Unexploded Ordnance Risk Assessment with Risk Mitigation Strategy

Project: **Nissum Bredning Vind**

Client: **Siemens Wind Power A/S**

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Client	SIEMENS

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Quality Assurance

Project Number	Status	Version	Date	Written	Imagery	Reviewed	Released
JM5303	Draft	1.0	18/11/16	AL/HM/TC	RB	LG	LG

Executive Summary

Background

Ordtek Limited (*Ordtek*) has been appointed as unexploded ordnance (UXO) risk management consultant to *Siemens Wind Power A/S (Siemens)* for the Nissum Bredning windfarm that will be situated in Nissum Bredning within Limfjorden lying close to the entrance of the North Sea by Thyborøn Kanal, on the North West Danish coast. The project consists of 4 WTG locations and associated inter array and export cables.

Unexploded ordnance (UXO) residue from World War One (WWI), World War Two (WWII), post-war dumping of explosive ordnance (EO) and modern military practice presents a potential risk to the development. Nevertheless, the UXO hazard can be managed safely and at best value to the project through a comprehensive understanding of the risks involved, the natural environment and the project development phases.

Military History

The North Sea saw considerable military action over two World Wars. There were substantial mine laying operations in both wars involving both German and British buoyant and ground mines, with minefield clearance of only limited effectiveness after each period of conflict.

However activity in this area to the North of Denmark was comparatively minor, and in particular the Limfjord appears to have been sheltered from much of this, in part due to the shallow depths and no significant military activity within the fjord. The Danish Navy have informed Ordtek that EOD of historic mines has taken place in the area by the Danish Navy, when North Sea weather prohibits safe disposal further offshore. However, this is unlikely to have occurred in the Nissum Bredning site area due to the shallow water depth making navigation difficult and the Site’s proximity to land.

The possibility of either buoyant or ground mines drifting into the Site from the minefields closest to the entrance to Limfjorden, at Thyborøn Kanal, is extremely unlikely.

While Allied bombing, naval surface conflict, modern naval exercises, shore artillery practice, coastal defences and munitions dumping have all played a part in potentially contaminating the Site, the narrow entrance to the Limfjord, as well as the lack of viable targets within the Limfjord, mean UXO is unlikely to have drifted or been carried in from the North Sea, or be present in a density that would significantly elevate the risk from UXO. Nevertheless, the accumulation of evidence points to air-dropped Allied mines and bombs presenting statistically the biggest risk to Project activity.

UXO Threat Assessment

The presence of UXO within the Nissum Bredning Vind Site is possible although remote. There is a background threat from a very wide range of EO, which includes, among others, mines and bombs. The table below reflects the expected density of UXO targets within the Site boundary.

Likely Density of UXO Types within Nissum Bredning Vind		
UXO Type	**Density**	**Remarks**
German Ground Mines	Low	German minefield B37 ~7km W from site in North Sea. However, unlikely to have drifted or been dragged into Nissum Bredning
British Air-dropped Ground Mines	Low	Hawthorn II British minefield ~7km W from site in North Sea. There are 10 known remaining mines, however these are unlikely to have drifted or been dragged into Nissum Bredning

Likely Density of UXO Types within Nissum Bredning Vind		
UXO Type	**Density**	**Remarks**
British WWI Buoyant Mines	Low	Known minefield ~11km W from Site in North Sea; will now be severely degraded
Land Service Ammunition	Low	Sources: coastal defence at Thyborøn, naval action and ad hoc training
Allied HE Bombs	Low	The main German WWII coastal convoy routes pass well to the west, however British aircraft flew frequent anti-ship bombing missions in the general area.
Torpedoes	Very Low	Much recorded surface ship and submarine action (e.g. Battle of Jutland) but none within Nissum Bredning.
Depth Charges	Very Low	No submarine wrecks with Nissum Bredning, unlikely given shallow waters
Inert Practice Munitions (all types)	Very Low	Ad hoc training conducted all around the Danish coast
WWII German buoyant mines	Very Low	Small possibility that mines from distant fields could have drifted in.
Chemical Warfare Agents	Very Low	No evidence in the study area but risk is not zero

Table ES1 - Likely density of UXO types within Nissum Bredning Vind study area

In accordance with this assessment, and the limited scale of the project it follows that the UXO risk is low.

Seabed Operations Prohibited Zone

The Nissum Bredning site is within a "Seabed Operations Prohibited" Zone marked on navigation charts (Appendix 2).

Within the zone, special regulations issued by the Danish Maritime Authority (DMA) apply. These rules are covered in the "Legislation and Guidance" section of this study. In essence, the person responsible for activities on the seabed is required to:

- Investigate the dangers and restrictions associated;
- Contact Admiral Danish Fleet if UXO or CW agents are found (and work is to temporarily stop);
- Obtain a special permit from the DMA to work in the zone.

Risk Assessment and Mitigation Requirement

Given the low probability of encounter, Ordtek considers that magnetometer survey is not required to reduce the risk to ALARP. While improvement in detection can be achieved utilising magnetometer survey, generally the detection and identification of all magnetic anomalies that could resemble UXO in the area is likely to be impractical as well as highly costly, when compared to the risk reduction. Investigating the resultant anomalies that ensued from data interpretation would be unjustified in both time and cost according to Ordtek's understanding of the ALARP principle. Accordingly, a high resolution acoustic survey is recommended. Geophysical anomalies modelling as UXO in subsequent analysis can be detected and avoided or investigated and removed/destroyed.

Ordtek considers that **the smallest significant UXO hazard item that needs to be mitigated for an ALARP sign-off is the British 250lb GP or MC bomb.** Assuming these items can be successfully detected and identified within the geophysical datasets, larger objects will also be detectable. While this will reduce the risk from large UXO, the bulk of risk reduction and risk management will be undertaken via physical and procedural measures. Nevertheless, the likelihood of detonation is very low and the overall UXO risk can be reduced satisfactorily to below the ALARP threshold through procedural mitigation measures alone.

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Abbreviations and Acronyms

ALARP	As Low As Reasonably Practicable
CW	Chemical Weapon
dGPS	Differential Global Positioning Systems
DTS	Desktop Study
EO	Explosive Ordnance
EOD	Explosive Ordnance Disposal
ERW	Explosive Remnants of War
GIS	Geographical Information System
HE	High Explosive
HSE	Health and Safety Executive
JSEODOC	Joint Service Explosive Ordnance Disposal Operations Centre
KHz	Kilohertz
Kg	Kilogram
Kv	Kilovolt
Km	Kilometre
M	Metres
MCM	Mine Countermeasures
mm	Millimetres
NEQ	Net Explosive Quantity
Nm	Nautical Mile
PLGR	Pre Lay Grapnel Run
ROV	Remotely Operated Vehicle
RN	Royal Navy
QA/QC	Quality Assurance/Quality Control
SOP	Standard Operating Procedure
SSS	Side Scan Sonar
SQRA	Semi Quantitative Risk Assessment
TNT	Trinitrotoluene
UK	United Kingdom
UXB	Unexploded Bomb
UXO	Unexploded Ordnance
WWI	World War One
WWII	World War Two

1 Introduction

1.1 Project Description and Background

Ordtek Limited (*Ordtek*) has been appointed as unexploded ordnance (UXO) risk management consultant to *Siemens Wind Power A/S (Siemens)* for the Nissum Bredning Vind offshore windfarm (OWF) that will be situated in Nissum Bredning within Limfjorden lying close to the entrance of the North Sea by Thyborøn Kanal, on the North West Danish coast (Appendix 1). The project consists of 4 Wind Turbine Generator (WTG) locations and associated Inter Array Cables (IAC) and Export Cable.

UXO presents a potential risk to the development. Explosive Ordnance (EO), both the result of military action and planned post-war dumping, is frequently encountered around the Danish coastline.

UXO contamination of the seabed has occasionally lead to inadvertent detonations, causing damage to equipment and the death of personnel. Three Dutch fishermen lost their lives in 2005 in British waters, when a WWII device exploded on board their fishing vessel after having been hauled aboard in fishing nets. Nevertheless, such explosions are an increasingly rare event and the UXO hazard can be managed safely and at best value to the project through a comprehensive understanding of the risks involved, the natural environment and the project development phases. For the purposes of this document, UXO is specified as the hazard and will be defined as “all ordnance and explosives contamination” including discarded or dumped, fired and/or unfired munitions.

1.2 Purpose of this Document

Siemens has provided Ordtek with a study area of interest (AOI) that encompasses the main OWF development area as well as a portion of the surrounding area. We have been commissioned to undertake a study to determine the potential presence, type and risk from UXO within the main development site and wider AOI.

This study will focus on two key components:

- **UXO Desk Based Study with Risk Assessment -** A desktop study of the risk of encountering munitions, UXO, dumped chemical warfare agent and other dangerous objects and substances at or near the sites.
- **UXO Risk Mitigation Strategy -** Recommendations for a general UXO strategy for the site. This will include:
    - A description of the regulation and legislation which applies to offshore work where risk from UXO or similar may be expected.
    - A discussion whether the ALARP principle may be applied and whether any legal or regulatory requirements exist that need to be taken into account when deciding or whether the risk is reduced to ALARP.

The purpose of the document is to serve as a valid operational risk assessment, not as a detailed historical treatise. Our research has drawn on the most convenient and reliable sources, cognisant of the need to limit cost and delay to the client. Nevertheless, the data presented is complete and appropriate for risk assessment purposes and fully in line with current best practice.

Should the client require further details of any particular aspect or issue raised within the following paragraphs, it can potentially be provided as an addendum to this report on request.

1.3 References

Key references used for the assessment are listed below:

A. AARSLEFF – Production, Transport and Installation of NISSUM BREDNING OWF, Method Statement, Rev 0 dated 09 September 2016.

B. AARSLEFF – Dredging Profile - WTG position (Excavation Profile), PAA-DWG-003 Rev 00 dated 09 September 2016.

C. COWI A/S – Cable Burial Risk Assessment – Nissum Bredning, Version 0.1 Rev Draft dated 29 July 2016.

D. COWI A/S – Nissum Bredning, Data Overview Map, Rev Draft dated 05 July 2016.

E. COWI A/S – Nissum Bredning, Seabed Mobility, DRAFT 2015 Orthophoto and sandbar outlines, Rev Draft dated 07 July 2016.

F. COWI A/S – Nissum Bredning, Seabed Mobility, DRAFT Inflow distribution, Rev Draft dated 07 July 2016.

G. COWI A/S – Nissum Bredning, Seabed Mobility, DRAFT Seabed changes from 1958 to 2005, Rev Draft dated 07 July 2016.

H. COWI A/S – Nissum Bredning, Seabed Mobility, DRAFT modelled seabed changes from 2005 to 2060, Rev Draft dated 07 July 2016.

I. DEEP BV – Field Operations, Calibration – Position Check (Measured Reference Point), dated 21 April 2016.

J. DEEP BV – Metadata van Projectresultaten, Singlebeam peiling, dated 21 April 2016.

K. DEEP BV – Survey Works Nissum Bredning Denmark, P3069-SBE-1/1-R01 Rev 01 dated 29 April 2016.

L. JD-Contractor A/S – S/B Victor Specifications (Multipurpose Barge)

M. JD-Contractor A/S – Light Jet Specifications (Light Weight Jetting Sledge)

N. Danish Energy Agency – Guidelines on Safety and Health Related Conditions on Offshore Installations etc., Rev 0 dated December 2012.

