SCOPE OF SERVICES

Project		Danish 3 GW offshore wind farm in the North Sea					
Assignment		Integrated Geological Model					
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1. Introduction

The Climate agreement for energy and industry etc. of June 2020 commits Denmark to build the world's first energy islands – one in the North Sea and one in the Baltic Sea near Bornholm. The North Sea Energy Island will be constructed with an installed capacity of 3 GW offshore wind surrounding an artificial island. This island can be further scaled up to allow for grid connection of up to 10 GW offshore wind and is expected to be in full operation by 2033. The Bornholm Energy Island is planned to be constructed with an installed capacity of 2 GW offshore wind and is expected to be fully operational in 2030.

The offshore wind farm (OWF) projects: "Danish 3 GW offshore wind farm in the North Sea", "*Offshore wind farm Bornholm 1*" and "*Offshore wind farm Bornholm 2" are* being investigated by Energinet and the Danish Energy Agency during 2021 - 2023 with the aim to initiate a tender process by end 2023 to identify a developer such that the OWF commission for operation is complete by end of 2033 in the North Sea and by end of 2030 in the Baltic Sea.

As part of the site investigations Energinet has procured geophysical surveys and geotechnical investigations of the offshore wind farm sites:
For the Danish 3 GW offshore wind farm in the North Sea: Geophysical surveys (2021 by MMT and 2021 by FUGRO) and Preliminary Geotechnical investiations (FUGRO 2022).
For the *Offshore wind farm Bornholm 1 and 2*: Geophysical survey (2021/2022 by Geoxyz) and geotechnical investigations (2022 by Gardline).

2. Scope of Services

2.1 Purpose of assignment

The purpose of the assignment is to establish an Integrated Geological Model to inform Tenderers, that are applying for the licence to develop and construct the OWFs, about the geology, the associated geotechnical properties and potential geo-hazards.

The output of the assignment must be applied for

- Assessment of the soil-related risks for installation of foundations.
- Sub-selection of specific OWF area within the area of investigation.
- Initial determination of foundation concept and design.
- Initial planning of the turbine layout.

These applications are relevant for both the license tender process and the subsequent development performed by the nominated developer.

2.2 Scope of Services

The Scope of Services is to deliver an Integrated Geological Model based on

- Exisiting ground model(s) from geophysical suveys.
- Preliminary geotechnical investigations.

The Integrated Geological Model must cover the area of investigaton provided in sections 3 and include information described in section 4.

The Integrated Geological Model must meet the requirements described in section 5.

The Scope of Services must include the following elements:

- Conceptual geological model.
- Spatial integrated geomodel.
- Geotechnical characterization of soil units.
- Geotechnical zones

2.3 Regarding amount of work

- Re-interpretation of all horizons of geotechnical significance must be included
- Interpretation of 2 new horizons across the area must be included. In case horizons has been interpreted in one of the projects and must be added in the other it counts as ½ new horizon.
- Velocity model: SEGY files are depth converted. Depth conversion of SEGY-files should not be included in the proposal.

3. Areas of investigation

The present assignment is split into two LOTs. One in the North Sea: ”*Danish 3 GW offshore wind farm in the North Sea*” and and another covering two subareas near Bornholm in the Baltic Sea: ”*Offshore wind farm Bornholm 1*” og ”*Offshore wind farm Bornholm 2*”. The LOTs are shown, orange polygons, in Figure 3-1.

This document covers Scope of Services related to LOT1: "*Danish 3 GW offshore wind farm in the North Sea*"

Figure 3-1. Overview of regional location of the areas of investigation. Orange polygons: Areas of investigation. Blue and green polygons: OWFs – existing or under construction.

3.1 LOT 1 : "*Danish 3 GW offshore wind farm in the North Sea*"

The "*Danish 3 GW offshore wind farm in the North Sea*" area of investigation is located ca. 80 km off the coast of Jutland in the Northsea and covers an area of ca. 1052 km^2, see Figure 3-1.

