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Data Gathering Process: Geotechnical Departures for Offshore Wind Energy

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Contents

1 INTRODUCTION

This document provides guidance to the Bureau of Ocean Energy Management (BOEM) regarding assessment of Construction and Operation Plan (COP) departure requests related to geotechnical investigations for offshore wind facilities.

1.1 Purpose

To enable BOEM to assess the proposed offshore wind developments in fulfilment of its obligation as the lead federal agency, offshore wind lease area owners are required to submit a COP as part of the 30 CFR part 585 requirements. The COP details all planned facilities and activities that will be required for the construction, operation, and decommissioning of the project including onshore and support facilities. The COP must demonstrate that the project is being designed, constructed, and operated in a manner that conforms to responsible offshore development per 30 CFR 585.621, and should provide adequate information to inform the NEPA review, which includes an assessment of environmental and social factors. As the lead federal agency, BOEM must also ensure all relevant legislative, policy, and consultation requirements are met, such as those pertaining to the Endangered Species Act (ESA), the Marine Mammals Protection Act (MMPA), the Migratory Bird Treaty Act (MBTA), the Coastal Zone Management Act (CZMA), the National Historic Preservation Act (NHPA), the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), and the American Indian Religious Freedom Act (AIRFA).

Information pertaining to the ground and sea bed conditions at the proposed development site is required to inform the developer's technical project design, and to describe the existing baseline environment within the proposed development areas. Guidance has been issued under the 30 CFR 585.626 (a)(4) which stipulates that "the results of adequate in situ testing, boring and sampling at each foundation location…" must be provided as part of the COP submittal. This level of information would typically be described as a Detailed Geotechnical Investigation.

BOEM has published "Guidelines for Providing Geophysical, Geotechnical, and Geohazard Information Pursuant to 30 CFR Part 585" dated 2 July 2015. BOEM typically requires prior BOEM approval of all survey plans for a Site Assessment Plan (SAP), General Activities Plan (GAP), and COP. BOEM will use this report as well as BOEM published guidelines and regulations to assess the suitability of any proposed survey plan.

In the current offshore wind industry realm, it is common for developers to employ a phased-approach to the geotechnical investigation, for example:

1. First undertaking a Desktop Study;
2. Then an Initial Geophysical Survey;
3. then a Preliminary Geotechnical Investigation; and
4. finally, a Detailed Geotechnical Investigation and potentially a second Detailed Geophysical Survey.

1.2 Phased Approach

The process at each stage is shown in Figure 1-1. Through this phased process, a ground model (also sometimes referred to as a geological model) is developed and progressively updated as new information is collected. The ground model is comprised of:

a) The Conceptual Geological Framework (often presented in 2 dimensional or 3 dimensional figures) – *The conceptual geological framework sets out the geological processes under which the site was formed. This includes the deep geology; below the likely foundation or anchor depth; and the shallow geology. The age and available information relating to the nature of the geological formations should be described. This is the first stage in the geo hazard assessment, and the geological framework should provide a base understanding on which the initial risk of geohazards may be based.*

b) Relevant Geotechnical Parameters for each pertinent geological unit identified – *The geotechnical parameters may be estimated from the available data at each stage. The estimate is likely to be a range which will become more refined as the project progresses, however this estimate will allow the impact of the offshore wind project infrastructure to be evaluated at each stage.*

c) The Geological Risk Register – *Geological features and geohazards that may affect the project in any way (design, siting, layout, installation method, operation, or risk profile) should be defined, and suitable actions identified to evaluate and mitigate the risk to an as low as reasonably practicable (ALARP) level.*

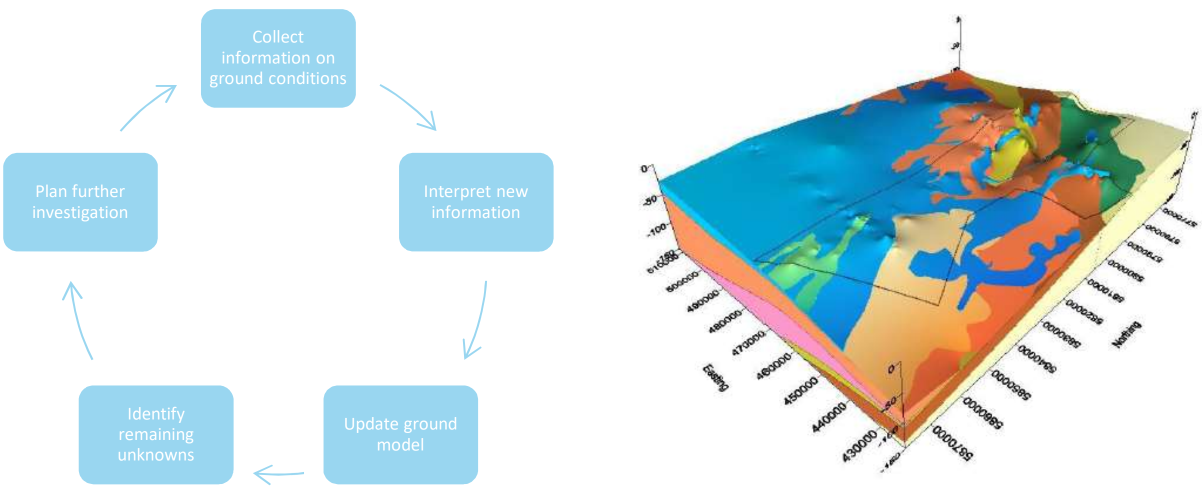

Figure 1-1 Process of ground model development

1.3 Project Design Envelope

The phased approach can be adopted alongside the Project Design Envelope (also known as the Rochdale Envelope), which facilitates permitting of the project to occur after the Preliminary Geotechnical

Investigation but prior to the Detailed Geotechnical Investigation. The objective of the Project Design Envelope approach is to provide sufficient information to understand the range of development options and associated worst case adverse effects while providing flexibility for offshore wind project developers. With this approach the Maximum Design Scenario for environmental impact is established based on the worst-case assumption in the ground model.

Benefits of this approach include reducing the pre-permit capital expenditures (CAPEX), ensuring adequate information on ground conditions is available to tailor the Detailed Geotechnical Investigation to requirements for the selected final foundation design, and enabling project layout changes after the permit is granted without requiring a second Detailed Geotechnical Investigation.

Due to the significant benefits of adopting the phased approach, and the proven success of this approach in Europe, BOEM is anticipating that developers will request a departure from the present COP information requirements. Thus, a methodology to assess the departure requests to establish whether a departure is allowable based on necessity for the project, and possible impacts on worker safety and protection of the environment, is required. This methodology is presented below.

Further information on the adoption of the Project Design Envelope is available in Draft Guidance issued by BOEM on 12th January 2018 (Bureau of Ocean Energy Management Office of Renewable Energy Programs, 12 January 2018).

1.4 Future BOEM Actions

BOEM is currently considering a rulemaking to deregulate, reform, and streamline the current 30 CFR 585 regulations. This rulemaking may include a revision to the geotechnical survey provisions in 30 CFR 585.626, which specify the surveys required to be included in a COP. Changes to geotechnical survey provisions could allow geotechnical surveys to be performed in phases, with only a preliminary level investigation required in a COP; final geotechnical surveys, including investigation of each turbine foundation location, would be required to be submitted with the Facility Design Report (FDR).

The recommended technical requirements for a preliminary geotechnical survey that meets the current COP geotechnical requirements described in this guideline may inform potential rule changes, which could eliminate the need for regulatory departures as described herein.

Unless or until BOEM's regulations are revised accordingly, these guidelines are expected to be used by project developers in preparing departure requests, and by BOEM in evaluating such request.

2 ASSESSMENT OF DEPARTURE REQUESTS

During project development, the COP should be developed and revised to address the resources, conditions, and environment which could be affected by the project. Additionally, a review of the environmental impact must be thoroughly considered in a parallel NEPA review process. To address these various reviews, the departure request methodology assessment (this document) considers three possible areas which will be applicable to the departure evaluation criteria and supplementary guidance and examples. These include the following:

- ***Technical:*** *The technical review must establish the feasibility of the proposals and consider how the development areas are located with special reference to any geohazards that may pose a Health Safety and Environmental risk. The data requirements for this component relate to the confidence in the project design;*
- ***Environmental:*** *The environmental assessment, refers to the environmental part of the NEPA review, and considers how the defined project will affect the existing baseline environment. The data requirements for this component relate to the definition of the baseline environment, and ensuring there is sufficient certainty in the ground conditions to determine the maximum impact of the project;*
- ***Socio-economic:*** *The socio-economic assessment refers to the socio-economic part of the NEPA review. The data requirements for this part of the review relate to having confidence in the proposed project description.*

The departure request methodology assessment (this document) is set into two parts:

- **Part 1: Evaluation criteria**

  The criteria are a set of tests that can be used to determine whether the level of geotechnical information is adequate for the project under review.

  These criteria are proposed as "essential requirements"; and hence must be passed by the developer's submission.

  The purpose of each criterion is presented to better inform the reader's understanding. As such, the reader will have a basis on which to demonstrate that the proposed departure still allows for completion of all required reviews.

- **Part 2: (a) Supplementary guidance, and (b) Examples**

  Guidance related to the assessment of geologic conditions, foundation types, and current technologies of investigation and foundation construction is provided.

  Examples of departure requests that meet the assessment criteria, and examples that do not meet the criteria for a shallow water Atlantic site, a deep water Pacific site and a Gulf of Mexico site are provided.

  The examples are not prescriptive, and are provided as examples to demonstrate process. The requirements for any specific project must be developed on a case by case basis.

3 PART 1: EVALUATION CRITERIA

3.1 Criterion Definition

In order to provide consistent assessment of the departure requests, a set of evaluation criteria leading to fulfillment of the key requirements in the COP are given below:

Criterion 1: Is there sufficient resolution and confidence in the ground model to:

a. Define the baseline geological conditions of the area directly impacted by the project described in the COP. The area should include the sea bed surface, validation of the depth of the geological units to the maximum depth and lateral extent affected by the project.

   Purpose:

   Ensure there is adequate knowledge on geological history, presence of geohazards, stratification, extent of sea bed features and depth of mobile sediments for the reviewers to have confidence in the ground model presented for the area directly affected by the project. An example of the required baseline environmental conditions is provided in Table 3-1. Table 3-2 provides typical project characteristics that may be described to allow the reviewers to conduct the assessments.

b. Define the baseline geological conditions of any area indirectly affected by the project described in the COP. The description should include the sea bed surface sediments, and may be based on available information at the time of the submission.

   Purpose:

   Ensure there is adequate knowledge on geological history, presence of geohazards, stratification, extent of sea bed features and depth of mobile sediments for the reviewer to have confidence in the ground model presented for any area surrounding the project that may be affected by the development. The reviewers must also consider the cumulative impact of any nearby projects. An example of the required baseline environmental conditions is provided in Table 3-1. Table 3-2 provides typical project characteristics that may be described to allow the reviewers to conduct the assessments.

c. Define any geological units that may contain surface or buried features of archaeological potential.

   Purpose:

   Ensure there is adequate knowledge of the geological history to identify any surface or sub surface geological units that have archaeological potential.

Criterion 2: Are the geotechnical characteristics of the pertinent geological unit adequately characterized to;

a. Demonstrate the maximum environmental actions of the proposed project have been established.

   Purpose:

   The developer must demonstrate that any assertions about the environmental impacts of the project included in the COP are justified with evidence. Examples of environmental impacts of the project characteristics are provided in Table 3-2.

b. Demonstrate the technical feasibility of the proposed project, and project alternatives, described in the COP. This is to ensure the project does not pose an unacceptable risk to health, safety and the environment.

   Purpose:

   The developer must demonstrate that any assertions about the physical project characteristics included in the COP are justified with evidence. Examples of project characteristics are provided in Table 3-2.

3.2 Describing the Baseline Environment and Project Characteristics

Examples of typical features of the baseline environment are provided in Table 3-1. Table 3-2 provides typical project characteristics that may be described to allow the reviewers to conduct the assessments.

Table 3-1 Information to define baseline environmental condition

Sufficient information to inform on	Geological Information required
Seabed mobility *Example: Sand waves, global seabed movements, transportability due to scour, sediment processes of accretion to and erosion from Permitted Site Area*	Geophysical survey and samples for sediment classification Published information on sedimentary regimes
Stratification *Example: Geological history, classification, lateral and vertical distribution of geological units*	Geophysical survey calibrated with borehole / in-situ testing (CPTu) and classification testing Published information on geological history of the region
Permitted Site Area to allow for project alternatives evaluation	Geophysical survey calibrated with borehole / in-situ testing (CPTu)

Potential export cable route(s)	Geophysical survey, potentially calibrated with borehole / in-situ testing (CPTu). [1] Published information on geological history of the *Permitted Site Area* Information on landfall(s)
Geotechnical parameters for pertinent geological units *Including soil classification, particle size distribution*	Sufficient boreholes, grab samples and or in-situ testing (CPTu) and laboratory testing
Presence / location of benthic organisms and reefs	Geophysical survey and shallow seabed samples (grab samples)
Presence / location of archaeological remains	Geological setting, geophysical survey calibrated with borehole / in-situ testing (CPTu)
Geohazards *Example: Faulting, shallow gas, salt domes, anthropogenic hazards (UXO, wrecks or debris), mud volcanos, landslide potential*	Geophysical survey calibrated with borehole / in-situ testing (CPTu) and laboratory testing Published information on geological history of the *Permitted Site Area*.

Table 3-2 Example of project characteristics to allow the assessment

Definition of Project Characteristics	Relevance for environmental and technical assessments
Locations / areas of development *"Project area" is defined in 30 CFR 585.112 as the geographic surface leased, or granted, for the purpose of a specific project.*	The technical review must establish the feasibility of the proposals and consider how the development areas are located with special reference to any geohazards that may pose a Health Safety and Environmental risk The environmental assessment will consider areas that will be impacted by the project; for example; areas being considered for wind farm infrastructure, and for vessel anchoring or jacking up; or areas that will be indirectly affected by any changes in the hydro sedimentary regimes. These items may also be described in sections of the COP that address potential environmental impacts due to project construction and operations activities.

[1] There are no specific requirements in the regulations that specify geotechnical investigation for the export route. A developer however may wish to obtain this information to inform preliminary engineering activities.

Definition of Project Characteristics	Relevance for environmental and technical assessments
Locations / areas of exclusion *"Project area" is defined in 30 CFR 585.112 as the geographic surface leased, or granted, for the purpose of a specific project.*	The technical review and environmental assessment must establish the feasibility of the proposals and consider how the location of the infrastructure or for vessel anchoring or jacking up in relation to ground conditions Areas that are proposed not to be developed should be identified. Examples of areas that the developer may wish to identify as areas of no development / disturbance that will not be affected by the project described in the COP. These may include; areas with projected reefs or benthic species; areas with archaeological significance; areas with any geohazards that may pose a Health Safety and Environmental risk if developed.
Maximum hub height, blade tip height and turbine size	The maximum hub height, and layout of turbines is related to the maximum turbine size and impact on the bird populations, bat populations, visual resources, and navigation.
Foundation or mooring type, size, zone of influence. Assertions should be supported with drawings and relevant calculations / design reports	The technical review will evaluate whether the project as described in the COP does not present an unreasonable risk to health, safety and the environment. This includes whether the developer has adequately demonstrated the technical feasibility of the COP.
Installation concept descriptions for foundation, anchors (including anchor chains) cable, cable landfall, offshore sub-station topside, wind turbine installation equipment, monitoring procedures, vessel selections, proposed sequences and timings. Assertions may be supported with drawings and relevant calculations / design reports. *Non exhaustive examples of quantification of installation concepts;* ***<u>Driven piles</u>**: Maximum hammer energy introduced into environment, number of piles, location / area of piles, time taken to drive each pile, sequencing of pile driving.* ***<u>Rock dumping (cable) / scour protection</u>**: Maximum volume of rock dumping in how many*	The technical review will establish whether there is sufficient geotechnical information available to have reliance on the details provided in the COP. The environmental assessment will utilize the baseline and project characteristics as described in the COP to inform avoidance, minimization, and mitigation measures; adequacy of any stakeholder consultation regarding these matters; and the appropriate on-going management of impacts pertaining to these characteristics.