O. CIRIA – Assessment and Management of Unexploded Ordnance (UXO) Risk in the Marine Environment, 2015

1.4 Study Area

This document covers a “Study Area”, which encompasses the boundary of the Nissum Bredning Vind OWF as defined in the Data Overview Map at Reference D, and shown graphically at Appendix 1.

In our assessment, we also consider a wider “Area of Interest” (AOI) that takes in the surrounding region to a distance considered relevant to any particular issue under examination.

The depth of water within the Nissum Bredning Vind main boundary is shallow, varying between ~0.5m-4.5m. The seabed consists of multiple layers of sand/gravel over clay/gyttja.

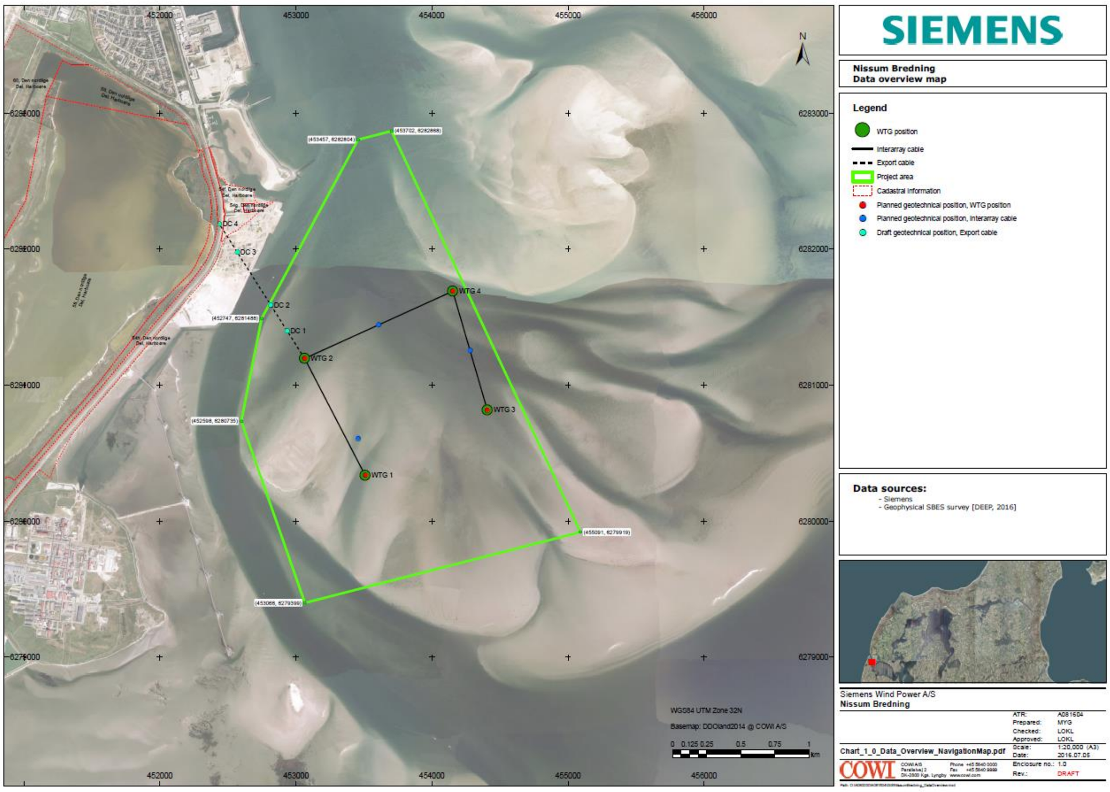


Figure 1.1 – Data Overview Map Reference D

1.5 Project Scope

The OWF installation operations and activities covered by this risk assessment are listed below.

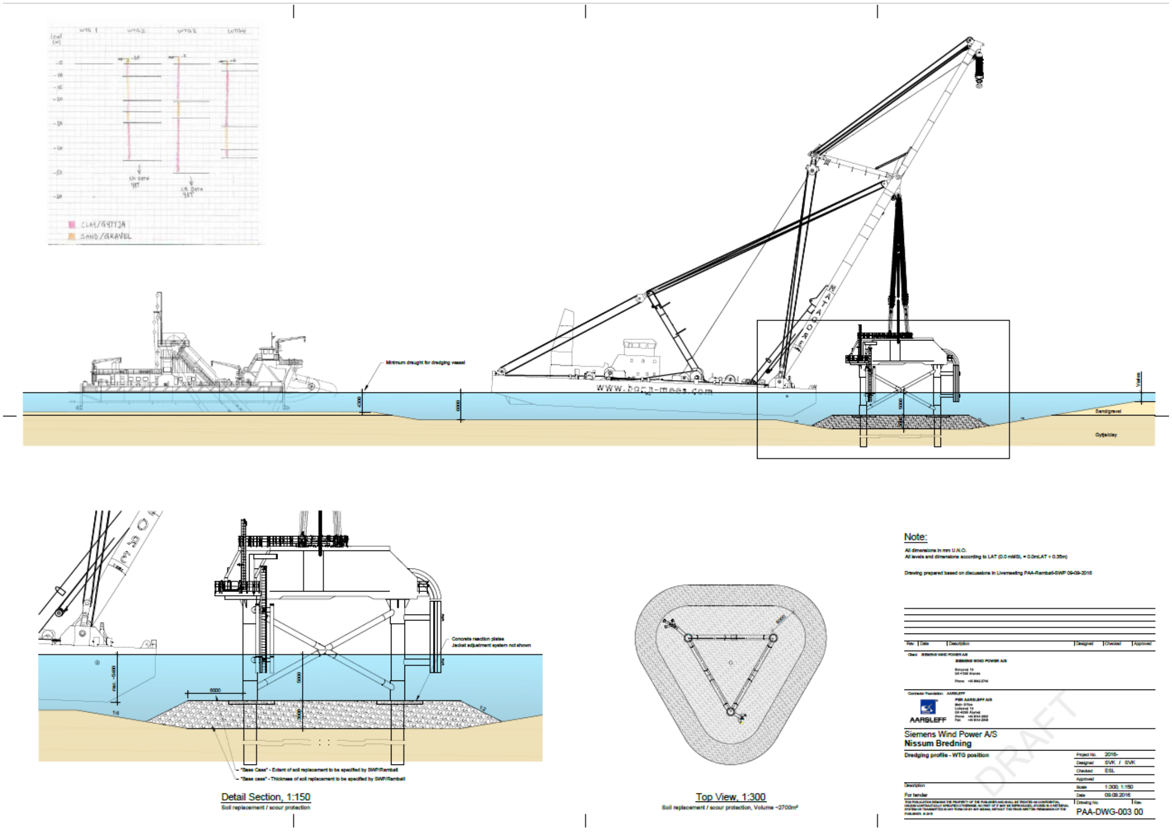


Figure 1.2 - Dredging Profile - WTG position (Excavation Profile) Reference B

1.5.1 Geotechnical Campaign

- Deep geotech investigation BH/CPT
- Shallow geotech investigation for cable installation

1.5.2 Foundation Installation

- Jacket Foundation installation at WTG
- Installation of TPs on top of the steel jackets
- In-water storage and handling of sub-structures prior to installation

1.5.3 Cable Installation

- Pre-Lay Grapnel Run (PLGR)
- Anchor spread and handling
- Inter-array cable installation via Cable plough/Jetting/Trenching
- Cable laydown areas

1.5.4 Operations and Maintenance

- Scour protection installation
- WTG Maintenance
    - Jack-up leg placement
    - Anchor handling.

1.6 Ordtek Desk Study Methodology and Objectives

An important part of this study has been to undertake a comprehensive review of all sources and data. We have independently evaluated each document and dataset in order to ensure that the results and conclusions in this report are founded on a valid baseline. We have then extracted relevant information to support our own comprehensive research and UXO risk assessment and mitigation recommendations for Nissum Bredning Vind; the purpose being to avoid duplication of effort and to save time and cost, thereby providing best value to the Client.

In preparing the recommendations contained in this study we will follow a logical process, *inter alia*, we will:

- Assess the baseline UXO risk in the study area to likely project activities.
- Develop and recommend a UXO risk mitigation strategy to achieve ALARP for the associated project activities.

For completeness we have considered all activities, past and present that could have contributed to UXO contamination. However, military archives and data sets, particularly older ones, are often very limited in both accuracy and detail. Determining specific and complete evidence of the amount of munitions dumped, laid, fired or dropped, live or inert is very rarely possible. Our risk assessment therefore is based on the data that is available, extrapolated to fill information gaps using similar situations from other sites, and built on ALARP principles using the expertise, judgement and high level of experience of our specialist analysts.

1.7 Research

In this study we have considered both wider regional and, where the information is available, site specific historical factors for the purpose of determining a baseline UXO hazard level. We match this baseline to the likely development operations to be carried out and assess the potential risk to the project from UXO.

Within the AOI, we seek to identify the dump sites, official and unofficial, the EO legacy of two World Wars and the modern military exercises that could potentially contaminate the Nissum Bredning Vind site with UXO, both now and during the full life cycle of the project. We also examine the likelihood of EO migrating from outside the area into the site.

Our research has focussed on the following:

- Military history of the area
- Official and unofficial munitions dumping sites
- Military weapon ranges and training areas
- Potential migration of dumped munitions
- Wrecks of vessels or aircraft that may have a legacy of UXO contamination
- Protective, defensive and offensive minefields laid by both German and British military forces
- Evidence of aerial warfare, including bombing, depth charge and torpedo deployment

- Evidence of naval surface and subsurface warfare and engagements

Information and data from a wide variety of sources have been collated to inform the study and risk assessment. The principal sources have been consulted from the following:

- UK Hydrographic Office (UKHO)
- The National Archives, London
- Royal Navy Historical Archive, Portsmouth
- The Ministry of Defence (MoD) and Danish Defence Command
- Pertinent authoritative British, American and German publications
- Web based archives
- *Ordtek*'s own comprehensive internal database
- Federal Maritime and Hydrographic Agency (BSH) in Hamburg
- Reports and information provided by Siemens (Reference A to O)

The extent of information presented within this paper does not represent the full volume of *Ordtek*'s research or all documentation obtained.

2 Legislation and Guidance

2.1 Construction Industry Duties and Responsibilities

2.1.1 Key Definitions

Several industry specific terminologies are used in this document. However, *Ordtek* considers the following worthy of special note.

- **Unexploded Ordnance (UXO)** – UXO is defined as military munitions that have been primed, fused, armed or otherwise prepared for action; have been fired, dropped, launched, projected or placed in such a manner as to constitute a hazard to operations, installations, personnel or material; and remain unexploded whether by malfunction, design or any other cause.
- **As Low As Reasonably Practicable (ALARP)** – The health and safety principle is that *any residual risk shall be as low as reasonably practicable.* For a risk to be ALARP it must be possible to demonstrate that the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained. The ALARP principle arises from the fact that infinite time, effort and money could be spent on the attempt of reducing a risk to zero.
- ***De minimis*** – A residual risk that is deemed to be too trivial or minor to merit consideration, especially in law. It is the failure to reach the threshold level required to be actionable.

2.1.2 European Law

In our experience, it is generally the case across Europe that there is no specific legislation covering the management and control of the UXO risk to the offshore construction industry (especially outside the 12 nm boundary). In view of the lack of specific UXO legislation, our considered opinion is that European Union (EU) law concerned with the protection of workers from work-place hazards will normally apply to offshore activities. This is the subject of *Council Directive 89/391/EEC of 12 June 1989 (amended up to 21 November 2008)*, which introduces measures to encourage improvements in the safety and health of workers at work. The Directive applies to all sectors of activity, both public and private (industrial, agricultural, commercial, administrative, service, educational, cultural, leisure etc.).

