Maryland Offshore Wind Project - Design report

Preliminary Cable Burial Risk Assessment

Lease Area

US Wind, Inc.
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ABBREVIATIONS

Abbreviation	Description
AIS	Automatic information system
ALARP	As low as reasonably practicable
ASL	Average seabed level
BOEM	Bureau of Offshore Energy Management
CBRA	Cable burial risk assessment
DNV	Det Norske Veritas
DoL	Depth of lowering
DWT	Dead weight tonnage
ECC	Export Cable Corridor
GEMS	Geoscience Earth & Marine Services
IAC	Intra-array cable(s)
MDOL	Minimum depth of lowering
MLLW	Mean lower low water
MOWP	Maryland Offshore Wind Project
MP	Monopile
NSRA	Navigation safety risk assessment
OCS	Outer Continental Shelf
OSS	Offshore Substation
PDE	Project Design Envelope
pUXO	Potential unexploded ordnance
TOC	Thickness of cover
TOP	Top of product
TP	Transition piece
TSS	Traffic separation scheme
UXO	Unexploded ordnance
WEA	Wind Energy Area
WT	Wood Thilsted
WTG	Wind turbine generator

1. Introduction

1.1. Project description

US Wind, Inc. (US Wind) is developing the Maryland Offshore Wind Project (MOWP), an offshore wind energy project of up to approximately 2 gigawatts of nameplate capacity within OCS-A 0490 (the Lease), a Lease area of approximately 80,000 acres located approximately 18.5 km (11.5 miles) off the coast of Maryland on the Outer Continental Shelf. Under a Project Design Envelope (PDE) approach, the MOWP could include as many as 121 wind turbine generators (WTG), up to four offshore substations (OSS), and one meteorological tower (Met Tower) in the Lease area. The MOWP will be interconnected to the onshore electric grid by up to four new 230-275 kV export cables to new US Wind substations, with an anticipated connection to the existing Indian River Substation near Millsboro, Delaware.

Figure 1.1 shows the location of the MOWP area on the Maryland Outer Continental Shelf (OCS). The trapezoidal-shaped Lease area includes nine full OCS Lease Blocks and portions of 11 other OCS Lease Blocks.

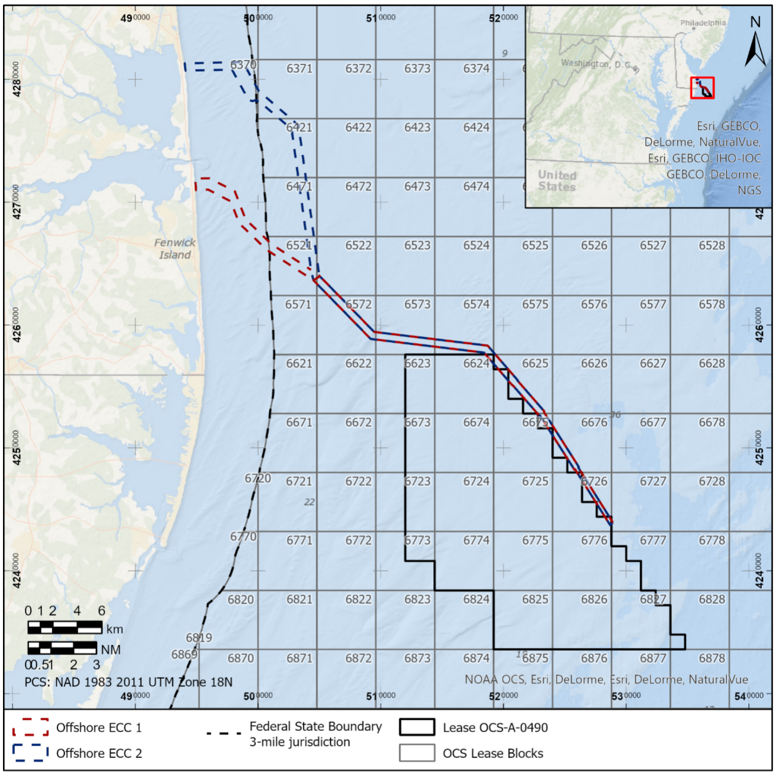


Figure 1.1: US Wind Lease area OCS-A-0490 location with OSS Lease Blocks and Offshore Export Cable Corridors (ECC).

Wood Thilsted Partners (WT) has been commissioned to conduct a preliminary cable burial risk assessment (CBRA) for the US Wind lease area.

The CBRA comprises (but is not limited to):

- Qualitative risk assessment considering e.g. seabed conditions, bathymetry, shipping and fishing activities.
- Quantitative risk assessment determination of burial depths for a range of risk-return periods.

1.2. Available data

The available data applied in this assessment are presented in Table 1.1

Table 1.1: Available data.

Data	Description	Source
Route Boundary	Cable corridor boundaries for both ECC's	Client provided shape file
AIS data	AIS tracking data for a period of two years from 1 January 2018 to 31 December 2019	AccessAIS [1]
Geotechnical and geophysical survey	Boreholes (BH) and cone penetration tests (CPT) at exploratory locations. MBES bathymetry, SSS imagery, medium penetration sub-bottom profiles, shallow penetration sub-bottom profiles and MAG data	Alpine [2] and Gardline [9] [10] [11]
Geotechnical and geophysical survey	BH and CPT at MarWin WTG locations. MBES bathymetry, side scan sonar, sub-bottom profiler, transverse gradiometer-configured magnetometer, single-channel ultra-high-resolution seismic, multi-channel ultra-high-resolution seismic and grab samples	TDI 2021 [19] [18], Fugro 2022 [8]
Fisheries assessment report	-	Sea Risk Solutions LLC [16]
Shallow Geohazards Interpretive Report (Draft)	Details the high-resolution geophysical data and grab sample acquisition (TDI and Fugro), and assesses the seafloor and shallow geologic hazards and constraints that may affect the MOWP	GEMS [12]
NSRA	Navigation safety risk assessment containing a traffic survey based on AIS data for 2019.	DNV [7]

1.3. Burial definition

The following definitions relevant for the understanding of the cable burial recommendations provided in this report are illustrated on Figure 1.2 and Figure 1.3. Where a definition is noted as a level this should be understood as being referenced to MLLW (or another agreed reference depth). Definitions given as a depth or distance are referenced between two levels and not to a particular datum.

- Sea level, MLLW: Mean lower low water.
- Stable seabed (SSB); The reference level at which the seabed is considered static i.e. not mobile.
- As-measured seabed; The seabed level to the noted datum at the moment of survey. This is commonly quoted prior to installation.
- As-installed seabed level; The as-measured seabed level at time of installation.
- Engineered seabed level: The seabed level resulting from seabed preparation, e.g. dredging, prior to cable installation
- Top of product (TOP); The shallowest level of the cable within the given measured range i.e. every metre or every 5 metres
- Depth of lowering (DoL); The distance from average seabed to TOP.
- Minimum depth of lowering (MDOL); The minimum DoL calculated by the CBRA to consider the cable safe referenced as depth below SSB.
- Depth of cover (DOC); The distance between the disturbed seabed (directly over the cable) and the TOP.

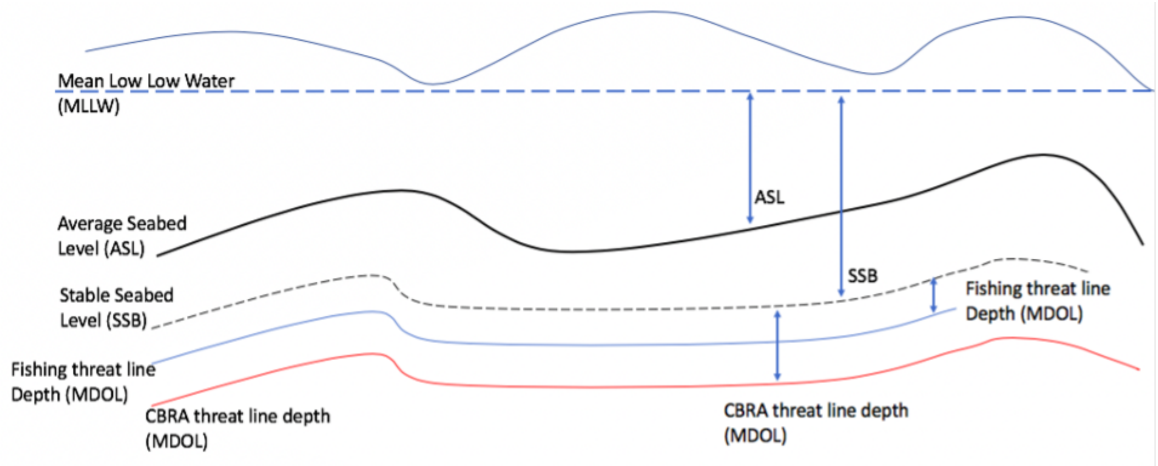


Figure 1.2: Global depth of lowering definitions.

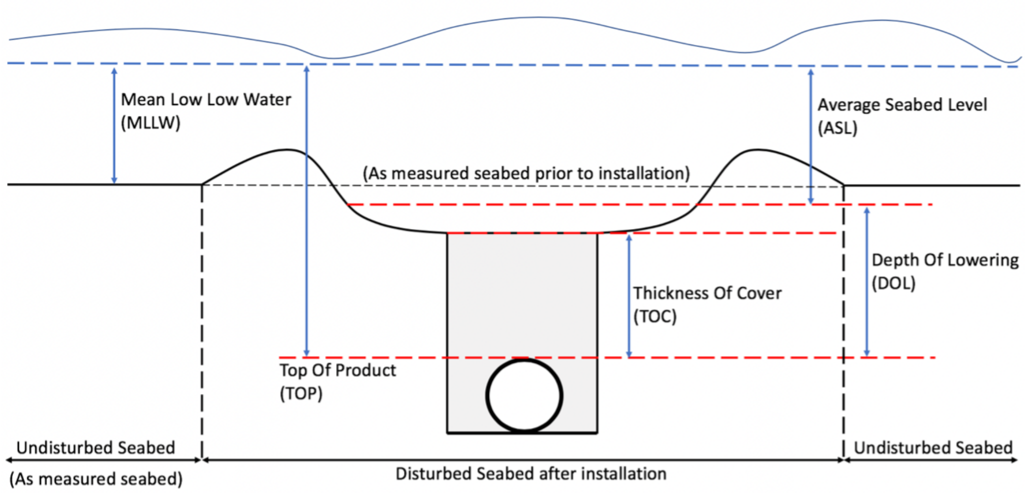


Figure 1.3: Detailed depth of lowering definitions.