Definition of Project Characteristics	Relevance for environmental and technical assessments
locations / areas, what is the size of the rock, what alternatives are being considered. ***Drilled and grouted piles:*** *Maximum volume of grout per foundation, how many maximum foundations. Volume of spoil and where it will be disposed of.* ***Pile to transition piece / jacket connection:*** *Bolted or grouted? If grouted what is maximum potential grout leak / dispersal.* ***Moorings and mooring chains:*** *What types of anchors will be used, where will these be installed, how much of the sea bed will be disturbed during installation, operation, maintenance, and decommissioning?* ***Cables;*** *Simultaneous lay burial or post lay burial, pre-lay grapnel run; jetting, ploughing, external protection.* ***Jetted cables:*** *length, location , depth, volume of suspended sediment.* ***Vessels:*** *Jack up or anchored, area / locations they will be active in, disposal procedures for discharges, duration of activities.* ***Sea bed preparation:*** *procedures, how much and what material will be installed.* ***Dredging:*** *Will any dredging be required? How much, where will the dredged soils be disposed of?*	
Quantified project operating and maintenance procedures *Survey frequency requirements, maintenance tasks for WTG and balance of plant (replacement of parts frequency, scour protection replacement, corrosion protection, structural integrity maintenance, vessel requirements).*	Surveys may provide information pertaining to the environment during the operation of the wind farm. Other operation and maintenance procedures allow the reviewers to assess any potential ongoing or future environmental impact, for example in line rock dumping or post lay cable jetting that may be necessary if the cables become uncovered due to sea bed mobility.
Decommissioning concepts / Site restoration plan	The environmental assessments will consider the impact the project will have during and after decommissioning. Examples of the information required include strategies for removal of wind turbines, and balance of plant

Definition of Project Characteristics	**Relevance for environmental and technical assessments**
Procedures for WTG, offshore sub-station topside, WTG foundation, moorings, scour protection / dumped rocks, subsea cable removal.	infrastructure, or any infrastructure the project intends to leave in place.
Project alternatives *Developer to provide justification for preferences and present alternative concepts.*	The reviewers must consider project alternatives in the assessments.

3.3 Data Quality and Quantity

When assessing the departure request the overall resolution and reliability of the ground model will be considered. This approach allows developers freedom to design their preliminary geotechnical investigations around the particular project requirements, and the flexibility to innovate as more data and new investigation techniques become available.

This flexibility includes the balance between geotechnical and geophysical data. There may be situations where there is excellent geophysical data, which may mean there is less need for geotechnical calibration; in contrast if the geophysical data quality is poor, increased number of geotechnical investigation may be necessary. In both of these situations, the departure request assessment is based on the level of information in the ground model and how it is used to design the project characteristics.

There may be some situations where information is not available. Developers may wish to determine their project characteristics by making conservative assumptions relating to the ground. This approach is acceptable so long as the assumptions are not baseless and are applied conservatively. Reviewers should consider whether the assumptions made are reasonable from a technical, health, safety and environmental risk perspective. It is the responsibility of the developer to consider commercial risks.

4 PART 2A: INDUSTRY PRACTICE

The following section of the guideline provides a common understanding for all departure request applicants in relation to current state of the art practice in relation to; assessment of geological conditions; current technologies of investigation; foundation types, and current technologies of foundation construction.

4.1 Assessment of Geologic Conditions

The typical process of assessment of geological conditions takes place as outlined in Figure 4-1 and Table 4-1. This is an example, and the appropriate process for each project will be based on the extent of knowledge of the geological conditions present, and complexity of the development. Additionally, the results of any of the surveys may contradict the previous information which can initiate a review of the data validity, interpretation and geological framework.

Table 4-1 Details of each stage in the geological survey

(Note: reference numbers in table link to Figure 4-1 below)

Stage	**Purpose & description**
Desk Study	To inform initial ground model, collate: • Published geological information • Historic bathymetry data from hydrographic maps • Areas of potential archaeological significance from site specific assessment • Site specific information (if available) Determine: • Conceptual geological framework and initial ground model including initial geological risk register [GM & GRR 1]
Geophysical Survey [1]	To obtain site specific data to assess the site for concept design and inform the geotechnical survey. If the Permitted Site Area is the same as the project area, then a 100% initial survey may be most efficient. Data consolidated in the GM & GRR [2].
Geotechnical Survey [1]	To inform concept design and the COP. If adequate historic geotechnical information (e.g., in the GoM) then there may be sufficient information to inform the COP without geotechnical survey. Data consolidated in the GM & GRR [3].
Decision: Adequate geophysical survey?	
Route 1: Detailed Geotechnical Survey [2]	To provide geotechnical profiles and geotechnical parameters for detailed design. Data consolidated in the GM & GRR [4].
Route 2: Geophysical Survey [2]	To provide 100% coverage on the Project Zone and / or provide a second geophysical survey for mobility assessment. Data consolidated in the GM & GRR [4].
Route 3: Detailed Geotechnical Survey [3]	To provide geotechnical profiles and geotechnical parameters for detailed design. Data consolidated in the GM & GRR [5].

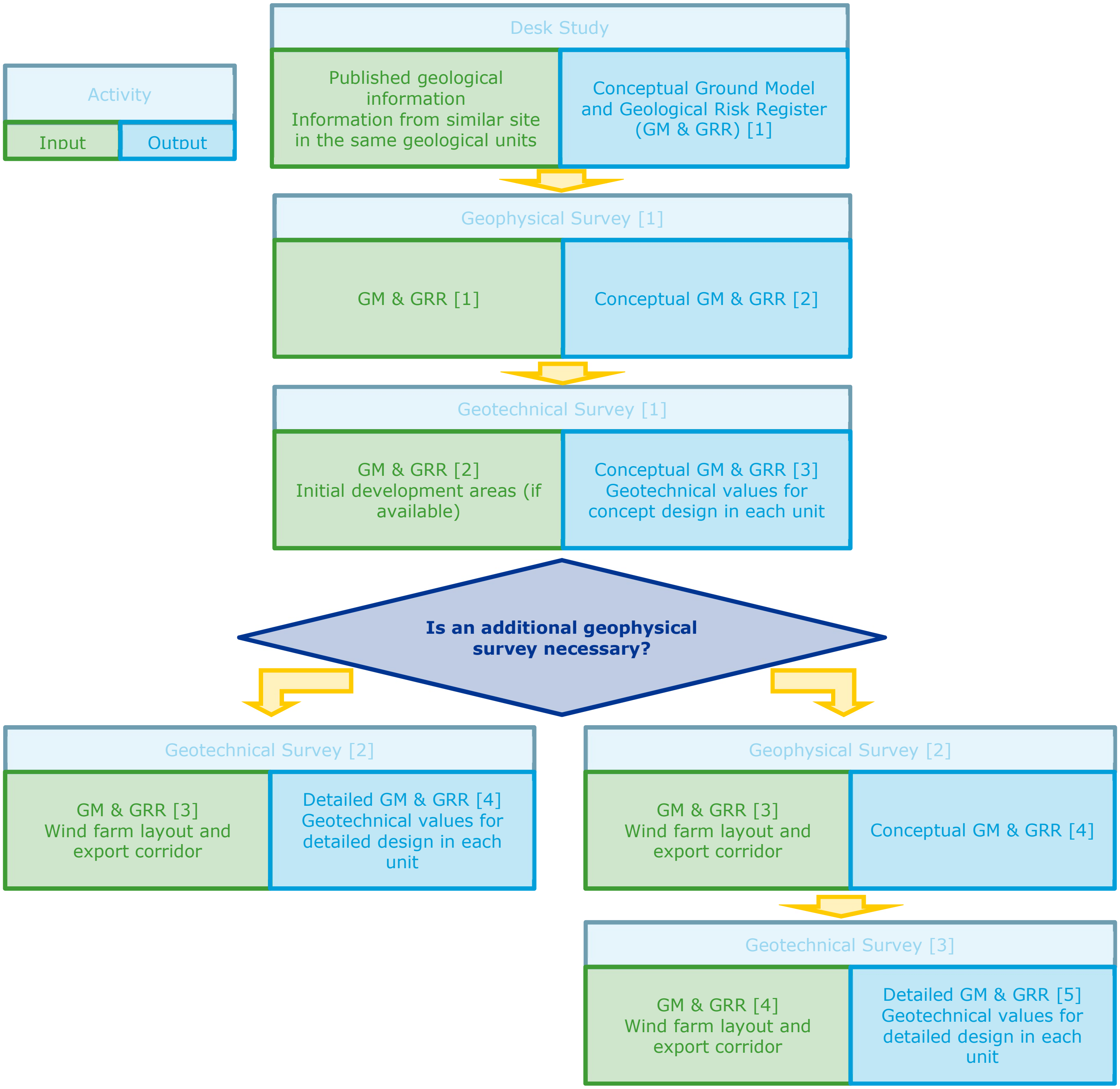

Figure 4-1 Typical process of geological survey

4.2 Current Technologies of Investigation

As previously discussed, the development of a geologic model requires the execution of both geophysical and geotechnical investigation campaigns. The current practice within the offshore wind industry is to perform a staged investigation approach, which is generally split into two investigation campaigns, preliminary and detailed. The preliminary investigation will typically focus on geophysical surveys of the entire offshore wind facility area and the likely export cable route, albeit with a broader grid spacing given that the project does not likely know the foundation solution or offshore wind facility layout. In addition, a limited number of geotechnical investigations will be performed to assist in developing the ground model, i.e. truthing the geophysical data, and to allow for a preliminary characterization of the site to narrow down foundation choice and rough dimensions. Detailed investigations will be performed once the foundation type is selected and the offshore wind facility layout is known. This phase will focus almost entirely on geotechnical investigations, although it is also common to include more detailed geophysical surveys along the foundation locations to better identify potential hazards. This phase will also typically include a geotechnical investigation of the chosen export cable route.

The following section will provide a summary of the current technologies which are often employed in support of offshore wind facility development for either the preliminary or detailed investigation campaigns. This is not meant to be an exhaustive list and, depending on the challenges of a project, may require use of non-typical technologies not described herein.

The geophysical surveys are typically used to identify or differentiate the following:

- Seabed bathymetry;
- Seabed condition (clay, sand, gravel or bedrock);
- Seabed obstructions (debris, boulders, existing structures or UXO);
- Seabed surface structures (ice gouges, sand waves or gas pockmarks);
- Seabed mobility;
- Archeologically/historically sensitive areas;
- Environmentally sensitive areas;
- Seabed ecology;
- Sub-seabed geology; and
- Geohazards (slope stability, faults, shallow gas).

Geophysical data is collected by towing a device, most commonly an acoustic instrument, which emits a sound wave and measures the response time for the returning sound wave after reflecting from the seabed. By utilizing sound waves of various frequency and loudness, detailed analysis of the measured response allows for correlation to various seabed, or sub-seabed, characteristics. Table 4-2 provides a list of the most common types of acoustic equipment and their corresponding applications.

Table 4-2 Summary of Geophysical Instruments

Instrument	Best For	Current Technology
Echo Sounders	Bathymetry and Seabed Topography (incl. Sand Waves)	Single or multibeam devices often mounted directly to the hull of the vessel. Multibeam, or MBES, is the preferable solution except in situations where it is impractical, such as in shallow water.
Side Scan Sonar	Seabed Condition and Features	Frequency dependent instruments which offer both single or dual channel operations. Dual channel, 100/400kHz systems are most often employed.
Sub-bottom Profilers	Shallow Seabed Geologic Profiling	These are single channel seismic survey devices (Pinger, Chirp, Spark or Airgun) used primarily to identify the near surface soils (0-5m) and shallow seabed soils (5-30m), but may achieve up to 100m depths depending on the soil. They typically operate between 50-8000Hz and the choice of instrument will depend greatly on the anticipated site conditions.
Multichannel Seismic	Shallow to Medium Seabed Geologic Profiling	These typically consist of towed sparkers or boomers together with a towed receiver array used to identify shallow to medium depth soil in the range of 30-100m.
Magnetometer	Identification of Ferrous Materials (buried cables/pipelines, shipwrecks, unexploded ordinance, etc.)	These are often used to compliment the side scan sonar surveys to better understand the presence of surface of buried objects. These are towed very closely to the seabed (<6m) and often consist of dual magnetometers operating in gradiometer mode.

For information on the planning, selection, positioning, management and interpretation of geophysical surveys, please refer to (Offshore Site Investigation and Geotechnics Committee, 2014).

Unlike geophysical surveys, geotechnical investigations rely on intrusive methods to measure and/or sample the ground conditions. A geotechnical investigation, such as a boring or Cone Penetration Test (CPT), is performed at a specific location to better define the geologic and geotechnical conditions with depth. Although its lateral extent is very limited, combining the specific knowledge of a geotechnical investigation, together with the correlated knowledge of geophysical surveys, allows for a robust and detailed ground model. As such, it is important that the geophysical surveys are used to identify data gaps or areas of uncertainty in which the geotechnical investigation can capture. Thus, the goal of the geotechnical campaign is to provide all relevant ground data required for a detailed geotechnical design of the chosen foundation. This is achieved by the execution of drilling and sampling campaigns, which allow for detailed inspection and testing of the collected soils or rocks, as well as detailed in-situ testing, such as CPT. Together, these two investigation approaches should ultimately allow for a detailed summary of the following engineering parameters for all relevant geologic units:

- Geologic Classification;

- Index Properties (e.g. unit weight, grain-size distribution, Atterberg limits, density, carbonate content etc.);
- Rock Mass Classification (e.g. RQD, RMR, Q-system, etc.);
- Strength Properties (e.g. undrained shear strength, friction angle, unconfined compressive strength, etc.);
- Stiffness & Damping Properties;
- Permeability & Consolidation Parameters; and
- Shear Wave Velocities.

To achieve these geotechnical parameters, a whole suite of in-situ tools and laboratory testing devices have been developed over the years. Table 4-3 provides a summary of the most commonly employed geotechnical investigations for offshore wind facilities.

Table 4-3 Summary of Geotechnical Investigations

Investigation	Best For	Current Technology
Surface Sampling	Capturing surface and near surface soil samples.	These surface sampling tools typically consist of gravity cores, but may also utilize vibrocores or box cores. These are most often employed during the geophysical campaign as a means to provide ground truthing data.
Geotechnical Boring	Sampling of soil at specified depths.	The most common geotechnical drilling systems utilize a 76mm sampling tools and are often employed on either a jack-up rig or a heave-compensated drilling vessel.
Rock Coring	Continuous core samples of rock.	These are rotary coring systems, such as the Geobor-S, which allows for continues, 100mm diameter sampling of rock or even very hard soils.
Cone Penetration Testing (CPT)	In-situ, continuous soil resistance profile (tip resistance, sleeve friction and pore pressure readings) which can be used to correlate to soil type, strength and stiffness parameters.	There are several CPT systems available which range in thrust capacity between 50-200kN. To achieve sufficient depth for foundation development, 200kN CPT rigs are recommended. However, for cable route investigations, lighter CPT rigs may be sufficient. Piezocones, also referred to as CPTu, are the preferred tool as it measures pore water pressure and can be used to perform dissipation tests.
Seismic CPT	In-situ shear and compression wave logging for use in correlating soil density and stiffness.	Similar to traditional CPT or CPTu tools, however these include geophone sensors which measure both shear (s) and compression (p) waves which are induced at the seabed surface.
P-S Suspension Logging	In-situ shear and compression wave logging for use in correlating soil density and stiffness.	A P-S suspension logging tool can be lowered down into a geotechnical boring and used to record both P & S waves. The tool includes both the source driver and recording geophones.
In-Situ Vane Shear Test	In-situ undrained shear strength.	These can be deployed both at the seabed, as well as within a geotechnical boring. Typically, they are

Investigation	Best For	Current Technology
		pushed 0.5m into the soil before an undrained shear test is performed. Additional shear testing provides remolded undrained shear strength measurements as well.
High Pressure Dilatometer / Pressuremeter	In-situ stiffness measurements for stiff soils or rock.	These are in-situ tests which are deployed in a geotechnical boring (or utilize self-boring techniques) and mobilize the soil or rock laterally be incrementally expanding a membrane. These tools directly measure a load-displacement curve, thereby deriving the soil stiffness.

4.3 Foundation Types

Offshore wind facility foundations will vary from project to project, even location to location, depending on the ground conditions, structural design limitations and construction limitations. Preliminary geotechnical surveys should provide sufficient information to enable foundation selection for concept design without risk of major changes after the detailed geotechnical survey.

The overall geotechnical survey (total works from both preliminary to detailed phase) typically includes one continuous CPT at every foundation location such that a design soil stratigraphy and engineering soil properties could be defined to the extent and depth of influence of each foundation. In addition, enough high-quality boreholes will be necessary to adequately correlate the CPT data to engineering properties. Where lateral and vertical soil variability is significant though, additional CPTs and boreholes are required to mitigate uncertainties in the design. Alternatively, where lateral and vertical soil variability is minimal, less CPTs and boreholes can be justified provided sufficient evidence of homogenous soil conditions are presented (for example from the detailed geophysical survey).

Definitions of typical offshore wind facility foundation types with corresponding site investigation recommendations are summarized in Table 4-4. The recommendations are for guidance and need not to be strictly adhered to as ground variability or ground homogeneity will govern the site investigation program.