Within the Directive, “Prevention” is defined as: all the steps or measures taken or planned at all stages of work in the undertaking to prevent or reduce occupational risks (Article 3 Definitions).

The Directive lays down the obligations of both employer and workers. Article 6 sets out the general principles of prevention, which include inter alia:

a) Avoiding risks;
b) Evaluating the risks which cannot be avoided;
c) Combating the risks at source;
d) Adapting the work to the individual …
Etc.

Article 18, directs that "Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with this Directive by 31 December 1992.

2.1.3 Danish Law

Danish Safety legislation pertaining to Health and Safety (H&S) is contained principally in the Danish Offshore Safety Act (Act No. 1424 dated 21 December 2005) and a number of supplementary Executive Orders (see Reference H). Our understanding is that Danish H&S law, based on European law, is similar to that of the UK and revolves around the principle of reducing risk to As Low As Reasonably Practicable (ALARP).

As a part of the Danish consent process, *Siemens* is required to present its UXO risk mitigation methodology and results to the Royal Danish Navy (FRK EOD) in order to gain approval for the geotechnical investigation and other installations activities. To date, the plan for the geotechnical campaign has been presented and approved.

2.2 UXO Risk Management Standards and Risk Assessment

Many regulatory authorities, including Danish Health and Safety legislation, require that operational risks should be within acceptable limits and ALARP, this is also the case with UXO. Determining that UXO risks have been reduced to ALARP involves an assessment of the UXO risk to be avoided, an assessment of the effort (in terms of money and time) involved in taking control measures to avoid or mitigate that risk, and a comparison of the two facets. The graph at *Figure 2.1* demonstrates how ALARP is measured.

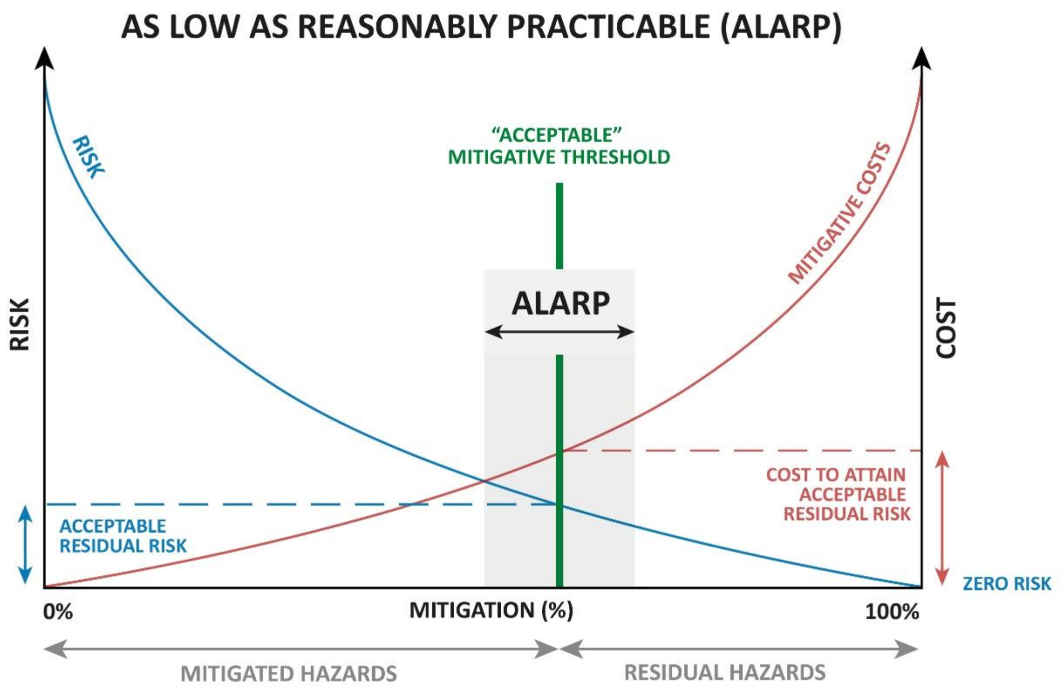


Figure 2.1 – Determining risk are ALARP by measuring Cost versus Effort

Although European and Danish law clearly lays out the obligations on various parties and general preventative principles, the absolute level of risk that is acceptable (if any) is not defined; it is expressed as a relative value.

Certainly in most practical situations in the maritime environment, the level of risk can statistically never be "Zero". The number of hazard items in a typical OWF development area is never known; the limitations of current survey equipment technology mean that the probability of detection can never be "1" and therefore the probability of encounter cannot be zero. Similarly, the sensitivity and stability of any UXO present is not known and, therefore the probability of detonation cannot be zero. Finally, if development activities are to take place, people and equipment will necessarily be put in "harm's way". There will always be a residual level of risk. The level will depend on the mitigation measures put in place.

To demonstrate that risks are ALARP, one must show that enough has been done to reduce risks. In cases where the risks are well-defined, it is sufficient to show that recognised "good practices" have been implemented. In more complex situations, i.e. where the industry or technology is new, to demonstrate risks are ALARP, it is necessary to show that all reasonably practicable risk reduction measures have been implemented, and that all other measures that could be implemented are shown to be unjustified. Risk criteria may be defined by national regulations, corporate guidance and well-established industry standards.

Through previous engagement on projects in the UK and Europe, *Ordtek* is acutely aware of the standards and guidance that need to be adhered to when managing UXO risk. This includes working in line with the guidance and research provided by the HSE and CIRIA. However where no official guidance exists, *Ordtek* will work within its proprietary framework.

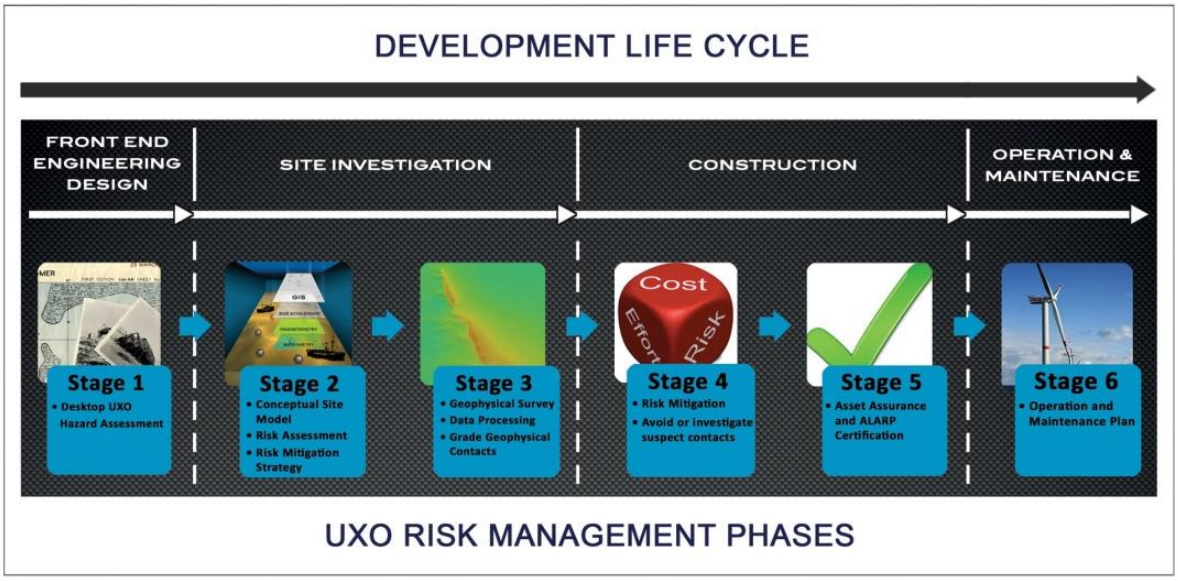


Figure 2.2 – Ordtek's UXO Risk Management Framework

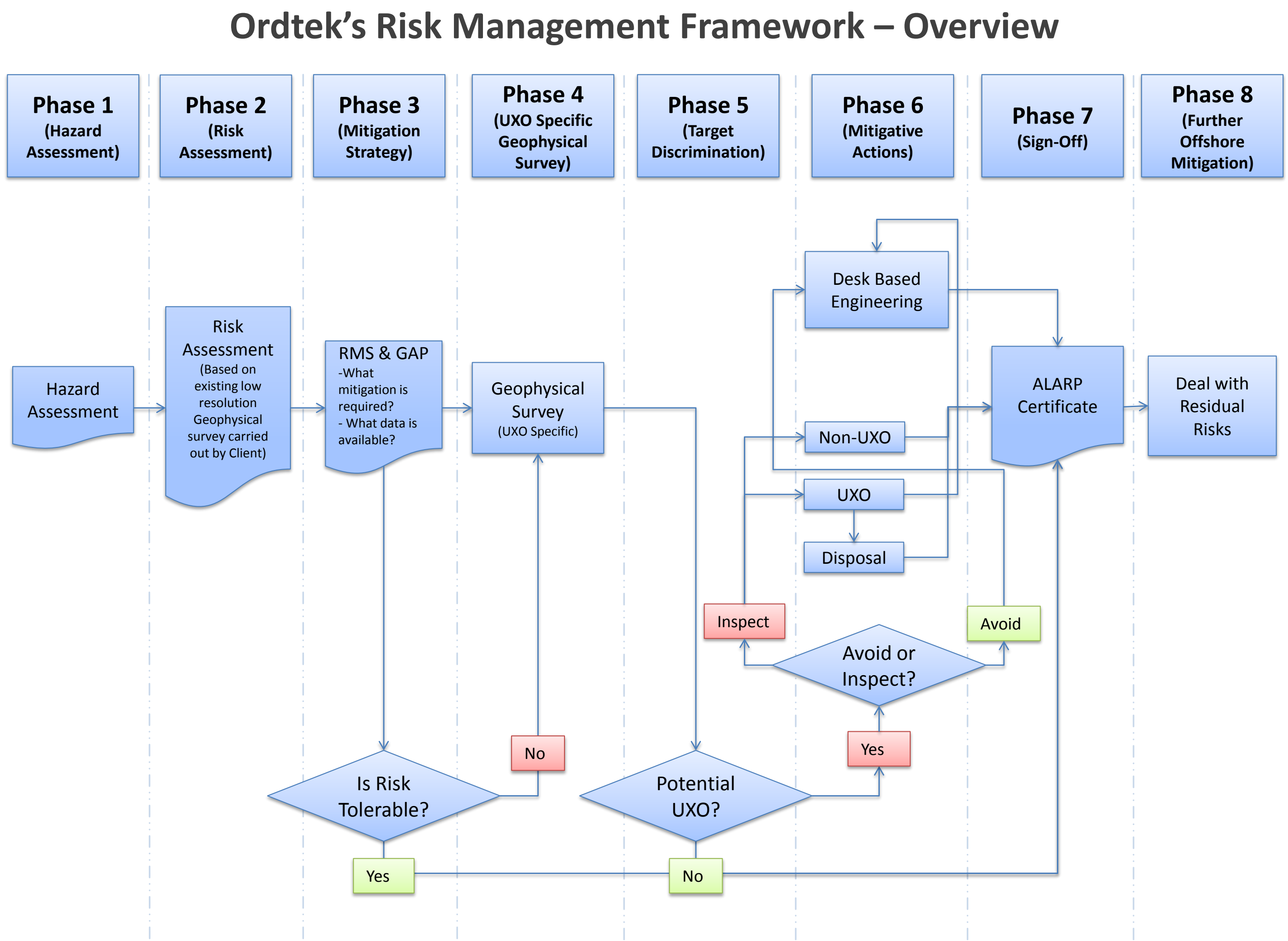


Figure 2.3 – Ordtek's risk management framework for the reduction of UXO risks.

