Netherlands Enterprise Agency

Site Studies Wind Farm Zone Borssele

Geological desk study

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REPORT

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Project number	14254		
Document number	RE14254a	Version	4

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Date	11-12-2014	

Rapport [RE14254a4]

Borssele wind farm zone
Geological desk study

Document bevat bladzijden op zowel A4 en A3 formaat

Documentlocatie:
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1 Introduction

1.1 General

The Dutch Government intends to assign wind farm areas within the wind farm zone Borssele, located in the Dutch North Sea, and wants to learn beforehand whether the soil conditions, as one of the dictating environmental boundary conditions, are suited for wind farm development. For this reason Crux Engineering BV, together with GisSense and ediGEO, has been commissioned to undertake a desk study, aiming at a geotechnical site reconnaissance. After collecting and compiling all soil data and geological data in a GIS model, areas will be identified which are best suited for wind farm development, including recommendations on the elements comprising the wind farm itself. The Borssele wind farm zone is located in the Dutch North Sea, west of Walcheren, in the Dutch Exclusive Economic Zone (EEZ) outside the 12 mile zone and is depicted in Figure 1 with a red dashed line, as abstracted from [1].

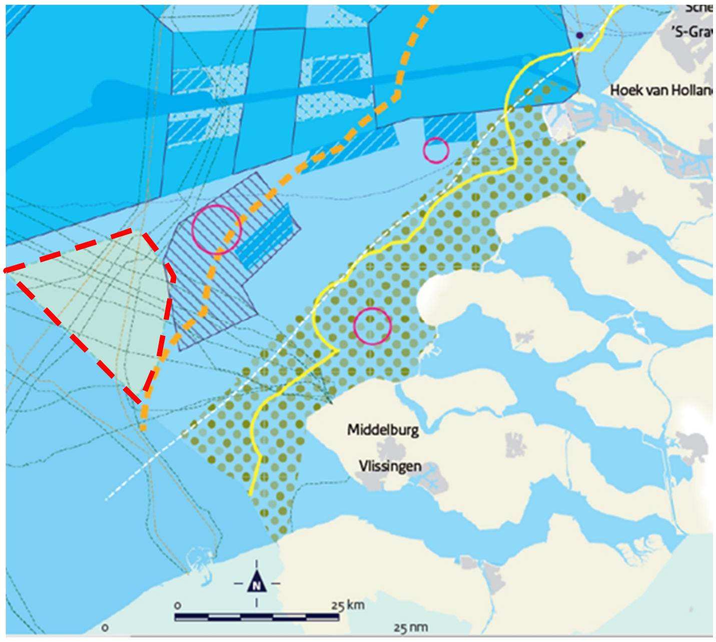


Figure 1: Borssele wind farm zone

The specific objective of this report is defined by the client in [2] and comprises of two main research questions:

1. Are the ground conditions of the Borssele wind farm zone suitable for the construction of offshore wind parks;
2. Can zones be defined within the Borssele wind farm zone where the ground conditions can be classified (for instance: excellent – good – bad – not useable) en can this be quantified in costs.

In the terms of reference [2] is also defined that the research questions should be answered based on a desk study using publicly available data (for instance the Dinoloket database: www.dinoloket.nl and available geological maps).

Netherlands Enterprice Agency (RVO.nl) have asked in [2] to investigate suitability of soil conditions for the installation and operation of wind turbine generators of size 5 – 10MW. Site characteristics will need to be determined, on the basis of which suitability shall be assessed. Characteristics may comprise, but are not limited to:

- Ability of the soil to withstand axial and lateral forces
- Installability (pile driving, suction assisted penetration)
- Bearing capacity of top soil stratum (for installation assistance provided by jack-up vessels as well as for shallow foundations / gravity base foundations)
- Trenchability (for in-field and export cables)

Characteristics would need to be determined not only for the foundations of the wind turbine generators, but also for auxiliary items such as, but not limited to, transformer stations. The desk top study would then be used as a decision tool regarding suitability of the Borssele wind farm zone, whereafter concessions are proposed to the market when judged favourable.

During the execution of the geological desk study it became clear that the publicly available geological and geotechnical data in the Borssele wind farm zone is scarce. This is most probably due to the fact that the (deeper) ground conditions in the Borssele wind farm zone have never been of high interest for public or private use. The lack of geotechnical site investigation data to a sufficient depth already became clear from the inventory made by TNO of the Dinoloket data in [3]. This document shows that only few borings are available with a depth of 1-5 m below the seabed and no borings are available deeper than 25 m. A search on the Dinoloket for available Cone Penetration Test (CPT) data shows that there are no CPTs available in the project area. As a consequence the desk study has relied on different geological maps that (partly) do cover the Borssele wind farm zone. This lack of specific technical ground data limits the detail level with which the clients questions can be answered. This aspect is discussed in the conclusions and recommendations of the report.

Besides a geological desk study, also other ground related objects are identified and collected. This includes:

- Wrecks;
- Pipelines and Cables;
- Sand banks and dunes;

Information of the geomorphology of the seabed, based on available public sources, is included in the research. Bathymetry has been given special attention. The publicly available sources on bathymetry generally have a relative low resolution with contour intervals of 5 to 10 m. Bathymetry data has been acquired from the Dutch Royal Navy (www.hydro.nl) and processed in the study.

The desk study also includes an overview of the foundation types and its characteristics. Based on the available data and analysis, its suitability is assessed for the Borssele wind farm zone.

1.2 Content

The available information for the geological desk study is presented in chapter 2. The geology of the Borssele wind farm zone, based on publically available sources is discussed in chapter 3. This is followed in chapter 4 by the information concerning other ground related aspects, such as pipelines and wrecks. The evaluation of the available foundation types is given in chapter 5. An analysis of the desk study result with respect to the Borssele wind farm zone is given in chapter 6. The report concludes in chapter 7 with a summary and answers to the research questions.

2 Available Information

2.1 General

The objective of the desk study is to collect and use all publicly available data. Both hardcopy and publicly available digital sources have been used.

The bathymetry figures and data are reproduced with the approval of the Hydrographical department of the Dutch Royal Navy (*De afbeeldingen/gegevens die betrekking hebben op bathymetrie zijn gereproduceerd met toestemming van de Dienst der Hydrografie van de Koninklijke Marine*).

The following references are used in the desk study:

[1] Ministry of Infrastructure and Environment, “Wind Energy Areas on the North Sea, current use of North Sea”, June 2013

[2] Memo Agentschap NL, Terms of Reference; *Onderzoek naar bodemgeschiktheid windgebied Borssele als offshore* windpark, 4 april 2014;

[3] Notitie TNO, <vnr-ext>, Data Bodemgesteldheid Uitrol Wind op Zee, d.d. 26 februari 2014.

[4] Renard Centre of Marine Geology (RCMG), Tertiary and Quaternary Geology of the Belgian Continental Shelf, 2003

[5] Rijks Geologische Dienst (in cooperation with the British and Belgium Survey), 1991, Ostend sheet 51°N-02°E, scale 1:250.000, consisting of 3 maps: Sea bed Sediments & Holocene; Quaternary Geology; Solid Geology.

[6] Rijks Geologische Dienst, 1996, geological map of Buitenbanken;

[7] Rijks Geologische Dienst, 1992, geological map of Rabsbank;

[8] Rijks Geologische Dienst, 1996, Paleogeographical maps of Zeeland - Holocene;

[9] Digital Bathymetrie data - Hydrographical department of the Dutch Royal Navy;

[10] Rijkswaterstaat, Noordzee atlas, (www.noordzeeatlas.nl);

[11] Dinoloket, www.dinoloket.nl;

[12] Deltares, 2011, 1201907-000-BGS-0008, The scientific validation of the hydrographic survey policy of the Netherlands Hydrographic Office, Royal Netherlands Navy,

[13] Admiralty Chart, WestKapelle to Stellendam and Maasvlakte

[14] Admiralty Chart, West Hinder and Outer Gabbard to Vlissingen and Scheveningen

[15] Admiralty Chart, Dunkerque to Vlissingen

[16] API (2011), Geotechnical and Foundation Design Considerations, ANSI/API Recommended Practice 2GEO, First Edition, April 2011 / ISO 19901-4: 2003 (Modified)

2.2 Geological and geotechnical data

During the execution of the geological desk study it became clear that the publicly available geological and geotechnical data in the Borssele wind farm zone is scarce. This is most probably due to the fact that the (deeper) ground conditions in the Borssele wind farm zone have never been of high interest for public or private use. The lack of geotechnical site investigation data to a sufficient depth already became clear from the inventory made by TNO of the Dinoloket data in [3]. This document shows that only few borings are available with a depth of 1-5 m below the seabed and no borings are available deeper than 25 m (see Figure 2). A search on the Dinoloket for available Cone Penetration Test (CPT) data shows that there are no CPTs available in the project area (see Figure 3). As a consequence the desk study is limited to geological data and has relied on different geological maps that (partly) do cover the Borssele wind farm zone ([5], [6], [7], [8]). South of the project area is the Belgium territory, where wind parks are developed at this moment. The site investigation data of these parks is not publically available. The Belgium geological study report [4], that has been made in 2003 prior to the development of these parks, has been used in the Borssele desk study. Maps displayed in this report also partly cover the Borssele wind farm zone. This information has been used in the geological maps presented in this report.

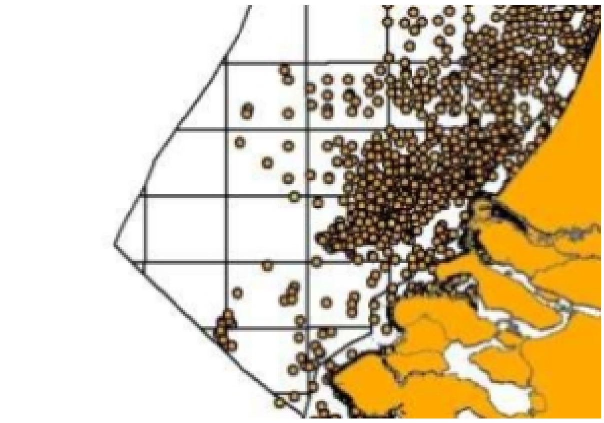
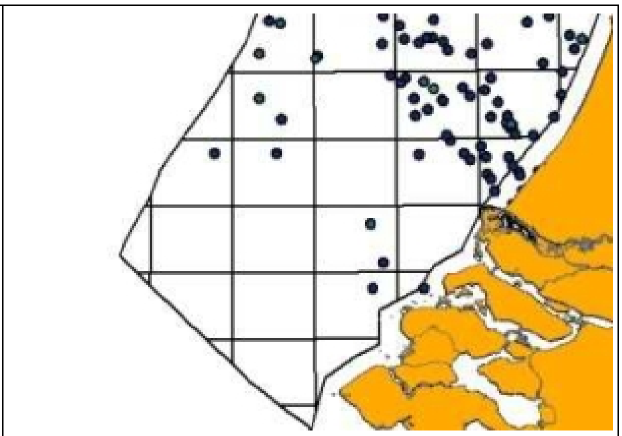
	
Borings 1-5 m	Boring >25 m

Figure 2: Overview of available borings Dinoloket [3].

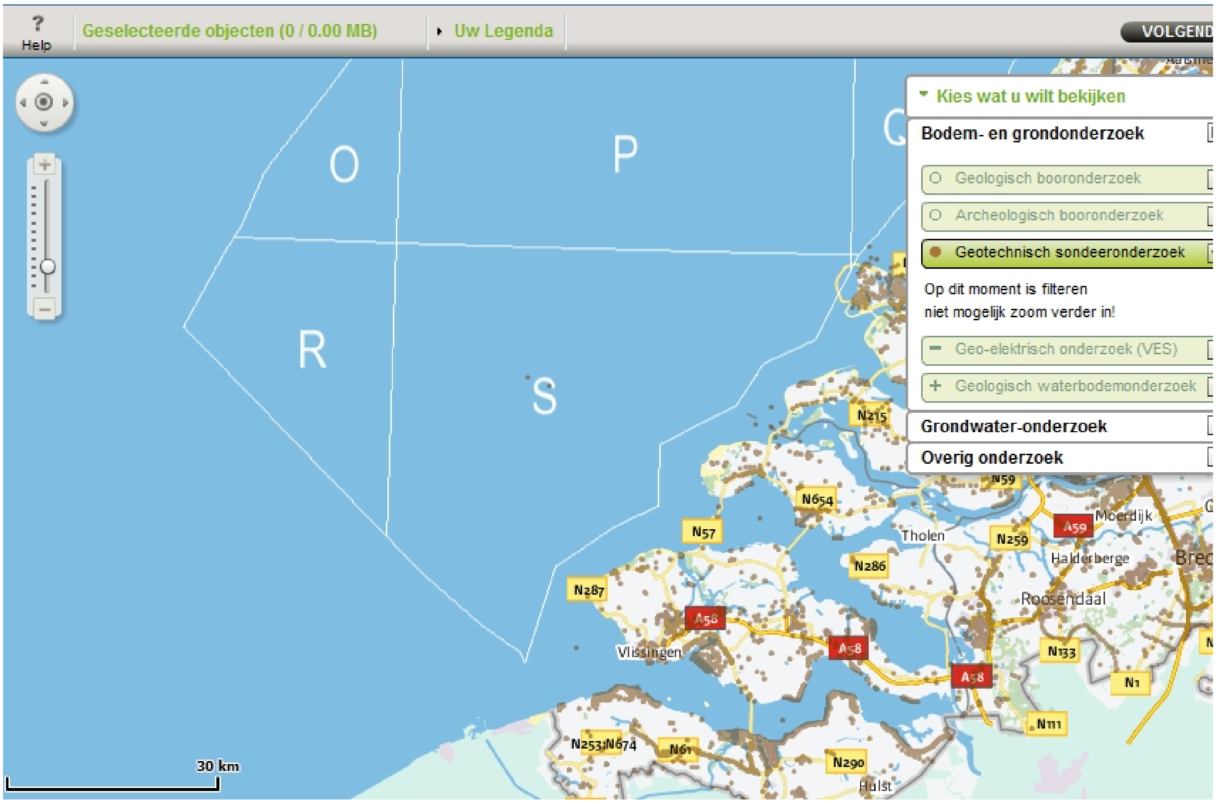


Figure 3: Available Cone penetration tests (CPT) on Dinoloket [11]

3 Geology

3.1 Introduction

The described geology in this report is based on the available geological maps of the area and reports. These different information sources are scanned and geo-referenced in a central GIS system, which makes it possible to create combined maps of the different sources. During the processing of the different geological maps, of different age and coverage of the area, it became clear that there are discrepancies between the different maps. This discrepancy will also be present in the conclusive maps.