Table 4-4 Site investigation for typical offshore wind turbine foundation types

Foundation type	Description	Site investigation recommendations
Gravity base	Gravity base foundations are typically a concrete base slab with short skirts. To resist large lateral forces and overturning moments, the foundation footprint can be large and may require additional ballast systems. The foundation capacity is governed by the ground conditions, foundation width and skirt depth.	The field investigation should include one continuous CPT and one borehole per foundation to a depth below skirt tip level of at least 1.5 times the width of the foundation or to the depth of any critical shear surfaces. For a base covering a large area, additional CPTs should be carried out to the extents of the base to identify any changes in ground stratigraphy below the base. If different units are identified in the additional CPTs then

Foundation type	Description	Site investigation recommendations
		additional borings should be carried out to collect samples for testing.
Monopiles	Monopiles are large diameter short steel piles which are predominantly subject to lateral loading. The wind turbine tower is connected directing to the top of the monopile. Lateral capacity and stiffness behavior of the pile is governed by the ground conditions and the pile embedment length.	One continuous CPT at the monopile location to 0.5 times the diameter below the pile toe is typical. Enough high-quality boreholes spread around the facility area will be necessary to adequately correlate the CPT data to engineering properties. At highly variable sites, more sampling boreholes should be carried out in in addition to the CPT, to define a representative design ground profile. Seismic CPTs should also be considered for in-situ small strain stiffness measurements.
Jacket piles	Jacket structures can have 3 or 4 legs supported by long steel piles. The jacket structure transfers the environmental loads to the piles such that they are under predominantly axial compression and tension loading through push-pull effect. Axial pile capacity is governed by the ground conditions and pile embedment length.	For the detailed design of jacket piles, one continuous CPT per turbine location with sufficient boreholes to correlate the CPT data. If there exists significant lateral variability of geological units over the jacket footprint, particularly near the pile tip, additional borings may need to be carried out to characterize the properties of different units. For piles which rely heavily on the end bearing, investigations should extend to a depth which excludes the possibility for punch-through failure.
Suction installed caissons	Suction buckets are used to support mono-towers or 3 to 4 leg jacket structures. For tension capacity, the buckets rely on the weight of the soil plug encapsulated within the bucket and the slow rate of suction dissipation during a storm. The suction bucket capacity is governed by the ground conditions and bucket dimensions.	One CPT per bucket with one borehole at the turbine site adjacent to a CPT is typical. These are to extend below the bucket tip by at least 1.5 times the diameter. If there exists significant lateral variability of geological units over the jacket footprint, additional borings may need to be carried out to characterize the properties of different units.
Anchors for floating towers	Floating wind turbines require a permanent mooring system such as suction anchor piles or fluke anchors to keep the floater in place. A mooring system are typically catenary and include 3 or more anchors.	Due to the distance between anchors, one CPT is expected at each anchor location to a depth of approximately 1.5 times the diameter of the suction anchor or the installation depth of a fluke anchor.

4.4 Current Technologies of Foundation Construction

This section provides a common understanding of typical construction techniques involved with the various foundation solutions utilized in offshore wind facilities. The intention of Table 4-5 is to provide a summary of the main construction steps together with relevant techniques, where applicable.

Table 4-5: Typical offshore wind turbine foundation installation techniques

Foundation type	Construction techniques
Gravity Base (GBS)	Preparation of seabed, typically to level the ground prior to installation of the GBS, • Installation of GBS, i.e. lowering in place including penetration of potential skirts or ribs, • Installation of scour protection, typically rock dumping, placement of concrete matresses

Monopiles	• Monopile installation using impact hammers or vibratory hammers,
	• Drilling and grouting of monopile, typically in rock and hard soils,
	  ○ Open hole drilling or under-reaming drilling
	  ○ Annular space grouting/pile-grout connection
	• Installation of transition piece
	  ○ Grouted connection
	  ○ Bolted connection
	• Installation of scour protection (if required), typically rock dumping

Jacket piles	• Pre-installed piles
	  ○ Installation of piles
	  ○ Landing of jacket on pre-installed piles
	  ○ Grouted connections
	• Piles installed through jacket legs or pile sleeves
	  ○ Landing of mudmats
	  ○ Mudmat skirt penetration
	  ○ Installation of piles
	  ○ Grouted connection
	• Pile installation
	  ○ Pile driving using impact hammers or vibratory hammers,
	  ○ Drilling and grouting of piles, typically in rock and hard soils,
	    ▪ Open hole drilling or under-reaming drilling
	    ▪ Annular space grouting/pile-grout connection
	• Installation of scour protection (if required), typically rock dumping

Suction installed caissons	• Lowering through splash zone and impact on seabed • Self-penetration of suction caisson • Required suction for installation to target penetration • Levelling of foundations • Installation of scour protection, typically rock dumping
Anchors for floating towers	• Driven piles • Suction installed caissons • Fluke anchors • Drag installed to sufficient holding capacity

5 PART 2B: EXAMPLES

The following examples show how the methodology described can be applied in different situations to produce a ground model that suitable for use in the COP. The various tables and figures are examples of approaches commonly adopted; these are however not prescriptive and the developer is free to adopt their preferred approach.

5.1 Atlantic Shallow Water Site

A developer has a Permitted Site Area, that they intend to develop as three 200-300 MW projects. Provisional Project Zones have been identified based on wind resources, bathymetry and marine traffic. They must conduct some geophysical survey to obtain more detailed knowledge on the bathymetry and ground conditions, and complete the shallow hazards survey requirements for the SAP and COP. Additionally, some geotechnical survey is necessary to inform the preliminary engineering and COP.

Stage 1: Initial Desktop study ground model

From publicly available data, the initial conceptual site / ground model can be identified as indicated in Figure 4-1.and Table 5-1. This has been derived from the pertinent geological information:

Folger, D. W., & Needell, S. W. (1983). *U.S. Geological Survey Program of Offshore Resource and Geoenvironmental Studies, Atlantic-Gulf of Mexico Region, from September 1, 1976 to December 31 1978.* Geological Survey Circular 870: U.S. Department of the Interior.

Foster, D. S., Swift, A., & Schwab, W. C. (1999). *Stratigraphic Framework Maps of the Nearshore Area of Southern Long Island from Fire Island to Montauk Point.* U.S. Geological Survey Open File Report 99-559.

Perlmutter, N. M., & Geraghty, J. J. (1963). *Geology and Ground Water Conditions in Southern Nassau and Southeastern Queens Counties Long Island, N. Y.* U.S Department of the Interior.

Table 5-1 Stratigraphic units in the region

Age	Unit	Description
Quaternary 0 to 3m (6.5ft)	Holocene: Surficial Sand	Mobile sand fine grained, well sorted, and are thought to be highly mobile.
Quaternary – Pleistocene glacial deposits 0 to 60m (ft 197ft) (uncertain)	Upper Pleistocene (Paleo channels)	Glacial outwash deposits with fluvial glacial deposits in paleochannels running from the coast.
	Gardiners Clay	Marine greyish green clay with occasional sand and silt layers. Can contain shells and peat. Deposited in shallow bays and estuaries. Tough and compact.
	Jameco Gravel	Dark brown and dark grey gravel and cobble in granular matrix – some clay silt lenses.
Cretaceous 300 to +400 m (984-1312 ft) (uncertain)	Monmouth Group	Greenish back glauconitic and lignitic clay, silt clay and silty sand.
	Matawan Group / Magothy Formation (Undifferentiated)	Grey and white fine to coarse sand with some clay.

Age	Unit	Description
	Raritan Formation	thinly bedded, dark-gray, micaceous clay and fine-grained, light-colored, micaceous quartz sand of marine and non-marine origin. Some lignitized wood, and reddish-brown secondary cementation is common in the strata of this interval.
Paleozoic / pre cambrian Bedrock	Undifferentiated	Metamorphic and granite bedrock.

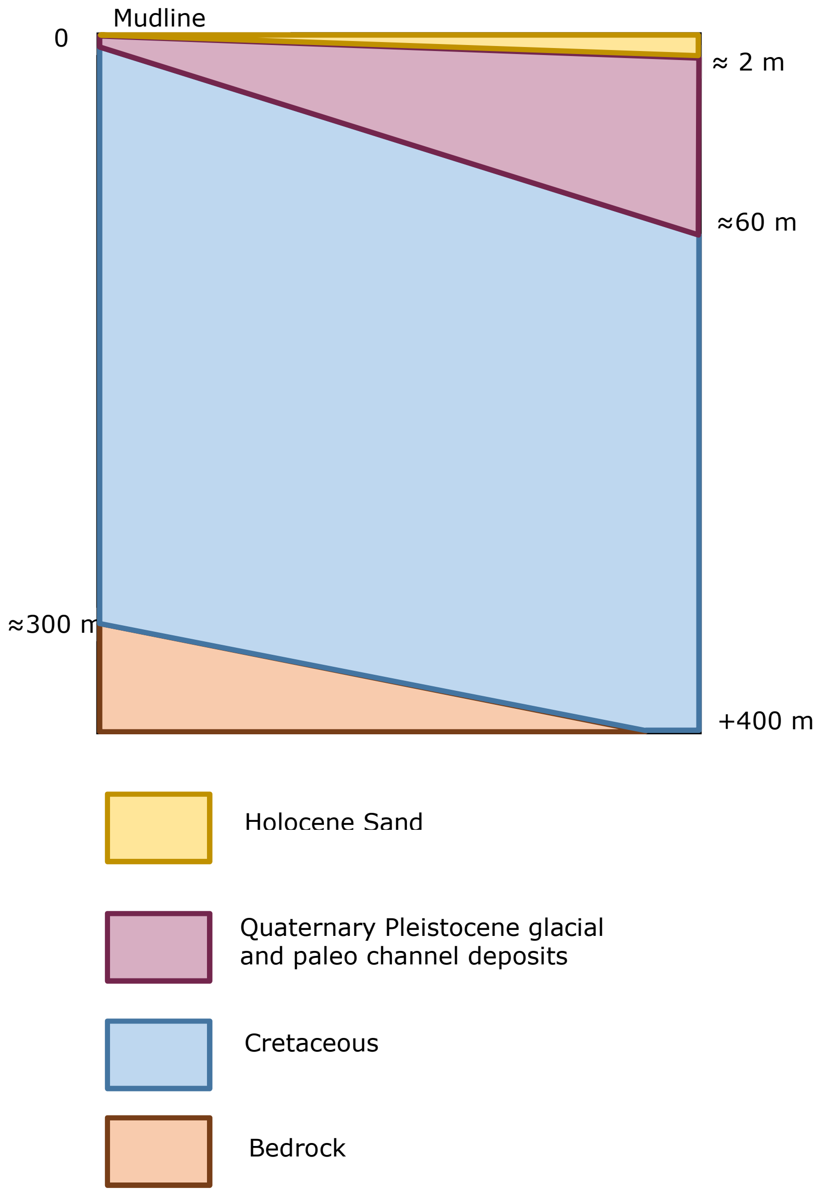

Figure 5-1 Assumed geological profile from published information

Quaternary – Holocene Surficial Sand

Modern sand deposits are reported as fine grained, well sorted, and are likely to be highly mobile. An isopach map (Foster, Swift, & Schwab, 1999) shows of the modern marine sand units as a series of sand ridges along the southern nearshore area of the southern edge of Long Island. Between the ridges the modern sand is thin to not present. The sand ridges are typically up to 5m, and run perpendicular to the long island coast. The data does not extend to the wind farm zones, however there is the potential for these sand waves to extend to the wind farm site.

Quaternary – Pleistocene glacial deposits

Anticipated to be till from the melting Laurentide ice sheet during interglacial periods. The deposits are thought to be predominantly from two glaciations (two drift sheets with morainal features), and marine beds that represent three warm intervals. The older drift predates 42,000 BP and is assigned to the early Wisconsinan, and Illinoian age. The structure may be affected by scoured valleys, moraines, eskers, and glacial-tectonic features (sheared sediments with planes of weakness). There is the potential of some paleo channels incised into the older Pleistocene deposits and underlying cretaceous deposits filled with a more recent transgressive sequence of glaciofluvial sediment.

The thickness of the deposits at the site are highly uncertain, but are interpreted from (Perlmutter & Geraghty, 1963) (Folger & Needell, 1983) (Foster, Swift, & Schwab, 1999).

Cretaceous – Sedimentary deposits

The cretaceous strata dominate the geological profile, potentially being up to 100% of the foundation zone of interest. These are marine and non-marine sedimentary deposits that have been identified and described from studies closer to the shore than the project site. It is assumed that the geotechnical nature of the units is consistent offshore to the Project Zone.

Paleozoic / Precambrian Bedrock

The bedrock is anticipated to be below the depth of interest; however, it is considered stable and not at risk of earthquakes. Igneous intrusions are not anticipated.

Table 5-2 High level geological risks

Geological Formation	Potential Geohazard															
	Seismic / liquefaction	Faulting / Structural unconformities	Shallow Gas	Pock marks	Surface boulders	Buried Boulders	Eskers / Moraines	Sink holes	Mud volcanos	Paleo Channels / soft surface sediments	Salt Dome / diapers	Igneous intrusions	Volcanic activity	Gas chimney	Sand waves	Sand banks	Large scale seabed movement
Surficial Sand					X										X	X	X
Upper Pleistocene (Paleo channels)			X		X	X	X			X							X
Gardiners Clay			X				X										
Jameco Gravel						X	X										
Monmouth Group																	
Matawan Group / Magothy Formation																	
Bedrock		X										X					

The key aims of the preliminary geological (geophysical and geotechnical) surveys are:

- Confirm stratification;
- Provide quantification of geotechnical parameters for units for preliminary analysis; and
- Evaluate key ground risks;
  - Cementation of the Cretaceous units
  - Provide project specific bathymetry for estimation of mobile sediment
  - Confirm presence of paleo channels, and whether they contain noxious gasses
  - Nature and depth of Jameco gravel
  - Extent of boulders in Pleistocene
  - Locations of and moraines / esker.

As there is no site-specific data it is not possible to differentiate any particular zones or locations of geological hazards. As such the provisional Project Zone are based on the published information such as bathymetry and wind speeds, shipping routes, and protected areas. The anticipated foundation types are shown in Table 5-3.

Table 5-3 Summary of high level foundation feasibility

Project	Water depth [m]	Soil / Rock	Monopile	Jackets	GBS
Project A	20-30	Soil unknown strength	X		X
Project B	45-75	Soil unknown strength	X	X	X
Project C	60-80	Soil unknown strength		X	X

Stage 2: Preliminary Geophysical Survey & Ground Model Update

A preliminary geophysical survey is specified to confirm the Permitted Site Area's bathymetry and allow for differentiation of geological zones. The geophysical survey grid is shown in Figure 5-2. Example is 200 m coverage at 500 m to 1 km spacing with cross lines at 3-5 km spacing. Spacing depends on size of area and homogeneity of the ground conditions.

The geophysical survey will comprise of:

- Sub bottom profiler from a shallow and deep source (e.g., Sparker and Chirper);
- Magnetometer data to identify any debris;
- MBES for bathymetry concept design; and
- SSS to identify seabed type.

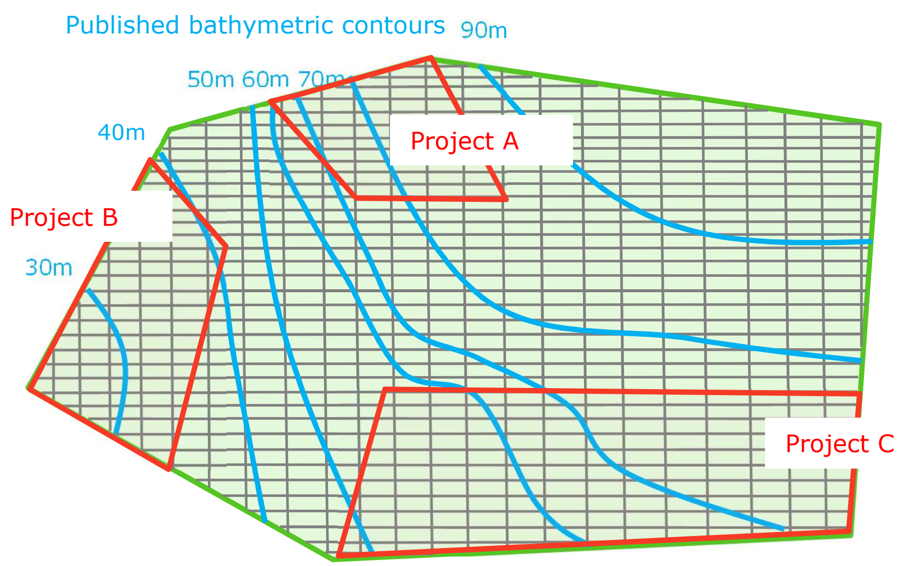

Figure 5-2. geophysical survey grid

The ground model and geological risk register are updated based on the preliminary geophysical site specific information as shown in Figure 5-3.