The framework consists of 8 interrelated and sequential phases, which are specifically designed to discharge clients' legal liabilities to *de minimis* in accordance with the ALARP principle.

3 UXO Threats and Hazard Items

3.1 Military History and UXO Hazard Findings - Overview

The North Sea saw considerable military action over two World Wars. There were substantial mine laying operations in both wars involving both German and British buoyant and ground mines, with minefield clearance of only limited effectiveness after each period of conflict.

However activity in this area to the North of Denmark was comparatively minor, and in particular the Limfjord appears to have been sheltered from much of this, in part due to the shallow depths and no significant military activity within the fjord. The Danish Navy have informed Ordtek that EOD of historic mines has taken place in the area by the Danish Navy, when North Sea weather prohibits safe disposal further offshore. However, this is unlikely to have occurred in the Nissum Bredning site area due to the shallow water depth making navigation difficult and the Site’s proximity to land.

The possibility of either buoyant or ground mines drifting into the Site from the minefields closest to the entrance to Limfjorden, at Thyborøn Kanal, is extremely unlikely.

While Allied bombing, naval surface conflict, modern naval exercises, shore artillery practice, coastal defences and munitions dumping have all played a part in potentially contaminating the Site, the narrow entrance to the Limfjord, as well as the lack of viable targets within the Limfjord, mean UXO is unlikely to have drifted or been carried in from the North Sea, or be present in a density that would significantly elevate the risk from UXO. Nevertheless, the accumulation of evidence points to air-dropped Allied mines and bombs presenting statistically the biggest risk to Project activity.

3.2 Seabed Operations Prohibited Zone

The Nissum Bredning site is within a “Seabed Operations Prohibited” Zone marked on navigation charts (Appendix 2).

Within the zone, special regulations issued by the Danish Maritime Authority (DMA) apply. These rules are covered in the “Legislation and Guidance” section of this study. In essence, the person responsible for activities on the seabed is required to:

- Investigate the dangers and restrictions associated;
- Contact Admiral Danish Fleet if UXO or CW agents are found (and work is to temporarily stop);
- Obtain a special permit from the DMA to work in the zone.

3.3 Potential Sources of UXO Contamination

This section of the study identifies the principal potential sources of UXO contamination in the AOI, and summarised in Table 3.1. It is possible that there may be others that were either never recorded or for which records have been lost.

Positional information drawn from historical documents, for activities such as mine-laying, should always be treated with caution. The navigation equipment in use at the time was rudimentary compared to systems available today and inherent errors were compounded in transmission and exacerbated by the fog and tension of war. This is particularly true for visual reports of enemy dropped ordnance.

Allied bombs are the items of UXO most likely to be found in the AOI and the accumulation of evidence is that these will pose the greatest risk to the Nissum Bredning Vind development.

Source of Potential UXO Hazard	**Findings**
British Minefields WWII	The British WWII *"Hawthorn II"* air-laid ground mine "garden" and the mine danger area (No.9) lie just outside the Thyborøn Kanal in the North Sea, ~7km W of the Site Area. Mine Danger Area No.9 is recorded on current navigational charts and in "Sailing Directions" (the *"Hawthorn II"* mine garden is not).
German and British Buoyant Minefields WWI	Both the Germans and British laid a number of buoyant minefields within the Southern part of the North Sea during WWI. The nearest British WWI minefield is the 'Heligoland Bight Minefield' ~11km W of the Site Area.
German Minefields WWII	During WWII, German mine barriers were located in the southern North Sea, predominantly at the western edge of the German Bight in a "Mine Warning Area" between 53°36'N and 56°30'N and 004°25'E and 006°02'E. Known as the West Wall Barrier, it was 110 km wide and approximately 330 km long. Between this barrier and the Frisian coast, there were further deeper laid anti-submarine barriers. The Germans also laid very extensive buoyant minefields in the Skagerrak; the closest field to Nissum Bredning Vind is 'B37' which is directly adjacent to the land mass separating the Site Area from the North Sea, with 'B36' below - further south along the coast. The Germans also laid an extensive barrier of KMA anti-invasion contact mines, close inshore, almost the full length of the Danish North Sea coast. The Danish EOD service considers these have been cleared in the AOI but there still remains a zone of 1nm acting as a restricted area by the Danish authorities.
Aerial Bombing / Jettisoned Bombs/ Rocket Attacks	German and British ships were frequently attacked by each other's aircraft in the region, using bombs and rockets. During WWII, although the main routes tended to be further south across the German Bight, Allied bombers occasionally flew across the coast of northern Denmark on their way to and from targets in the Baltic and Germany. If their aircraft had been badly damaged, or weather otherwise prevented them from completing the mission, crews were known to jettison their bomb loads before landing at their home airbases.

Source of Potential UXO Hazard	Findings
Submarine Torpedo Attacks/ Depth Charges	Ordtek have found no evidence of submarines operating within the Nissum Bredning Vind AOI. British and German submarines regularly operated in the southern North Sea, in the German Bight, off Heligoland and in the entrances to the Baltic. Records show a number of submarine and surface ship engagements using torpedoes in the general area. However, these are unlikely to affect the Nissum Bredning Site.
Land Service Ammunition	Over 100 gun, radar, ammunition and personnel bunkers at Thyborøn protected the entrance to Limfjord. They formed part of the German "Atlantic Wall" coastal defence system. The main armament consisted of 4 captured French K331(f) 10.5cm guns, firing HE shells to a range of approximately 12km. There were also several 2.5cm and 5cm AAA guns and numerous machine gun positions.
Naval Projectiles	Many naval engagements took place in the wider region, including the WWI Battle of Jutland. The majority of exchanges of fire with large calibre weapons took place in WWI. We have found no direct evidence of ship to ship naval engagements taking place close to or within the Nissum Bredning Vind AOI. However, it cannot be discounted completely. Any size of projectile could be encountered, but most are likely to be small; sub - 5kg NEQ.
Shipwrecks	There are no shipwrecks of military or UXO relevance within the Nissum Bredning Vind AOI. Records show the closest is a SM U-20 which ran aground on the Danish coast at Vrist, near Thorsminde ~20km to the south of the Site Area and was destroyed by her bow torpedos detonated by the crew. There are multiple non-military shipwrecks with Nissum Bredning and one actually within the south of the Nissum Bredning Vind Site Area recorded in 1926 as being a Ketch loaded with cement.
Military Practice and Exercise Areas (Appendix 6)	There are no formal current Military Firing Areas within the immediate vicinity of Nissum Bredning Vind; the closest is "15 Nymindegab", ~100 km to the south. Mine Countermeasures and other general naval training is routinely conducted along the whole length of the coast but live ordnance is only used in the designated exercise areas or further out to sea, well away from the AOI. However, it is very probable that, taken over a period of several decades, some *ad hoc* training evolutions will have taken place in the local region, including live firing of small arms. Exercises using naval gunfire (typically up to 105mm) and larger anti-submarine weapons could also have taken place but, if they have at all, they are likely to have been much further offshore. A modern Air Force practice and exercise area covers the Nissum Bredning Vind Site Area, as shown at Appendix 6.
Explosives/Munitions Disposal	There are chemical and conventional weapons dumping sites recorded in the North Sea, Skagerrak and Baltic but there are none known within the vicinity of the Study Area. The presence of unofficial, unrecorded dumping cannot be discounted but we have found no evidence of such.

3.4 Sea Mines

Mines are generally classified by their position in the water and their method of firing (actuation).

3.4.1 Buoyant Mines

The first and the most commonly employed in WWI, but also extensively deployed in WWII, is the buoyant mine, which is designed either to float just below the surface, tethered to the seabed by a mooring wire and sinker (anchor), or to drift with the ocean currents. Buoyant mines consist of a spherical or ovoid casing with a charge weight of typically 40kg - 250kg of HE, taking up approximately a third of their volume. They are most commonly actuated by contact with the target, using either mechanical switch horns to close a battery-powered firing circuit or “Hertz” horns. The latter are also known as “Chemical Horns”. A Hertz horn consists of a soft lead or copper sheath enclosing a glass phial of acid at the base of which is a dry battery cell. On contact with a target vessel, the glass phial breaks, releasing the acid to act as the battery cell’s electrolyte, which then provides power to the mine’s detonator. The increased danger a Hertz horn presents over a switch horn is that it does not rely on a battery, which will discharge over time, but can provide power to the detonator indefinitely.

Other variants of moored mines, but used in much less numbers, were the Antenna Mine, an anti-submarine contact mine that used the current generated by two dissimilar metals rubbing together to fire, and the Magnetic mine, an “influence” mine that was actuated by the small electro-magnetic current generated when a target vessel’s moving magnetic field cut the mine’s internal coiled rod sensor.

Drifting mines are not particularly effective as an anti-ship weapon – their value lay in the fear and disruption they caused – and were not often employed. However, hundreds of thousands of moored mines were laid during the two world wars. A moored mine frequently became a drifting mine when its cable parted due to the wear and tear of wave motion. In accordance with the Hague Convention of 1905, mines breaking free from their moorings are required to self-neutralise but, in reality, either by design or malfunction, early mines often remained active. They continued to be a danger to shipping and to civilians, if swept ashore. Most eventually sank, often a considerable distance from where they were originally laid. Consequently, estimating the risks posed in any particular area by the mines laid either defensively or offensively during the two world wars is exceptionally difficult. So many were laid that a general assumption is that buoyant mines could be present in any area of the North Sea, the coast of Northern Europe and the approaches to the Baltic.

Figure 3.1 - Hertz (Chemical) Horn

3.4.2 Ground Mines

Although they were in existence towards the end of WWI, ground mines were neither very effective nor common at that time. However, from 1939 onwards, both British and German influence ground mine technology advanced rapidly.

The influence ground mine, as its name suggests, is designed to lay on the seabed. It can be laid by surface vessel, submarine or aircraft, and it is most commonly cylindrical in shape. It has a single or a combination of magnetic, acoustic and pressure sensors to detect the influence "signature" of passing target vessels. To be close enough to create sufficient damage to its target, a ground mine must be laid in relatively shallow water; generally not more than 70m but more usually around 30m or less. For the same reason, and because the mine does not have to float, the size of the main charge is considerably bigger than in a buoyant mine, typically 300kg - 750kg. Both Germany and Britain had versions that could be fitted with direct impact bomb fuses in addition to magnetic and acoustic firing circuits.

British ground mine casings were generally made of steel and subject to corrosion over time unless they became buried in hypoxic sediment. The mines relied on batteries to power sensors and firing circuit; these will now be discharged and the mine will not function as designed. Charge weights were between 227kg - 499kg, except for two specialist mines that had much smaller NEQs of 45 kg and 91 kg. The British continued to develop ground mines throughout the WWI, starting with A MKs I-IV in the early years, finally progressing to the A Mk IX by 1945.

WWII German ground mines were made of aluminium and superbly engineered, with reliable *Rheinmetal* fuses and, consequently, are frequently found in excellent condition after decades in the water. German air dropped "parachute" mines are likely to be found intact and the mines could function as designed if sufficient battery power was available. However, their batteries will have discharged. Many variants were fitted with booby traps and anti-disturbance devices; some of these relied on battery power, some employed mechanical inertia designed to operate on impact with a cocked-striker initiator, some had clockwork delay mechanisms and others relied on human intervention; all could be in a very sensitive condition and could function if disturbed.