The geological layers of importance for the foundation of wind mills in the project area are not older than the Tertiary. The geological description is consequently limited to the Tertiary, Pleistocene and Holocene deposits. An overview of the relevant geological formations is given in Table 1. The most important characteristics of each formation, as can be interpreted from the available data, is summarized in this table. In the following paragraph each of the formation will be discussed in more detail, from old to younger formations.

Table 1: Overview of the relevant geological formations

Formation	Soil type	Top of formation (depth below sea level)
Sand waves, bank or ridge (Bligh Bank Formation)	Medium sand (250-500 µm), clay laminae	-10 ÷ -30 m
Holocene Elbow formation, Buitenbanken formation , Bligh Bank formation.	Clay, Peat, Fine and medium sand, clay laminae with gravel content	-20 ÷ -35 m
Pleistocene Kreftenheye Formation, Eem formation.	Medium grained calcareous sand	-25 ÷ -45 m Also areas where no pleistocene is present
Tertiary Rupel formation Dongen Formation, Tongeren Formation.	Marine dark brown-grey clays (Boom clay), with a varying number of sand layers. Calcareous clays with intercalated sand	-30 m ÷ -50 m

3.2 Tertiary formation

The level of top of the Tertiary formation is described in several available geological maps. The Ostend series [5] describes the base of the Quaternary (or top of the Tertiary) being at a level higher than -50 m below average sea level. The eastern part of the Borssele wind farm zone is covered in more detail in the Rabsbank [7] and Buitenbanken [6] maps. The coverage of these maps is illustrated in Figure 4. Information of the western part of the area is not available in geological maps. The geological report [4] of the Belgium area does however cover part of the Dutch side. With this information, the border zone can be covered as well. The coverage of this information in the project area is presented in Figure 5. The legend of the contours in the figure is unfortunately of low quality due to the resolution of the original document. With detailed analysis it was possible to distinguish between the different contour levels. There remains however an area in the middle for which detailed geological map information is lacking, leading to a relative broad bandwidth in the level of the top of the Tertiary. All the available information is summarized in the map in Appendix 1. On this map can be seen that the contours are governed by the different information sources, which leads to relative sharp transitions for the different levels. This is unfortunately a consequence of the available data.

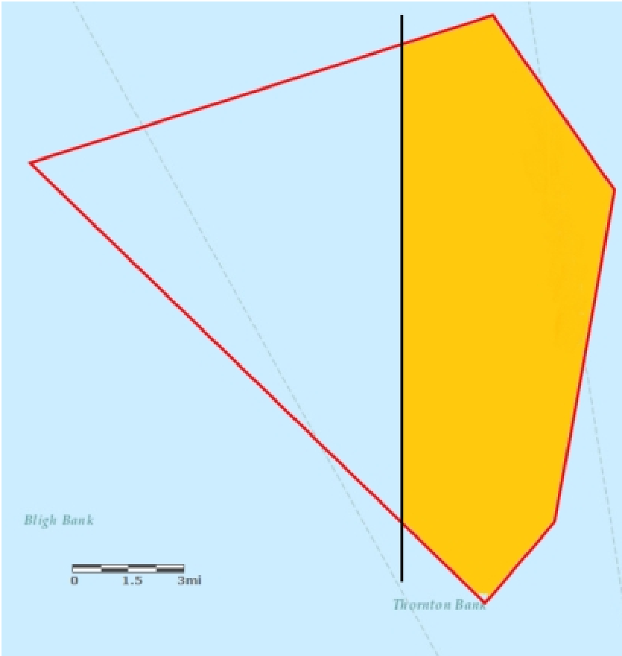


Figure 4: In yellow the area covered by Buitenbanken and Rabsbank maps

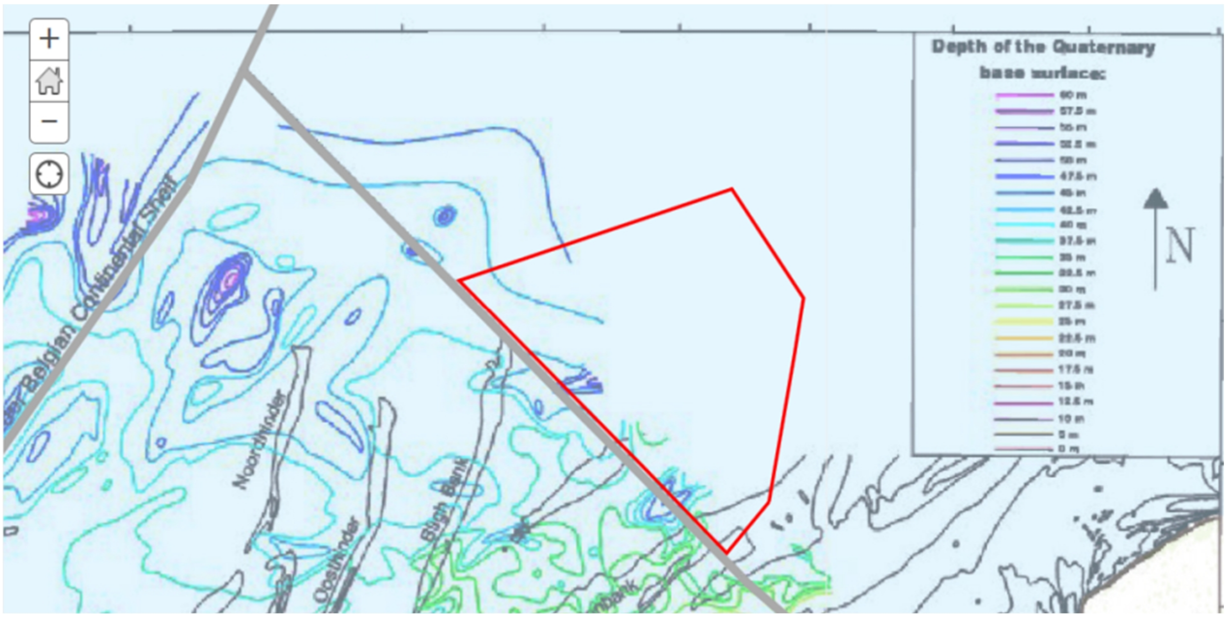


Figure 5: Top of the Tertiary from the Belgium geological report [4] falls within the project area

The distribution of the different Tertiary formations that sub-outcrop at the base of the Quaternary is presented in the Ostend map, which shows that the Tongeren and Dongen formations are of importance in the project area. The Tongeren formation overlies the Dongen formation.

Rupel Formation (Late Oligocene)
The main part of the formation consists of heavy, marine dark brown-grey clays (Boom clay), with a varying number of sand layers.

Tongeren Formation (Lower Oligocene)
Consists of shallow marine, epi-continental and continental sediments, predominantly clay and sand from the late Eocene and early Oligocene epochs (between 37 and 30 million years old). The lower part of the formation consists of sands. The upper part consists of clays with thin intercalations of sands and lignites. The sands were deposited in an shallow-marine environment, the clays in a lagoonal to coastal-plain environment.

Dongen Formation (Eocene)
Marine Formation of dark-grey, green and brown, slightly calcareous clays, with an intercalated, glauconitic sand to sandstone body, which to a marly unit at the base of the deposit.

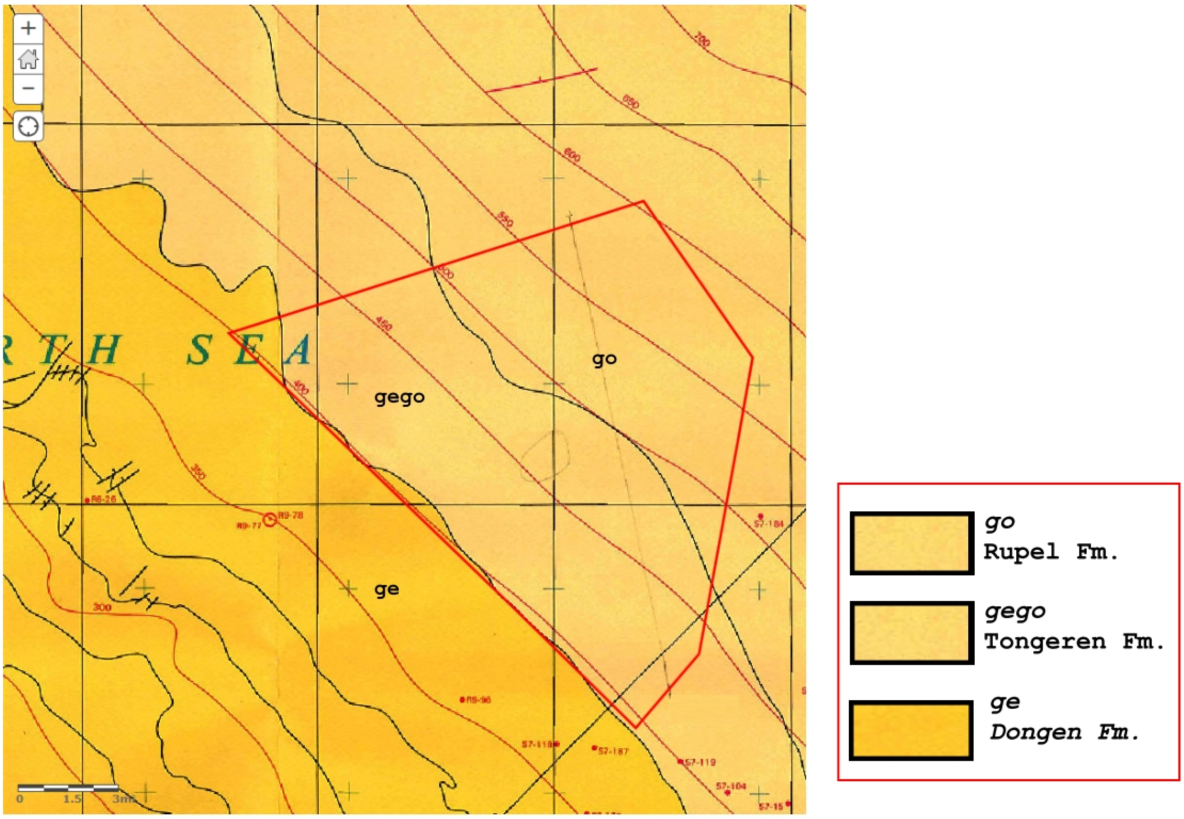


Figure 6: Sub-outcrop of the Rupel, Tongeren and Dongen formations at the top of the Tertiary [5].

3.3 Pleistocene formation

The level of the top of the Pleistocene formation is described in several available geological maps. The Ostend series [5] describes the top of the Pleistocene in the total project area. The eastern part of the Borssele wind farm zone is covered in more detail in the Rabsbank [7] and Buitenbanken [6] maps. The contours of both maps fits well where both maps have a shared boundary. The coverage of these maps is illustrated in Figure 4. Information of the western part of the area is based on the Ostend map. The Ostend map also indicates that in the south western part no Pleistocene deposits are present. All the available information is summarized in the map in Appendix 1. On this map can be seen that the contours are governed by the different information sources, which leads to relative sharp transitions for the different levels. This is unfortunately a consequence of the available data.

Pleistocene

The Pleistocene period is characterized by the succession of numerous glacial and interglacial stages. During interglacial stages, large budgets of sediments were carried out into the southern North Sea Basin by large rivers such as the Thames, Meuse and the Rhine. The formations that, according to the available data occur in the project area are the Kreftenheye and Eemien formations. The Pleistocene sediments seem to consist mainly of sands, essentially medium to very coarse. The Eemian deposits (Eem Formation) consist predominantly of medium-grained sand locally with clay laminae and some gravel.