Error! Reference source not found. shows a detailed chart of the investigation area. Coordinates of the polygon vertices defining the area of investigation are listed in Error! Reference source not found..

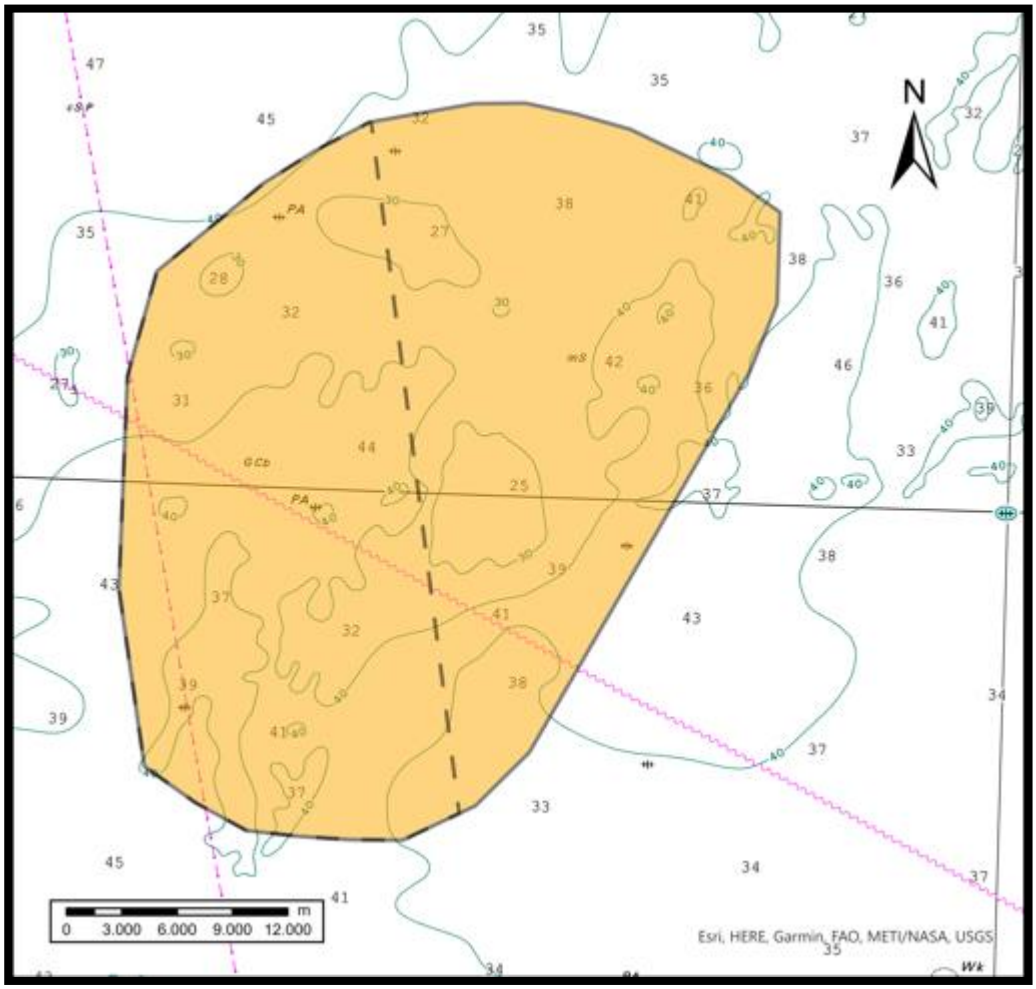

Figure 3-2 Area of investigation (orange polygon) displayed with admiralty chart 93 © Danish Geodata Agency. Dashed line separates two subareas west and east.