1.4. Constraints and limitations

This desk study is prepared considering the particular instruction and requirements of US Wind. It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party.

The CBRA is based on the data available at the time of writing. The results presented are suitable for planning and are indicative of the depth of lowering (DoL). The currently available data, see Table 1.1, is considered appropriate for characterization of the ground conditions and burial constraints for this preliminary analysis.

2. Site Conditions

The site conditions are assessed for the lease area based on geophysical and geotechnical survey data, see Table 1.1.

2.1. Geophysical survey results

Results from the 2021-22 high resolution geophysical surveys show that the majority of material at the seafloor is coarse-grained with very minor areas comprising clay at the surface [12]. This is consistent with BH and CPT results. Further refinement of the ground model is ongoing and will be included in subsequent design stages.

2.2. Geotechnical investigations

Geotechnical survey locations within the Lease area are shown on Figure 2.1 [9], [8]. The geotechnical units within the upper 3 m of seabed at all locations are coarse-grained.

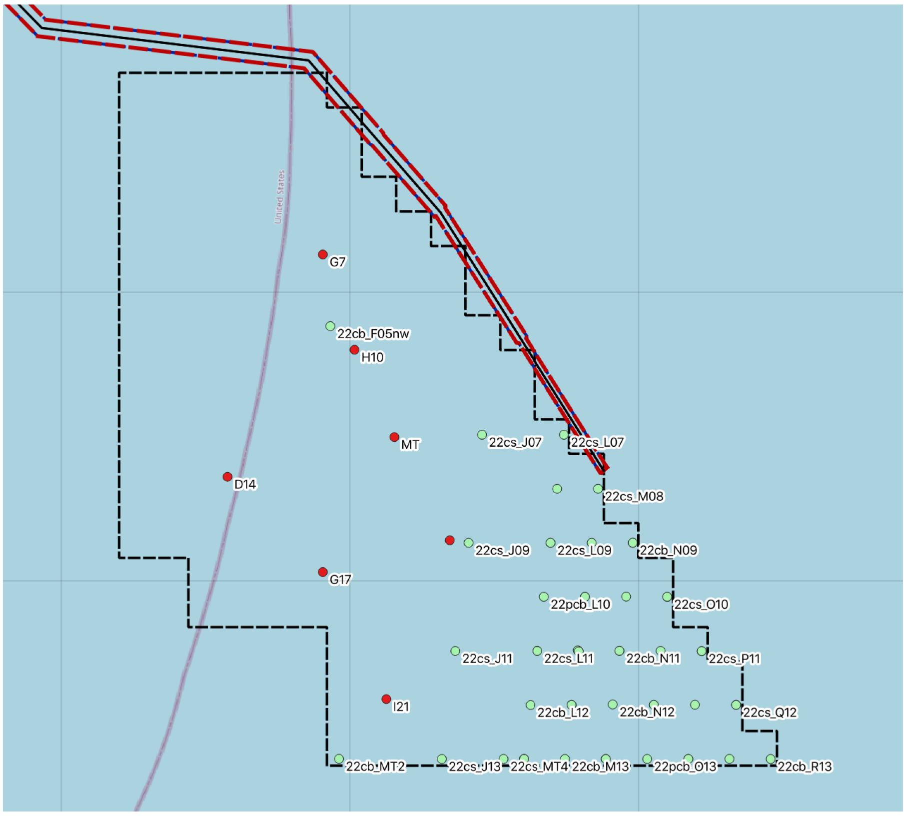


Figure 2.1: Geotechnical survey locations - Lease area. Red (Alpine [2]). Green (Fugro [8]).

2.3. Classification of soils for quantitative assessment

Classification of the geotechnical conditions is an important factor in determining the required burial depth and to identify any obstacles/challenges to the installation process. Classification is completed in accordance with the Carbon Trust guidance for cable burial risk assessments [5] where soft silt and clay is considered soft soil with the non-soft category being sands and firm to stiff clays. The soil conditions within the entire Lease area are categorised as hard soil within the depth of interest for cable installation on the basis of the geophysical interpretation and observed coarse-grained upper units in the BHs and CPTs.

3. Qualitative risk assessment

3.1. Anthropogenic risks

3.1.1. Shipping activity

The Lease area is located just south of the Delaware Bay Southeastern Approach Traffic Separation Scheme (TSS). Traffic separation schemes are usually created in areas with heavy traffic in different directions. It is an area where the navigation of vessels is highly regulated with lanes of vessels travelling the same direction.

A Navigation Safety Risk Assessment (NSRA) is carried out by DNV for the Lease area [7]. This risk assessment includes a traffic survey based on AIS data which identifies shipping traffic in the area. The NSRA found that most cargo and tanker vessels in the vicinity of the Lease area pass to the north of the Lease area. However, the traffic exiting the outbound lane of the TSS and heading south, and the traffic coming from the south and entering the inbound lane of the TSS, pass through the Lease area. The shipping traffic in the vicinity of the Lease area is assessed based on AIS data from 1 January 2019 to 31 December 2019 is shown in Figure 3.1.

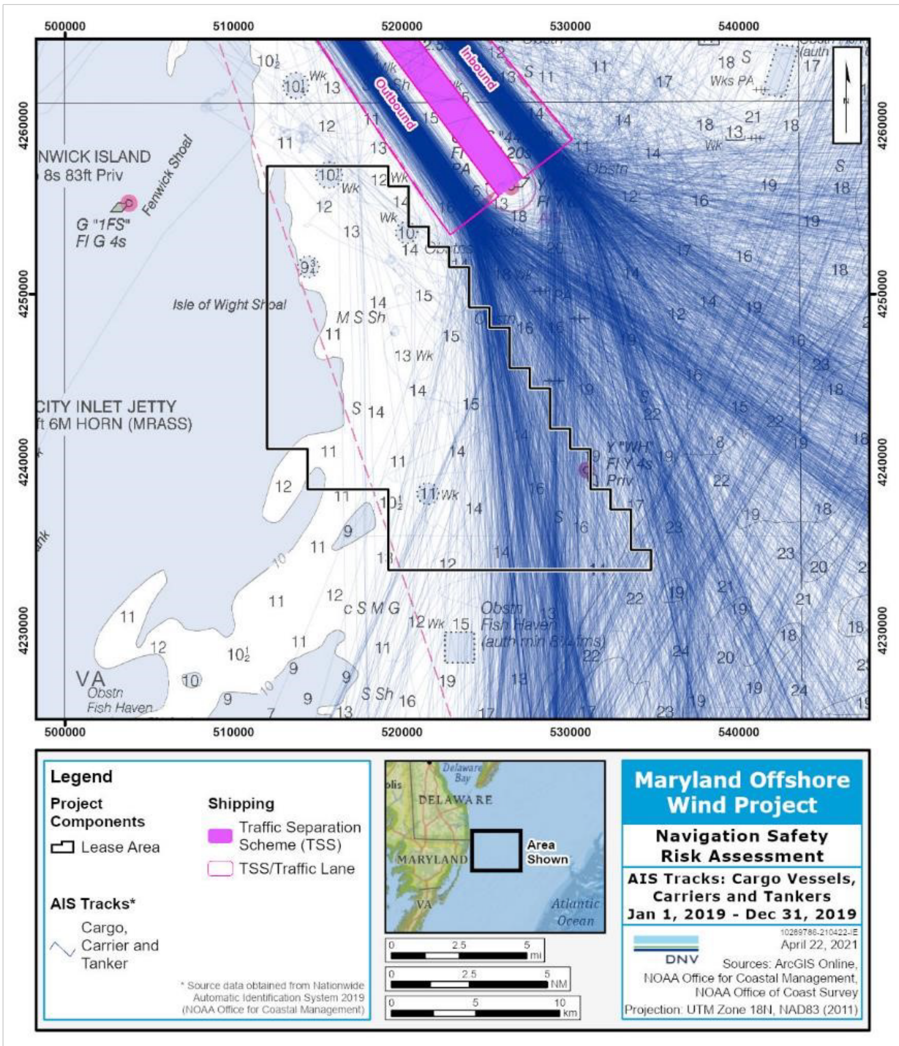


Figure 3.1: AIS Tracks for Cargo/Carriers and Tankers in the Lease area from DNV NSRA report [7].

Figure 3.1 shows that some cargo and tanker vessels traverse through the Lease area. According to the DNV NSRA [7] many deep draft vessels such as cargo and tanker vessels are expected to choose not to navigate through an operational wind farm based on input from industry organizations and mariners. However, the extent to which vessels will adjust their course is a matter of speculation.

3.1.2. Fishing activity

A fisheries assessment report in and around the MOWP area was conducted by Sea Risk Solutions LLC [16]. The findings from this assessment are summarised below.

Bottom otter trawl fishing effort exists to a limited extent within the central and southern parts of the Lease area however bottom trawl fishing has not been frequently observed within the Lease area.

Fishing with pots and traps occurs diffusely throughout the Lease area. It is most intensive along the eastern and southeastern boundaries. This type of fishing can cause challenges for the survey and installation process because caution must be taken in order not to snag either the vertical buoy lines or the lines connecting the traps. Black sea bass traps are most often set in strings of about 12 to 36 traps connected by a ground line. This gear may need to be removed where cables are planned to cross. This is to install the cable without damaging the gear as well as protect the cable. This type of fishing can also be of concern to the survey and installation process but is not of high risk to the cables once installed. It is expected fishing using pots will contribute to the Lease area traffic intensity.

Bottom gillnet fishing occurs inside and outside of the Lease area to some extent. However, this type of fishing has low penetration of the seabed (10 cm for anchors) and is not of high concern for the cable.

Targeted sea scallop fishery has not been observed within the Lease area. The scallop fishing activity observed in AIS data is most likely to be transit to and from port.

There has been few recent sightings of surf clam and ocean quahog fishing within the Lease area. This is in contrast to higher frequency of sightings historically. Surf clam dredging operations with hydraulic dredges penetrate the seabed deeper than other mobile fishing and harvest gear such as scallop dredges and otter trawls according to the North American Submarine Cable Association (NASCA).

Historically submarine telecom cables in the Northeast US seaboard have suffered several cases of damage from hydraulic clam dredges. Incidents of penetration up to 1 m have been reported. Though little activity is currently spotted, test tows may still be made on occasion in the Lease area. Therefore, planning should consider that surf clam dredging operations may still take place. It should be noted that given the slow growing nature of the surf clam species and the existence of suitable habitat throughout the Lease area, any shift in fishing activity may only be temporary.