3.5 Minefields

3.5.1 General

The Southern North Sea, the German Bight and approaches to the Baltic were heavily mined, both defensively and offensively, during both World Wars.

Both the British and the Germans laid a number of buoyant minefields within the Southern part of the North Sea during WWI but none are recorded in Nissum Bredning. The nearest were a British minefield 18 km to the south of the Thyborøn Kanal and a German minefield 100 km to the south off Blaavands Huk (See Appendices 3 & 4). These are still marked as danger areas on current navigational charts.

During WWII, German mine barriers were located in the southern North Sea, at the western edge of the German Bight in a "Mine Warning Area" between 53°36'N and 56°30'N and 04°25'E and 06°02'E (known as the West Wall Barrier, it was 110 km wide and approximately 330 km long) - between this barrier and the Frisian coast, there were further deeper laid anti-submarine barriers - and very extensive minefields in the Skagerrak. The closest recorded German minefield, 30km to the north of the Thyborøn Kanal, contained 142 EMC contact mines and 191 EMR (these were decoy mines that simulated the EMC but had no explosive charge).

3.5.2 KMA Anti-Invasion Contact Mines

In WWII the Germans laid an extensive barrier of KMA anti-invasion contact mines, close inshore, almost the full length of the Danish North Sea coast. These formed part of the “Atlantic Wall” coastal defence system. The closest to Nissum Bredning is minefield ‘B37’ and ‘B36’. Records show 5,389 KMA mines were laid within ‘B34’, ‘B35’, ‘B36’, ‘B37’ and ‘B38’. The KMA mines contained a 75kg Hexanite charge but were non-buoyant and static, consisting of a recessed concrete block, fitted with a 1.5 metre steel tri-pod and snag-line. As such, the likelihood of the mines coming free from their fixing and drifting into the Nissum Bredning Vind Site Area is very remote. However, there is a chance one could have been dragged through the Kanal and into the Nissum Bredning area by a vessel.

3.5.3 Heligoland Bight Minefield

Experience during WWI had shown the British, the advantage of offensive mine laying to restrict coastal shipping and to introduce a risk factor to German naval operations. After two early attempts to lay buoyant minefields in the Helgoland Bight in 1939 and again in 1940, mine laying by surface ships in the Southern North Sea was abandoned due to lack of navigation aids, Germany’s own defensive mining and the loss of a Royal Navy destroyer. Thereafter, the majority of mines in the region were delivered by air.

3.5.4 Hawthorn II

During WWII, British ground mines were used almost exclusively as an offensive weapon. They were dropped by aircraft, coastal forces mine layers, motor torpedo boats and submarines in shallow enemy controlled waters, causing significant disruption to seaborne logistic traffic and stretching German mine clearance forces.

The routinely re-seeded (replenished) mine “gardens” laid by the Royal Air Force (RAF) around the NW European coast, including off Denmark, are a good example of the operations conducted. Aircrew slang for mine-laying operations was ‘gardening’ and the mines were referred to as being ‘sown’ when they were dropped at low-level into the sea. The British WWII *Hawthorn II* garden lies just outside the Thyborøn Kanal in the North Sea, ~7km from the Site. 25 type A Mk I-IV mines containing 375kg of explosives were laid in Hawthorn II and whilst 15 mines were cleared, 10 remain, according to Danish Naval sources. A total of approximately 2,987 mines were dropped into *Hawthorne I, II, III* and neighbouring *Rosemary* between 1941 and 1945. The vast majority of these mines were laid in *“Rosemary”*, around 2,700. We have no reliable estimate of how many of these mines remain on the seabed. Considerable effort was put in by German and later Allied Mine Countermeasures (MCM) forces during and after WWII to remove the threat these mines presented. Understandably, these efforts concentrated on important shipping lanes. Many of these mines undoubtedly still remain, evidenced by regular finds of British air-laid ground mines on neighbouring OWF projects.

The British WWII *“Hawthorn II”* air laid ground mine “garden”, which itself is in the “catch-all” mine danger area (MDA) No.9 shown on navigational charts that was based on danger areas promulgated to mariners immediately after the war. The *Hawthorn* series of minefields were designed to interdict German shipping using the coastal convoy route around the NW of Jutland (see Appendix 5).

During the early years of WWII, older aircraft with a limited mine load were used for this offensive mining campaign: Hampdens (1), Swordfish (1), Beauforts (1) and Albacores (1). From 1942 onwards, the operation intensified with heavier bombers such as the Manchester (4) and Lancaster (6) being employed to lay over 1,000 mines per month (in all gardens).

The area around the entrance to Limfjord was not in the mined areas declared by Britain at the beginning of WWII (map dated 04 September 1939) and later, Hawthorn II and Hawthorn III were shown as “disused” mine gardens on an Admiralty mining chart dated July 1944. They were, however, included on a chart from the end of the war dated 17 August 1945, which summarised all minefields in the North Sea and associated “Q” navigational warning messages. It can be assumed therefore that the *Hawthorn I* and *Hawthorn II* fields were routinely sown with mines from April 1940, when the aerial mining campaign began, until a point when it was decided the minelaying aircraft should be prioritised elsewhere, probably around spring of 1943.

Figure 3.2 - Hampden being loaded with British ground mine

The Bomber Command War Diary and records at the British National Archives show that minelaying sorties were carried out regularly in the region. A representative sample is shown below:

- ***17/18 December 1942*** *– 50 aircraft were dispatched to lay mines from Denmark to southern Biscay. – 1 Lancaster lost.*
- ***7/8 November 1942 –*** *1 Group minelaying in many areas from* St *Nazaire to Denmark. 1 aircraft lost.*
- ***21/22 October 1942*** *– 7 Stirlings and 7 Wellingtons dispatched to lay mines off Denmark and in the Frisians but the Wellingtons were recalled. 1 Stirling lost*
- ***24/25 October 1942*** *– Minor Operations: 26 Wellingtons of 1 Group minelaying in several areas between La Pallice and Denmark. 2 Wellington minelayers lost.*
- ***28/29 October 1942*** *– 9 Wellingtons minelaying off St Nazaire and Denmark. 1 aircraft lost.*
- ***8/9 January 1943*** *– 73 aircraft minelaying off the Danish and German coasts. 2 minelaying Lancasters lost.*

- ***13/14 March 1943*** *– Minelaying: 51 Wellingtons and 17 Lancasters to areas between Lorient and the Kattegat. 2 Wellingtons and 1 Lancaster lost.*

It is clear from contemporary records that that the heaviest concentration of mining was directed at the Frisian Islands, German Bight and later into the Baltic. From a close study of the Bomber Command war diary, we can find no reference – direct or oblique – of RAF minelaying off Jutland after early 1943. While the attacks continued into the Frisians and German Bight ports and the French Atlantic coast, further north it seems that the "Danish" effort switched to the mine gardens within the Baltic itself.

The figures in Table 3.2 below, which were provided to Ordtek, come from an internal Danish FKP EOD memo dated 25 August 1988. They show that 25 mines were laid in *"Hawthorn II"* and, at the time the memo was written, there were 10 remaining.

Minefield	Mines laid	Mines Cleared	Mines Remaining
Hawthorn I	180	50	130
Hawthorn II	25	15	10
Hawthorn III	42	20	22
Total	**247**	**85**	**162**

Table 3.2 – Mine statistics for Hawthorn gardens

These relatively low numbers fit with what we already know about *"Hawthorn II"*; that it was not in use for the whole of the war and that the priority for mine laying soon shifted away from the North West Jutland area. A memo from HQ Coastal Command to Bomber Command, No.5 Group, dated 8th June 1940 laid out the priority for the Hampden squadrons:

> *"The following gardens have equal priority- Wallflowers, Forget-me-nots (Kiel Bay), Eglantine (Weser & Elbe approaches), Quinces (Langelands Belt) and Radishes (Fehmarn Belt) and 6 should be planted in each per week. The programme should be arranged in such a way that no regularity occurs."*

As we know, the numbers laid, with larger, more capable aircraft were considerably greater later in the war.

By now, the mines themselves will present little threat unless vigorously disturbed. Their batteries will have run down and they are likely to be severely corroded. They will not function as designed.

We have written to the service Danish EOD and the information we have received supports our assessment. Their view is that:

- the success of the MCM effort since WWII could have been over-estimated; technology was rudimentary by today's standards;
- the numbers of mines recorded as laid could be inaccurate;

- the reported lay positions were probably inaccurate due to the limitations of navigational equipment at the time plus the stress factor;
- fishing trawlers could have dragged mines out of their original position.

In summary, there are likely to be more mines remaining in Danish waters than expected; possibly up to plus or minus 20% than current assessments.

Minefield No.9 is a broad "catch-all" area that is based on immediate post-war published danger areas. It embraces all the North Sea mine gardens and is still shown on UKHO Admiralty navigational charts, although the information on which it is based has, in many instances, been superseded. It is interesting to note that the danger area on local Danish charts is shown only from the Lodberg Light northwards around Hanstholm Light and not around Limfjorden AOI, which would be expected if it was based on the "*Hawthorn*" minefields.

3.5.5 Minesweeping and Mine Clearance Operations

It is appropriate to mention the minesweeping and other mine clearance efforts that went on after both World Wars.

Minesweeping was the standard method for clearing moored mines during and WWI and WWII and in the immediate post-war period. The technique used special abrasive wires, latterly with explosive cutters attached, that were towed behind one or more ships. These sweep wires cut the mines' mooring cable and, once free of its sinker; the mine would either self-destruct (in accordance with the Hague Convention 1905) or could be sunk by gunfire.

Minesweeping continued well after the armistice in November 1918 with 55 different flotillas still operating in June 1919. The British searched over 40,000 square miles until November 1919. At the end of the war when great efforts had to be made to clear the sea of mines, it was observed that about 85% of the mines laid had "disappeared" due to various causes and only a small fraction could be found and eliminated.

An extract from BGen Michael Clemson's paper *"The Danish Armed Forces 1909-1918"* shows typical evidence of why buoyant mines are often found some distance from their laying position:

> *"Fighting ended on 10th November, but not the main wartime task of the Danish Navy. Before the work had ended, nearly six thousand mines from the belligerents had been disarmed or destroyed, about 90 percent on Danish beaches. Nearly five hundred had been found drifting - a major threat to shipping. Only 8 foreign mines were still anchored when taken care of."*

Many reports refer to the "clearance" of barrier minefields after WWI. The term here should not be confused with what is understood by the modern usage of the word clearance, which includes removal of the UXO threat completely, usually by countermining.

Minesweeping was not effective against mines that had already broken free and sunk to the seabed. And while minesweeping removed the threat for surface vessels and submarines, the practice of sinking them with gunfire has left a significant legacy hazard to modern seabed operations. The mine sinkers also present solid targets for modern sonars and magnetic sensors that have to be identified and discounted, increasing the effort and time required for the survey of a contaminated area.

We have found no reference to German minesweeping forces based in Limfjorden or anywhere near the AOI during WWII hostilities.