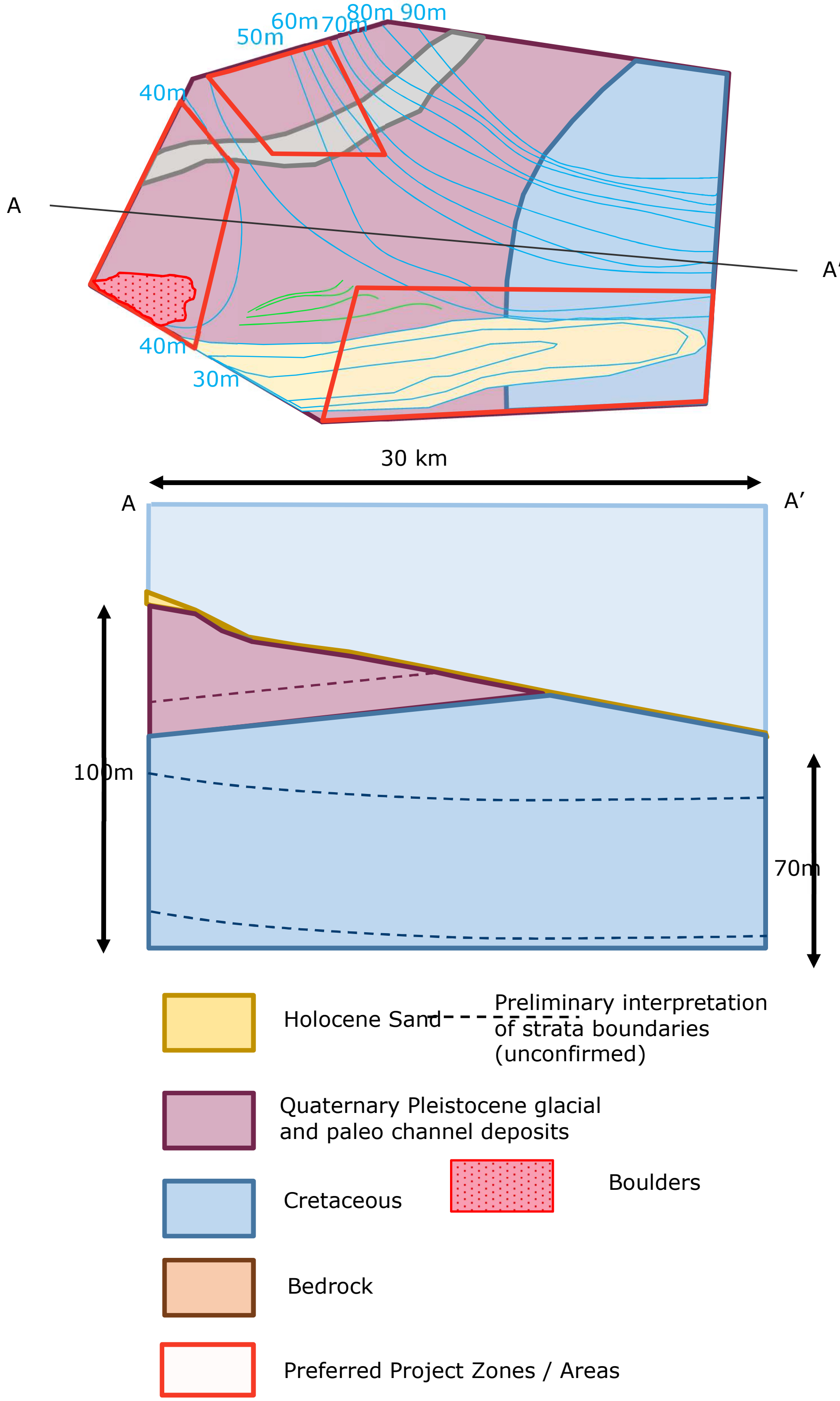

Figure 5-3 Project Zone ground model based on preliminary geophysical data

Table 5-4 Geological Risk Register for Project C

Hazard Identified	Receptor Activity				Description and Consequence	Recommended Action	Residual Hazard
	Investigation	Design	Construction	Operation			
Sand waves	X	X	X	X	Sand waves lead to a variable and changing sea bed surface. If not accounted for they could adversely affect the design of an offshore structure and subsea cable. Identified in Project Zone C.	Collate published bathymetry data. Plan future geophysical survey to quantify movement. If the areas are developed, a comprehensive seabed mobility assessment will be needed.	Ongoing surveys may be needed during operation to validate design assumptions. If movement is inadequately quantified the stability of the assets if put at risk, and worst case a remediation campaign is anticipated.
Sand Bank		X	X	X	Sand bank identified in Project Zone C. Sand bank anticipated to be comprised of Holocene sand. If mobile under storms or normal met ocean condones could reduce embedment of foundations and cables.	Use preliminary geotechnical survey to investigation the composition of the sand bank. Plan future geophysical survey to quantify movement.	If movement is large, then layout will be affected. If movement is inadequately quantified the stability of the assets if put at risk, and worst case early decommissioning or remediation campaign.
Buried boulders	X		X		Buried boulders in foundation depth (particularly Jameco gravel) can lead to refusal of drilling, foundations buckling, cable damager during installation	Size, composition, density and location critical in defining risk. Calibrate geophysical interpretation and composition with geotechnical survey. Identify any onshore exposed deposits to quantify boulder density.	Density and nature of boulders will inform foundation decisions. Further high resolution sub bottom geophysical survey anticipated in project specific zone.
Shallow gas in channel features	X		X		Volume of toxic gas released. Can be noxious, cause buoyancy issues, explosive. Reduces geotechnical parameters	Gas blanking observed, geotechnical testing to identify gases. Geotechnical testing to confirm impact of dissolved gasses on geotechnical properties.	Hazard during geotechnical survey to be managed by contractor. Action for project results of testing. Either can be managed, or areas must be avoided.
Surface boulders					Obstruction for cables and foundations	Project specific 100% coverage geophysical survey.	Hazard remains, but locations are known. Cost benefit on avoidance vs boulder removal or sea bed preparation campaign.

Hazard Identified	Receptor Activity				Description and Consequence	Recommended Action	Residual Hazard
	Investigation	Design	Construction	Operation			
Unconfirmed stratification		X	X		Uncertainties in the stratification inadequate basis for project and foundation design.	Validation and calibration of preliminary geophysical survey with geotechnical investigation to adequate depth spaced across the Permitted Site Area.	Preliminary surveys have relatively large resolution. Either more detailed project / location specific geotechnical survey for detailed design, or better resolution geophysical data necessary. Project specific survey design at later stage of development.
Geotechnical parameters		X	X		Poor understanding of geotechnical parameters leads to uneconomic range between upper and lower bound and in adequate knowledge for detailed design and installation assessments.	Gap analysis to identify properties and testing for concept design. Geotechnical testing of each soil unit.	No location specific parameters, large range between upper and lower bounds. Project specific survey design at later stage of development.

Stage 3: Preliminary Geotechnical Survey & Ground Model Update

From the preliminary geological risk register the preliminary geotechnical survey is required to;

- Calibrate the geophysical sub bottom survey;
- Confirm gas composition if present in paleo channel;
- Provide geotechnical data for each unit for preliminary engineering activities;
- Provide geotechnical data for concept design; and
- Confirm composition of sand bank in Project C.

An example high level specification could include;

- 14 Boreholes with alternate CPTu and down the hole sampling. Distributed in the Project Zones, in each geological unit and in the Permitted Site Area as shown in Figure 5-4. The number and location of investigation points should be determined by an experienced geotechnical engineer; it should consider the variation of geology, size of the project, foundation types and geological risks.
- Boreholes to a depth of at least 60 meters in Project Zone A, 80 meters in Project Zone B and C, or 90 meters from the top of the sand bank. This variation is due to variation in the foundation depth; identifying the depth of the lowest geological unit; evaluate the geotechnical properties of the lowest geological unit of interest.

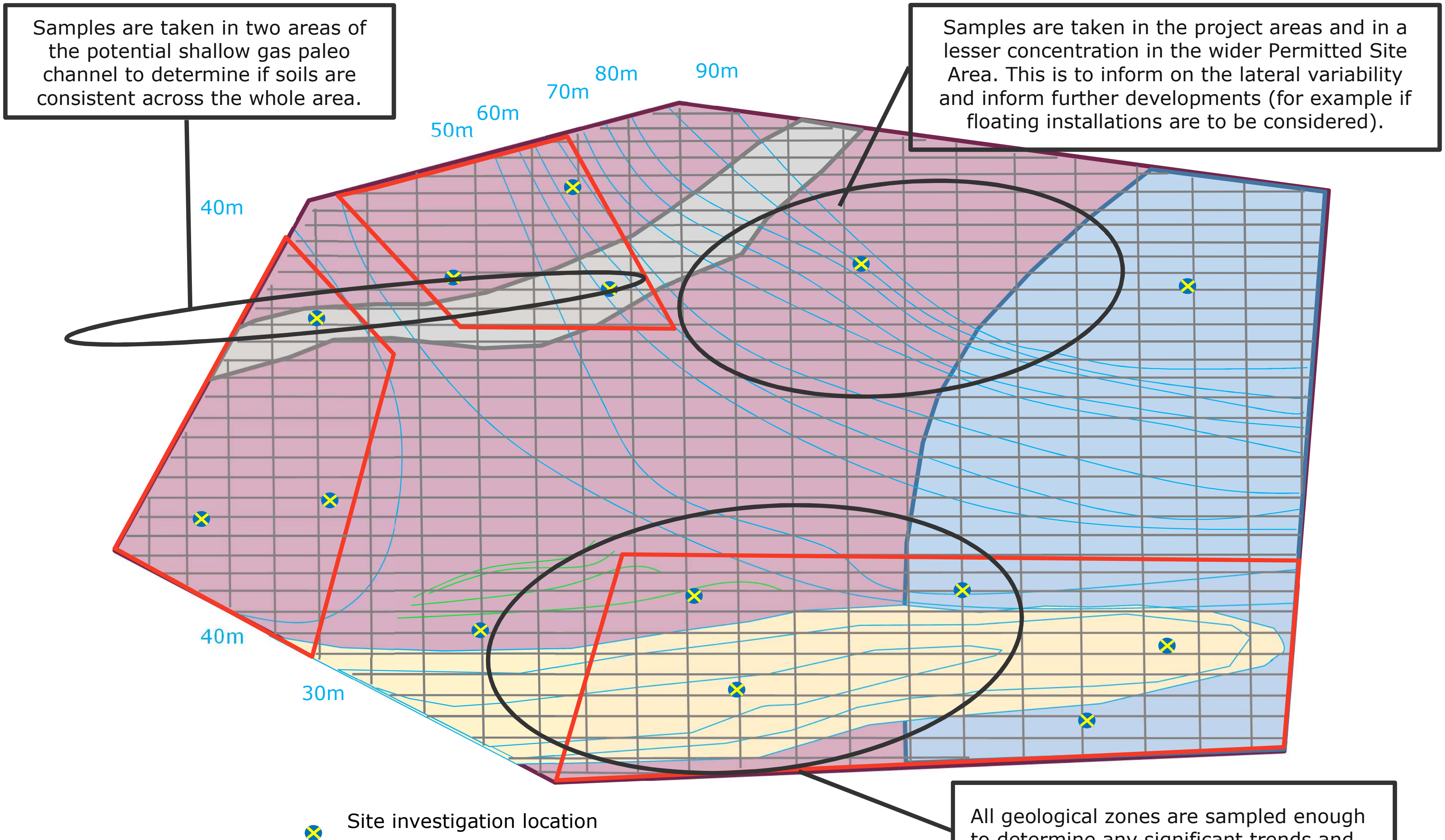

Figure 5-4 Proposed preliminary site investigation

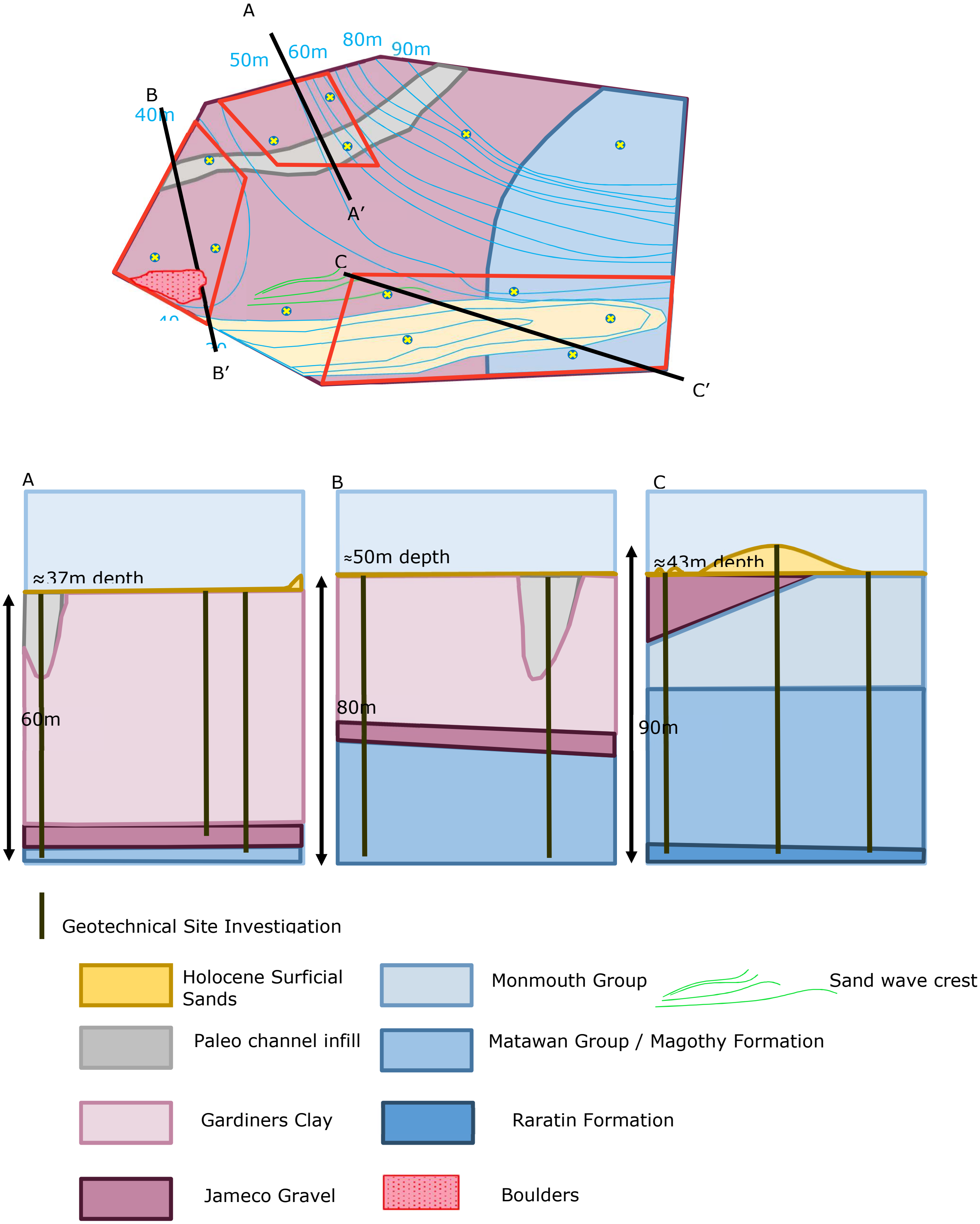

Figure 5-5 Example geotechnical cross sections

Based on the survey results project specific ground models containing the distribution of strata (2D or 3D), geotechnical properties and a geological risk register may then be determined. Examples of part of these components are shown in Figure 5-5, Table 5-2 and Table 5-6, and an example table of contents is outlined in Appendix A.

It should be noted that the geotechnical parameters included for these geological units are fictional and are not based on testing.

