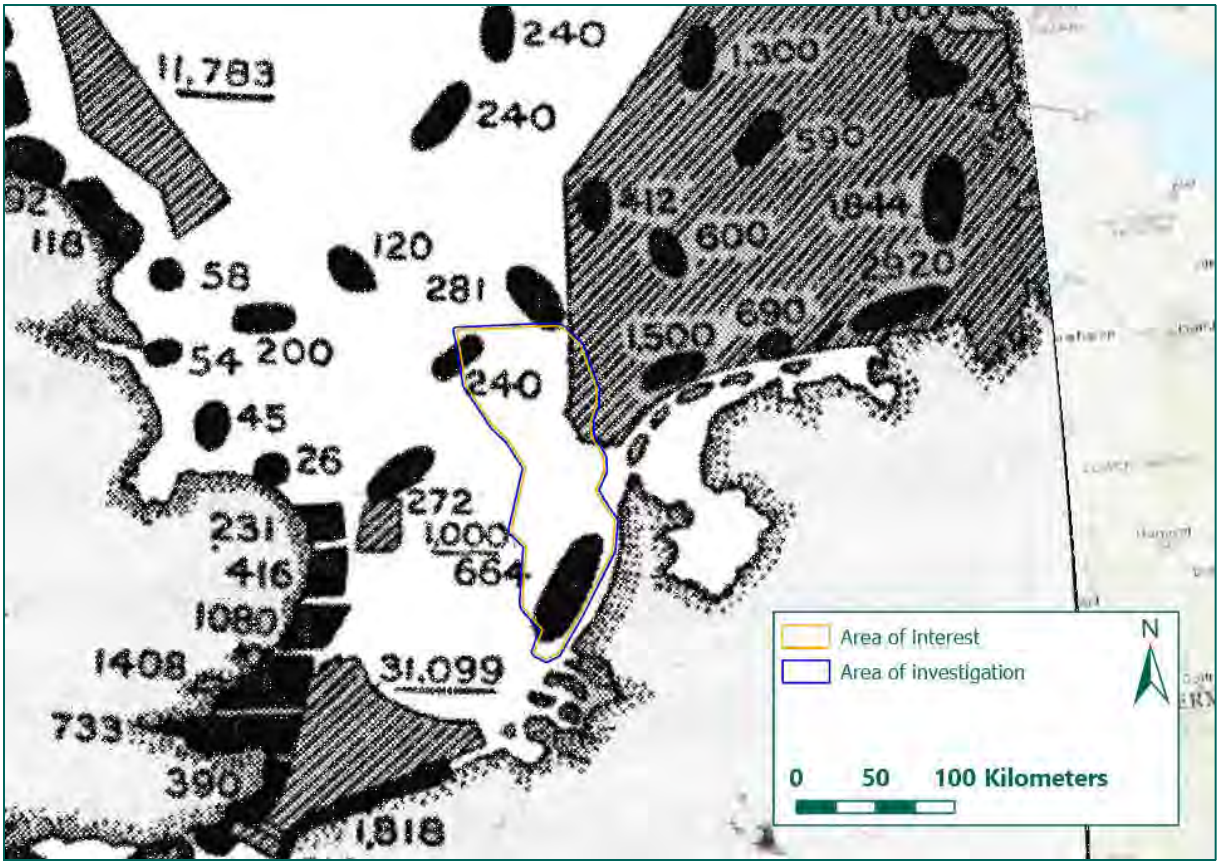


Figure 3: British, German and American mines laid during the First World War (Source: Literature CRO 62).

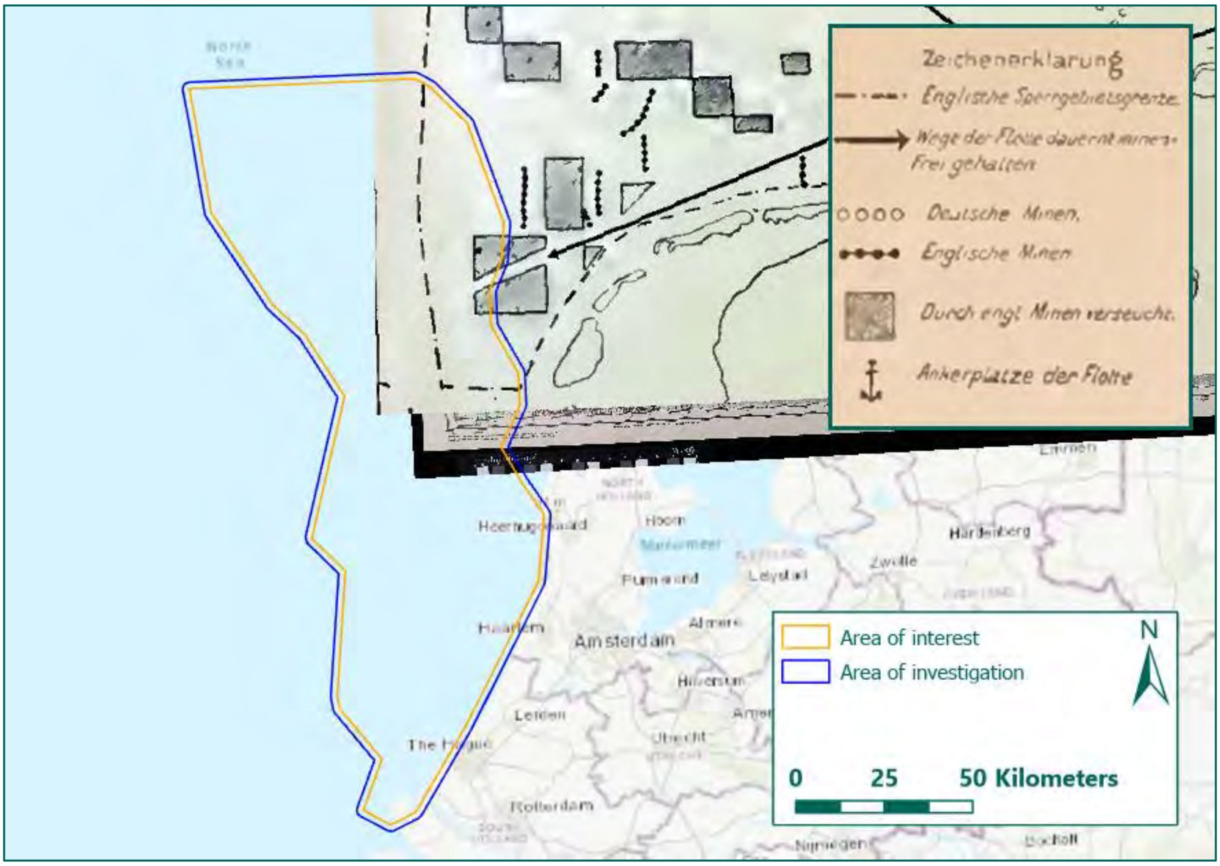


Figure 4: Details about minefields near the Dutch coast (Source: Literature SCH 288)

According to German sources derived from the Bundesarchiv, the area of investigation has overlap with an area which is suspected to have been mined. Reports from the *Kommando der Hochseestreitkräfte* (Command of the Naval Forces) contain a map showing the minefield. *Treibende Minen* (Contact mines) were laid on the Dutch Coast. Additional information about these minefields is not given.

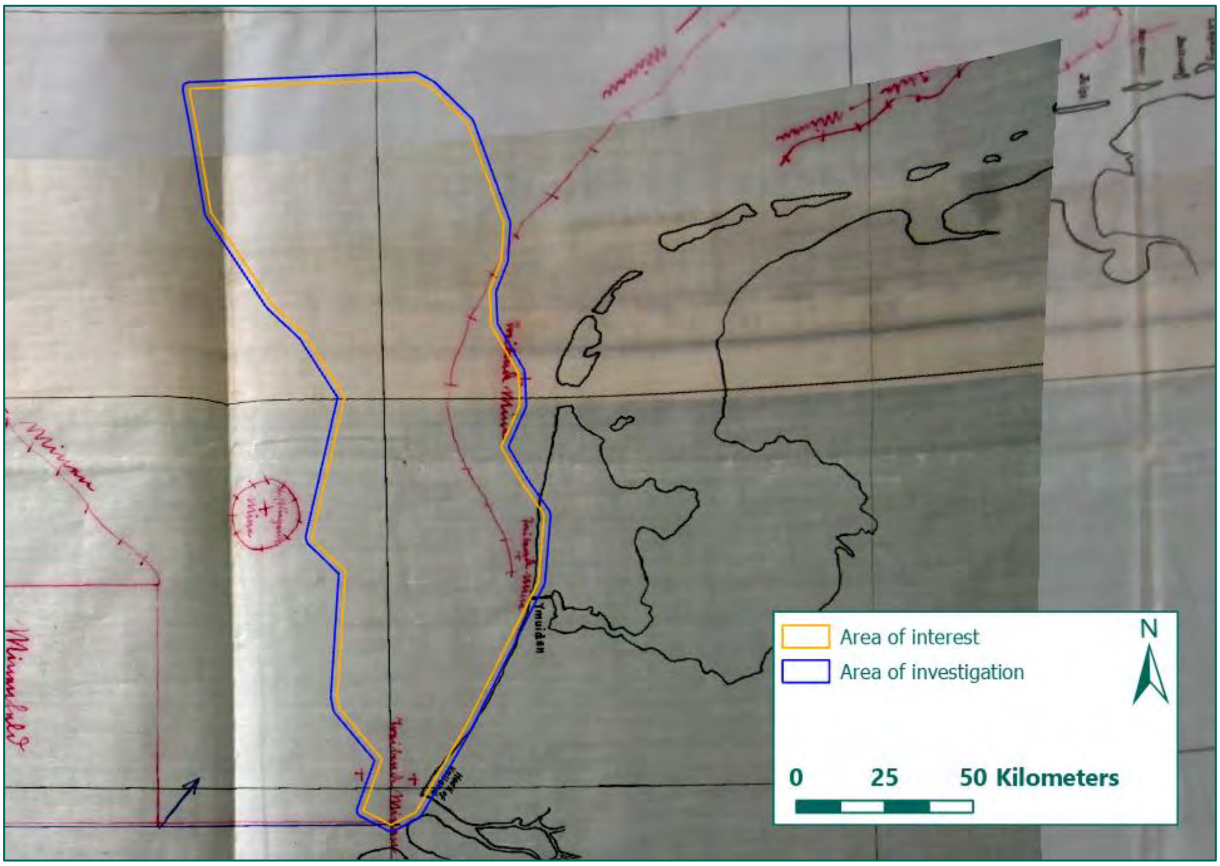


Figure 5: German map showing the suspected Allied minefield, according to the situation of March 1915 (Source: BaMa, RM 5/4721K).

During the First World War, a lot of mines broke loose from their anchor and drifted away. A total of 6.000 mines washed ashore on the Dutch beaches. Amongst those mines 4.981 were from British origin, 431 were German, 81 were French, and 500 mines were from other or unknown origins. It is estimated that no less than 240.000 mines have been spread out in the North Sea.

The information about minefields have been entered into our GIS-system. Relevant minefields within the area of investigation are shown below.

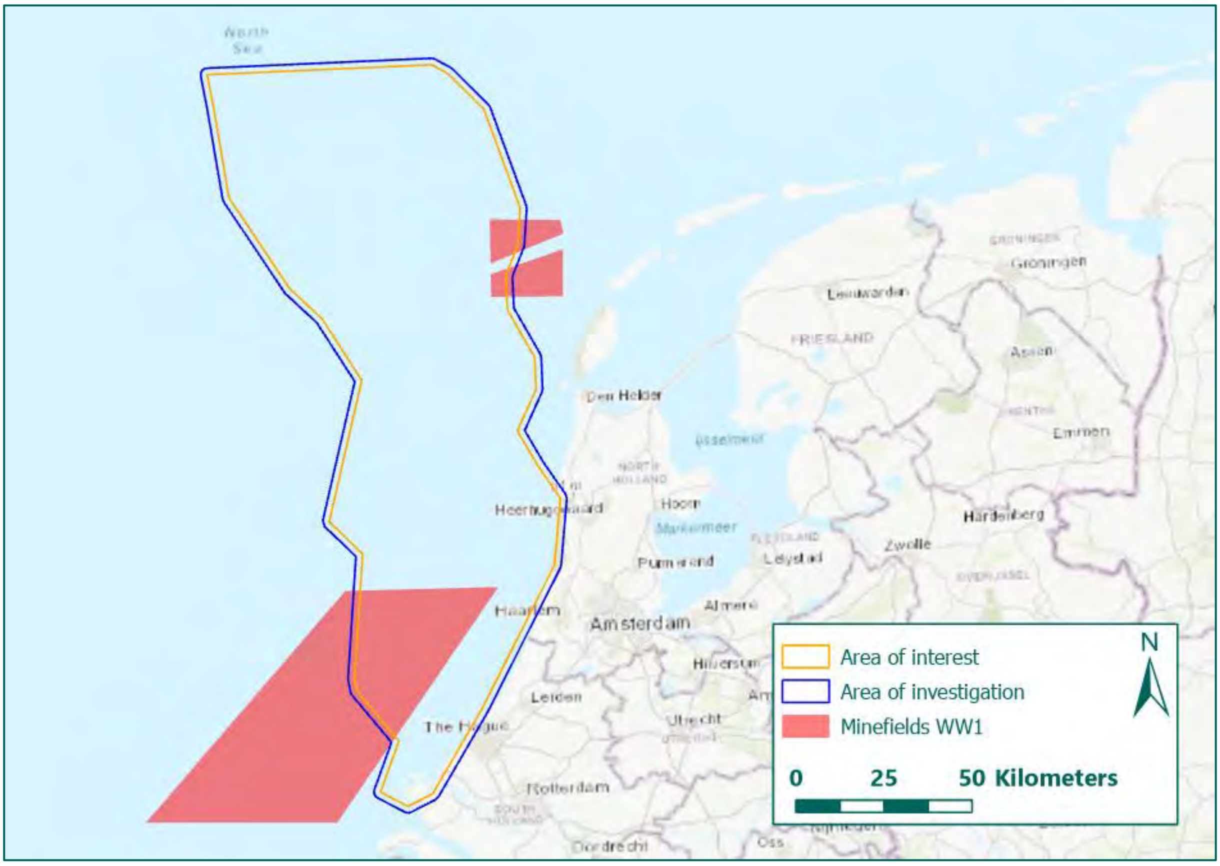


Figure 6: British and German minefields during WW1 (Source basemap: ESRI).

Records from The Dutch National Archives (see Annex 3) contain evidence that mines were present in the area of investigation during the First World War. On a map obtained in the "Nationaal Archief" (Dutch National Archives) it is shown that during 1914-1916 multiple Dutch ships ran onto mines. Most of these accidents happened outside of known minefields. One of these incidents occurred within the area of investigation. As can be seen in the figure below, the black dots indicate the locations where Dutch ships ran onto contact mines. Several black dots are visible within the area of investigation. However, no details have been provided about the ship that sunk at this location. Because there are no known minefields near the locations of the incidents, it is possible that the ships ran upon a contact mine that broke loose from the minefields seen in Figure 2, Figure 3, Figure 5.

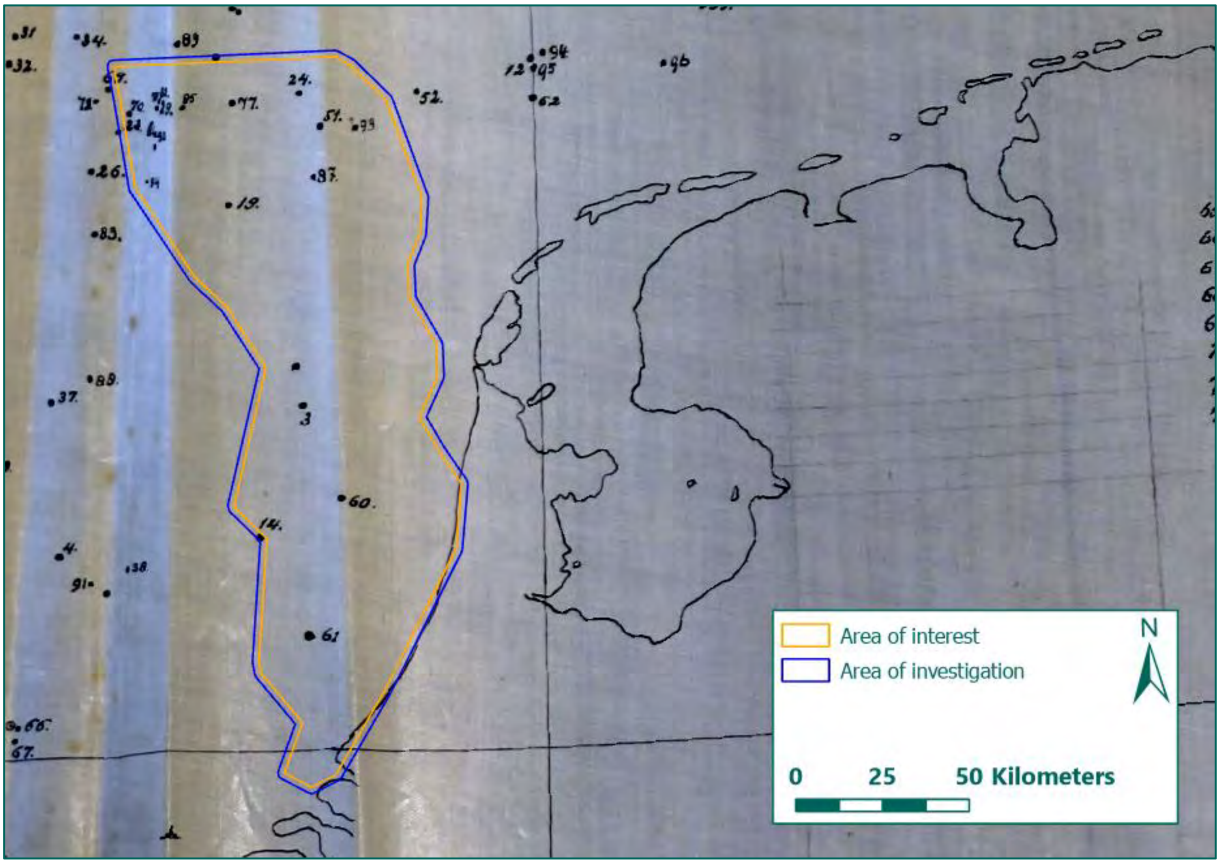


Figure 7: Map showing locations where Dutch ships ran onto mines during 1914-1916 (Source: NA, 2.05.32.09, file 44).

Wrecksite.eu also shows a lot of wrecks within the North Sea. A total of 39 ships were sunk due to mines laid in WW1 and WW2. Besides that a lot of ships were sunk due to unknown causes. The book 'HP39 Wrakkenregister, Nederlands Continentaal Plat en Westerschelde' (abbreviated to HP39), drawn up by the Dutch navy, show an abundance of wrecks (ships and aircraft) within the area of interest. In HP39 no details are given about the reason/cause of the sinking of the ships or aircraft. However. An overview of all wrecks according to this book is shown below.

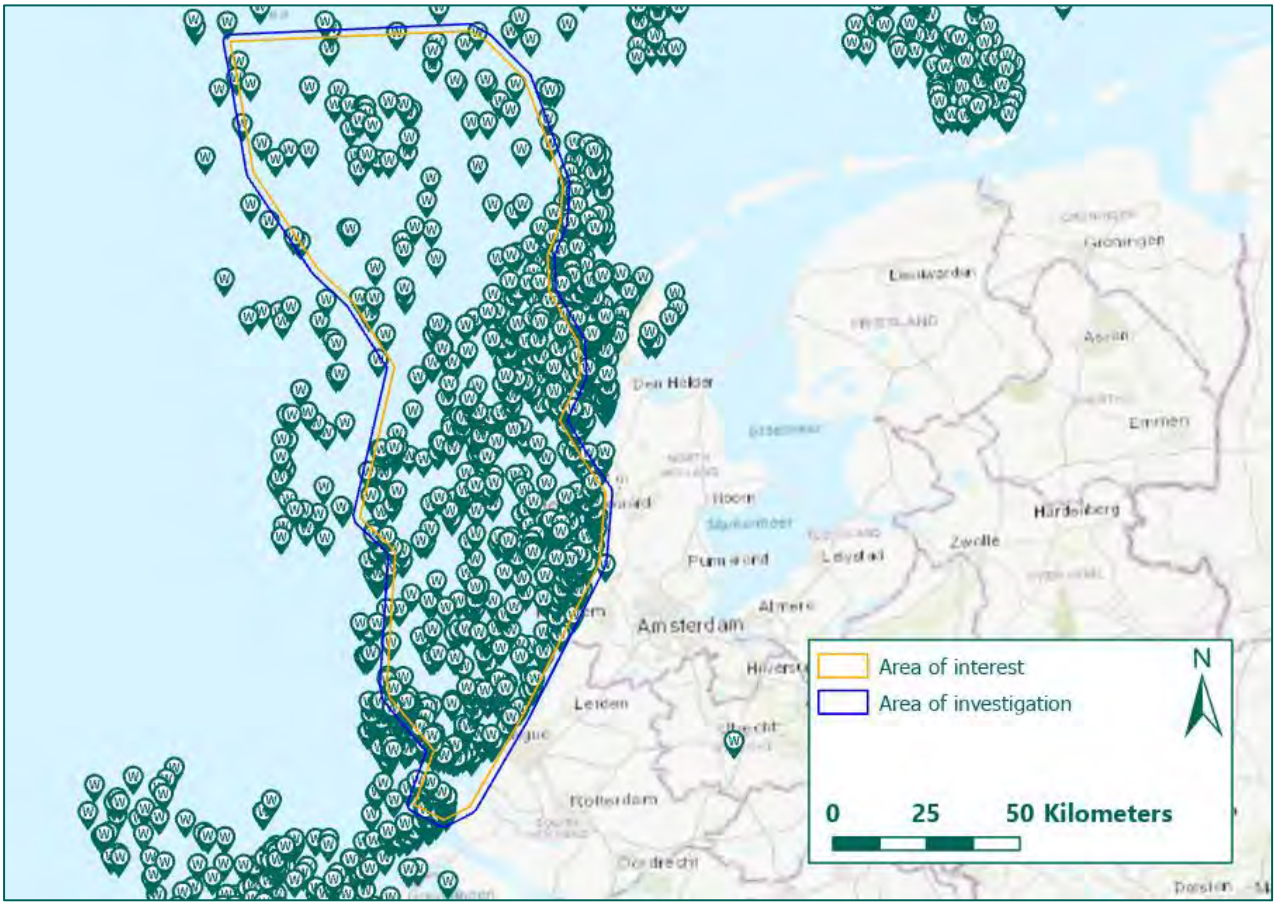


Figure 8: Overview of wrecks within the area of interest according to HP39 (Source: HP39).

According to sources that were consulted by REASeuro British and German minefields overlapped the area of investigation during the First World War. Several ships were sunk due to mines laid within the Area of investigation.

Based upon the sources available, it is concluded that First World War German and British contact mines could be present in the area of investigation. Since no information is found about the precise types of the mines, it is presumed that the most common types of German and British mines could be present in the area of investigation, the German E-Mine and British Vickers / British Elia and H Mark II moored contact mines. Conclusions about the UXO Risk Area as a result of naval mines is given in paragraph 4.1.4.

4.1.2 Second World War

During the Second World War several German minefields were laid in the area of investigation. The German minefields were laid defensively, with the intention to hinder allied ships from approaching the Dutch Coast. British offensive minelaying was aimed against German convoy routes sailing by the Dutch Coast. Some of these British offensive minefields overlap the area of Investigation.

Different sources show maps and coordinates of German and British minefields within the area of investigation. The German minefields within the area of investigation are well documented. During the war the British authorities were quite aware of the locations of German minefields, as can be seen in Figure 9 several minefields overlapped with the area of investigation. The large minefield 404X consists of many smaller minefields. Detailed information about these, and other, minefields that overlap with the area of investigation can be found in the Bundesarchiv (see Figure 10). The German minefields were also littered with sweeping obstructers, suchs as Exploding floats, *Sprengboje* (with explosive load) and Static cutters/Static Conical Sweep Obstructor, *Reisboje* (without explosive load). It is also known that some Dutch minefields were laid in the beginning of WW2. Most Dutch and German mines were laid by surface crafts. Although the British used surface craft as well, they also deployed aircraft.

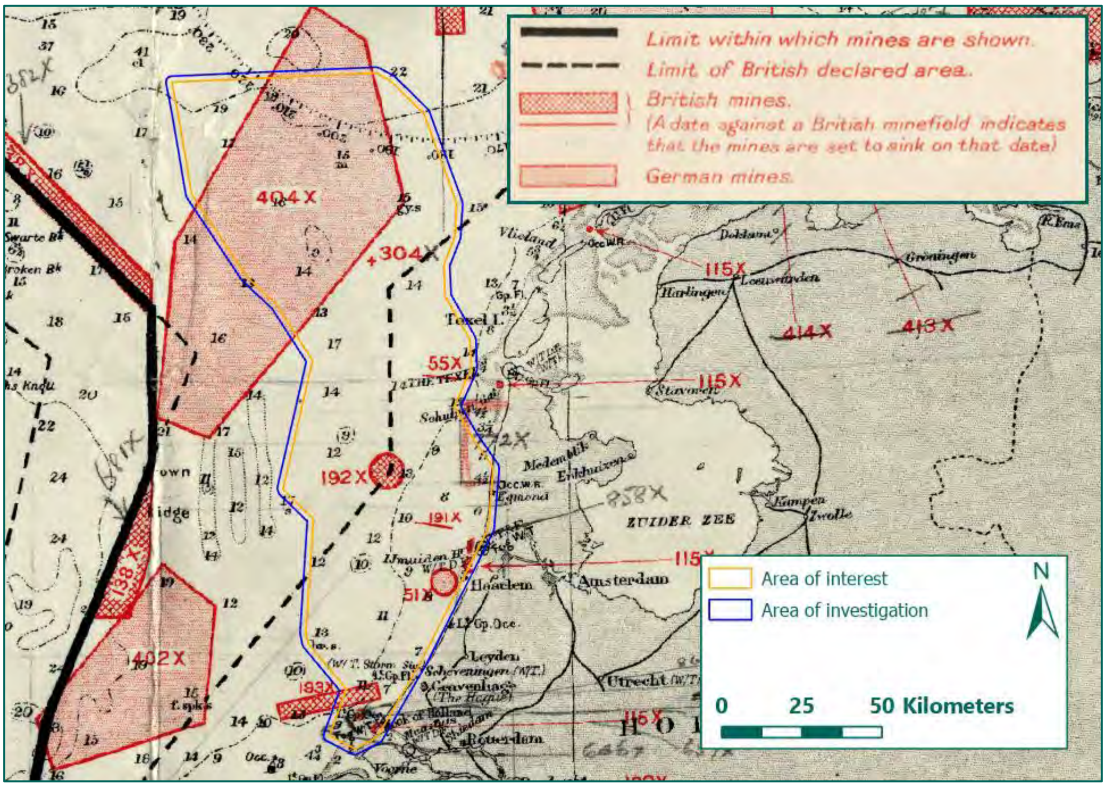


Figure 9: British map showing German and British minefields (Source: TNA, ADM 239/304).

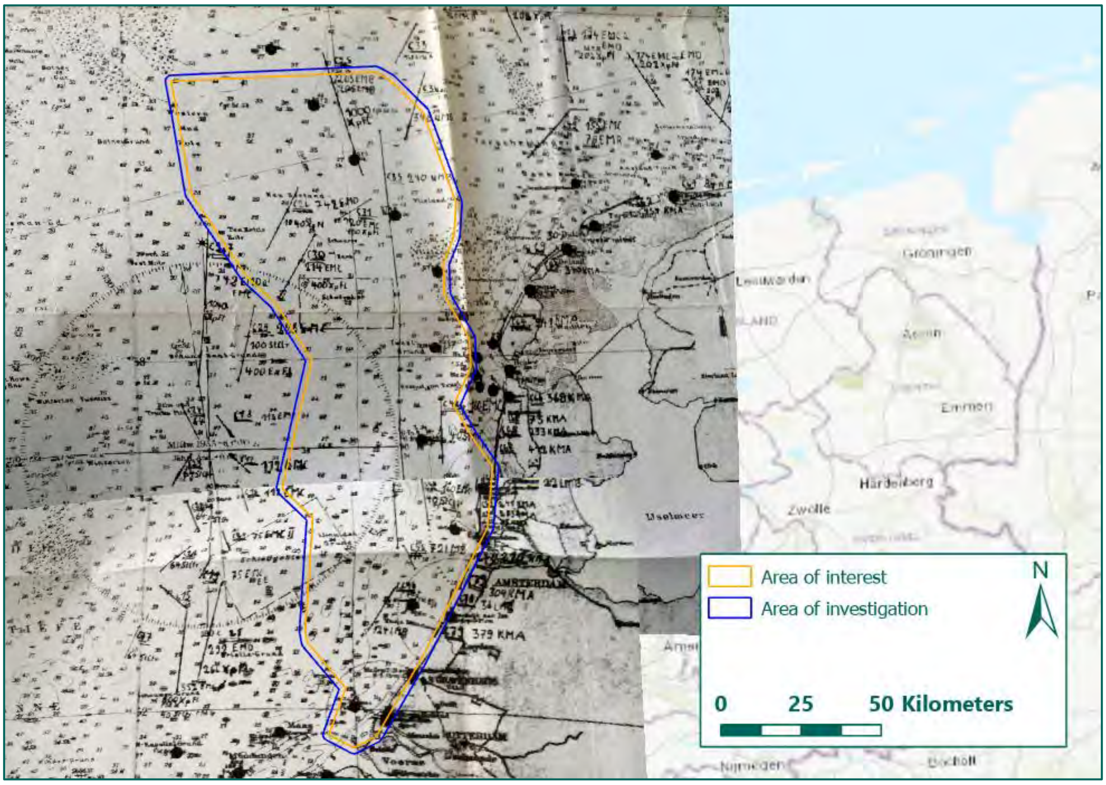


Figure 10: Naval chart showing numbered German minefields. Multiple minefields are present in the area of interest. (Source: BAMA, ZA 5/27).

Another means of minelaying were the "Gardening" operations. These operations were carried out by the Royal Air Force. Planes dropped mines into designated zones. Three zones laid in front of the Dutch coast. Two of these zones, "Whelks" and "Trefoil", have overlap with the area of investigation. The mines laid by planes were ground mines. Over 1200 mines were laid in these 'gardens'.

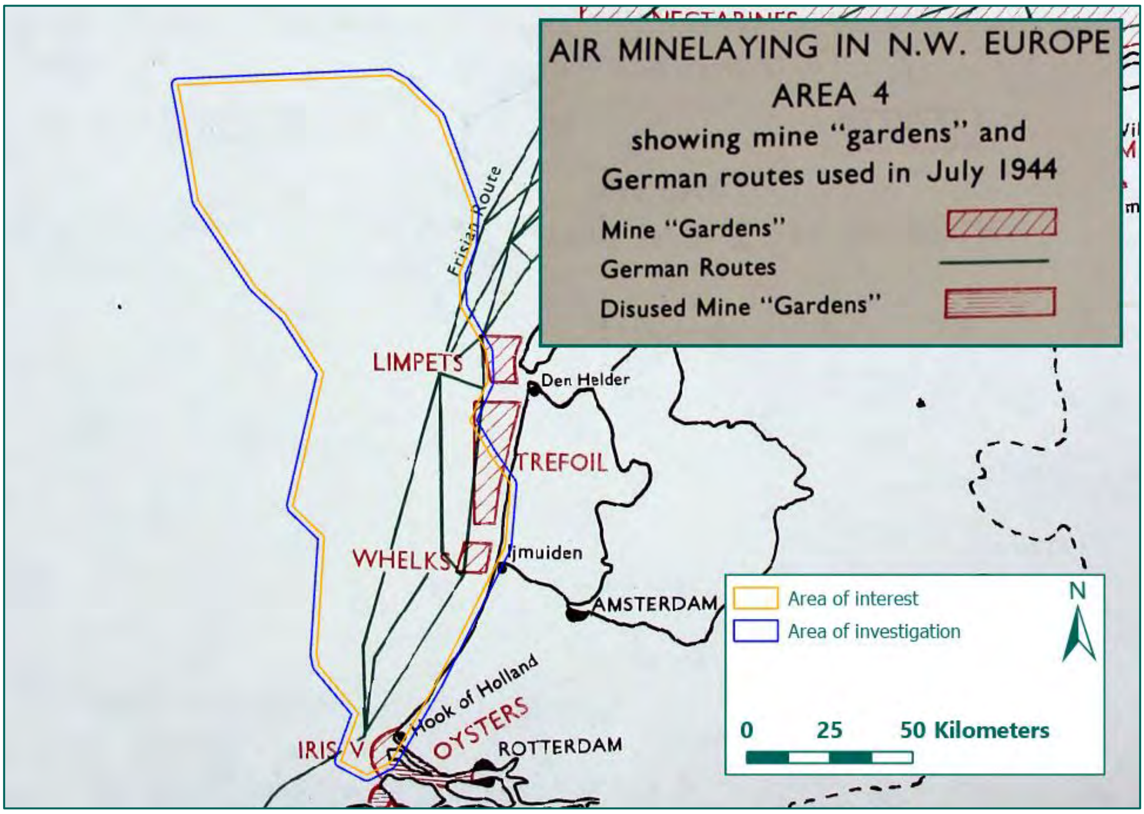


Figure 11: British 'Gardens' within the area of investigation (Source: TNA, ADM 234/561).

All minefields that were mentioned within the consulted sources have been incorporated in our GIS-system. In the figure below all these minefields are shown.

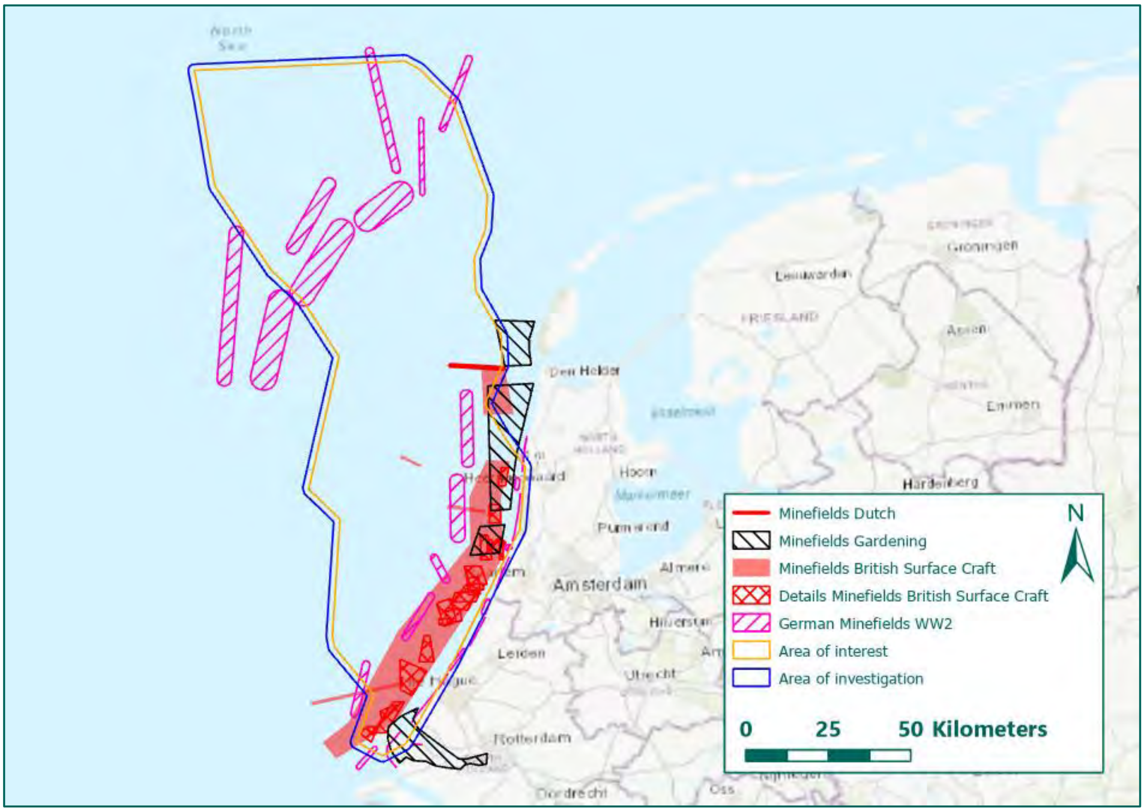


Figure 12: Minefields in WW2 (Source basemap: ESRI).

It is not known what kind of mines were laid in the Dutch and British minefields. Therefore, it is assumed that the most common types of mines were used within these minefields. In the Dutch minefields it is assumed that contact mines from the type 'Model 1921 2e soort' can be encountered. The British minefields consist of minefields laid by surface craft and aircraft. Mines dropped by aircraft were ground mines, mines laid by surface craft are either ground mines or contact mines. The most used types of British ground mines are Mk I-IV. The most common types of British contact mines are Mk VII- VIII and Mk XIV contact mines. The German mines used within the Area of investigation are EMB, EMC, EMD UBA and KMA contact mines, and LMB ground mines. Some German minefields were also fitted with German sweep obstructers: Exploding floats, *Sprengboje* (with explosive load) and Static cutters/Static Conical Sweep Obstructor, *Reisboje* (without explosive load).

4.1.3 Post-war mine clearance

After the First World War, a large effort was made to clear shipping lanes of naval mines. It took several months and a fleet of minesweepers to clear the minefields. Sweeping was carried out by sweeping a cable with anchors below the water surface. The cable was dragged by two ships (see Figure 13).

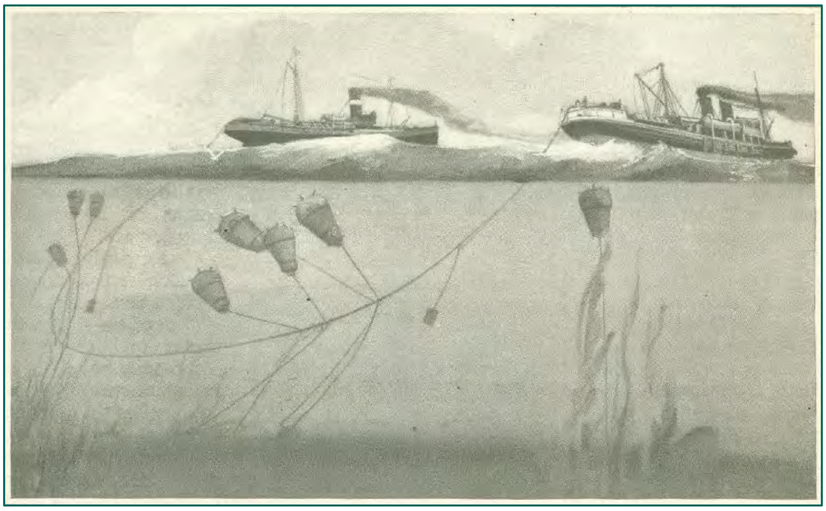


Figure 13: Post WWI-mine sweeping. (Source: http://www.digitalhistoryproject.com/2012/06/submarine-mines-in-world-war-i-byleland.html)

Mines also continued to pose a danger to shipping after the Second World War. In order to combat this threat, a large-scale minesweeping campaign was set up. The area of investigation was situated in the Dutch sweeping zone. Charts of the *Marinemuseum* (see Annex 3) show some details of minesweeping in the area of investigation. Details about minesweeping have not been found in the consulted sources. Minesweeping was conducted with a variety of methods. Moored mines were usually swept with Oropesa sweeping gear[4] (see Figure 14).

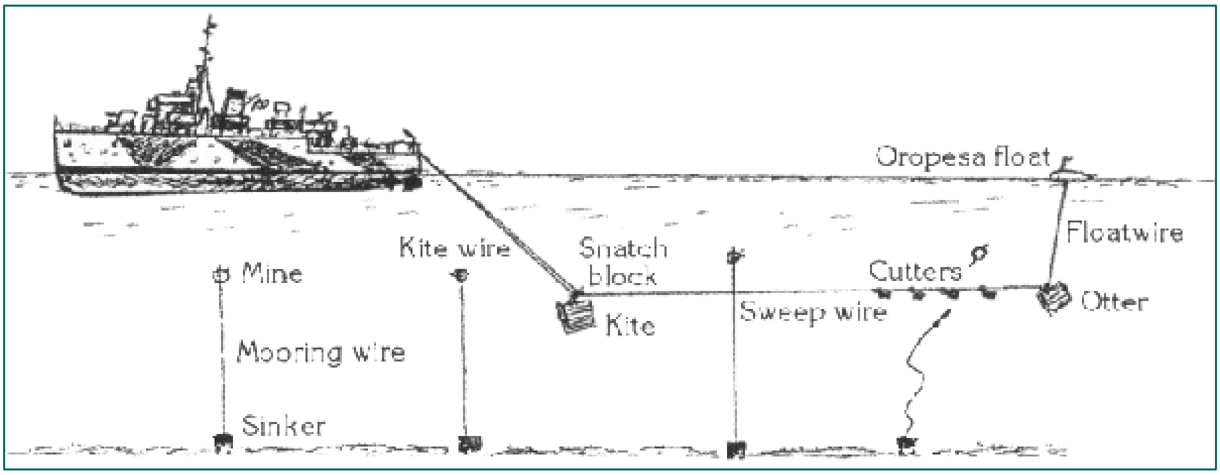


Figure 14: Oropesa sweeping (source: 'The 'Art' of Minesweeping', 27 May 2013, http://www.minesweepers.org.uk/sweeping.htm, consulted 2 August 2019).

The moorings of the mines were cut with cutters dragged on a wire behind a ship. Cutting the mooring wires/cables caused the mines to float to the surface, where the mines could easily be shot with cannon or rifle fire (see Figure 15). Shooting the mines caused them to sink or to detonate. Ground mines were swept with acoustic hammer boxes, triggering the acoustic mines, or by magnetic sweeping gear to trigger magnetic mines.

[4] So named after the World War I trawler in which the technique was first developed. Till then all sweeping was done using two ships joined by a single wire.

Figure 15: Mine disposal team preparing to fire on swept mines. (Source: TNA, ADM 199/154).

Minesweeping was not synonymous to mine clearance. Objective of the operations was to clear the shipping lanes for navigation. The sea bottom is still littered with unexploded mines, including swept and sunken moored mines, self-disarming mines and ground mines with empty batteries[5]. Nowadays, fishermen and dredging ships still encounter these naval mines on a regular basis.

As a result of clearance operations, tidal and other weather conditions, moored mines could break loose from their anchor and migrate. Furthermore, due to extensive pair and beam trawling there is often no clear relation between the positions of encountered mines and the locations of historical minefields. This observation is confirmed in the paragraphs 4.1.1 and 4.1.2. These paragraphs show mine incidents/ encounters outside known minefields. Clearance reports of the Dutch Coast Guard and the OSPAR Commission also show that mines can be found outside the boundaries of known minefields. In Figure 16 the locations of cleared mines are shown relative to the area of investigation.

[5] According to international laws, mines are obligated to include mechanisms to automatically disarm or 'self-sterilize' them after a set time. Moored mines were to sink to the seabed after a given time through, for example, a soluble plug, while ground mines disarmed automatically through a timing mechanism or simply at the end of their battery life. These mechanisms move the mine out of harm's way, but do not disable mechanical fusing mechanisms like *herz horns* and anti-handling devices.

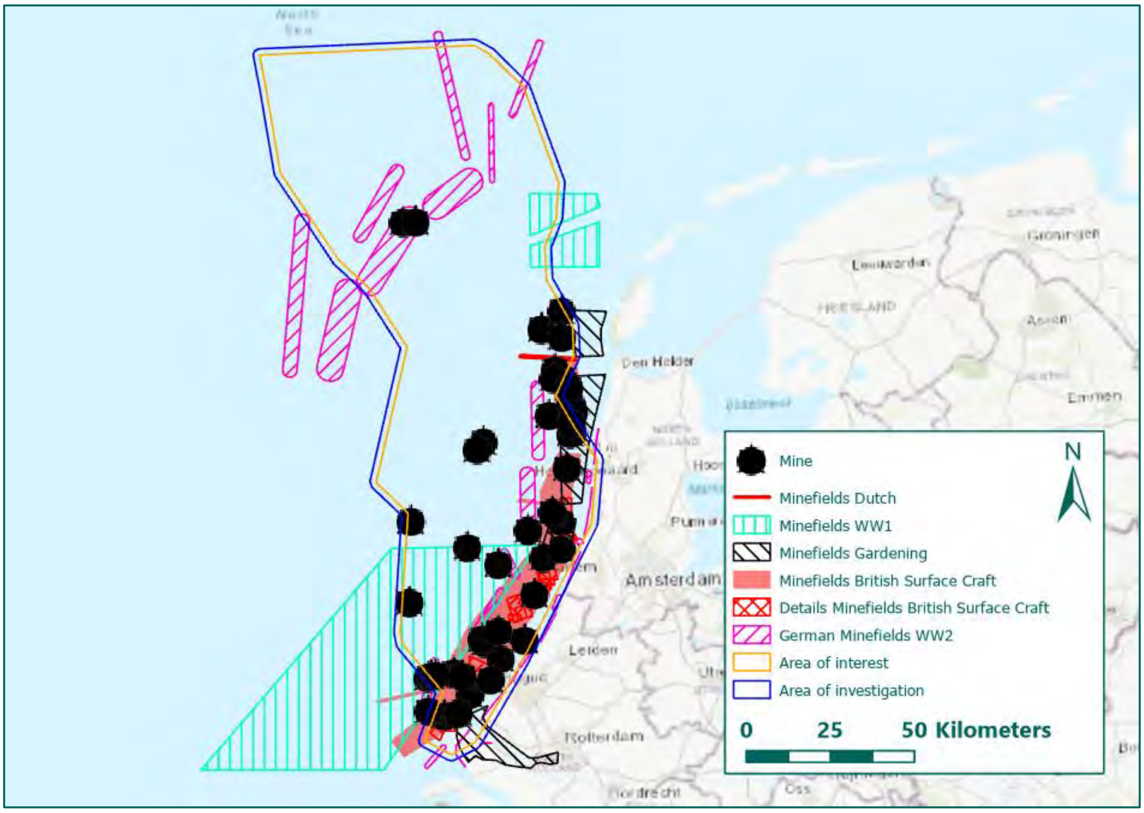


Figure 16: Locations of known minefields and locations where the Dutch Coastguard cleared mines (Source basemap: ESRI).