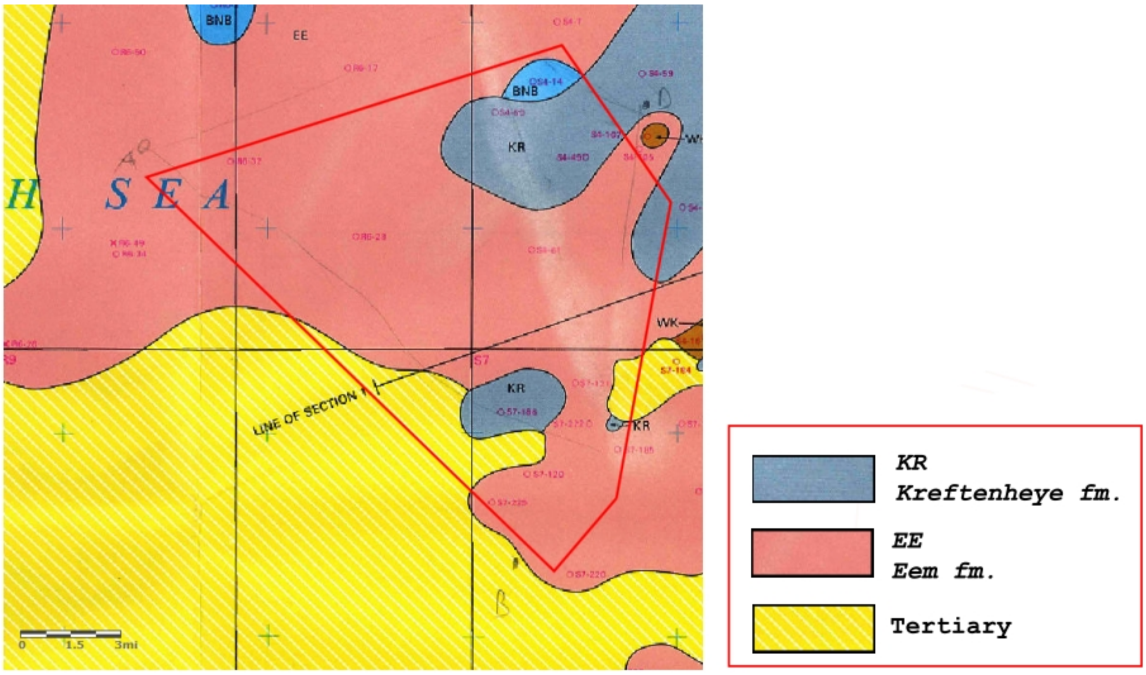


Figure 7: Sub-outcrop of Kreftenheye and Eemien formations at the top of the Pleistocene [5].

Kreftenheye Formation (Medium/late Pleistocene to Early Holocene)

This Formation is present in the north-east of the area and consists mainly of medium to very coarse grained sand (0,180 – 0,500 mm), which has been deposited by the rivers Rhine and Meuse. The thickness of the formation varies from <1 to 14m. The sand is locally gravelly and can contain shells and wood remains. It also can contain reworked Eemian molluscs. Near the northern margin of the area thin layers of volcanic tuff occur in the sand these having been deposited from late Weichselian volcanoes active in the Eifel area.

Eem Formation (Pleistocene)
The formation consists of marine medium grained sand, locally with clay laminae and some gravel. The unit is typically around 10-15 m thick. In the glacial basins, thickness can be as much as 70 m.

3.4 Holocene Formation

The thickness and distribution of the Holocene deposits is described on the geological maps in such low resolution that it is not included as a separately prepared map in the report. Obviously the sea bed (bathymetry) is the top of the Holocene deposits. The difference between the bathymetry map (see Appendix 1) and the top of the Pleistocene gives the best indication of the thickness of the Holocene. The Bligh Bank formation is the youngest Holocene formation and makes up the sand banks and dunes. The Ostend map [5] does describe the thickness of the Holocene deposits underlying the Bligh Bank formation in contour steps of 0-5 m thickness and 5 – 20 m thickness. The Rabsbank and Buitenbanken map gives a more detailed map of the thickness of the Holocene deposits (Figure 8). At the boundary of both maps there is however a discrepancy of the contour lines. This high uncertainty in thickness and quality of data has lead to the conclusion that compiling a map of the top of the Holocene deposits is not feasible due to a lack of sufficient and consistent data.

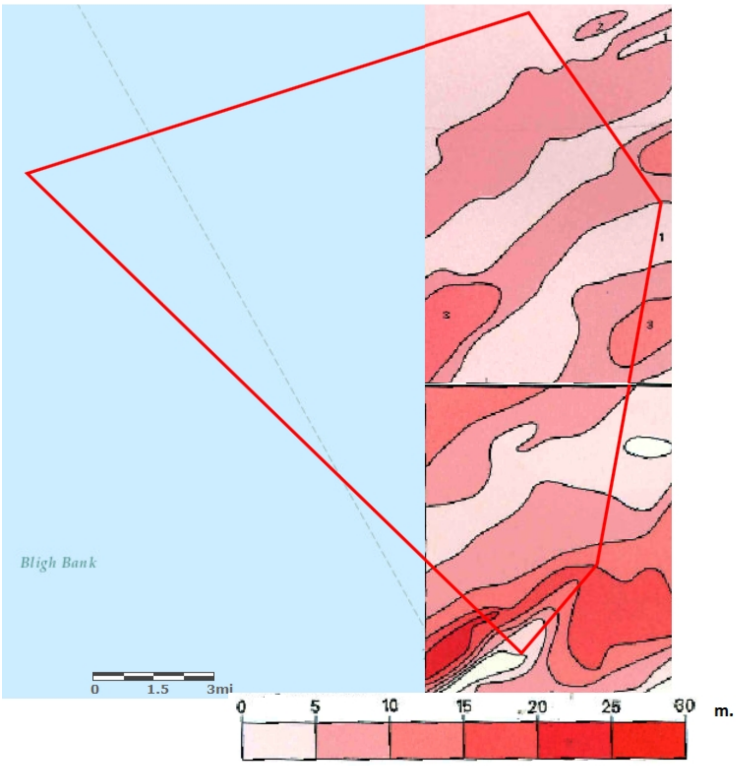


Figure 8: Thickness of Holocene deposits [6], [7]

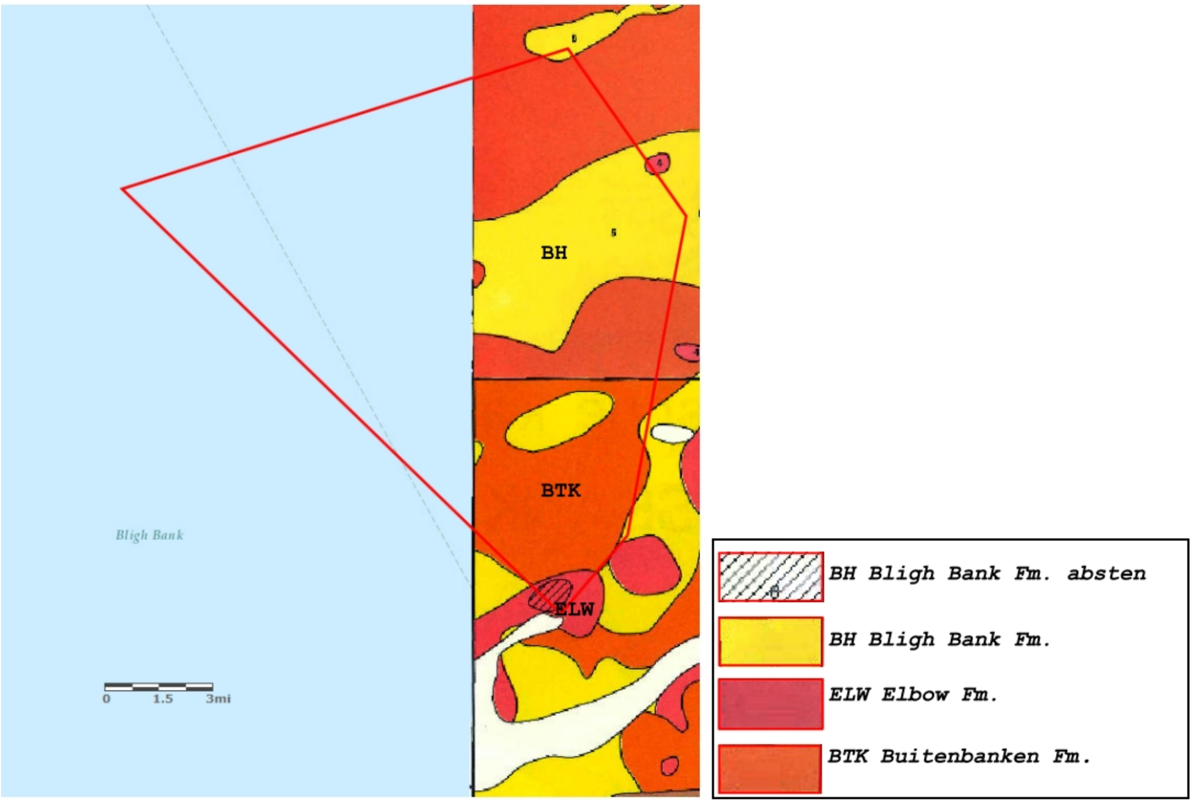


Figure 9: Holocene formations (under Bligh Bank formation) based on [6], [7]

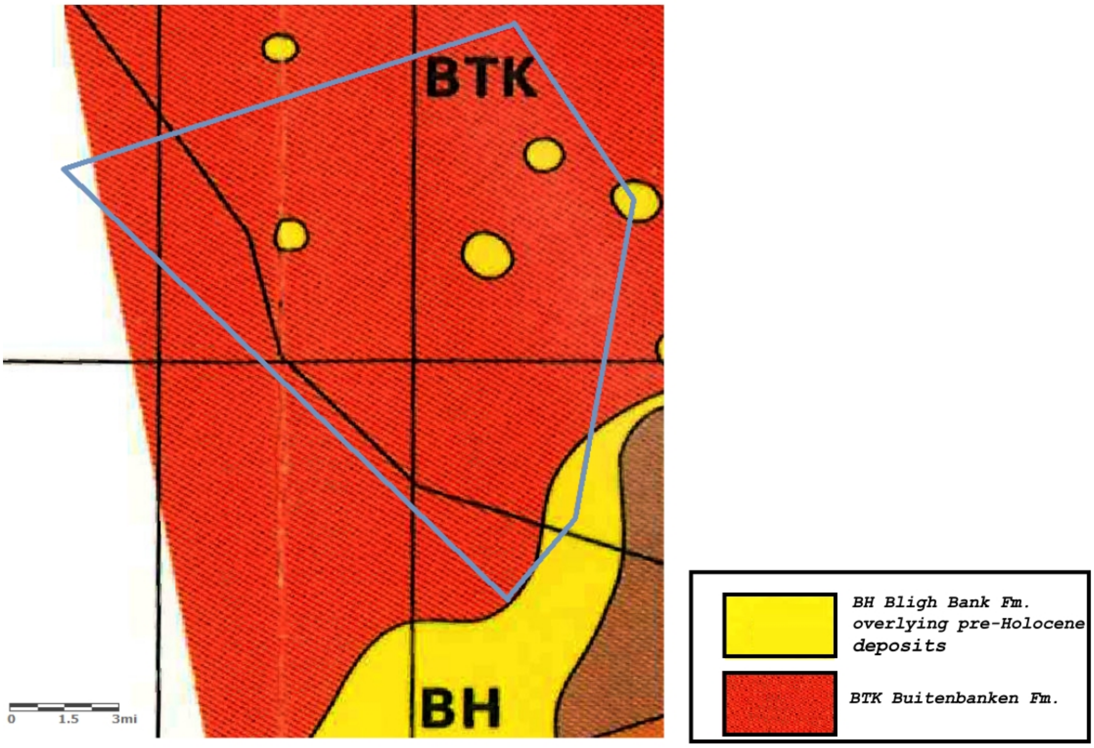


Figure 10: Holocene formations (under Bligh Bank formation) based on [5]

The following formations are present within the Holocene formation (see Figure 9 and Figure 10):

Elbow Formation (Holocene)
This formation consists of Holocene tidal flat and other tidal delta deposits and is present mainly as an erosional remnant in the south-east part of the Dutch sector. The Formation mainly consists of clay or fine silty sand with clay laminae. Early Holocene peat layers are present in places at the base and they are overlain locally by Early Holocene freshwater or brackish to brackish-marine clays. The thickness varies from <1 to >14metres.

Buitenbanken Formation (Holocene)
The Buitenbanken Formation is often difficult to distinguish from the underlying Pleistocene Kreftenheye or Eem Formations. This can only be done on the basis of the macro fauna although locally it may be separated from the Pleistocene formations by a seismic reflector. The Formation is mainly distinguished from the overlying Bligh Bank Formation in cores by greater gravel content, lesser shell content and a different mollusc fauna. The reflector at the base of the sand waves does not always represent the base of the Bligh Bank Formation. The formation consists of yellow-brown, fine and medium (180-500 microns) sand; in the west and north-west however it is gravelly (indicative of a Rhine, Meuse and southern origin in the west and north, and River Scheldt and local origin in the south-east). In the south-east very small patches of very fine to fine sand occur. The sand contains a derived mollusc fauna with Late Pleistocene marine and freshwater species and Early Pleistocene marine species. The thickness ranges from <1 to >7 meters in the north and west; in the south-east, however, it is mainly <1 meter.

Bligh Bank Formation (Holocene)
Mainly yellowish-brown, becoming yellowish-grey to the west, medium (250-500microns) sand (Figure 11). The data in Figure 11 is form the Noordzee Atlas [10] and is confirmed by the different geological maps. This information will have been prepared based on the shallow borings in the Dinoloket [11]. The greatest thickness is present in sand banks. Inshore of the banks the formation is very thin and locally may be absent; in places clay laminae and fine gravel are present. The mollusc fauna is characterised by the presence of Angulus pygmaeus. The thickness of the formation varies from <1 to >16 meters.

Figure 11: Sand grain size of Bligh Bank Formation [10]

3.5 Geomorphology

Although the report is primarily a geological desk study, geomorphology data is included in the report. The geomorphological data presented is taken from different sources. This collection should not be considered a thorough geomorphological study. This will require further research.

The bathymetry gives an immediate impression of the sand wave and banks that are present in the area. The Noordzee atlas [10] also provides geomorphological data, see Figure 12. This data is combined with the bathymetry in the map in Appendix 1.