Table 5-5 Key geotechnical properties for geological units

Material	**Unit Weight γ' kN/m³**	**Strength**			**Stiffness**
		Qc MPa	**Friction Angle Φ°**	**Undrained Shear Strength Su kPa**	**Strain at half the deviator stress E_{50} %**
Holocene: Surficial Sand	9.2	10-30	24		
Upper Pleistocene Paleo channels	8.4	0.225-1.2		15-80	0.02
Gardiners Clay	9.8	2.25-4.5		150-300	0.004
Jameco Gravel	10.2	80->100	42		
Monmouth Group fine grained	9.4	3.75-9		250-600	0.002
Monmouth Group coarse	9.4	40	32		
Matawan Group / Magothy Formation (Undifferentiated)	9.6	60	35		
Raritan Formation	10.1	6-12		400-800	0.001

Table 5-6 Geological risk register [2] post geotechnical survey

Hazard Identified	Receptor Activity				Description and Consequence	Recommended Action	Residual Hazard
	Investigation	Design	Construction	Operation			
Sand waves	X	X	X	X	Sand waves lead to a variable and changing sea bed surface. If not accounted for they could adversely affect the design of an offshore structure and sub-sea cable. Identified in Project Zone C.	Collate published bathymetry data. Plan future geophysical survey to quantify movement. If the areas are developed, a comprehensive seabed mobility assessment will be needed.	Ongoing surveys may be needed during operation to validate design assumptions. If movement is inadequately quantified the stability of the assets if put at risk, and worst case a remediation campaign is anticipated.
Sand Bank		X	X	X	Sand bank identified in Project Zone C. Sand bank comprised of Holocene sand. If mobile under storms or normal met ocean condones could reduce embedment of foundations and cables.	~~Use preliminary geotechnical survey to investigation the composition of the sand bank.~~ Plan future geophysical survey to quantify movement.	If movement is large, then layout will be affected. If movement is inadequately quantified the stability of the assets if put at risk, and worst case early decommissioning or remediation campaign.
Buried boulders	X		X		Buried boulders in foundation depth (particularly Jameco gravel) can lead to refusal of drilling, foundations buckling, cable damager during installation. No large boulders encountered in geotechnical campaign. Boulder density onshore mapped as 1 boulder over 20cm diameter per XXX m3.	Size, composition, density and location critical in defining risk. Use UHR survey or sonic corer at WTG locations to assess in situ risk. ~~Calibrate geophysical interpretation and composition with geotechnical survey.~~ ~~Identify any onshore exposed deposits to quantify boulder density~~ .	Density and nature of boulders will inform foundation decisions. Further high resolution sub bottom geophysical survey anticipated in project specific zone.
Shallow gas in channel features	X		X		Volume of toxic gas released. Can be noxious, cause buoyancy issues, explosive. Reduces geotechnical parameters. Gas confirmed, H_2S and CO.	~~Gas blanking observed, geotechnical testing to identify gases.~~ ~~Geotechnical testing to confirm impact of dissolved gasses on geotechnical properties.~~ Avoid construction in Paleo-channels on HSE risk basis. Foundation likely to be very large also as low geotechnical parameters.	~~Hazard during geotechnical survey to be managed by contractor.~~ ~~Action for project results of testing.~~ ~~Either can be managed, or areas must be avoided.~~ Negligible as geohazard avoided.

Hazard Identified	Receptor Activity				Description and Consequence	Recommended Action	Residual Hazard
	Investigation	Design	Construction	Operation			
Surface boulders					Obstruction for cables and foundations	Project specific 100% coverage geophysical survey.	Hazard remains, but locations are known. Cost benefit on avoidance vs boulder removal or sea bed preparation campaign.
Un confirmed stratification		X	X		Uncertainties in the stratification inadequate basis for project and foundation design. Medium accuracy of stratification along surveyed lines and close to site investigation locations. No critical strata (such as rock head).	~~Validation and calibration of preliminary geophysical survey with geotechnical boreholes to adequate depth spaced across the permitted area.~~	Preliminary surveys have relatively large resolution. Either more detailed project / location specific geotechnical survey for detailed design, or better resolution geophysical data necessary. Project specific survey design at later stage of development.
Geotechnical parameters		X	X		Poor understanding of geotechnical parameters leads to uneconomic range between upper and lower bound and in adequate knowledge for detailed design and installation assessments. Site specific geotechnical properties estimated with statistical methods. Concept design is able to progress with range of geotechnical parameters, and to be demonstrated to be within project design envelope.	Gap analysis to identify properties and testing for ~~concept~~ detailed design. Further geotechnical testing of each soil unit to refined geotechnical range.	No location specific parameters, medium ~~large~~ range between upper and lower bounds. Project specific survey design at later stage of development.

Summary

Initially at the end of stage 1, there was a high level of uncertainty relating to the ground characterization, and there was inadequate information on which to base a concept design that meet the criteria outlined in Part 1: Evaluation Criteria (see Table 5-7 below). After the preliminary surveys at the end of stage 3 there is adequate information to be able to meet the evaluation criteria as per Table 5-8, thus the level of information in the COP would be considered adequate for the technical, environmental and socioeconomic assessments required.

Table 5-7 Evaluation of the initial ground model

Criteria	Detail	Evaluation
Criterion 1: Is there sufficient resolution and confidence in the ground model to;	a. Define the baseline geological conditions of the area directly impacted by the project described in the COP. The area should include the sea bed surface, validation of the depth of the geological units to the maximum depth and lateral extent affected by the project.	**Criteria not met:** The anticipated sequence of the geological units has been described, but the extent has not. For example, the extent of Pleistocene deposits. This is particularly significant as paleo channels may be present which may significantly alter the project design, and health and safety risks. No characterization of the sea bed surface has been made.
	b. Define the baseline geological conditions of any area indirectly affected by the project described in the COP. The description should include the sea bed surface sediments, and may be based on available information at the time of the submission.	**Criteria met:** The regional geology is described in Stage 1: Initial Desktop study ground model which is included in the wider regional characterization included in the Appendices of the COP.
	c. Define any geological units that may contain surface or buried features of archaeological potential.	**Criteria not met:** The anticipated sequence of the geological units has been described, but the extent has not.
Criterion 2: Are the geotechnical characteristics of the pertinent geological unit adequately characterized to;	a. Demonstrate the maximum environmental actions of the proposed project have been established.	**Criteria not met:** The maximum extent of the environmental impacts is unknown. For example, it is not possible known how much sediment may be dispersed in the water column by cable installation as no accurate quantification of Holocene sands if possible. It is no known whether pile driving will be possible in the "tough and compact" Gardiners clay or Jameco gravel, or if it they are present. If drilling is necessary, it is not known what type of sediment will be dispersed into the water column (and hence how far it may travel). It is not possible known how much sediment may be dispersed in the water column by cable installation as no accurate quantification of Holocene sands if possible.
	b. Demonstrate the technical feasibility of the proposed project, and project alternatives, described in the COP. This is to ensure the project does not pose an unacceptable risk to health, safety and the environment.	**Criteria not met:** The level of information does not allow characterization of the geohazards, ground profiles, and geotechnical properties to an adequate level to be able to fully demonstrate concept feasibility. For example, it is not possible to establish whether any areas being developed are at risk of shallow gas.

Table 5-8 Evaluation of the ground model after preliminary surveys

Criteria	Detail	Evaluation
Criterion 1: Is there sufficient resolution and confidence in the ground model to;	a. Define the baseline geological conditions of the area directly impacted by the project described in the COP. The area should include the sea bed surface, validation of the depth of the geological units to the maximum depth and lateral extent affected by the project.	**Criteria met:** The sequence and extent of the geological units has been defined and demonstrated. The seabed surface has been characterized.
	b. Define the baseline geological conditions of any area indirectly affected by the project described in the COP. The description should include the sea bed surface sediments, and may be based on available information at the time of the submission.	**Criteria met:** The regional geology is described in Stage 1: Initial Desktop study ground model which is included in the wider regional characterization included in the Appendices of the COP.
	c. Define any geological units that may contain surface or buried features of archaeological potential.	**Criteria met:** The sequence and extent of the geological units has been defined and demonstrated.
Criterion 2: Are the geotechnical characteristics of the pertinent geological unit adequately characterized to;	a. Demonstrate the maximum environmental actions of the proposed project have been established.	**Criteria met:** The maximum extent of the environmental impacts is known. For example, the amount of sediment on site is known, and the amount and composition of sand banks is known. This is adequate information to base the assessment of hydro-sedimentary dispersion during cable installation on. The geotechnical properties are known for the foundation extent, and hence it is possible to demonstrate that pile driving is possible. A maximum hammer energy has been specified which allows the environmental impact on migratory species to be determined. Drilling may occur during if unexpected refusal occurs, however this is not anticipated to be all locations. The nature of the sediment dispersed during drilling is known. It is not possible known how much sediment may be dispersed in the water column by cable installation as no accurate quantification of Holocene sands if possible.
	b. Demonstrate the technical feasibility of the proposed project, and project alternatives, described in the COP. This is to ensure the project does not pose an unacceptable risk to health, safety and the environment.	**Criteria met:** The extent of the geohazards, ground profiles and geotechnical properties has been evaluated. There is adequate information on which the concept design may be based and adequate information is available to have confidence in the preliminary engineering assessments. The project is able to describe areas that are high health and safety risk which will be avoided during the project layout.

5.2 Gulf of Mexico Site

A developer has a Permitted Site Area, that they intend to develop as one 400 MW project. They have developed projects in the area previously, and have some geotechnical data on the specific soil units. Additionally there is some publicly available geophysical data.

Stage 1: Initial Desk Based Ground Model

From the publicly available data the initial conceptual site / ground model can be identified as indicated in Figure 5-6and Pertinent Geological Information referenced:

Baker, E. T. (1995). *Stratigraphic Nomenclature and Geological Sections of the Gulf COastal Plain of Texas.* Austin, Texas: U.S Department of the Interior - U.S Geological Survey.

Beckman, J. D., & Wlliamson, A. K. (1990). *Salt Dome Locations in the Gulf COastal Plain - SOuthern Central United States.* Austin, Texas: U.S Department of the Interior - U.S Geological Survey.

Bureau of Ocean Energy Management Office of Renewable Energy Programs. (12 January 2018). *Draft Guidance Regarding the Use of a Project Design Envelope in a Construction and Operations Plan.* UNITED STATES DEPARTMENT OF THE INTERIOR.

Folger, D. W., & Needell, S. W. (1983). *U.S. Geological Survey Program of Offshore Rescources and Geoenvironmental Studies, Atlantic-GUl of Mexico Region, from September 1, 1976 tp December 31 1978.* Geological Survey Circular 870: U.S. Department of the Interior.

Foote, R. Q. (1984). *Summary report on the regional geology, petroleum potential, environmental consideration for development, and estimates of undiscovered recoverable oil and gas resources of the United States Gulf of Mexico Continental Margin in the area of proposed Oil a.* U.S. Department of the Interior - U.S. Geological Survey & U.S. Minerals Managment Service.

Foster, D. S., Swift, A., & Schwab, W. C. (1999). *S tratigraphic Framework Maps of the Nearshore Area of Southern Long Island from Fire Island to Montauk Point.* U.S. Geological Survey Open File Report 99-559.

Minerals Managemnt Service. (1983). *Regional Environmental Impact Statement Volume 1: Gulf of Mexico.* Metairie, LA: U.S Department of Interior .

Offshore Site Investigation and Geotechnics Committee. (2014). *Guidance notes for the planning and execution of geophysical and geotechnical ground investigations for offshore renewable energy devleopment.* Society for Underwater Technology.

Perlmutter, N. M., & Geraghty, J. J. (1963). *Geology and Ground Water Conditions in Southern Nassau and Southeastern Queens COunties Long Island, N. Y.* U.S Department of the Interior.

RICE University Gulf of Mexico Research Group. (2005, August 16). *RICE University Gulf of Mexico Research Group: Systems Tracts & Sand Bodies*. Retrieved from http://gulf.rice.edu/

Site specific geophysical and geotechnical data is available from historic site investigation campaigns and interpreted in:

Eckles, B.J., 1996, Late Quaternary Evolution of the Central Texas Shelf: Sequence Stratigraphic Implications: M.A. thesis, Rice University, Houston, 119 p.

Eckles, B.J., M.L. Fassell, and J.B. Anderson, 2004, Late Quaternary Evolution of the Wave-Storm-Dominated Central Texas Shelf: Late Quaternary Stratigraphic Evolution of the Northern Gulf of Mexico Margin: SEPM Special Publication No. 79, p. 271-287.

Propriety geotechnical information on the relevant soil units is included from three boreholes in the Central Texas region of the Gulf of Mexico; these are not located on the Permitted Site Area.

Table 5-9 Stratigraphic units in the region

Periods	Unit	Description
Quaternary: Holocene & Late Pleistocene Top 30-50 meters	Mud Unit 4	Texas Mud Blanket – Soft clay
	Sand unit 3	Sand
	Mud Unit 4	Texas Mud Blanket - Soft Clay
Early Neogene: Pliocene to Late Pleistocene 50m to up to 1km (proven to 200m)	Beaument Clay, Lissie formation & Goliad & Willis Sand	Soft fine grained soil (to at least 200m), followed by stratified silts, sand and clay.
Late Neogene to Paleogene Over 1km	Miocene – Flemming formation to Jackson group Oligocene - Jackson Group Eocene -Wilcox & Claborne Group Paleocene – Midway Group	Clastic sediments. Potential hydrocarbon bearing rock strata
Cretaceous	Narcaro Group to Durango Group	Clastic sediments. Potential hydrocarbon bearing rock strata
Jurassic >11km	Upper Jurassic- Gilmer Limestone to Norphlet Formation	Clastic sediments. Potential hydrocarbon bearing rock strata
	Middle Jurassic	Evaporitic formation of Louann Salt: Base of salt dome formation.

Quaternary – Holocene & Late Pleistocene

Early Quaternary Highstand (125,000 to 40,000 ybp), near shore side of site experienced deposition of sands during stage 5d, the lateral extent of this unconfirmed in north / south direction. During stage 3 (late Highstand) the deposition of muds across the site commenced.

The Lowstand systems tract (40,000 to 16,000 ybp) consists of incised fluvial valleys / incisions and slope canyons across the site. Valley / incision depths decrease offshore. These valleys bifurcate, shallow, and become narrower channels offshore. The fluvial sediments that were transported likely bypassed the shelf, feeding the Lowstand slope fans. No significant deposition anticipated.

During the last transgressive (15,000 years to present) is carpeted by transgressive marine muds of the "Texas Mud Blanket" up to 40m in depth (Shideler, 1976). These muds onlap and bury the earlier sandy Highstand coastal deposits on the west of the site.

Pliocene to Late Pleistocene

During this period the experienced continual series of deposition with eroded sediment transported from onshore. Stratified thick deposits of sand silt and clay units are anticipated.

Early Neogene to Late Cretaceous

During this period the experienced continual series of deposition with eroded sediment transported from onshore. Stratified and cemented thick deposits of sand silt and clay units are anticipated that form Clastic deposits of sandstones, silt stones and shale.

Jurassic

Geological units that formed the salt domes are deposited in this time. The extent of the salt domes is reported as precluding the site from being at risk (Beckman & Wlliamson, 1990).