4.1.4 Conclusion

The area of investigation intersects several minefields. During World War I, British and German minefields overlapped the area of investigation. Within the area of investigation, several mine related incidents occurred during the First World War. Most of these incidents happened outside of known minefields.

During the Second World War the German navy laid 33 minefields that intersect with the area of investigation. No information about the clearance of these fields is known to REASeuro. Several British and two Dutch minefields also overlapped with the area of investigation. Information about the clearance of these fields is also unknown to REASeuro.

Post-war (both World War I and II) minesweeping succeeded in securing the shipping lanes, but did not manage to dispose of all mines. Many mines still litter the seabed, with fuzes still intact. Sweeping, trawling, tides and currents have caused these mines to migrate over the years, resulting in a situation in which there is no longer a clear link between the location of the original minefields and the current positions of the naval mines. As a result of this, it is possible that UXO is still encountered within the area of investigation.

A distinction needs to be made between the likelihood of encountering UXO related to World War I and to World War II. During World War II multiple minefields overlapped the area of investigation. A total of thousands of mines were laid by German surface craft and British surface craft and aircraft. Sweeping operations could have these mines and sweep obstructors (*Sprengboje*) to have sunken to the seabed within the area of investigation. The likelihood of encountering UXO related to World War II minefields is deemed certain within the borders of the minefields and, due to migration, probable outside of these borders.

During World War I the area of investigation only overlapped with a single suspected German minefield and some small British minefields. The consulted sources do not state the amount or types of mines laid in this field. However, factual evidence points out that multiple mine related incidents occurred within the area of investigation. Because of the relative sparse amount of information known about World War I minefields within the area of investigation the likelihood of encountering UXO related to World War I minefields is lower than the World War II minefields. Therefore encountering UXO of WW1 naval mines is deemed probable to within the borders of the WW1 minefields, and feasible outside of these minefields.

UXO type	Reference Nr.	Type/calibre	Condition
Naval Mines	1	German E-Mine moored contact mines	Armed
	2	British Vickers / British Elia and H Mark II moored contact mines	Armed
	Outside the borders of the known minefields all abovementioned types of naval mines can be encountered. The likelihood of presence outside the known minefields is set to feasible.		

Table 1: Expected UXO due to WW1 Minefields.

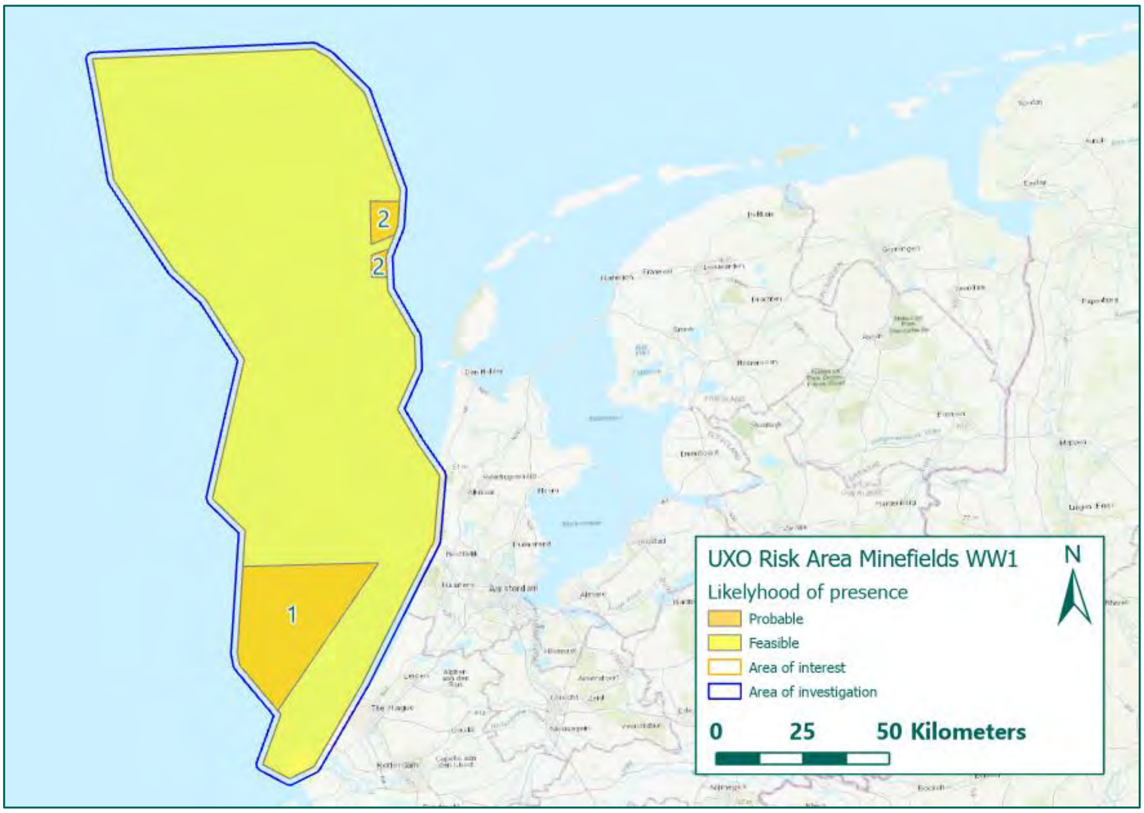


Figure 17: Likelihood of presence of UXO as result of the WW1 minefields. (Source basemap: ESRI).

UXO type	Reference Nr.	Type/calibre	Condition
Naval Mines	1	British ground mines Mk I-IV	Armed
	2	German EMB Contact mines and Exploding Floats	
	3	German EMC Contact mines (also non explosive sweep obstructors)	
	4	German EMC Contact mines and Exploding Floats	
	5	German EMD Contact mines and Exploding Floats	
	6	German KMA Contact mines	
	7	German LMB Ground mines	
	8	German LMB Ground mines and German EMC Contact mines	
	9	German UMB Contact mines	
	10	German RMA Contact mines	
	11	British Mk I-IV ground mines and British Mk VII-VIII and Mk XIV contact mines	
	12	Dutch Model 1921 '2e soort'	
	Outside the borders of the known minefields all abovementioned types of naval mines can be encountered. The likelihood of presence outside the known minefields is set to probable.		

Table 2: Expected UXO due to WW2 Minefields.

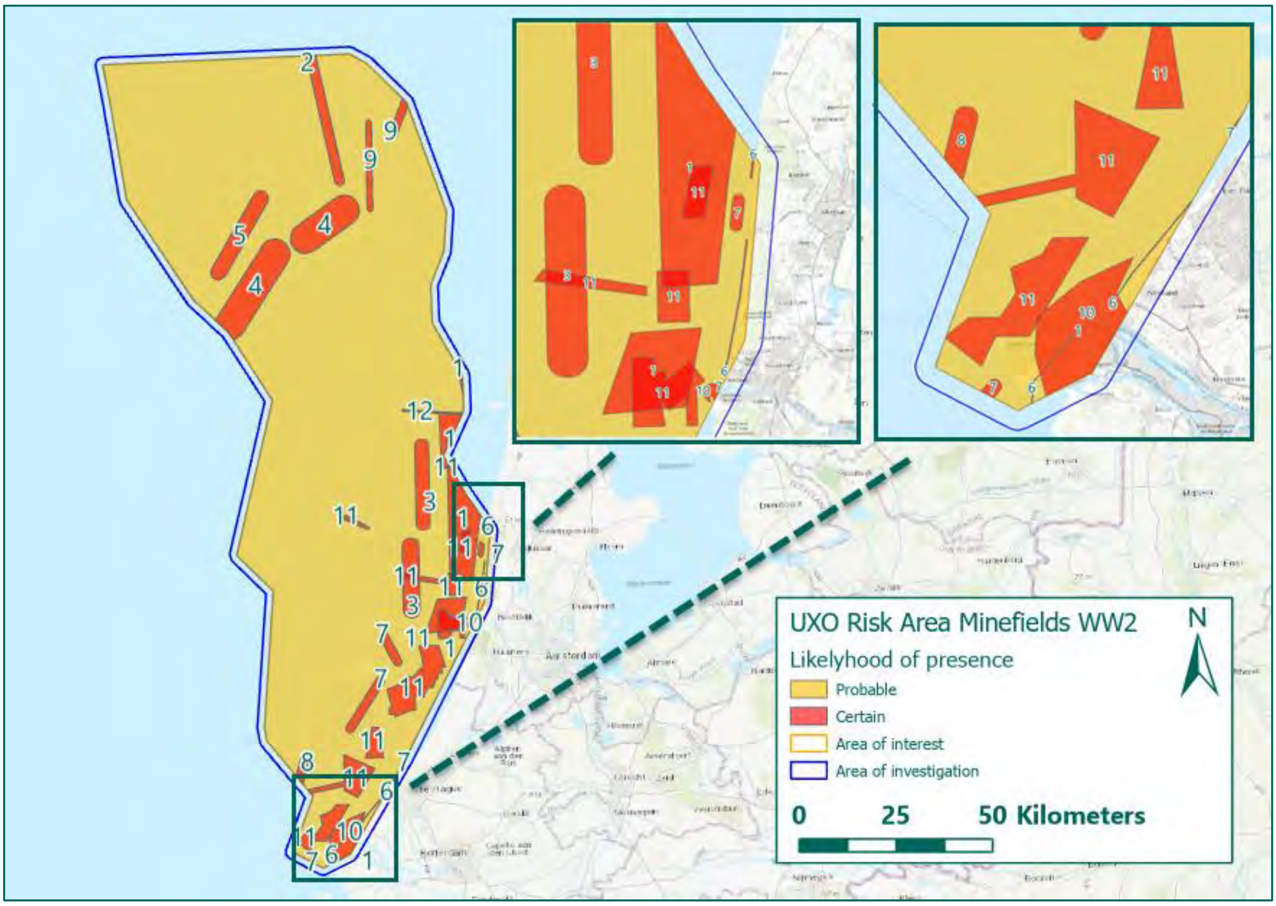


Figure 18: Likelihood of presence of UXO as result of the WW2 minefields. (Source basemap: ESRI).

4.2 AIR WAR

In and in the vicinity of the area of investigation many events relating to the air war did occur. This concerns air strikes on shipping, jettisons of bombs, and anti-aircraft gunfire.

4.2.1 Air strikes on surface vessels

A German convoy route crossed the area of analysis. During the Second World War the British Air Force almost continuously attacked the German convoys and other ships like minesweepers or the *Vorpostenboote*. From November 1944 onwards, attacks were also carried out on submarines and midget submarines (Anti-Seehund missions) which threatened the Allied convoys towards the harbour of Antwerp.

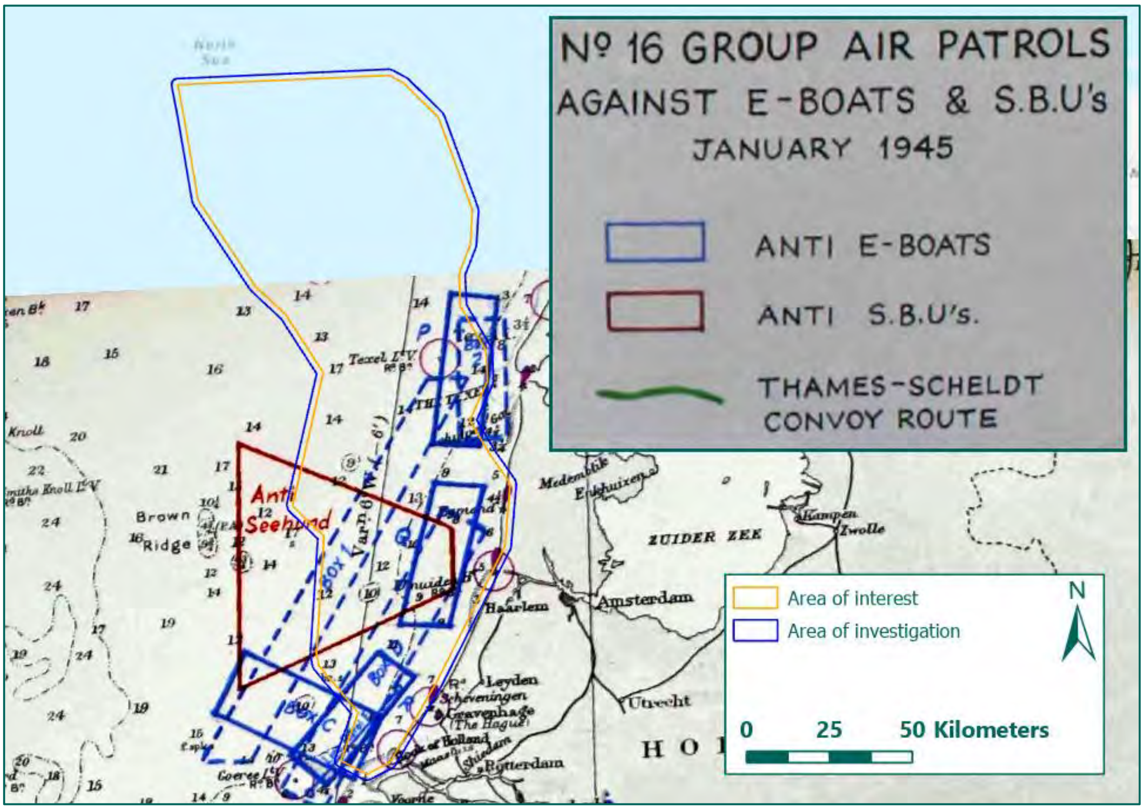


Figure 19: Coastal Command, No.16 Group, Air Patrols against E-Boats & S.B.U.'s January 1945 (Source: CAB 101/324).

The locations of the air strikes are seldom very accurate. Navigating above the sea was not an easy task. The consulted literature (see Annex 2) points out that a lot of ships were attacked along the Dutch coast. It started with the German invasion on 10 May 1940.

The air attacks by the British Bomber Command and Coastal Command are added in a geodatabase, if possible. Coastal Command used a code instead of decimal degrees. According to the information entered in the REASeuro database, a total of 508 attacks were made within the area of investigation by Coastal Command and Bomber Command. It is outside the scope of this research to examine the target and the results of each of these missions. Due to the large amount of attack locations near the known German routes, it is to be expected that a large amount of the attacks by the RAF was targeted at German shipping. In the figure below the relevant locations of attacks by Coastal Command and Bomber Command is shown. The locations of German convoy routes are also shown.

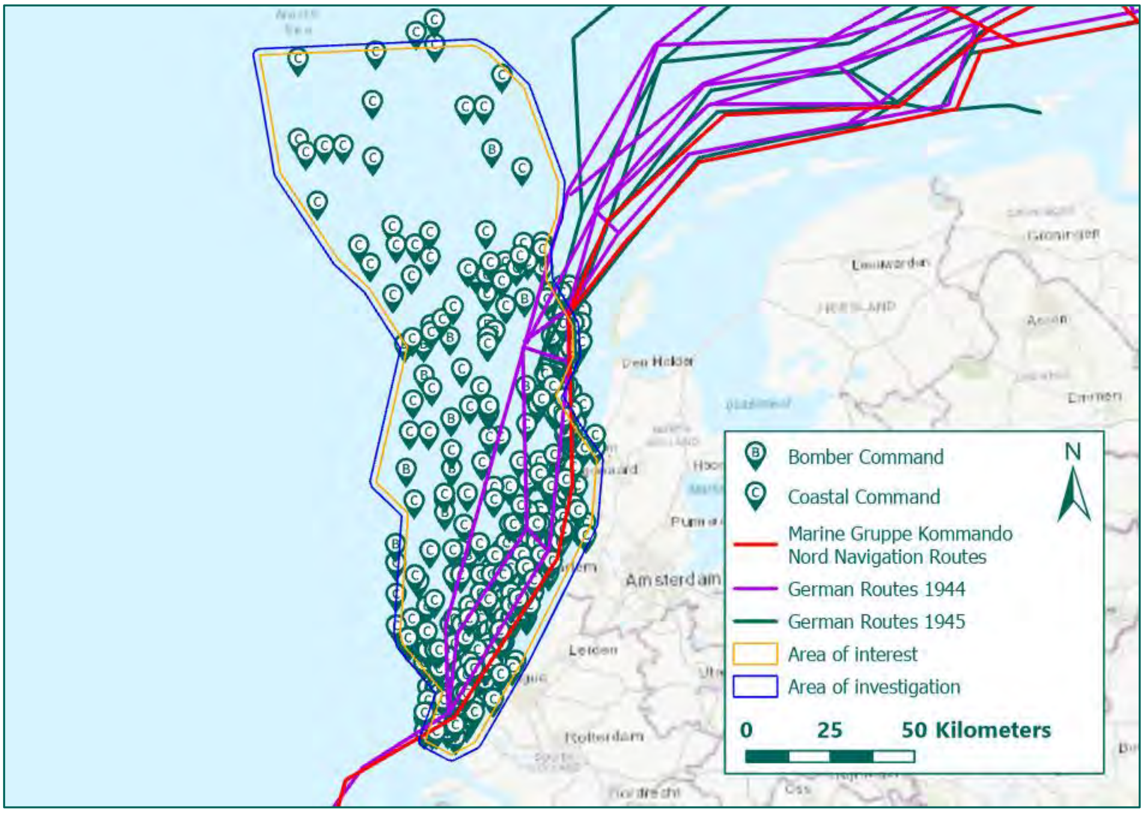


Figure 20: Attacks made by Coastal Command and Bomber Command, and relevant German convoy routes (Source basemap: ESRI).

Since more than 500 attacks took place in the area of investigation, it is expected that UXO remain. Air strikes on ships were carried out with aerial bombs, depth charges, torpedoes, and 3 inch rockets with a 60 lbs warhead semi armour piercing (SAP). The definition of the UXO risk area and the calibres is explained in paragraph 4.2.5.

4.2.2 Jettisoned bombs

During the Second World War groups varying from few to many British and American bombers flew almost on a daily basis (day and night) towards targets in Germany or German-occupied territory. The flight paths towards targets and back to base (in the United Kingdom) ran across the North Sea.

The Allied bombers were often attacked by German fighters in order to prevent the bombers from bombing their targets. Hundreds of planes were hit and/or shot down. When a bomber was involved in an air battle the procedure was to jettison the bombs. This would reduce the weight of the bomber enabling it to increase the speed and manoeuvrability, and thus the crew's chance to survive. Normally, bombs had to be jettisoned in a safe, thus unarmed, condition. This procedure is documented in a record from The National Archives (see annex 3).

Jettisons in the sea also happened when aircraft could not find a suitable target or in other cases when a crew could not drop their bombs. The reason to jettison the bombs was to avoid a landing with the bomb load, which was a risky event. Jettisons were seldom accurately documented. Furthermore, bombs were also jettisoned live, thus without their safety. An example of this is shown in the figure below.

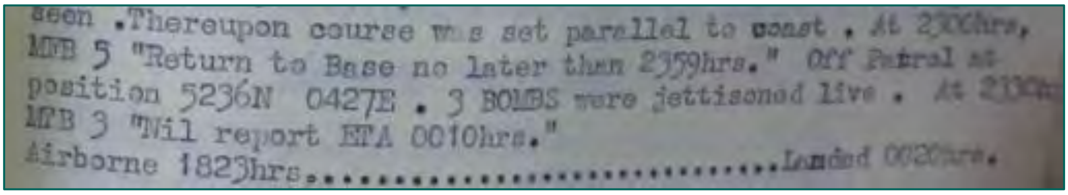

seen .Thereupon course was set parallel to coast . At 2300hrs,
MTB 5 "Return to Base no later than 2359hrs." Off Patrol at
position 5236N 0427E . 3 BOMBS were jettisoned live . At 2330hrs
MTB 3 "Nil report ETA 0010hrs."
Airborne 1823hrs.................................Landed 0020hrs.

Figure 21: Example of a live jettison within the area of investigation, night 12/13 October 1944. (Source: TNA, AIR 25/367).

It is not clear how many times such jettisons occurred. The figure below gives an example of a flight path that crosses the area of analysis.

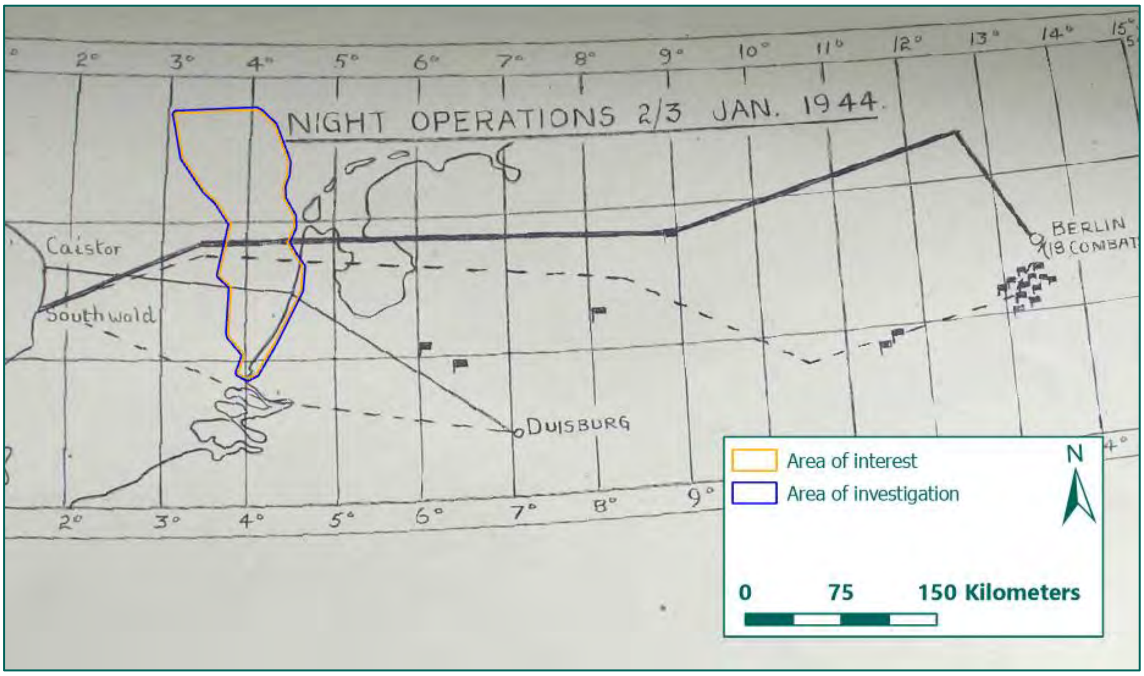


Figure 22: Example of a flight path over the area of investigation of bombers from Bomber Command, 2/3 January 1944 (Source, TNA, AIR 24/264).

Based upon the consulted sources, it is concluded that aerial bombs remain in the area of investigation as a result of jettisons. Because it is not possible to define the calibres specifically, the most common allied bombs are taken into account. The UXO risk area is specified in paragraph 4.2.5. Detailed information on the UXO is given in annex 10.

4.2.3 Anti-aircraft gunfire

The guns which were placed onto the German Vorpostenboote and escort ships were also used against enemy airplanes. The calibres of the guns vary from 2 cm to 8.8 cm. Machine guns (7.92 cm, 13,2 mm, 15 mm) completed the anti-aircraft weaponry on ships. Every time when ships and convoys were attacked, they opened fire.

Taking into account the large amount of air strikes on ships, UXO of anti-aircraft weapons are present in the area of investigation. Unexploded shells could come down and hit the sea level and sink to sea bottom. The UXO risk area is defined in paragraph 4.2.5

4.2.4 Post-war UXO encounters

As showed in annex 5, aerial bombs are encountered throughout the entire area of analysis. A total of 52 bombs have been encountered and disposed of since 2005. These bombs could originate from air strikes and/or jettisons. The Dutch Coastguard also encountered a lot of UXO that have not been specified. It is therefore unknown whether more bombs have been cleared. It is also unknown how many bombs have been encountered before 2005. Next to aerial bombs, torpedoes, depth charges and artillery shells have also been encountered. The latter were possibly caused by the use of anti-aircraft gunfire. A total of 130 artillery shells have been cleared by the Dutch Coastguard. In the figures below the locations of encountered UXO are specified. A combined total of 31 torpedoes and depth charges were encountered.

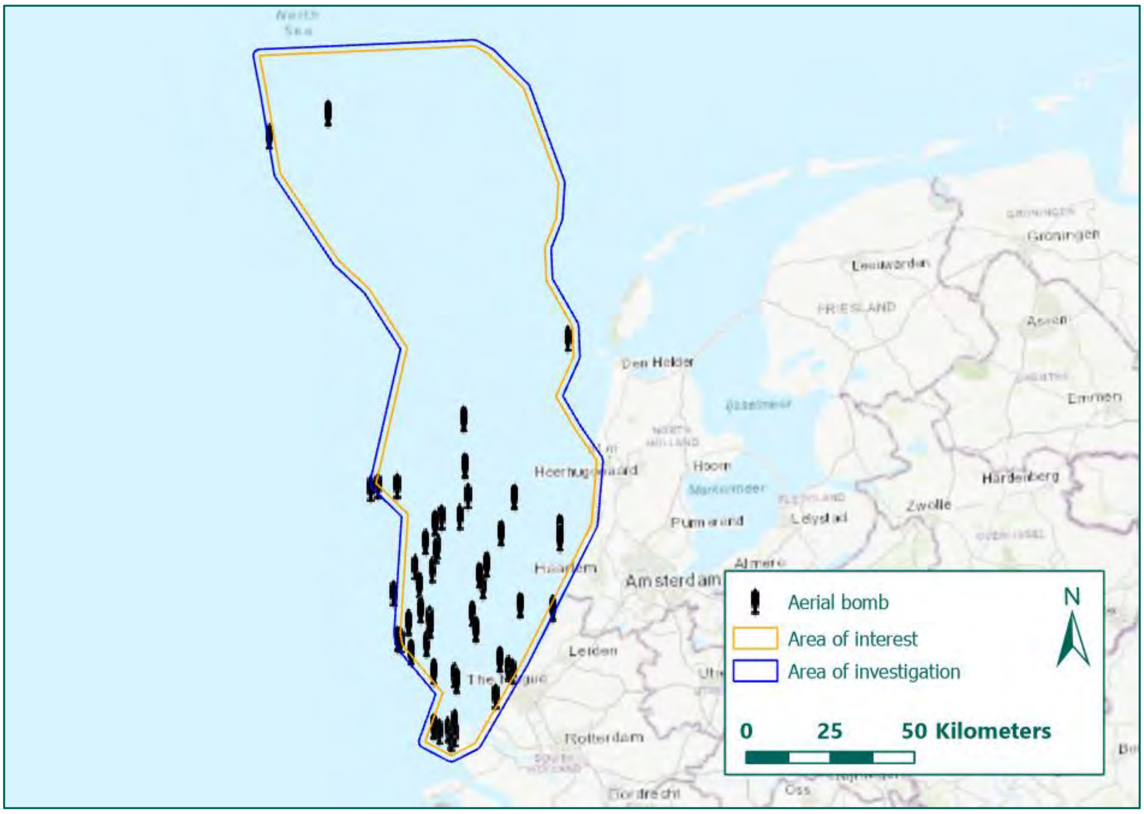


Figure 23: Cleared aerial bombs within the area of investigation (Source basemap: ESRI).

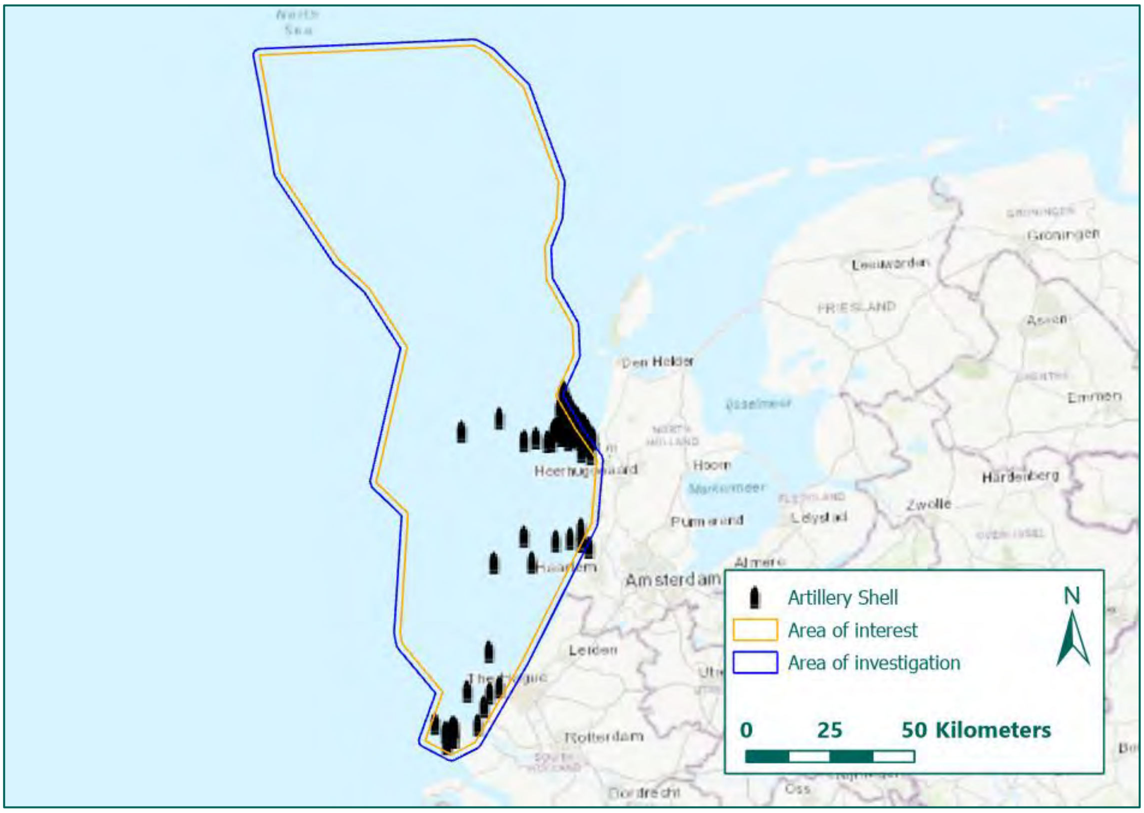


Figure 24: Cleared artillery shells within the area of investigation (Source basemap: ESRI).

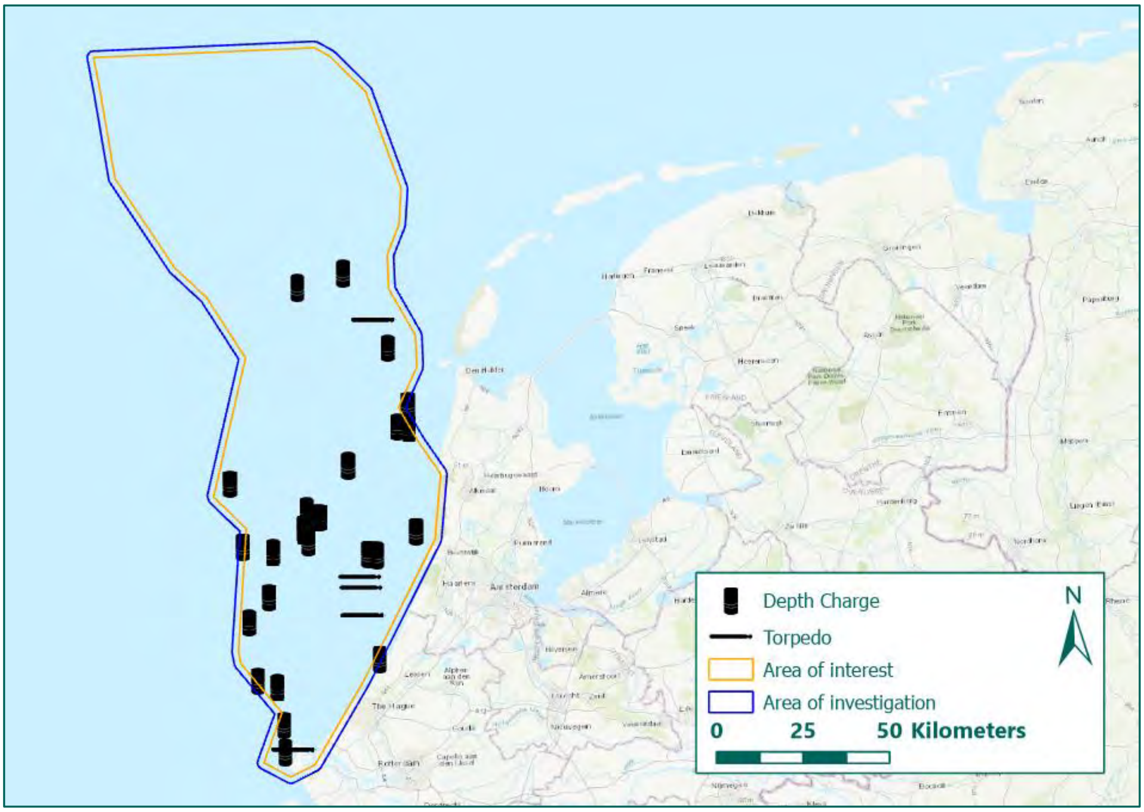


Figure 25: Cleared torpedoes and depth charges within the area of investigation (Source basemap: ESRI).

4.2.5 Conclusion

As a result of the various air strikes and jettisons UXO might still remain in the area of investigation. This is proved by the fact that since 2005 UXO have been encountered and disposed of in the area of investigation. Therefore, a UXO risk area is defined. The most probable locations of attacks are near the German convoy routes. This is confirmed by attack locations specified in the source material. Therefore the likelihood of presence of UXO regarding the air war is deemed certain along the convoy routes. The UXO risk area is projected between the most western route and the Dutch coast. A buffer of 1 nautical mile (1.852 meter) is taken into account for navigational inaccuracy of ships and aircraft. In the rest of the area of investigation the likelihood of presence of UXO is deemed probable due to the large amount of jettisons in the North Sea. In the figure and table below the UXO Risk Area regarding air war is shown. Details about calibres are also specified in the separately supplied shapefiles.

UXO type	Type/calibre	Condition
Aerial bombs	4 lbs, 25 lbs, 30 lbs, 100 lbs, 250 lbs, 260 lbs, 300 lbs, 500 lbs, 1.000 lbs, 4.000 lbs	Armed/not armed (safe)
Under water ammunition	18 inch torpedo Mk XV	Armed
	Depth charge	Armed
Rockets	3 inch rocket with 25 lbs or 60 lbs (SAP) warhead	Armed

Table 3: Expected UXO.

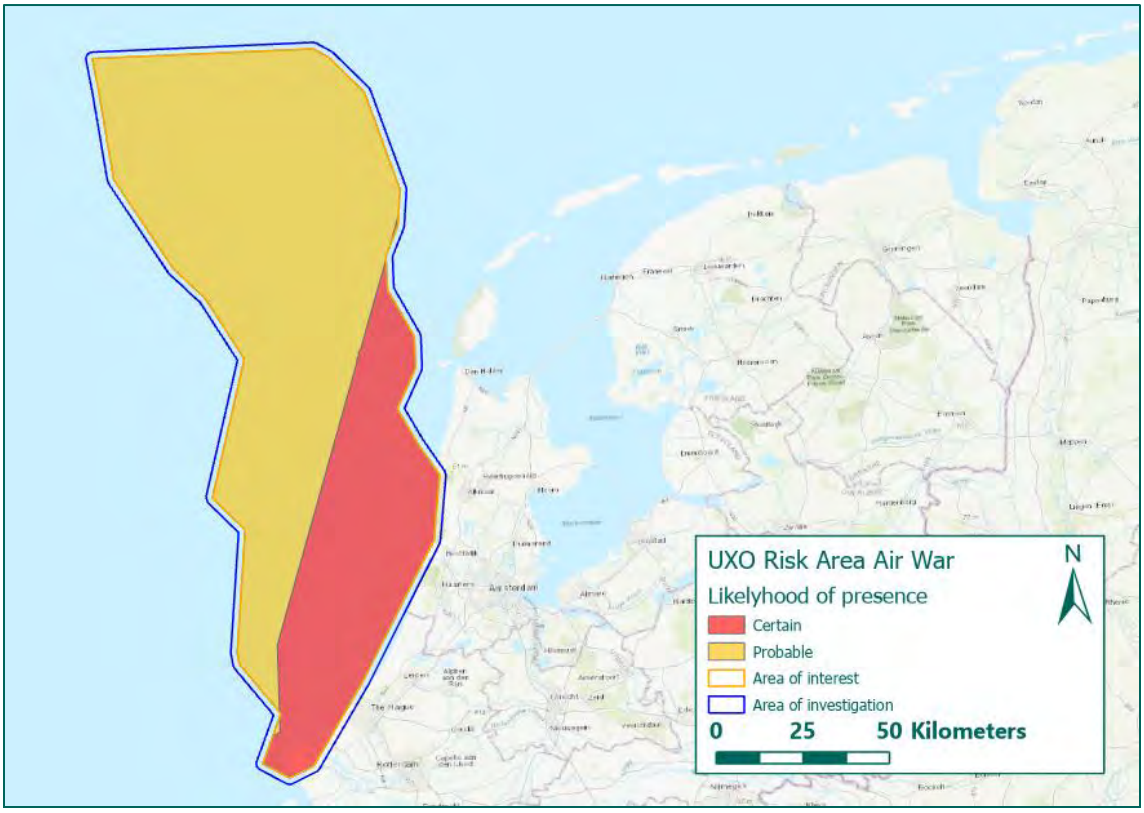


Figure 26: Likelihood of presence of UXO as result of the air war. (Source basemap: ESRI).

As on land, it is not possible to define a UXO risk area in response to the usage of anti-aircraft gunfire. The gunfire was aimed towards a moving target in the air. Unexploded shells could come down almost anywhere. It should be noted that probably most AA-projectiles came down between the shore and to the west of the convoy route. Part of this area was also covered by coastal guns. UXO of artillery shells that might be present in the coastal region will be further analysed in paragraph 4.3 and 4.4.

4.3 COASTAL GUNS

Coastal guns were traditionally used in strongpoints that had to defend harbours from enemy ships. At the start of WW2 some coastal guns were already installed on the Dutch Coast. After the German occupation of the Netherlands, a large amount of coastal guns were installed on the Dutch coast as part of the *Atlantikwall.* Source material shows that the German guns were used to stave off Allied ships nearing the Dutch Coast. Information from The National Archives (TNA) show that within the area of investigation shells fired by coastal guns exploded during an attack of the RAF. Below a strike photo is shown where the impact of a shell is highlighted.

Figure 27: Strike photo showing the impact of a shell, fired by a German coastal battery. 4 May 1942. (Source: TNA, AIR 28/595).

Various sources such as literature, records from the Dutch National Archives, the Bundesarchiv, maps and aerial photographs were used to determine the locations of coastal guns. These positions have been entered in the REASeuro GIS-database. The largest calibre that could strike the Area of investigation are 28 cm guns. They could hit targets at a range of 41100 meter. This range is extraordinary. Besides the 28 cm guns, guns from the calibres 17 cm and smaller were deployed along the coast. The maximum range of these 'smaller' calibre guns was 22000 meters. The known coastal guns near the area of investigation are shown in the figure below

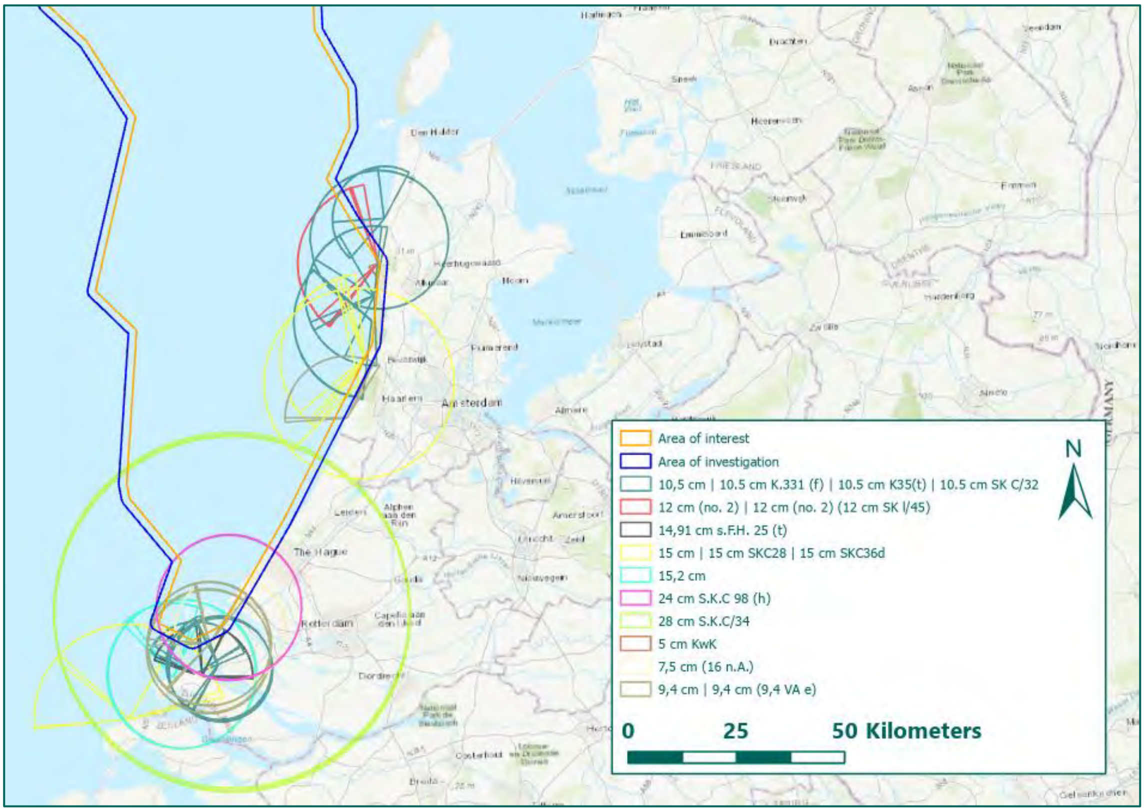


Figure 28: Locations and range of coastal guns near the area of investigation (Source basemap: ESRI).

Entering data in the REASeuro GIS-database is done on a project-by-project basis. Because REASeuro has not yet carried out Offshore Projects near the Dutch coast in the area between IJmuiden and Beverwijk, REASeuro does not yet have data on the coastal guns in this area. Consulting the Dutch 'Nationaal Archief' shows that strongpoints and military infrastructure were constructed on the Dutch coast. In order to find out the locations, calibres and range of the coastal guns on Texel and between IJmuiden and Beverwijk, REASeuro would need to visit the 'Nationaal Archief', analyse additional aerial photographs and consult literature and the internet. This is outside the scope of this research. As an example, a cutout of an 'Blokkaart' of the 'Nationaal Archief' is shown below. The map shows the contours of military infrastructure near Katwijk. Detailed information about the specific types of military infrastructure are not shown on these map, as is already mentioned, additional information is to be consulted separately.