As has been the case with the Block Island Wind Farm and the Coastal Virginia Offshore Wind Pilot Project, it is likely that the presence of turbines will attract additional recreational activity. It should be expected that recreational fishing activity, and sightseeing, will increase in the offshore area once the wind farm is in operation.

Hiddink et al. [17] conducted a systematic literature review of both North American and European studies that provide measurements of fishing gear penetration depth, including any study for which penetration depth of a fishing gear or a gear component (e.g., doors, sweeps,and bridles of an otter trawl) was measured or inferred. The three primary fishing practices of concern identified were; trawling, towed dredging and hydraulic dredging. These fishing methods are illustrated in Figure 3.2. The penetration depths into the seafloor were modelled by Hiddink et al. [13] and are shown in Table 3.1.

Carbon Trust recommendations [5] states that the maximum penetration depth of towed fishing techniques is 0.3 m. However, it is common practice to apply a safety factor of 2 to the calculated penetration of fishing gear.

The recommended minimum cable burial depth that protects against fishing is 1.0 m. This value is the conservative choice for this preliminary analysis to account for the incident reports from hydraulic dredges.

Table 3.1: Predicted fishing gear penetration [13].

Gear	Penetration Mean ± standard deviation
Hydraulic Dredge	0.161 ± 0.058
Towed Dredge	0.055 ± 0.022
Otter trawl	0.024 ± 0.011

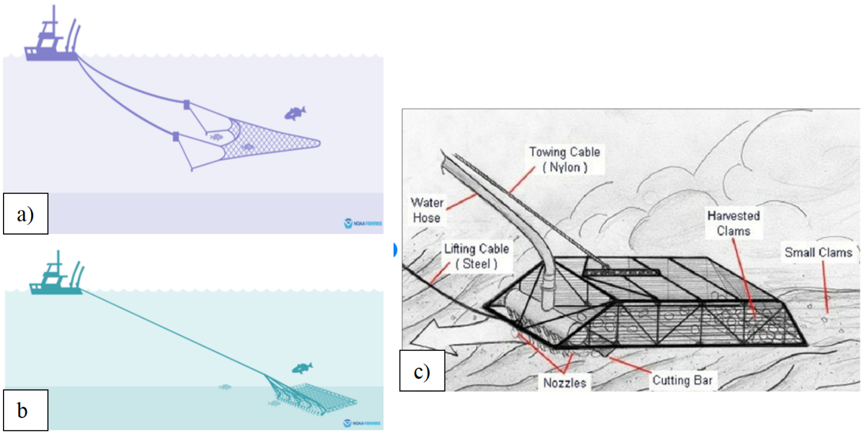


Figure 3.2: Fishing gear: a) Otter trawl. b) Towed dredge. c) Hydraulic dredge.

3.1.3. Potential unexploded ordnance

The presence of unexploded ordnances (UXO) is possible throughout Lease area due to active present and past military use in Warning Area 386 (W-386) [2]. W-386 is special-use airspace over VACAPES OPAREA-Areas 1-12 off the coast of Maryland in which missile, gunnery, and rocket exercises using conventional ordnance are authorized [21]. Many minor magnetic anomalies were identified with potential to be related to shallow buried UXO [2].

3.1.4. Existing infrastructure

Pot/trap fishing is known in the Lease area. Seabed contacts identified at Possible or Probable lobster or crab pot/traps are shown in Figure 3.3 [22]. Pots and traps can complicate installation operations as these should be avoided.

Four known shipwrecks and two potential wrecks were identified from the Alpine G&G survey [2], which has been superseded by the 2021-22 survey results. However only three wrecks were identified from the TDI and Fugro 2021-22 surveys as interpreted by GEMS [12]. Table 3.2 shows an overview of the known and possibly unknown wrecks in the Lease area as found from the Alpine survey. The most recent discussion of potential wrecks is found in the Marine Archaeological Resource Assessment [15].

Table 3.2: Wrecks - alpine

Wreck	Length	Width	Hight	Latitude	Longitude	Region
WK001	32 m	13.5 m	2.6 m	38.46135719	-74.82020131	northwest
WK002	13 m	4.4 m	0.5 m	38.45718862	-74.78516352	northern
WK003	43.5 m	13.1 m	1.4 m	38.36502478	-74.77023709	middle
WK004	25.8 m	5.7 m	1.6 m	38.29178876	-74.75442606	southeastern
Target 89(392)	-	-	-	38.45702412	-74.78525021	northern
Target 752	-	-	-	38.29139174	-74.75657636	southeastern

WK001, WK002 and WK003 are also identified from the TDI and Fugro surveys. Target 89(392) is very close to WK002 and possibly identified as the same wreck in the GEMS interpretation. WK004 and target 752 are not accounted for in the GEMS interpretation.

According to the fisheries assessment report [16] three wreck sites in the northern half of the Lease area are often targeted by recreational vessels for diving and lobster hunting.

Two buoys are located in the Lease area. The location of these are given in Table 3.3.

Table 3.3: Existing Buoys within the Lease area [12].

Buoy	Easting	Northing
UMCES Buoy	531039.42	4239493.97
US Wind Buoy	521535.60	4245007.05

No pipelines, wells, or other existing man-made infrastructure are located within the survey area [12].

3.1.5. Dredging and dumping sites

No dredging or dumping sites are identified from nautical charts in the Lease area.

3.1.6. Designated anchorages

No designated anchorages are identified from nautical charts in the Lease area. However, the DNV NSRA identified some presumed anchoring activity within the Lease area indicated by speed less than 1 kt [7]. Most of the vessels presumed to be at anchor in the vicinity of the Lease area are reported to be deep draft vessels. Impact of possible anchorage area must be accounted for in the quantitative assessment.

3.2. Natural risk

3.2.1. Seabed contacts

Seafloor features have been reported by GEMS [12] from MBES, SSS, and MAG based on data acquired by TDI and Fugro in 2021-22, which obtained full coverage within the Lease area. A total of 7,696 sonar point contacts have been identified within the Lease area.

The SSS point contacts generally represent modern debris associated with shipping, storms, fishing, or exploration activities, or are geologic in nature [12]. 22 contacts identified as wrecks are related to three individual wrecks, see Section 3.1.4. A total of 6,442 contacts are unspecified debris or unknown items.

Figure 3.3 shows an overview map of the SSS contacts [12] following reclassification by WT to align the combined SSS contact database (using TDI's primary contact classification and Fugro's secondary contact classification) [22], including potential shipwrecks. Interpretation of contacts with regard to cultural resources is provided in [15].

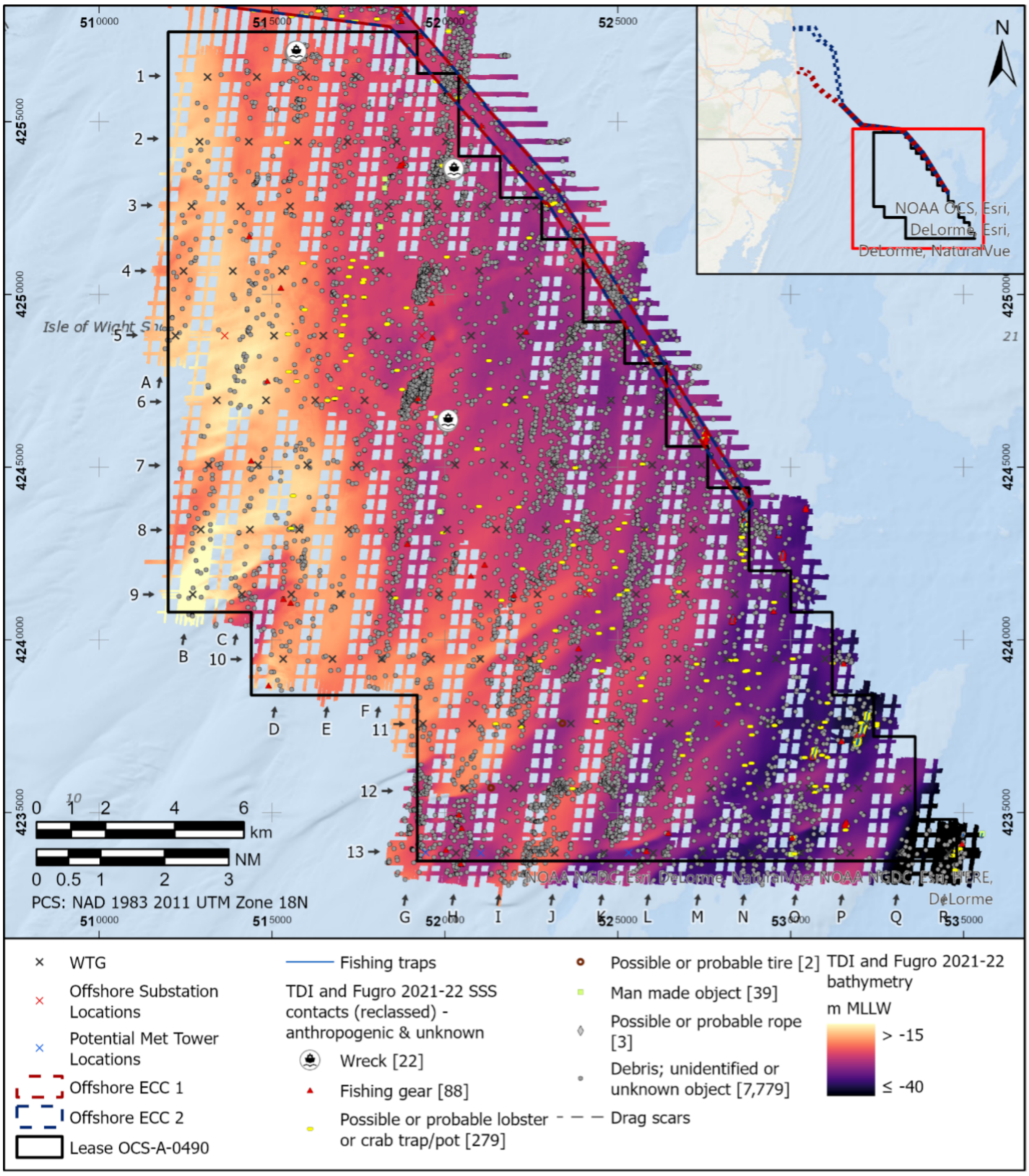


Figure 3.3: Overview map of SSS contacts from the TDI and Fugro surveys in 2021-22 [22].