Directly following the end of WWII a major effort was made to clear areas of international water where minefields had been laid during the conflict. In addition to mechanical (wire) minesweeping, influence (magnetic and acoustic) equipment and techniques were developed to counter both the residual and emerging influence ground mine threat. These for the most part were asset intensive and not particularly effective. The Danish navy has a strong tradition of mine countermeasures (MCM) and in the years since WWII has continued to clear the waters around its coast; concentrating as one would expect on main coastal shipping lanes and the entrances to ports. Its dedicated minesweepers were decommissioned in 1999 and since then it has operated a modular MCM capability from multi-role vessels. It also has the Navy EOD service. As is common in British and other north European waters, items of UXO are routinely found during present day naval MCM exercises.

Despite the mine clearance efforts, in the years immediately after the war, ships routinely continued to hit mines and sink with loss of life. Between May 1945 and the end of 1957, 159 ships were hit by mines in the North Sea. The last incident, we have record of, was in 1960: the *SS Marmara* was severely damaged when it strayed out of the compulsory shipping channel in bad weather and hit a mine. Since then, UXO has been regularly encountered during fishing, dredging, mine counter measures and diving operations; providing strong evidence that there is still a substantial legacy of UXO in the Eastern North Sea, which potentially includes the Nissum Bredning site.

Figure 3.3 – "LL" Magnetic Mine Sweeping

3.6 Air Dropped Bombs and Rockets

Almost any category of Allied bomb could be encountered in the waters of Nissum Bredning. Air dropped ordnance will come from two sources:

- The result of attacks on shipping or coastal defences, where the EO missed its target; these weapons are likely to have been armed and will present a UXO risk;

- Bombs jettisoned by aircrew in an emergency on the way to or from an inland target. These bombs may or may not have been armed on release. For risk assessment purposes, it must be assumed that they were armed.

Bombs dropped and rockets fired from fighter bomber aircraft are likely to be in the region of 5kg-50kg NEQ; those destined for inland raids but jettisoned over the sea could be considerably larger; up to 2,000kg and more. But, the most prevalent are likely to be typically British or American 250kg-500kg General Purpose (GP) or Medium Capacity (MC) bombs (the German equivalent is SC). The charge to weight ratio of an MC was approximately 50%, giving NEQs for the two examples above of 125kg and 250kg.

British and German bombs could be fitted with several kinds of fuses, including singly or in combination: impact, long delay and anti-disturbance. However, any anti-disturbance fuse that relied on a power source is now highly unlikely to function. Moreover, the majority of mechanical fuses or pistols will have been subject to significant corrosion and are also unlikely to function as designed. Nevertheless, it cannot be discounted that some may be in an extremely sensitive state.

German coastal convoy routes pass through the region. The majority of raids on German coastal shipping during WWII were carried out by British Bristol Blenheim and Beaufort squadrons of Coastal Command. These aircraft routinely carried the 250lb General Purpose (GP) and Medium Capacity (MC) bombs and these are the bomb types most likely to predominate in the AOI; as such, the 250lb GP bomb has been chosen as the smallest threat item for ALARP sign-off.

3.7 Naval Projectiles

We have found no record of significant naval engagements taking place close to the Nissum Bredning site sufficient to produce the density of munitions required to pose a meaningful threat to the OWF activities, but the possibility of finding naval projectiles cannot be discounted as many naval engagements took place in the general area (though outside the Limfjord).

3.8 Coastal Artillery and Anti Aircraft Ammunition

At Thyborøn, on the coastal strip immediately adjacent to the Nissum Bredning Vind site, the Germans built over 100 gun, radar, ammunition and personnel bunkers that protected the entrance to Limfjord. They formed part of the German “Atlantic Wall” coastal defence system. The main armament consisted of 4 captured French K331(f) 10.5cm guns, firing HE shells to a range of approximately 12km. There were also several 25mm and 50mm AAA guns and numerous machine gun positions. The smaller weapons would have had the range to reach the proposed OWF main array site but would most likely be firing seaward and, in the AA role, would most likely have been fired with a high trajectory, thereby reducing the horizontal distance the projectiles would travel. In any event, the risk small calibre projectiles pose to Project activities is extremely low, tending to zero.

4 Environmental Conditions

4.1 Overview

The water depths in the Nissum Bredning study area vary between approximately ~0.5m-4.5m. The maximum water depth is located on a ridge in the northeast of the site and the minimum water depth lies in the south of the area.

Given the highly mobile sands, subsequent UXO burial due to scouring and sand migration is both possible and very likely. Once covered by sand or sediment, UXO will usually remain close to the surface, within 0.5m – 1.0m. Over time, as further sediment movement occurs, items of UXO will occasionally re-appear.

Migration into the site of large new items of EO once the AOI has been cleared of UXO is considered very unlikely, unless inadvertently dragged there by fishing vessel or in dumped dredge spoil.

4.2 Dredging within Nissum Bredning

Dredging occurs within the Limfjorden, especially in the Thyborøn Kanal in order to maintain a desired water depth of 8m-9m. However, it is noted in Reference C that the Nissum Bredning project area has not been dredged. Within the North of the NIssum Bredning Vind Site there is a known dredging dump. Up to 250,000m^3 of dredge spoil is permitted to be dumped in the area up to September 2018; 7 dredgers used the dump site in 2015.

Figure 3.4 – Dredge dump site (pink outline)

Any UXO within the Thyborøn Kanal expanse of water has possibly been relocated unknowingly to the dumping area. (Reference C COWI A/S – Cable Burial Risk Assessment – Nissum Bredning, Version 0.1 Rev Draft dated 29 July 2016). However it should be noted that any small item of UXO that has been inadvertently been dumped in this area would be deemed reality stable as it has passed through the dredging process.

4.3 UXO Burial

4.3.1 Overview

In dynamic sediment conditions, UXO items are likely to become buried; the depth of burial depending on a number of variables that will be explored below. Within the Nissum Bredning Vind study area, burial is likely to be due to one or a combination of four mechanisms:

- Initial impact
- Liquefaction
- Scour
- Sediment migration, including accretion over time

4.3.2 Impact Penetration

The first mechanism for UXO burial to consider is that due to initial impact. The depth an air-delivered bomb will penetrate to on land is well understood; there is ample empirical data from WWII on which to base a reasonably accurate estimate. However, determining how far an UXB will penetrate into the seabed is more problematic. As on land, it depends among other factors upon its speed of entry, which is a function of the height from which it is dropped, its weight and construction, its shape, the angle of entry, and the properties and underlying geology of the sediment. However, in the maritime environment, the bomb's kinetic energy is rapidly attenuated by the water it passes through. The depth of water, therefore, is also an important factor in estimating the likely burial depth.

To our knowledge, there is no comprehensive and proven data on which to base a reliable calculation regarding how far a bomb will penetrate into the seabed in various depths of water and in differing sediment conditions. However, experiments on Mk84 bombs in the USA show that the trajectory of a bomb falling into water at an angle of entry of ~90° is rapidly altered by the new medium, reaching near parallel to the seabed by a depth of around 5m (*Chu et al* 2010). For a period subsequently, the bomb orientates to fall tail first, but by now it can be assumed that most of the kinetic energy gained through its fall through the air has bled off and at whatever angle the bomb finally strikes the seabed, its burial due to impact will be minimal unless it falls into very soft silt or mud.

Consequently, given the seabed geology, our assessment is that in the sections of the study area where the depth of water > ~5m, the likelihood of any significant burial of air-dropped bombs due to initial impact is extremely high.

4.3.3 Scour and Sedimentation

Both observed and experimental empirical evidence has shown that over a period of time, depending on the sediment type and its firmness, UXO burial caused by the mechanisms of scouring and sand migration is very likely. Once covered by sand or sediment UXO will usually remain close to the surface, within 0.5m – 1.0m. Over time, as further sediment movement occurs, items of UXO will occasionally re-appear.

When an item of UXO is situated on an unconsolidated sediment bed in in the tidal flow, wave motion and currents of a marine environment, scour will develop in its immediate vicinity. There are three stages in this UXO/seabed interaction process: scour; sinking; and backfilling. As the process continues, the underlying bearing area reduces, placing an increasing load on the sediment. Eventually, the bearing capacity of the sediment is exceeded and it fails. The failure occurs by sliding in an outward direction. As the scour continues, this process is repeated, leading to the permanent sinking of the UXO. The process stops when the UXO is at a depth where it is protected against the scour. Experiments and modelling have shown this depth to be ~ 0.6 x diameter for cylindrical objects in sand. In coarse gravel, scour is much less.

The scour process above depends upon sediment grain size; as this becomes coarser, and approaches gravel size, seabed scour will cease and UXO burial will not occur. Neither will UXO burial occur by this mechanism on hard consolidated surfaces such as glacial till clay or chalk.

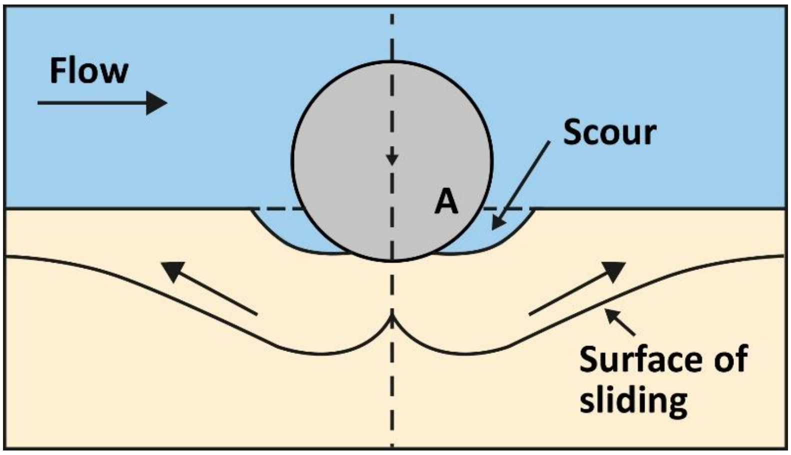


Figure 4.2 – Scour mechanism

The sediment regime across the Nissum Bredning Vind Study Area consists of multiple layers of sand/gravel over clay/gyttja. Table 4.3 below matches each sediment type to the potential for UXO burial by the scour mechanism.

Sediment Class	Potential for UXO Burial due to Scour
Silty/Fine Sand	Burial to maximum scour depth
Medium/Coarse Sand	Burial to maximum scour depth
Slightly Gravelly Sand	Probable burial to maximum scour depth

Gravelly Sand	Some burial but to less than maximum scour depth
Sandy Gravel	Significant burial unlikely
Gravel	Significant burial unlikely
Rock	No Burial

Table 4.3 – Potential for UXO burial due to scour for different sediment types

4.3.4 Movement of Bedforms

UXO burial (and exposure) is also caused by the formation and migration of bedforms such as sand waves, ripples and mega ripples. There are bedforms with varying degrees of mobility across much of the study area. Sand waves and other features form because sand grains have a roughness which creates turbulence as water flows over the surface. When the drag on a particle gives it an uplift force which exceeds its weight, it is transported along the seabed. Relatively slow flow speeds can achieve this effect for sand particles. Gravel, however, because it is heavier than the uplift force that is generated over its surface, tends to be more stable.

As a sediment bedform moves across the seabed, any UXO in its path will be alternatively buried and exposed. For very large formations, such as migrating dunes, the resulting motion and burial depth of UXO has the potential to be quite complex, depending on where the UXO originally falls; whether, for instance, it lands on the forward slope, crest or back slope of the feature. The UXO will tend to gravitate towards the base of a slope but not necessarily reach equilibrium at the deepest point. However, taking the worst case, it follows that the burial depth of the UXO will vary with the depth of any bedform that covers it.

It is evident that this mechanism of UXO burial is applicable to several areas within the Nissum Bredning Vind site.