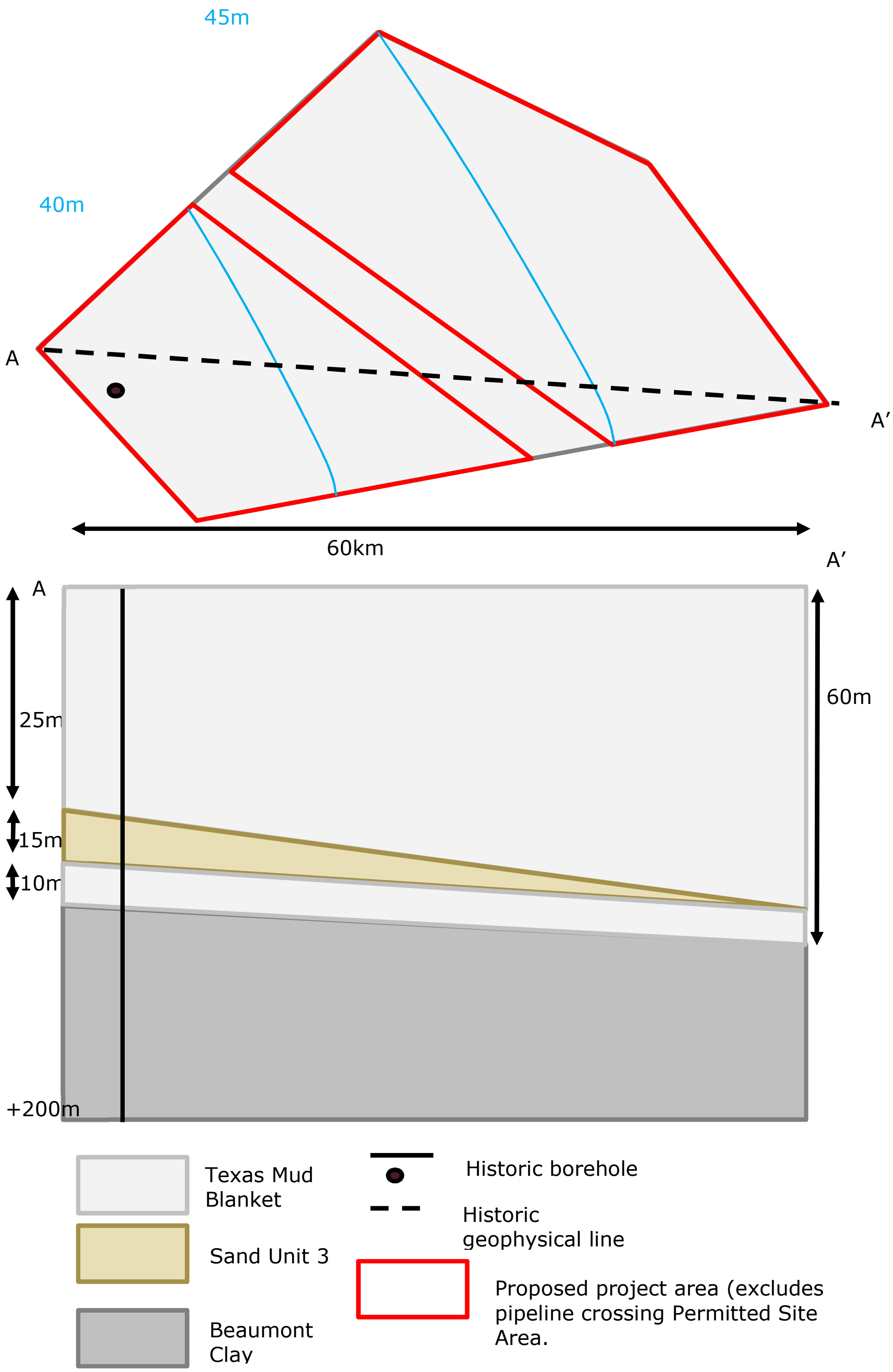

Figure 5-6 Geological profile at the Project Zone

Table 5-10 Initial Geohazard Assessment for Gulf of Mexico Site

Hazard Identified	Receptor Activity: Investigation	Receptor Activity: Design	Receptor Activity: Construction	Receptor Activity: Operation	Description and Consequence	Recommended Action	Residual Hazard
Low strength clays at surface	X	X	X	X	Deep Jack Up leg penetration for installation vessels. Difficulty in obtaining accurate geotechnical parameters in laboratory due to consistency.	High quality sampling and site investigation methods for very soft soils (T bar, large cone CPTu, fall cone strength). Confirmation of available jack up capabilities. Consider cautiously in design.	Negligible
Stratified deposits & channel features					Inadequate information for design profiles. Punch through & inadequate design.	High resolution geophysical survey across site.	Low certainty (considering accuracy for shallow foundation) in uncalibrated geophysical interpretation. Consider location specific geotechnical site investigation.
Shallow gas in channel features	X		X		Volume of toxic gas released. Can be noxious, cause buoyancy issues, explosive. Reduces geotechnical parameters	High resolution geophysical survey across site.	Hazard during geotechnical survey to be managed by contractor. Action for project depends on results of testing. Either can be managed, or areas must be avoided.
Salt domes		X	X	X	Significant impact on design of the project and feasibility. Low likelihood as the Project Zone is beyond the edge of the Salt Domes.	High resolution geophysical survey across site.	Negligible
Geotechnical parameters		X	X		Poor understanding of geotechnical parameters leads to uneconomic range between upper and lower bound and in adequate knowledge for detailed design and installation assessments.	Gap analysis to identify properties and testing for detailed design. Amalgamate properties from same soil units from other sites & statistically analyze to define upper and lower bound for concept design.	No location specific parameters, large range between upper and lower bounds. Project specific survey design at later stage of development.
Dropped objects/debris	X		X		The region has had significant past development and there is the potential for dropped objects / debris.	Magnetometer survey.	Coverage not 100%, however risk will be reduced to ALARP.

As well as the publicly available data, the developer of the site has access to proprietary data from other projects, but in the same soil units. A summary of the strength data is shown in Figure 5-7. The strength data shows there is variation in the soil units, however there is an adequate amount of data for statistical analysis, and the spread is not large enough to not allow concept designs to be progressed.

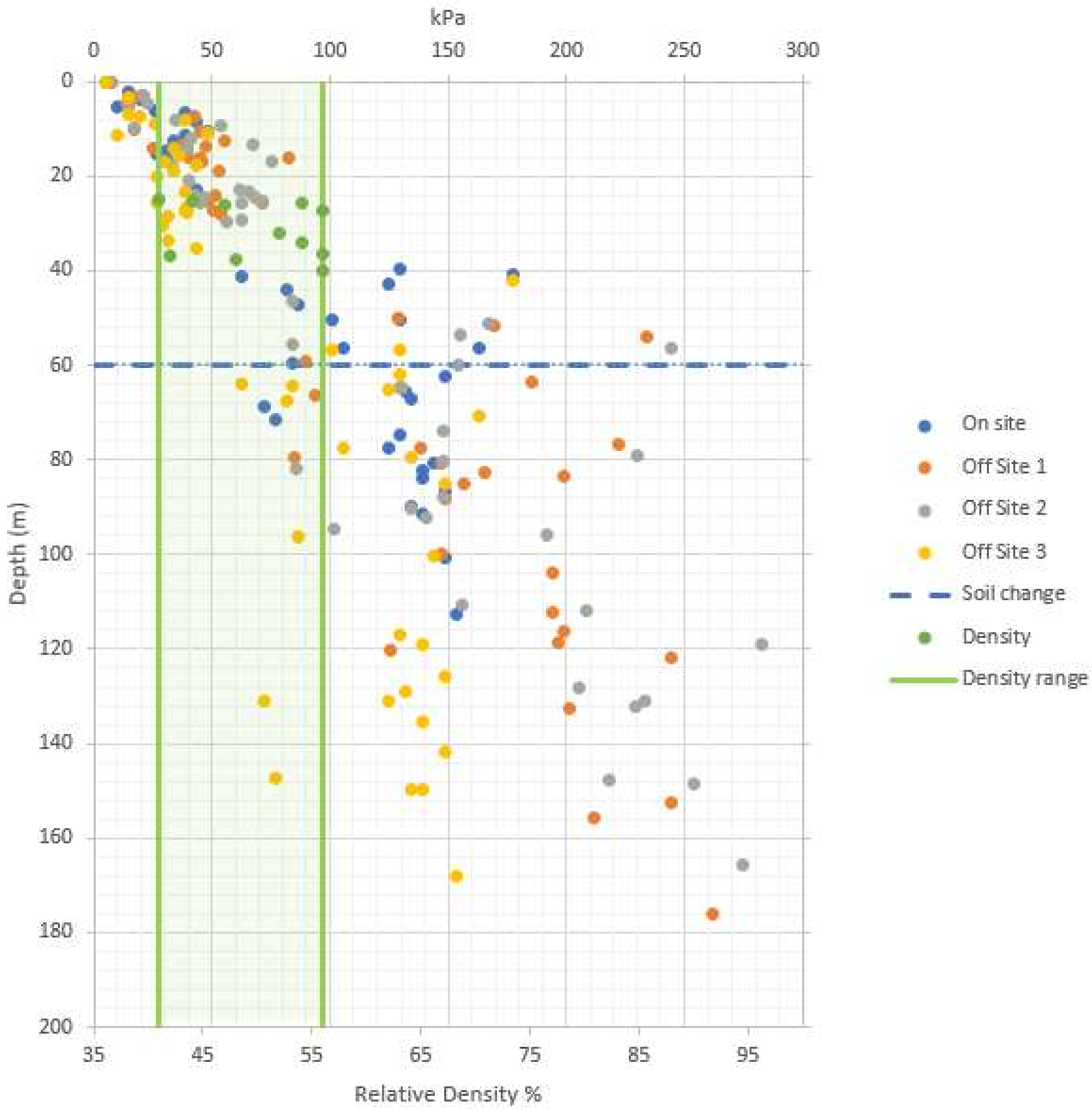

Figure 5-7 Undrained shear strength and relative density data from the historic borehole on site and adjacent sites

Stage 2: Preliminary Geophysical Survey & Ground Model Update

As defined from the geo hazard assessment there is insufficient information to;

- Characterize the geological zones across the site considering the potential for paleo channel incisions and salt domes (low likelihood, however high consequence combines to be a risk that must be evaluated);
- Evaluate the presence of any shallow gas deposits.

A geophysical survey containing MBES, sub-bottom profiling, side scan sonar and magnetometer is a cost-effective method to reduce the ground uncertainty, improving the concept design accuracy; providing recent accurate bathymetry and additionally provides information on the benthic habitat and organisms. Example is 200meter coverage at 1km spacing with cross lines at 4km spacing.

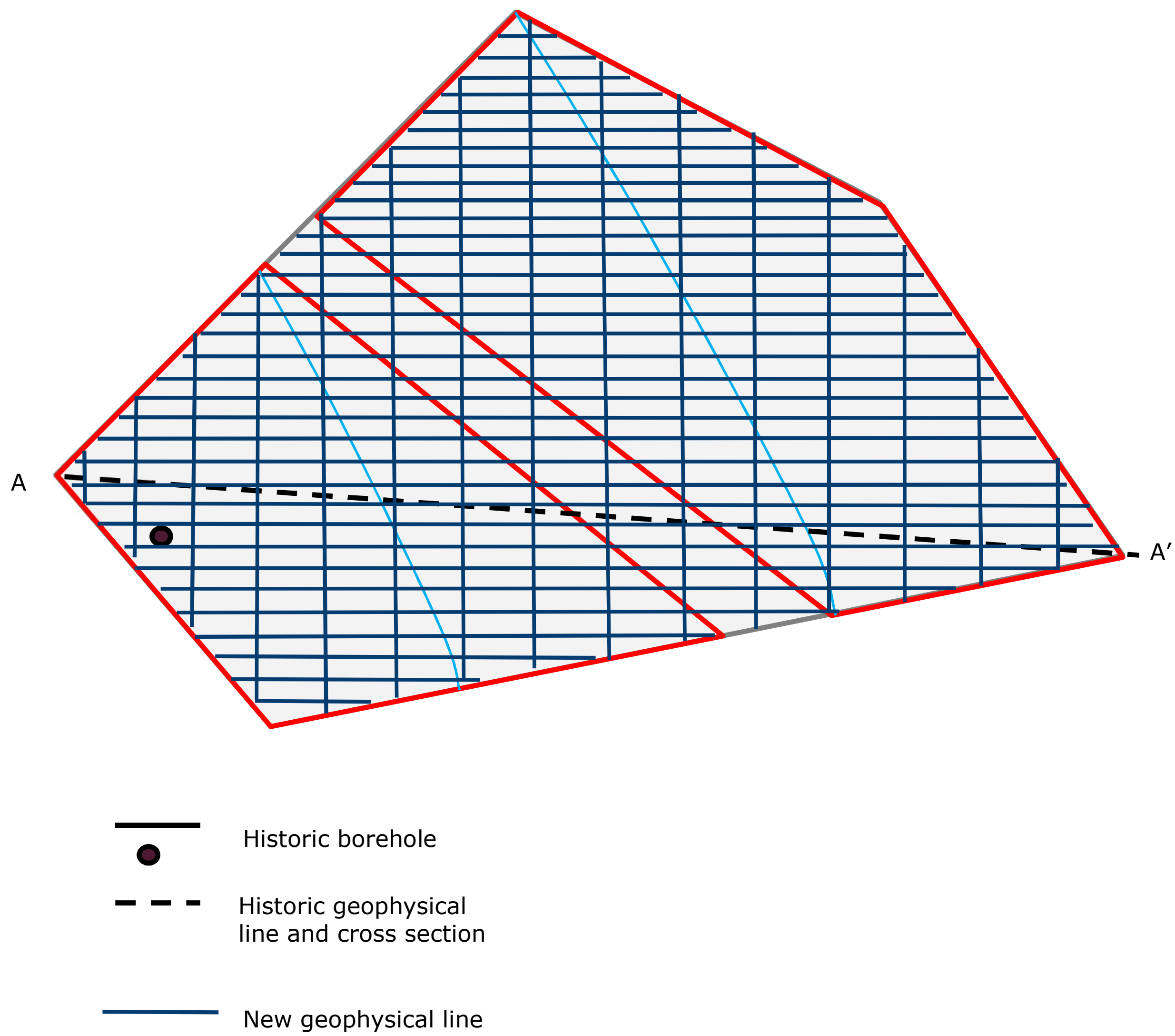

Figure 5-8 Grid of preliminary geophysical survey

The geophysical survey results shown in Figure 5-9:

- Confirms no salt domes;
- Confirms no incisions / paleo channels;
- Confirms no shallow gas;
- Provides the extent of the sand unit;
- Identifies areas where metal debris has sunk into the soft clay seabed.

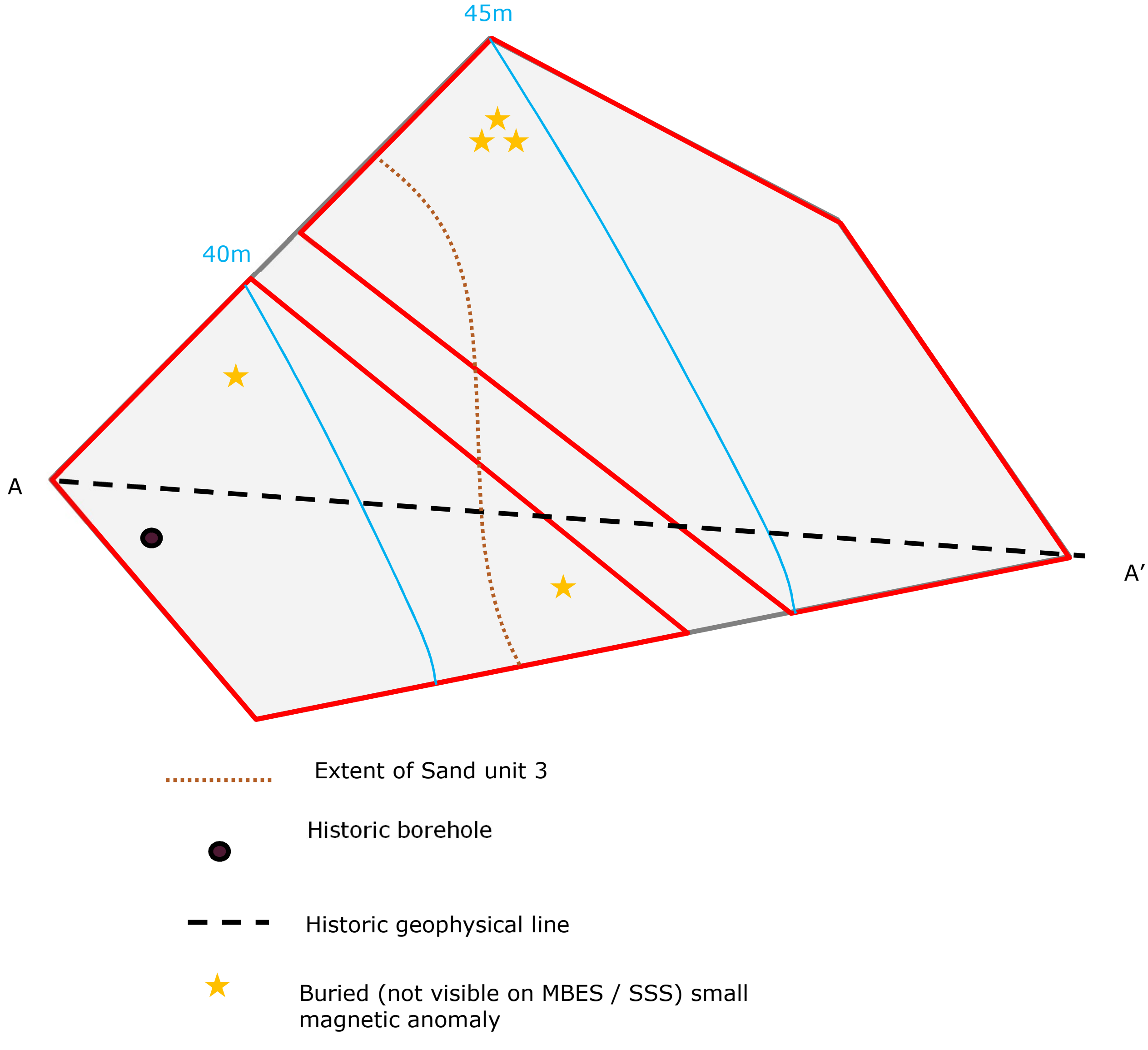

Figure 5-9 Ground model update

Table 5-11 Update to the geohazard assessment for Gulf of Mexico Site

Hazard Identified	Receptor Activity				Description and Consequence	Recommended Action	Residual Hazard
	Investigation	Design	Construction	Operation			
Low strength clays at surface	X	X	X	X	Deep Jack Up leg penetration for installation vessels. Difficulty in obtaining accurate geotechnical parameters in laboratory due to consistency.	High quality sampling and site investigation methods for very soft soils (T bar, large cone CPTu, fall cone strength). Confirmation of available jack up capabilities. Consider cautiously in design.	Negligible
Stratified deposits & channel features					Inadequate information for design profiles. Punch through & inadequate design. Geophysical data is good quality and high resolution. Adequate information on stratification for concept design.	~~High resolution geophysical survey across site conducted.~~ Additional boreholes required to calibrate geophysical data for detailed design.	~~Low certainty (considering accuracy for shallow foundation) in uncalibrated geophysical interpretation.~~ ~~Consider location specific geotechnical site investigation.~~ Negligible once detailed geotechnical campaign conducted
Shallow gas in channel features	X		X		~~Volume of toxic gas released. Can be noxious, cause buoyancy issues, explosive.~~ ~~Reduces geotechnical parameters~~ Geophysical survey shows none present.	~~High resolution geophysical survey across site~~ None.	~~Hazard during geotechnical survey to be managed by contractor.~~ ~~Action for project depends on results of testing.~~ ~~Either can be managed, or areas must be avoided.~~ None
Salt domes		X	X	X	~~Significant impact on design of the project and feasibility.~~ ~~Low likelihood as the project zone is beyond the edge of the Salt Domes.~~ Geophysical survey confirms no salt domes.	~~High resolution geophysical survey across site.~~ None	None
Geotechnical parameters		X	X		~~Poor understanding of geotechnical parameters leads to uneconomic range between upper and lower bound and in adequate knowledge for detailed design and installation~~	~~Gap analysis to identify properties and testing for detailed design.~~ ~~Amalgamate properties from same soil units from other sites & statistically analyze to define upper and lower bound for concept design.~~	~~No location specific parameters, large range between upper and lower bounds.~~ ~~Project specific survey design at later stage of development.~~ Negligible once detailed geotechnical campaign is