Tabel 3-1 Area of investigation. Danish 3 GW offshore wind farm in the North Sea. *Coordinates of polygon vertices as shown in Figure 3-2*

PointID	Easting ETRS89 UTM_Z32 [m]	Northing ETRS89 UTM_Z32 [m]	Latitude [DD mm.mmm]	Longitude [DD mm.mmm]
1	330 721	6 276 594	56° 36.178' N	6° 14.538' E
2	336 563	6 281 414	56° 38.898' N	6° 20.058' E
3	339 413	6 283 197	56° 39.917' N	6° 22.777' E
4	342 250	6 284 687	56° 40.777' N	6° 25.497' E
5	347 929	6 285 695	56° 41.433' N	6° 31.017' E
6	350 709	6 285 722	56° 41.501' N	6° 33.736' E
7	353 508	6 285 119	56° 41.230' N	6° 36.497' E
8	356 385	6 284 305	56° 40.845' N	6° 39.339' E
9	361 807	6 281 725	56° 39.553' N	6° 44.729' E
10	364 533	6 279 789	56° 38.558' N	6° 47.455' E
11	364 373	6 274 835	56° 35.887' N	6° 47.455' E
12	362 907	6 271 194	56° 33.900' N	6° 46.139' E

13	350 927	6 250 491	56° 22.532' N	6° 35.163' E
14	347 985	6 247 579	56° 20.907' N	6° 32.409' E
15	344 051	6 245 723	56° 19.831' N	6° 28.659' E
16	341 211	6 245 748	56° 19.787' N	6° 25.905' E
17	338 418	6 245 934	56° 19.831' N	6° 23.191' E
18	335 589	6 246 243	56° 19.939' N	6° 20.437' E
19	332 808	6 247 764	56° 20.700' N	6° 17.683' E
20	330 046	6 249 727	56° 21.698' N	6° 14.929' E
21	328 657	6 259 365	56° 26.857' N	6° 13.204' E
22	328 791	6 262 667	56° 28.637' N	6° 13.204' E
23	329 125	6 270 920	56° 33.088' N	6° 13.204' E
24	330 721	6 276 594	56° 36.178' N	6° 14.538' E

4. Site investigations

Site investigations comprise geophysical surveys MMT (2021) and FUGRO (2021) preliminary geotechnical investigations FUGRO (Planned 2022) as described in the following.

4.1 LOT1 : Danish 3 GW offshore wind farm in the North Sea

For the geophysical site investigations, the area was split in two parts, west and east, see figure 3-2. The geophysical site investigations were conducted by different contractors (FUGRO and MMT) for the two subareas. Regular meetings were held to align quality and interpretations, but the areas are provided as two separate sets of deliverables.

Survey lines have a dense coverage of approximately north-south oriented lines. Near-west-east UHRS crosslines are surveyed for every km. Three UHRS lines, crossing both the eastern and western area, were collected by both survey companies, for comparison, and alignment of interpretation strategy, see Figure 4-1.

Velocity models were exchanged for alignment but may not be identical. The Kingdom projects for the two subareas contains 10 and 12 interpreted horizons of which 6 are shared across both subareas.

4.1.1 Geophysical survey 2021: North Sea Western area, by FUGRO

The geophyscial survey by FUGRO (2022) was performed using an Innomar sub-bottom profiler for resolution of the upper 10 m, and a 2D Ultra-High resolution seismic survey using a 96 channel seismic hydrophone streamer with group intervals of 1 m and a 900 J Multi-level Stacked Sparker system with the aim to map the soil conditions to at least 100 m below sea-bed.

Summary of survey line distribution:

- 62.5 m line spacing for SBP near-north-south oriented.
- 250 m line spacing for 2D Ultra-High Resolution Seismic (UHRS) main lines (near-north-south).
- 1.000 m line spacing for UHRS cross lines.
- 10.000 m (10 km) line spacing equals 3 cross-lines crossing both subareas.

The total line length amounts to:

- SBP seismic profiles, in total 6471 line-km.
- 2D UHRS profiles, in total 2770 line-km.

Of relevance to the present assignment the geophysical survey supplied the following output (Deliverables specified are of the same format for both geophysical surveys):

- Bathymetry: A high-resolution DTM of the seabed surface available as grids with 0.25m spatial resolution as ASCII XYZ files and GeoTIF.