4.4 UXO Migration/Drift and Longevity of Geophysical Survey Results

It is often a misconception that sediment migration is equal or similar to UXO movement. The probability of an item of UXO migrating along the seabed due to water flow (tidal stream/current) is a function, among others, of seabed composition, firmness and morphology (slopes, ripples, troughs, boulders etc.); the current strength, duration and persistence of direction; and the weight, shape (particularly protrusions, such as lifting lugs) and orientation of the UXO. As noted above, the wind-induced current can reach as much a 1.5m/s along the Danish coast. Our view is that UXO migration due to this mechanism is considered highly unlikely.

Some smooth, cylindrical types of UXO, such as German LMB/LMA (GD/GC) ground mines and torpedo warheads, have been known to roll along the seabed when conditions are favourable; i.e. if the seabed is flat and without obstruction and if it is firm, if the current is strong enough and is predominantly uni-directional. But given that mine burial is likely to have occurred very soon after lay and that by now most of the mines will be at least partially if not completely buried, and given the small entrance to the Limfjord, it is very unlikely that these conditions will be met at the Nissum Bredning site.

It is very common for fishing trawlers to encounter UXO; either knowingly by bringing it into the vessel in their nets or inadvertently by dragging an item for a distance along the seabed before it eventually falls free. In fact, 50% of finds reported to the OSPAR commission have been due to fishing. Anecdotally, fishermen that have recovered UXO in their nets have also been known to occasionally dump it back into the sea rather than report the incident. *Ordtek* considers that this is the most likely vector for any migration of UXO into or within the main array site and export cable pathway in the years since WWII.

Of note, in reality it is very difficult to quantify this migration mechanism within a risk assessment; mainly because finds are rarely recorded. Those that are, are not usually done so collectively as a coherent archive. The number of encounters and post-find disposal areas cannot therefore be measured with any accuracy. Moreover, unseen, inadvertent movement of UXO, i.e. items dragged by a trawl for a distance and then released, is by its nature unquantifiable. However, from speaking to fishermen local to the region, modern trawls do not penetrate the seabed; they are designed to ride over boulders and other debris. UXO already buried will not be moved by this process and it is very unlikely that even modern EO deposited as the result of relatively recent ad hoc naval and air exercises in the area will be caused to move.

On balance, we consider that geophysical survey results should remain valid for at least 3 years; a period after which the validity should be reviewed.

5 UXO Risk Factors Analysis

5.1 General

In this section, we consider the baseline UXO hazards to the Nissum Bredning Vind site prior to any works and before to any mitigative measures being implemented. We provide generic information about the potential causes of inadvertent detonation and typical mechanisms and causes of damage and injury. This is then tailored to the specific activities associated with the Project to permit a detailed risk assessment and recommendations for mitigation to be formulated.

The risk that UXO poses to a Project activity is the product of three key elements:

- The likelihood of encountering an item of ordnance
- ***If*** that encounter happens, the likelihood of the UXO detonating
- ***If*** the UXO detonates, the severity of the consequence to vulnerable receptors (people and equipment)

5.2 Probability of Encounter

Probability of encounter, the first element, is a function of the density of UXO items and the total area of intrusive interaction of as a proportion of the total area of the site (to be accurate: by volume to the maximum intrusive depth). We will never know precisely how many items of UXO are potentially present within the site boundary but we make a judgement call based on the results of our historical search, our experience and our knowledge of the types of project activities to be undertaken.

The factors to consider for the study area in relationship to each other are:

- Likelihood of UXO burial
- Likely density of UXO by type
- Areas covered
- Project activities
    - Intrusive (deep)
    - Intrusive (shallow)
    - Non-intrusive

Ordtek has assumed that cables will typically be installed to depths 1.5 – 2.0m below bed level within the main array area. There is no doubt that WTG foundations will be installed though the entire UXO burial horizon and given that in most cases the UXO burial depth will be relatively shallow – < 1.0m – UXO encounter is possible during all intrusive activities across the majority of the site.

Despite the military history of the region, given the separation of Nissum Bredning by the Thyborøn Kanal from the North Sea the potential for UXO contamination of the *Nissum Bredning Vind* Study Area is judged to be low overall. Table 6.1 below summarises UXO types and the likelihood of them being encountered during Project work. It is evident, given the military history of the region – both combat and practice – that any of the UXO hazard items identified could be present within the site.

However, the predominant threat comes from British air-dropped ground mines; the density of other UXO items – HE bombs and projectiles (from both naval ship and land sources) is likely to be much less.

The Likelihood of Encounter is only one factor of the risk calculation and a relatively high Likelihood of encounter of a particular UXO type does not necessarily mean that the overall risk to all Project activities will necessarily also to be high. Risk Assessment calculation results are shown at Table 6.3 in the next section.

Table 5.1 shows the likely density of UXO by generic type within the Nissum Bredning Vind study area. This density can be linked to likelihood of encounter for any particular activity.

Likely Density of UXO Types within Nissum Bredning Vind		
UXO Type	**Density**	**Remarks**
German Ground Mines	Low	German minefield B37 ~7km W from site in North Sea. However, unlikely to have drifted or been dragged into Nissum Bredning
British Air-dropped Ground Mines	Low	Hawthorn II British minefield ~7km W from site in North Sea. There are 10 known remaining mines, however these are unlikely to have drifted or been dragged into Nissum Bredning
British WWI Buoyant Mines	Low	Known minefield ~11km W from Site in North Sea; will now be severely degraded
Land Service Ammunition	Low	Sources: coastal defence at Thyborøn, naval action and ad hoc training
Allied HE Bombs	Low	The main German WWII coastal convoy routes pass well to the west, however British aircraft flew frequent anti-ship bombing missions in the general area.
Torpedoes	Very Low	Much recorded surface ship and submarine action (e.g. Battle of Jutland) but none within Nissum Bredning.
Depth Charges	Very Low	No submarine wrecks with Nissum Bredning, unlikely given shallow waters
Inert Practice Munitions (all types)	Very Low	Ad hoc training conducted all around the Danish coast
WWII German buoyant mines	Very Low	Small possibility that mines from distant fields could have drifted in.
Chemical Warfare Agents	Very Low	No evidence in the study area but risk is not zero

Table 5.1 – Likely density of UXO types within Nissum Bredning Vind study area

5.2.1 Types of Encounter

How a piece of equipment interacts with an item of UXO will determine whether a detonation is initiated and the main types of encounter and detonation mechanisms are discussed in Section 5.3 below. However, it is also important to consider what might be considered "primary" and "secondary" encounters.

When calculating the risk and potential consequences of an inadvertent detonation of an item of UXO to equipment, a vessel or a crew within a vessel, the primary (or initial) interaction is usually the one considered – i.e. the crushing effect of a jack-up barge leg; the kinetic blow of a dredger bucket; the disturbance caused by a cable plough; the whiplash to a vessel caused by the "bubble pulse" from an underwater detonation etc.

When considering potential consequences to people or soft-skinned equipment working on the deck of a vessel, or similar situation, "secondary" encounters are also important. For example, it is common during pre-lay jetting during cable burial to fit a "debris hook" to the vertical injector head. There is the potential for small items of UXO – projectiles, small bombs, rocket heads etc. – to be snagged by the flukes of the hook and brought to the surface. A similar situation can occur during a PLGR operation. The "primary" encounter of debris hook and UXO item is unlikely to cause a detonation and, if it did, the consequence to the equipment would probably be minimal. However, a "secondary" encounter incident, where the UXO dropped from the debris hook onto the deck of a vessel and then detonated could have devastating consequences for unprotected personnel.

The possibility for secondary encounters must be allowed for when developing procedural mitigation measures.

5.3 Probability of Detonation

5.3.1 Factors Affecting Likelihood of Detonation

The second element, *Probability of the UXO detonation*, we cannot know with any accuracy: most UXO that has been in the ground for a long time is relatively stable, even if subjected to unintended vigorous stimuli but, if the explosive ordnance is for any number of reasons particularly sensitive, or it is hit hard or crushed, it could detonate. However, the risk of detonation can be reduced by the adoption of certain mitigation measures, considered later in this report.

The factors, among others, that will affect the UXO's susceptibility to inadvertent detonation are:

- Condition and type of UXO
  - Sensitivity to impact (kinetic energy)
  - Sensitivity to crushing
  - Sensitivity to friction, heat, static electricity
  - Sensitivity to movement and vibration
    - Cocked strikers
    - Clockwork fuses re-starting
    - Highly sensitive metallic salts within fuse pockets etc.
  - Sensitivity to sympathetic detonation
    - Burial depth
    - Orientation
    - Proximity to donor charge / energy source (e.g. piling)
- Type of Interaction
  - Kinetic blow, crushing, vibration etc. as above

Before a weapon can detonate, a sequence of events must happen, called the Explosive Train (also known as the Firing Train), which starts with the removal of any safety measures and culminates in the detonation of the main charge of high explosive.

The accidental detonation of an item of UXO that has lain undisturbed on the seabed for several decades is a rare event, even when subjected to quite a heavy shock such as being struck by heavy equipment or dragged by a ship's anchor.

Most HE weapons have four principal components: a fuse (the part of the weapon that initiates function), a safe and arm mechanism/unit (often contained within the fuse), a detonator and a main charge. Additionally, most EO has a booster charge (also known as the primer or gaine) between the detonator and the main filling, to give the detonation shock wave from the initiating detonator sufficient energy to ensure the weapon's complete detonation.

The detonator is filled with a Primary explosive, such as Lead Azide, which is extremely sensitive to stimuli such as impact, friction, heat or static electricity and a relatively small amount of energy is required for its initiation. The detonator's purpose is to trigger the primer and, subsequently, the larger main charge. This is made of much less sensitive Secondary Explosive and requires substantially more energy to be initiated but is relatively safe to store and transport. The safe and arm system ensures that the detonator and main charge remain separated and the firing chain broken until the weapon is clear of its carrier/launcher and is in a position to function as designed.

Although it may not actually be the case, when UXO is encountered, it must always be assumed that the explosive train is intact: that is, all safety measures have been removed and the detonator is in contact with the main charge.

Nevertheless, the main filling is inherently stable and such a detonation is a rare event, even when UXO has been subjected to robust handling, for example when a bomb is caught up in a dredger head or ship's anchor. Most UXO – particularly EO that has lain on the seabed for several decades – will have been the subject of significant corrosion to its casing and to any mechanical moving parts. It is extremely rare for UXO found on the seabed to function as intended; detonation will almost always be the result of unusual and vigorous kinetic stimuli.

5.3.2 Detonation Mechanisms

From the previous paragraphs it can be seen that for a detonation to occur, the UXO must be in a sensitive state and a certain set of conditions satisfied. It is evident from the many items of UXO that are recovered from building sites, farmers' fields, anchor flukes, fishing nets and dredger suction heads every year that these conditions are hardly ever met and an accidental detonation is unusual.

The potential for UXO to be initiated if encountered during project operations will depend on its condition and the energy with which it is struck or moved, or if it is subjected to crushing, friction, static electricity or excessive heat. The movement of vessels and implementation of non-intrusive surveys will not result in the initiation of ordnance through influence alone.

The UXO could be caused to detonate several ways: if the detonator is struck accidentally with sufficient force or is subjected to heat, static charge, friction or crushing; if a fuse containing a temporarily jammed cocked striker is jarred and the striker is released; similarly if a seized clockwork mechanism restarts; or if the sensitive iron picrates associated with a picric acid filled munitions are subjected to friction, heat or are knocked, particularly if they have been allowed to dry out. In addition to the danger of iron picrates, some other HE can exude metallic azides and salts that, once they dry out, are extremely sensitive. These salts are often hidden within fuse pockets and not readily seen.