The Ostend geological map also provides geomorphological data with a relative low resolution, see Figure 13. The morphodynamics of the North Sea are described in detail in [12]. A vertical nodal dynamics chart is given in Figure 14. This figure shows that part of the Borssele wind farm zone is not covered.

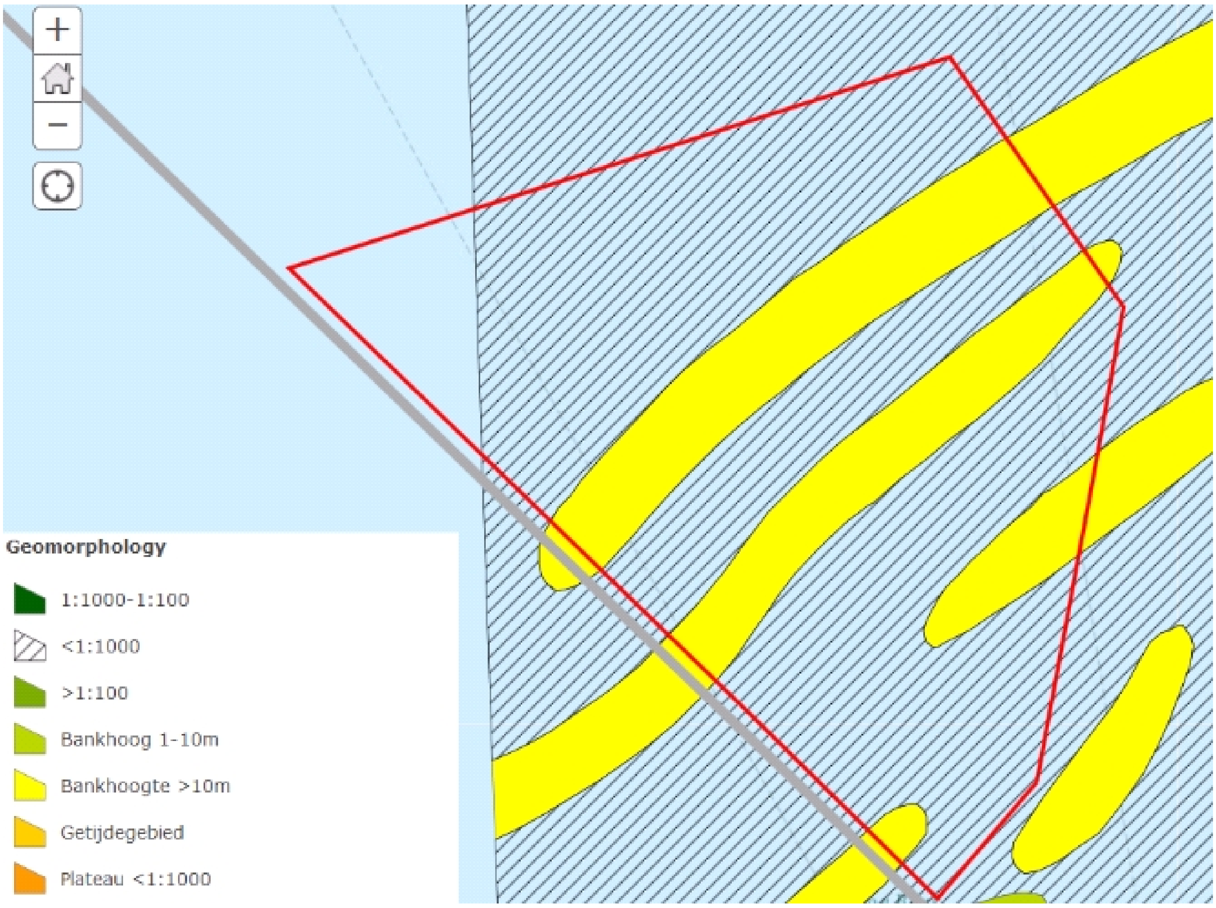


Figure 12: Geomorphology information from the Noordzee Atlas [10]

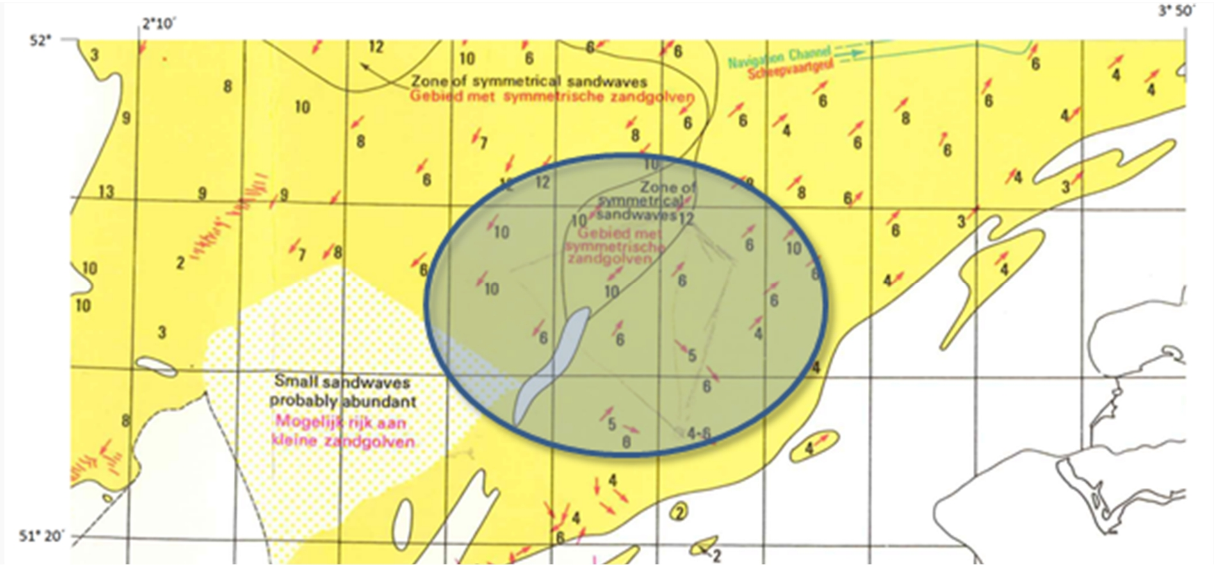


Figure 13: Distribution of sandbanks according to Ostend geological map [5]

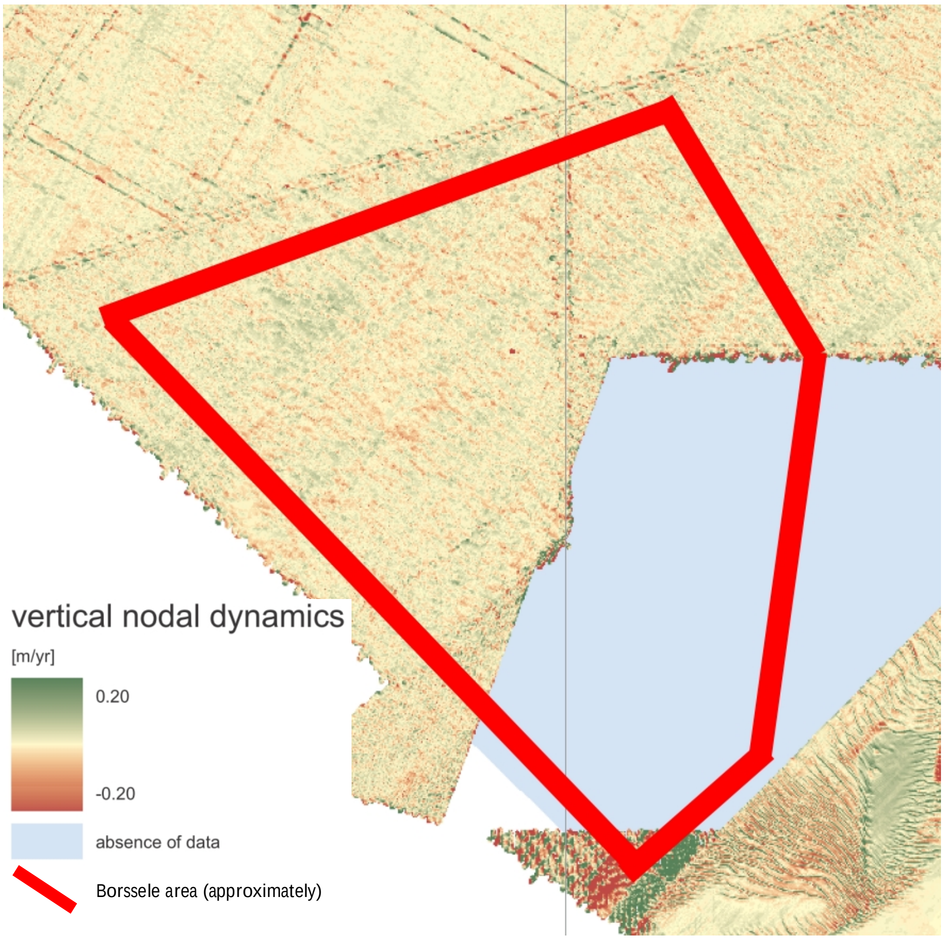


Figure 14: Vertical Nodal dynamics [12]

4 Other ground related aspect

Other ground related objects are collected and presented in the maps in Appendix 1. The pipeline, cable and wrecks data is collected from [10].

The Borssele wind farm zone is crossed for a total of 6 pipelines and cables that are in use (see Figure 15):

- 2 pipelines with direction SW-NE;
- 3 phone cables with direction SW-NE of which one is considered to be recently abandoned (information gathered by the client and based on discussions with KPN);
- 1 phone cables with direction NW-SE.

On this map also abandoned cables and pipelines are shown. It is unclear though whether or not the line infrastructure is buried, let alone at what depth.

Three wrecks present in the Borssele wind farm zone are 3, and their approximate coordinate are (see Figure 15), no information is available on the type of wreck:

1. Longitude: 2.949888, latitude: 51.654982;
2. Longitude: 3.011686, latitude: 51.703306;
3. Longitude: 3.027822, latitude: 51.757955.

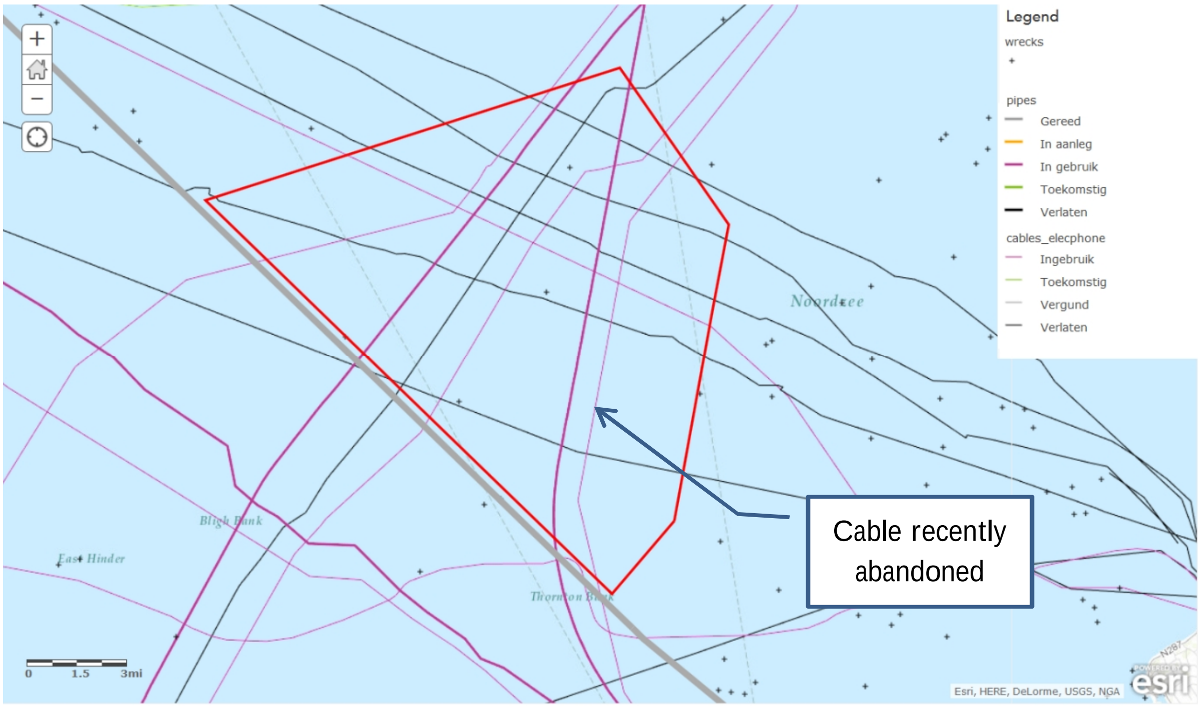


Figure 15: Wrecks, pipes and cables in the Borssele wind farm zone [10]

The geological information and other information sources do not give indications of the presence of boulders or other large geological obstacles. The available maps do not give indications for mud gullies. This, however does not mean that these will not be present in the project area.

No information could be acquired on bombs or other WWII ammunition dump sites.

5 Evaluation of available foundation types for WTGs

5.1 Introduction

This chapter contains an overview of common wind farm structural elements and its limitations considering specific soil conditions. Section 5.2 contains a description of the various wind farm elements, where after sections 5.3 and 5.4 detail the various options available with respect to installation or in-place behaviour into or onto the sea bed of the foundations available.

Before commencement it is worth noting that within geotechnical engineering, a structural element transmitting loads into the soil is addressed as being a foundation, whereas within the offshore renewables industry, a foundation is considered being the whole structure below the wind turbine support mast. For the sake of clarity, the former is considered describing a foundation, whereas the structure between the soil and the mast will be addressed as substructure.