- Seismic recordings (SBP and 2D UHRS). Processed seismic recordings, SEGY-format.

- Seismic interpretation of soil layer interfaces. Geological soil layer horizons interpreted from the seabed to 100m below seabed, provided as grid surfaces with 5 m spatial resolution. Available as ASCII XYZ files and GeoTIF. Referenced vertically as depths below seabed and as absolute elevation. Interpretation points are provided as in CSV-format.

- Seismic workspace project. A Kingdom project is available containing the SBP and 2D UHRS seismic recordings both in TWT and as depth conversion, and the interpreted horizons also in TWT and depth.

The described survey data as well as other parts of the geophysical survey will be made available to the Consultant.

4.1.2 Geophysical survey 2021: North Sea eastern area, by MMT

The geophyscial survey (MMT, 2021) included an SBP (sub-bottom profiler) seismic survey using an Innomar medium 100 SBP for resolution of the upper 10 m. Further, 2D Ultra-High resolution seismic (UHRS) data collection was performed using a 96 channel seismic hydrophone streamer with group intervals of 1 m and a 3 x 400 J Stacked Light Weight sparker source with the aim to map the soil conditions to at least 100 m below seabed.

Summary of survey line distribution:

- 70 m line spacing for SBP main lines semi-north-south oriented.
- 210 m line spacing for 2D Ultra-High Resolution Seismic (UHRS) main lines (semi-north-south).
- 1.000 m line spacing for UHRS cross lines.
- 10.000 m (10 km) line spacing equals cross-lines crossing both subareas.

In total line length amounts to:

- 363 SBP seismic profiles, in total 5243.2 line-km.
- 156 2D UHRS profiles, in total 3197.5 line-km.

Of relevance to the present assignment the geophysical survey supplied the following output (Deliverables specified are of the same format for both geophysical surveys):

- Bathymetry: A high-resolution DTM of the seabed surface available as grids with 0.25m spatial resolution as ASCII XYZ files and GeoTIF.

- **Seismic recordings (SBP and 2D UHRS)**. Processed seismic recordings, SEGY-format.

- **Seismic interpretation of soil layer interfaces**. Geological soil layer horizons interpreted from the seabed to 100m below seabed, provided as grid surfaces with 5 m spatial resolution. Available as ASCII XYZ files and GeoTIF. Referenced vertically as depths below seabed and as absolute elevation. Interpretation points are provided as in CSV-format.

- **Seismic workspace project.** The SBP and 2D UHRS seismic recordings both in TWT and as depth and the interpreted horizons also in TWT and depth are available as a Kingdom project.

The described survey data as well as other parts of the geophysical survey will be made available for the Consultant.