3.2.2. Magnetic anomalies

The GEMS interpretation [12] identified a total of 7,744 magnetic anomalies in the Lease area. Most of the interpreted targets are of a relatively low amplitude, with a median target amplitude of only 9.4 nT. Only 662 targets (8.5%) have an amplitude equal to or exceeding 50 nT.

TDI targets are classified as 'Possible geology', 'Possible small object', 'Possible medium sized object', and 'Possible wreck'. Fugro targets are classified as 'Discrete', 'Non-discrete', and 'Shipwreck' [22]. The distribution of interpreted targets is shown in Figure 3.4 and a summary is given in Table 3.4.

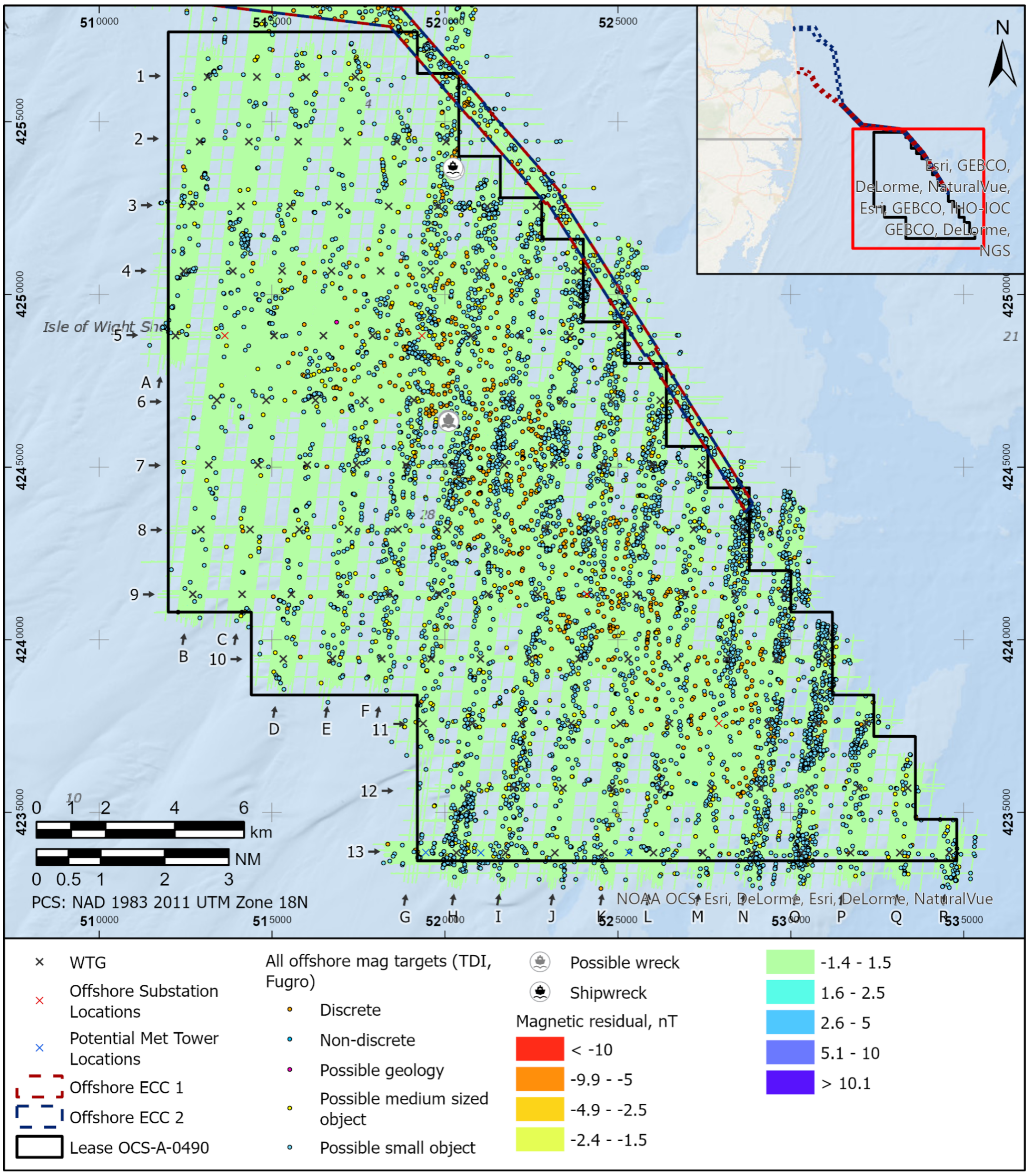


Figure 3.4: Magnetometer anomalies superimposed on magnetic residual grids from the TDI and Fugro surveys 2021-22 [22].

Table 3.4: Summary of magnetometer contacts within the Lease area boundary [22].

Target class	$< 30\,\text{nT}$	$\geq 30\,\text{nT}$	Total
Discrete	796	85	881
Non-discrete	19	6	25
Possible geology	0	42	42
Possible medium sized object	0	1026	1026
Possible small object	5760	0	5760
Possible wreck	3	6	9
Shipwreck	0	1	1
Total	6578	1166	7744

Given the dynamic seabed and conditions within the Lease area there is the potential for objects to become covered and uncovered due to bedform and sediment migration and due to self-burial, and potentially also for objects to move over time. It should also be noted that the coastal and OCS regional magnetic environment offshore Maryland is characterized by a strong geologic influence [2].

3.2.3. Water depth

The water depth in the Lease area ranges from -11.6 to -42.0 m MLLW generally deepening from northwest to southeast and with an average of −25.64 m MLLW. The bathymetric data is acquired by TDI in 2021 and Fugro in 2022 and merged by WT [22]. Shallower water depths are generally limited to the locations of the taller sand ridges (dunes). Deeper water depths are typically restricted to the southeastern corner of the Lease area [22]. An overview is shown in Figure 3.5.

Shallower waters with water depths less than 15 m can complicate the cable installation as some installation vessels are not able to operate in shallow waters. Special considerations for cable installation may apply to the westernmost part of the Lease area.

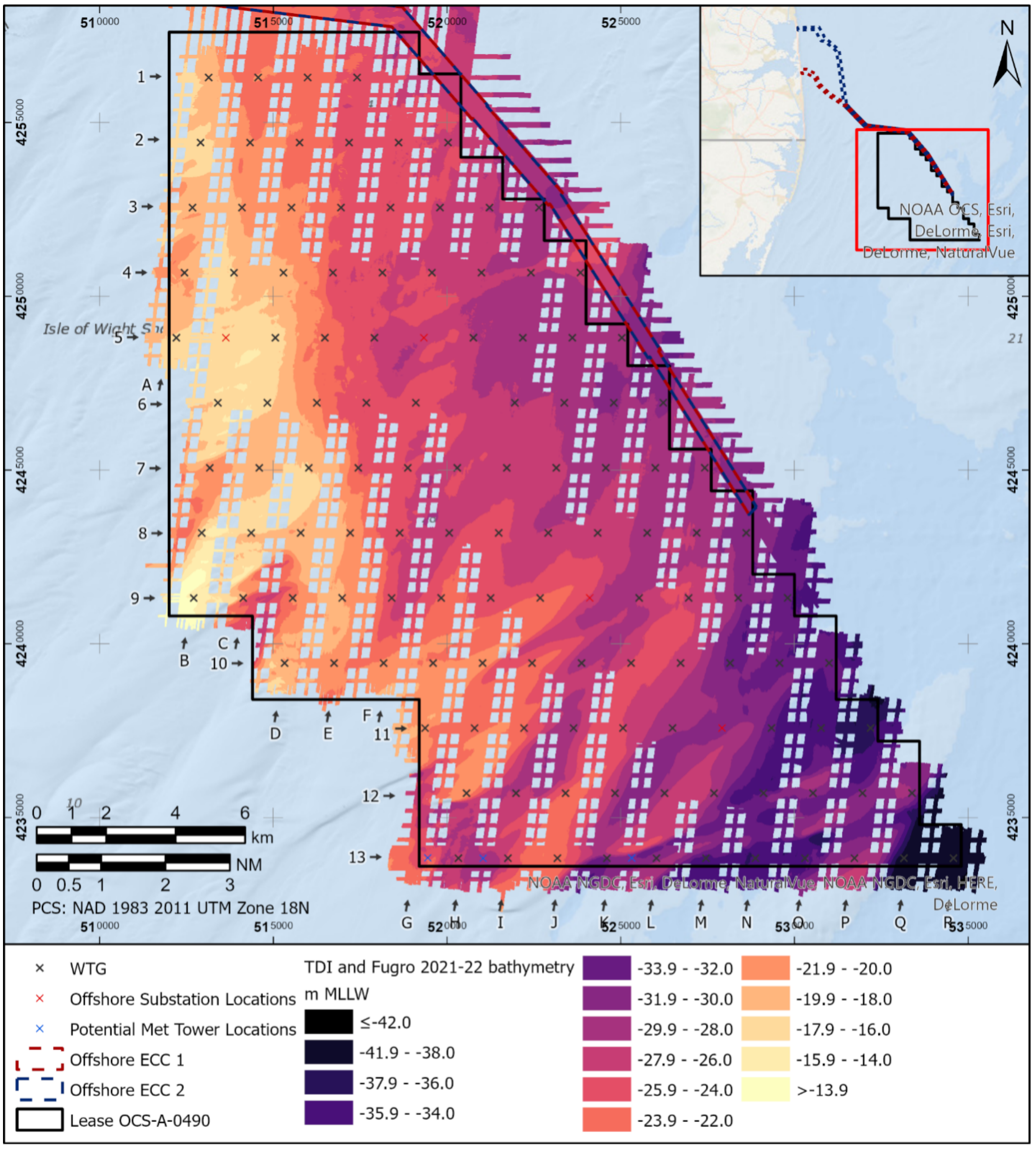


Figure 3.5: Merged TDI and Fugro 2021-2022 bathymetry, Lease area, 0.5x0.5 m resolution [22].

3.2.4. Slopes

Regionally, the seafloor across the Lease area slopes from west to east at a gentle gradient of less than 1 percent. However, a field of prominent elongated seafloor ridges or dunes are identified, which have steeper slopes. In general, slopes do not exceed 1° for 93% of the Lease area and additionally slopes do not exceed 2° for 99% of the Lease area [22]. The distribution of slopes within the Lease area is shown in Table 3.5.