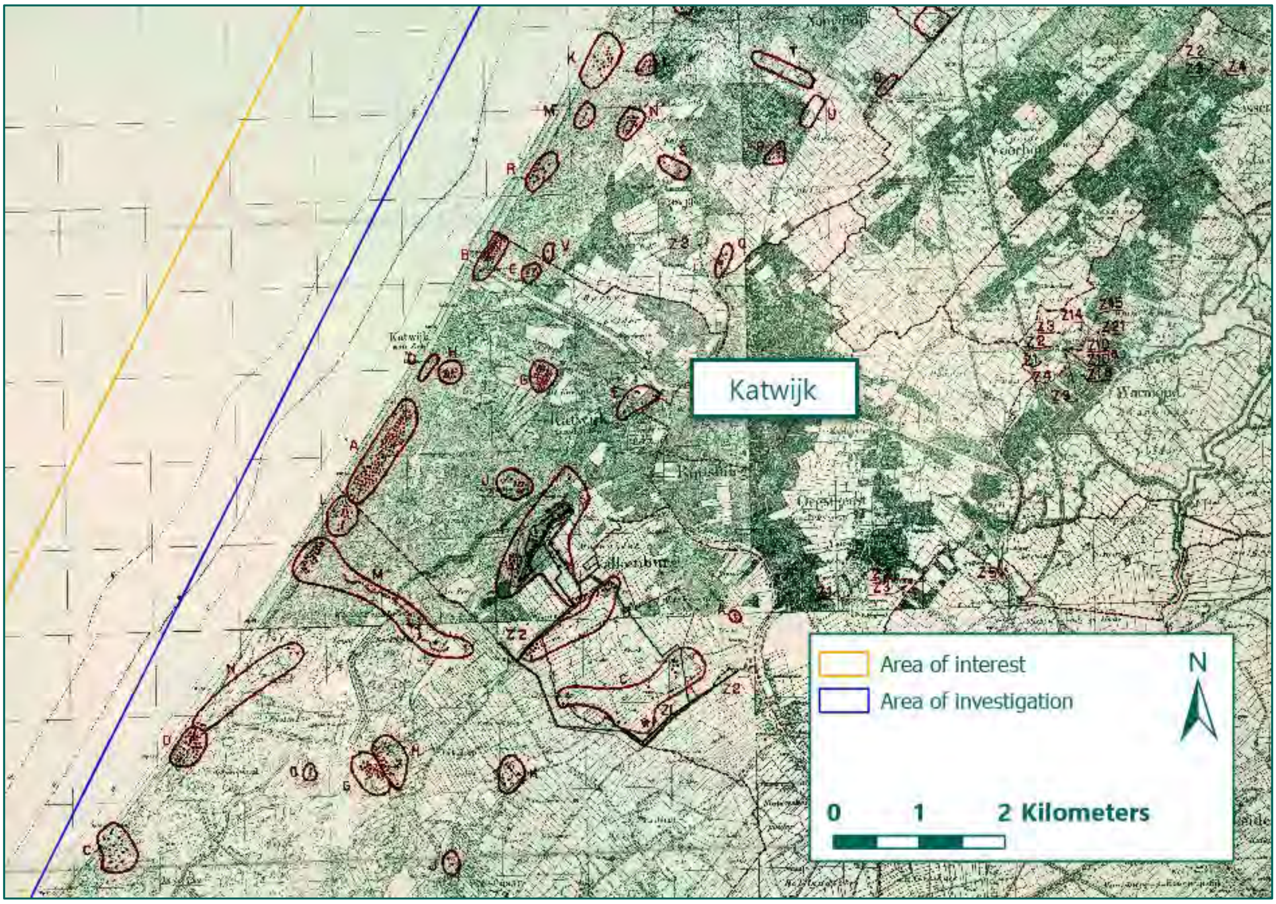


Figure 29: Cutout from a 'Blokkaart' showing the contours of military Infrastructure (Source: Nationaal Archief, 'Blokkaart' 275 3G).

4.3.1 Conclusion

Different guns could reach the area of investigation. Although the sources give only a few hints about the action of the coastal guns, it is estimated that all guns and crews had to practice from time to time. Due to the deployment of- and training with coastal guns it is probable that UXO of artillery shells are present in the area of investigation. These shells could possibly be encountered within, but no farther than, the maximum range of the coastal guns.

To cover the gap in knowledge about the coastal guns on Texel and between IJmuiden and Beverwijk the maximum range of coastal guns, not being 28 cm guns, is projected from the Dutch coast. This range is 22000 meters. Within the range of the known coastal guns and the range projected from the Dutch coast of Texel and between IJmuiden and Beverwijk an UXO Risk Area is projected. This UXO Risk area is shown in the figure below. Details about calibres are specified in the separately supplied shapefiles.

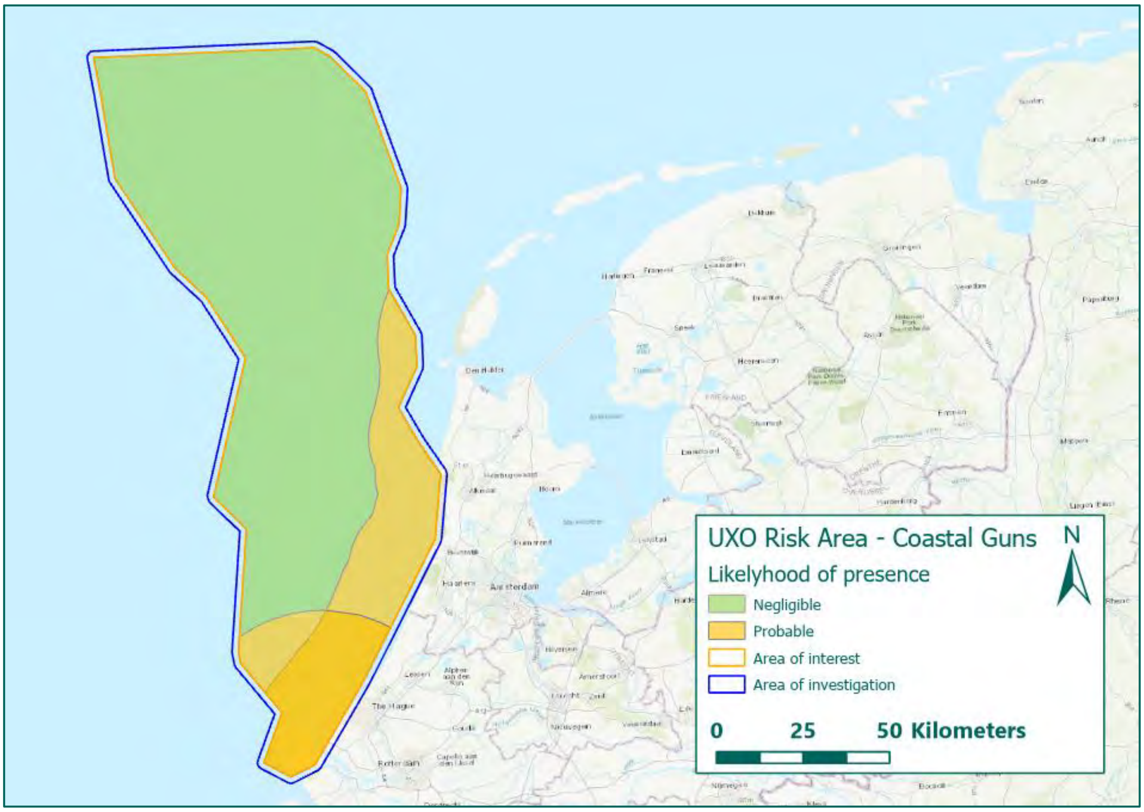


Figure 30: Likelihood of presence of UXO as result of the presence of coastal guns. (Source basemap: ESRI).

4.4 WAR AT SEA

Considering the surface craft battles, a large section of the area of investigation is situated on former German convoy routes. The convoys were accompanied with armed escort ships. Also, the convoy route itself was guarded by armed vessels and trawlers, the so-called "*Vorpostenboote*" that patrolled between checkpoints. The convoy routes are shown in Figure 31. Besides, IJmuiden and its harbour overlap the area of investigation. During the Second World War IJmuiden became an important base for the German fast attack boats (*Schnellboote*, S-Boats), for which a bunker was constructed. Later on, midget submarines also operated from IJmuiden.

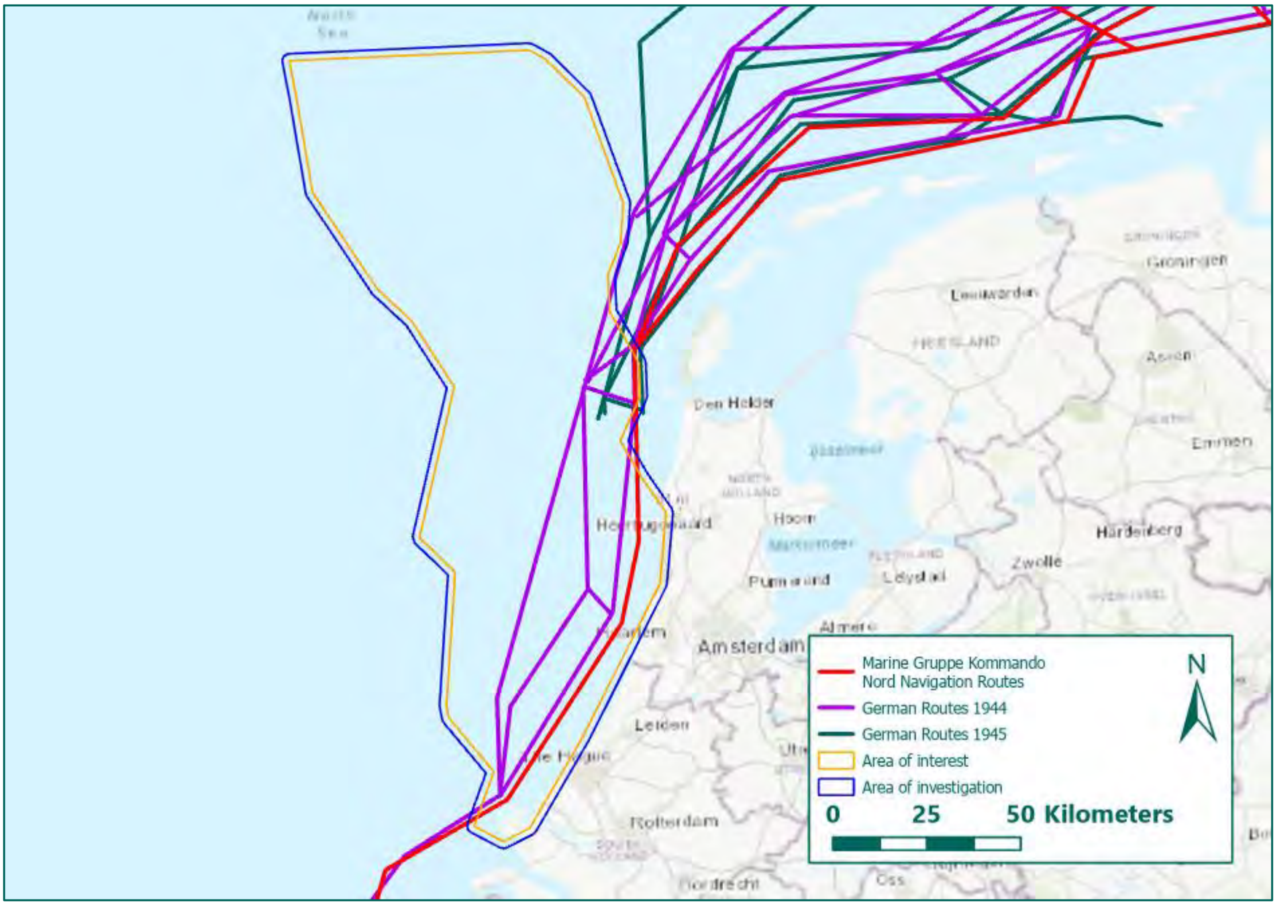


Figure 31: Convoy route "Weg Rot" and the quadrants used by the German navy. (Source basemap: ESRI).

The armed escorts and Vorpostenboote did not prevent the British Coastal Forces from attacking these ships and convoys. Detailed records about armed encounters between British and German ships can be found in German (BAMA), British (TNA) and American (NARA, Captured German Records) archives. Studying these records is outside the scope of this report. However, previously conducted studies by REASeuro (Amongst others 73556/RO-190149 Final Report DTS HKW Beta Export Cable Routes version 1.0) point out that near IJmuiden alone 36 confrontations between British and German vessels took place. The localisation is mainly based on the quadrants used by the German navy. The accuracy of these quadrants is not better than six to six nautical miles. For many of the surface craft battles only one source is available. Nevertheless, the German records show that most battles took place in a zone from the coast to the west of the convoy route.

4.4.1 Conclusion

Because of the large amount of naval battles that took place, an UXO risk area is defined. It is deemed probable that AA-shells and munition that could be used against enemy shipping might still be present in the area of investigation. UXO might be present near the convoy routes used by German ships. Therefore a UXO Risk Area is projected between the Dutch coast and the convoy routes. A buffer of 1 nautical mile (1.852 meter) is taken into account to mitigate the navigational inaccuracy. The likelihood of presence of UXO outside of the area between the Dutch coast and the convoy routes is deemed remote. In the table and figure below the UXO Risk Area is shown.

UXO type	Type	Condition
Small calibre ammunition	.303	Fired
	.50	
	13,2 mm	

	15 mm	
Artillery shells	2 cm/20 mm	
	2 pr. pompom	
	3.7 cm	
	6 pr.	
	8.8 cm	

Table 4: Expected UXO.

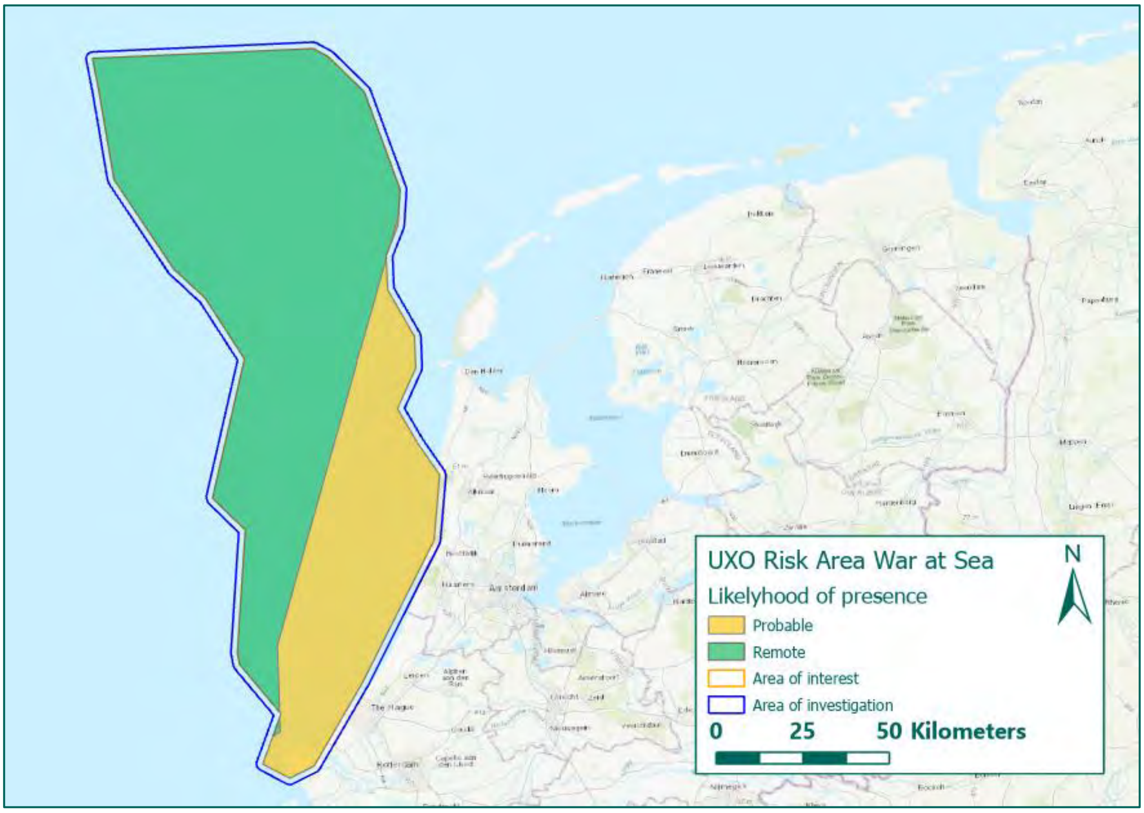


Figure 32: UXO risk area caused by surface craft battles. (Source basemap: ESRI).

4.5 MILITARY EXERCISE

On maps that show German minefields (used in paragraph 4.1.2) a German 'Schieβgebiet' ('Shooting area') can be seen that overlaps with the area of investigation. The 'Schieβgebiet' was drawn onto a map concerning German minefields in the North Sea. In the consulted sources there is no further mention about the 'Schieβgebiet'. It is therefore unclear what kind of exercising took place within this area. It could either be exercises carried out by the Kriegsmarine or the Luftwaffe. It is expected that within this area small arms calibres and artillery shells have been used. It is known that wartime exercises are often carried out with live ammunition, this in contrast to post-war exercises.

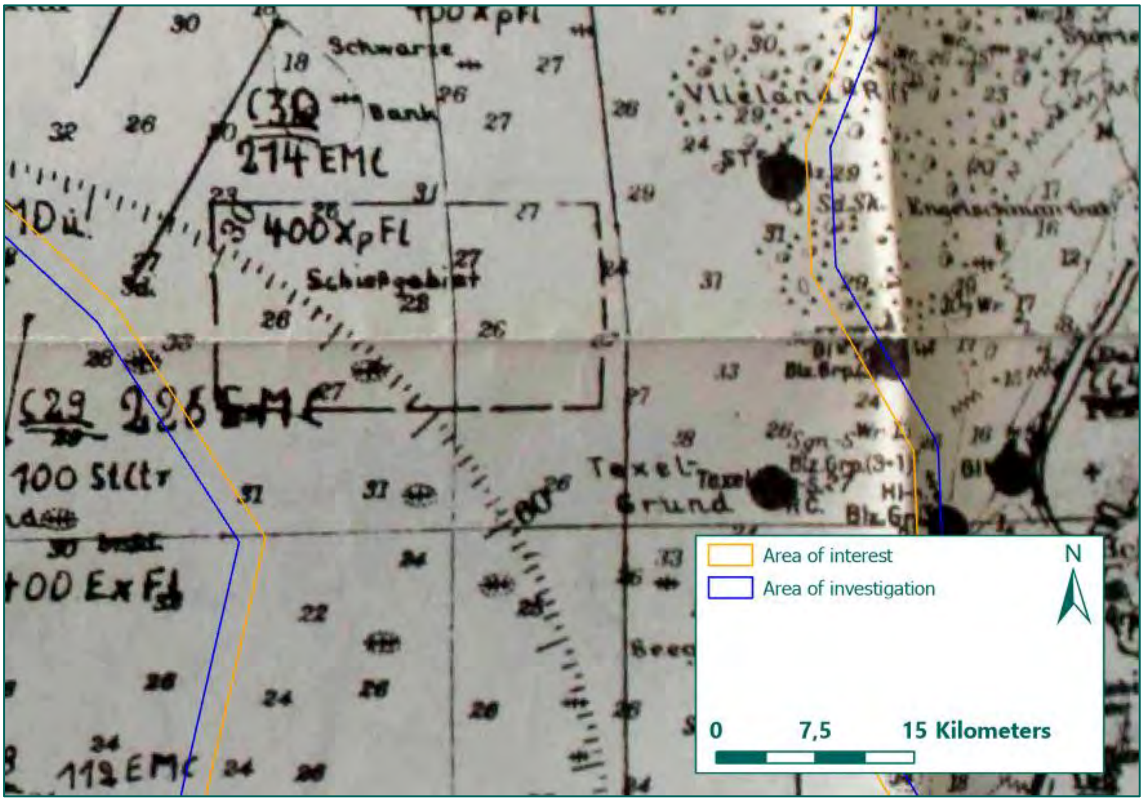


Figure 33: German map showing minefields and a 'Schieβgebiet' ('Shooting area') within the area of analysis (Source: BAMA, ZA 5/27).

Based upon information from the 'Nationaal Archief' in the Hague it is known that the above mentioned 'Schieβgebiet' was used by the Dutch Navy after World War II. The contours of the military exercise area appear to have an exact overlap with the contours of the German 'Schieβgebiet' discussed above. Sources from the Noordzeeloket (see Annex 3) show that this military exercise zone was used as a "laag vlieggebied" (low fly zone) where one of the activities carried out was 'gun fire'[6]. The map on which the military exercise area is drawn dates from 1965. It is not known for how long the Dutch Navy used the area for exercises and whether only 'gun fire' was carried out.

[6] It is expected that in this low fly zone exercises with both machine gun- and cannon fire were carried out with aircraft.

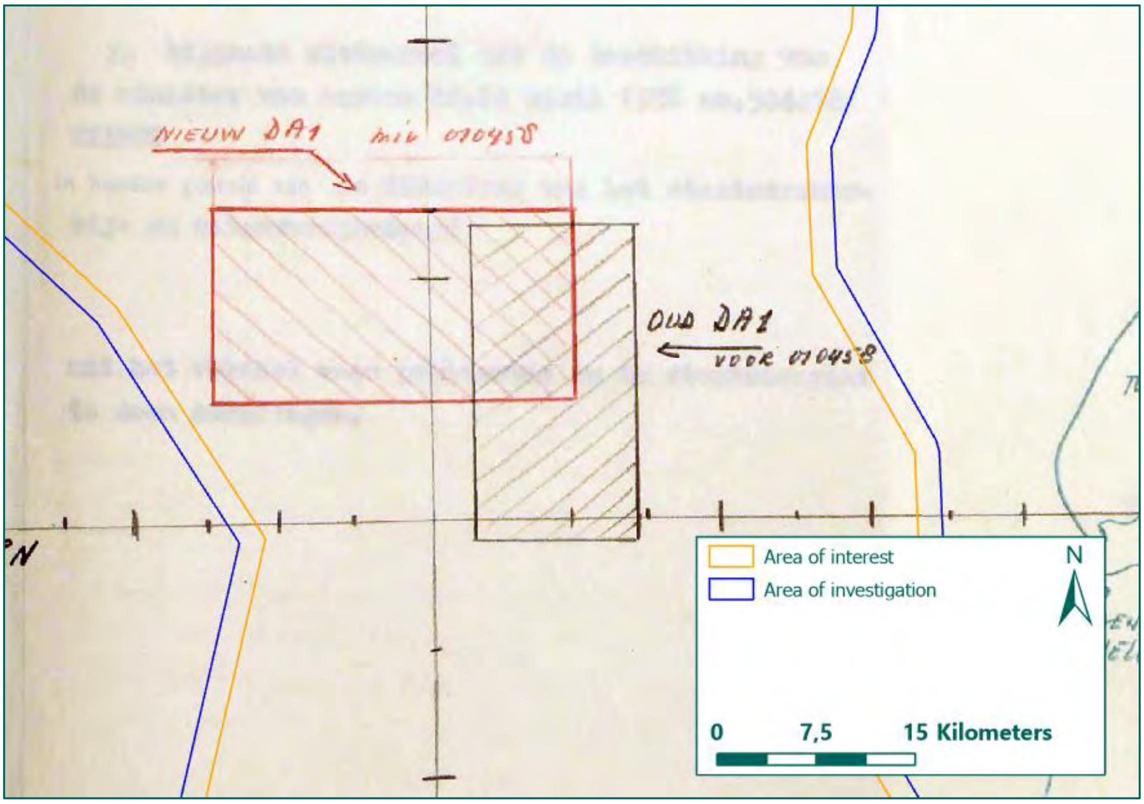


Figure 34: maps showing the location of a Dutch military exercise area within the area of investigation (Source: Nationaal Archief Toegang 2.12.56, folder 939).

Both during and after the war a military exercise area overlapped with the area of analysis. Normally, explosives are no part of exercise ammunition. However, as a result of German wartime practicing within the ‘Schieβgebiet’, UXO could be encountered within the ‘Schieβgebiet’ as wartime exercises were often carried out with live ammunition. It is to be expected that Dutch post-war exercises were carried out with small arms calibres and artillery shells. During peacetime military exercises would often be carried out with practice ammunition. Practice ammunition can incorporate devices to simulate the impact, like smoke markers or relatively small amounts of high explosives.

Besides the abovementioned ‘Schieβgebiet’, several other military exercise zones were located within the Area of investigation. It is known that some of these zones were in use during World War II. However, it is not clear whether this is the case for all exercise zones. It is outside the scope of this HDTS-UXO to conduct research in the usage of each of these zones. Because of the possible usage of live munition within the different exercise areas, it cannot be ruled out that UXO might still be present within the area of investigation.

The different military exercise zones as mentioned in the consulted sources are shown in the figure below.

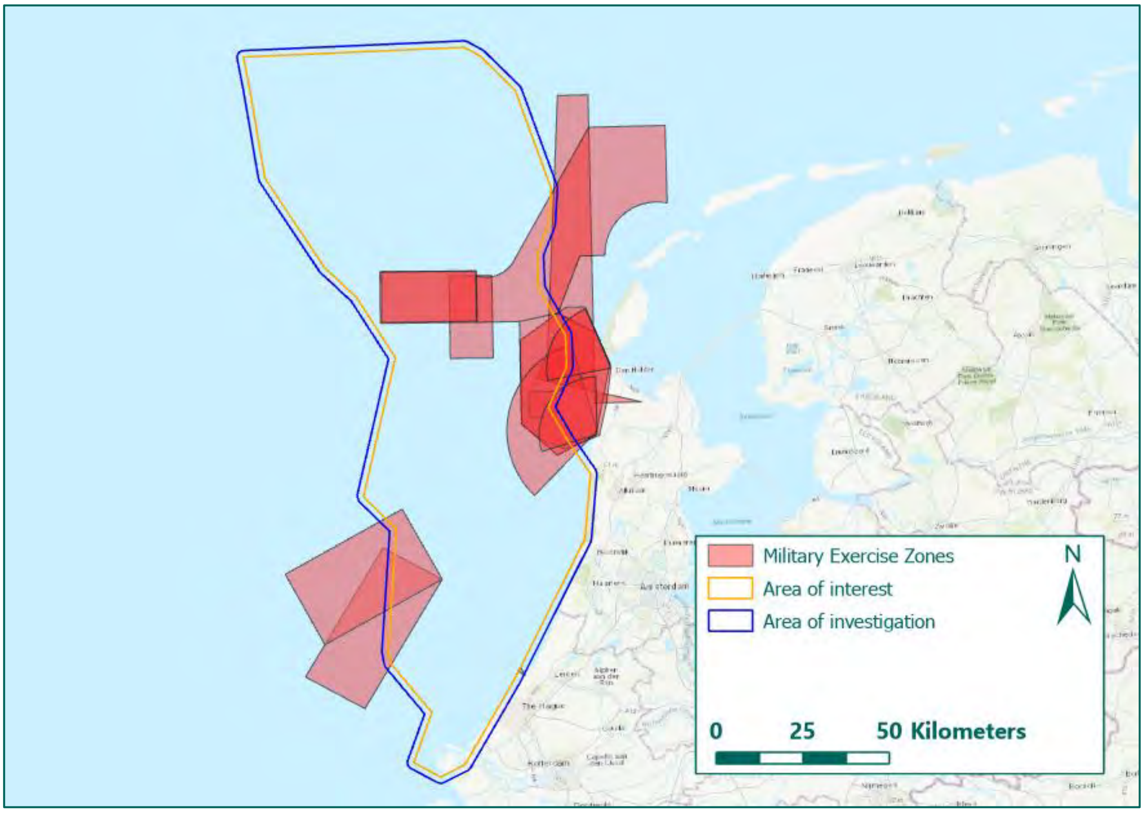


Figure 35: Military exercise zones within the area of investigation (Source basemap: ESRI)

4.5.1 Conclusion

The presence of several military exercise zones within the area of investigation, of which some were used during World War II, leads to the conclusion that UXO (either exercise ammunition or live ammunition) could still be present within the area of investigation. Additional research may be necessary to determine the type of munition used in each of the zones, and to determine whether or not live ammunition was used within the zones. This additional research is outside the scope of this research.

The sort, type, amount and condition of the munition used within the different military exercise zones can, at this time, not be determined. The consulted sources do not provide information about this. However, it cannot be ruled out that UXO might still be present within the area of investigation. Therefore, a UXO Risk Area is projected at the location of these military exercise zones. The likeliness of presence of UXO in these zones is deemed probable. The likeliness of presence of UXO in the other parts of the Area of investigation is deemed negligible.

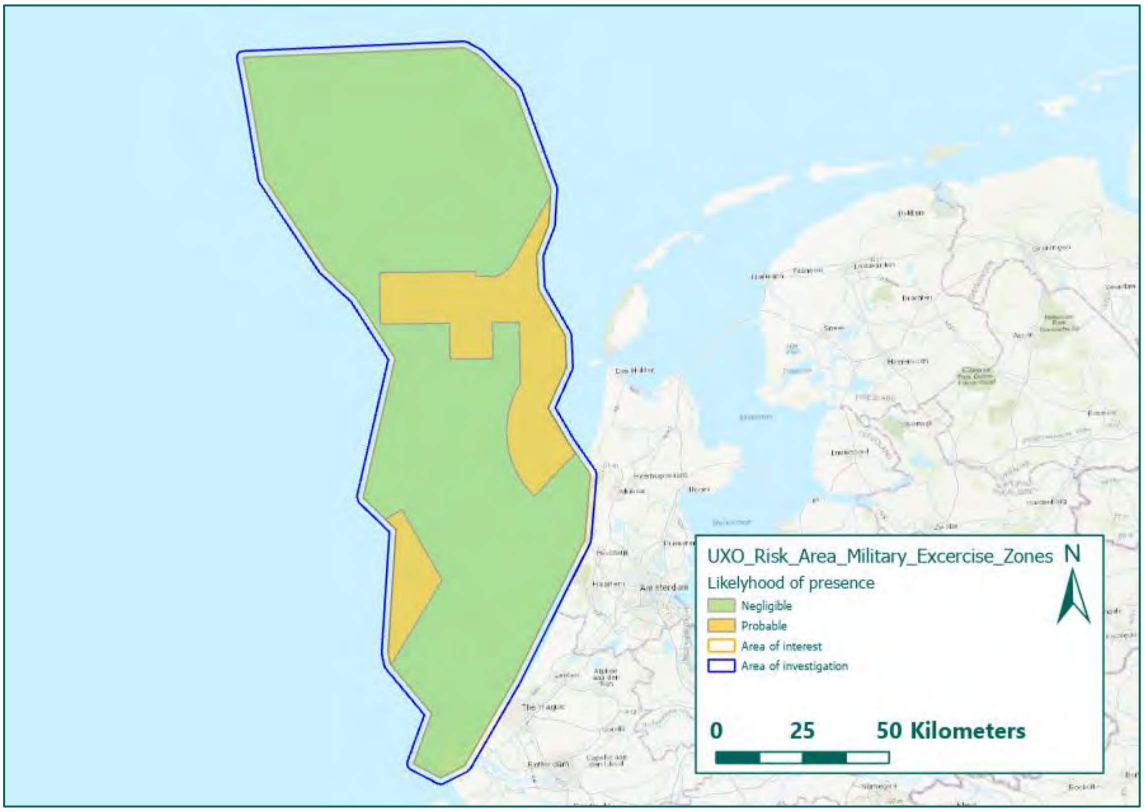


Figure 36: Likelihood of presence of UXO as result of the presence of coastal guns. (Source basemap: ESRI).

4.6 WRECKS

According to consulted sources (website of the Wrecksite and HP39 Wrakkenregister), various airplanes crashed into the area of investigation and boats sunk in the North Sea. For many crashes and shipwrecks the exact location is not known. Some wreck locations are therefore indicatively marked.

The wreck register (HP39 Wrakkenregister) shows 609 shipwrecks in the area of investigation (see annex 5). Detailed information about most wrecks are unknown. However, in some cases the name of the sunken vessel is known. It is possible to research whether or not these vessels sunk due to war related events. However, it is deemed outside the scope of this research to find additional information about 97 wrecks. Therefore, this additional research will not be conducted. In the figure below a total of all wrecks near the Area of investigation is shown.

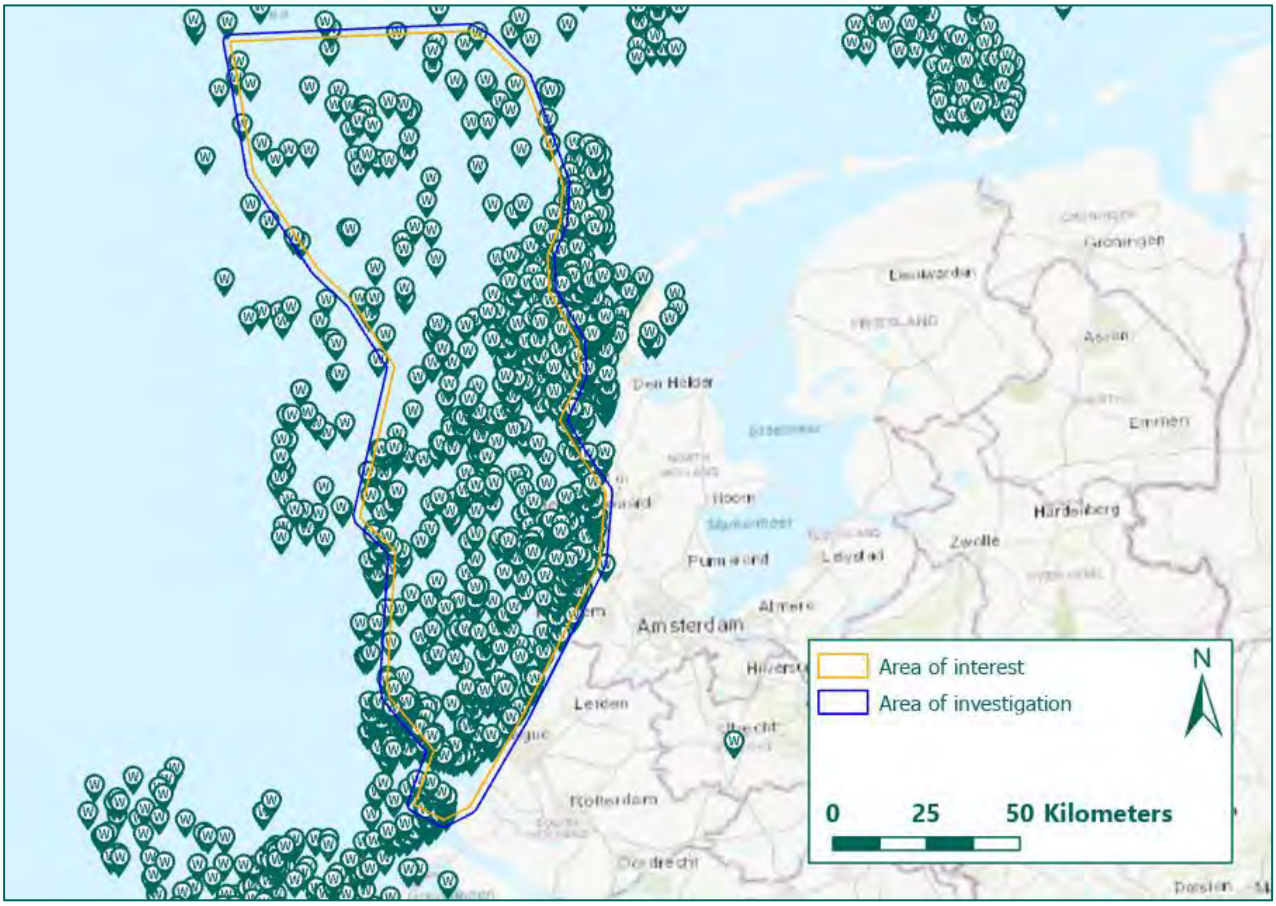


Figure 37: Overview of wrecks within the area of interest according to HP39 (Source: HP39).

The website of 'Wrecksite' also provides a lot of information about wrecks. Near the area of investigation, a total of more than 1800 wrecks lay within and near the area of interest. Plotting all these wrecks in the GIS-system would be too comprehensive and falls outside the scope of this report. In the table below a list of war related causes of sinking of ships/aircraft within the area of interest is shown. It should be mentioned that in most cases, no cause of sinking was mentioned.

Cause of sinking	Total number sunk
Airplane crashes, WW2	75
Air raids, WW2	19
Charges/explosives, WW1 and WW2	8
Depth charges , WW2	2
Explosions, WW2 and after WW2	4
Gunfire – shelled, WW1 and WW2	152
Mine, WW1 and WW2	39
Naval battles, WW1 and WW2	10
Torpedo, WW1 and WW2	21
War loss (Not specified), WW1	1

Table 3: Listing of ships/aircraft sunk by war related events.

4.6.1 Conclusion

As can be seen, most of the wrecks mentioned in this table can be ascribed to war related events described in paragraphs 4.1-4.3. The demarcation of UXO Risk Areas resulting from these war related events is also described in these paragraphs. Additional UXO Risk Areas will not be demarcated because of the possible presence of wrecks of ships or aircraft. However, if a wreck is encountered during activities in the Maasvlakte the authorities are to be alerted. Wrecks can possibly still house the bodies of fallen troops or might be considered cultural heritage.

4.7 MUNITION DUMPING

As shown on the map of the Noordzeeloket (Figure 38) and the naval chart of the Royal Netherlands Navy Hydrographic service (Figure 39), ammunition dumping sites are situated within the area of investigation. According to archival documents, tons of German left behind ammunition were dumped into this zone shortly after World War II. In the 1960's, it appeared that fishermen encountered also ammunition outside the most northern dumping site, therefore a larger zone was marked as "*dangerous for fishing, intrusive, and seismographic activities*". The centre of the dump ground is marked with a buoy in position 52-33,5N, 04-03,6E. The dangerous area is defined by a radius of three nautical miles around this buoy. For the two southern dumping sites no such 'danger zones' were determined. In the figures below, the location of the dumping sites are indicated.

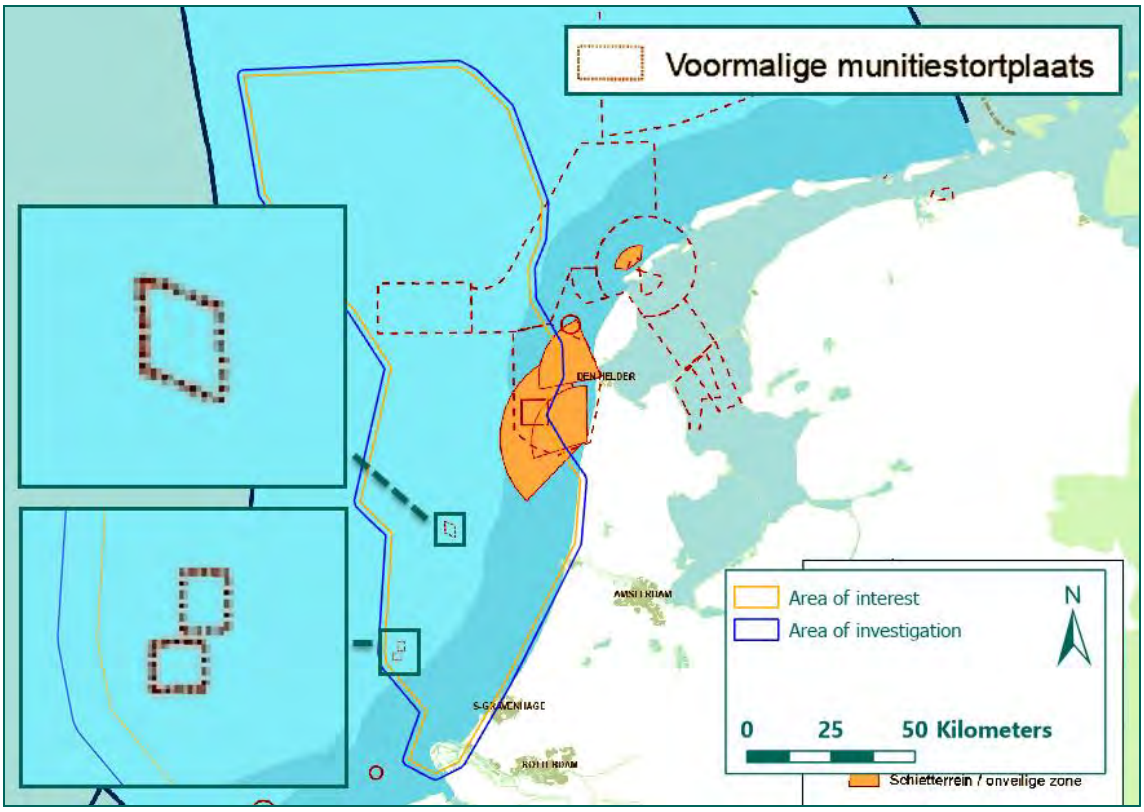


Figure 38: Map showing the military usage of parts of the North Sea, including munition dumping sites (Source: NZL).

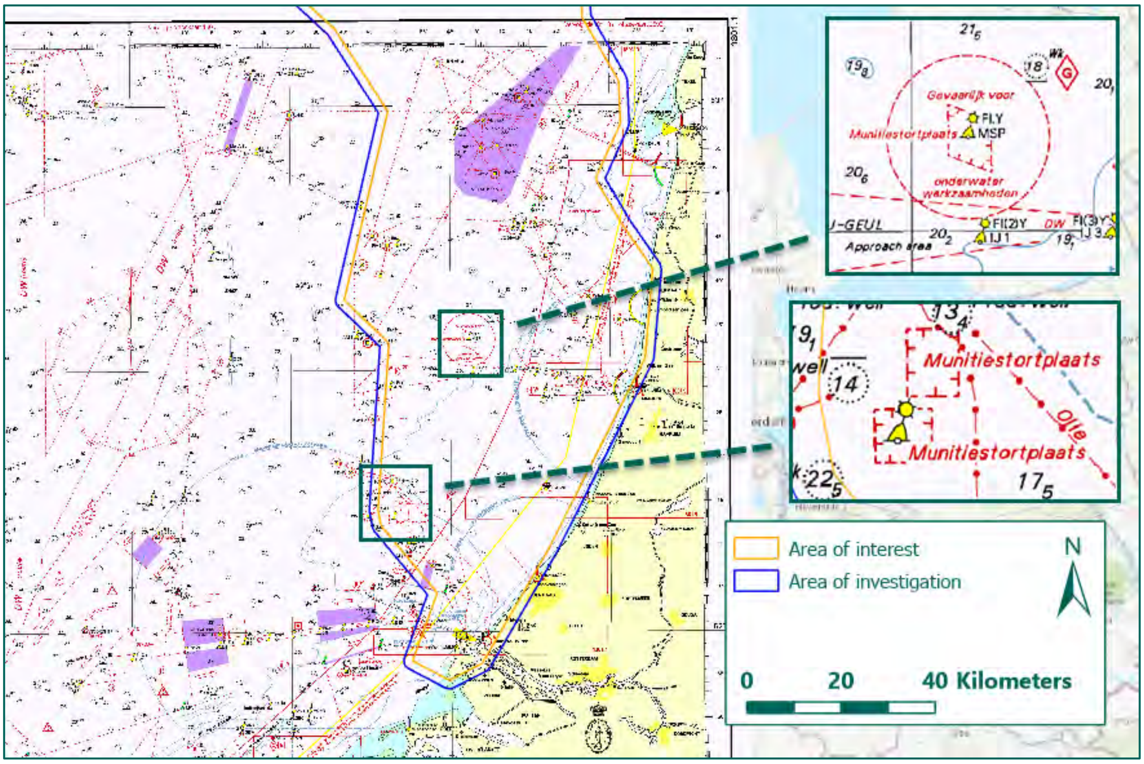


Figure 39: Naval chart (Source: Royal Netherlands Navy Hydrographic service).

4.7.1 Conclusion

Because of the large amounts of munition dumped within these sites, it is certain that UXO is still present within the dumping sites. It is also probable that munition was dumped outside of the determined dumping sites, as was the case near the most northern dumping site. Therefore, a buffer of three nautical miles is projected around these two munition dumping sites as well. Within these buffer zones the likelihood of presence is deemed probable. No information is available on the exact amount and type of the ditched ammunition. Therefore, the sort, type, amount and condition cannot be determined.

The consulted sources do not provide information about munition dumping in other parts of the Area of investigation. Therefore, the likeliness of presence of dumped munition in the other parts of the Area of investigation is deemed negligible.