5.2 Wind farm typical elements

A typical wind farm does not only contain wind turbines, but a variety of structures, each with its own properties. The following elements are identified and briefly described:

- Wind turbines
- Met mast
- Transformer station
- In-field cables
- Export cables

In addition, depending on the size and distance from shore of the development, converter stations can be identified. As converter stations basically consist of very large transformer stations and actually find themselves in the range of large O&G facilities, this element is not further discussed.

Wind turbines

Wind turbines are the core component within a wind farm. The wind turbine consist of a nacelle with rotor blades, a support structure and a foundation. The support structure is commonly subdivided in a tower, a transition piece (connection between tower and substructure) and a substructure. This is further clarified in Figure 16. It must be noted that this subdivision is mandatory nor necessary, but is normally dictated by the contractual parties (nacelle supplier insists on delivering the tower as well) and creates the necessity of an (understood to be) relatively expensive transition piece.

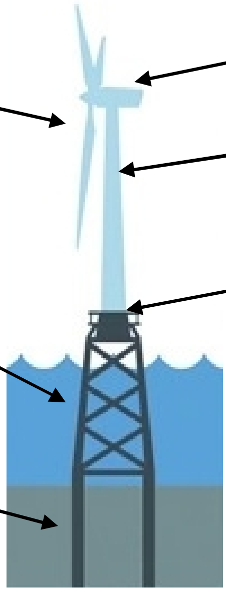


Figure 16: Typical wind turbine elements

Since the number of wind turbines within a wind farm is high, repeatability is desirable to allow for standardization and optimization of fabrication and installation. Furthermore, as the environmental conditions are more or less comparable, adopting similar structures within a wind farm seems logical.

Met mast
In order to optimize the energy output from a wind farm, detailed statistical information on wind direction, speed and altitude is desirable. In order to collect this information, a met mast can be installed prior to the development of the wind farm itself, which is a slender structure containing measurement equipment. During a period of normally one or two years this structure measures the wind characteristics as a minimum, which can be used in optimizing nacelle height, blade shape and energy generation elements. As the met mast becomes redundant after fabrication of the wind farm, the met mast is normally removed. Optionally its substructure can be used to support a wind turbine, but this would increase the size of the substructure, hence cost, at a point in time where financial possibilities are small.

Transformer station
In order to deliver a constant flow of electricity to shore, all electricity generated by the wind turbines is collected in one point and transformed to the predetermined voltage and frequency. The transformer station size can be compared with a medium-sized O&G facilities, which is why its structure is mostly found equivalent. Transformer stations can be either manned or unmanned, the former allowing day-to-day wind farm operation management to be performed on site, the latter not requiring permanent lodging facilities but travel up and down when needed; this obviously can only be done when the distance to shore is reasonable. It needs to be understood though that even unmanned structures are visited by maintenance crew very regularly, even daily, which imply availability of sufficient safety equipment including full lodging facilities.

In-field cable
In order to transport the generated power from the turbine to the transformer station, cables are installed in between. To avoid damage by scratching anchors or fish nets, cables are to be buried

below the sea bed, which requires thorough understanding of the shallow sea bed conditions. However, since any geotechnical site investigation normally concentrates on the structure locations, it is highly recommended performing a detailed geophysical survey at the cable routes, potentially extended with shallow borings or CPTs.

Export cables
The electricity is transported from the transformer station to shore through the export cables. The same applies as mentioned for the in-field cables, but special care should now also be given to the shore landing point of the cable; not seldom (in The Netherlands) a water barrier is to be crossed, which implies special measures assuring the barrier remains intact at all times.

5.3 Foundation types

Wind turbines, met masts and transformer stations need to be founded on or into the sea bed. Roughly two types of foundations are recognized to date, being:

1. Pile foundations, who penetrate to substantial depth into the soil
2. Shallow foundations, who do not penetrate or penetrate only to limited depth into the soil

Furthermore, shallow foundations (item 2 above) can be subdivided into:

a. Slab foundations (with or without skirts), positioned on top of the sea bed without mechanical aid affecting the soil
b. Suction caisson foundations, installed in the top few metres of soil with mechanical aid affecting the soil

Above options are further discussed below.

Pile foundations
Piles are long, slender, normally steel pipes which penetrate deep, say more than 20 metres, into the soil. Installation is normally done by a hammer, which drives the piles down with repetitive blows. During driving axial and shaft resistance of the soil is exceeded temporarily, resulting in the pile penetrating into the soil. Recent novel developments comprise drilling techniques for offshore pile installation as well as pile vibration.

Vibrated piles are installed by means of a vibrator rather than a hammer. The vibration creates excess pore pressures (in sand only) at the pile tip and along the shaft, as such reducing the soil resistance and allowing the pile to penetrate down. For drilled piles different concepts are currently being developed. Two are known to the author and are therefore further described below.

The drilled pile as designed by Ballast Nedam, can be compared with drilling a tunnel, but vertical rather than horizontal; the boring machine drills down, and concrete rings are inserted at the top at the same time. After installation the boring machine is retrieved, and the rings remain. This technique is still in the conceptual phase, and aims at installing large diameter monopiles of relatively cheap material, ie. concrete rather than steel.

The MIDOS pile technique is developed by Bauer. During drilling down, the soil is mixed in place with cement whilst inserting a steel casing. After installation the drilling tool is retrieved, leaving the cemented casing in place. First test results seem to indicate that axial resistance achieved is higher than for driven steel pipe piles, considered due to the higher cement – soil adhesion when compared with the steel – soil adhesion. Moreover, as the steel casing does not suffer from installation fatigue, under equal circumstances the wall thickness is smaller than for a driven pile. Full scale tests are currently ongoing, hence final results are not yet available.

In harder soils like rock, to aid in achieving sufficient penetration depth, predrilling or drilling during penetration will be required inevitably. Vibrating or drilling a pile, especially in sandy soil conditions, seems promising in terms of installation speed and noise emission. It needs to be understood though that current offshore pile design methods for the determination of axial (=vertical) resistance are calibrated against driven test piles only, which is why the axial resistance of both drilled and vibrated piles will need to be treated with caution.

Two main types of pile foundations exist: monopiles or multiple pile foundation; the former results in vertical compression and overturning moment load transfer from the substructure into the sea bed, the latter in vertical compression and tension load transfer. This is further detailed in Figure 17 below, wherein the green arrows depict the environmental loading (consisting of wind, waves and current) and the red arrows show the predominant resulting load transfer on the soil.

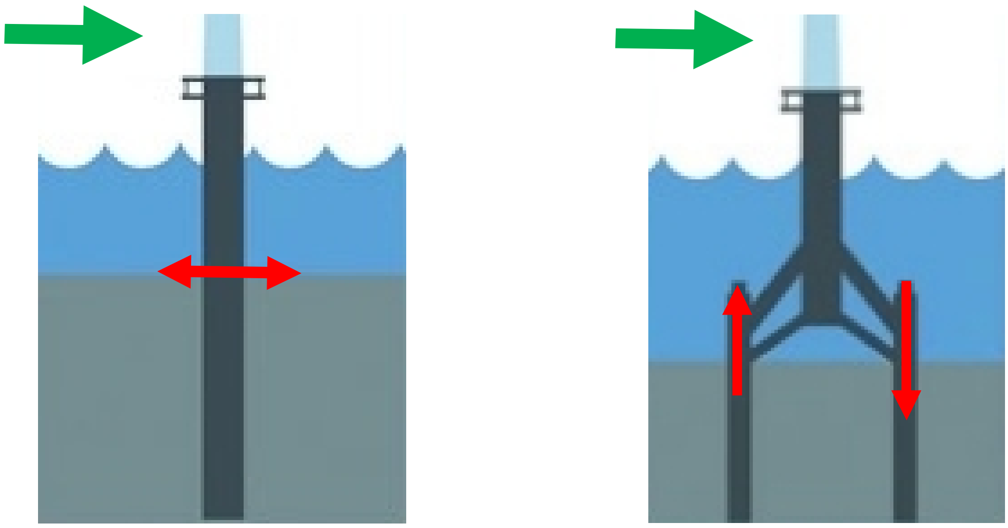


Figure 17: load transfer on monopile and multi-pile foundation

Monopile foundations are a novel foundation type when compared with multi-pile footings, the former of which do exist since 1994 (Lely near shore wind farm, IJsselmeer) but have been adopted in offshore conditions since 2003 only (Arklow Bank wind farm, Irish Sea) in 25m water depth. Ever since, monopiles have been favoured above other foundation types because of their anticipated low fabrication (one single tube) and installation (one pile driving operation) cost. For the predominant lateral load from the pile on the soil, in-place design is undertaken whilst making use of the API [16] PY curves method, which implies representation of the soil response with horizontal, fully uncoupled springs. It needs to be understood though that this method has been established some 40 years ago for horizontal (O&G) jacket pile response for design storm conditions (maximum waves) on small diameter (maximum 36'') piles, and therefore may not be suited for larger diameters. For jackets, because of their stiff behavior, horizontal response is of secondary importance. Moreover, the predominant design condition for monopile foundations consist of smaller fatigue waves, larger in number but smaller in size than the design storm condition governing (O&G) jacket pile design. Whether this PY curves method remains applicable for large diameter piles loaded by the more frequent but smaller fatigue waves is uncertain, but recent measurements on an operational wind turbine indicate that monopile foundations' response is (much) stiffer than anticipated beforehand. With the eigenfrequency design window between 1P (rotor single rotation) and 3P (blade passing the mast) this is a concern and therefore will need to be addressed before a foundation choice is made. Still, but to be regarded as a contingency only, the turbine rotational speed may be reduced, to artificially modify the 1P and 3P frequencies, but since this will result in less energy this option is not favoured. Note that this topic is currently the subject of a large joint industry project (PISA), results of which are unfortunately only expected in a few years' time.

Multiple pile foundations are used since the start of the offshore O&G industry, where a number of piles support offshore processing facilities. Within the wind industry, 3 and 4 pile lattice jackets are adopted, as well as tripods. Alternatives like 6-legged jackets are considered as well, but are not yet adopted in practice. Because lattice jackets and tripods are quite stiff, fatigue waves do not dominate design, which is why design storm conditions are much more relevant.

In-place design is performed in accordance with API [16] main text or appendix methods, the former of which is proven to be over-conservative when compared with the latter, which are found to be more appropriate in very dense, over-consolidated soils found in the North Sea. Nevertheless, where O&G jackets are very heavy and basically load piles in compression only, relatively light-weight wind turbines exercise alternating compression and tension loads. This results in a reduced capacity, which will need to be duly considered. Note that this phenomenon is currently well understood and implemented in good geotechnical engineering practice.

Pile foundations can be installed in all sands, ranging from fine to coarse and from loose to very dense, and in all clays, ranging from soft to hard. Installation in weak rock, like chalk, can still be done whilst driving, but for more competent rock drilling may be needed in addition. Pile drilling is therefore suited for all soil types. Pile vibration is more suited for sands than for clays, as excess pore pressures in clay do not reduce soil resistance. The drilled Monopiles are very susceptible to scour; when scour develops, lateral resistance decreases, which is why scour protection by means of rock dumping, (artificial sea weed) mat installation or gravel bags may be required. Multiple pile foundations are much less sensitive to scour; as mentioned before, lateral resistance is of only secondary importance, and the majority of the axial resistance follows from deeper soil layers anyway. Therefore, for multiple pile footings, scour protection can be omitted.

Slab foundations

A slab foundation consists of a flat base plate, which is positioned on top of the sea bed. Depending on the soil conditions and morphology, but generally required, the sea bed will need to be prepared prior to installation by gravel or rock dump, potentially preceded with top soil removal (dredging). Slab foundation design is considered proven practice and slab foundations have been used in the O&G industry for decades. Worth noting is the large weight required to resist the predominant overturning moment load, necessary because the slab - soil interface cannot be loaded in tension. This is why this foundation type in many occasions is also referred to as Gravity Base Foundation, or GBS. The large affects the fabrication and installation cost, which is why this foundation type has not been adopted at large numbers successfully thus far. In order to reduce the risk of scour in (especially) sandy soil conditions, and in order to make use of more competent soils further down below the sea bed, concrete or steel vertical circumferential sheets may be incorporated in the base plate. These skirts enhance capacity but may create difficulty during transport.

Slab foundations can be installed onto sandy soils, but it must be noted that fine or loose sand may require soil improvement (removal of less competent top layer) beforehand. Soft clay is normally not possible because of possible uneven settlement as a result of mono-directional loading, but stiff clay normally do not pose a problem. Rocky sea beds may require an adaptable base plate by means of eg. grout insertion between the base plate and the sea bed, for which controlled concepts exist.

Suction caisson foundations
Suction caisson foundations exist since the early 80's of the 20th century, and are frequently and successfully used in the O&G industry to serve as an anchoring point or substructure / platform foundation. Suction caissons, also referred to as suction piles or bucket foundations, are an intermediate solution, aiming at combining the best between piles and slab foundations. The name refers to both the installation procedure and the shape; suction caissons can be seen as large buckets, which are sucked into the soil upside-down by means of the creation of an active water pressure difference (with water pumps) between inside and out. After installation the pumps are stopped, hence the pressure difference is released, and a bucket inside the soil remains. For in-place design, because of the deeper penetration, benefit is found in the bearing capacity of deeper, more competent soil when compared with slab foundations. At the same time installation is swift and silent, other than driven piles, as only a water pump is required. As an added benefit retrieval after operational life time is easily done by reverting the flow direction of the re-installed pump, ie. By applying pressure rather than suction. Despite their apparent history, suction caissons are only seldom favoured, mainly because no straight-forward, standardized design approach exists. Furthermore, suction caissons perform poorly in withstanding sustained tension loads, relevant for light-weight turbine foundations as indicated previously, and since they are not only steel pipes but because of their large diameter require a decent load transfer structure on top, fabrication may be more costly. Nevertheless, two years ago the Global Tech One transformer station has been successfully installed within predetermined design limits, being the first-ever suction caissons in Germany as well as the first-ever suction caissons in offshore wind. Both installation and design procedures have been developed fit-for-purpose and found appropriate for use. Suction caisson sizes adopted are 11m diameter and 8m penetration (4 of). Since then, several monobucket foundations (ref section 5.4) have been successfully installed as well, proving the technique is gaining confidence, with a wind turbine lattice structure on suction caissons to follow later 2014.