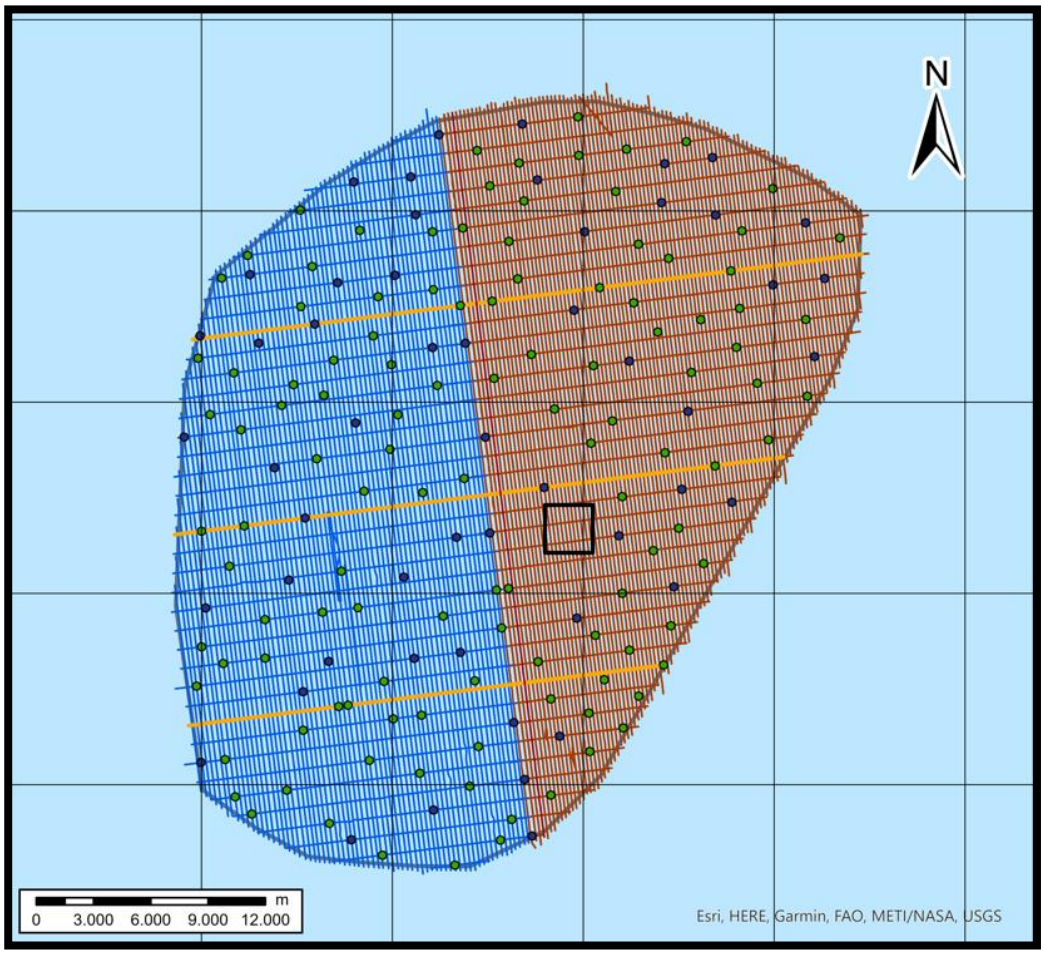

Figure 4-1 Geophysical main lines and cross lines (UHRS). Blue lines: Fugro (2021), Red lines: MMT (2021). Orange lines: Cross-area lines collected in both geophysical surveys. Planned locations of combined CPT and boreholes (Blue circles) and CPT (green circles) for the preliminary geotechnical campaign (2022). Black square: Site: Energy Island.

4.1.3 Geotechnical investigations North Sea, 2022 by FUGRO

The Client has employed the company FUGRO to carry out preliminary geotechnical investigations for the "*Danish 3 GW offshore wind farm in the North Sea"*.

The planned program includes the following elements:

- 53 locations with combined borehole drilling and seabed CPTs including OSS stations
- 170 locations with seabed CPTs
- 7 CPT locations performed with seismic CPT
- 8 borehole locations subject to P-S logging
- 7 down the hole CPT in boreholes below refusal of continuous CPT
- Optional : blind drilling of 2 separate boreholes for CPT below refusal of seabed CPT
- Laboratory testing: Including visual geological description, sample photos, Pocket Penetrometer, Shear Vane, Classification testing, Chemical testing, Special geotechnical laboratory testing (CID, CAU, Cons)

The boreholes and CPTs are planned to be performed to a target depth of 70m below seabed. Seabed CPTs will be supported by down-the-hole methods and blind-drilled borehole to support meeting the target.

The locations of these planned boreholes and CPTs are shown in Error! Reference source not found..