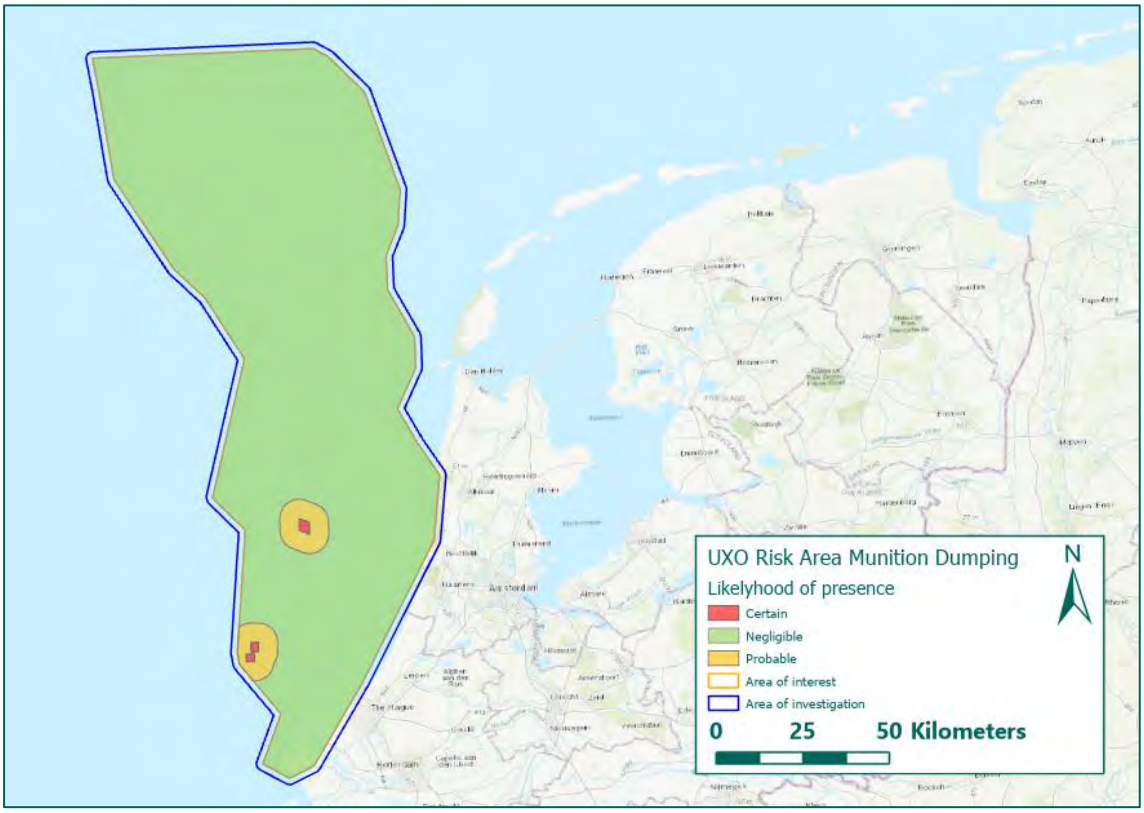


Figure 40: UXO risk area due to munition dumping. (Source basemap: ESRI).

4.8 V1 AND V2 BOMBS

During the last years of World War II, the German High Command started using new weapons with the hopes of stopping the Allied build-up and advance. These new weapons were the Vergeltungswaffe 1 (V1) and Vergeltungswaffe 2 (V2). The V1 was an early cruise missile with a pulsejet for power. The V2 was the world's first long-range guided ballistic missile. These weapons were targeted against, amongst others, Allied cities and harbours.


Figure 41: photographs of a V1 and V2 (Source: REASeuro-database).

V1 and V2 launch sites were constructed all over German-occupied territories. London was one of the main targets of the V1 and V2. Many of the V1s and V2s launched did not reach their target but landed prematurely or overshot their target due to navigational or technical errors. V1s and V2s were also vulnerable to Allied countermeasures such as anti-aircraft guns.

The consulted sources show that V1s and V2s could also land in the sea near the United Kingdom (see Figure 42). It is possible that, either through navigational or technical errors or through Allied countermeasures, UXO of V1s and V2s are left within the Area of investigation. However, in the consulted sources there are no indications that this has occurred.. A UXO Risk Area can therefore not be determined.

Figure 42: V1 and V2 bombs hitting targets in the United Kingdom (Source: V2, See Annex 2)

4.8.1 Conclusion

Although it is known that V1s and V2s could at times strike down at the sea, there are no indications in the consulted sources that this has occured within the area of investigation. It is therefore not possible to determine a UXO Risk Area within the Area of investigation.

5 GAPS IN KNOWLEDGE

During the analysis and review of historical sources some gaps in knowledge occurred that could not be filled in with the consulted sources:

- Knowledge of previous UXO clearance operations is often absent. Therefore, it is not fully known if during the period 1914-2016 UXO were encountered in and/or removed out of the area of investigation.
- It is unclear whether the source material concerning German convoy routes is complete. The consulted sources mention several attacks on convoys sailing outside the convoy routes that are known by REASeuro.
- Pinpointing the locations of all 1800 wrecks within and near the Area of Investigation was considered too comprehensive a task with regards of the scope of this research. Therefore, not all (approximate) locations of wrecks as mentioned in the consulted sources are pinpointed.
- The REASeuro-database did not contain detailed information about all individual coastal guns on the Dutch coast bordering the Area of investigation.
- Detailed records about armed encounters between British and German ships are not yet entered into REASeuro's GIS-Database. Therefore, it was not possible to give an overview of all (approximate) locations of these encounters.
- The type and amount of ammunition used by German and allied submarines, planes and ships is not always known.
- The types, calibres and amounts of munition used in the different military exercise zones are not always known
- It is unclear which types, calibres and amounts of munition were dumped in the munition dumping ground within the area of investigation.
- The REASeuro database does not contain every sortie made by Coastal Command planes during the Second World War.

Besides these gaps of knowledge, there are also some uncertainties concerning source material relevant for this report:

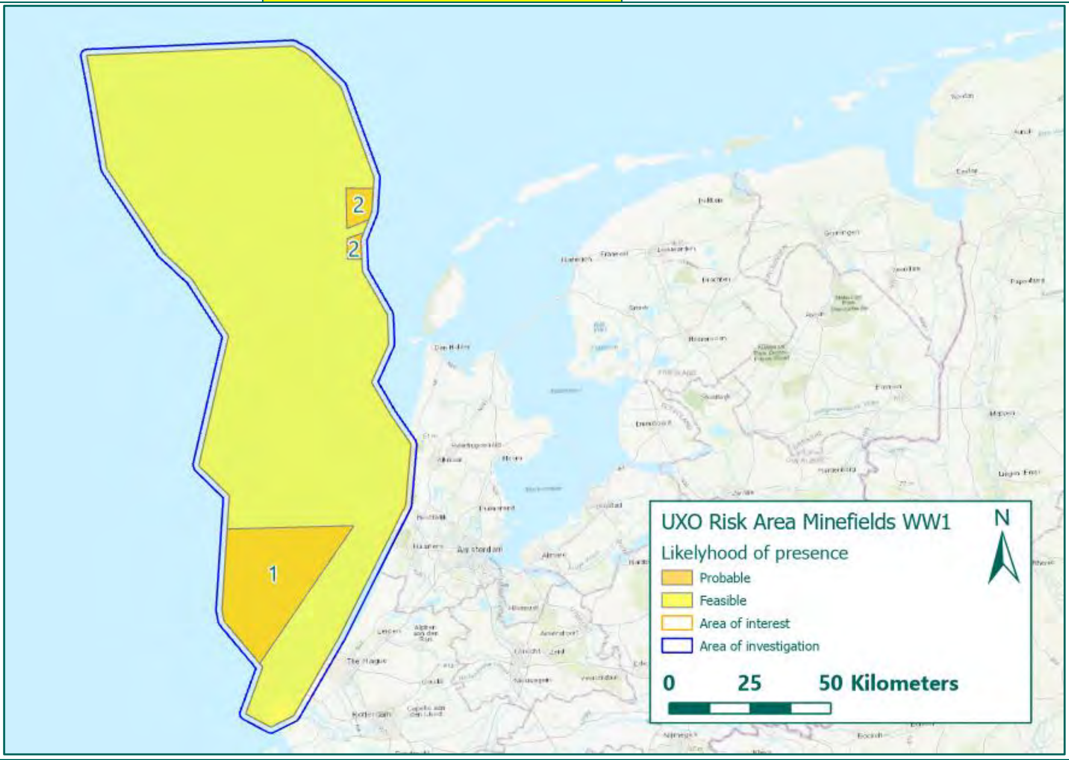
- It is not possible to pinpoint exact locations of war-related events at sea. This problem is partly solved by defining a large area of investigation. Events that took place within this area could have led to a UXO risk area.
- Compared to land, the North Sea offers few reference points. Therefore, specific information about locations is often lacking. Furthermore, it must be noted that information can be inaccurate.
- Because of the systematic destruction of the *Luftwaffe* archives, there is only sporadic information available on German Air Force activity.
- Crash locations of planes during World War II are not exactly known. This is also the case for many shipwrecks, which are also unknown on Wrecksite.eu.
- There is no exact information about the locations, amounts, conditions and types of dropped bombs during aerial attacks or jettisoning above the North Sea.

6 OVERVIEW OF UXO RISK AREAS

Based on the assessment and analysis of the source material, several UXO Risk Areas have been identified within the area of investigation. The main types of UXO found in each UXO risk area are outlined in chapter 4. The horizontal demarcation of UXO Risk Areas is discussed per type of warfare in the conclusions of paragraph 4.1, 4.2, 4.3, 4.4, 4.5, 4.7 and are presented in tables below.

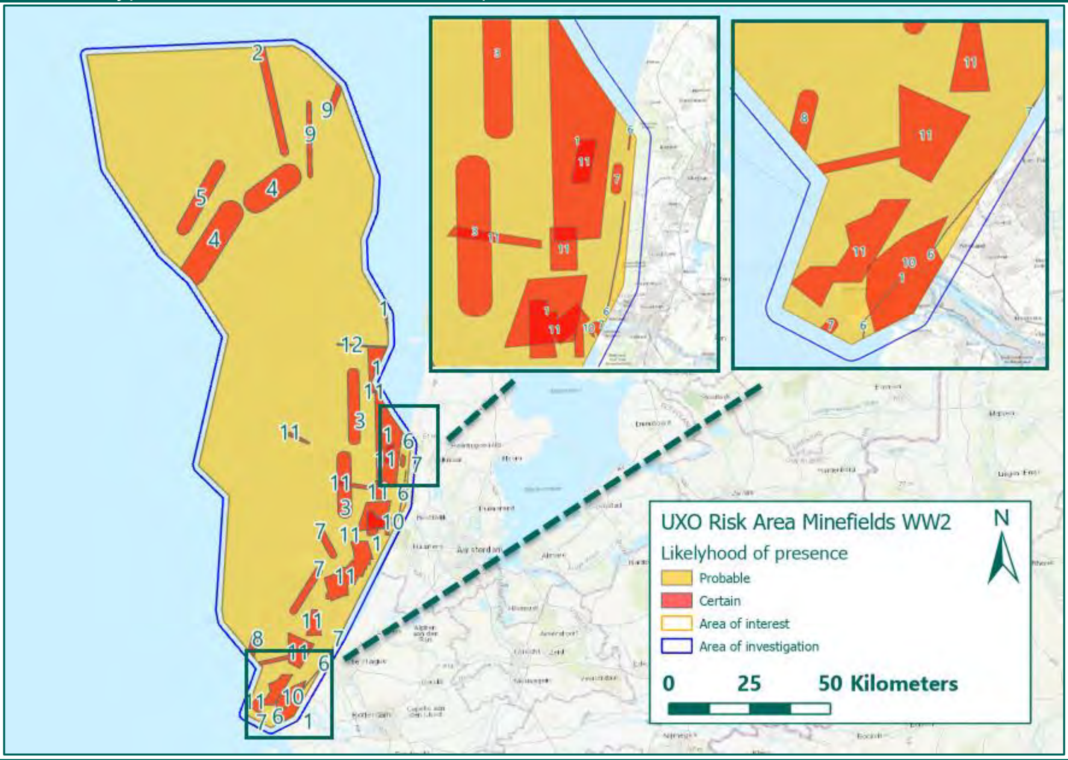
UXO Risk Area as a result of the naval mines (paragraph 4.1)

UXO (sub)type and calibre	Likelihood of presence	Demarcation
Naval Mines WW1: German E-Mine moored contact mines, British Vickers / British Elia and H Mark II moored contact mines	Probable	Within the boundaries of known minefields.
	Feasible	Outside the boundaries of known minefields.



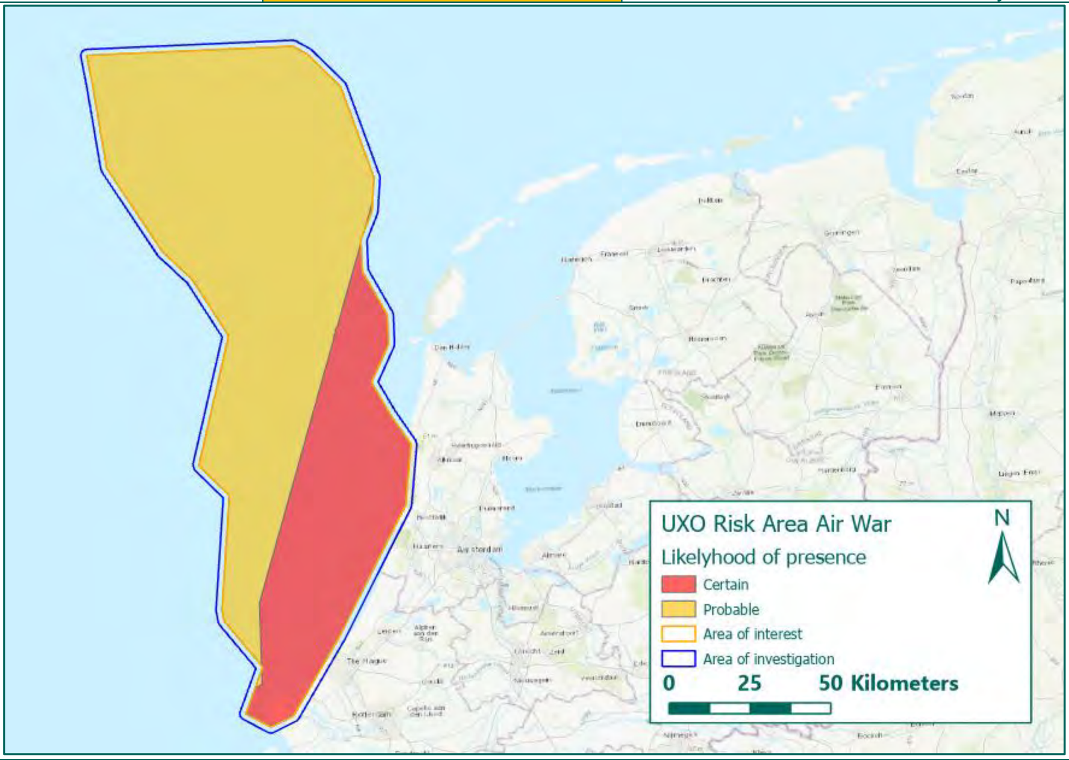
Naval mines WWII: British Mk I-IV ground mines and British Mk VII- VIII and Mk XIV German EMB, EMC, EMD, UMA, RMA, KMA contact mines German LMB Ground mines German Exploding Floats (and also non explosive sweep obstructors) Dutch Model 1921 '2e soort'	Certain	Within the boundaries of known minefields.
	Probable	Outside the boundaries of known minefields.

UXO (sub)type and calibre	Likelihood of presence	Demarcation



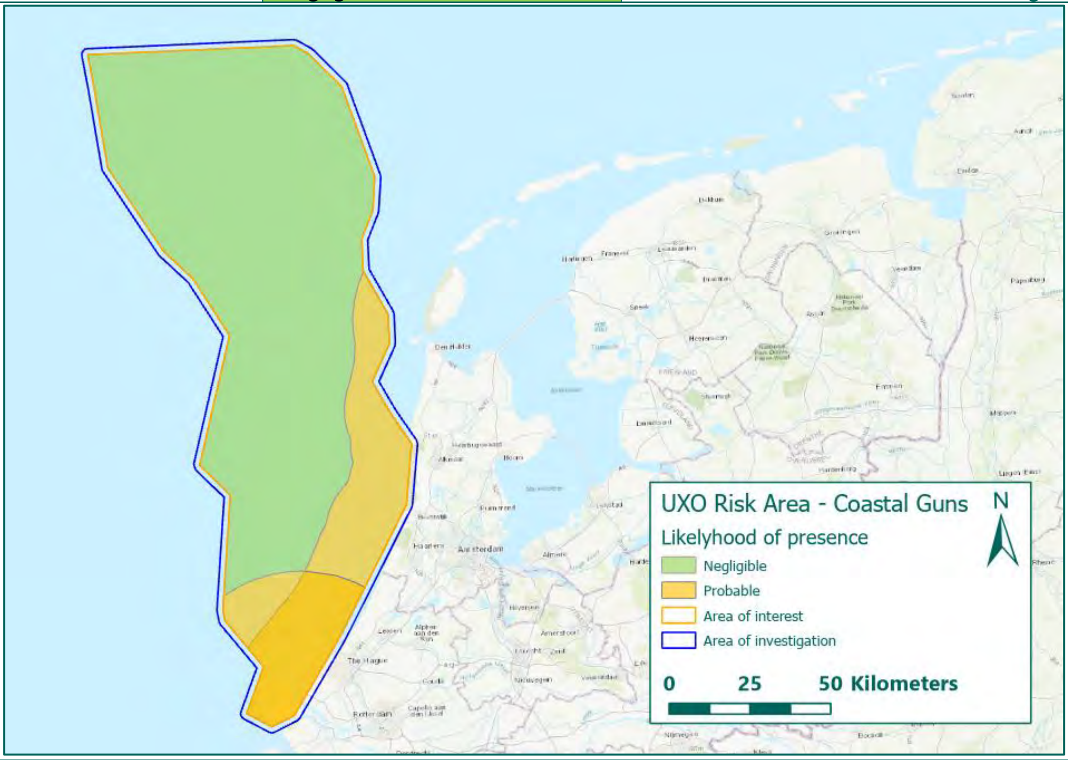
UXO Risk Area as a result of the air war (paragraph 4.2)

UXO (sub)type and calibre	Likelihood of presence	Demarcation
Aerial bombs: 4 lbs, 25 lbs, 30 lbs, 100 lbs, 250 lbs, 260 lbs, 300 lbs, 500 lbs, 1.000 lbs, 4.000 lbs	Certain	The UXO risk area is projected between the most western convoy route and the Dutch coast. A buffer of 1 nautical mile (1.852 meter) is taken into account for navigational inaccuracy of ships and aircraft.
	Probable	Areas outside of the known convoy routes.
Under water ammunition: 18 inch torpedo Mk XV Depth charge	Certain	The UXO risk area is projected between the most western convoy route and the Dutch coast. A buffer of 1 nautical mile (1.852 meter) is taken into account for navigational inaccuracy of ships and aircraft.
	Probable	Areas outside of the known convoy routes.
Rockets: 3 inch rocket with 25 lbs or 60 lbs (SAP) warhead	Certain	The UXO risk area is projected between the most western convoy route and the Dutch coast. A buffer of 1 nautical mile (1.852 meter) is taken into account for navigational inaccuracy of ships and aircraft.
	Probable	Areas outside of the known convoy routes.



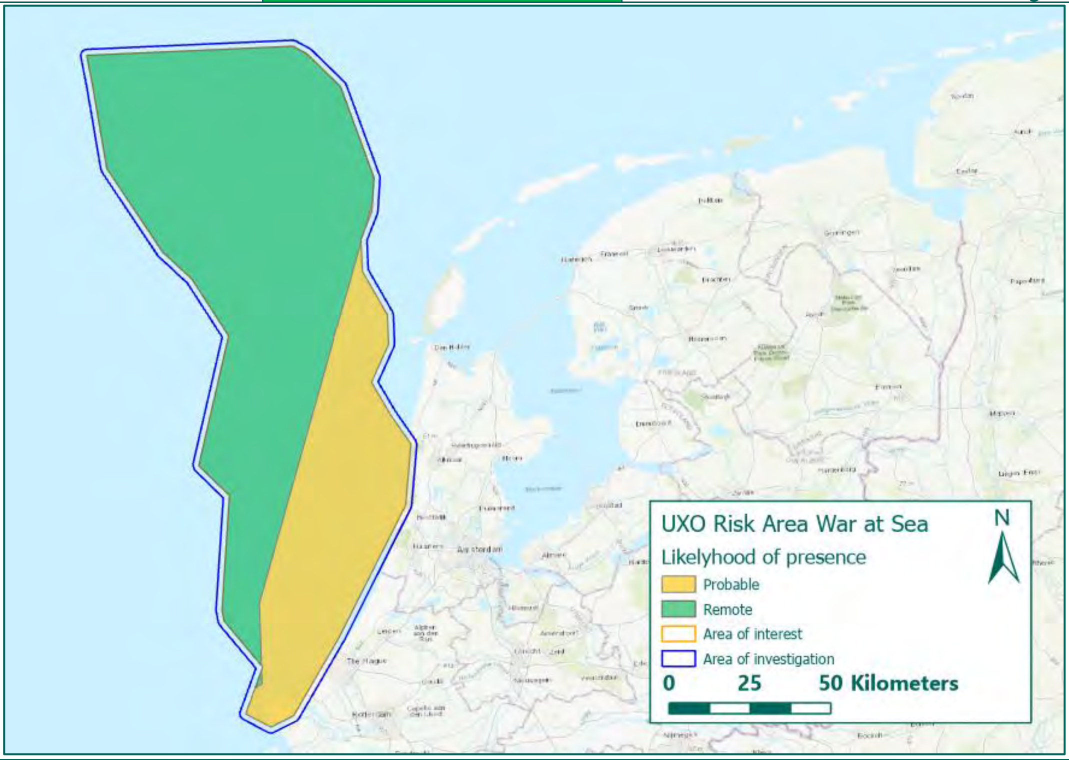
UXO Risk Area as a result of the coastal guns (paragraph 4.3)

UXO (sub)type and calibre	Likelihood of presence	Demarcation
Artillery shells: 5 cm, 7,5 cm, 9,4 cm, 10,5 cm, 12 cm, 14,91 cm, 15 cm, 15,2 cm, 24 cm, 28 cm	Probable	Within reach of the coastal guns. Where the REASeuro Database lacked information about coastal guns, the maximum range of coastal guns, not being 28 cm guns, is projected from the Dutch Coast.
	Negligible	Areas outside of reach of the coastal guns.



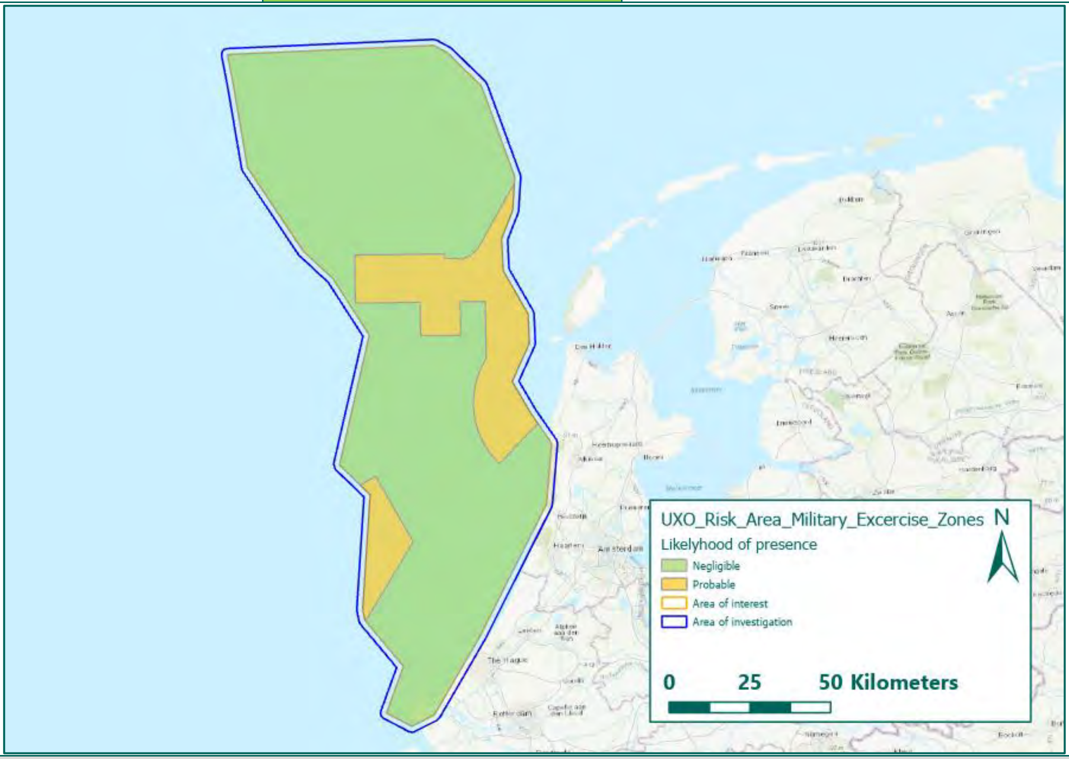
UXO Risk Area as a result of the war at sea (paragraph 4.4)

UXO (sub)type and calibre	Likelihood of presence	Demarcation
Small Calibre Ammunition: .303, .50, 13,2 mm, 15 mm Artillery Shells 2 cm/20 mm, 2 pr. Pompom, 3.7 cm, 6 pr., 8.8 cm	Probable	The UXO risk area is projected between the most western convoy route and the Dutch coast. A buffer of 1 nautical mile (1.852 meter) is taken into account for navigational inaccuracy of ships and aircraft.
	Remote	Areas outside of reach of the coastal guns.



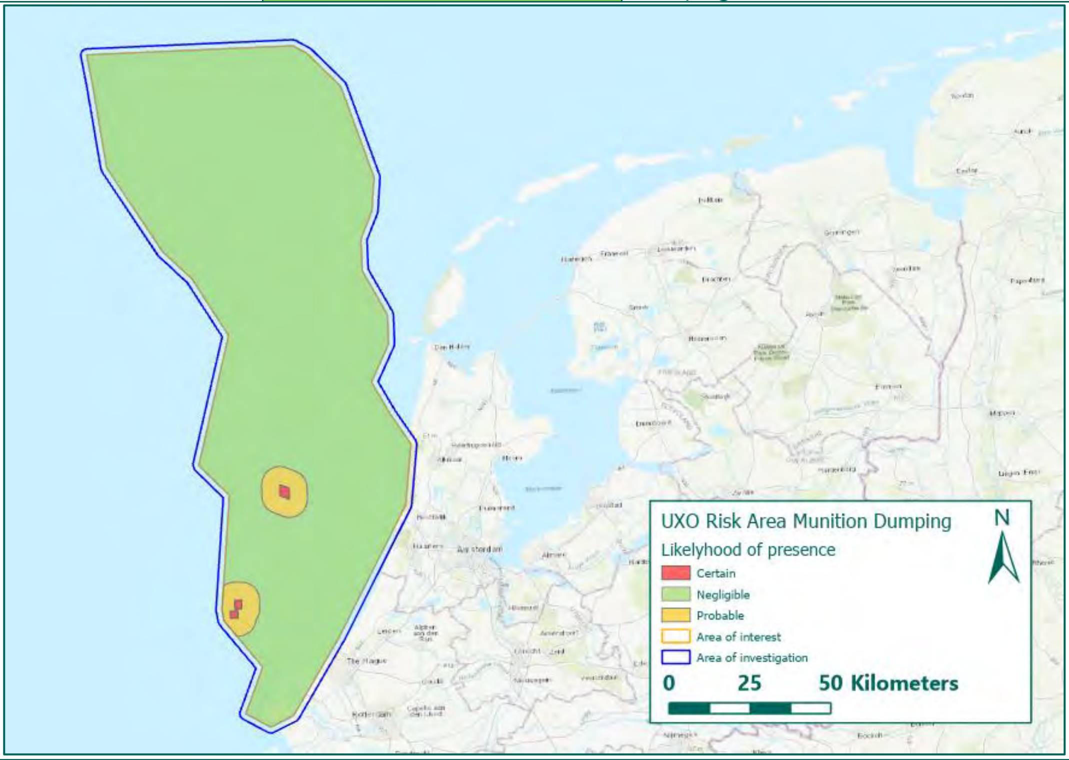
UXO Risk Area as a result of military exercises (paragraph 4.5)

UXO (sub)type and calibre	Likelihood of presence	Demarcation
Unknown (exercise) munition: Each military exercise zone had it’s own purpose, it is outside the scope if this research to determine the munition used in each zone.	Probable	Within the boundaries of known military exercise zones.
	Negligible	Outside of the boundaries of known military exercise zones.



UXO Risk Area as a result of munition dumping (paragraph 4.7)

UXO (sub)type and calibre	Likelihood of presence	Demarcation
Unknown dumped munition	Certain	Within the boundaries of known munition dumping sites
	Probable	Three nautical miles around the munition dumping sites due to large amounts of munition being found outside the munition dumping sites
	Negligible	Outside of the boundaries of known munition dumping sites



7 CONCLUSION AND ADVICE

The Historical Desktop Study leads to the conclusion that the presence of UXO within the whole Area of interest ranges from certain to negligible, depending on the type of UXO involved. In particular, the presence of UXO resulting from minefields, aerial warfare and the dumping of munition is deemed certain. Therefore, there is a severe risk of encountering UXO within the Area of interest.

Only a few specific locations wherein certain types of UXO could be present can be demarcated in this HDTS-UXO. Performing a full Historical Research will produce some further results. REASeuro advises to implement an UXO Risk Assessment (RA) alongside full Historical Research. The purpose of the RA is defining the risk that UXO poses to the planned activities in the area of analysis. This risk is a function of the 'Likelihood of Occurrence' and the 'Hazard Severity'. The 'Likelihood of Occurrence' is the product of the 'Likelihood of Presence' as defined in this HDTS-UXO and the likelihood of initiation of an item of UXO, which will be assessed in a RA. Therefore, the likelihood of presence alone is not enough to define the risk of UXO to the planned activities.

Several factors like the burial of UXO, migration of UXO, the planned intrusive activities, hazards of UXO likely to be encountered and effects of detonation are analysed and assessed for use in a Semi Quantitative Risk Assessment (SQRA). The following matrix is used to quantify the risk. Each generic UXO hazard is assessed for severity and likelihood of occurrence. This model is generally considered best practice for assessing risk in the marine environment, although it has been modified where required to ensure it is UXO centric. The risk matrix is presented in Table 3.

Once the risks have been identified fitting mitigation strategies to bring the risk down to an acceptable level will be proposed. The mitigation strategies are focused on bringing the risk down to a level that is defined as 'As Low As Reasonably Practicable' (ALARP).

Likelihood of Occurrence	Hazard Severity				
	1 = Negligible	2 = Slight	3 = Moderate	4 = High	5 = Very High
1 = Very Unlikely	1 LOW	2 LOW	3 LOW	4 LOW	5 LOW/MODERATE
2 = Unlikely	2 LOW	4 LOW	6 LOW/MODERATE	8 MODERATE	10 MODERATE/HIGH
3 = Possible	3 LOW	6 LOW/MODERATE	9 MODERATE	12 MODERATE/HIGH	15 HIGH
4 = Likely	4 LOW	8 MODERATE	12 MODERATE/HIGH	16 HIGH	20 HIGH
5 = Very Likely	5 LOW/MODERATE	10 MODERATE/HIGH	15 HIGH	20 HIGH	25 HIGH

Red	Unacceptable
Orange	ALARP with reduction measures
Yellow	ALARP
Green	Acceptable

Table 3: UXO Risk Assessment Matrix.

8 ANNEXES

ANNEX 1 GLOSSARY TERMS

Term	Definition
Historical Desk Study - UXO	Preliminary desk study in which war related events in the 1940-1945 period (including post-war detection and clearance) are being analysed. The aim is to determine whether there can be a UXO risk area in the area of interest. The historical desk study UXO consists of: - Reports. - Affirmative or negative recommendation. - In case of an affirmative recommendation: - Horizontal delimitation UXO-Risk area(s). - UXO risk map.
Historical Quick Scan - UXO	A narrower preliminary desk study than a Historical Desk Study – UXO. The aim of a HQS is to examine whether UXO cannot be excluded within the area of interest and if there are areas with an increased risk of UXO.
Unexploded ordnance (UXO)	- Unexploded ordnance (UXO) is explosive ordnance that has been primed fused, armed, or otherwise prepared for use and used in an armed conflict. It may have been fired, dropped, launched or projected, and should have exploded, but failed to do so. - For the purposes of this publication, the term UXO is used generically to also refer to explosive ordnance that has not been used during an armed conflict, which has been left behind or dumped by a party to an armed conflict, and is no longer under control of that party. Such UXO may or may not have been primed, fused, armed or otherwise prepared for use.
Area of interest	Area of focus for the historical desk study. The area of investigation is wider than the area of investigation in order to get a full view of any war related events which could be relevant.
Area of investigation	The area specified by the client in which regular work unrelated to UXO will be performed or in which a change of function will be implemented.
Detection area	The possibly contaminated area within the area of investigation where UXO detection is recommended prior to commencing regular work activities.
War related event	Events that could possibly have led to the presence of UXO. Examples of war related events are: - Aerial Bombardment - Artillery fire - Ammunition dumping or jettisoning - Ammunition related accidents - Aircraft crashes
UXO Risk map	Cartographic view of the UXO risk area(s).
UXO Investigation (Five phases policy)	REASeuro developed a five phases policy: the integral total approach to UXO related issues comprised of five separate phases. This allows the client to make a well-considered decision for each phase and to plan follow-up actions with the aim of keeping the client in control of the project. Five phases policy: 1. Historical research 2. Project risk assessment 3. Project management plan 4. Execution 5. Clearance certificate and final report
Risk assessment	The process of identifying potential threat and estimating the risks of harm and loss associated with that threat. A risk assessment also contains the evaluation of the acceptability of the assessed risk including the consequences of a materialised risk and identifies potential risk reduction and control measures.
Risk mitigation	Eliminating risk or reducing it from an identified unacceptable risk to an acceptable level.

Term	Definition
As low as reasonably practicable (ALARP)	A risk tolerability principle that has particular connotations in UK health and safety law. It requires a developer to reduce the risks from UXO until or unless the cost of implementing those measures is considered to be grossly disproportionate to the risk averted.
"CS-OOO"	The CS-OOO is the Dutch branch specific certification plan for the system certificate "detection of conventional explosives". This includes guidelines, process requirements and expertise standards. Since January 1st 2020, the CS-OOO has been the successor to the "*Werkveldspecifieke certificatieschema voor het Systeemcertificaat Opsporen Conventionele Explosieven*" (WSCS-OCE) and is legally anchored in the Working Conditions Act (Arbowet). In order to safeguard societal interests – health and safety in relation to work – the government has opted for a mandatory certification plan to guarantee the quality and safety of detecting conventional explosives.

ANNEX 2 LITERATURE

The scope of this research was to insight in the possible chance of encountering UXO within the area of investigation by consulting the REASeuro-Database. In addition several books have been consulted in order to get a clear depiction of war related events within the area of interest. In consulting literature the focus has been placed on the First World War to fill the gaps in the REASeuro-Database. For this research the following literary sources have been consulted:

Abbreviation	Author	Title	Relevant
AAS	Air and Space	*These Amateur Archaeologists Dig Up the Buzz Bombs That Fell on England in WW2* *Two brothers scour the English countryside for remnants of Hitler's vengeance weapons.*	Yes
CRO	Crossley, J.,	*The Hidden Threat. The story of mines and minesweeping by the Royal Navy in World War I* (South Yorkshire 2011).	Yes
SCH	Scheer, R.	*Germany's High Sea Fleet In The World War* (London 1920)	Yes
VER	Vergeltungswaffen	*http://www.vergeltungswaffen.nl/*	Yes
V2	V2 Rocket	*http://www.v2rocket.com*	Yes

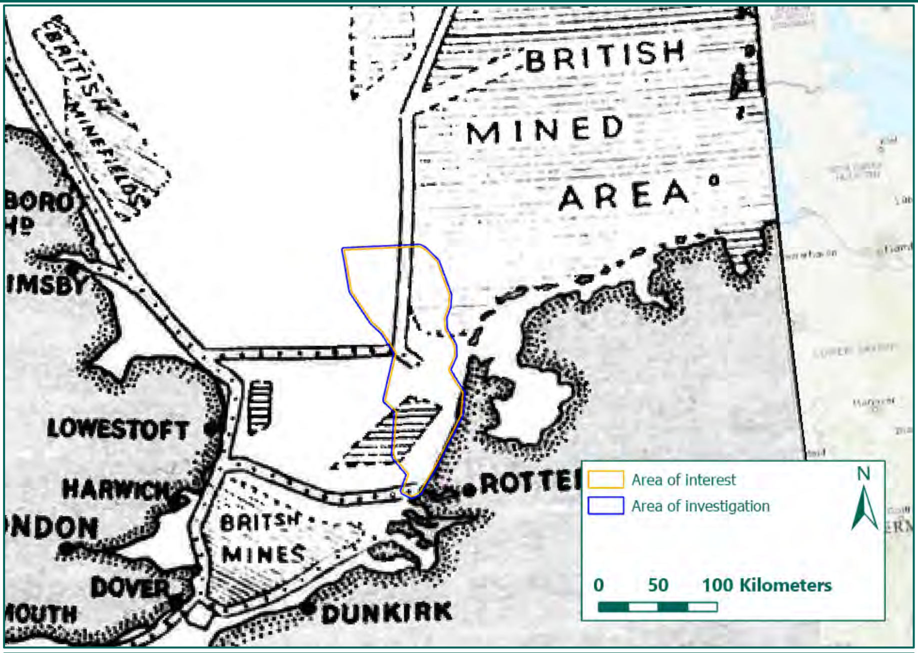
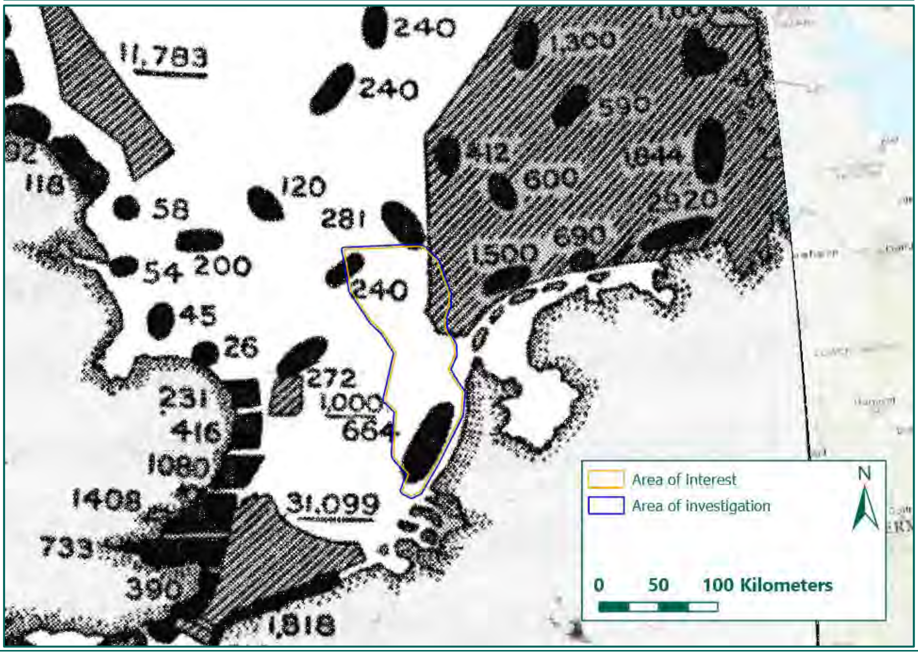
Table 4: Reference to literature.

The annex in this table contain the events that are considered relevant for the area of interest.

First World War mobilization and interbellum, 1914-1939

The First World War forced the armed forces of many nations to mobilize. Coastal guns were installed to protect strategic positions on the coast. Furthermore, shipping took considerable damage from mine and U-vessel warfare. Dozens of merchant vessels were sunk by the thousands of mines laid by the German and British navies. Large scale efforts to clear the minefields after the First World War did not succeed in clearing all these mines. The following literature is relevant for this period:

Date / year	Event	Source	Page
1914-1918	British, German and American mines laid during the war. The German minefields are in black, whereas the Allied fields are shaded. The underlined figures are numbers of Allied mines, and other figures are numbers of German mines. With their vastly greater resources, the Allies laid far more mines in the latter part of the war placing them strategically where they would effectively trap the maximum numbers of U-vessels. German mines were placed mainly close to headlands where ships would make landfalls and around the approach to major ports. From 1916 onwards, most of the German mines were laid by submarines, whereas the Allies were able to use surface ships, especially fast destroyer-minelayers, to operate close to enemy coasts. The chart gives an idea of how dangerous mine laying and minesweeping operations were as both enemy and friendly mines might be laid in the same areas. *Hatched areas in the figure below indicate allied minefields, solid areas indicate German minefields. No minefields are shown within the area of interest.*	CRO	55, 62

Date / year	Event	Source	Page
			
1918	Mines, of course, remain deadly irrespective of peace treaties or armistices. No fewer than 240,000 mines were scattered about the seas, some in their original position, some having dragged their moorings and settled in a new location, and some drifting freely. These constituted a major danger to shipping after the end of the war. To clear them up an international committee was formed, which included most belligerent and neutral countries, and was eventually joined by the defeated powers. This was called the International Mine Clearance Committee (IMCC) and was organized principally by the Royal Navy. All members carried out mine clearance activities and reported regularly to the IMCC, who issued regular charts and updates showing safe areas and known danger zones. The main part of the clearance work was divided between the maritime nations, Germany being responsible for sweeping Heligoland Bight, France the waters off the French and Belgian coasts, America the Northern Barrage and the UK, most of the rest, working through a new organization called the Mine Clearance Service. The service	CRO	149-160

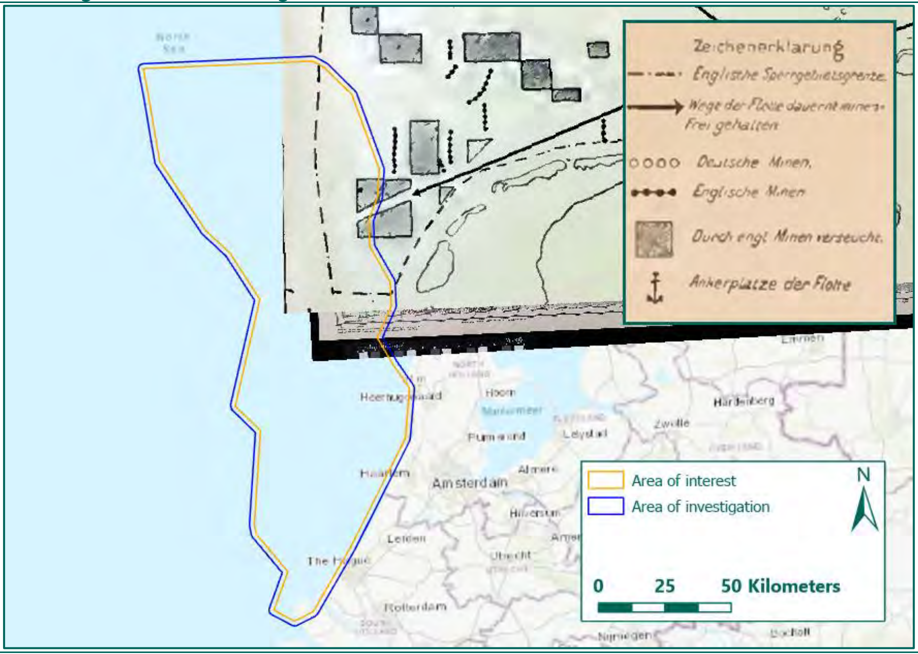
Date / year	Event	Source	Page
	was manned mainly by Royal Navy personnel and fishermen and consisted of 14,500 men and 700 officers at its peak. A particular danger when clearing dense fields was what was known as 'counter mining'. This occurred when exploding one mine would set off others in the vicinity – possibly dangerously close to the sweeper involved. Normally, deep minefields were left until last, as they did not constitute a serious danger to shipping, but sometimes some of the mines were laid incorrectly and finished up close to the surface. It was determined to skim of any of these shallow mines first, and the sweep began in the normal way. The intensive mining of the eastern North Sea also affected the German Navy to such an extent that it could not even undertake exercises safely, the British offensive mining campaign contributed to the collapse of fleet discipline and hence to the popular revolt against the Kaiser's government, which resulted in the Armistice.		
		SCH	288

Table 5: Overview of events World War 1 – Interbellum.

German invasion and subsequent occupation, 1939-1945 and Post-war period

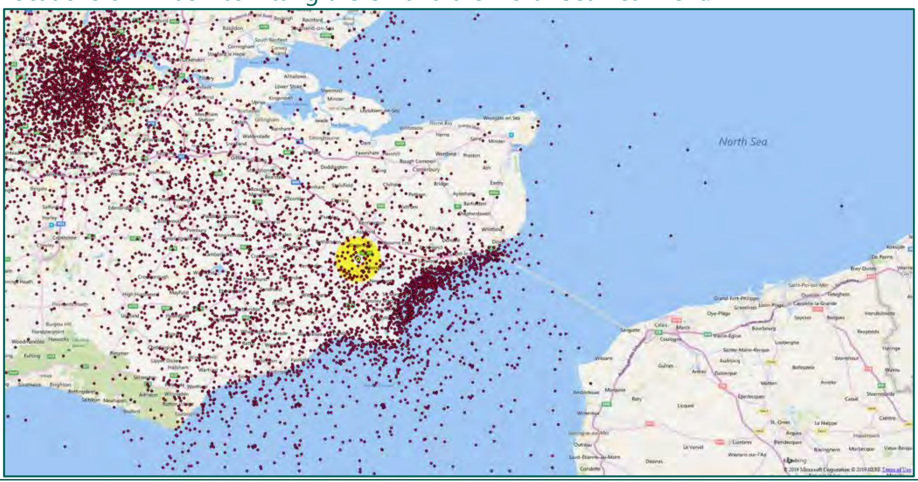
When the inevitability of the Second World War became clear in August 1939, the allied and non-aligned armies of the countries surrounding Germany once again mobilized to prepare for an imminent attack. While serious naval threats were not foreseen, preparations also took place on the coast and the sea. Coastal guns were once again installed, and vital waterways were mined.