Suction caisson foundations can be installed in all sands, ranging from fine to coarse and from loose to very dense, and in all clays, ranging from soft to hard. Coarse gravel bands may result in early installation failure though, and installation in rock is not possible. Depending on the soil conditions, suction caissons have large diameter and shallow embedment or smaller diameter and larger penetration. Layered soils, especially clay over sand, will need to be duly considered, but design procedures have been developed to cover inhomogeneity. As with slab foundations but being less sensitive, since suction caissons depend on the top soil layer, scour protection may be needed, depending on the soil conditions being susceptible to scour.

5.4 Substructure types

The foundation types discussed in section 5.3 may serve as a foundation for a variety of substructures, which altogether are indicated as 'foundations' in the offshore wind industry. The section briefly describes the variety of substructures available, including their possible foundations.

Monopiles
As indicated previously, monopiles actually refer to the foundation rather than the substructure concept. Since monopiles are driven (or vibrated) upto the intended penetration depth, secondary components such as boat landings and J-tubes for cables are mounted only afterwards. Therefore, a transition piece has been developed, basically a cylinder which is positioned over the monopile after installation, afterwards connected by means of grout or bolts. This transition piece also serves as the foundation for the tower, and creates a working platform just above maximum wave height. The transition piece, although prepared onshore, is considered an expensive component, which is why eg. London Array wind farm has adopted welding of secondary steel directly to the monopile. It is not

known whether this was an advantage or not. Monopiles by itself are relatively slender, therefore flexible structure, which require much heavier, therefore more costly, tower sections than with other, stiffer concepts like jackets. However, as contractual splits are normally made at the transition piece level, both in design as in fabrication, information on total cost is scarce. Monopiles are considered fit-for-purpose for both small and larger water depths, the latter of which requires XXL monopiles (with diameters well in excess of 7m) to resist the loads applied. Installation of monopiles is quite straight-forward but the weight of XXL monopiles may reach 1000mT or higher, therefore requires considerable lifting capacity at height, for which only a limited number of vessels are available to date. The majority of the installed wind capacity to date is founded on monopiles.

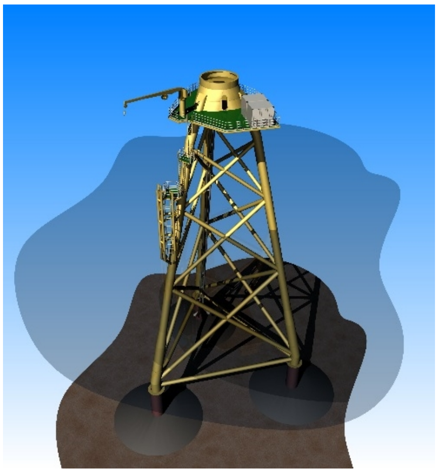
Jackets

Jackets basically are lattice structures, rising from the sea bed upto the transition level; the transition piece is integrated and forms the top of the jacket substructure. Lattice jackets require considerable welding, which is why fabrication, although lighter than large diameter monopiles, is considered to be expensive, but the large stiffness asks for less heavy tower sections, which should be considered in parallel. Jackets are suited for larger water depths, and can be founded on piles, on a slab foundation and on suction caissons.

When piles, the piles will be either pre- or post-installed, which demands 3 (for 3-pile) or 4 (for 4-pile) piling operations. Weight of the piles is (much) less than large diameter monopiles, which enables a large number of installation vessels. The jackets though will need to be installed by a vessel with considerable lifting capacity, which are limited in number, but probably larger than for XXL monopiles currently.

When equipped with either a slab foundation or suction caissons, the foundation itself can be either pre-installed or already connected to the jacket itself. The latter option requires considerable lifting capacity, for which only a limited number of vessels are available, but as an option a self-floating installation can be considered as well. Load-out will then need to be carefully considered though.
Apart from the Beatrice demonstrator project (2 No. jackets, installed in 2007 in the UK North Sea) and several wind farms installed afterwards, the majority of the O&G facilities are supported on lattice jacket structures. Two examples of jackets are provided in Figure 18.

OWECTower Quattropod



KCI three-pile lattice jacket

Figure 18: Examples of lattice jacket structures

Tripods

Tripods consist of 3 stiff triangular structures, with less but larger braces than a jacket. Fabrication requires significant welding and the structure is a bit heavier than a lattice jacket, but the tripod has been successful in Germany as it is adopted to local requirements and already installed on 3 separate wind farms. As for the lattice jacket, a tripod can be founded on piles, a slab foundation and on suction caissons. Similar advantages and disadvantages apply as for the jacket. Some examples are provided in below Figure 19 for clarity.

OWT tripod

Ithaca Energy tripod

Figure 19: Examples of tripod structures

Special shapes

There exists a large number of special concepts which are / have been developed by individual stakeholders. The (considered) most important ones are briefly described hereunder, but by no means this list can be regarded conclusive.

- Tripile: Concept owned by Bard; 3 monopiles, interconnected with complicated and heavy transition piece above the water line, loading regime as for monopile, large overall weight; suited for larger water depths, adopted for Bard offshore wind farm, Germany; suited for same soils as for piles
- Twisted jacket: Concept owned by Keystone; one central pre-installed pile, thereafter jacket stabbed and 3 remaining piles post-piled; pile stabbing under an angle whilst at considerable lifting height may be troublesome; suited for larger water depths, used for met mast as well as for 2 O&G facilities in the Gulf of Mexico; suited for same soils as for piles
- MonoBaseWind: Concept owned by MonoBaseWind BV; self-floating and installing GBS, together with tower and nacelle, suited for larger water depths and larger turbines; no full-scale project yet; suited for same soils as slab foundations
- Monobucket: Concept owned by Universal Foundations; one central large diameter suction caisson with substructure (tube) upto and including transition piece; self-floating possible, otherwise by lift vessel; adopted as met mast substructure for several met masts to date; suited for same soils as for suction caisson foundations

The pictures in Figure 20 below provide visual information on the special shapes mentioned.

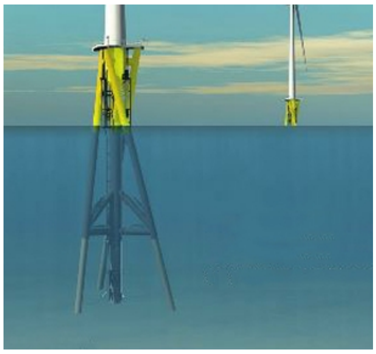
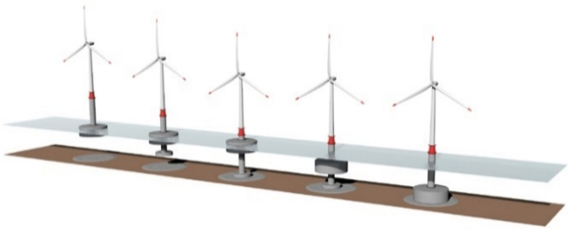
 Bard tripile	 Keystone twisted jacket
 MonoBaseWind GBS	 Universal Foundations Monobucket

Figure 20: Special shapes

6 Analysis

6.1 Introduction

The Dutch Government intends to assign wind farm areas within the Borssele wind farm zone, located in the Dutch North Sea, and wants to learn beforehand whether the soil conditions, as one of the dictating environmental boundary conditions, are suited for wind farm development. For this reason Crux Engineering BV, together with GisSense and ediGEO, has been commissioned to undertake a desk study, aiming at a geotechnical site reconnaissance. After collecting and compiling all soils data and geological data in a GIS model, areas will be identified which are best suited for wind farm development, including recommendations on the elements comprising the wind farm itself.

This chapter contains analysis on feasibility of wind farm structural elements. Section 6.2 contains a brief summary of the key elements identified from the soils data and geological data, whereafter in section 6.3 foundation types are judged feasible or not. Section 6.4 suggests possible substructure types and provides recommendations for design; other wind farm components are considered in section 6.5. Section 6.6 includes an assessment of suitability of the Borssele wind farm zone, discretized for various areas.

6.2 Desk study key results

Data has been collected comprising both man-made and soils information. In general it can be observed that the area soil properties have never attracted much attention in the past, since detailed information is not available. The top of sea bed is found between 10m below sea level where sand banks, oriented South-West to North-East, are present, to up to 35 – 40m below sea level in-between the sand banks. Where the sand banks mainly consist of medium SAND, although with CLAY laminae identified, mobility of the banks or the identified sand waves seems obvious and has been reported previously [12], which will need to be duly considered.

Underlying the sand banks, the remainder of the Holocene deposits have been identified, consisting of three different formations. Very limited information is present on its consistency, but may vary from medium SAND (Bligh Bank) to CLAY and PEAT. The bottom of the Holocene obviously is marked by the top of the Pleistocene. With the global sea bed level declining in the same order of magnitude as the top of Pleistocene from South-East to North-West, its thickness is estimated at 5m (in-between the sand banks) up to 25m at the sand banks' location.

Underneath the Holocene, the Pleistocene deposits are present. The Pleistocene soils mainly consist of dense SANDS, although with some CLAY laminae identified. The Pleistocene is not present in the South-West, and has a thickness of around 5 to 15m in other regions of the Borssele wind farm zone, consisting of medium to very coarse SAND. Below the Pleistocene, Tertiary deposits remain within the depth of interest for foundations, consisting of CLAY with intercalated SAND. The CLAY, due to its age and glacial impact, is assumed to be stiff.

Summarizing, soil characteristics are medium SAND, with CLAY, locally PEAT laminae, up to 5 (in between sand banks) to 25m (at sand banks' location) depth with respect to mud line. Following, 5 to 15m of medium to very coarse SAND is found, followed by calcareous CLAY.

No shipping lanes cross the area and no evidence of considerable vessel activity is observed, but two pipelines cross the area from North to South and one from West to East. Also a large number of both abandoned and life cables are present. It is unclear though whether or not the line infrastructure is buried, let alone at what depth. Three wrecks are identified within the zone, although this information may be incomplete. No (glacial) boulders, mud gullies or gravel banks have been observed in the available information.

6.3 Feasibility of foundation types

On the basis of the available information no clear distinction can be made in terms of soil provinces. It is therefore hard identifying areas of different best-suited foundations. As a result, the section details possibilities and limitations or the various foundation types, duly considering the generic soil layering found.

Pile foundations
The whole Borssele wind farm zone is well suited for pile foundations. Due consideration would need to be given to scour development, as well as sand bank – and sand wave mobility, which may affect the embedment depth of piles, for which monopile foundations are much more susceptible than multiple pile footings like jackets and tripods. Installation by pile driving as well as by drilling following the MIDOS technique or similar seems the best possible solution, wherein it would need to be noted that no approved design methods have yet been developed for the latter.

Both jack-up installation vessels as well as floating vessels may be deployed for installation purposes, wherein it would need to be noted that anchored vessels should refrain from the existing, possibly unburied, existing infrastructure.

Slab foundations
Given the consistency of the sea bed, slab foundations seem less attractive. In order to have a flat sea bed over the larger area of the slab, a considerable foundation area would need to be improved and / or dredged. Moreover, given their high susceptibility to development of scour, a considerable scour protection would need to be installed, in order to remain stable during its design life. Finally, when sea bed mobility is found considerable, slab foundations positioned on top of the mobile sand banks or sand waves may suffer from loss of stability when the surrounding sea bed repositions.

Suction caisson foundations
Soil conditions indicate sufficient bearing capacity for suction caisson foundations. Moreover, no highly variable soils have been found, which could result in an increase of caisson size required. Although less susceptible, scour protection would need to be installed, and as with slab foundations, when sea bed mobility is found considerable, installation on top of the migrating sand banks may result in loss of stability.

Summarizing, below Table 2 indicates a relative qualification considering design, installation and retrieval, wherein it should be noted that perhaps other criteria may dictate a choice for either foundation type.

Table 2: Relative qualification of identified foundation types

	Piles	Slab foundations	Suction caissons
Installation	+/- (straight-forward but noisy)	- (heavy, therefore large vessels)	+ (swift and silent)
In-place behavior	+ (well-documented*)	- (sea bed preparation required)	+ (well-documented)
Scour / sea bed mobility	+ (less sensitive)	- (highly sensitive to both)	+/- (moderately sensitive to both)
Retrieval	- (not industry practice)	+/- (similar to installation)	+ (similar to installation)

* Care should be given to larger diameter monopiles, for which no properly justified design guidance exists to date

6.4 Suggestions and recommendations for substructures

Choice for substructures would need to be determined largely by the choice of turbine (size) and water depth, the latter of which is found ranging from 10 to 40m. For the shallower areas, monopiles may be considered a feasible solution. Lateral resistance will need to be properly considered in design, in relation with both response to the smaller fatigue loads and susceptibility to scour as to larger design loads. The migrating sand waves will put additional pressure on the design effort, as the sea bed level may vary with 5 to 10m over the life time of the structure, compromising lateral resistance of the monopiles highly. It is recommended not to install monopile foundations on the top of migrating sand waves.