For the subarea of the planned Energy Island (Black square in Figure 4-1) denser geotechnical information will be available and should be included in the present assignment. The planned program includes:

- 109 locations with seabed CPT's
- 6 borehole locations to 120 m depth below seabed
- 3 borehole locations
- Laboratory testing: Including visual geological description, sample photos, Pocket Penetrometer/Shear Vane, Classification testing, Chemical testing, Special geotechnical laboratory testing (CID, CAU, Cons)

The preliminary geotechnical investigations are planned to be carried out after the following schedule in 2022:

- Marine CPT and Borehole investigations, Jan 2022 – May 2022
- Laboratory work, June - October 2022
- Interrim delivery package, CPTs, end of July 2022
- Interrim delivery package, Boreholes, early September 2022
- Draft factual geotechnical report, end of October 2022
- Revised factual geotechnical report, end of December 2022

The interim delivery packages are intended for supporting the present assignment and will include:

- CPTs:

  - CPT logs for all performed CPTs (PDF format)
  - Digital CPT data as AGS4 format.

- Boreholes
  - Preliminary borehole logs with soil profiles and CPT data (PDF-format).
  - Digital borehole soil- and layer-data in AGS4 format.

The described geotechnical data as well as other parts of the data will be made available for the Consultant as soon as possible and very likely with the timing suggested by the schedule above. Preliminary CPT's and Borehole logs are expected to be delivered in AGS4 format by sign-off in May.

5. Requirements

The requirements specified in this section apply for the Consultants solution of the present assignment.

5.1 Main parts

The solution includes the following main parts:

1. Provision of a conceptual geological model.

2. Provision of a 3D digital and Spatial integrated geomodel.

3. Provision of a geotechnical characterization of the soil units of the Spatial integrated geomodel.

4. Geotechnical zones

5.2 General requirements

5. Items #1 to #3 (section 5.1) establish a description of the geology that is consistent in terms of definition and naming of soil units in terms of lithology, depositional environment and depositional age.

6. The following reference apply for the engineering geological descriptions: *A guide to engineering geological soil description*. G. Larsen et. al. DGF-Bulletin 1. Danish Geotechnical Society.

7. The vertical height system is Mean Sea Level (MSL) via the model DTU21MSL.

8. The coordinate system is ETRS89 UTM zone 32N.

5.3 Conceptual geological model

9. A conceptual geological model is provided based on a combined analysis and evaluation of the geophysical surveys 2021 and the geotechnical investigations 2022 (see chapter 0).

10. The conceptual geological model is documented as schematic diagrams providing indicative and conceptual illustration of all soil units, their stratigraphic relationships, and their variation.

11. The conceptual geological model is supported by a description of all soil units, their lithology, depositional age and environment. The description also include a summary of the regional geological history related to the area of investigation.

5.4 Spatial integrated geomodel

12. A 3D digital, Spatial integrated geomodel is provided based on the geophysical surveys, 2021, and the geotechnical investigations, 2022 (see chapter 0).

13. The Spatial integrated geomodel integrates the geophysical and geotechnical results such that optimal consistency is achieved between the geotechnical results (boreholes and CPTs) and the geophysical results (interpreted layer interfaces). The model could potentially be represented by 3D visualisation such as Voxel modelling or other geometric modelling concepts.

14. The Spatial integrated geomodel cover at least the area of investigation (chapter 3) and has a vertical range from the seabed surface and at least to 100m below seabed.

15. The Spatial integrated geomodel has a spatial resolution of
    a. 5 m horizontally.
    b. 0.4 m vertically within the depth range 0m to 40m below seabed.
    c. 1.0 m vertically for depths larger than 40m below seabed.

16. In addition to item #6, the Spatial integrated geomodel also cover geo-hazards, suchs as shallow gas, and structural elements such as faults or joints and potential identification of areas with a high density of boulders.

17. The documentation of the Spatial integrated geomodel includes:
    a. A description of the modelled soil units and their physical characteristica such as horizontal and vertical extension.
    b. Representative seismic Imagery examples illustrating the identification of the soil unit horizons.
    c. A description of the consistency between the model interfaces and the soil interfaces found in the geotechnical results (boreholes and CPTs) supported by example illustrations and/or statistics.