Table 3.5: Lease area seafloor slopes [22].

Classification	Gradient (°)	Lease coverage
Very gentle	< 1	92.9%
Gentle	1-4.9	7.1%
Moderate	5-9.9	0.0%
Steep	10-14.9	0.0%
Very steep	> 15	0.0%

The seafloor interpretation identifies locally steeper slopes located by the south-western border of the Lease area, where local slopes over 20° are identified. Steep slopes of more than 10° complicates installation operations as cable laying tools cannot operate on steep slopes. Figure 3.6 shows the seafloor slopes within the Lease area.

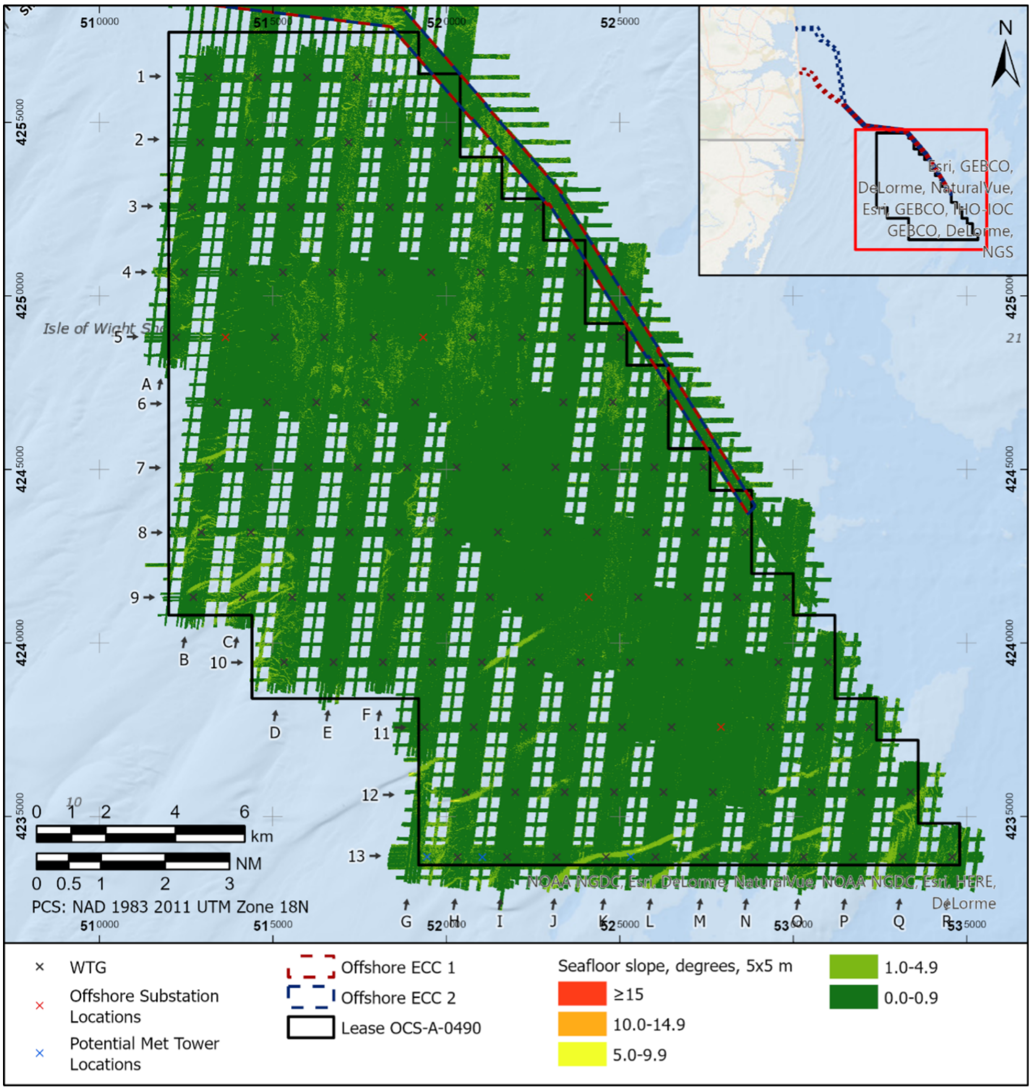


Figure 3.6: Seafloor slope [22].

As can be seen from figure 3.6 steep slopes generallly do not occur within the Lease area, however cable lay bestween turbines towards the south-western border should be investigated further.

3.2.5. Seabed mobility

Evidence of seabed mobility is demonstrated throughout the Lease area [22]. Minor bedforms (minor sand ridges, sand waves/dunes, bedforms in irregular seafloor areas) are migrating at a significant rate relative to the project lifetime. Major sand ridges area also migrating, albeit at a slower rate. A high-level classification of different seabed mobility zones based on vertical differences between successive bathymetric surveys within the Lease area are shown in Figure 3.7 [22].

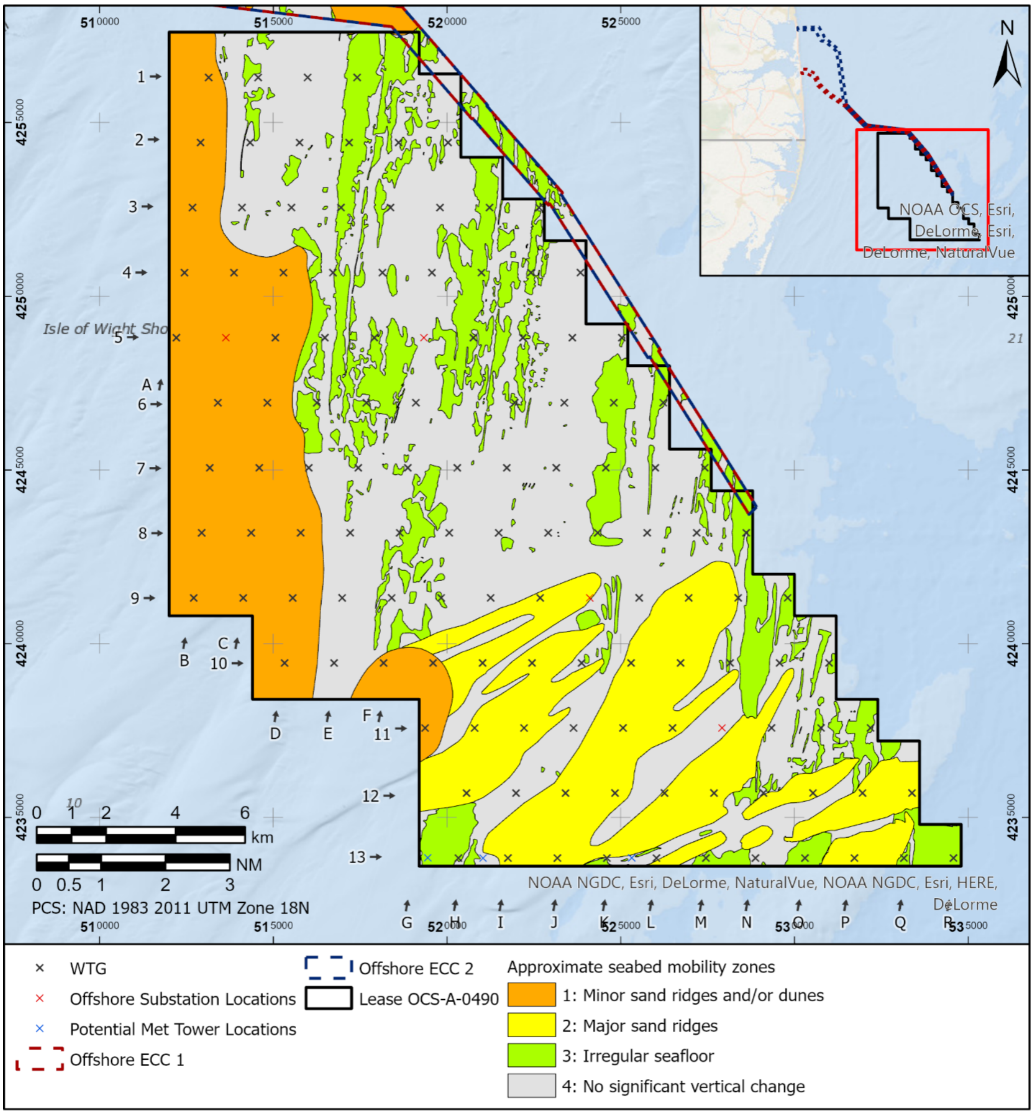


Figure 3.7: Seabed mobility zones [22].

The Lease area is an area prone to bottom currents that are capable of transporting sediments and causing scour. Supported by the presence of morphologic features relatively high potential for sediment transport and scour is expected. The variability in seafloor reflectivity observed between subsequent SSS passes, combined with the presence of mobile bedforms, highlights that the seafloor is highly dynamic, with both bedform and sediment transport movement ongoing [22].

Large seabed mobility activity, whether it is sand waves or scour, should be considered due to the risk of exposing or over-heating the cable where there are high volumes of sediment transport.

4. Quantitative Risk Assessment

Quantitative assessment of the cable burial risk is performed according to the methodology outlined by Carbon Trust [4] [5]. Calculation methods and detailed results are presented in Appendix A. Preliminary analysis is completed considering the entire Lease area.

4.1. AIS data

Vessel traffic is assessed from available automatic identification system (AIS) tracking in the area. The AIS data for this assessment is obtained from [1] for a period of 2 years. The AIS data set is processed to establish unique vessel timestamps and AIS type codes. Approximately 12% of the total data set for the Lease area is ignored because of missing vessel length information that is used to estimate vessel dead weight tonnage (DWT). Changes to the vessel traffic pattern due to construction of the wind farm are not considered in this preliminary assessment. Further refinement of the AIS data and anticipated vessel traffic patterns following construction should be considered in subsequent design stages.

The Lease area is divided into two zones for quantitative analysis based on the existing vessel traffic patterns, with soil conditions considered hard soil in both zones based on the available geotechnical data (Section 2). Zone 2 to the east is characterised by higher shipping volume. The two zones are illustrated on Figure 4.1.