Hazard Identified	Receptor Activity				Description and Consequence	Recommended Action	Residual Hazard
	Investigation	Design	Construction	Operation			
					~~assessments.~~ Adequate information for concept design, but too large scatter for economic detailed design.	Determine most cost effective strategy for detailed design, and necessary parameters depending on selected foundation type.	conducted.
Dropped objects / debris	X		X		~~The region has had significant past development and there is the potential for dropped objects / debris.~~ Dropped objects identified, however coverage is not 100%.	~~Magnetometer survey~~ Evaluate the coverage once the layout for the arrays and wind turbines has been determined. Remove or avoid any obstructions. Determine if it is necessary to survey any gaps.	Coverage not 100%, however risk will be reduced to ALARP.

Summary

Pre-survey there was a medium level of uncertainty relating to the ground characterization as there was geotechnical data, however the bathymetry, stratigraphic, and geohazard information was limited to one cross section and further information was needed to characterize the whole site area to allow conceptual design, and to meet the criteria outlined in Part 1: Evaluation Criteria (see Table 5-12 below). After the preliminary surveys at the end of stage 2 there is adequate information to be able to meet the evaluation criteria as per Table 5-13, thus the level of information in the COP would be considered adequate for the technical, environmental and socioeconomic assessments required.

Table 5-12 Evaluation of the initial ground model

Criteria	Detail	Evaluation
Criterion 1: Is there sufficient resolution and confidence in the ground model to;	a. Define the baseline geological conditions of the area directly impacted by the project described in the COP. The area should include the sea bed surface, validation of the depth of the geological units to the maximum depth and lateral extent affected by the project.	**Criteria not met:** The anticipated sequence of the geological units has been described, but the extent has not. For example, the presence of incisions / paleo valleys is no known. No characterization of the sea bed surface has been made, only sub bottom data is available.
	b. Define the baseline geological conditions of any area indirectly affected by the project described in the COP. The description should include the sea bed surface sediments, and may be based on available information at the time of the submission.	**Criteria met:** The regional geology is described in Stage 1: Initial Desktop study ground model which is included in the wider regional characterization included in the Appendices of the COP.
	c. Define any geological units that may contain surface or buried features of archaeological potential.	**Criteria not met:** The anticipated sequence of the geological units has been described, but the extent has not.
Criterion 2: Are the geotechnical characteristics of the pertinent geological unit adequately characterized to;	b. Demonstrate the maximum environmental actions of the proposed project have been established.	**Criteria met:** The maximum extent of the environmental actions may be demonstrated based on the available information. For example, it is not possible known how much sediment may be dispersed in the water column by cable installation as no accurate quantification of soft surface clays if possible.
	b. Demonstrate the technical feasibility of the proposed project, and project alternatives, described in the COP. This is to ensure the project does not pose an unacceptable risk to health, safety and the environment.	**Criteria not met:** The level of information does not allow characterization of the geohazards, ground profiles across the whole site to an adequate level to be able to fully demonstrate concept feasibility. For example, it is not possible to establish whether any areas being developed are at risk of shallow gas.

Table 5-13 Evaluation of the ground model after preliminary surveys

Criteria	Detail	Evaluation
Criterion 1: Is there sufficient resolution and confidence in the ground model to;	a. Define the baseline geological conditions of the area directly impacted by the project described in the COP. The area should include the sea bed surface, validation of the depth of the geological units to the maximum depth and lateral extent affected by the project.	**Criteria met:** The sequence and extent of the geological units has been described. Characterization of the sea bed surface has been made.
	b. Define the baseline geological conditions of any area indirectly affected by the project described in the COP. The description should include the sea bed surface sediments, and may be based on available information at the time of the submission.	**Criteria met:** The regional geology is described in Stage 1: Initial Desktop study ground model which is included in the wider regional characterization included in the Appendices of the COP.
	c. Define any geological units that may contain surface or buried features of archaeological potential.	**Criteria met:** The sequence and extent of the geological units has been described.
Criterion 2: Are the geotechnical characteristics of the pertinent geological unit adequately characterized to;	a. Demonstrate the technical feasibility of the proposed project, and project alternatives, described in the COP. This is to ensure the project does not pose an unacceptable risk to health, safety and the environment.	**Criteria met:** There is adequate information to support the project conceptual design. This is supported through technical evaluations based on upper and lower bound geotechnical parameters which; though not site specific; are statistically justified for each soil unit.
	b. Demonstrate the maximum environmental actions of the proposed project have been established.	**Criteria met:** The maximum extent of the environmental actions may be demonstrated based on the available information. For example, it is not possible known how much sediment may be dispersed in the water column by cable installation as no accurate quantification of soft surface clays if possible.

5.3 Deep Water Pacific Site

A developer has a Permitted Site Area, that they intend to develop as a floating wind project of 500 MW. There is an earthquake risk, and very little site specific information available.

Stage 1: Initial Desk Based Ground model

From publicly available data, the initial conceptual site / ground model can be identified. Pertinent Geological Information referenced;

Baker, E. T. (1995). *Stratigraphic Nomenclature and Geological Sections of the Gulf COastal Plain of Texas.* Austin, Texas: U.S Department of the Interior - U.S Geological Survey.

Beckman, J. D., & Wlliamson, A. K. (1990). *Salt Dome Locations in the Gulf COastal Plain - SOuthern Central United States.* Austin, Texas: U.S Department of the Interior - U.S Geological Survey.

Bureau of Ocean Energy Management Office of Renewable Energy Programs. (12 January 2018). *Draft Guidance Regarding the Use of a Project Design Envelope in a Construction and Operations Plan.* UNITED STATES DEPARTMENT OF THE INTERIOR.

Folger, D. W., & Needell, S. W. (1983). *U.S. Geological Survey Program of Offshore Rescources and Geoenvironmental Studies, Atlantic-GUl of Mexico Region, from September 1, 1976 tp December 31 1978.* Geological Survey Circular 870: U.S. Department of the Interior.

Foote, R. Q. (1984). *Summary report on the regional geology, petroleum potential, environmental consideration for development, and estimates of undiscovered recoverable oil and gas resources of the United States Gulf of Mexico Continental Margin in the area of proposed Oil a.* U.S. Department of the Interior - U.S. Geological Survey & U.S. Minerals Managment Service.

Foster, D. S., Swift, A., & Schwab, W. C. (1999). *S tratigraphic Framework Maps of the Nearshore Area of Southern Long Island from Fire Island to Montauk Point.* U.S. Geological Survey Open File Report 99-559.

Minerals Managemnt Service. (1983). *Regional Environmental Impact Statement Volume 1: Gulf of Mexico.* Metairie, LA: U.S Department of Interior .

Offshore Site Investigation and Geotechnics Committee. (2014). *Guidance notes for the planning and execution of geophysical and geotechnical ground investigations for offshore renewable energy devleopment.* Society for Underwater Technology.

Perlmutter, N. M., & Geraghty, J. J. (1963). *Geology and Ground Water Conditions in Southern Nassau and Southeastern Queens COunties Long Island, N. Y.* U.S Department of the Interior.

RICE University Gulf of Mexico Research Group. (2005, August 16). *RICE University Gulf of Mexico Research Group: Systems Tracts & Sand Bodies*. Retrieved from http://gulf.rice.edu/

Table 5-14 Stratigraphic units in the region

Age	Unit	Description
Quaternary- Shelf, slope and basin deposits 0 to 1600 ft (uncertain)	Holocene: Surficial Sand	Sand, fine to very fine grained, well sorted, seaward thinning sediment wedge over Pleistocene deposits
	Pleistocene: Sand and silt	Sand and silt interbedded with minor gravel, clayey silt with abundant coarse debris
Neogene 0 to 1600 ft (uncertain)	Late Miocene and Pliocene Tuffaecous siltstone member	Tuffaceous sandy siltstone and claystone, coal bearing/rich in organics
Eocene 1600 to +5000 ft (uncertain)	Eocene through Middle Miocene	Primarily siltstone and sandstone with interbedded volcanic and volcaniclastic rocks.

Quaternary – Shelf, slope and basin deposits

Pleistocene sand and silt unit is stratigraphically youngest unit over most of central Oregon shelf and slope but is locally overlain uncomfortably by a seaward-thinning holocene sediment wedge (Clarke, et. al). The deposit reaches a maximum thickness of 1600 ft with the Pleistocene deposits primarily consisting of sand and silt interbedded with minor gravel and the Holocene deposits reported as fine to very fine grained, well sorted sand. The shelf, slope and basin deposits extend to the potential wind farm development zones located within 12 to 50 miles from shore (Musial, et. al) for Oregon.

Neogene – Tuffaecous siltstone member

Deposits is widely exposed on the inner continental shelf and in anticlinal axes elsewhere. Strata described as tuffaceous sandy siltstone and massive olive-gray siltstone and claystone dated as late Miocene and middle Pliocene marine sedimentary deposits that outcrop locally along the southern Oregon coast. Deposits encountered at water depths of about 400 ft. The thickness of the deposits offshore Coos Bay Oregon are highly uncertain, but are interpreted to be at least 1600 ft (Clarke, et. al).

Eocene - Eocene through middle Miocene deposits

Deposits inferred to be upper Eocene to middle Miocene based on stratigraphic position and equivalence to regional unconformities onshore. Strata reported as consisting of siltstone interbedded with turbidite sandstone and volcanic rocks. Older bedrock deposits are anticipated to be below the depth of interest. The site is located in a subduction zone and earthquake risk will be an important design consideration for wind farm structures.

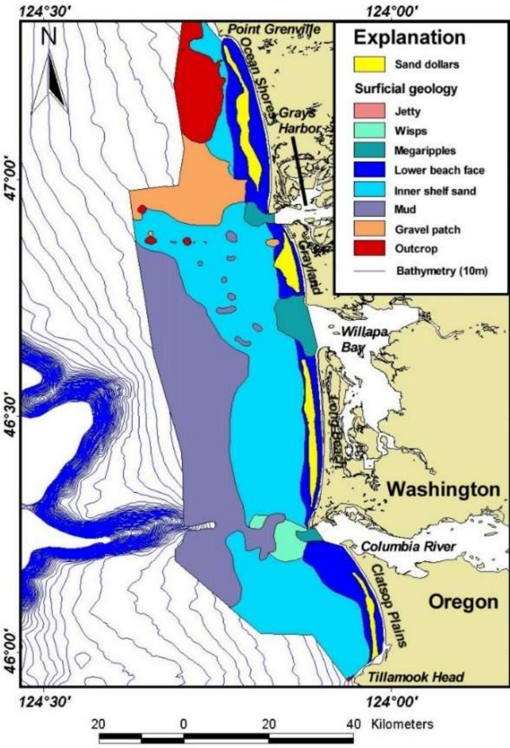

Figure 5-10 Surficial geology interpretation of Permitted Site Area (USGS OFR 00-167)

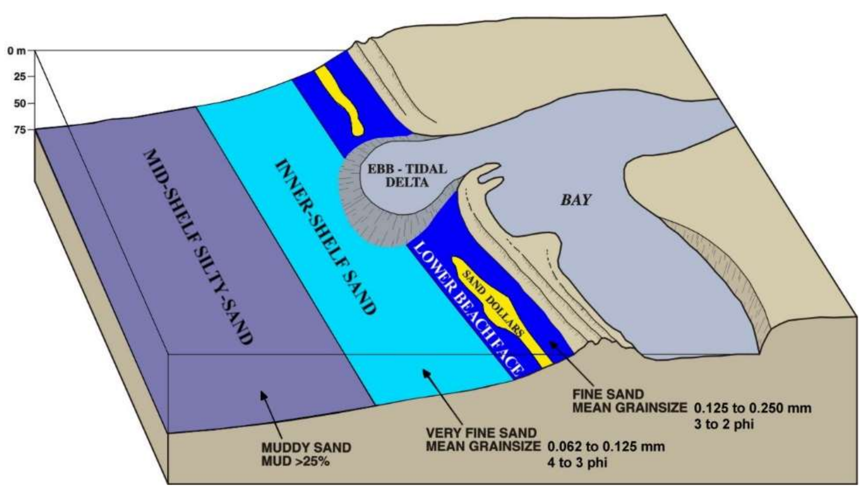

Figure 5-11 Geologic block diagram Permitted Site Area (USGS OFR 00-167)

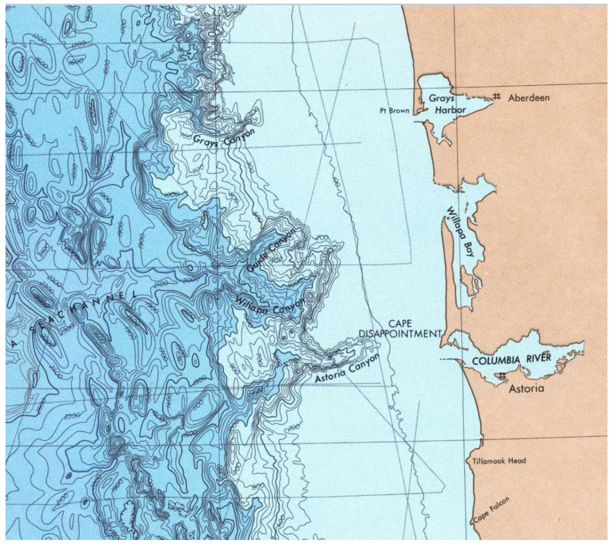

Figure 5-12 Bathymetry at the Permitted Site Area

The bathymetry of the Permitted site area is shown in Figure 5-12. The water depth is > 200m, and hence fixed foundations are not feasible. Floating turbines with anchors must be considered. The suitability of anchor types for different ground conditions are shown in Table 5-15.

The likely geological hazards and conditions at the Permitted Site Area have been assessed and are presented in Table 5-16.