5.5 Geotechnical characterization

18. Geotechnical parameters are summarized for the soil units of the Spatial integrated geomodel including typical values and variance based on the factual geotechnical report (see chapter 4.1.3).

19. The geotechnical parameters include classification properties, strength and deformation properties. The Geotechnical parameters should be documented by uncertainties, best estimates or variabilities.

5.6 Geotechnical zones

20. An outline of geotechnical zones represented by similar geotechnical conditions. For each geotechnical classification zone a typical soil profile should be provided. A reference to a CPT from the site, which is typical for the zone would be a possible solution.

5.7 Deliverables

21. All deliverables are provided on an external harddrive in a draft edition for Client review.

22. After Client review, the deliverables are revised by the Consultant based on the Client's comments. All deliverables are re-issued in a revised (final) edition and provided on an external harddrive (two identical copies) to the Client.

23. Language for all deliverables is English.

24. All reports and drawings are provided digitally as PDF files.

5.7.1 Integrated Geological Model Report

25. The report shall include at least the following:

    a. Executive summary
    b. Introduction with project summary and scope of services
    c. Description of the area of investigation
    d. Applied geodetic systems – vertical and horizontal.
    e. Method descripton
    f. Presentation of conceptual geological model (include items #10 and #11)
    g. Presentation of the Spatial integrated geomodel (include item #17)
    h. Images with visualizations from the digital model workspace of key interfaces or key soil units
    i. Presentation of geotechnical properties of model soil units (include items #18, #19 and #20)
    j. Overview of drawings and digital deliverables

The Consultant may supplement the report content if deemed relevant.

5.7.2 Drawings

The Integrated Geological Model Report shall enclose at least the following drawings:

26. For all charts the Consultant propose content and layout for the Clients approval.

27. Overview chart with location plan with at least

    a. Area of investigation
    b. 2D UHRS lines colour coded in accordance with profile quality
    c. Locations of geotechnical investigations

28. Elevation charts, all soil unit interfaces (Top of soil units)

29. Isochore charts (vertical layer thickness), all soil units

30. Shallow gas charts, top of horizons

31. Cross-section profiles, 10 to 15 profiles

    a. Consultant propose profile locations for Client approval
    b. Profiles provide spatial coverage of the area of investigation.
    c. Profiles show soil units and geotechnical logs (boreholes and CPTs)

32. Geotechnical zone maps or similar illustrating variation in geotechnical properties of the site. Suggested approach and layout by the consultant for the Clients approval.

The Consultant may supplement the list if deemed relevant.

5.7.3 Digital deliverables

The Integrated Geological Model Report is supplemented with at least the following digital deliverables. GeoTIF and shape files should be delivered in a geodatabase compatible with ArcGIS PRO:

33. Kingdom project including the Spatial integrated geomodel

34. All soil unit interfaces are provided as elevation grids in the digital formats ASCII XYZ and GeoTIF.

35. Shallow gas interfaces are provided as elevation grids in the digital formats ASCII XYZ and GeoTIF.

36. All soil units are provided as isochore grids (vertical layer thickness) in the digital formats ASCII XYZ and GeoTIF.

37. Geotechnical zone map in the digital formats GeoTIF and shape.

The Consultant may supplement the list if deemed relevant.

6. Time Schedule

The Client is obligated to have issued all interim results from the geophysical site investigations as well as preliminary CPT's and borehole profiles no later than 01-08-2022. Thus, results of laboratory test will be pending in accordance with the time schedule section: 4.1.3.

The Client request that the following apply for the time schedule of the present assignment:

1. The revised edition of all deliverables is provided to the Client no later than 01-10-2023.

2. The Client use 2 weeks for review of the draft edition of all deliverables.

The time schedule contains the milestones listed in Table 6-1.

Table 6-1. Overview of contract milestones that are subject to liquidated damages as described in the contract agreement

Event	Milestone	Date
All deliverables has been delivered in **draft** edition	M1	01-08-2023
All deliverables has been delivered in **revised** edition	M2	01-10-2023