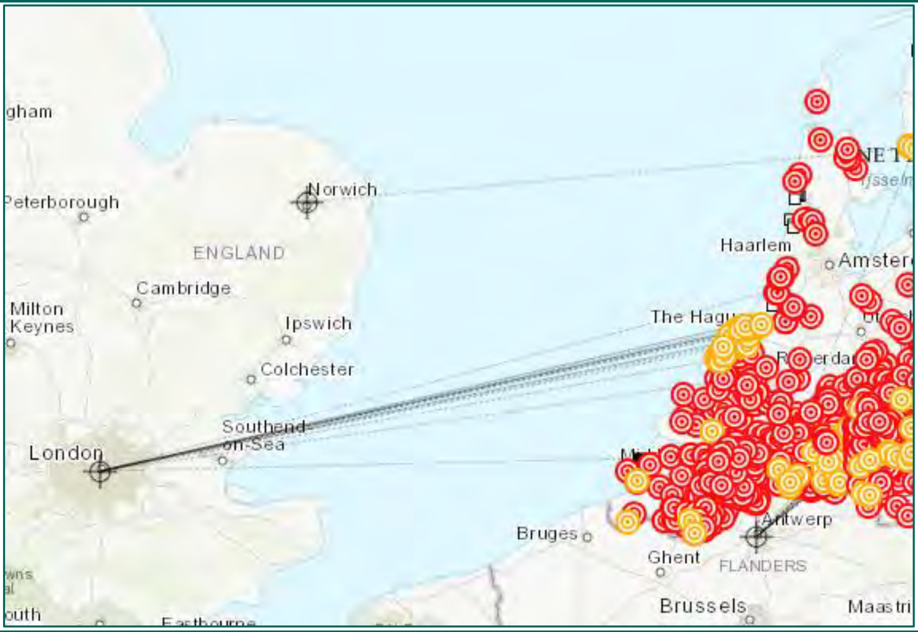
The North Sea became the frontline between Great-Britain and occupied mainland Europe. Fast attack craft from the Royal Navy coastal forces attacked German shipping close to the coast and laid mines to further hamper German navigation of the North Sea. Patrolling allied aircraft attacked convoys, submarines and surface vessels with all possible means, while heavy bombers dropped even more mines in the waters around de occupied European Coast. To make matters worse, thousands of aircraft flew over the North Sea on route to targets in Germany, jettisoning their bombs in the sea when they encountered German fighters or anti-air guns.

Immediately after the war, the reconstruction Europe began. Defensive works, bunkers and remaining UXO were cleaned up.

Literature about this period was not consulted for this report. The REASeuro-Database already contains a large quantity of sources about war related events within the North Sea. Moreover, consulting literature about this period is outside of the scope of this research.

Some information about the locations of V1s and V2s was consulted:

Date / year	Event	Source	Page
1944-1945	V1 and V2 bombs hitting the UK  	V2	-
	Locations of V1 bombs hitting the UK and the North Sea near Kent.  	AAS	-
	V1s and V2s were also launched from the Netherlands to the UK. It is possible that bombs that did not reach the UK landed in the North Sea and possibly within the Area of interest.	VER	-

Date / year	Event	Source	Page
			

ANNEX 3 (INTERNATIONAL) ARCHIVES

Several international archives have been consulted in order to gain information on the war related events in the area of investigation. The REASeuro database contains a large quantity of documents from the British, American and German archives. The following international archives yielded relevant documents for this desk top study:

- Noordzeeloket, The Netherlands.
- Dienst der Hydrografie, Koninklijke Marine, The Netherlands
- Nationaal Archief, The Hague, The Netherlands
- Nederlands Instituut voor Militaire Historie, The Hague, The Netherlands
- Marinemuseum (Navy Museum), Den Helder, The Netherlands
- UK Hydrographic Office (UKHO), Taunton, Somerset, United Kingdom.
- Library of Congress (LOC), Washington D.C., United States.
- The National Archives (TNA) in London, United Kingdom.
- National Archives and Records Administration (NARA) in College Park (MD), United States.
- Bundesarchiv-Militärarchiv (BaMa) in Freiburg, Germany.

Noordzeeloket (NZL)

The Noordzeeloket is a comprehensive website, covering relevant Dutch maritime policy related North Sea information. On the Website relevant information about the locations of Voormalige munitiestortplaatsen (Former munitions dump locations), Oefengebieden Mijnenruimen (Mine clearance training areas), (Laag)vlieggebieden ((Low) flying areas) and Schietterrein / onveilige zone (Shooting site / unsafe area) is available

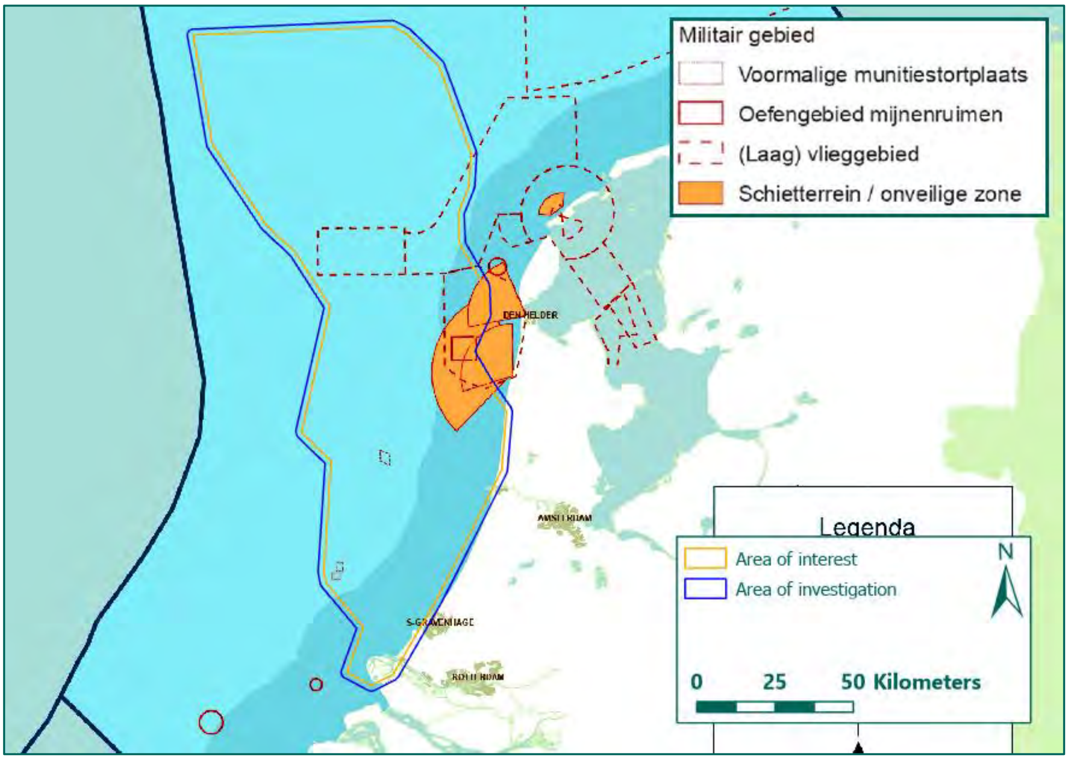


Figure 43: Map showing the military usage of parts of the North Sea (Source: NZL).

Dienst der Hydrografie, Koninklijke Marine (Royal Netherlands Navy Hydrographic service)

Naval charts of the area of analysis have been acquired through the Hydrographic Service. Besides naval charts the HP39 (wreck registry) publication has been consulted to gain information on possible wrecks in the area of investigation.

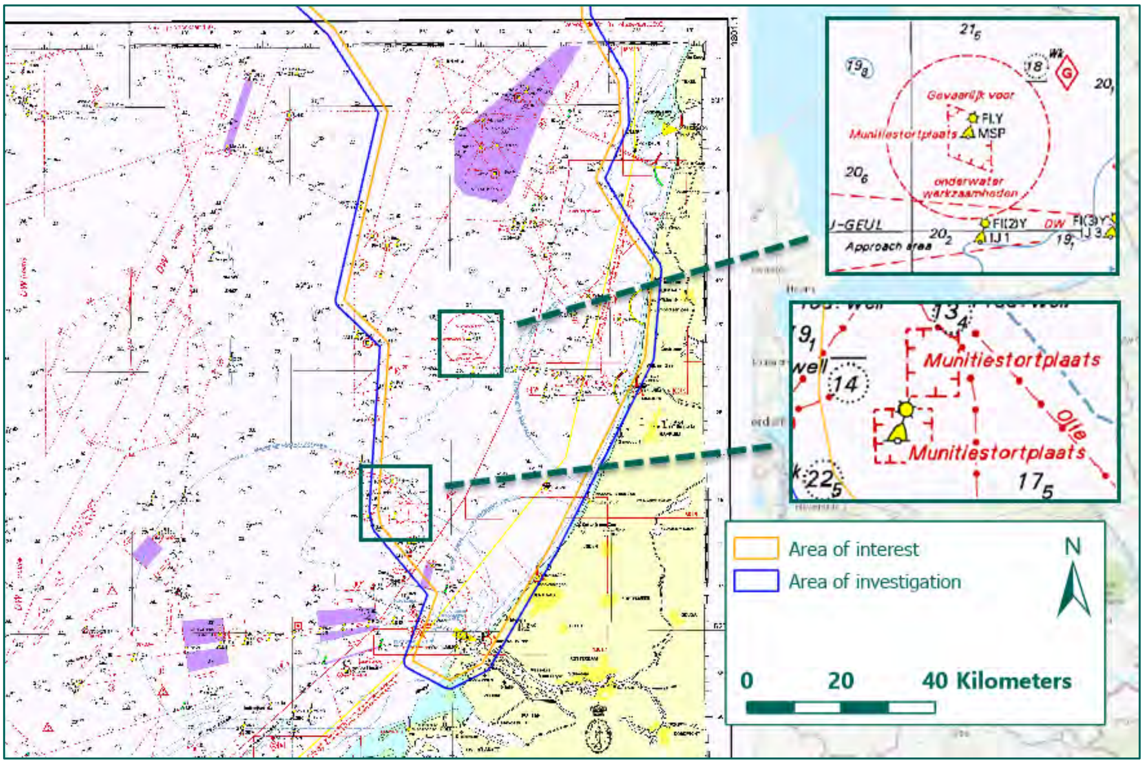


Figure 44: Naval chart (Source: Royal Netherlands Navy Hydrographic service).

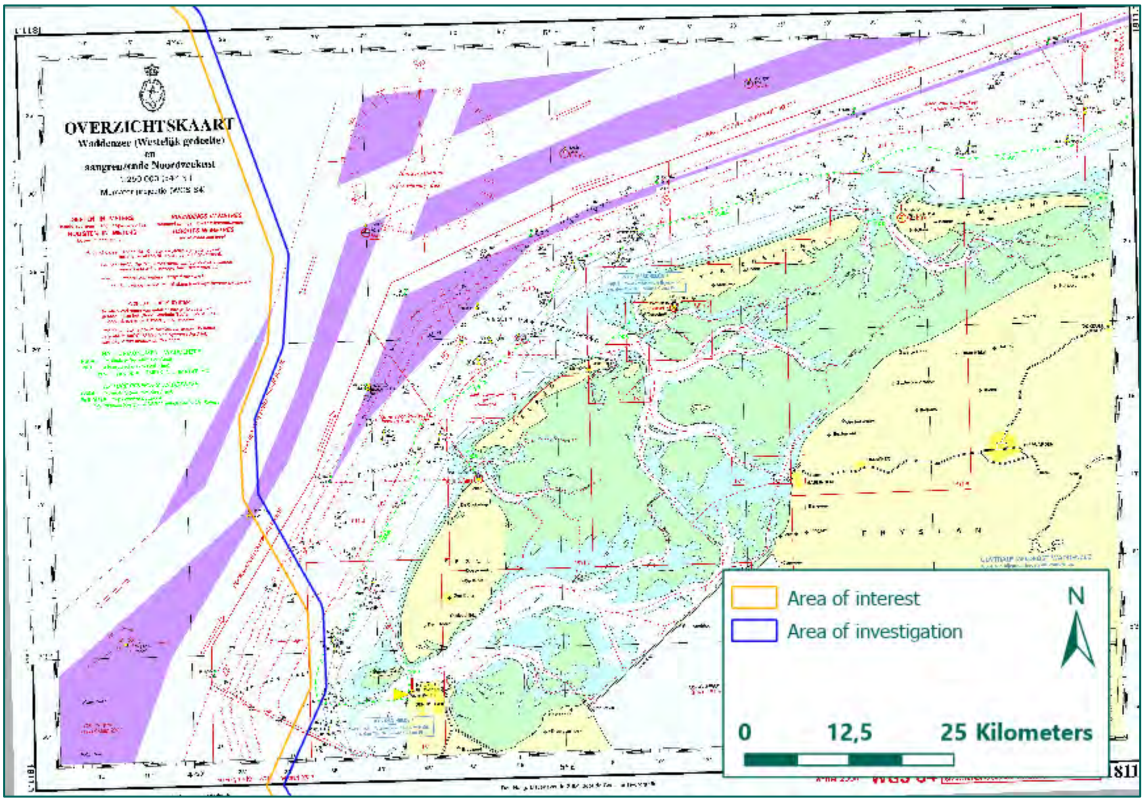


Figure 45: Naval chart (Source: Royal Netherlands Navy Hydrographic service).

Nationaal Archief

The Dutch 'Nationaal Archief' (National Archives) has been consulted for more information on the dumping of explosives, naval minefields and minesweeping, shipwrecks and other relevant information for the area of investigation.

Toegang 2.12.18: Archief van de Koninklijke Marine: Chef van de Marinestaf te ''s-Gravenhage, 1886-1942	
Inventaris 162	Stukken betreffende verboden en gevaarlijke vaargebieden 1914-1939
Map showing area’s that are ‘gevaarlijk voor de visserij’ (Dangerous for fishing activities):	

Onder verwijzing naar circulaire N°. 41 der Visscherij-Inspectie, vestigt de Hoofdinspecteur der Visscherijen de aandacht van belanghebbenden er op, dat vanaf 22 November 1917, het door Duitschland als gevaarlijk aangegeven gebied in de Noordzee, inzooverre is gewijzigd, dat als Oostgrens daarvan dient te worden aangenomen een lijn loopende van het einde der Nederlandsch-Belgische grens over het punt:

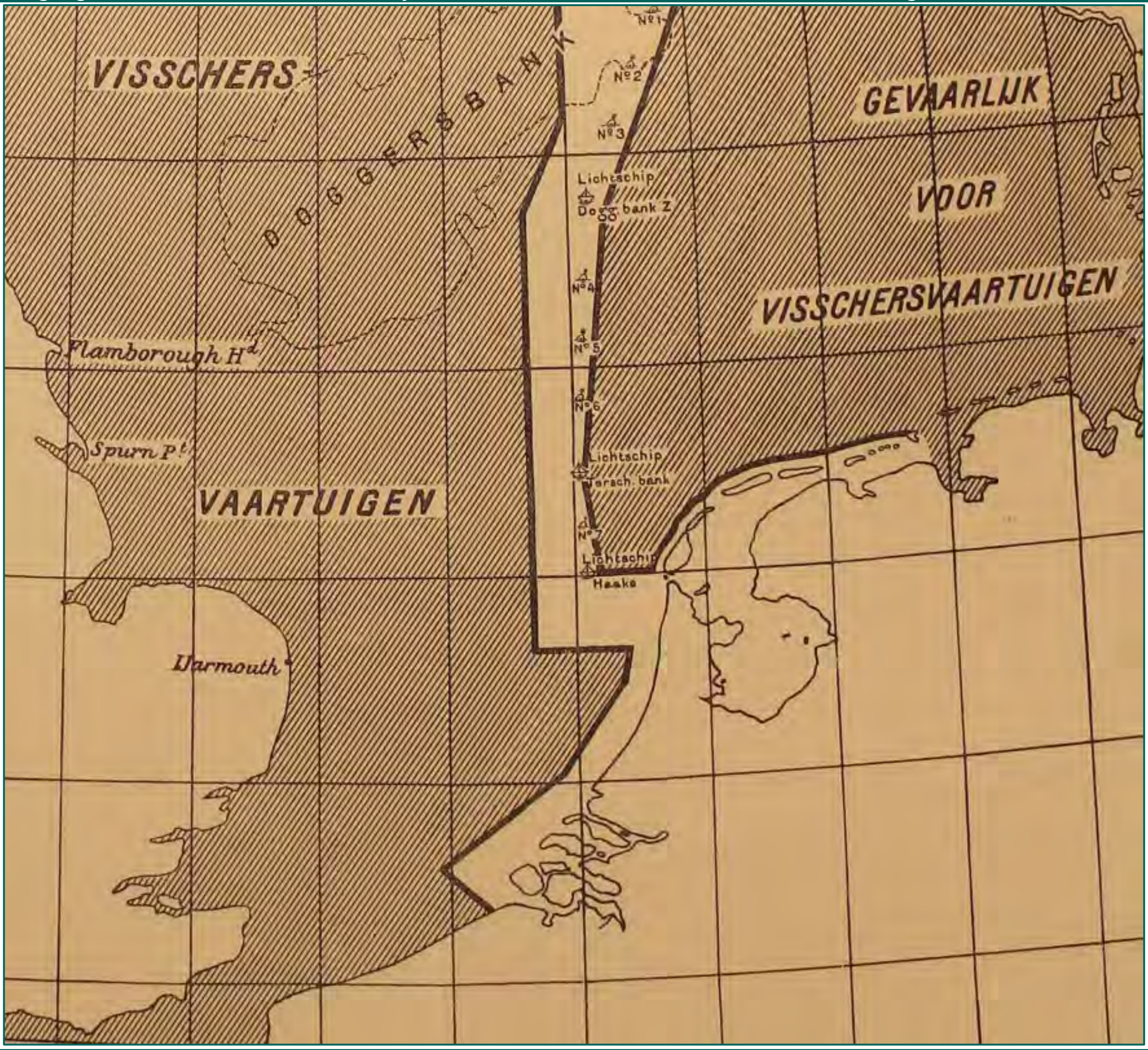
	51° 35′ N.B.	2° 57′ O.L.
naar	52° 2′ N.B.	3° 52′ O.L.
„	52° 28′ N.B.	4° 22′ O.L.
„	52° 40′ N.B.	4° 25′ O.L.
„	52° 40′ N.B.	3° 40′ O.L.
„	54° 45′ N.B.	3° 40′ O.L.
„	55° 10′ N.B.	4° 0′ O.L.
„	56° 0′ N.B.	4° 0′ O.L.
„	56° 0′ N.B.	4° 50′ O.L.

verder daarvandaan langs den lengtegraad 4° 50′ O. tot op een punt, dat 10 zeemijlen van den vuurtoren van Udsire af ligt.

Het thans voor de visscherij gevaarlijke gebied in de Noordzee, alsmede de ligging van lichtschepen en lichtbrulboeien, zijn op bijbehoorend kaartje aangegeven.

'S-GRAVENHAGE, 26 November 1917.

De Hoofdinspecteur voornoemd,
J. M. BOTTEMANNE.

Toegang 2.12.18: Archief van de Koninklijke Marine: Chef van de Marinestaf te ''s-Gravenhage, 1886-1942


Toegang 2.12.56: Marine na 1945	
Inventaris 939	Vaststelling oefengebieden voor schietoefeningen. 1950-1975
Maps and information about Military training area's in the North Sea. Relevant maps and information regarding the area of investigation are shown below: Training Ground Aircraft:	

Toegang 2.12.56: Marine na 1945

B e p a a l t:

dat de navolgende gebieden, voorzover zij vallen onder het gebied des Rijks, gesloten worden verklaard voor de luchtvaart, en voorzover zij niet vallen onder het gebied des Rijks, worden bekend gesteld als terrein, waar regelmatig militaire schiet-oefeningen worden gehouden.

1. het luchtgebied gelegen binnen de volgende hoekpunten tot op een hoogte van 1000 m

52° - 05' N, 03° - 40' E; 52° - 25' N, 04° - 00' E; 52° - 10' N, 03° - 25' E; 52° - 30' N, 03° - 25' E

Training Ground Cruisers

Ingevolge Uw telefonisch verzoek hierbij de dzz. voorgestelde onveilige gebieden i.v.m. schietoefeningen, nabij den Helder.

1. Kruiseroefenterrein
   tussen meridianen 4° - 16' - 20 " en
   4° - 26' - 40 "
   en parallellen 52° - 52' - 0 "
   en 53° - 4' - 40 "

2. Vanaf Oostbatterij, sector tussen peilingen 276° en 308° tot afstand 6 mijl.

3. Erfprins vanaf Kaap Hoofd sector tussen peilingen 260° en 340° tot afstand 8 mijl.

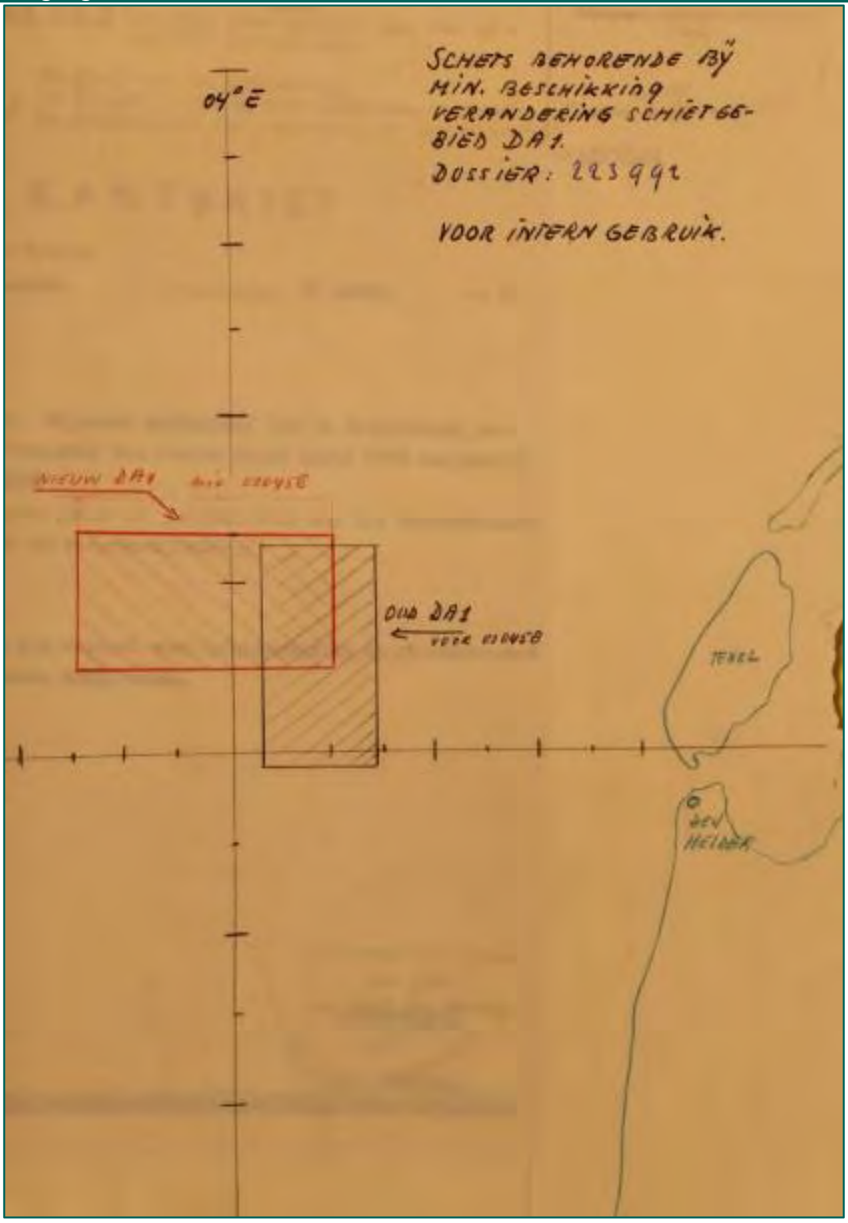
4. L.A. Schietoefeningen omgeving Haaks met gebruik "Stereomatrelage Erfprins.
   Gebied begrensd door Kaap Hoofd naar

   52° - 52' N / 4° - 40' E naar 52 - 52 N / 4° - 52' E naar 52 - 56 N / 4° - 28' E

   naar 53° - 0' N / 4° - 28' E naar 53° - 4' N / 4 - 32' E naar 53° - 4' N / 4° - 40' E

   naar Kaap Hoofd.

Old en new site of DA1:



Training Grounds in the North Sea:

Besluiten:

I.1. In de hieronder nader omschreven gebieden zijn de Commandant der Zeemacht in Nederland, de Chef van de Generale Staf en de Chef van de Luchtmachtstaf, ieder voor zover hem aangaat, bevoegd om in overleg met de Directeur Generaal van de Rijksluchtvaartdienst de uitoefening van de burgerlijke luchtvaart in verband met militaire oefeningen te beperken dan wel geheel te verbieden.

DA 1 (Den Helder I)

Het gebied, begrensd door een lijn, welke de volgende posities verbindt:
53.05.00 N — 03.45.00 O; 53.13.00 N — 03.45.00 O;
53.13.00 N — 04.10.00 O; 53.05.00 N — 04.10.00 O,
tot een hoogte van 9150 meter.

Toegang 2.12.56: Marine na 1945

DA 2 (Den Helder II)

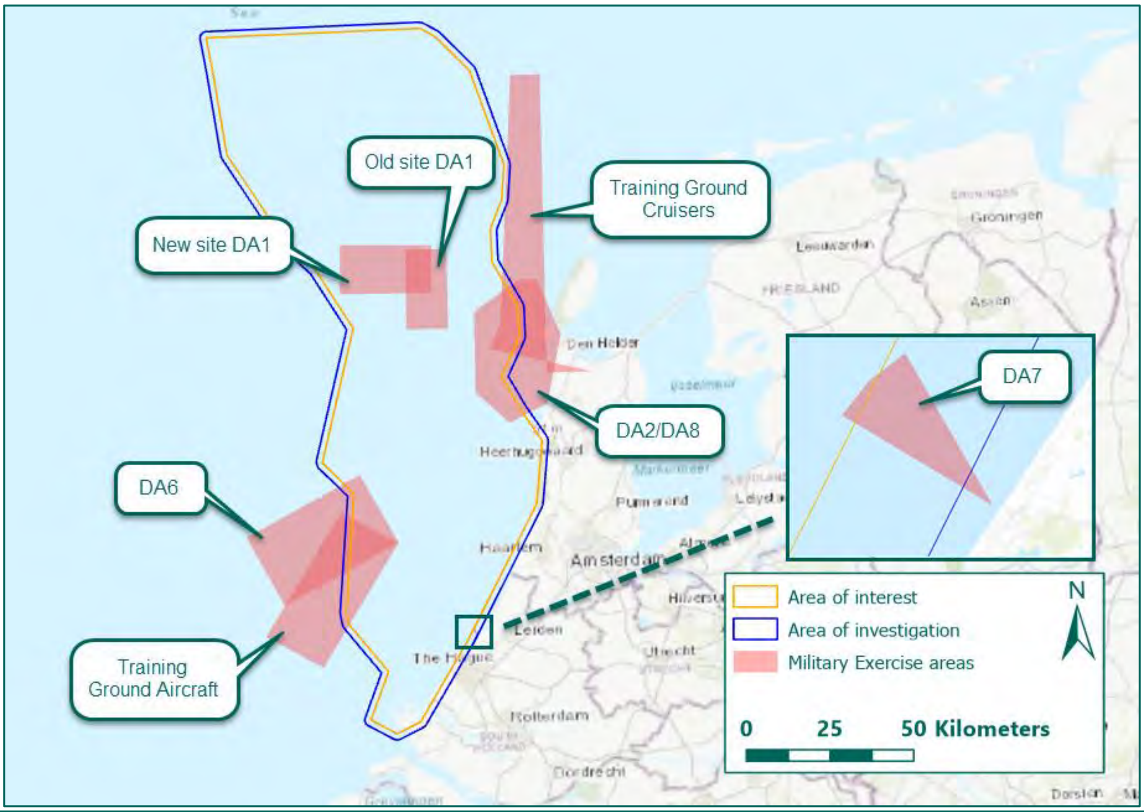
Het gebied, begrensd door een lijn, welke de volgende posities verbindt:
52.58.00 N — 04.44.00 O; 52.47.00 N — 04.40.00 O;
52.44.00 N — 04.30.00 O; 52.49.00 N — 04.21.00 O;
53.02.00 N — 04.21.00 O; 53.07.00 N — 04.33.00 O en
53.07.00 N — 04.38.00 O,
tot een hoogte van 10.000 meter.

DA 6 (Noordzee)

Het gebied, begrensd door een lijn, welke de volgende posities verbindt:
52.26.00 N — 03.20.00 O; 52.36.00 N —03.50.00 O;
52.25.00 N — 04.00.00 O; 52.15.00 N —03.30.00 O,
tot een grootste hoogte van 900 meter.

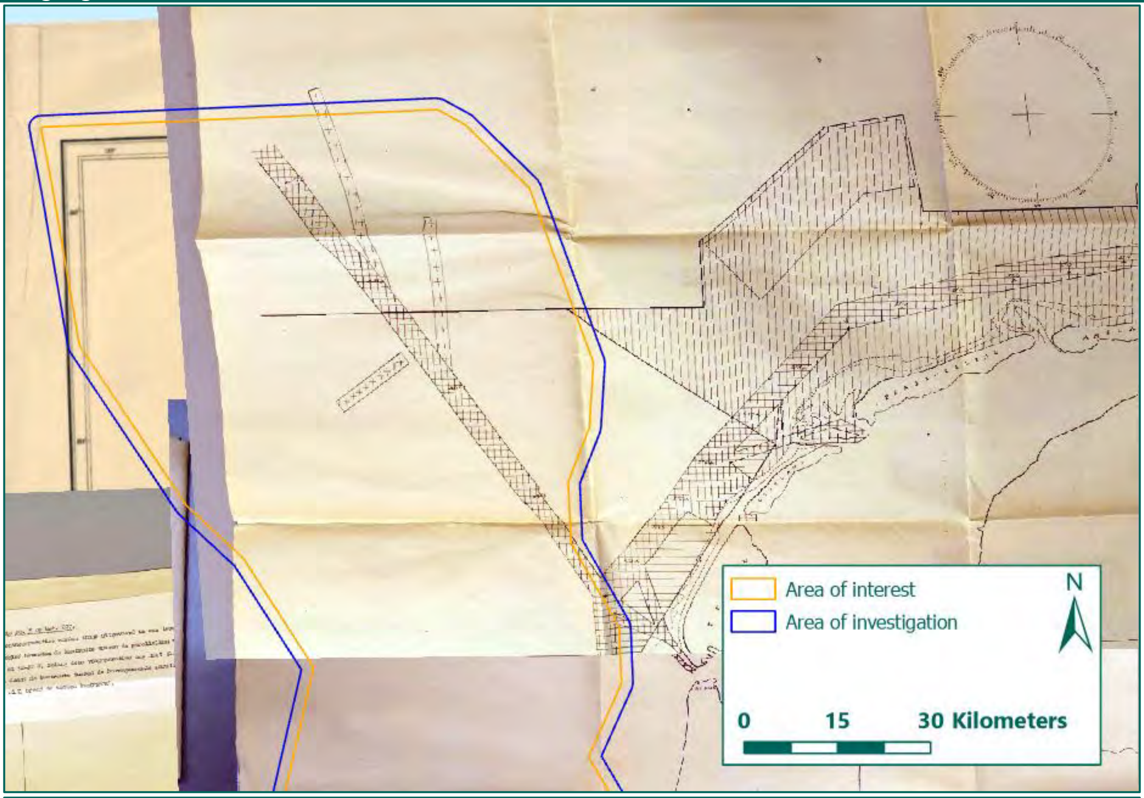
DA 7 (Wassenaarse slag)

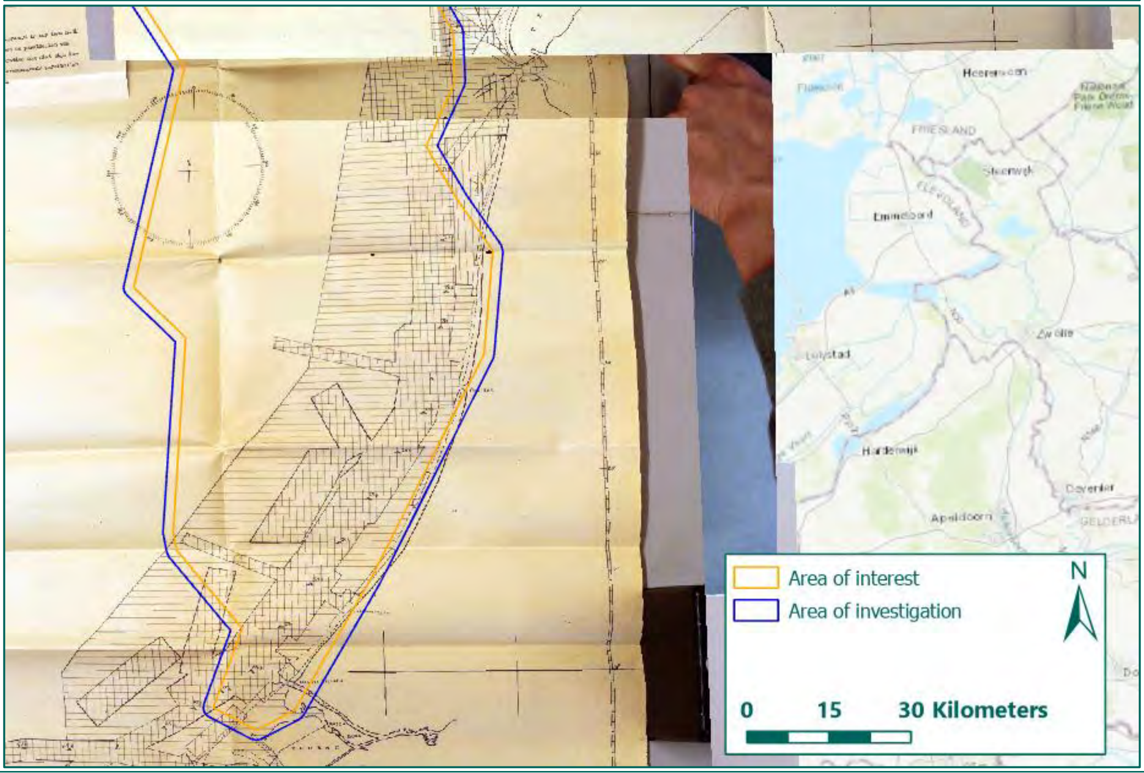
Een sector uit de positie 52.09.48 N — 04.20.45 O, in de richting 300° rechtwijzend door 315° naar 330° rechtwijzend, met een straal van 1,4 zeemijlen, tot een hoogte van 500 meter.



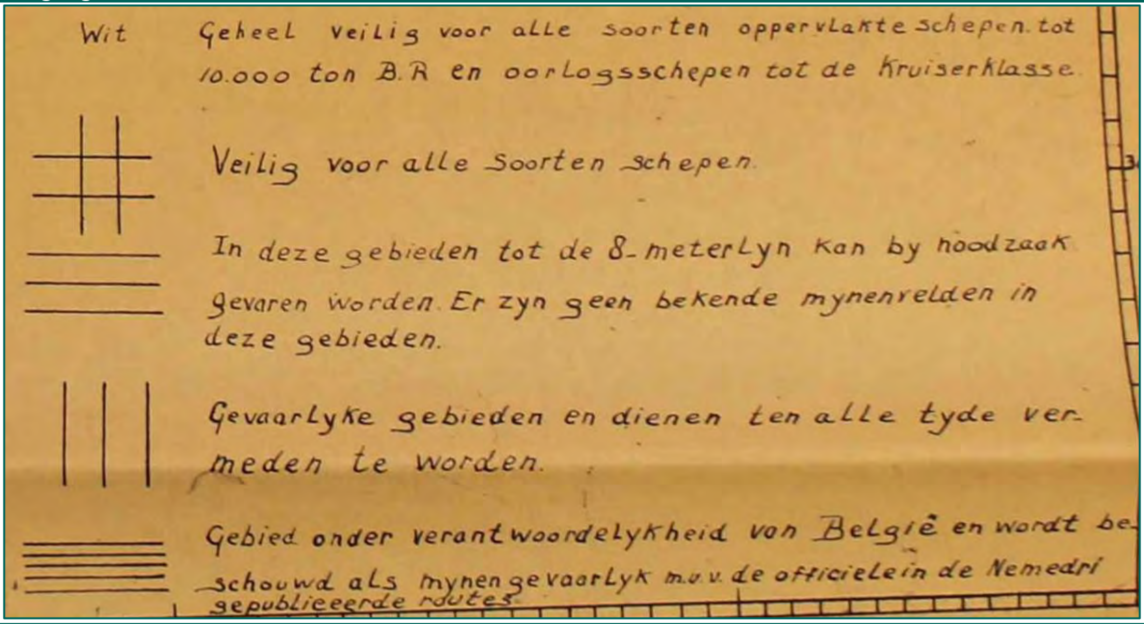
Inventaris 1882	Situatiekaarten van mijnen voor de Nederlandse kust. 1949-1950

Toegang 2.12.56: Marine na 1945





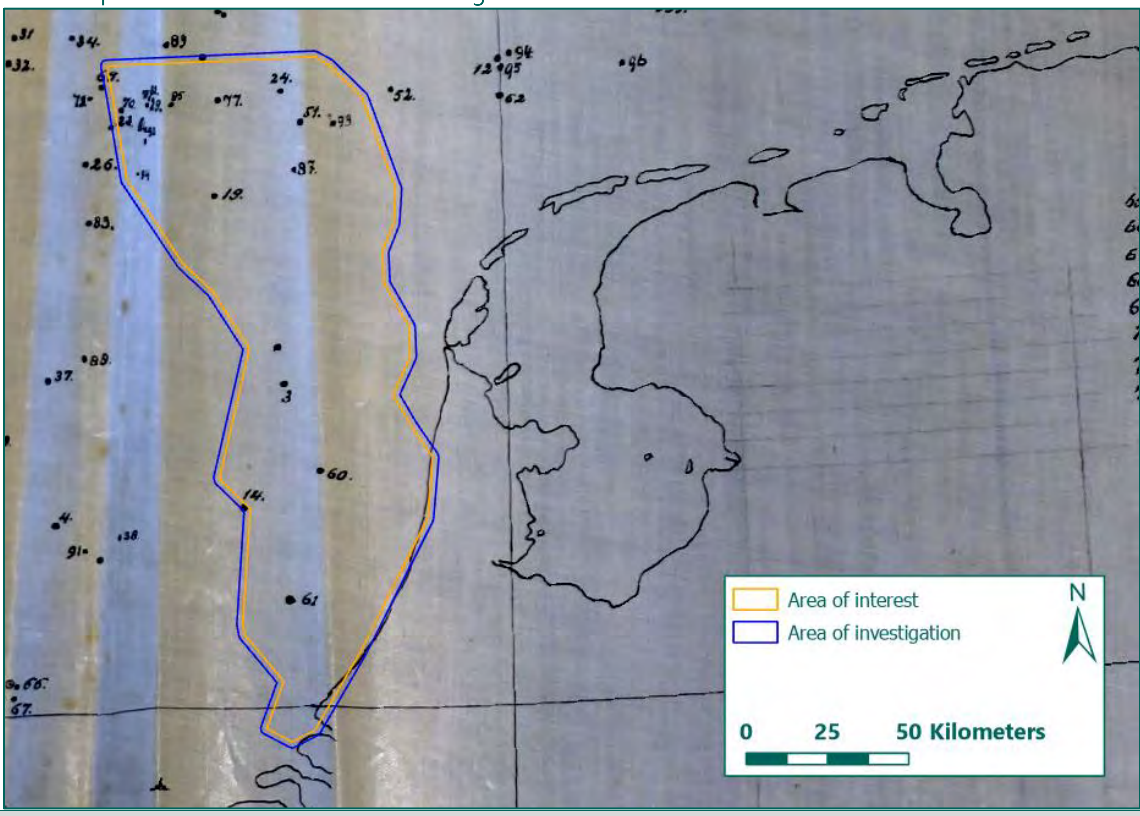
Toegang 2.12.56: Marine na 1945



Toegang 2.05.32.09 BuZa/Zeeoorlogschade

Inventaris 44	Kaart van de Noordzee met opgave van de plaatsen waar verankerde mijnen lagen, waarop Nederlandse schepen zijn gevaren in de jaren 1914-1916, op linnen, zonder datum

Dutch ships sunk due to contact mines during WW1



Nederlands Instituut voor Militaire Historie (NIMH)

The NIMH is a knowledge and research centre in the field of Dutch military history. The institute houses, amongs others, information about Dutch minefields in the North Sea. Some minefields were laid within the area of investigation.

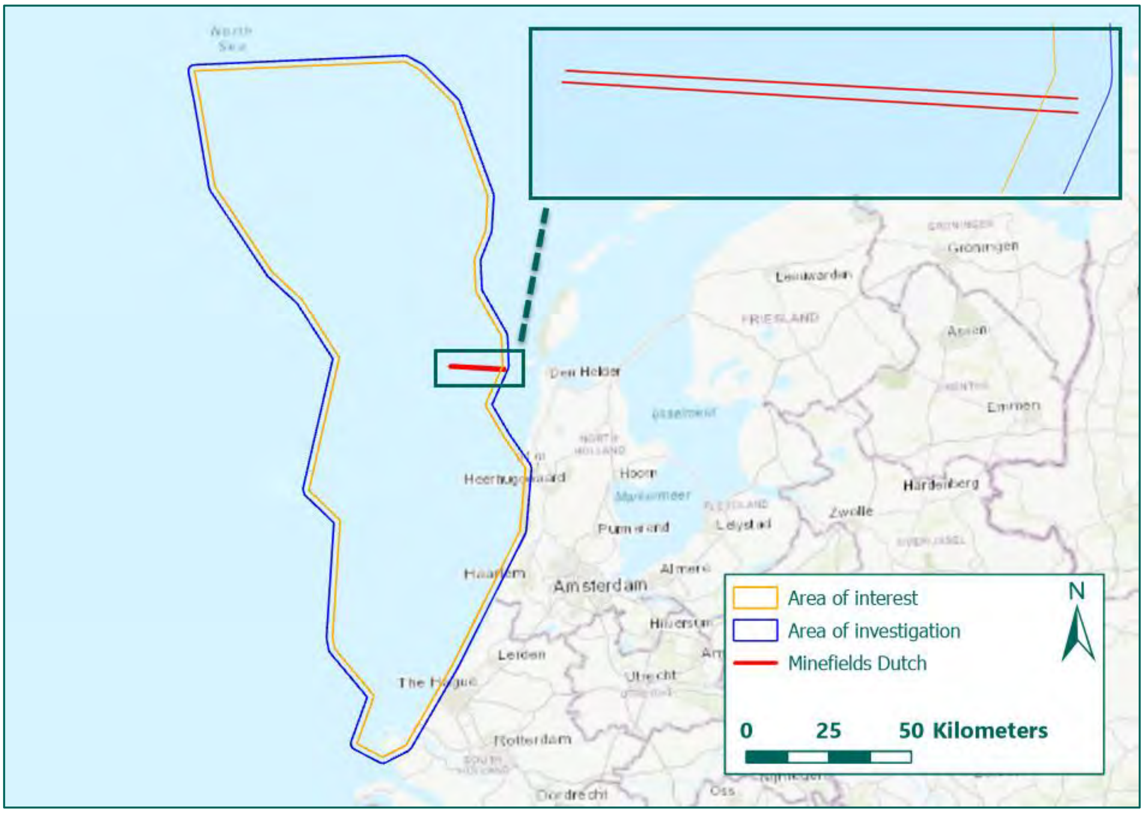


Figure 46: Dutch minefields within the Area of investigation (Source: NIMH 092).

Tactische versperring Middelrug-Haaks
bestaande uit:

Twee rijen mijnen model 1921 2e soort.