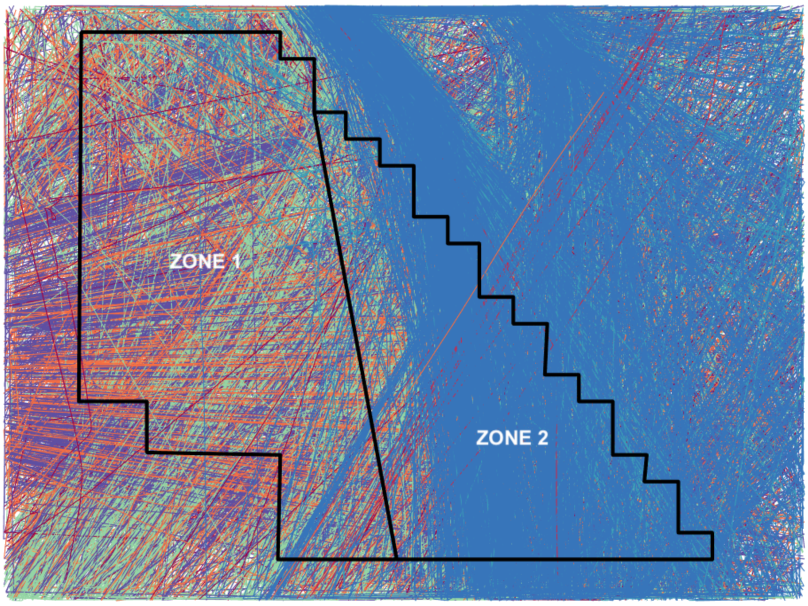


Figure 4.1: Lease area zones showing vessel traffic patterns from AIS data for quantitative burial risk assessment.

4.2. Input parameters

The burial depths are defined based on the fluke penetration of standard anchors and the type of sediment encountered. The cable burial risk assessment (CBRA) method only considers anchorages in emergency cases (e.g. due to a mechanical failure or to prevent a collision). The probability of strike (p_{strike}) is based on vessel size, vessel speed when emergency anchoring, probability of emergency anchoring and ground conditions/cable burial depth. Details on anchor models and calculation of p_{strike} and DoL are provided in Appendix A. Table 4.1 summarises the main inputs adopted for the quantitative CBRA for the Lease area.

Table 4.1: Main input parameters for the quantitative CBRA for the Lease area.

Parameter	Value	Description
$P_{traffic}$	1	Modifier for traffic within each route section
P_{wd}	0.9	Modifier for water depth
V_{ship}	4kts	Based on peak tidal current speed
$P_{incident}$	0.01	Conservative value from findings by SAFECO [14]

4.2.1. Water depth modifier

The water depth profile and adjacent obstacles govern a vessel's need for performing emergency anchorage if it loses control (e.g. due to engine failure). The value for P_{wd} should represent the degree of constraints that the vessel master faces in assuring the safety of vessel and crew in case of an incident. A P_{wd} value of 0.9 is conservatively adopted for the preliminary analysis given the presence of WTGs increases the likelihood of needing to deploy an anchor in an emergency to avoid collision. Further optimisation may be possible in subsequent design stages to adopt a lower value for P_{wd} on the basis that the Lease area is characterised by deeper water.

4.2.2. Vessel speed when anchoring

The vessel speed at which a safe emergency anchorage would normally occur is 1-2 knots dependent on vessel size [5]. The larger the vessel the lower the acceptable speed for anchorage. The speed of vessel drift is assumed to be governed by local current speeds, particularly tidal currents. A value of 4 kts is conservatively adopted for V_{ship}. The value may be refined for final design based on analysis of the maximum tidal current speeds for the Lease area.

4.2.3. Incident rate

Literature provides a large range for the incident rate, $P_{incident}$. DNV [6] reports incident rates as low as 0.0002 for loss of control when on collision course and up to 0.1752 based on engine failure of single-engined tankers in the North Sea. A $P_{incident}$ value of 0.01 is adopted for preliminary analysis based on WT experience and engineering judgement. Sensitivity is assessed by performing analysis considering the upper and lower bound $P_{incident}$ values indicated by DNV [6]. Results of the sensitivity study are presented in Section 5.3.

4.3. Results of quantitative analysis

DoL is derived for a range of return periods, presented in Appendix A. Results for DoL are reported for risk level 1 in 100,00 yrs in Section 5, which is considered neglible risk [20]. Results are summarised in terms of burial depth for defined risk levels and vice versa in Section 5. The detailed results of the CBRA are included in Appendix A.

5. Depth of lowering

The depth of lowering (DoL) is considered from the stable seabed level. The DoL is selected to reflect the acceptable risk level to the project and considers:

- Results of the qualitative risk assessment (i.e. threat of damage from anthropogenic and natural risks)
- Results of the quantitative CBRA (i.e. the risk of anchor strike to the cable)

Fishing activity is seen to be the main qualitative risk directly affecting the depth of lowering. Vessel traffic intensity and vessel size coupled with geotechnical conditions govern the quantitative risk level. Results are presented in Appendix A both soft and hard soils. This is to provide an upper bound burial depth should soft soils be identified in specific areas of the site. However, as discussed in Section 2, WT expect this to be unlikely and the recommended DoL is based on results for hard soils. The recommended DoL reported below constitutes the target level from an engineering perspective for a 1 in 100,000 year return period of anchor strike. The target DoL for installation must be decided based on the project acceptable risk level and account for local permitting requirements for minimum burial depth.

5.1. DoL by acceptable risk level

Table 5.1 present the minimum depth of lowering (MDOL) for protection against:

- Snagging and/or impact of fishing gear
- An anchor strike occurrence of 1 in 100,000 years (10^{-5}yrs)

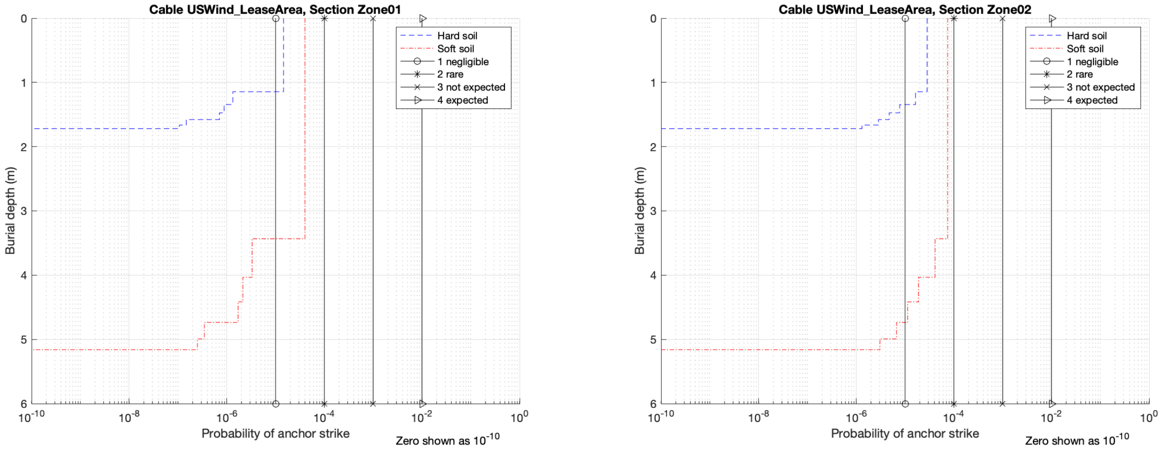
The detailed results presented in Appendix A presents the MDOL for more frequent return periods in intervals of an order of magnitude, e.g. 1 in 10,000 years, 1 in 1,000 years, and 1 in 100 years.

Table 5.1: Recommended DoL below stable seabed for the Lease area.

Zone	Fishing DoL	Vessel interaction DoL	Recommended DoL
1	1.0 m	1.1 m	1.1 m
2	1.0 m	1.3 m	1.3 m

5.2. Risk level by depth

The risk of anchor strike for a specific DoL is derived for zone 1 and 2. Results are presented in Figure 5.1. These charts may be helpful in assessing the balance between burial depth, risk appetite and cable installation tool constraints. A specific risk level (horizontal axis) can be read for a given burial depth (vertical axis).



(a) Zone 1 **(b)** Zone 2

Figure 5.1: Risk level by DoL.

5.3. Sensitivity analysis - $P_{incident}$

Results of sensitivity analysis is presented in Table 5.2. The results show that the required DoL is relatively insensitive to that value of $P_{incident}$. Therefore, the preliminary assumption adopting 0.01 is deemed acceptable. Further refinement is recommended for subsequent design stages.

Table 5.2: DoL below stable seabed for the Lease area for different values of $P_{incident}$.

Zone	$P_{incident,LB}$	$P_{incident,BE}$	$P_{incident,UB}$
1	0.0 m	1.1 m	1.6 m
2	0.0 m	1.3 m	1.7 m

6. Recommendations for future assessment

AIS data quality is identified as a key issue given that over 10% of data points from the original data set were ignored due to lack of vessel lengths in the available data set. There is a risk that a statistically significant amount of vessels are not included in the preliminary assessment and that the overall risk is underestimated and recommended burial depths are too shallow. WT recommend the AIS data is refined or appropriate assumptions made to provide better quality estimates of vessel type, traffic patterns, dimensions and DWT.

Interpretation of geotechnical survey is ongoing at the time of writing. It is recommended that classification of geotechnical conditions for CBRA is confirmed during detailed assessment of intra-array cable (IAC) corridors. An upper bound of burial depth is provided in Appendix A for consideration where soft soils may be present at the seafloor, although WT considers it unlikely that substantial soft soils will be identified along the IAC corridors within the Lease area.

WT identify the following opportunities for optimisation:

- Consideration of future vessel traffic patterns to potentially remove shipping vessels that may divert around the Lease area following construction. This would reduce the risk of incident and likelihood of deeper anchor penetrations resulting in a more favourable target burial depth.
- Subdivision of analysis area into IAC corridors/routes
- Optimisation of input parameters (P_{wd}, V_{ship}, $P_{incident}$)

7. Conclusion

A preliminary cable burial risk assessment is undertaken for the US Wind Lease area. A qualitative risk assessment is completed to identify anthropogenic and natural threats to the cables within the Lease area. A quantitative risk assessment is evaluated to determine the required burial depth for a range of risk-return periods.

Quantitative assessment is completed following the methodology outlined in the Carbon Trust guidelines. Two zones are considered based on existing shipping traffic patterns. Geotechnical conditions for the entire Lease area are classified as hard soil on the basis that shallow deposits are identified as sandy soils in the preliminary geophysical interpretation as well as existing borehole and cone penetration test locations within the area. Sand ridges in the area pose a risk of steep slopes which should be assessed further for safe cable installation operations.