Both jackets and tripods are suited as well. When founded on piles, provided that pile driving of the (smaller in diameter but longer) piles remains feasible, because of the shallower dense sands and deeper stiff clays. As these structures are much less sensitive for lateral behavior, installation in an area with migrating sand waves is not impossible. When founded on suction caissons, as mentioned above, areas of large sea bed mobility would need to be avoided.

From the special shapes, all but the Bard tripile seems worth considering, where it would need to be noted that the MonoBaseWind would probably need considerable draft during transport to site, possibly to be mitigated with buoyancy aids.

6.5 Suggestions and recommendations for other wind farm components

The inter-array and export cables would need to be buried to sufficient depth, in order to remain buried at all times. This may become a challenge when migrating sand waves are identified and would need to be crossed. Due consideration would need to be given to the in-situ soil conditions; the installation tool of choice highly depends on, and varies with, soil type: when clay layers are encountered, a different installation strategy (tool) would need to be adopted.
Jack-up vessels operations are considered not posing a problem, but due consideration should be given to the presence of weaker Holocene clay laminae. A preliminary site investigation would need to justify their presence. No evidence of weak infill channels is found (in the available data) which may endanger cable installation or jack-up vessel operation.

6.6 Qualification of the Borssele wind farm zone suitability for wind farm development

It is unclear how sea bed mobility affects the position of the sand banks and smaller sand waves. In Belgium it has been decided to abandon the deeper areas in favour of the sand banks, which suggests the sand banks' availability over a wind farm life time, but this information should be treated with caution. The larger area in the North-West seems relatively homogeneous in depth, with only little sea bed level difference, and the sand waves in this area seem to be symmetrical, which suggests little to no sea bed level rise and fall with time. However, the existing pipeline and cables crossing this area may require a large safe-distance. The area in the lower (South-East) corner seems very shallow, again with little sea bed level difference. However, evidence suggests a higher sea bed mobility, which will need to be carefully considered [12]. Also the existing cable would probably require a safe-distance. The level of detail in the information found and subsequently presented does not allow further discretization of the Borssele wind farm zone in favourable and less favourable areas of interest for wind farm development from a geotechnical perspective.

7 Conclusions and Recommendations

7.1 Conclusions

Based on the studies and analyses performed, the following conclusions are drawn:

- The present desk study considers an area which has proven not of interest in the past; only limited soil data is available and no clear soil provinces can be identified.
- In general the Borssele wind farm zone comprises of Pleistocene and Holocene deposits in the top 10 to 40m, which includes sand banks of about 20m height, underlain by stiff clays.
- Geological maps have been prepared and reported in Appendix 1. These maps have been constructed from different sources and may therefor have apparent inconsistencies. This is however due to the discrepancy in the underlying sources.
- Both pile foundations and suction caisson foundations seem relevant for use in this area, with a substructure consisting of either monopiles or jackets / tripods.
- A large number of pipelines and cables cross the area, in various directions. Burial depth, if any, is unknown at this stage and would need to be thoroughly documented. The line infrastructure may very well dictate wind farm lay-out and (export) cable routing.
- Following the current study, the areas in the North-West as well as the smaller area in the South-East seem homogeneous, but any further discretization of the Borssele wind farm zone is not possible, due to lack of critical information.

The specific objective of this report is defined by the client in [2] and comprises of two main research questions:

1. Are the ground conditions of the Borssele wind farm zone suitable for the construction of offshore wind parks;
2. Can zones be defined within the Borssele wind farm zone where the ground conditions can be classified (for instance: excellent – good – bad – not useable) en can this be quantified in costs.

Research question 1 can be confirmed that the ground conditions in the Borssele wind farm zone are suitable for the construction of offshore wind parks, with the remarks and observations made in this report. For research question 2 it has to be concluded that it is not possible to classify the Borssele wind farm zone in different zones with specific ground conditions due to the lack of geological and geotechnical data.

7.2 Recommendations

Based on the studies and analyses performed the following recommendations are given:

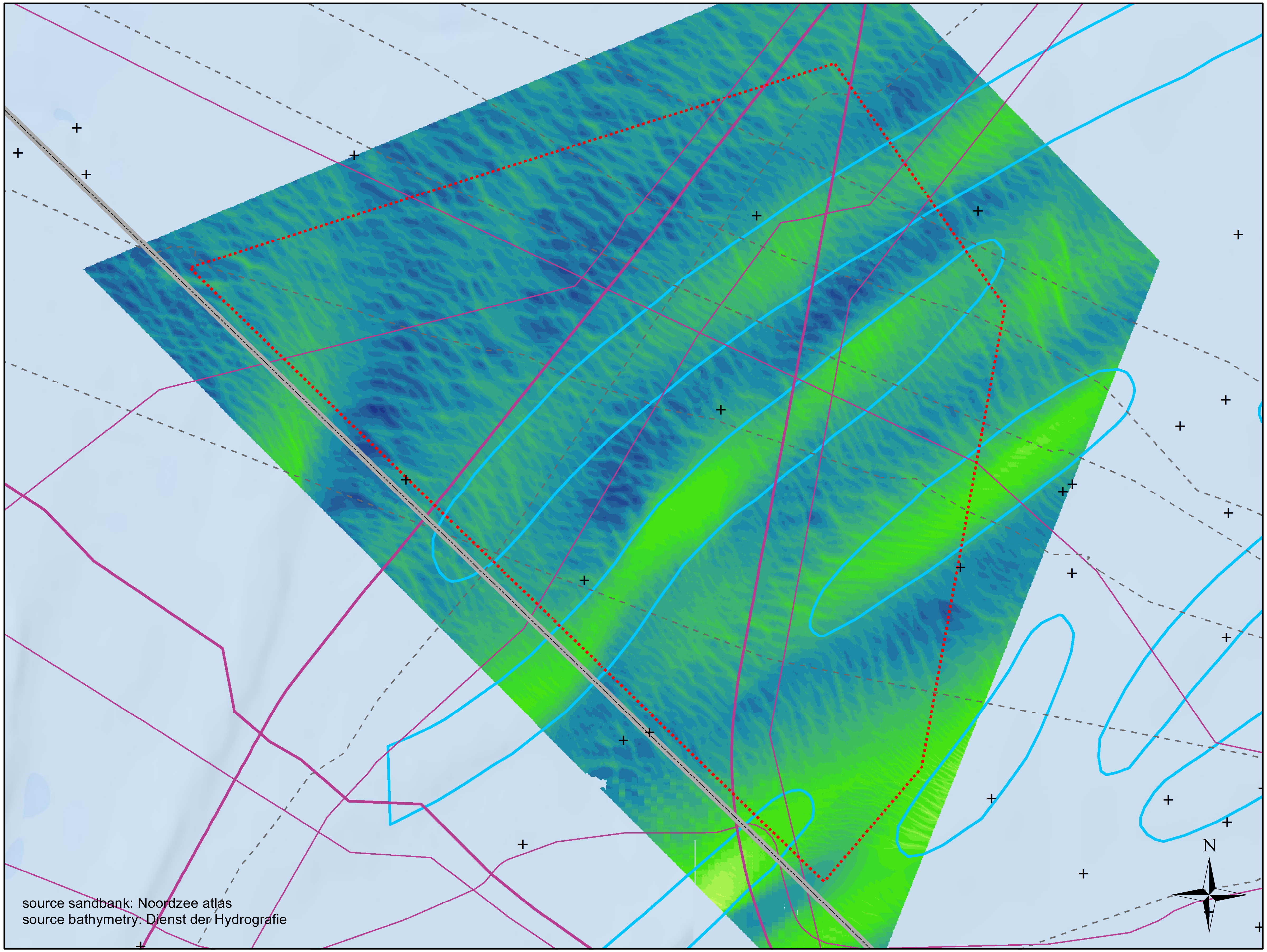
- It is recommended performing a preliminary site investigation, comprising of CPTs covering the whole area, combined with a limited number of boreholes with visual classification as a minimum, accompanied with well-chosen index and strength testing.
- As the Borssele wind farm zone is positioned adjacent to the Belgian wind farm developments. It is recommended to investigate the possibility of sharing of in-situ soil information.

- It is considered highly important to assess mobility of sand waves (banks and ridges) by comparing current bathymetry results with historic data, as the (in) mobility of the sea bed largely dictates feasibility of foundation types and cable trenching, therefore wind farm development.

Appendix 1: Maps

Borssele wind farm zone

Geological Desk Study



Legend

- wrecks
- limit
- project area
- sandbank

Pipes

- In use

Cables

- In use
- Abandoned

Bathymetry

m below average sea level

-44
-42
-40
-38
-36
-34
-32
-30
-28
-26
-24
-22
-20
-16
-14
-12
-10
-8
-6
-4

Scale: 1 : 125000

0 1.25 2.5 5 7.5 10 Kilometers

By:

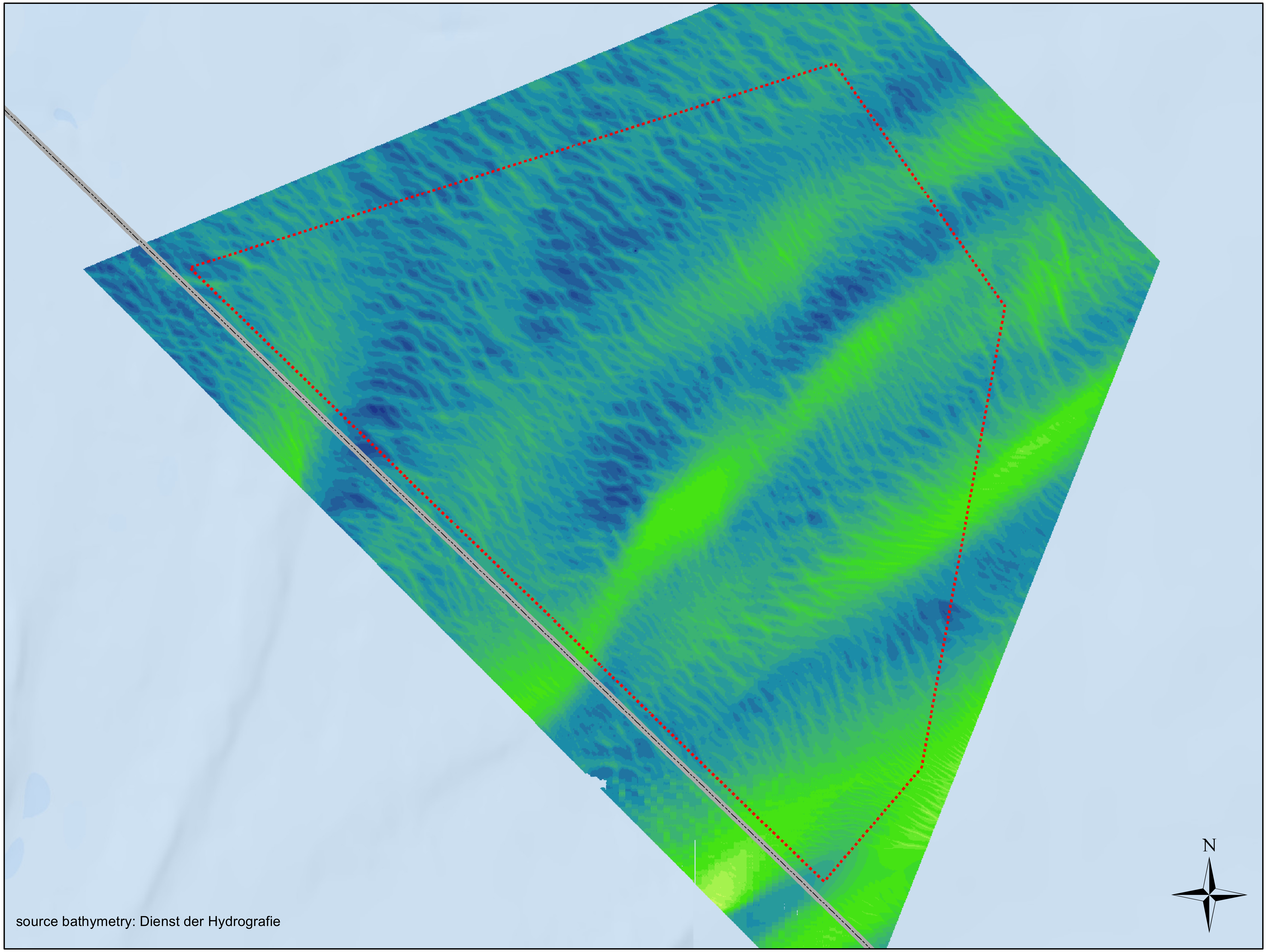
CRUX ediGEO GisSense

Date: 2014-06-29

Coordinate System: ETRS 1989 UTM Zone 31N
Projection: Transverse Mercator
Datum: ETRS 1989
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: 3.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter

Borssele wind farm zone

Geological Desk Study



Legend

Bathymetry

m below mean sea level

- -44
- -42
- -40
- -38
- -36
- -34
- -32
- -30
- -28
- -26
- -24
- -22
- -20
- -16
- -14
- -12
- -10
- -8
- -6
- -4
- limit
- project area

By:

CRUX ediGEO GisSense

Date: 2014-06-29

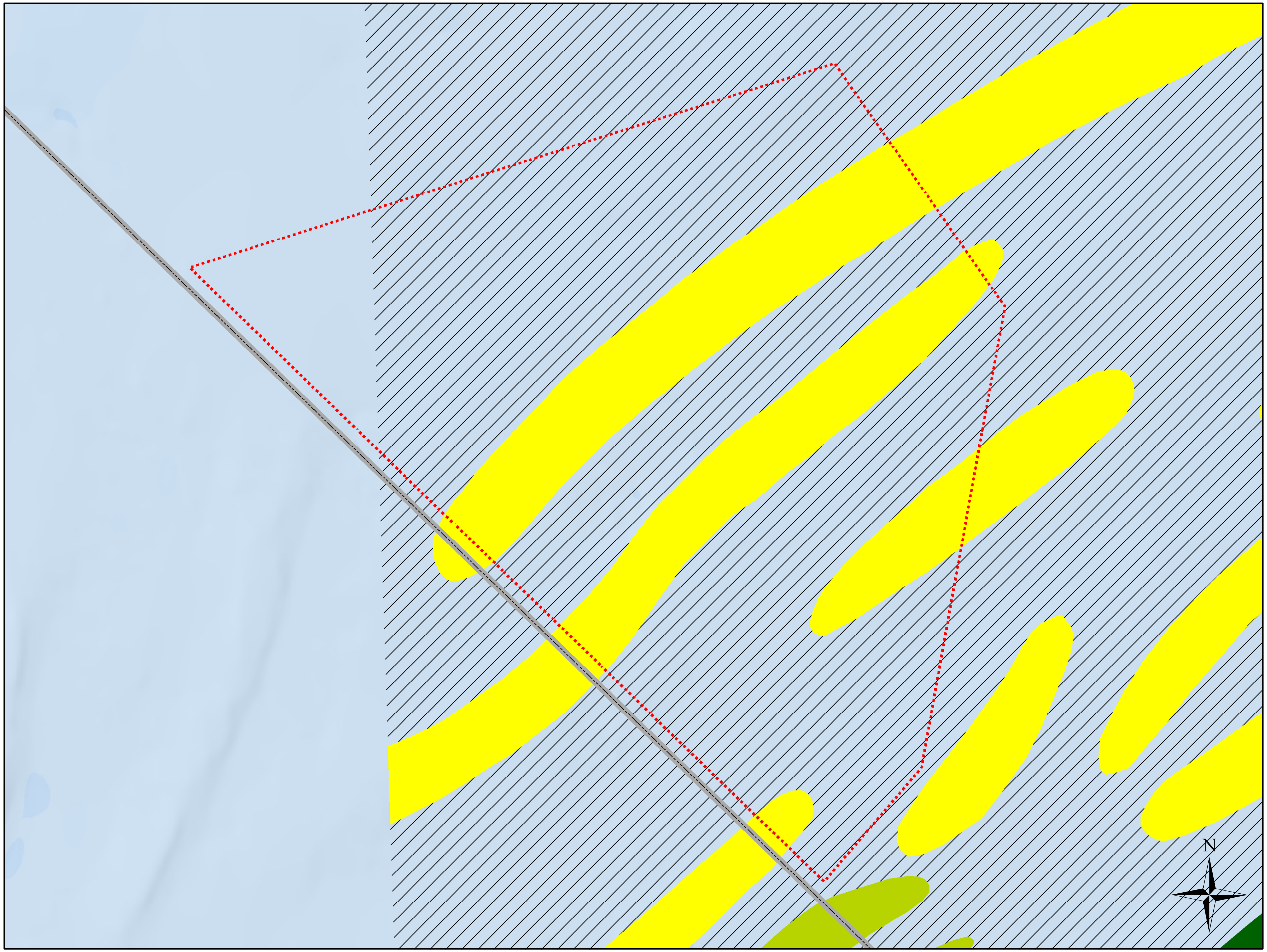
Coordinate System: ETRS 1989 UTM Zone 31N
Projection: Transverse Mercator
Datum: ETRS 1989
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: 3.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter

Scale: 1 : 125000

0 1.25 2.5 5 7.5 10 Kilometers

Borssele wind farm zone

Geological Desk Study



Legend

project area

limit

Geomorphology

1:1000-1:100

<1:1000

>1:100

Bank height 1-10m

Bank height >10m

Tide area

Plateau <1:1000

ebb delta

fairway

N

By:

CRUX

ediGEO

GisSense

Date: 2014-06-29

Coordinate System: ETRS 1989 UTM Zone 31N
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Datum: ETRS 1989
False Easting: 500,000.0000
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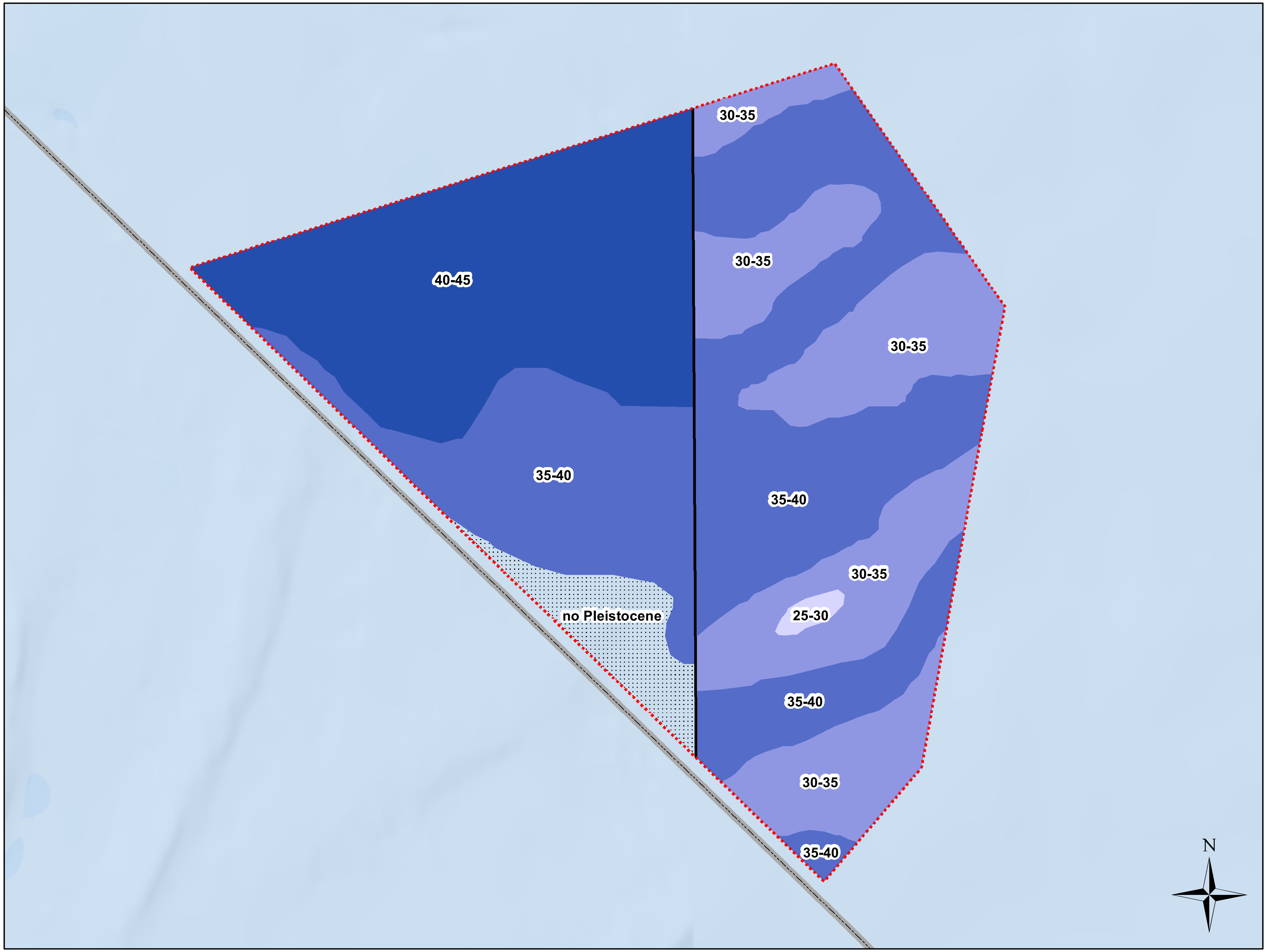
Latitude Of Origin: 0.0000
Units: Meter

Scale: 1 : 125000

0 1.25 2.5 5 7.5 10 Kilometers

Borssele wind farm zone

Geological Desk Study



Legend

- project area
- limit
- border of different information sources

top Pleistocene

m below average sea level

- 25-30
- 30-35
- 35-40
- 40-45
- no Pleistocene

Scale: 1 : 125000

0 1.25 2.5 5 7.5 10 Kilometers

By:

CRUX ediGEO GisSense

Date: 2014-06-29

Coordinate System: ETRS 1989 UTM Zone 31N
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Datum: ETRS 1989
False Easting: 500,000.0000
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Scale Factor: 0.9996
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Units: Meter

Borssele wind farm zone

Geological Desk Study

Legend

- project area
- border of different information sources
- limit

top Tertiary

m below average sea level

- 30-35
- 30-40
- 30-50
- 35-40
- 40-45
- 40-50

By:

CRUX ediGEO GisSense

Date: 2014-06-29

Coordinate System: ETRS 1989 UTM Zone 31N
Projection: Transverse Mercator
Datum: ETRS 1989
False Easting: 500,000.0000
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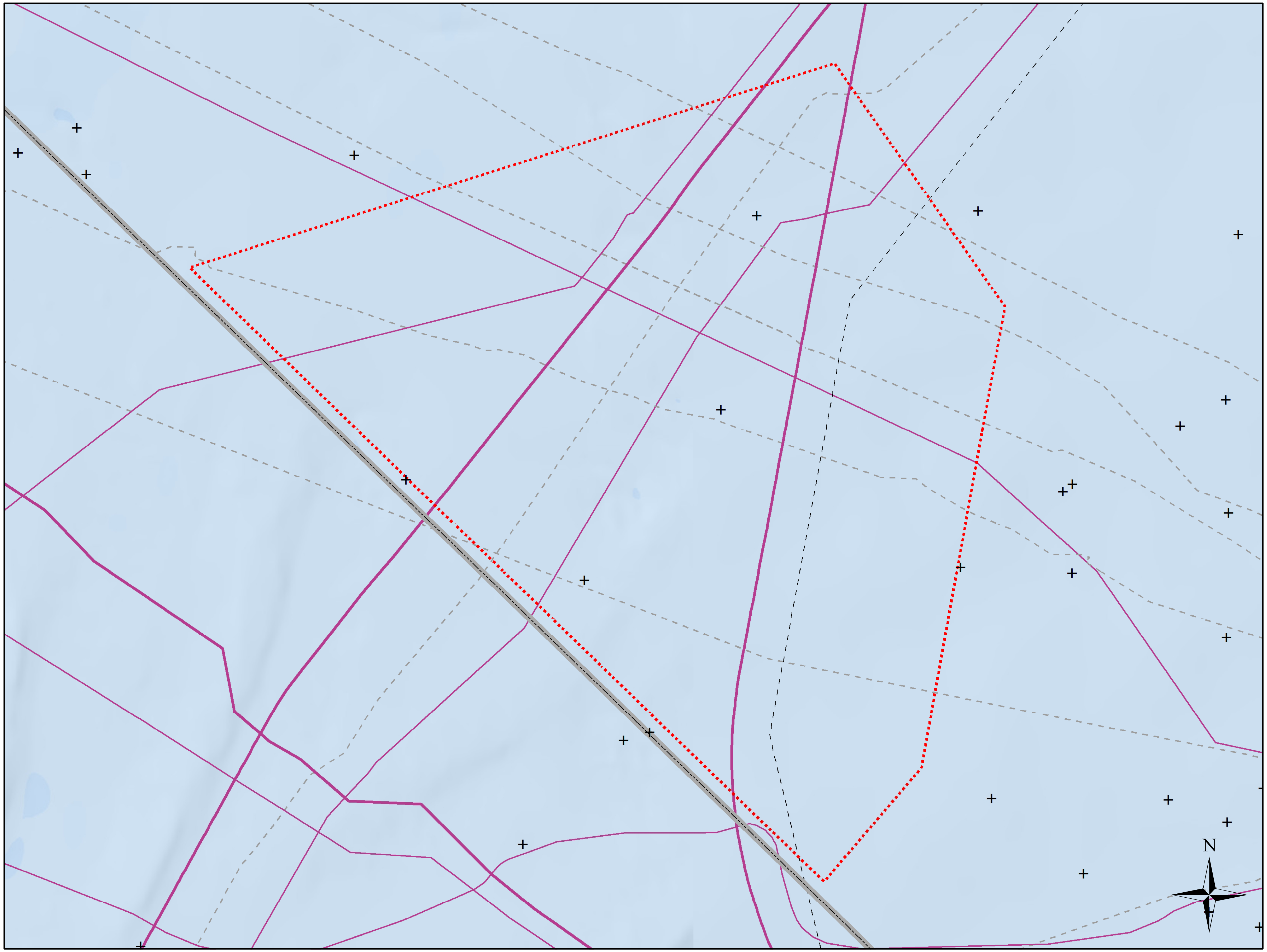
Latitude Of Origin: 0.0000
Units: Meter

Scale: 1 : 125000

0 1.25 2.5 5 7.5 10 Kilometers

Borssele wind farm zone

Geological Desk Study



Legend

- wrecks
- limit
- project area

Pipes

- In use

Cable

- In use
- Abandoned
- Recently abandoned

Scale: 1 : 125000

0 1.25 2.5 5 7.5 10 Kilometers

By:

Date: 2014-07-22

Coordinate System: ETRS 1989 UTM Zone 31N
Projection: Transverse Mercator
Datum: ETRS 1989
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: 3.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter

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Netherlands Enterprise Agency (RVO.nl) | December 2014