Ligging 1e mijnenrij van 52-57-20 N. / 04-33-30 E. naar 52-58-00 N. / 04-18-40 E. (12 Mei '40 ± 14h30 J.v. Brakel 80 mijnen

aantal mijnen : 120. Onderlinge afstand 150 m. 12 Mei '40 ± 15h00 Nautilus 40 mijnen)

Ligging 2e mijnenrij van 52-57-05 N. / 04-33-30 E. naar 52-57-48 N. / 04-18-33 E. (12 Mei '40 ± 14h30

aantal mijnen : 120. Onderlinge afstand 150 m. W. v.d. Zaan)

55 mijnen in deze rij zijn voorzien van ontglippers. De mijnen zijn gelegd op 12 Mei 1940.

Figure 47: information about relevant Dutch minefields (Source: NIMH 092).

Marinemuseum (Navy Museum), Den Helder

The map collection of the Marinemuseum (Navy Museum) in Den Helder has been consulted. NEMEDRI-maps were found in this collection. These maps offer information on minesweeping after the Second World War. The NEMEDRI maps show some locations some 'geveegde geulen' (shipping route in which minesweeping took place) within the area of investigation shortly after the war. The area of investigation is consequently shown in a ubiquitous Danger Area, owing to naval mines.

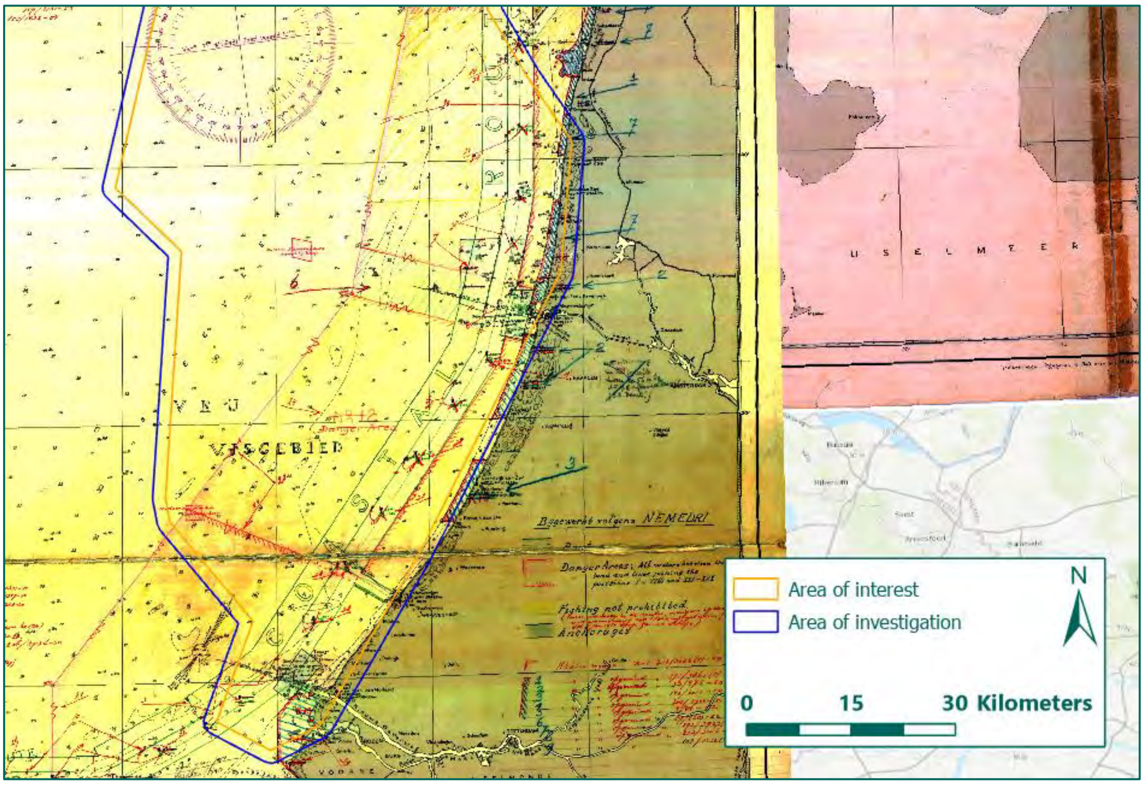


Figure 48: Map offer information on minesweeping after the Second World War (Source: Navy Museum NEMEDRI 227 West-Hinder tot Texel).

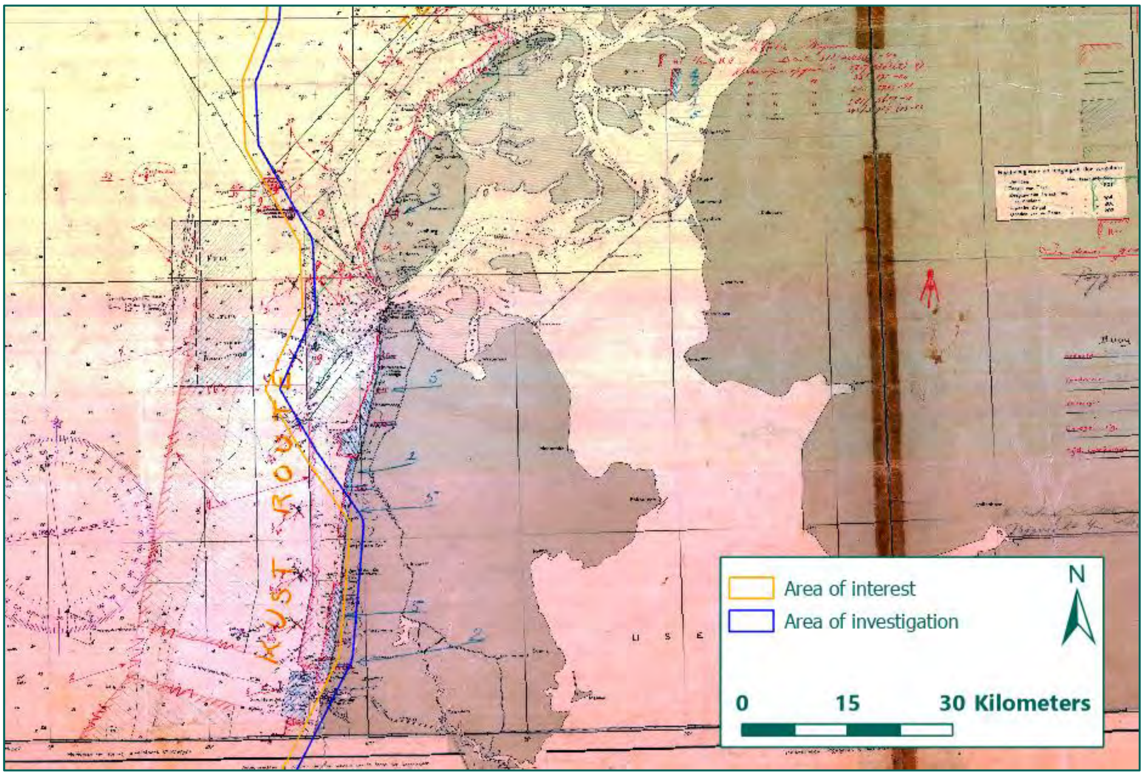


Figure 49: Map offer information on minesweeping after the Second World War (Source: Navy Museum NEMEDRI 226 IJmuiden tot de Weser).

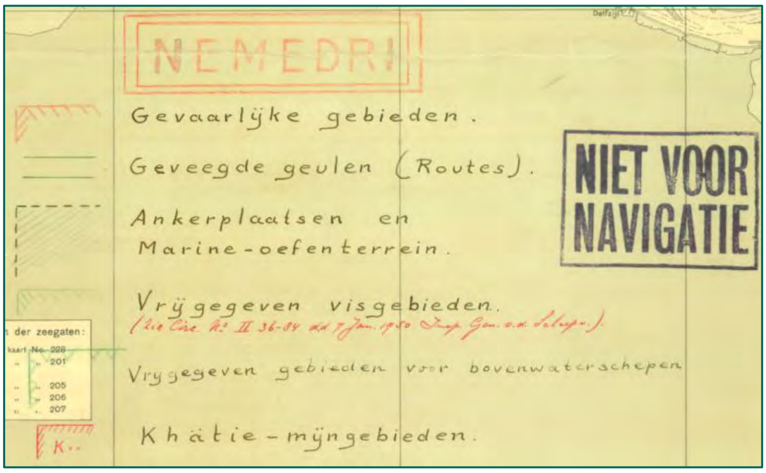


Figure 50: Legend of NEMERDI maps (Source: Navy Museum NEMEDRI 226 IJmuiden tot de Weser).

UK Hydrographic Office (UKHO)

The UK Hydrographic Office has a large amount of historical, maritime maps. This collection also includes maps showing the locations of minefields and shipping routes. These maps have been consulted.

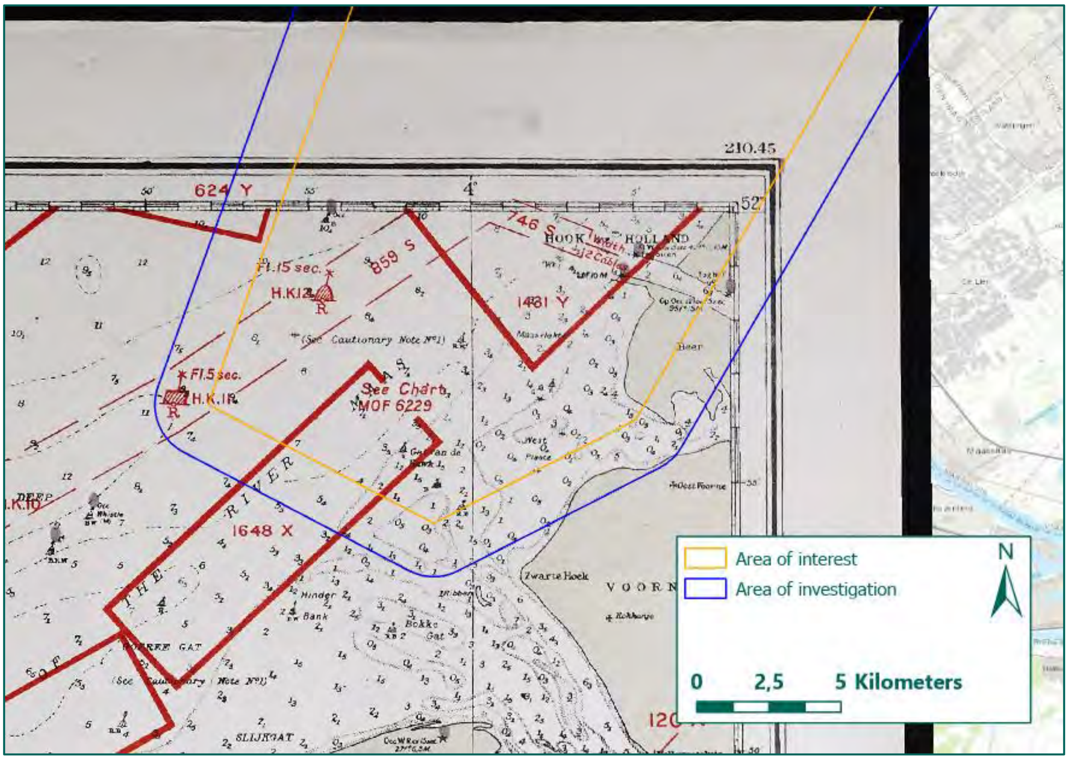


Figure 51: OCB MO F6550 Dunkerque to Hook of Holland, 1945. The red squares indicate minefields (Source: UKHO, Shelf 35).

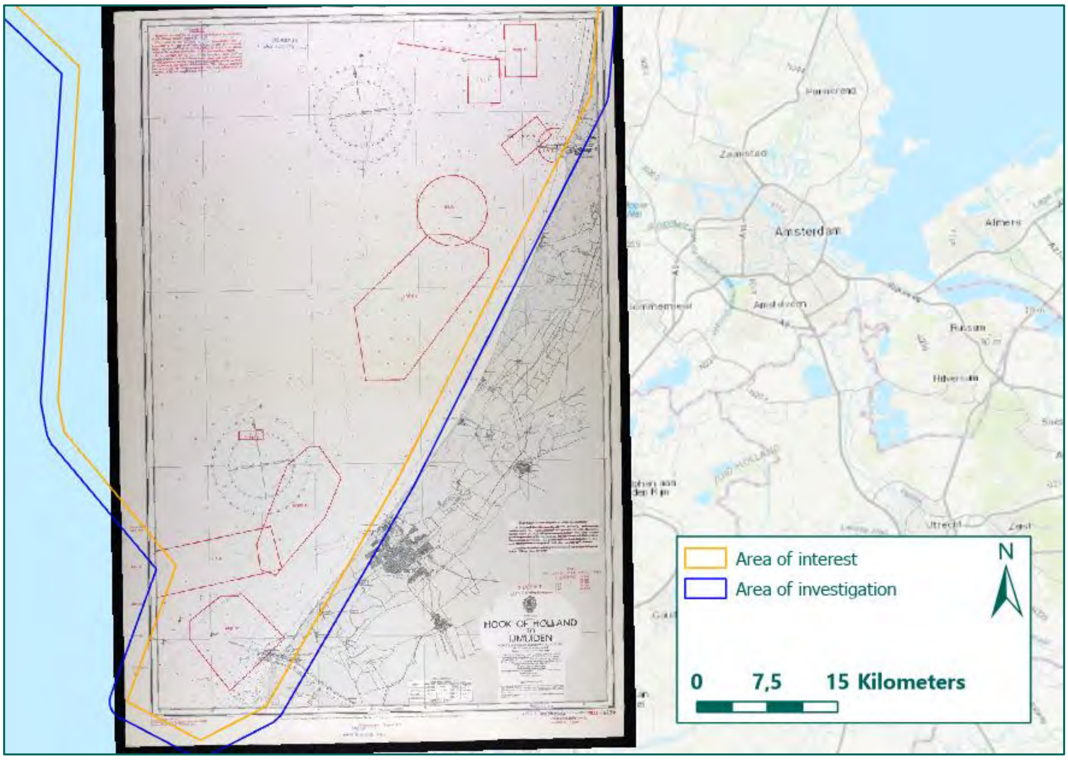


Figure 52: OCB MO F6229 Hook of Holland 1944. The red squares indicate minefields (Source: UKHO, Shelf 35).

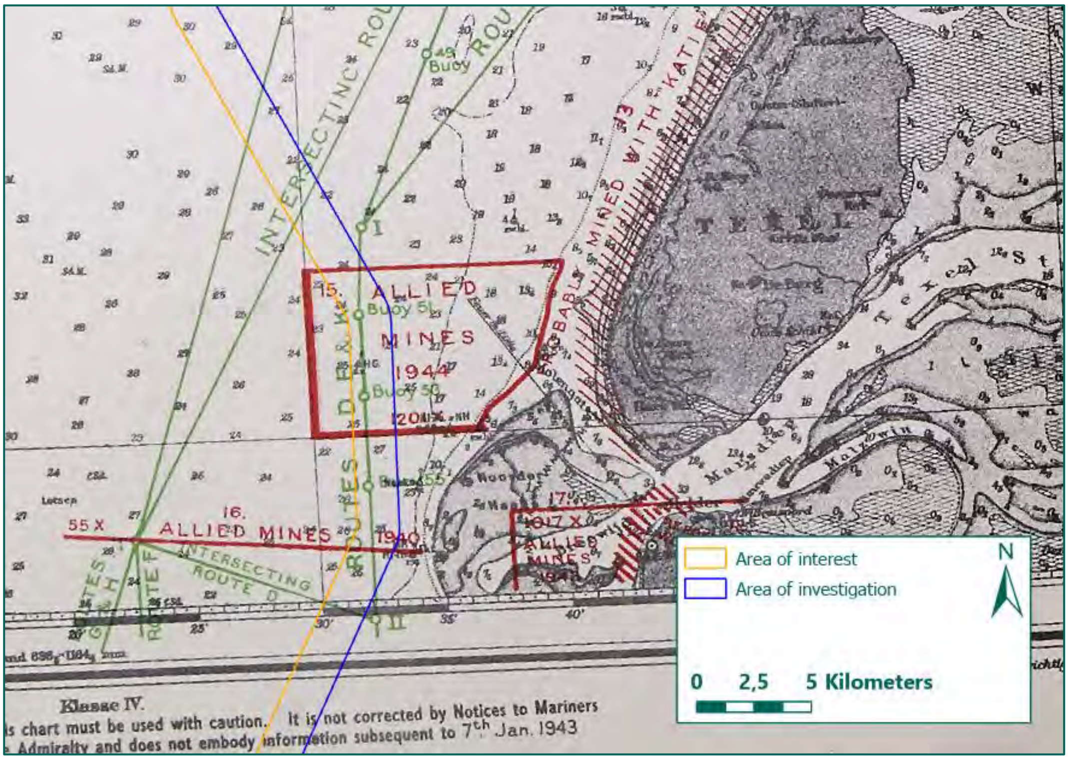


Figure 53: OCB MO 6590 Texel Bis Cuxhaven 1945. The red squares indicate minefields, green lines indicate convoy routes (Source: UKHO, Shelf 35).

Library of Congress

Library of Congress (LOC) has been consulted. Several maps about the First World War have been consulted in the LOC. Relevant maps are shown below.

Figure 54: locations of sunken ships due to submarine attacks between 1 February 1917 – 1 February 1918 (Source basemap: LOC).

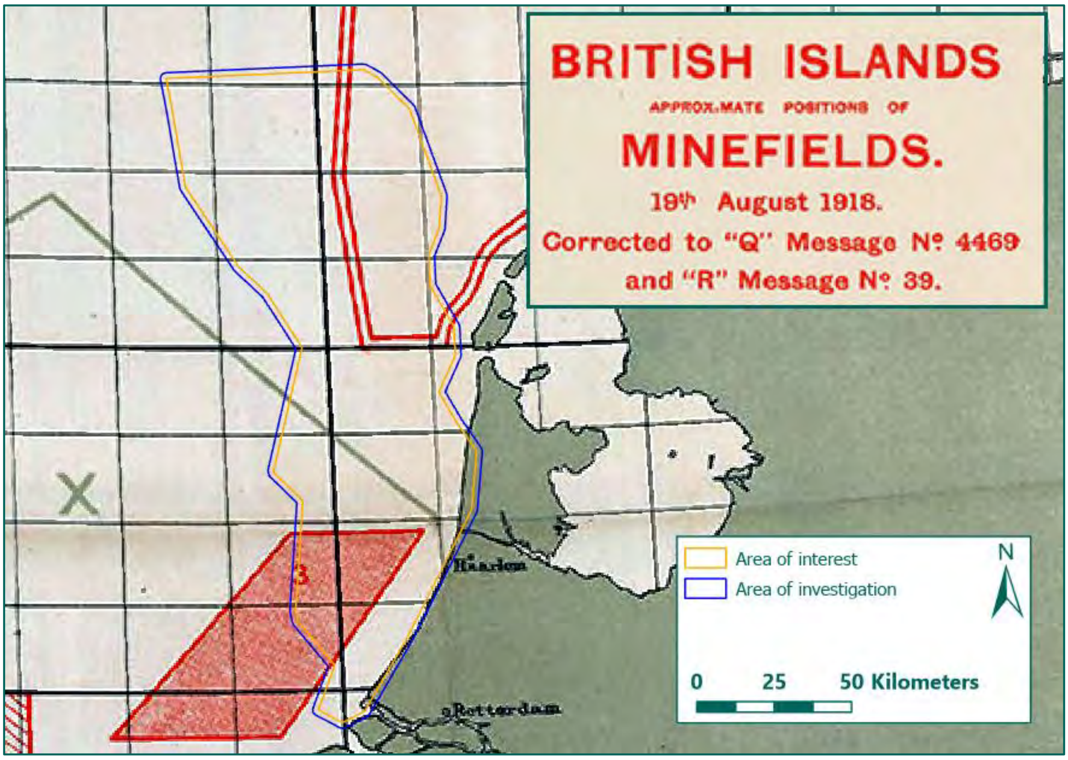


Figure 55: Minefields in the North Sea during 19 August 1918 (Source basemap: LOC).

The National Archives

The National Archives (TNA) have been consulted for more information on maritime and aerial warfare in the area of investigation. This annex contains relevant information from TNA. Information regarding maritime and aerial warfare is mentioned consecutively.

Admiralty series

The admiralty series (ADM) have been consulted for information concerning wrecks, naval combat, minefields and air strikes. Consulting these series yielded several files containing relevant information. These files are shown in the tables below.

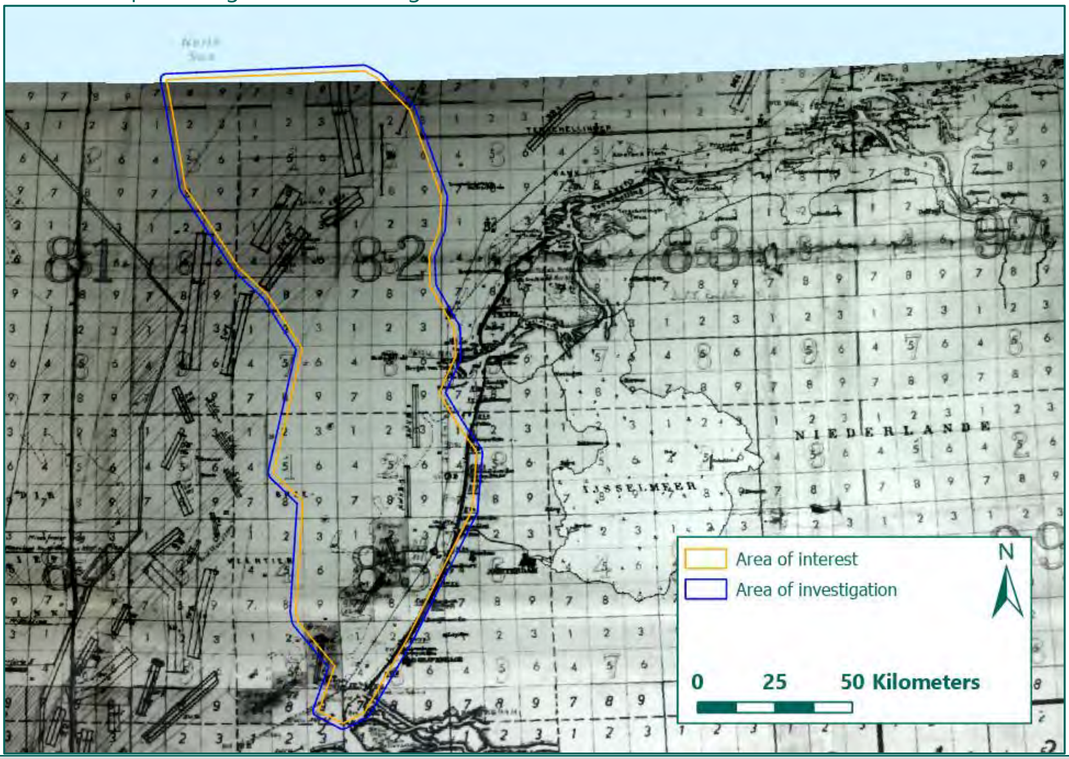
Admiralty, and Ministry of Defence, Navy Department: Correspondence and Papers (ADM)	
ADM 1/18996	Results of British minelaying offensive.
General information about total amount of laid/dropped mines, 3rd September 1939 – 5th May 1945: MINES LAID IN ENEMY WATERS By Fast Minelayers and Destroyers 11,100 By M.T.Bs, M.Ls and M.G.Bs 6,450 By Submarines 3,000 By Aircraft 53,100 Total 73,650 Mines	
ADM 1/19745	Post-war mine clearance in European waters: first interim report of International Central Board. With charts, 1946-1947.
Relevant information: o Dangerous areas existing in March 1946.	

Admiralty, and Ministry of Defence, Navy Department: Correspondence and Papers (ADM)

ADM 199/154	British mining operations 1939-1945: Vol 1.

Relevant information:

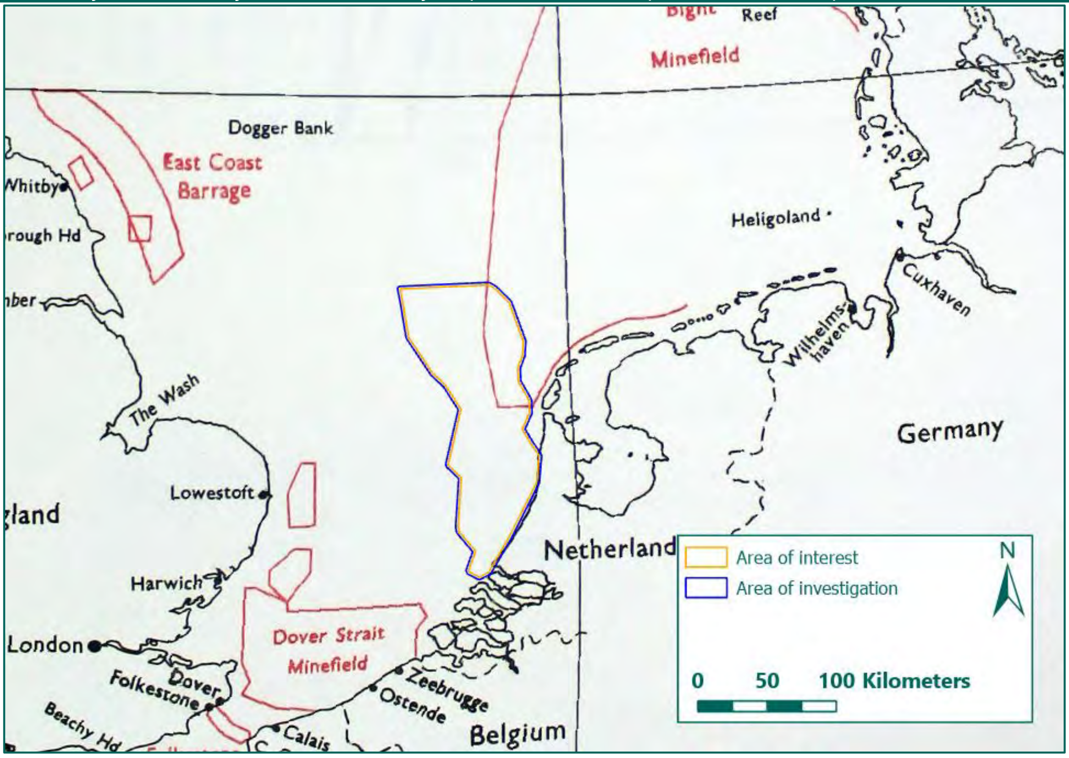
- Map showing minefields along the Dutch coast:



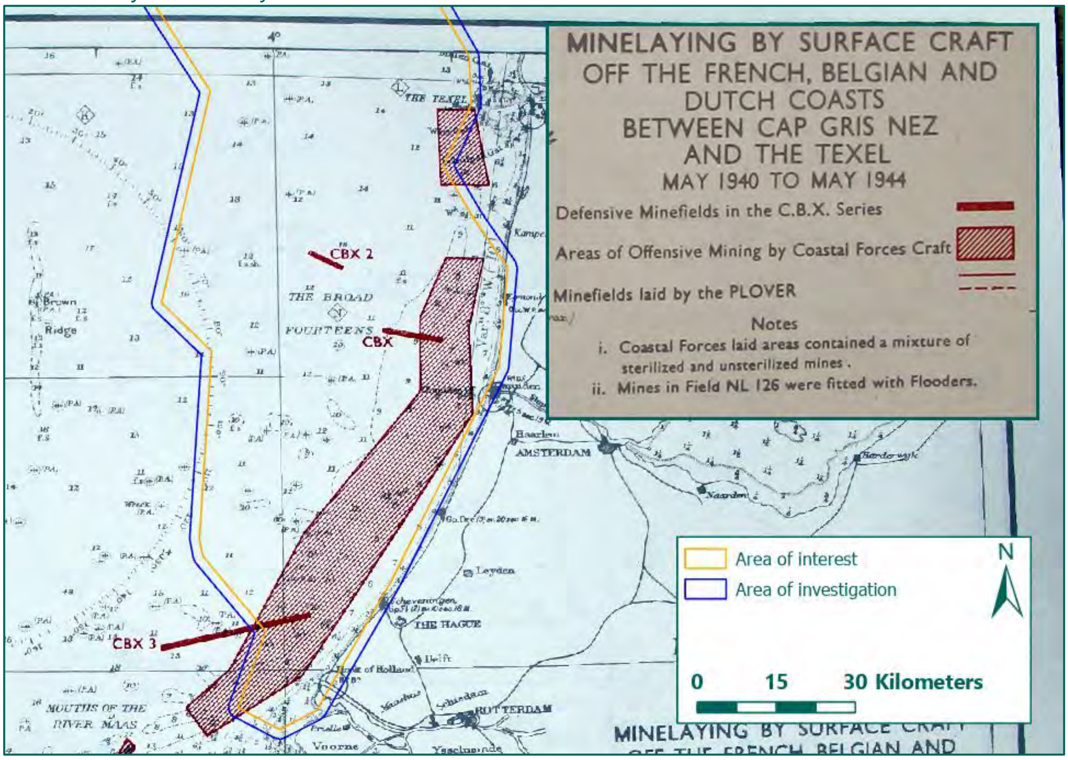
ADM 234/561	British mining operations 1939-1945: Vol 2.

Relevant information:

- Map showing:
  British Minefields laid in the Chanel, North Sea and Kattegat 1914-1918. No minefields within area of interest.

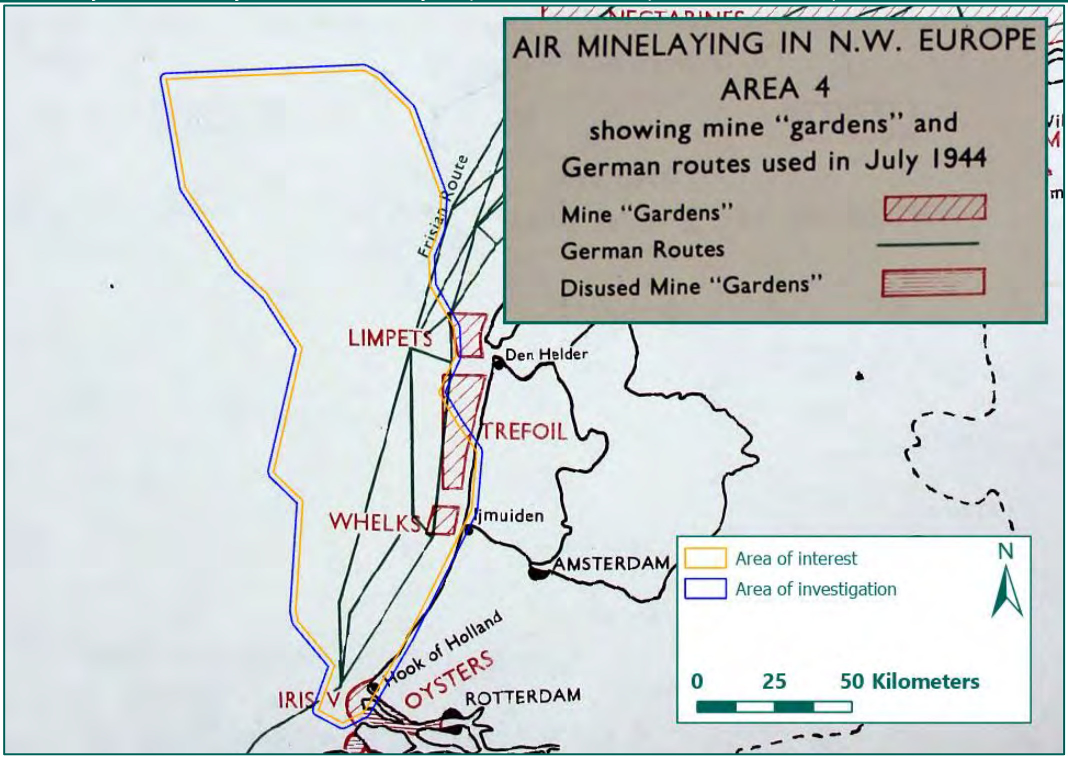


- Map showing:
  Minelaying by surface craft off the French, Belgian and Dutch Coasts between Cap Gris Nez and The Texel, May 1940 – May 1944:



- Map showing:
  Air Minelaying in NW Europe:

Admiralty, and Ministry of Defence, Navy Department: Correspondence and Papers (ADM)



In ADM 234-560 it is stated that mines were laid within the Minefields limpets, Trefoil, Whelks, Iris V and Oyster:

AREA 4

ANALYSIS OF OPERATIONS

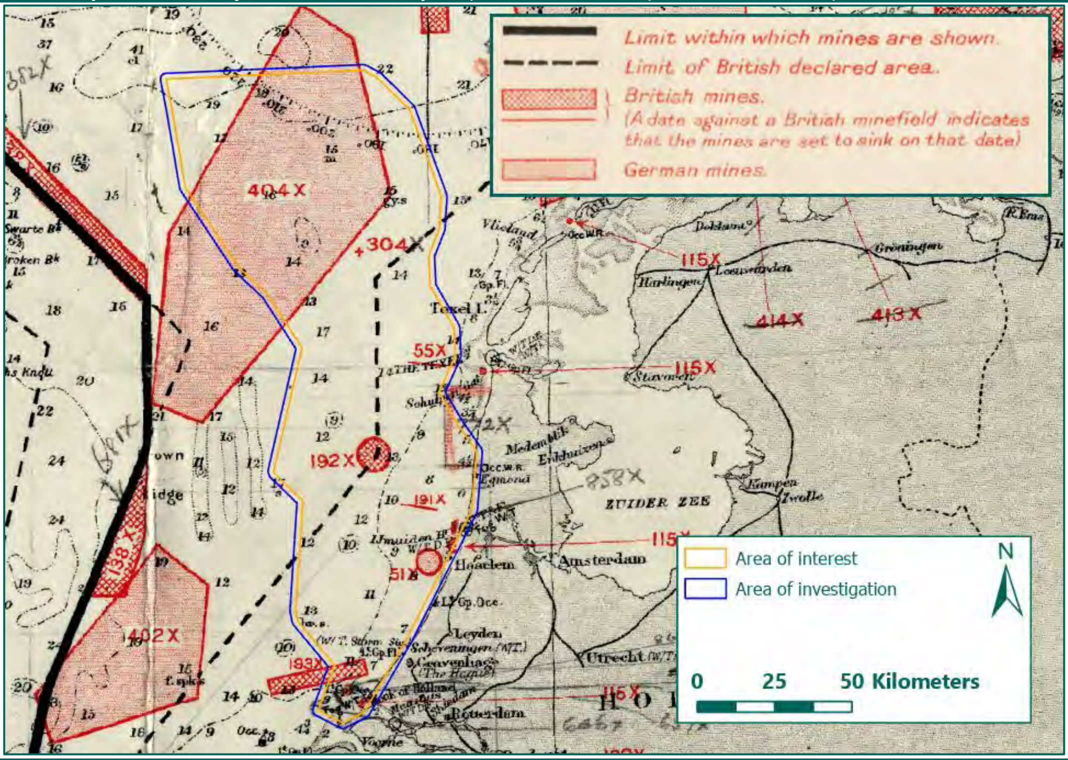
		DANISH COAST Hawthorn Rosemary	ELBE & WESER Eglantine Yams	GERMAN COAST & FRISIAN Is. Xeranthemum Zinnia Mussels Nectarine	DUTCH WEST COAST Limpets Whelks Trefoil	HOOK OF HOLLAND Oysters Iris V	SCHELDT Newts Juniper Iris II Flounders	ALL AREAS
1940	Mines Casualties Ratio	- - -	139 8 1:17	127 10 1:13	45 10 1:4.5	60 7 1:8.5	70 5 1:14	441 40 1:11
1941	Mines Casualties Ratio	37 1 1:37	116 11 1:10.5	268 18 1:15	- 4 ∞	2 2 1:1	- - -	423 36 1:11.7
1942	Mines Casualties Ratio	698 18 1:39	133 10 1:13	3,921 67 1:58	170 4 1:42	- - -	- - -	4,922 99 1:49.5
1943	Mines Casualties Ratio	156 12 1:13	63 4 1:16	6,288 32 1:197	372 - ∞	- - -	- - -	6,879 48 1:143
1944	Mines Casualties Ratio	1,800 53 1:34	150 11 1:13.6	1,468 19 1:77	491 8 1:61	88 5 1:18	252 8 1:31	4,249 104 1:41
1945	Mines Casualties Ratio	296 1 1:296	361 14 1:26	- - -	- 2 ∞	- - -	- - -	657 17 1:39
OVERALL	Mines Casualties Ratio	2,987 85 1:35	962 58 1:16.6	12,072 146 1:83	1,078 28 1:38.5	150 14 1:10.7	322 13 1:25	17,571 344 1:51

ADM 239/304	North Sea: chart 736 showing position of British and German minefields.

Relevant information:

- o British map showing German and British minefields. There are two German minefields within the area of interest:

Admiralty, and Ministry of Defence, Navy Department: Correspondence and Papers (ADM)

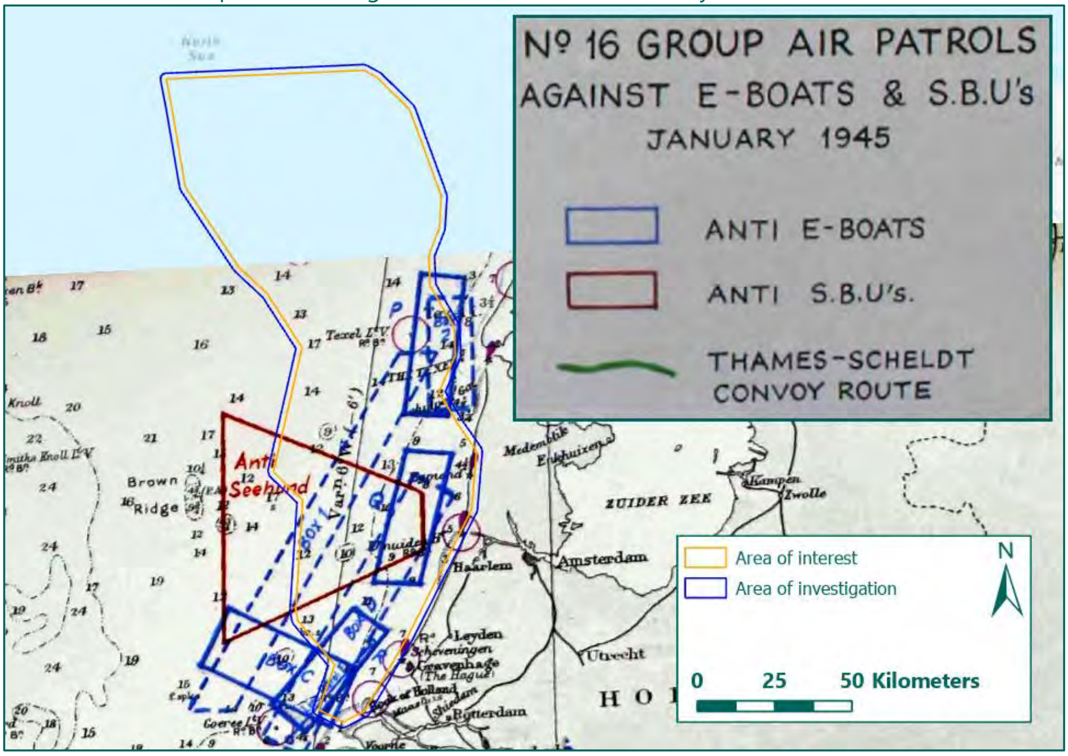


Cabinet and its committees (CAB)

Cabinet and its committees (CAB)	
CAB 101/324	Air Offensive Against Enemy Shipping and Bomber Command Minelaying Operations, 1 September 1944 - 5 May 1945

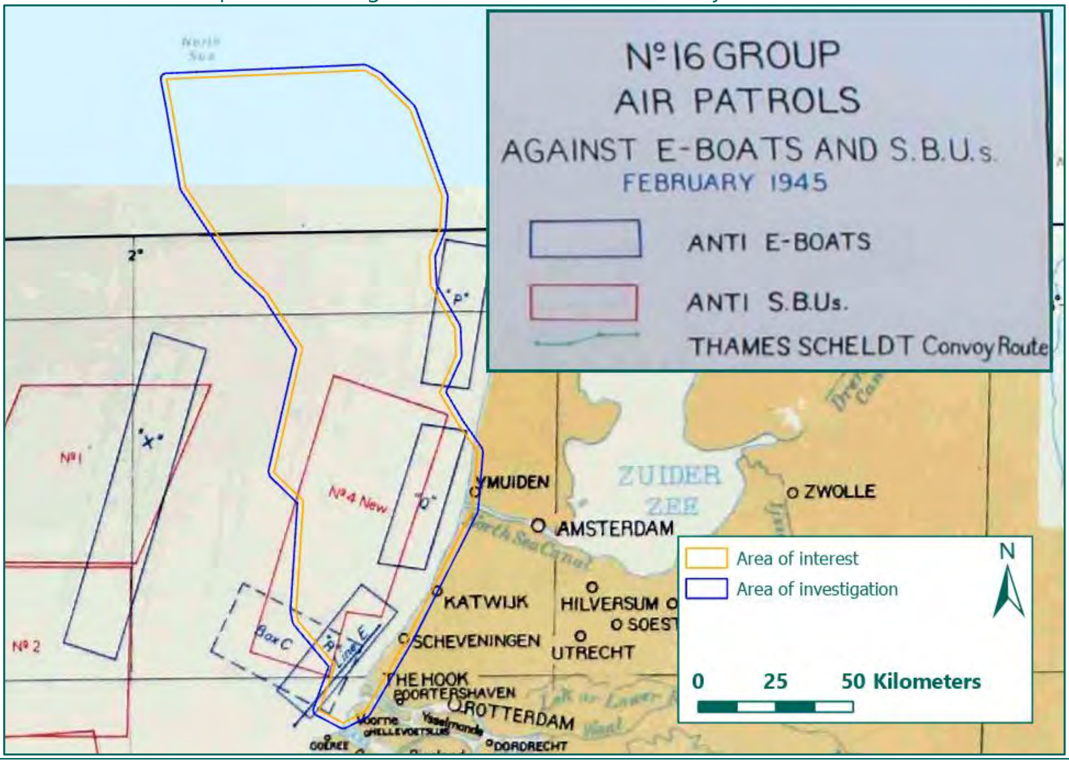
Relevant information:

- No.16 Group Air Patrols against E-Boats & S.B.U.'s January 1945.



Relevant information:

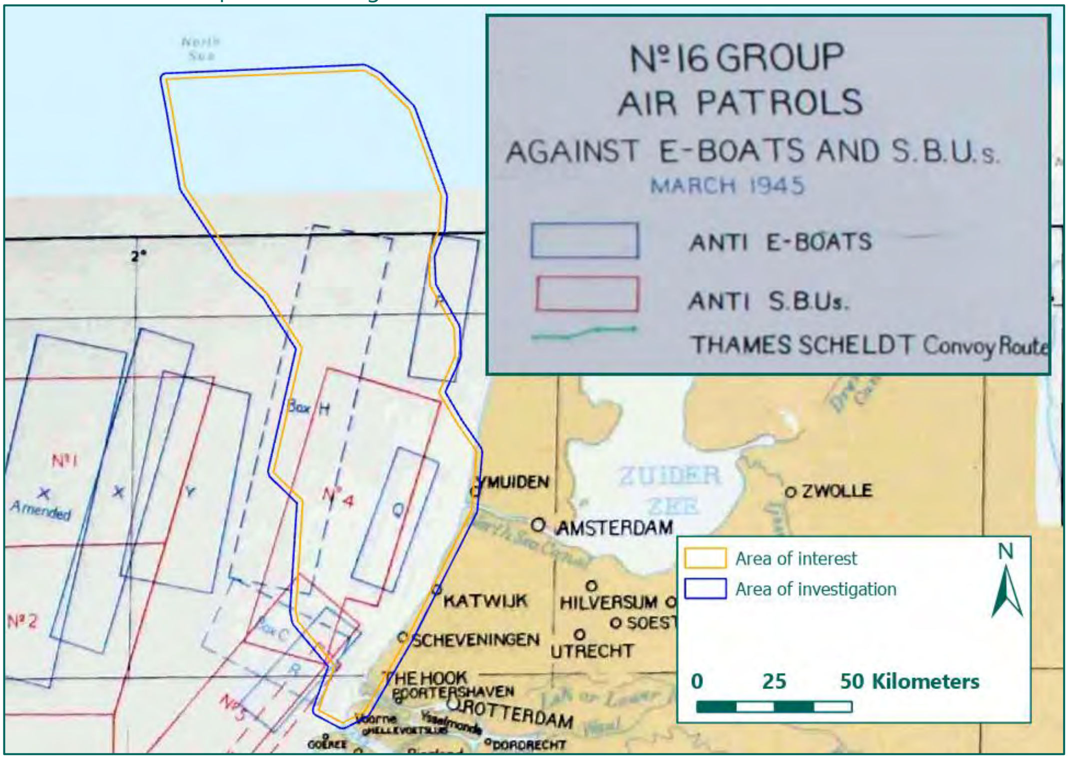
- No.16 Group Air Patrols against E-Boats & S.B.U.'s February 1945.