Potential hydraulic dredging operations in the Lease area poses a risk to the cable once installed. Previous incidents of penetrations up to 1 m have been reported, hence a minimum DoL of 1 m should be pursued to mitigate threats from fishing activity. A minimum DOL of 1.1-1.3 m is recommended to account for fishing activity and risk of anchor strike. This is driven by the current vessel traffic intensity.

Shipping activity through the area is expected to decrease once the turbines are installed though recreational traffic is expected to increase. However, WT has identified issues with the quality of AIS data used for the quantitative assessment. It is recommended that the AIS data is refined or appropriate assumptions made in subsequent design stages to better capture the vessel details and traffic patterns.

A high number of magnetic anomalies are identified in the Lease area with data and known military activity in the area indicating risk of potential UXO's (pUXO). At the time of writing US Wind is conducting a review of the survey data to identify any pUXO to be avoided or removed for cable installation operations.

Avoidance of shipwrecks and potential cultural resources will be required and therefore are not expected to pose additional risk.

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Specific revisions of WT design basis/brief documents are excluded from this list of references, because of the inter-related nature of the documents going through separate and concurrent review and certification cycles. The document numbers and titles are correct: please refer to the latest version of the master document register (MDR) for a confirmation of the final revision number that is applicable to each individual design basis/brief.

A. CBRA Probability Report for Lease Area

A.1. Vessel movement

Vessel movement has been assessed using AIS data as presented in Section 4.1. Table A.1 provides a summary of the vessels crossing the Lease Area. Section A.5 and A.6 details the number of vessels crossing each zone for each vessel size over the data set period.

Table A.1: Vessel classifications.

Vessel classification	Number of vessels	Number of crossings	Maximum DWT (t)
Cargo, Hazardous category A	11	51	97544
Cargo, Hazardous category B	2	10	73785
Cargo, No additional information	7	25	98473
Cargo, all ships of this type	523	1891	171886
Fishing	168	1622	1043
Other Type, Reserved for future use	1	1	32
Other Type, all ships of this type	41	120	7871
Passenger, all ships of this type	30	129	147666
Pleasure Craft	341	1191	995
Sailing	90	131	559
Tanker, No additional information	2	2	23856
Tanker, all ships of this type	143	545	75341
Towing	166	1260	467
Towing: length exceeds 200m or breadth exceeds 25m	1	1	19
Tug	2	3	251
Unknown	5	14	69986

A total of 83821 of 702879 data points were ignored from the analysis due to missing vessel length information.

The most common vessels were:

- F/V BETTY C, Fishing class, 82 tonnes, 325 crossings
- CAPT JEFF, Fishing class, 44 tonnes, 217 crossings
- CHRISTY, Fishing class, 113 tonnes, 141 crossings
- DORIS MORAN, Towing class, 271 tonnes, 94 crossings
- DOLE CHILE, Cargo, all ships of this type class, 32510 tonnes, 91 crossings

The largest vessels were:

- GUSTAV MAERSK, Cargo, all ships of this type class, 171886 tonnes, 1 crossings
- COSCO HARMONY, Cargo, all ships of this type class, 171886 tonnes, 1 crossings

- ARNOLD MAERSK, Cargo, all ships of this type class, 153809 tonnes, 2 crossings
- ALBERT MAERSK, Cargo, all ships of this type class, 153809 tonnes, 1 crossings

A.2. Anchor and ship models for probabilistic anchor strike assessment

Table A.2 shows the anchor model used.

DWT is estimated using Equation A.1 (dimensions in metres, DWT in tonnes) (ref [3], Fig 1.3):

$$DWT = (length/5.32)^{(1/0.351)} \tag{A.1}$$

Displacement is taken as $1.7 \times DWT$ (ref [3]), adopting container ship parameters.

Anchor mass is estimated from (ref [5], Fig 9.2).

Fluke length is estimated using Equation A.2 from data for stockless anchors from the Dreyfus and Vryhof anchor catalogues (fluke length in metres, anchor mass in tonnes):

$$\text{Fluke length} = 0.9909(\text{anchor mass})^{0.3441} \tag{A.2}$$

Anchor penetration is based on soil type (ref [17]):

$$\text{Fluke pen.} = \begin{cases} 1 \times \text{fluke length} \times sin(45°) & \text{in hard soils} \\ 3 \times \text{fluke length} \times sin(45°) & \text{in soft soils} \end{cases} \tag{A.3}$$

Ultimate holding capacity is based on soil type, (UHC in kN and penetration in metres):

$$UHC = \begin{cases} 294.99 \times \text{Fluke pen.}^{2.5276} & \text{in hard soils} \\ 3.91 \times \text{Fluke pen.}^{2.9525} & \text{in soft soils} \end{cases} \tag{A.4}$$

Table A.2: Anchor model.

Vessel category	DWT (1000t)	Disp. (1000t)	Anchor mass (kg)	Fluke length (m)	Fluke pen hard soil (m)	Fluke pen soft soil (m)	UHC hard soil (kN)	UHC soft soil (kN)
1	0-18	30	4159.2	1.6	1.14	3.43	414.7	149.2
2	18-35	60	6645.1	1.9	1.34	4.03	623.3	240.1
3	35-52	89	8653.6	2.1	1.47	4.42	784.2	314.0
4	52-70	119	10600.0	2.2	1.58	4.74	935.6	385.9
5	70-88	149	12350.0	2.4	1.66	4.99	1068.6	450.7
6	88-105	178	13600.0	2.4	1.72	5.16	1162.0	497.0
7	105-122	208	13600.0	2.4	1.72	5.16	1162.0	497.0
8	122-140	238	13600.0	2.4	1.72	5.16	1162.0	497.0
9	140-158	268	13600.0	2.4	1.72	5.16	1162.0	497.0
10	158-175	298	13600.0	2.4	1.72	5.16	1162.0	497.0

Table A.3 shows the ship model used.

D$_{ship}$, the estimate of distance an anchor is dragged, is calculated using Equation A.5 (ref [4]), D$_{ship}$ in metres, Disp in tonnes, v_{ship} in knots, UHC in kN, 0.51444 kts $>$ m/s:

$$D_{ship} = \frac{Disp \times 0.51444(v_{ship})^2}{4UHC} \tag{A.5}$$

Table A.3: Ship model.

Vessel category	DWT (1000t)	Vship (kts)	Ptraffic (-)	Pwd (-)	Pincident (-)	Dship hard soil (m)	Dship soft soil (m)
1	0-18	4.0	1.0	0.9	0.0100	75.95	211.14
2	18-35	4.0	1.0	0.9	0.0100	101.05	262.34
3	35-52	4.0	1.0	0.9	0.0100	120.47	300.91
4	52-70	4.0	1.0	0.9	0.0100	134.64	326.48
5	70-88	4.0	1.0	0.9	0.0100	147.36	349.42
6	88-105	4.0	1.0	0.9	0.0100	162.61	380.17
7	105-122	4.0	1.0	0.9	0.0100	189.71	443.54
8	122-140	4.0	1.0	0.9	0.0100	216.81	506.90
9	140-158	4.0	1.0	0.9	0.0100	243.91	570.26
10	158-175	4.0	1.0	0.9	0.0100	271.02	633.62

A.3. Probabilistic anchor strike assessment for surface lay

Table A.4 shows the probability of anchor strikes for surface laid cables. Full results including vessel categories and counts are shown in Section A.6. The highest risk (per km) cables are:

- USWind_LeaseArea, LeaseArea_Zone02, RPhard 52824934 yr/km, RPsoft 20102245 yr/km
- USWind_LeaseArea, LeaseArea_Zone01, RPhard 80734240 yr/km, RPsoft 29326265 yr/km

The probability an anchor of a particular vessel size crosses the cable at seabed is estimated as (ref [5]), D$_{ship}$ in m, v$_{ship}$ in kts, 8766 hr/yr, 1852 kts $>$ m/hr:

$$P_{strike} = \frac{p_{traffic} \times p_{wd} \times vessel_{count} \times D_{ship} \times p_{incident}}{v_{ship} \times 1852 \times 8766} \tag{A.6}$$

Considering the vessel movements as independent, the total probability of an anchor strike over the cable length is (P$_{s.n}$ is the P$_{strike}$ of individual vessel sizes):

$$P_{strike.total} = 1 - (1 - P_{s.1})(1 - P_{s.2})(1 - P_{s.3})...(1 - P_{s.n}) \tag{A.7}$$

When the probabilities are very small the above method is equivalent to summing the individual probabilities.

Return period (RP) is taken as the inverse of probability of anchor strike. The length of the cable is used to calculate the return period per kilometre of cable.

Table A.4: Surface lay probabilistic assessment.

Cable	Section	Hard soil return period	Soft soil return period	Rank
USWind_LeaseArea	LeaseArea_Zone01	68725 yr, 80734240 yr/km	24964 yr, 29326265 yr/km	2
USWind_LeaseArea	LeaseArea_Zone02	35244 yr, 52824934 yr/km	13412 yr, 20102245 yr/km	1

A.4. Probabilistic anchor strike assessment for buried cables

The probability of anchor strike for buried cables has been calculated by removing the vessels from the analysis where the fluke penetration shown in Table A.2 is less than the depth considered. Table A.5 shows the required burial depths to achieve certain target frequencies, defined as:

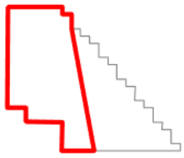
- Category 1, $< 10^{-5}$, So low frequency that event considered negligible
- Category 2, $< 10^{-4}$, Event rarely expected to occur
- Category 3, $< 10^{-3}$, Event individually not expected to happen, but when summarised over a large number of cables have the credibility to happen once a year
- Category 4, $< 10^{-2}$, Event individually may be expected to occur during lifetime of the cable
- Category 5, $> 10^{-2}$, Event individually may be expected to occur more than once during lifetime of the cable

Appendix A.7 shows the anchor strike frequency for buried cables, with zero frequency taken as 10^{-10} for plotting purposes.

Table A.5: Burial depths to achieve target frequencies.

Cable	Section	Hard, 1.0e-02	Soft, 1.0e-02	Hard, 1.0e-03	Soft, 1.0e-03	Hard, 1.0e-04	Soft, 1.0e-04	Hard, 1.0e-05	Soft, 1.0e-05
USWind_-LeaseArea	LeaseArea_Zone01	0.0	0.0	0.0	0.0	0.0	0.0	1.1	3.4
USWind_-LeaseArea	LeaseArea_Zone02	0.0	0.0	0.0	0.0	0.0	0.0	1.3	4.7

A.5. Vessel movement maps



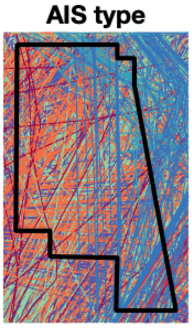


Figure A.1: Vessel movement,Cable USWindLeaseArea, Section-LeaseArea-Zone01.