Table 5-15 Summary of high level Anchor Type feasibility

	Sea floor type									
Anchor type	**Soft clay >10m**	**Soft clay overlying hard layer**	**Stiff clay**	**Sand**	**Hard glacial till**	**Boulders**	**Soft rock**	**Hard rock**	**Moderate slopes**	**Steep Slopes**
Drag Embedment	✓	≈	✓	✓	≈	×	×	×	✓	×
Deadweight	✓	✓	✓	✓	✓	✓	✓	✓	✓	×
Pile	≈	✓	✓	✓	✓	×	✓	≈	✓	✓
Direct Embedment	✓	×	✓	✓	✓	×	≈	×	✓	✓
Suction Anchor	✓	≈	✓	×	✓	×	≈	×	✓	✓

✓generally suitable, ≈ can be suitable, × not normally suitable

Table 5-16 Geohazard Assessment for Pacific Coast

Hazard Identified	Receptor Activity: Investigation	Receptor Activity: Design	Receptor Activity: Construction	Receptor Activity: Operation	Description and Consequence	Recommended Action	Residual Hazard
Low density granular deposits	X	X	X	X	Liquefaction of saturated loose granular deposits & potential to have liquefaction induced slope failure. Excessive settlement Bearing capacity reduction Increase in lateral loads on structures due to lateral spreading Deep embedment required for anchors or piles. Potential to have hard rock underlying This.	High quality sampling and site investigation methods for loose to medium sands (SPT, CPTu) Determine seismic design requirements for project area Quantify risk of slope failure and impact on project. Consider cautiously in design.	Appropriate mitigation can be implemented based on results of analyses
Stratified deposits & channel features					Inadequate information for design profiles. Punch through & inadequate design.	High resolution geophysical survey across site.	Low certainty (considering accuracy for shallow foundation) in uncalibrated geophysical interpretation. Consider location specific geotechnical site investigation.
Gravel or cemented layers in upper soils	X	X	X		Restricts embedment of anchor leading to inadequate penetration and capacity.	High accuracy in upper 10m of soils. Geotechnical investigation considered if geophysics is uncertain.	Localized hazard at the actual location of anchors affects the anchor installation.
Shallow gas in channel features	X		X		Volume of toxic gas released. Can be noxious, cause buoyancy issues, explosive. Reduces geotechnical parameters	High resolution geophysical survey across site.	Hazard during geotechnical survey to be managed by contractor. Action for project depends on results of testing. Either can be managed, or areas must be avoided.
Salt domes					Significant impact on design of the project and feasibility. Low likelihood as the Project Zone is beyond the edge of the Salt Domes.	High resolution geophysical survey across site.	Negligible

Hazard Identified	Receptor Activity				Description and Consequence	Recommended Action	Residual Hazard
	Investigation	Design	Construction	Operation			
Geotechnical parameters	X	X	X	X	Poor understanding of geotechnical parameters leads to uneconomic range between upper and lower bound and in adequate knowledge for detailed design and installation assessments.	Gap analysis to identify properties and testing for detailed design. Amalgamate properties from same soil units from other sites & statistically analyze to define upper and lower bound for concept design.	No location specific parameters, large range between upper and lower bounds. Project specific survey design at later stage of development.
Dropped objects / debris					The region has had significant past development and there is the potential for dropped objects / debris.	Magnetometer survey.	Coverage not 100%, however risk will be reduced to ALARP.

The key aims of the preliminary geological (geophysical and geotechnical) surveys are;

- Confirm stratification;
- Provide quantification of geotechnical parameters for units for preliminary analysis;
- Evaluate key ground risks;
  - Relative density and fines content of Quaternary units for liquefaction assessment
  - Cementation of the Quaternary units
  - Provide project specific bathymetry for estimation of mobile sediment
  - Confirm presence of paleo channels, and whether they contain noxious gasses
  - Nature and depth of granular deposits
  - Extent of boulders in Quaternary units
  - Locations of and moraines / esker.

As there is no site-specific data it is not possible to differentiate any particular zones or locations of geological hazards. As such the provisional Project Zones are based on the published information such as bathymetry and wind speeds, shipping routes, and protected areas.

Stage 2: Preliminary Geophysical Survey

A preliminary geophysical survey is specified to confirm the Permitted Site Area's bathymetry and allow for differentiation of geological zones. Example is 200meter coverage at 500m to 1km spacing with cross lines at 3-5km spacing. Spacing depends on size of area and homogeneity of the ground conditions.

The geophysical survey will comprise of;

- Sub bottom profiler from a shallow and deep source (e.g., Sparker and Chirper);
- Magnetometer data to identify any debris;
- MBES for bathymetry concept design;
- SSS to identify seabed type.

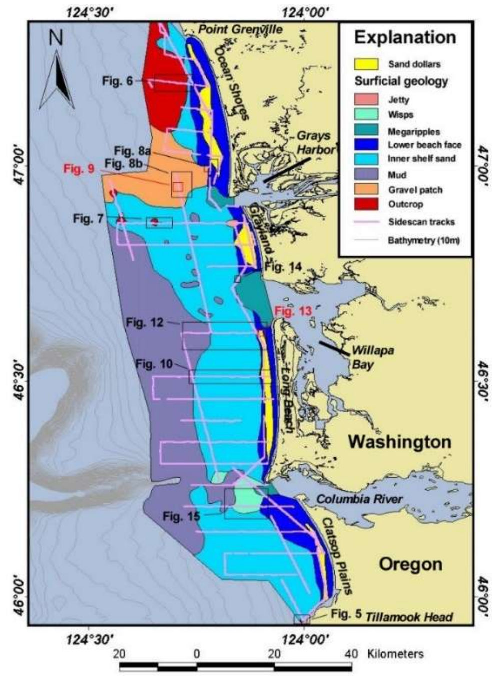

Figure 5-13 Bathymetry and Geophysical survey tracks for project area (USGS OFR 00-167)

The geophysical survey and sediment sample results shown in Figure 5-14:

- Confirms no salt domes;
- Confirms no incisions / paleo channels;
- Confirms no shallow gas;
- Provides the extent of the sand unit;
- Identifies areas anticlines/outcrops may be present.

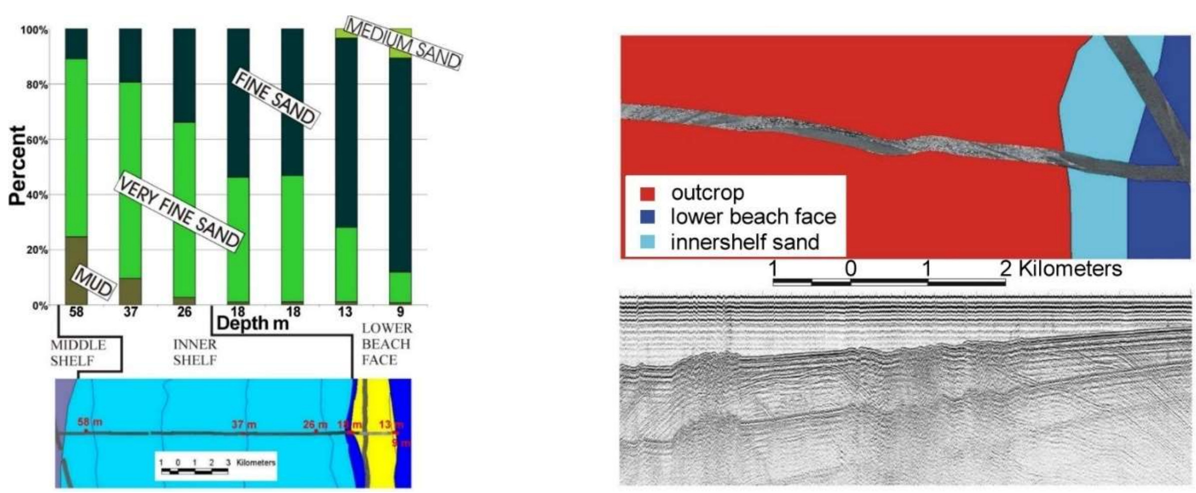

Figure 5-14 Sidescan-sonar survey and sediment sample results (USGS OFR 00-167)

Stage 3: Preliminary Geotechnical Survey & Ground Model Update

Some preliminary geotechnical data is necessary to evaluate the density of the sand so that the risk of slope failure caused by liquefaction during an earthquake can be assessed. This risk is considered critical as should this be realized the anchors could be swept away, threatening the safety of the project. This must be evaluated at the preliminary engineering stage to determine the project feasibility. Obtaining this site specific geotechnical data can also inform on anchor type, as piled anchors may be necessary if deep liquefaction is a potential.

The geotechnical survey will comprise of 5 seabed CPTu's. This will provide accurate information on the in situ density of the sand deposits for the liquefaction analysis. Seabed CPTu was selected because of the speed of the test, and it is able to provide accurate information on the density of the sands in the upper 20-30m of soil. Five locations were selected; in each corner of the site and one in the center; as the relative cost of each test is marginal once the mobilization cost have been considered, and the benefit of understanding any lateral variation outweighs the cost.

The CPTs show the sand is dense from one meter below seabed, this informs the liquefaction and slump analysis informing the project that there is no risk of large scale slope failure; additionally the site is suitable for all types of anchors.

Table 5-17 Ground model update

Hazard Identified	Receptor Activity: Investigation	Receptor Activity: Design	Receptor Activity: Construction	Receptor Activity: Operation	Description and Consequence	Recommended Action	Residual Hazard
Low density granular deposits	X	X	X	X	Sand confirmed as dense to very dense from 1m depth. ~~Liquefaction of saturated loose granular deposits~~ ~~Excessive settlement~~ ~~Bearing capacity reduction~~ ~~Increase in lateral loads on structures due to lateral spreading~~ ~~Deep embedment required for anchors or piles. Potential to have hard rock underlying This.~~	~~High quality sampling and site investigation methods for loose to medium sands (SPT, CPTu)~~ ~~Determine seismic design requirements for project area~~ Consider cautiously in design.	~~Appropriate mitigation can be implemented based on results of geotechnical campaign and liquefaction analyses~~ Location specific analysis to be conducted at detailed design stage based on location specific CPTu at detailed design stage.
Stratified deposits & channel features					Inadequate information for design profiles. Punch through & inadequate design. Geophysical data is good quality and high resolution. Adequate information on stratification for concept design.	~~High resolution geophysical survey across site.~~ Additional boreholes required to calibrate geophysical data for detailed design	~~Low certainty (considering accuracy for shallow foundation) in uncalibrated geophysical interpretation.~~ ~~Consider location specific geotechnical site investigation.~~ Negligible once detailed geotechnical campaign is conducted
Gravel or cemented layers in upper soils	X	X	X		Restricts embedment of anchor leading to inadequate penetration and capacity.	~~High accuracy in upper 10m of soils.~~ ~~Geotechnical investigation considered if geophysics is uncertain.~~ Geophysical information confirms sand is present to over 20m across the site area.	~~Localized hazard at the actual location of anchors affects the anchor installation.~~ Negligible
Shallow gas in channel features	X		X		~~Volume of toxic gas released. Can be noxious, cause buoyancy issues, explosive.~~ Reduces geotechnical parameters	~~High resolution geophysical survey across site.~~ Negligible	~~Hazard during geotechnical survey to be managed by contractor.~~ ~~Action for project depends on results of testing.~~ ~~Either can be managed, or areas must~~

Hazard Identified	Receptor Activity				Description and Consequence	Recommended Action	Residual Hazard
	Investigation	Design	Construction	Operation			
							~~be avoided.~~ Negligible
Salt domes					~~Significant impact on design of the project and feasibility.~~ ~~Low likelihood as the project zone is beyond the edge of the Salt Domes.~~ Geophysical survey confirms no salt domes	~~High resolution geophysical survey across site.~~ Negligible	Negligible
Geotechnical parameters		X	X		~~Poor understanding of geotechnical parameters leads to uneconomic range between upper and lower bound and in adequate knowledge for detailed design and installation assessments~~. Adequate information for concept design but too large scatter for economic detailed design	Gap analysis to identify properties and testing for detailed design. Amalgamate properties from same soil units from other sites & statistically analyze to define upper and lower bound for concept design.	No location specific parameters, large range between upper and lower bounds. Project specific survey design at later stage of development. Percentage fines and density assumed for liquefaction analysis to be confirmed at detailed design stage.
Dropped objects / debris					~~The region has had significant past development and there is the potential for dropped objects / debris.~~ No objects identified	~~Magnetometer survey~~ None	Coverage not 100%, however risk will be reduced to ALARP.

Summary

Initially at the end of stage 1, there was a high level of uncertainty relating to the ground characterization, and there was inadequate information on which to base a concept design that meet the criteria outlined in Part 1: Evaluation Criteria (see Table 5-18 below). After the preliminary geophysical survey at the end of stage 2 there was a good level of information on the distribution of the geological units, however it was not possible to determine the risk of lateral spreading during liquefaction. This could be critical to the safety o the project, and hence it was necessary to obtain geotechnical information relating to the density and fines content of the sand. Once this was obtained adequate information to be able to meet the evaluation criteria as per Table 5-19, thus the level of information in the COP would be considered adequate for the technical, environmental and socioeconomic assessments required.

Table 5-18 Evaluation of the initial ground model

Criteria	Detail	Evaluation
Criterion 1: Is there sufficient resolution and confidence in the ground model to;	a. Define the baseline geological conditions of the area directly impacted by the project described in the COP. The area should include the sea bed surface, validation of the depth of the geological units to the maximum depth and lateral extent affected by the project.	**Criteria not met:** The anticipated sequence of the geological units has been described, but the extent has not. For example, the presence of incisions / paleo valleys is no known. No characterization of the sea bed surface has been made, only sub bottom data is available.
	b. Define the baseline geological conditions of any area indirectly affected by the project described in the COP. The description should include the sea bed surface sediments, and may be based on available information at the time of the submission.	**Criteria met:** The regional geology is described in Stage 1: Initial Desktop study ground model which is included in the wider regional characterization included in the Appendices of the COP.
	c. Define any geological units that may contain surface or buried features of archaeological potential.	**Criteria not met:** The anticipated sequence of the geological units has been described, but the extent has not.
Criterion 2: Are the geotechnical characteristics of the pertinent geological unit adequately characterized to;	a. Demonstrate the maximum environmental actions of the proposed project have been established.	**Criteria met:** The maximum extent of the environmental actions may be demonstrated based on the available information. For example, it is not possible known how much sediment may be dispersed in the water column by cable installation as no accurate quantification of soft surface clays if possible
	b. Demonstrate the technical feasibility of the proposed project, and project alternatives, described in the COP. This is to ensure the project does not pose an unacceptable risk to health, safety and the environment.	**Criteria not met:** The level of information does not allow characterization of the geohazards, ground profiles across the whole site to an adequate level to be able to fully demonstrate concept feasibility. For example, it is not possible to establish whether any areas being developed are at risk of shallow gas.

Table 5-19 Evaluation of the ground model after preliminary surveys

Criteria	Detail	Evaluation
Criterion 1: Is there sufficient resolution and confidence in the ground model to;	a. Define the baseline geological conditions of the area directly impacted by the project described in the COP. The area should include the sea bed surface, validation of the depth of the geological units to the maximum depth and lateral extent affected by the project.	**Criteria met:** The sequence and extent of the geological units has been described. Characterization of the sea bed surface has been made. Density of the sand units has been demonstrated.
	b. Define the baseline geological conditions of any area indirectly affected by the project described in the COP. The description should include the sea bed surface sediments, and may be based on available information at the time of the submission.	**Criteria met:** The regional geology is described in Stage 1: Initial Desktop study ground model which is included in the wider regional characterization included in the Appendices of the COP.
	c. Define any geological units that may contain surface or buried features of archaeological potential.	**Criteria met:** The sequence and extent of the geological units has been described.
Criterion 2: Are the geotechnical characteristics of the pertinent geological unit adequately characterized to;	a. Demonstrate the maximum environmental actions of the proposed project have been established.	**Criteria met:** There is adequate information to support the project conceptual design. This is supported through technical evaluations based on upper and lower bound geotechnical parameters which are site specific.
	b. Demonstrate the technical feasibility of the proposed project, and project alternatives, described in the COP. This is to ensure the project does not pose an unacceptable risk to health, safety and the environment.	**Criteria met:** There is adequate information to support the project conceptual design. This is supported through technical evaluations based on upper and lower bound geotechnical parameters which are site specific.

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Appendix B Glossary

Composite Borehole: A borehole with alternating sampling and wireline CPTu.

CPTu: Cone penetration testing with pore water pressure measurement.

Gas Blanking: A reduction of amplitude of the seismic reflection, caused by the presence of gas hydrates. This is observed as blank areas on the sub bottom profile.

Geophysical Survey: Survey which uses methods, such as seismic, gravitational, magnetic, electrical and electromagnetic equipment to measure the physical properties of the seabed surface and subsurface, along with the anomalies in those properties.

Geotechnical Borehole: Geological core sampling. This includes a range of sampling techniques such as virbro core, gravity core, rotary drilling or piston sampling.

Geotechnical Investigation: General term for any geotechnical technique such as geotechnical borehole, composite borehole or CPTu.

Geotechnical Survey: Survey including physical testing, probing or sampling to obtain the material properties of soil and rock.

Ground Model: The conceptual model of the stratigraphic units, geological features and ground hazards present at a site. This typically is comprised of 2D or 3D mapping, geohazard risk register and geotechnical properties of the stratigraphic units.

Project Area: As defined in 30 CFR 585.112, the geographic surface leased, or granted, for the purpose of a specific project.

Permitted Site Area: The area that a COP is being applied for. This may be the entire Project Area, within which there are numerous phased projects. Alternatively, the COP may cover a single zone that is part of the wider Project Area, or that is equal to an entire Project Area.

Project Zone: A specific zone within the Project Area.

Su: Undrained shear strength, the typical strength measurement for clay

Φ: Peak friction angle the typical strength measurement of sand

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