Cabinet and its committees (CAB)

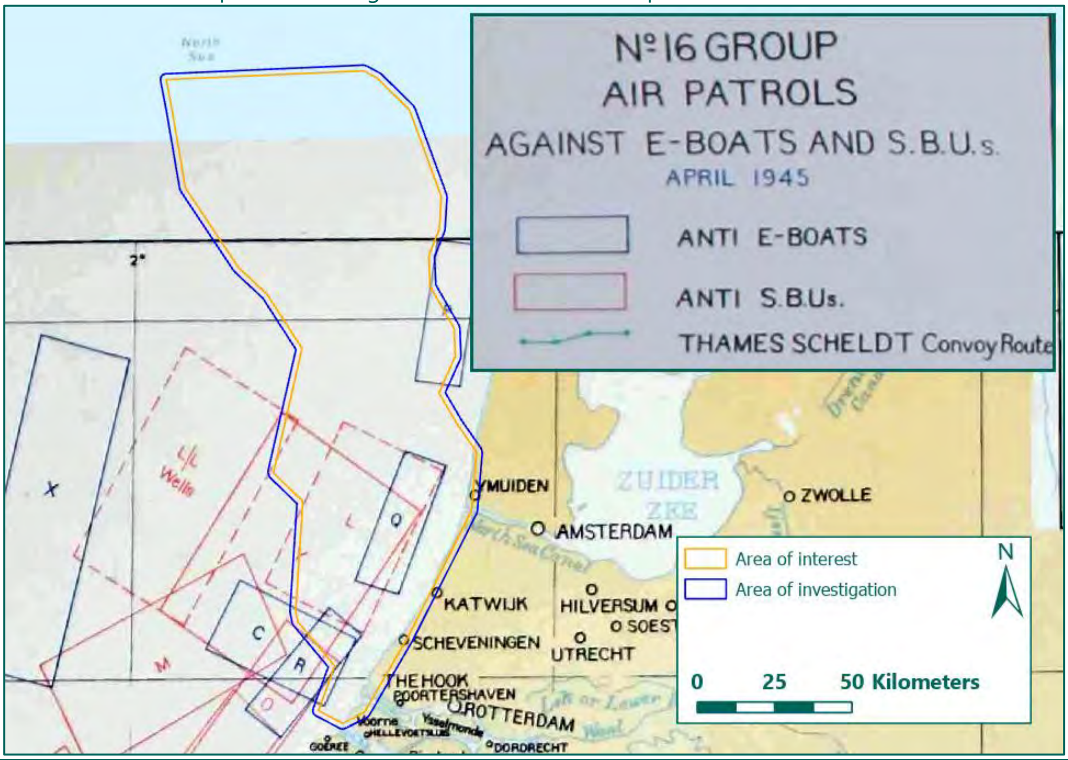
Relevant information:

- No.16 Group Air Patrols against E-Boats & S.B.U.'s March 1945.



Relevant information:

- No.16 Group Air Patrols against E-Boats & S.B.U.'s April 1945.



Air Ministry series
The Air Ministry series (AIR) contain information on aerial warfare during the Second World War. The Operations Record Books (ORBs) of units that operated in or near the area of investigation have been consulted:

- Headquarters Coastal Command, 1940-1945 (AIR 24/372 t/m AIR 24/427)
- 16 Group Coastal Command, 1940-1945 (AIR 25/313 t/m AIR 25/374)
- Headquarters Bomber Command, 1940-1945 (AIR 24/217 t/m AIR 24/319)
- Intelligence on USAAF missions (AIR 40)

16 Group Coastal Command patrolled the North Sea, attacking German shipping and conducting rescue operations. ORBs from this unit contain locations of air strikes, jettisoning, aircraft wreckages and Anti-Aircraft Artillery (AAA). Until halfway through 1942 the locations were noted in Coastal Command cypher which has only partially been decrypted by REASeuro. From 1942 onwards the ORBs mention locations in coordinates, based on decimal degrees. One must take into account that Coastal Command operated during the night as well, severely hampering navigational accuracy. When possible, war related events mentioned in the Coastal Command records have been coupled with records from the German point of view, resulting in more accurate positioning based on multiple sources.

Bomber Command, Coastal Command's famous land-based counterpart, was also active against German shipping during the first years of the war. Besides intentional bombing, Bomber Command aircraft also jettisoned bombs when in trouble. The jettisoning preferably took place over sea, since this dramatically reduced the chance of collateral damage.

In the figure below the attacks, jettisons, crashes and relevant observations from Bomber Command and Coastal Command are shown. Each feature refers to a passage of a primary source.

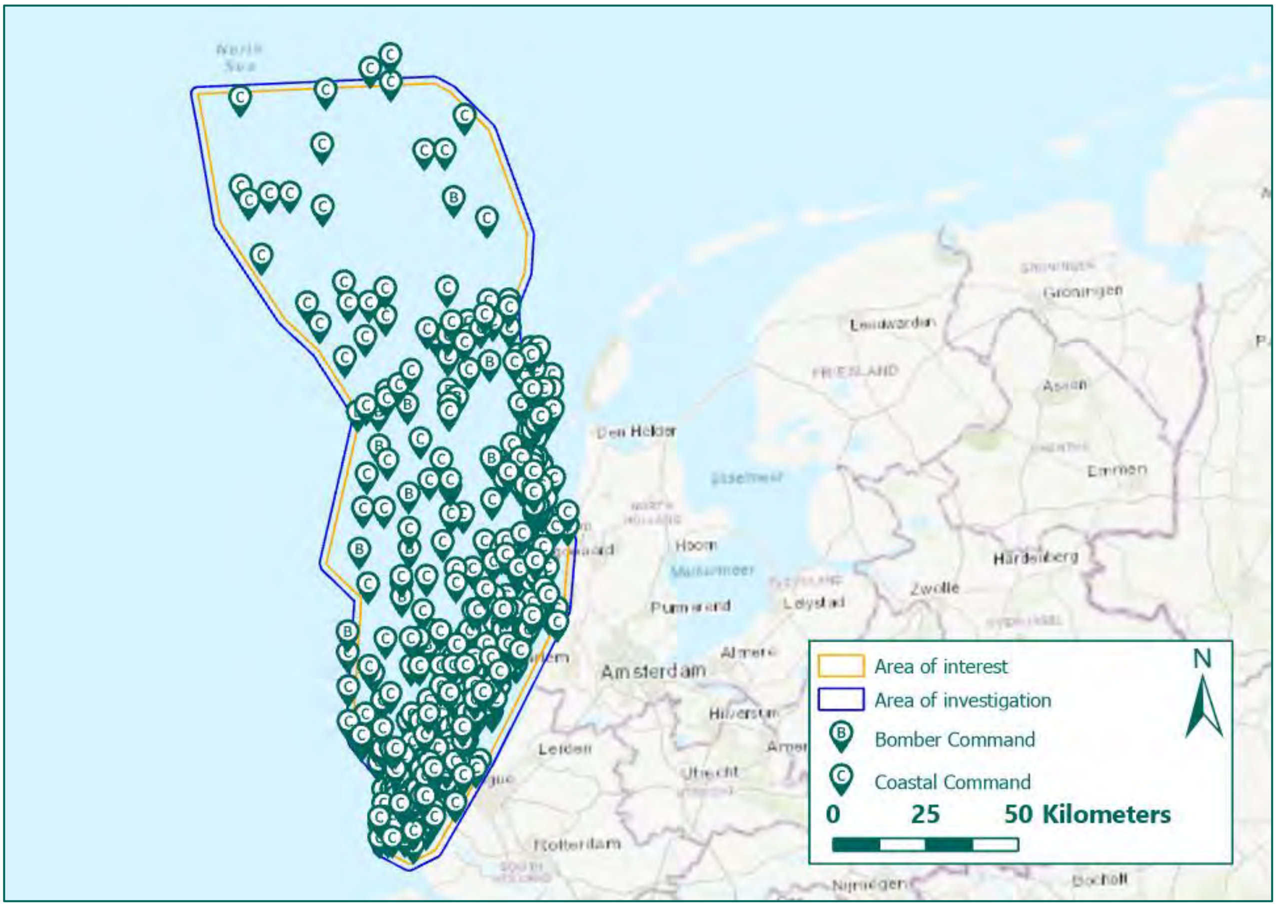


Figure 56: Locations of attacks, jettisons, crashes and relevant observations from Bomber Command and Coastal Command (Source basemap: ESRI).

The North Sea theatre of war saw also action of fighter planes of Fighter Command and 2nd Tactical Air Force (2TAF). Fighter Command patrolled the sea in order to intercept German planes heading for Britain and escorted bombers. From 1944 onward Fighter Command was involved in the war against the German V1 and V2 weapons. 2TAF mainly supported the ground forces by carrying out attacks on tactical ground targets, but also enemy shipping near the shores was attacked. No locations have been found of Fighter Command's and 2TAF's attacks within the area of interest.

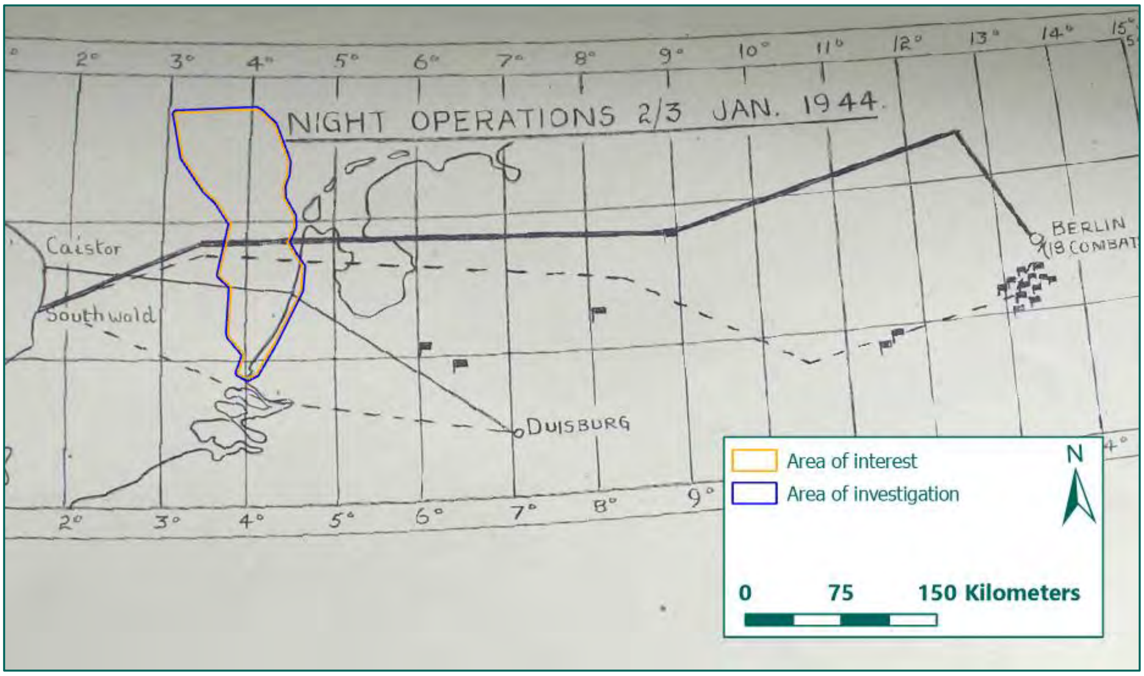


Figure 57: Example of a flight path over the area of investigation of bombers from Bomber Command, 2/3 January 1944 (Source, TNA, AIR 24/264).

Remark on jettisoning and flight paths
Related to the air war are jettisoning of bombs and the numerous flight paths of incoming and outgoing bombers above the North Sea. During bombing raids, allied bombers followed certain routes towards their target and backwards to base. In case of emergency or to avoid landing with the bomb load, the bombs were often released above the North Sea. The figure underneath is a document from The National Archives (AIR 14/110 Disposal of bombs not dropped on allotted targets) that describes what to with the remaining bomb load. It is stated that a captain could decide where ever the bombs are dropped, as long as they are dropped in safe condition. Despite this document, the logs of Coastal and Bomber Command prove that bombs were also jettisoned in live condition.

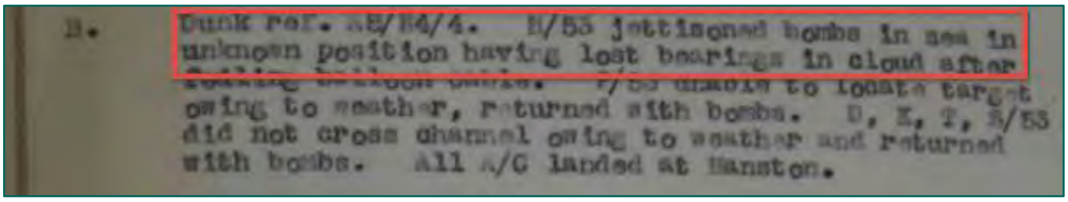

B. Dunk ref. B/B4/4. B/53 jettisoned bombs in sea in unknown position having lost bearings in cloud after ... owing to weather, returned with bombs. D, X, T, /53 did not cross channel owing to weather and returned with bombs. All A/C landed at Manston.

Figure 1: Blenheim Bomber jettisoned its bombs at an unknown position in the Northsea (Bron: TNA, AIR 24/375).

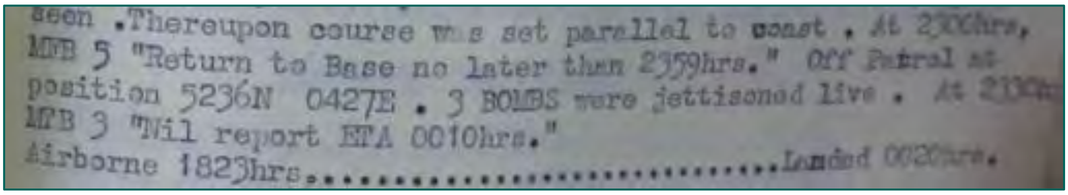

seen .Thereupon course was set parallel to coast . At 2300hrs, MTB 5 "Return to Base no later than 2359hrs." Off Patrol at position 5236N 0427E . 3 BOMBS were jettisoned live . At 2300hrs MTB 3 "Nil report ETA 0010hrs." Airborne 1823hrs..............................Landed 0020hrs.

Figure 58: Example of a live jettison within the area of investigation, night 12/13 October 1944. (Source: TNA, AIR 25/367).

Spitfires found 10/10th cloud over target. 1 Sqdn jettisoned bombs in sea, 1 Sqdn brought bombs back.

Figure 2: A Squadron of Spitfires jettison their bombs in sea after being unable to locate the assigned target (Bron: TNA, AIR 37/713).

[redacted]
WELLINGTONS FROm Bircham Newton to be armed with 5 x 500lb bombs and 25 flares and to reconnoitre enemy inner convoy route from 5335N 0620E to 0800E and back to 5355N 0630E and to R/V with Beaus in this position at 0300. Wellington to be at 5335N 0620E at 0230. W/T Org 1a R/T Org 4. TOrbeaus to be armed with torpedoes 10ft setting.
Patrol carried out. At 0250 MTB 1 'Nil sighting' and VHF MT Beaufighters 'Nothing'. At 0258 2 bombs were jettisoned safe but one exploded. [redacted]

Figure 3: Wellington bombers jettisoned two bombs at an undisclosed location at sea. Although the bombs are jettisoned "safe", one exploded (Bron: TNA, AIR25/363).

DISPOSAL OF BOMBS NOT DROPPED ON TARGETS.

1. In the event of Captains of Aircraft having to return from bombing missions without having dropped all bombs, discretion is left to the Captain of the Aircraft as to whether it is wise for him to land with

(i) all bombs
(ii) a portion of bombs
(iii) no bombs.

2. If the Captain of the Aircraft decides to drop his bombs in the sea, they are to be jettisoned "safe".

Figure 4: Extract from AIR 14/110 (Disposal of bombs not dropped on allotted targets) (Source: TNA).

Coastal guns

Coastal guns were traditionally used in strongpoints that had to defend harbours from enemy ships. Shortly before the beginning of World War II, more modern batteries were installed on the Dutch Coast. After the German Occupation the amount of Coastal Guns grew in order to strengthen the *Atlantikwall*. It is known that Coastal guns were active in the area of investigation. In the TNA a photograph showing an explosion of a shell from land battery was consulted. The photograph was dated 4 May 1942 and located at 52 36N, 04 22E (within the area of investigation).

Figure 59: Strike photo showing the impact of a shell, fired by a German coastal battery. 4 May 1942. (Source: TNA, AIR 28/595).

National Archives and Records Administration (NARA)

The following Record Groups have been consulted in the NARA:

- Record Group 18: Mission Reports.
  The mission reports contain detailed information on allied bombing raids, including height, air speed and the deployed munitions.
- Record Group 342: Records of U.S. Air Force Commands, Activities, and Organizations
  Record Group 342 contains additional details not mentioned in Record Group 18.

These Record Groups show several attacks by the USAAF on targets along the Dutch Coast. It is known that these aircraft operated above the area of investigation. No specific targets within the area of investigation were mentioned. It is possible that due to technical or navigational failures war related events took place within the area in investigation. In the figure below an example of a flight path over the area of investigation is shown.

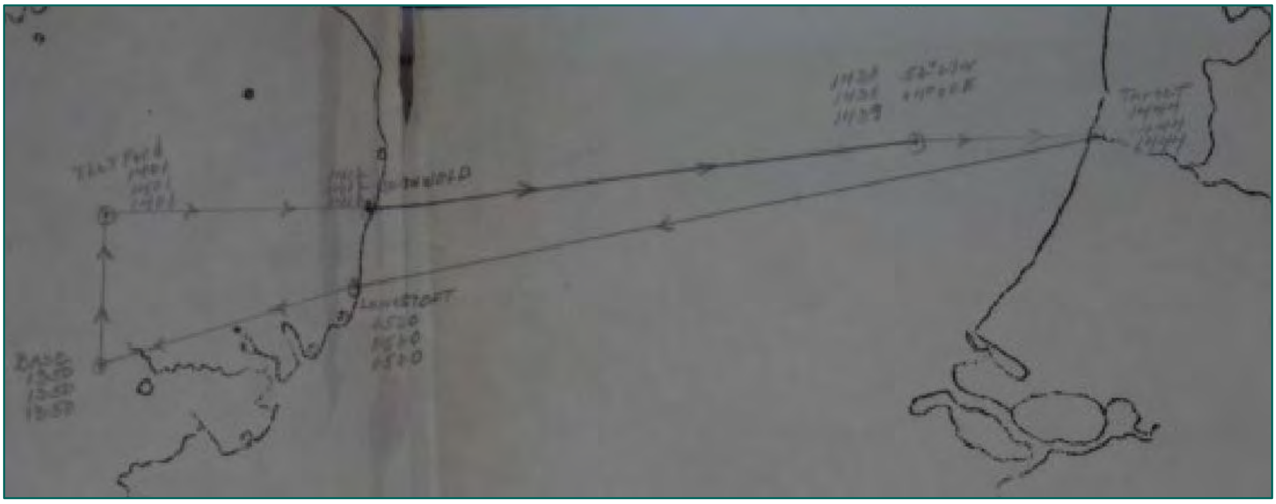


Figure 60: The flightpath of aircraft of USAAF on 26 March 1944 (Source: NARA Box RG18, Box 1388).

No further files have been consulted with regards of the area of investigation. Consulting these sources is outside the scope of this research.

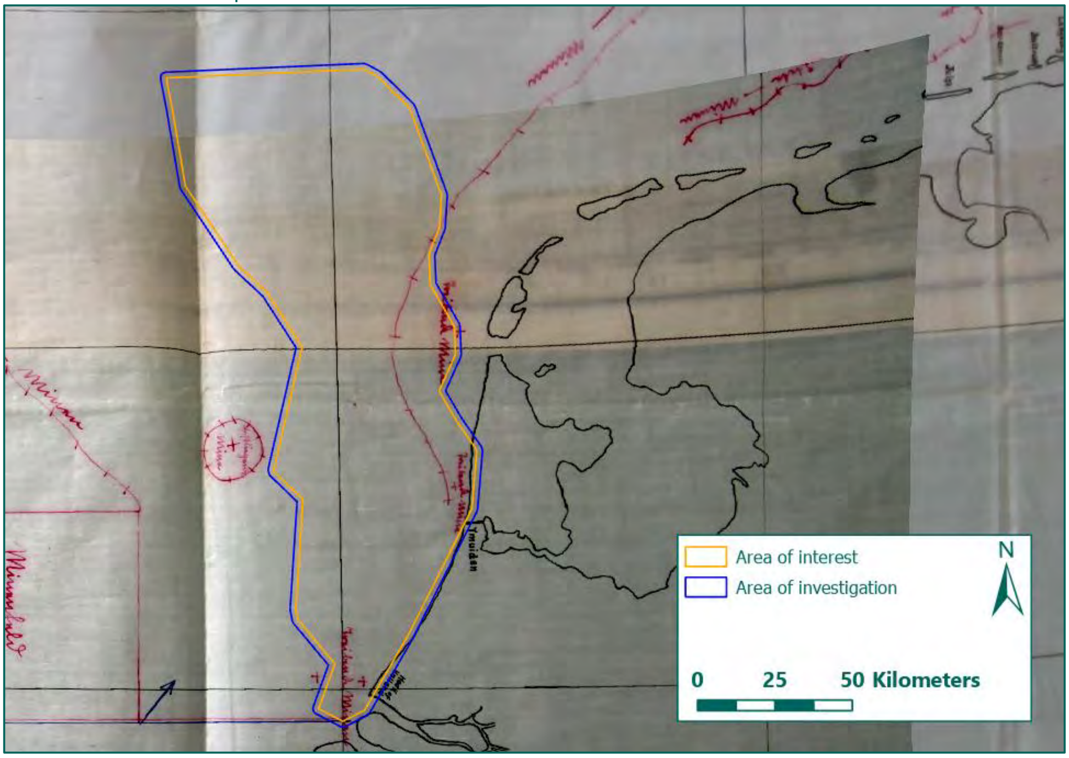
Bundesarchiv-Militärarchiv (BAMA)

The German military archives have been consulted in the BAMA in Freiburg. This archive contains the documents from the German military in the Second World War. The following record groups have been consulted by REASeuro to gain more information about the German perspective of naval warfare in the area of investigation:

- RM 5: Admiralstab der Marine / Seekriegsleitung der Kaiserlichen Marine.
- ZA 5: Deutscher Minenräumdienst (German Minesweeping Administration).

The following documents have been found relevant for the area of investigation:

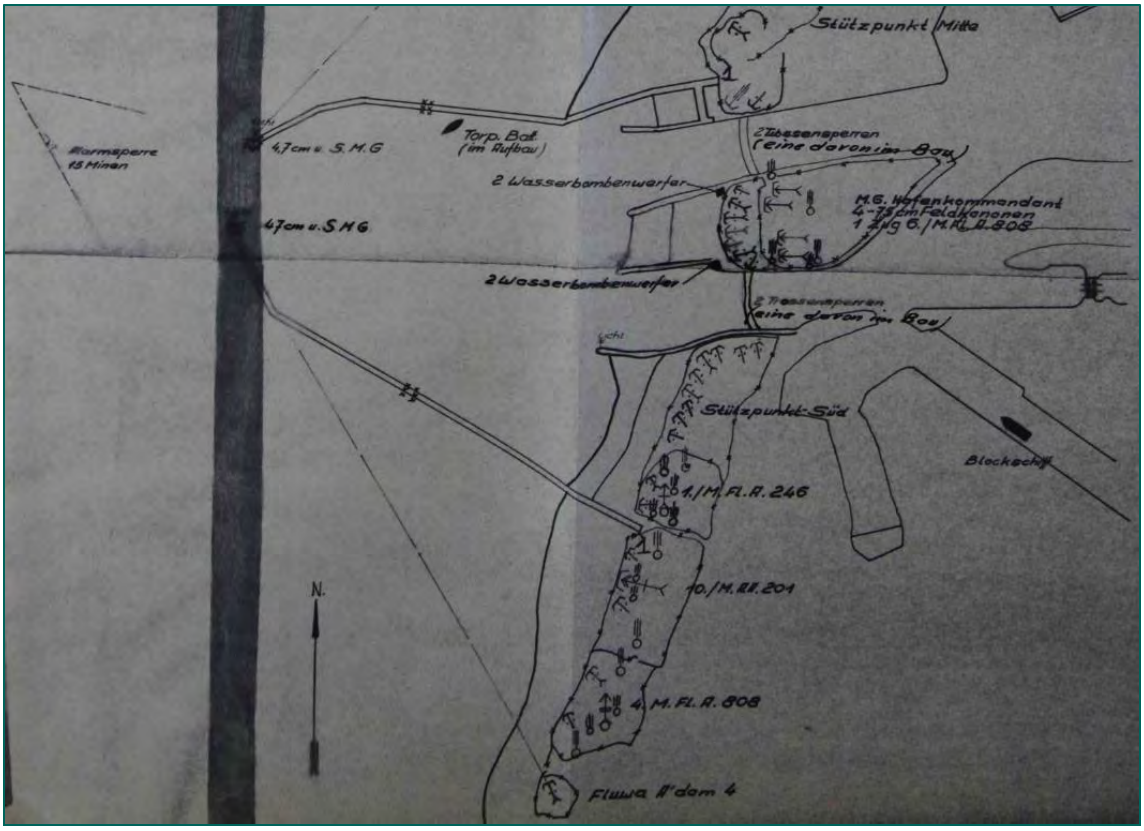
RM 5: Admiralstab der Marine / Seekriegsleitung der Kaiserlichen Marine.	
The Admiralty of the Imperial Navy was the highest level of command of the German Navy during the First World War. Record Group RM5 contains documents from the admiralty. The following documents are considered relevant for the area of investigation.	
RM 5/4721K	Kommando der Hochseestreitkräfte: "Zusammenstellung der bisher bekannten Minensperren und minenverdächtigen Gebiete". Druck, 3.3.1915
Map showing known and suspected allied minefields, situation March 1915. The area of interest has no overlap with an area which was suspected to be mined.	

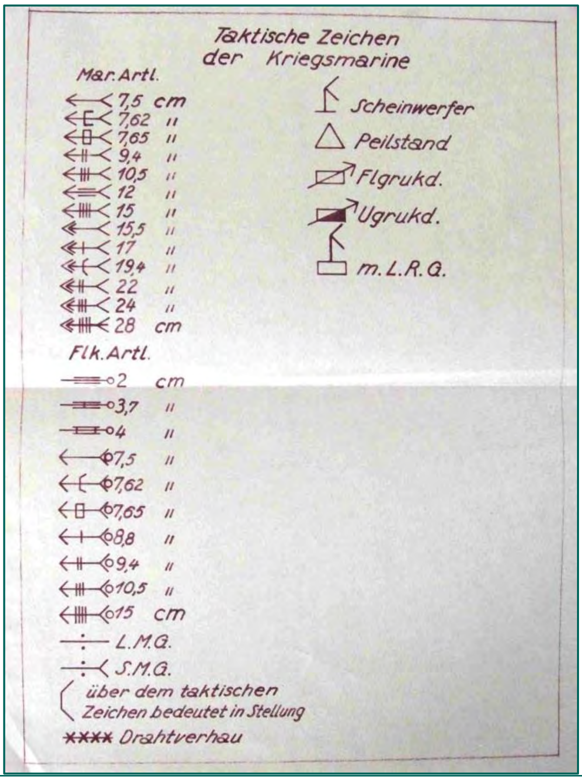


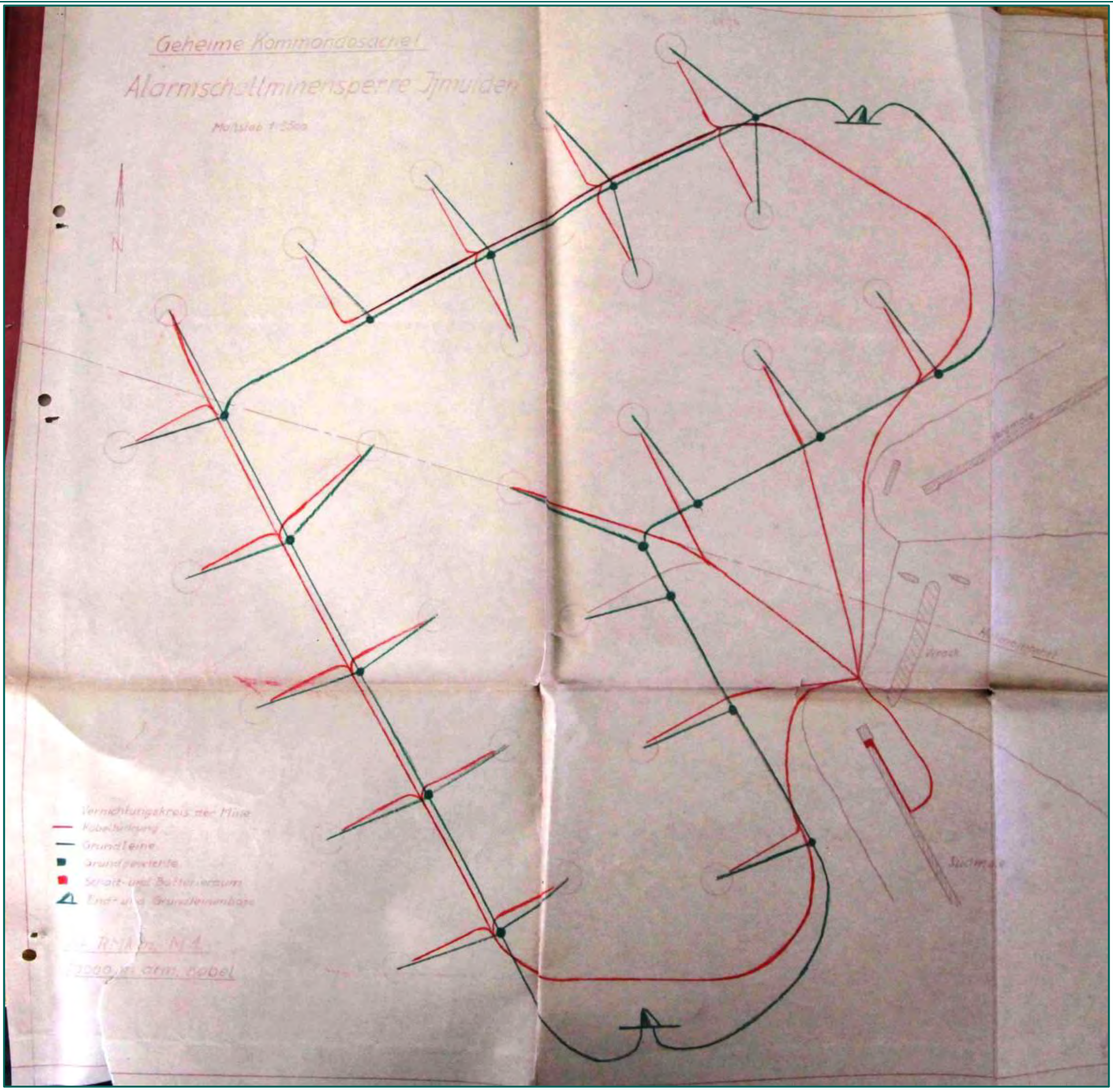
Within the area of investigation the map shows 'Treibende Minen' (Contact mines).	

RM 35-I: Marinegruppenkommando Ost – Nord der Kriegsmarine.	
The *Marinegruppenkommando Ost – Nord* operated as the commander of the units that had to secure the East and North Sea.	
RM 35-I/277	Minenlage Nord (M.L.N.) 1. Mai 1942 - 1. Okt. 1943

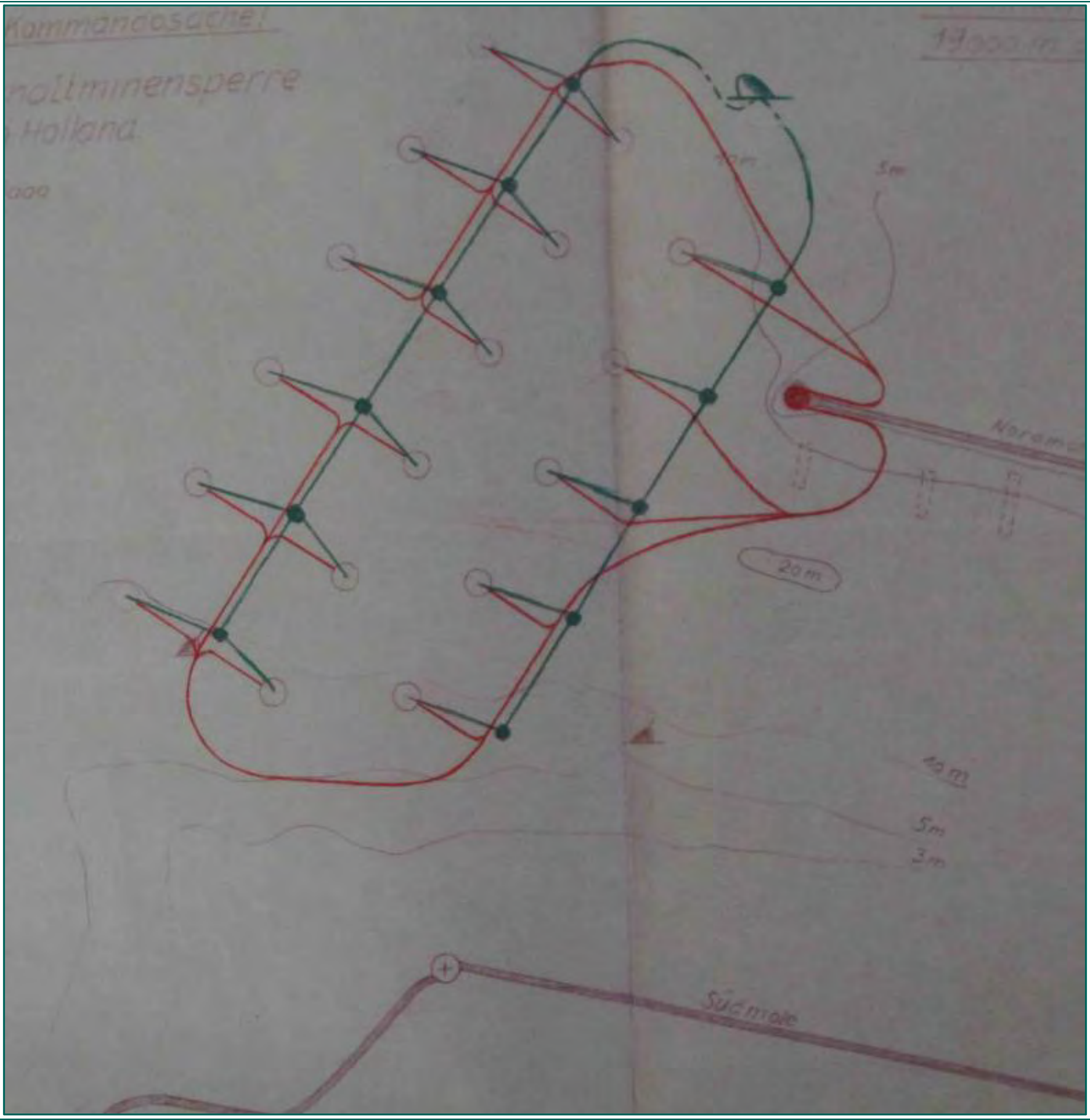
Map showing the defences of IJmuiden harbour. A warning minefield is situated in front of the port entrance. The minefield consisted of 24 RMA magnetic ground mines. The mines had a remote controlled detonator and each mine was coupled to a device on land. This gave the German defender the option to turn the mines on and off.



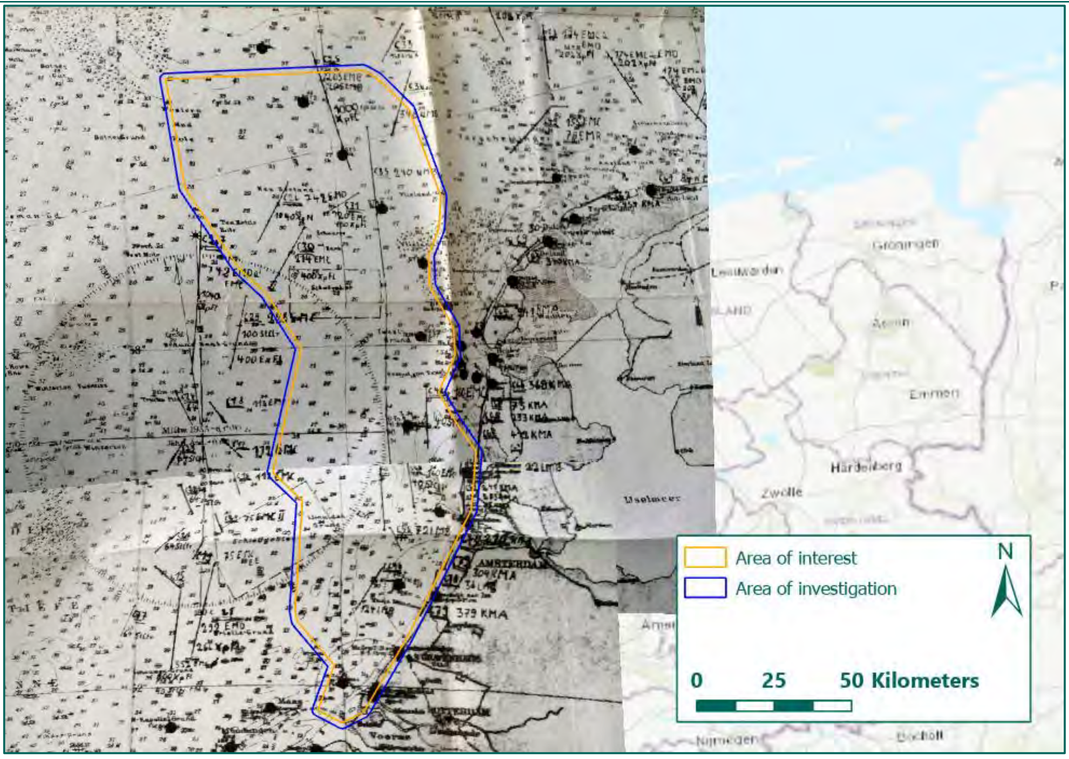




Map showing a minefield consisted of 17 RMA magnetic ground mines at the Hoek van Holland.



ZA 5 Deutscher Minenräumdienst (German Minesweeping Administration)	
The German Minesweeping Administration was responsible for post-war mine clearance of German waters. This administration also summarized and mapped all German minefields laid during the Second World War.	
ZA 5/27	Im Kriege geworfene Minensperren in der Ost- und Nordsee etc.
Naval chart showing numbered German minefields. Multiple minefields are present in the area of interest. For a more detailed map, see ZA 5/47.	



A large amount of minefields were present in the area of investigation:

- C25
- C26
- C27
- C29
- C30
- C31
- C35
- C36
- C44
- C45
- C46
- C47
- C48
- C67
- C69
- C70
- C71
- C72
- C73
- C78
- C79
- E25
- E26
- E38
- E41
- E42
- E43
- E44
- E45
- E46
- E47

- E69

ZA 5/44	Chart B: The North Sea – Central Sheet

C25-C27

C25	SW-0	9/40	53 30.0 N 04 05.0 E 53 49.5 N 03 58.0 E	.5	205 EMB 205 EMB 1000 XpFl		M M M	8 8 17		1) 1))	220-(300(	With AE Switch. Without AE Switch. To west of mines. Considered safe.
C26	SW-1	8/40	53 27.8 N 03 46.5 E 53 17.5 N 03 36.5 E	1	742 EMD 1040 XpFl		M M	7 16	65	3	50	AE Switch "OFF" Considered safe.
C27	SW-2	8/40	53 20.0 N 03 21.0 E 52 56.0 N 03 17.5 E	1	742 EMD and EMC 1040 XpFl		M M	7 17	65 50	3		AE Switch "OFF" Considered safe.

C29-C31

C29	SW-9	7/42	53 08.5 N 03 33.1 E 52 56.3 N 03 28.2 E	2	226 EMC 100 StCtr 400 ExFl		M M M	10 20 20		2 1		With 50 feet lower antenna. The 400 Ex-Floats are for lines C.29, C.30 and C.31. They are in the space between the mine lines.
C30	SW10	7/42	53 20.0 N 03 49.7 E 53 10.0 N 03 38.9 E	2	214 EMC 400 XpFl		M M	10 20		2		With 50 feet lower antenna. The 400 Ex-Floats are for lines C.29, C.30 and C.31. They are in the space between the mine lines.
C31	SW11	7/42	53 26.0 N 04 06.0 E 53 22.1 N 03 56.8 E	2	120 EMC 400 XpFl		M M	8 20		2		With 50 feet lower antenna. The 400 Ex-Floats are for lines C.29, C.30 and C.31. They are in the space between the mine lines.

C35-C36

C35	4c	10/43	53 26.0 N 04 12.0 E 53 38.2 N 04 12.0 E	.25	240 UMB		M	12		3	160	(Comment-another version shows 340 UMB). With SNAG LINES. Eight mines are missing from S. end of centre row.
C36	4d	10/43	53 36.6 N 04 17.8 E 53 48.0 N 04 25.7 E	.4	348 UMB		M	12		3		With SNAG LINES.

C44-C48

C44	SWK3	6/44	52 37.5 N 04 36.0 E 52 39.0 N 04 36.3 E	.25	22 LMB		G	30	250	2	165	Mean MINE sp. cing 125 yds.
C45	SWKA-1b	9/44	52 26.5 N 04 13.5 E 52 22.8 N 04 16.6 E	.5	72 LMB	DM-1	G		240	2	165	Mean MINE spacing 120 yds. Arming delay 24 hours (?)
C46	SWKA-2	9/44	52 20.2 N 04 12.5 E 52 13.6 N 04 05.5 E	.5	124 LMB	DM-1	G		260	2	165	Mean MINE spacing 130 yds. Arming delay 24 hours.
C47	SWKB-1	11/44	52 30.0 N 04 20.0 E 52 39.0 N 04 20.0 E	1	160 EMC 40 StCtr		M) M)	10	270	3	220	With chain 4 mines to 1 obstructor. Mean spacing 135 yards.
C48	SWKB-2	11/44	52 42.0 N 04 23.0 E) 52 53.0 N 04 23.0 E)	½-1	160 EMC) 40 StCtr)		M	10	330	3	330	Mines with chain. Four mines to one obstructor. Mean spacing 150 yards.

C67

C67	K-6	5-7 1944	52 46.0 N 04 39.1 E 52 40.2 N 04 37.5 E	Fairly accur-ate	412 KMA		G		58	2	33-66	Mean mine spacing 29 yards.

C69-C73

C69	K-7	7-8 1944	52 33.4 N. 04 36.2 E 52 36.7 N 04 37.0 E	Fairly accur-ate	241 KMA		G	3-8ø	56	2	43-55	ø Below HIGH water springs Mean mine spacing 28 yards.
C70	K-8	5/44	52 28.9 N 04 34.5 E 52 29.9 N 04 35.0 E	Exact	75 KMA		G	7ø	55	2	43-55	ø Below HIGH water springs. Mean mine spacing 27.5 yards.
C71	K-8a	5-7 1944	52 29.9 N 04 35.0 E 52 33.4 N 04 36.2 E	Exact	285 KMA		G	5-11ø	52	2	43-66	ø Below mean HIGH water springs. Mean mine spacing 26 yards.
C72	K-9	5-8 1944	52 24.0 N 04 31.7 E 52 20.0 N 04 29.1 E	Fairly accur-ate	304 KMA		G	5-8ø	55	2	43-55	ø Below high water springs. Mean mine spacing 27.5 yards.
C73	K-9a	5/44	52 26.4 N 04 33.7 E 52 24.0 N 04 31.7 E	Exact	210 KMA		G		55	2	43	Mean mibe spacing 27.5 yards.

C78-C79

C78	SWK-6	6/44	52 17.3 N 04 26.4 E 52 19.3 N 04 27.8 E	.25	36 LMB		G	28	246	2	165-190	Mean mine spacing 123 yards.
C79	K10	8/44	52 16.7 N 04 27.0 E 52 12.0 N 04 22.6 E	Fairly accurate	379 KMA		G	5-10	55		44-55	Mean mine spacing 27½ yards. Below HIGH water springs.

E25-E26

E25	SWK7	6/44	52 08.2 N 04 17.1 E 52 11.4 N 04 21.1 E	.125	78 LMB	M1	G	23-30	210	2	165	Mean mine spacing 105 yds.
E26	SWK9	4/44	51 55.5 N 03 57.1 E 51 52.4 N 03 52.5 E	.25	90 LMB	M1	G		190	2	220	Mean mine spacing 95 yds.