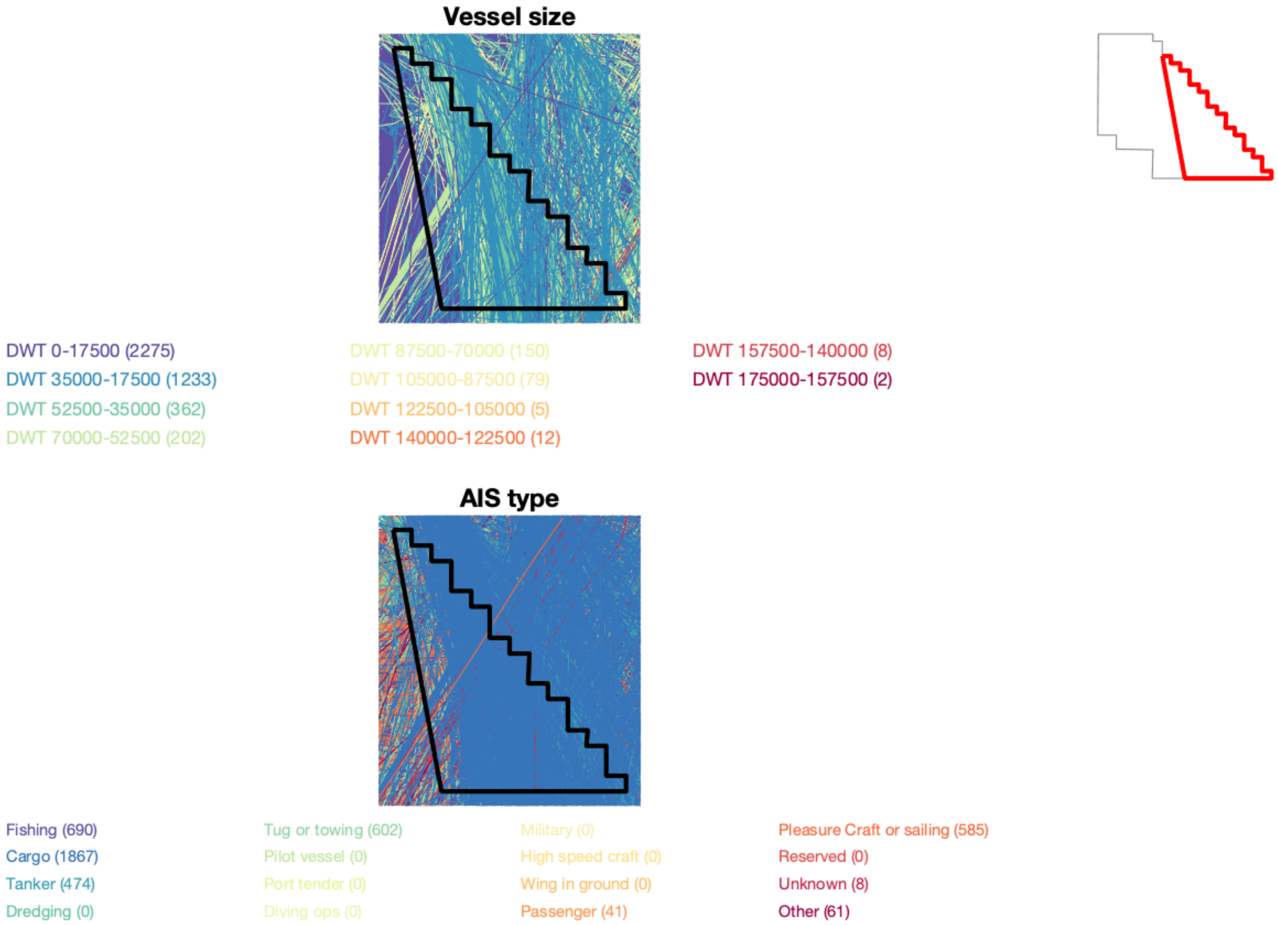


Figure A.2: Vessel movement,Cable USWindLeaseArea, Section-LeaseArea-Zone02.

A.6. Full anchor strike assessment for surface lay

Table A.6: Surface lay probabilistic assessment (full results)

Cable	**Section**	**Vessel cat.**	**Vessel count**	**Pstrike hard soil (-)**	**Pstrike soft soil (-)**	**Hard soil** **Total Pstrike (-)** **Return period (yr)** **Return period (yr/km)**	**Soft soil** **Total Pstrike (-)** **Return period (yr)** **Return period (yr/km)**
USWind_- LeaseArea	LeaseArea_- Zone01	1 2 3 4 5 6 7 8 9 10	2510 64 21 60 4 8 0 0 1 0	1.32e-05 4.48e-07 1.75e-07 5.60e-07 4.09e-08 9.02e-08 0 0 1.69e-08 0	3.67e-05 1.16e-06 4.38e-07 1.36e-06 9.69e-08 2.11e-07 0 0 3.95e-08 0	1.46e-05 68725 yr 80734240 yr/km	4.01e-05 24964 yr 29326265 yr/km
USWind_- LeaseArea	LeaseArea_- Zone02	1 2 3 4 5 6 7 8 9 10	2275 1233 362 202 150 79 5 12 8 2	1.20e-05 8.64e-06 3.02e-06 1.89e-06 1.53e-06 8.91e-07 6.58e-08 1.80e-07 1.35e-07 3.76e-08	3.33e-05 2.24e-05 7.55e-06 4.57e-06 3.63e-06 2.08e-06 1.54e-07 4.22e-07 3.16e-07 8.79e-08	2.84e-05 35244 yr 52824934 yr/km	7.46e-05 13412 yr 20102245 yr/km

A.7. Anchor strike probability graphs for buried cables

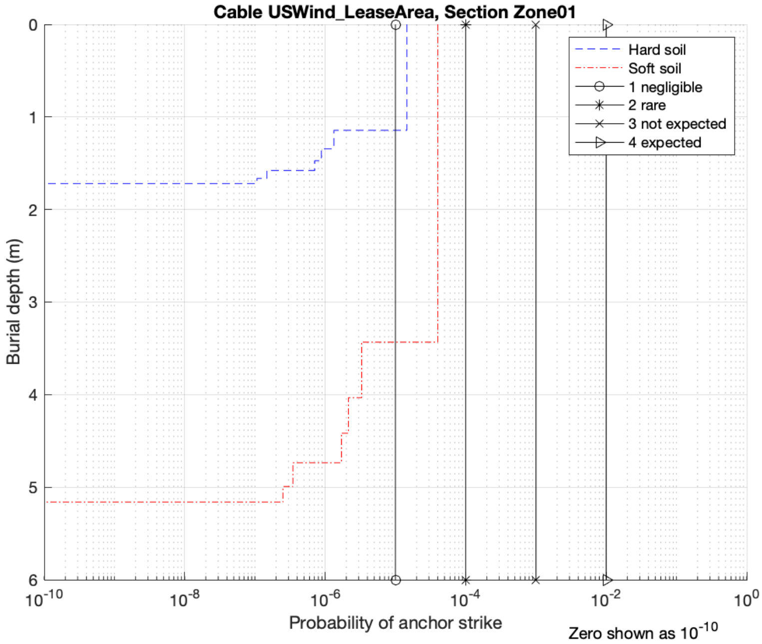


Figure A.3: Anchor strike risk vs burial depth, Section LeaseArea-Zone01.

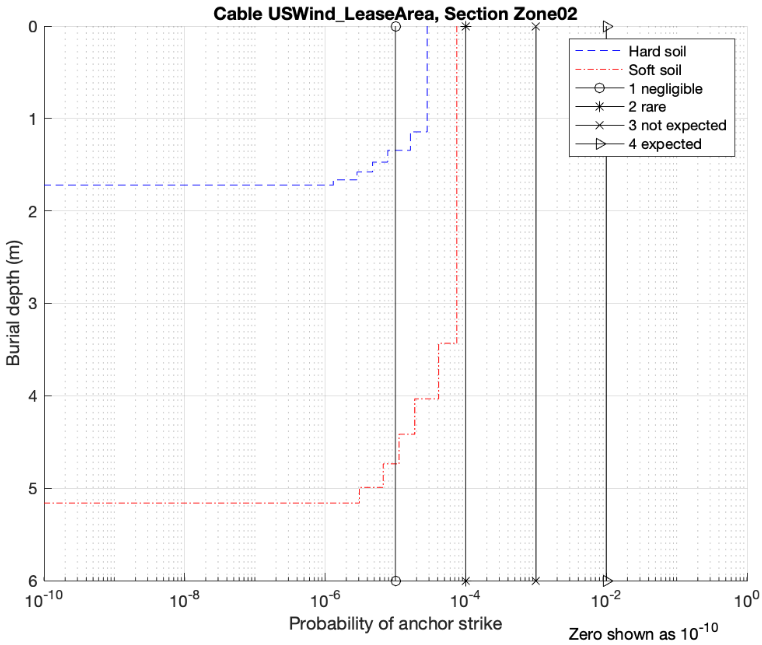


Figure A.4: Anchor strike risk vs burial depth, Section LeaseArea-Zone02.

A.8. Anchor strike probability tables for buried cables, by section

Table A.7: RP for burial depths, hard soil.

Depth (m)	LeaseArea_Zone01	LeaseArea_Zone02
0.00	68725	35244
0.25	68725	35244
0.50	68725	35244
0.75	68725	35244
1.00	68725	35244
1.25	750690	61002
1.50	1412025	211475
1.75	Inf	Inf

Table A.8: RP for burial depths, soft soil.

Depth (m)	LeaseArea_Zone01	LeaseArea_Zone02
0.00	24964	13412
0.25	24964	13412
0.50	24964	13412
0.75	24964	13412
1.00	24964	13412
1.25	24964	13412
1.50	24964	13412
1.75	24964	13412
2.00	24964	13412
2.25	24964	13412
2.50	24964	13412
2.75	24964	13412
3.00	24964	13412
3.25	24964	13412
3.50	302283	24241
3.75	302283	24241
4.00	302283	24241
4.25	466440	53125
4.50	586265	88731
4.75	2878811	149322
5.00	3992869	326533
5.25	Inf	Inf