E38

E38	SWK A3	9/44	52 09.2 N 03 55.0 E 52 01.2 N 03 51.7 E	.5	90 LMB	TM3	G		180	1	165	Mean mine spacing 90 yds. Arming delay 24 hours. EMC with chain.
					90 EMC		M	10	180	1		

E41-E47

E41	K10	8/44	52 16.7 N 04 27.0 E 52 12.0 N 04 22.6 E	Fairly exact	739 KMA		G	5-10	55		44-55	Mean mine spacing 27½ yards. Below HIGH water springs.
E42	K11	5-8 1944	52 05.0 N 04 14.0 E 52 07.5 N 04 16.7 E	Exact	179 KMA		G	6-13	55		44	Mean mine spacing 27½ yards. Below HIGH WATER springs.
E43	K12	5/44	51 59.6 N 04 06.8 E 52 01.1 N 04 08.5 E	Exact	135 KMA		G		55	2	44	Mean mine spacing 27½ yards.
E44	K12A	4/44	52 01.1 N 04 08.5 E 52 04.8 N 04 13.6 E	Exact	334 KMA		G		55	2	44	Mean minespacing 27½ yards.
E45	K13	7-8 1944	51 58.4 N 04 04.2 E 51 56.7 N 04 01.8 E	Exact	134 KMA		G	5-8 below H.W.S.	66		44	Mean mine spacing 33 yards.
E46	K14	8/44	51 54.5 N 04 00.1 E 51 55.7 N 04 00.3 E 51 56.7 N 04 01.8 E	Exact	164 KMA		G	6-7 below H.W.S.	55	2	44	Mean mine spacing 27½ yards. (Comment: Alternative version gives 182 KMA).
E47	K15	8/44	51 54.3 N 04 00.1 E 51 52.3 N 04 02.5 E	Exact	182 KMA		G	6 below H.W.S.	55	2	44	Mean mine spacing 27½ yards.

E69

E69		11/44	Brielschegat from net barrage at Seuberg to 04 10E.	Exact	147 KMA	G	to 13 below H.W.S.	70	2	55	Mines scattered.

The information from ZA 5/27 and 5/44 is shown in the figure and table below.

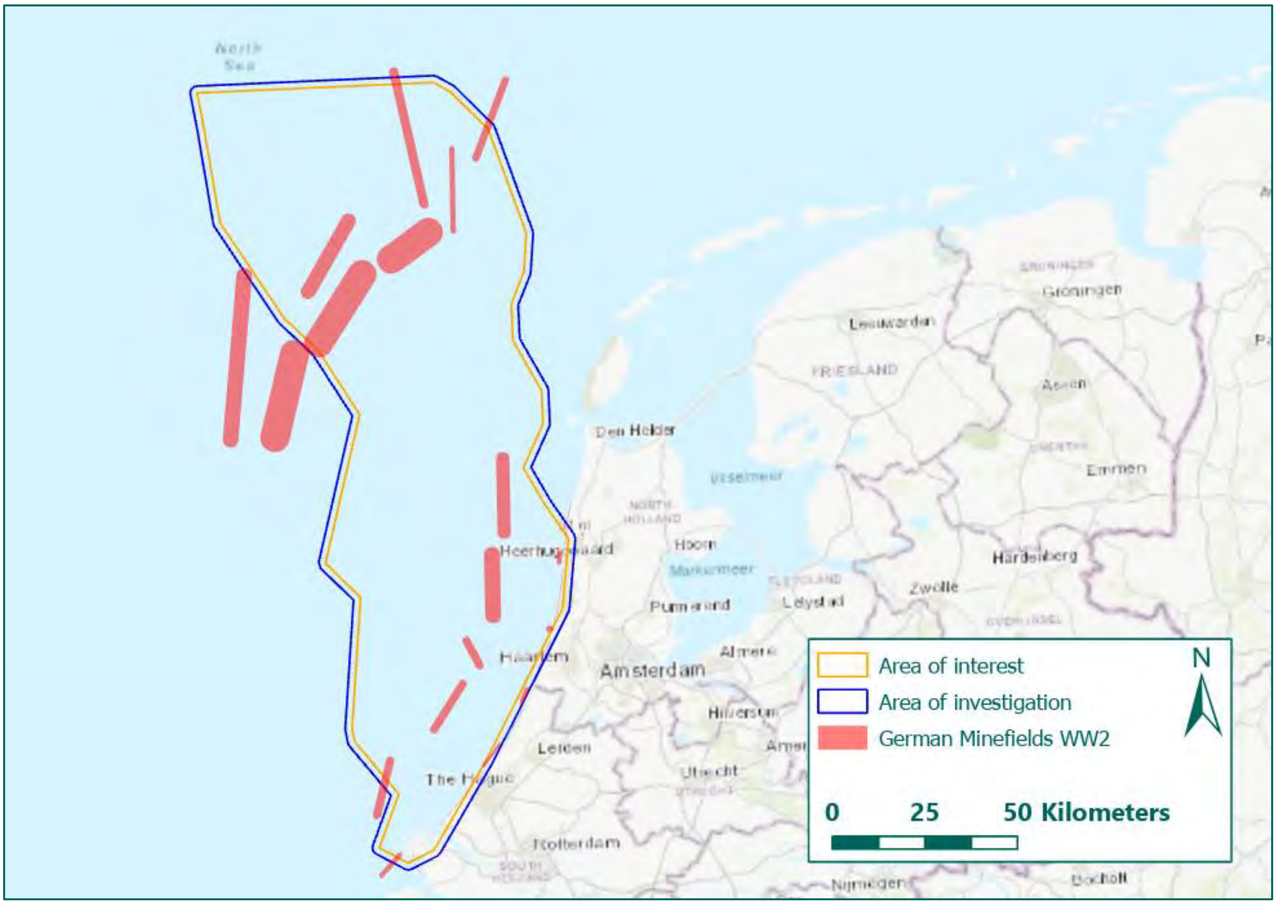


Figure 61: German Minefields within the Area of investigation (Source basemap: ESRI).

Number	Amount of mines	Rows	
		Amount	Spacing
C25	205 x EMB[7], 205 x EMB, 1000 x XpFl[8]	2	220/300 yards
C26	742x EMD[9], 1040 x XpFl	3	65 yards
C27	742 x EMD/EMC[10], 1040 x XpFl	3	65 yards
C29	226 x EMC, 100 x StCtr[11], 400 x XpFl	2, 1	Unknown
C30	214 x EMC, 400 x XpFl	2	Unknown
C31	120 x EMC, 400 x XpFl	2	Unknown
C35	240 x UMB[12]	3	Unknown
C36	348 x UMB	3	Unknown
C44	22 x LMB[13]	2	Unknown
C45	72 x LMB	2	Unknown

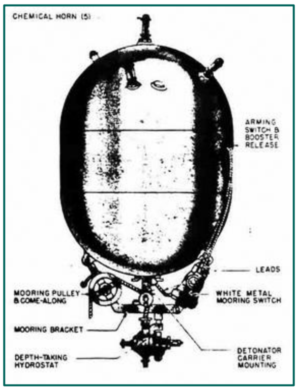
[7] *Einheidsmine* – Type B, Contact mine
[8] Exploding floats, *Sprengboje*
[9] *Einheidsmine* – Type D, Contact mine
[10] *Einheidsmine* – Type C, Contact mine
[11] Static cutters/Static Conical Sweep Obstructor, *Reisboje*
[12] *U-Bootabwehrmine* – Type B, Contact Mine
[13] *Luft Mine* – Type B, Influence Mine

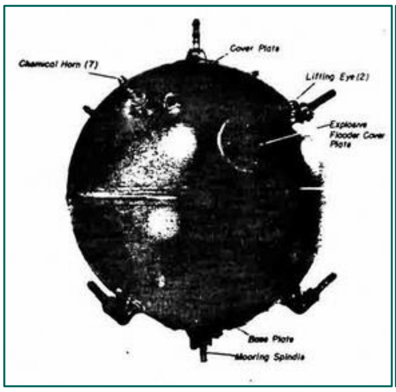
Number	Amount of mines	Rows	
		Amount	Spacing
C46	124 x LMB	2	Unknown
C47	160 x EMC, 40 x StCtr	3	Unknown
C48	160 x EMC, 40 x StCtr	3	Unknown
C67	412 x KMA[14]	2	Unknown
C69	KMA (unknown amount)	2	Unknown
C70	75 x KMA	2	Unknown
C71	285 x KMA	2	Unknown
C72	304 x KMA	2	Unknown
C73	210 x KMA	2	Unknown
C78	36 x LMB	2	Unknown
C79	379 x KMA	Unknown	Unknown
E25	78 x LMB	2	Unknown
E26	90 x LMB	2	Unknown
E38	90 x LMB, 90 x EMC	2	Unknown
E41	739 x KMA	Unknown	Unknown
E42	179 x KMA		Unknown
E43	135 x KMA	2	Unknown
E44	334 x KMA	2	Unknown
E45	134 x KMA	Unknown	Unknown
E46	164 x KMA	2	Unknown
E47	182 x KMA	2	Unknown
E69	147 x KMA	2	Unknown
Unknown, Harbour Hoek of Holland	17 x RMA[15]	-	-
Unknown, Harbour IJmuiden	24 x RMA	-	-
Unknown, Harbour IJmuiden	LMB (unknown amount)	Unknown	Unknown

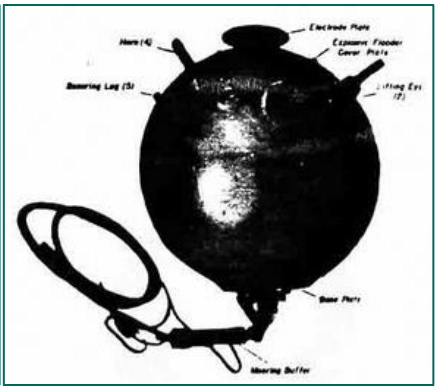
[14] Küstenmine – Type A, Contactmine
[15] Regulare Mine – Type A, Contactmine

German Mines (and sweep obstructors) within the area of investigation)

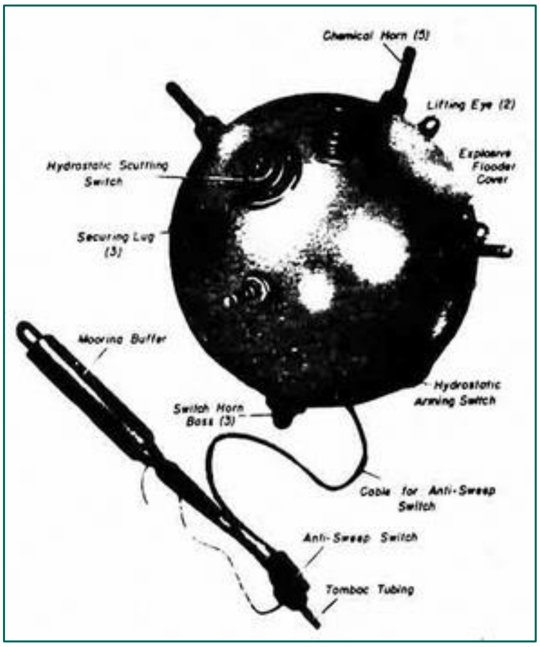
Einheidsmine – Type B, C and D Contact mine



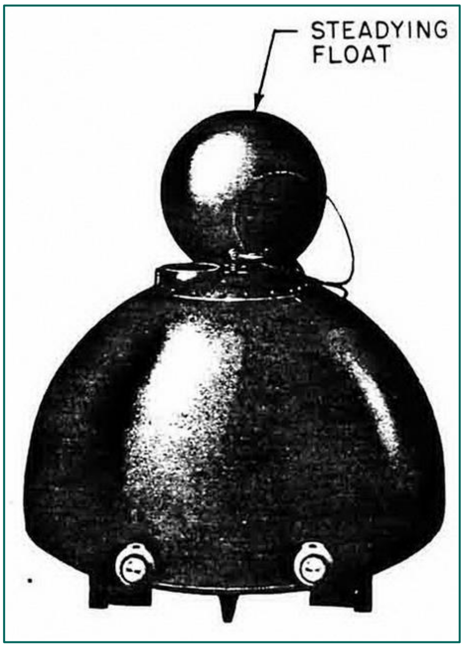




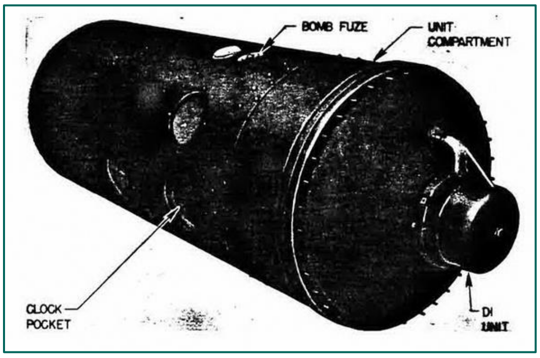
U-Bootabwehrmine – Type A, Contact Mine



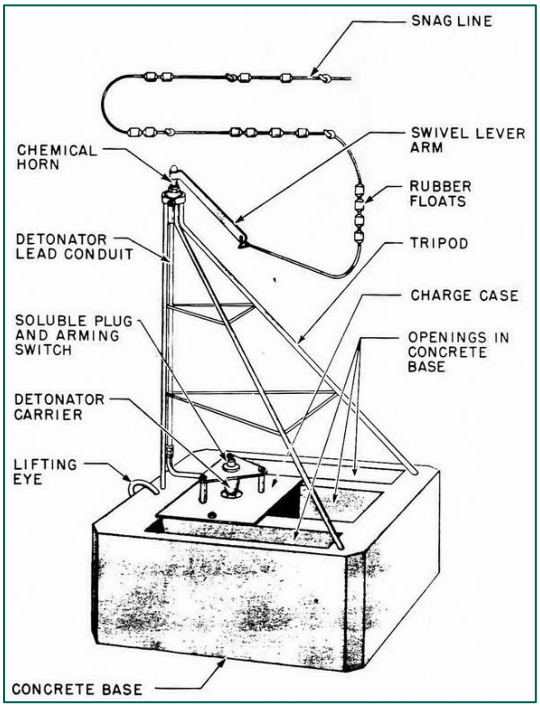
Regulare Mine – Type A, Contactmine



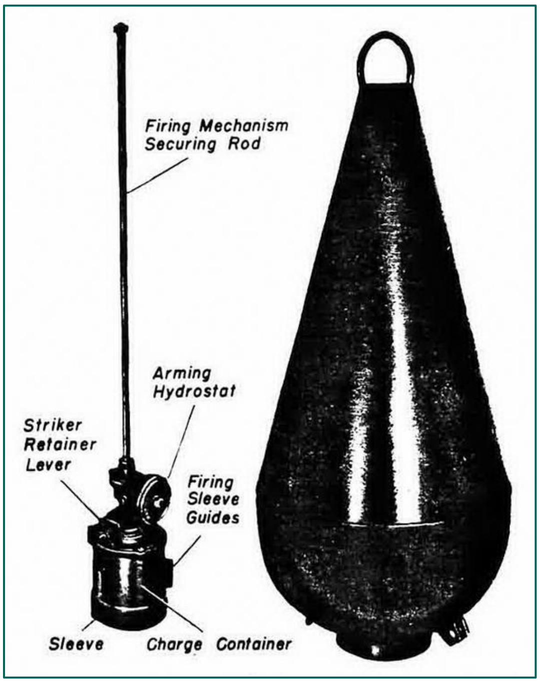
<table>
<tr><th colspan="2">German Mines (and sweep obstructors) within the area of investigation</th></tr>
<tr><td>Luft Mine – Type B, Influence/Ground Mine



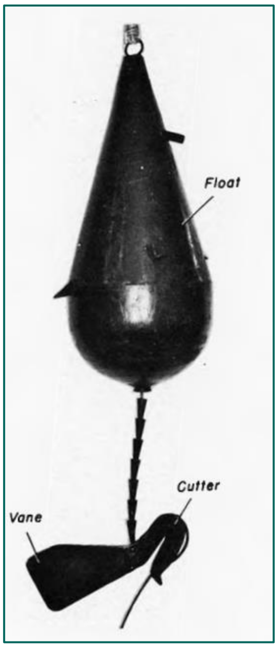

</td><td>Küstenmine – Type A, Contactmine



</td></tr>
<tr><td>Exploding floats, Sprengboje (Explosive)



</td><td>Static cutters/Static Conical Sweep Obstructor, Reisboje (Non explosive)



</td></tr>
</table>

Table 6: German Mines (and sweep obstructors) within the area of investigation.

ANNEX 4 WRECKS WITHIN THE AREA OF INTEREST

The website 'Wrecksite' and the book 'HP39 Wrakkenregister, Nederlands Continentaal Plat en Westerschelde' (abbreviated to HP39), drawn up by the Dutch navy, show an abundance of wrecks (ships and aircraft) within the area of interest. In HP39 no details are given about the reason/cause of the sinking of the ships or aircraft. However. An overview of all wrecks according to this book is shown below.

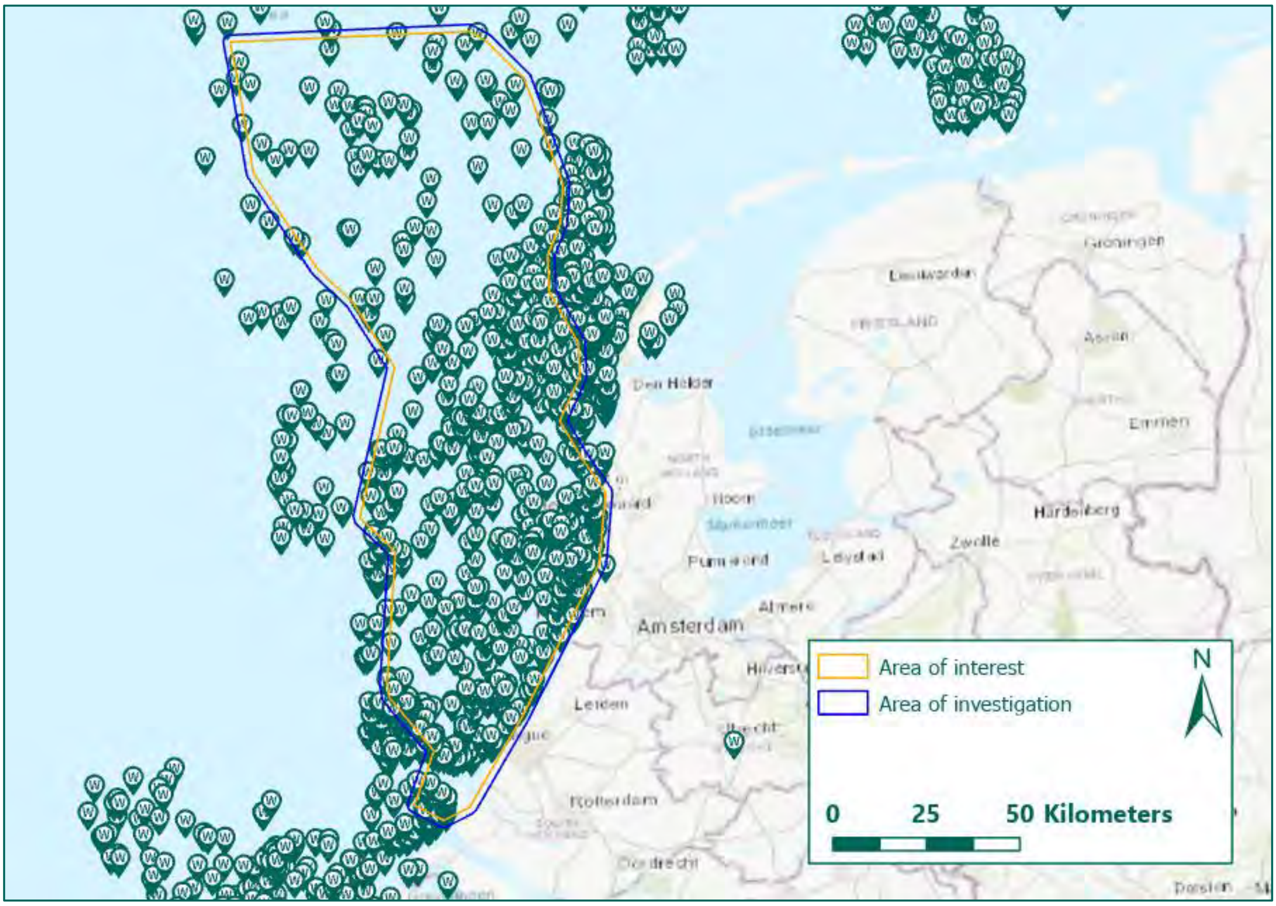


Figure 62: Overview of wrecks within the area of interest according to HP39 (Source: HP39).

The Website 'Wrecksite' shows more details with regards to the wrecks in the North Sea. The website shows a total of more than 1800 wrecks within and near the area of interest. Plotting all these wrecks in the GIS-system would be too comprehensive and would outside the scope of this report. In the table below a list war related causes of sinking of ships/aircraft within the area of interest is shown.

Cause of sinking	Total number sunk
Airplane crashes, WW2	75
Air raids, WW2	19
Charges/explosives, WW1 and WW2	8
Depth charges , WW2	2
Explosions, WW2 and after WW2	4
Gunfire – shelled, WW1 and WW2	152
Mine, WW1 and WW2	39
Naval battles, WW1 and WW2	10
Torpedo, WW1 and WW2	21
War loss (Not specified), WW1	1

Table 7: Listing of ships/aircraft sunk by war related events.

ANNEX 5 POST-WAR UXO CLEARANCE

OSPAR Commission

OSPAR is the mechanism by which 15 governments and the European Union cooperate to protect the marine environment of the North-East Atlantic. Since 1972 the OSPAR Convention has worked to identify threats to the marine environment and has organised, across its maritime area, programmes and measures to ensure effective national action to combat them. One of the Policy Issues of the OSPAR Convention is to report encounters with conventional and chemical munitions in the OSPAR maritime area. These encounters are kept in a database[16]. The munition encounters from 1999 onwards within the area of interest are rendered in Figure 63. Multiple UXOs were lifted from the area of interest. The exact type of UXO lifted is not mentioned in all cases. However, it is known that several aerial bombs, flares, mines, torpedo's and shells were lifted.

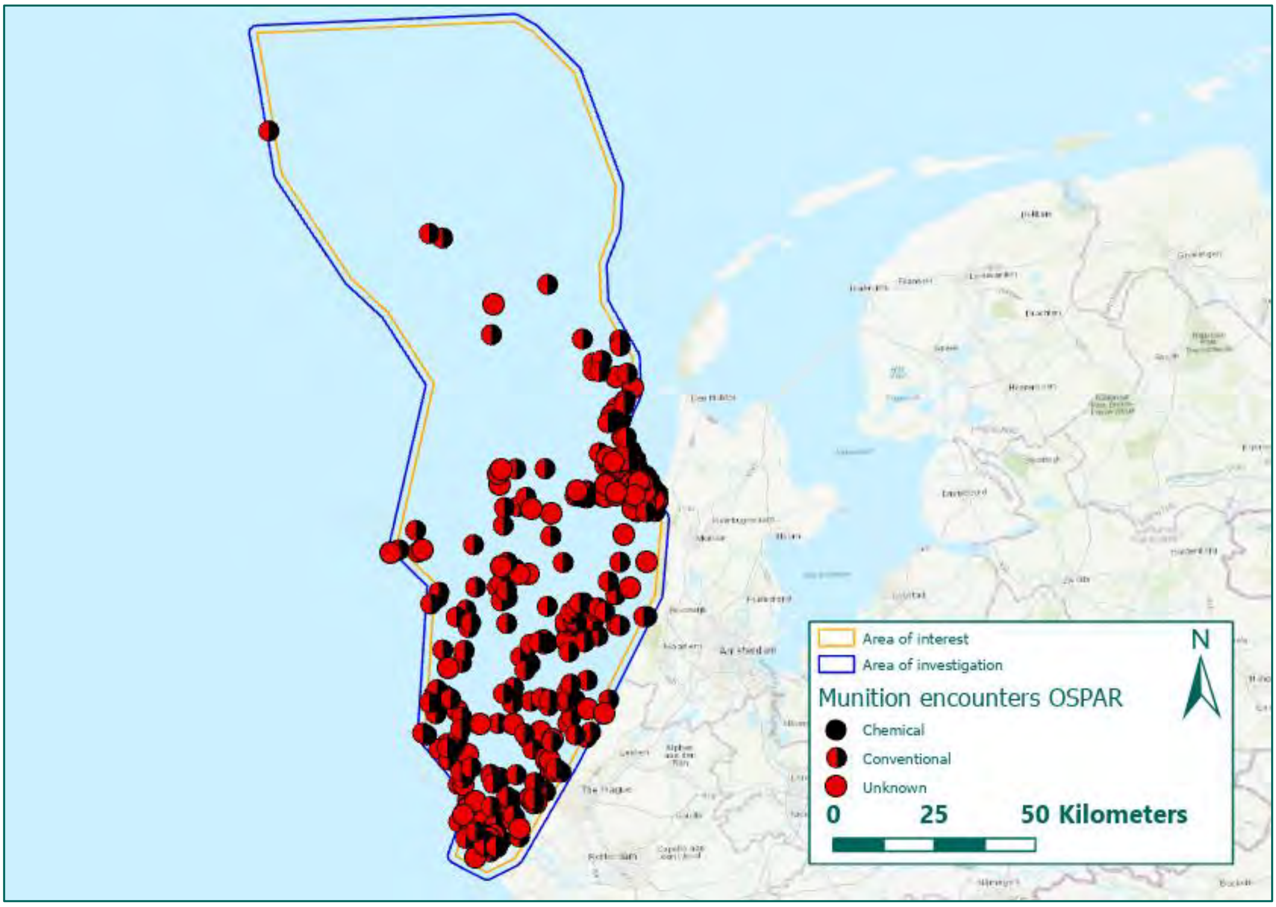


Figure 63: Overview OSPAR ammunition encounters within the area of interest (Source: OSPAR).

Dutch Coastguard (Nederlandse Kustwacht) and Beneficial Cooperation

The Dutch Coastguard (Nederlandse Kustwacht) cleared hundreds of UXO in the North Sea. Coordinates were used to keep track of the locations of encountered UXO. The Dutch Coastguard also cooperated with the Belgian Navy in clearing ammunition. This joint venture operates under the name Beneficial Cooperation.

The Dutch Coastguard manufactured lists that could help citizens (mainly citizens active in the fishing industry) identify any UXO found at sea. This additional information helped the Coastguard to be better prepared. These lists are shown at the end of this annex for clarification. When known, the numbers referring to the different types of UXO are shown in the GIS-shapefiles of the Dutch Coastguard and

[16] This database can be consulted at http://odims.ospar.org/layers/?limit=100&offset=0.

Beneficial Cooperation. The figures below respectively show cleared UXO reported by the Dutch Coastguard and Beneficial Cooperation.

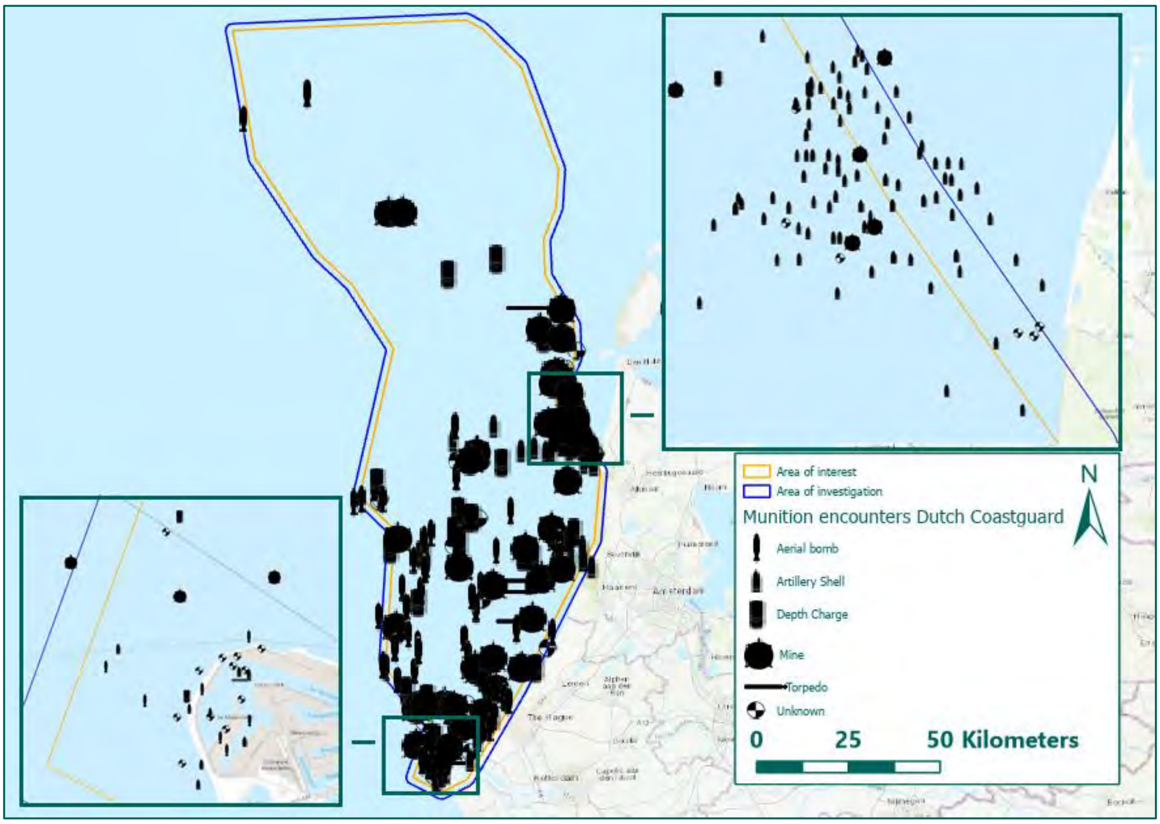


Figure 64: Overview of UXO lifted by the Dutch Coastguard (Source basemap: ESRI).

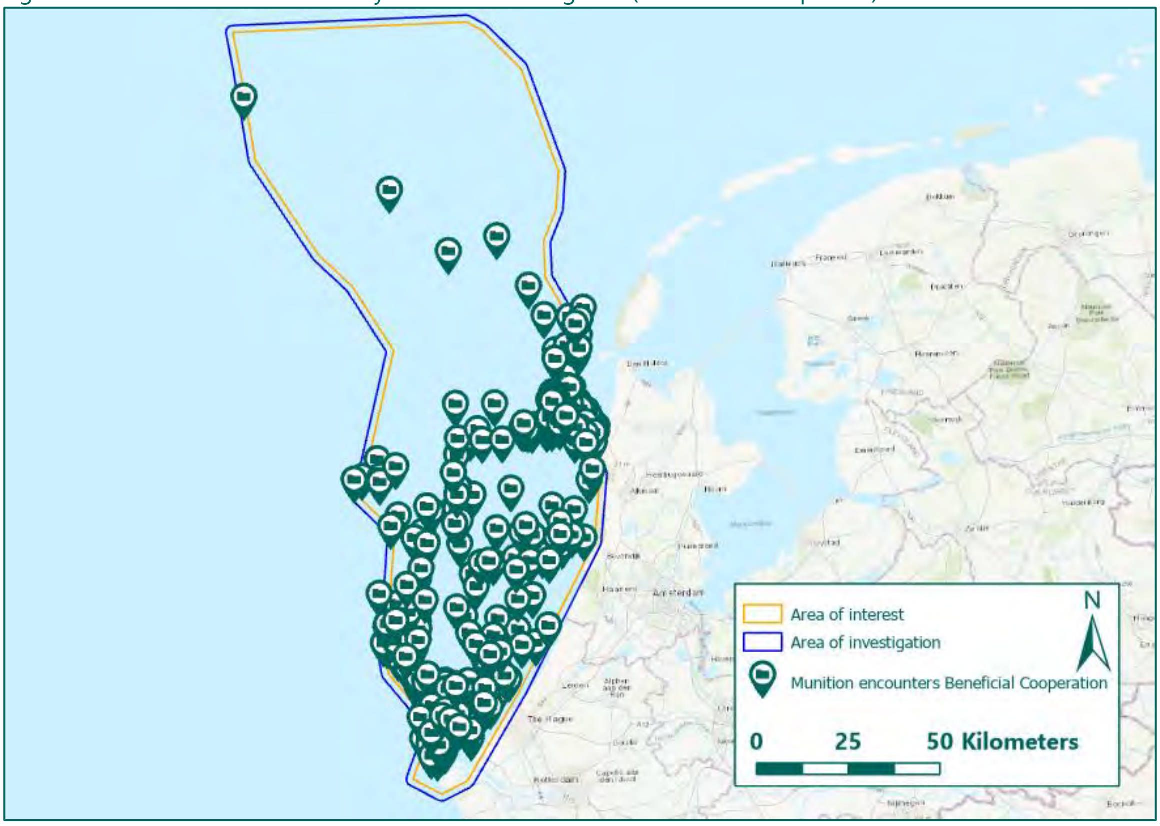
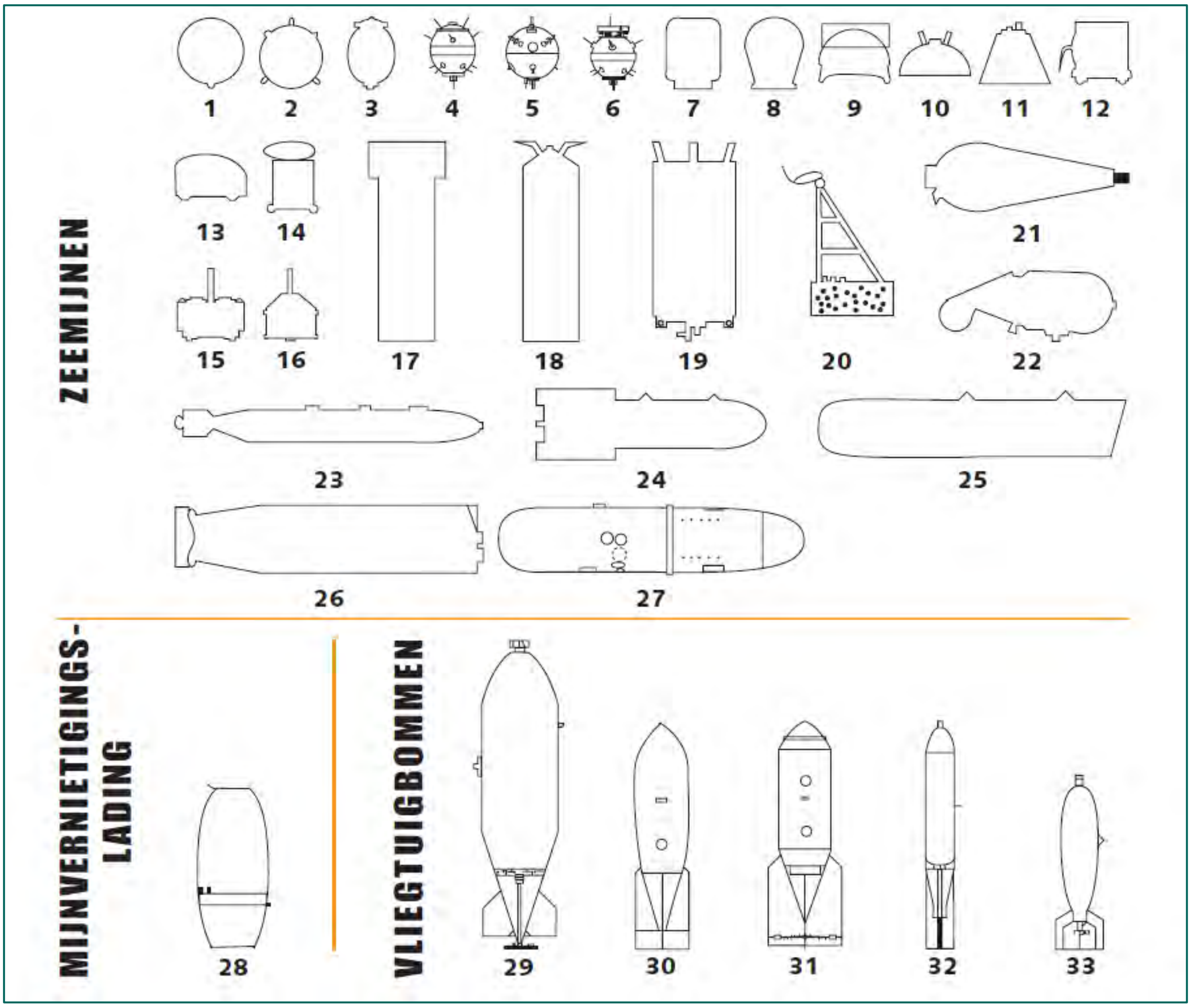


Figure 65: Overview of UXO lifted by the Beneficial Cooperation (Source basemap: ESRI).


ZEEMIJNEN
1 2 3 4 5 6 7 8 9 10 11 12
13 14
15 16 17 18 19 20 21 22
23 24 25
26 27
MIJNVERNIETIGINGS-
LADING
28
VLIEGTUIGBOMMEN
29 30 31 32 33

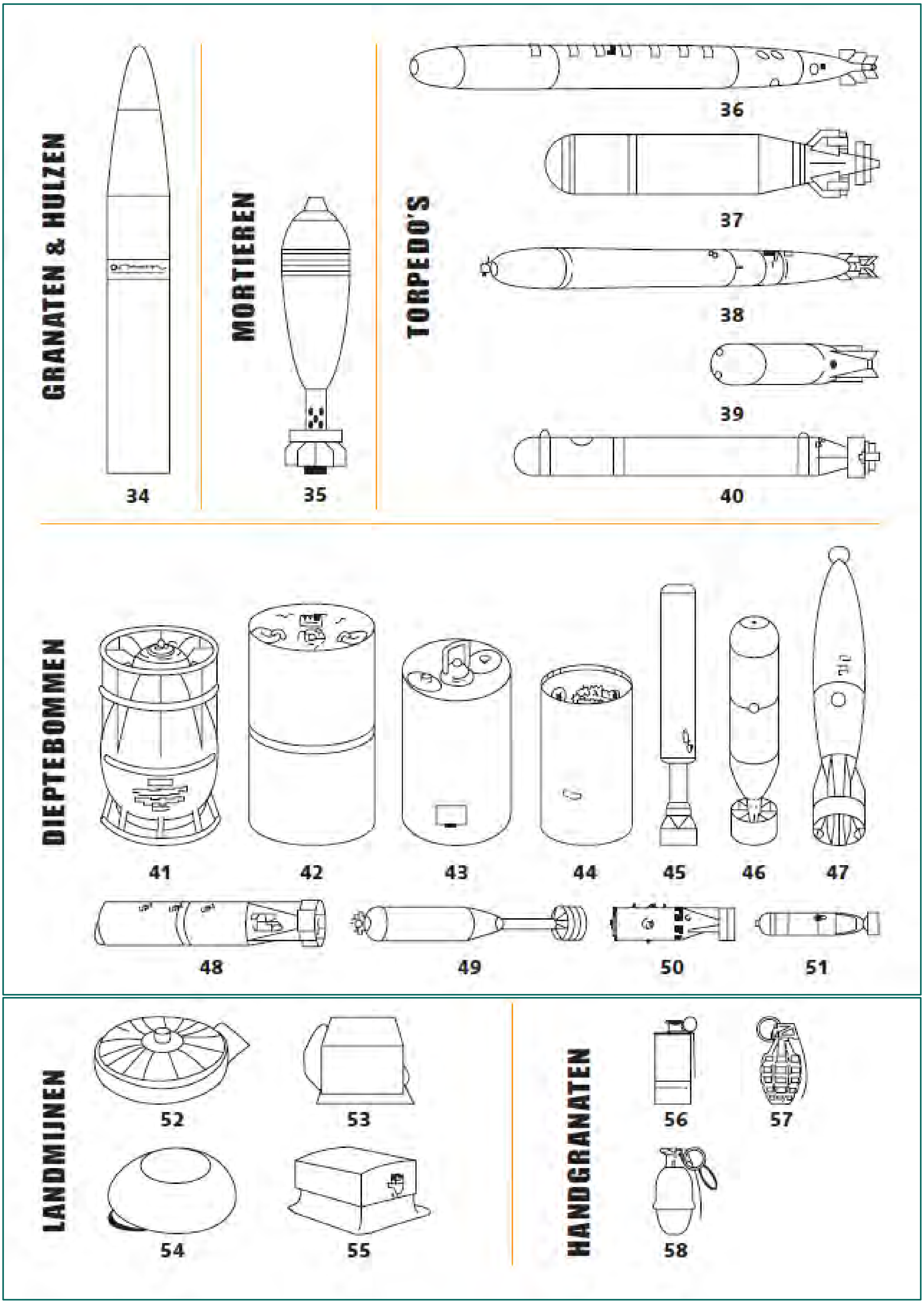


Figure 66: 'Explosievenkaart' (Explosives chart) of the Dutch Coastguard. This chart is used to help identify UXO (Source: Dutch Coastguard).

Dutch 'Explosieven Opruimingsdienst' (EOD)

Every year, the Dutch EOD clears an average of 2,500 explosives from the Second World War in the Netherlands. Most of these clearances take place onshore. However, the Dutch Navy does assist the Coastguard with offshore UXO encounters. In the figure below the locations of multiple UXO encounters are shown. The same 'Explosievenkaart' (Explosives chart) is used to identify these UXO. When known, the numbers referring to the different types of UXO are shown in the GIS-shapefiles of the EOD.

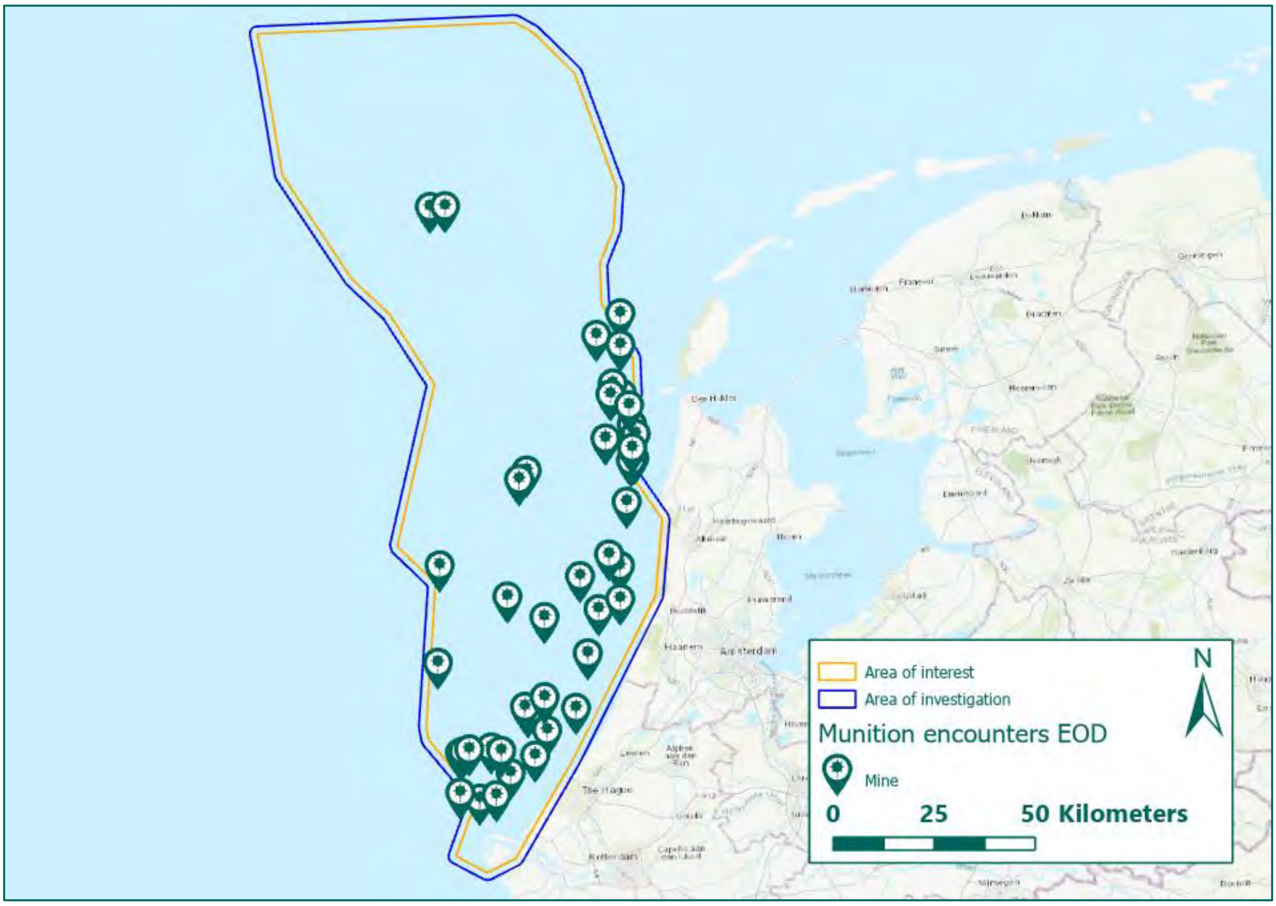


Figure 67: Overview of UXO lifted by the Dutch EOD (Source basemap: ESRI).