The main mechanisms that have the potential to cause unintended detonation of an item of UXO are:

- Crushing of the casing, imparting energy to the EO's detonator leading to its detonation (the main filling is unlikely to be initiated independently).
- A blow with sufficient energy by heavy equipment or, perhaps, a rock against a sensitive fuse pocket or exposed detonator.
- Sympathetic detonation caused by another item of UXO sufficiently close by or by a shock wave with sufficient energy imparted by an activity such as percussive piling.

Small items of UXO, such as AA, naval and artillery projectiles and small air-dropped bombs are relatively thick-cased and are considerably more likely to be pushed into the soft sediment of the seabed than crushed (this is obviously not true for outcrops of rock where the sediment is very thin and the underlying surface is hard). Other than in unusual circumstances on hard rock, the probability of a detonation via this mechanism for these types of EO is low.

Larger naval weapons, such as depth charges, sunken buoyant mines, British ground and, particularly, German ground mines have thinner cases and are therefore more likely to be susceptible to crushing. Nevertheless, the likelihood, again, is that in the prevailing seabed conditions they would be pushed benignly into the sediment rather than detonating, even if some crushing was to occur.

In all but the most unusual circumstances, for a high order detonation initiated by the detonator to occur, the EO needs to have been armed; i.e. the detonator is in intimate contact with the primer and main charge.

Typical activities that could cause inadvertent UXO detonation during engineering works are:

- Jack-Up barge leg deployment – crushing.
- Back Hoe/Cutter Dredger – high kinetic energy blow.
- Rock dumping (scour protection) – crushing, high kinetic energy blow.
- Borehole drilling –kinetic energy blow, vibration (in contact with sensitive UXO).
- Anchor deployment – crushing or blow.
- PLGR – dragging (with UXO striking hard object on seabed, e.g. boulder).
- Cable Plough – crushing (unlikely but possible), disturbance.
- Jetting – disturbance.
- Percussive monopole piling – crushing, vibration, sympathetic energy due to shockwave.

Ordtek has assumed that inter-array cables will be installed using a dynamically positioned (DP) vessel with a six-point mooring system and 7.5 tonne delta flipper anchors. This will be in conjunction with handling tugs and associated anchor management system. This should permit the anchors to be placed precisely, assuming inherent operational constraints, therefore avoiding known survey anomalies.

A 7.5 ton delta flipper anchor have the potential to crush the casing of an item of UXO and shock the sensitive detonator within; even if the fusing system of the EO is no longer able to function as intended due to corrosion or lack of battery power. A glancing blow from an anchor or cable link against a fuse pocket or fuse, could be sufficient to initiate a detonation, but this is unlikely. A blow to a chemical (Herz) horn could cause a sunken moored (buoyant) mine to function; but the degradation of wiring and internal components by corrosion makes this highly unlikely. An item of UXO may be in a sensitive state, with movement across the seabed sufficient to cause detonation. This movement could be caused by an anchor, cable or wire dragging the UXO. In shallow water (less than 10m), the wake or shallow water suction effect between keel and seabed could be sufficient to move an item of UXO without actually touching it.

Friction and heat are much less likely to cause a detonation underwater than impact or movement. However, it is possible for a small item to become wedged in the flukes of an anchor and be raised to the surface. In such an event, if the UXO was then subsequently allowed to dry out, sensitive salts (picrates and metallic azides) that had exuded through fuse pockets or corroded shell casing could be very sensitive to heat and friction.

In all cases, encounter and interaction with the UXO must occur first.

5.4 Effects and Consequences of Detonation

5.4.1 Overview

Severity of consequence of detonation, the third element of the risk calculation, is a multifaceted issue depending on a wide range of variables – sensitivity of receptor (e.g. robustness of the vessel/equipment) and protection (are deck crew below the water line, on deck, under hard cover etc.), range from UXO, type of weapon (casing, filling type, charge weight, orientation), depth of water, depth of burial, sediment/ground consistency etc. Quantifying the precise damage that may occur to a vessel or equipment from a specific item of UXO will depend on how its construction reacts to the shock and impulse generated. *Ordtek* can therefore only offer generic advice. The equipment manufacturer and naval architects are best placed to make this calculation.

5.4.2 Effects of Detonation Underwater

When an item of UXO detonates on the seabed underwater, several effects are generated, most of which are localised at the point of detonation; such as crater formation and movement of sediment and dispersal of nutrients and contaminants. Surface vessels and submarine equipment are also susceptible to the rapid expansion of gaseous products known as the “bubble pulse”; in this instance damage is caused by a water jet preceding the bubble and lifting and whiplash effect that can break the back of a ship. Once it reaches the surface, the energy of the bubble is dissipated in a plume of water and the detonation shock front rapidly attenuates at the water/air boundary. Fragmentation (that is shrapnel from the weapon casing and surrounding seabed materials) is also ejected but does not pose a significant hazard underwater for receptors more than ~10m away.

The effect that causes damage to structures and vessels is shock transmitted through the seabed and water column.

5.4.3 Shock

The principal effect that causes damage to vessels and structures in the far field is shock transmitted through the water column and the seabed (ground). The severity of consequence of UXO detonation will depend on many variables but principally the charge weight and its proximity to the receptor. In simple terms, the larger the UXO charge weight and the closer it is to any given structure, the more damage it may cause.

The shock wave from a detonation consists of an almost instantaneous rise in pressure to a peak pressure, followed by an exponential decay in pressure to the hydrostatic pressure. Initially, the velocity of the shock wave is proportional to the peak pressure but is rapidly settles down to the speed of sound in water, around 1,525 metres per second (m/s). In consolidated sediments and rock this can increase to ~1,800m/s. After detonation the shock wave will expand spherically outwards and will travel towards any particular receptor in a straight line – i.e. line of sight. Therefore, unless the wave is reflected, channelled or meets an intervening obstruction, for all practical purposes, the object will not be affected by the pressure wave if it is out of line of sight.

There is very little literature that covers the seismic damage to buried structures from a detonation of explosive ordnance underwater, situated on the seabed. Most studies deal with the effect of shock through the water column, which is reasonably understood and well-documented. The peak pressure and decay constant depends on the size of the explosive charge and the stand-off distance from the charge. The Peak Pressure (P_{max}) and Impulse (I) (momentum) experienced by a receptor (vulnerable structure) at distance R from a charge W can calculated using Coles' equations, which for TNT are:

$$P_{max} = 52.4 \, (W^{1/3}/R)^{1.13} \quad \text{MPa}$$

$$I = 5.75. \, W^{1/3}(W^{1/3}/R)^{0.89} \quad \text{MPa-ms}$$

5.4.4 Seismic Shock

The peak pressure experienced by a buried structure (e.g. a cable) will depend principally on the range from the UXO, the sediment type, whether the UXO is on the surface of the seabed, partially or wholly buried and the charge weight.

Quantifying the shock experienced by a buried receptor is difficult: there are a great many variables. Seismic shock propagation in earth media is a complex function of the dynamic constituent properties of the sediment, the explosive products and the geometry of the explosion. No single sediment index or combination of indices can adequately describe the process in a simple way for all cases. In particular, whether the sediment is unconsolidated or consolidated makes a significant difference to both the speed of propagation and attenuation rate of the seismic wave. The attenuation rate has been found to be greater in the latter (we have assumed that the cable is buried in unconsolidated sediment, in this case sand).

The optimum depth of water for maximum efficiency of energy transfer from the medium of water into the sediment is calculated as

$d=38.41*W^{2/11}$

Some of the energy of detonation will also be expended in the formation of a crater and the ejection of seabed material from it and on detonation. Energy is lost across the boundary of the two mediums, water and sediment. Taking all these losses into consideration, energy transfer into the sediment from a detonation of a UXO item on the seabed is usually, at most, around 50%-60% of the initial energy generated by the detonation and therefore it is the distance of the receptor from the UXO through the water column that is the dominant consideration.

5.5 Shock Factor

The most widely used parameter for describing shock severity is the shock factor value. Normally applied to vessels, this value is a shock input severity parameter that is a function of charge weight and charge distance (stand-off from a receptor). A small explosive charge close to a receptor can give the same SF as a larger one further away, although the pressure characteristic and damage mechanism may be different. Shock damage to the hull area of a vessel can vary quite appreciably, depending on the charge size, orientation and proximity to the hull. If the charge is located directly or almost directly underneath and/or close to a vessel, the bubble collapse onto the ship's hull and the whipping caused by the bubble pulse will contribute to the damage.

In simple terms, the larger the UXO charge weight and the closer it is to any given structure, vessel, equipment or person, the more damage it may cause. A deep draft vessel is at more risk of damage than a shallow draft one operating in the same depth of water. A vessel is more at risk at Low Water than at High Water. The formula used to calculate the HSF is based on simple spherical spreading of the shock wave and is:

$$HSF = \frac{\sqrt{C}}{R}$$

where C is the charge weight equivalent in Kg of TNT and R is the distance to the nearest point of the receptor.

When the charge is on the seabed and measured relative to the keel of a ship on the water' surface, the angle of incidence of the shock wave with respect to the vessel is also taken into account, the calculated value is referred to as the Keel Shock Factor (KSF) or sometimes "Q" or just the Shock Factor (SF).

In this case,

$$KSF = \frac{\sqrt{C}}{R} \cdot \frac{(\sin \Theta + 1)}{2}$$

In the hypothetical case that a receptor on the seabed (such as a cable or pipeline), rather than a vessel, is subject to the effects of a HE detonation, Sin Θ will tend to zero and the SF received by the cable will therefore be $= \frac{\sqrt{C}}{2R}$

The table below, which shows typical vessel damage symptoms for SF values, is taken from the US Navy Salvage Engineer's handbook. The representative damage shown can only be indicative and must be treated with a great deal of caution: the construction of civilian vessels varies considerably and, in deeper water, the bubble pulse must also be taken into account.

SF (√kg/m)	Typical Damage
<0.22	Minor damage (defects to fuses, destruction of light bulbs/luminescent tubes and the like.
0.22 to 0.33	Damage to piping with leaks, possibly individual pipe ruptures, damage to fuses, lamps, electronic failures and the like.
0.33 to 0.44	Increase in the above described damage symptoms, piping ruptures and misalignment of machinery on its base likely.
>0.44	Serious damage to ship, general machinery damage
>1.1	Typically total loss of ship.

Table 5.2 – Shock factors with typical damage symptoms (taken from US Navy Salvage Engineers' Handbook, converted by Ordtek for kg/m)

5.6 Effects above Water

Above water, the blast effect is relatively short range and decays rapidly. After detonation, the shock wave will expand spherically outwards and will travel towards any particular receptor in a straight line – i.e. line of sight. Therefore, unless the wave is reflected, channelled or meets an intervening obstruction, for all practical purposes, the receptor will not be affected by the pressure wave if it is out of line of sight. This is also true for the shrapnel that will be simultaneously ejected outwards with very high kinetic energy from heavier cased items.

In air, fragmentation (shrapnel), together with secondary products such as gravel etc., can be thrown considerable distances. Typically this is 1-2 km or more for medium sized bombs and projectiles. Isolated heavy fragments such as fusing components, lugs and baseplates etc. of large bombs and mines have the potential to travel in excess of 3km. For UXO underwater, the kinetic energy the fragmenting case receives from the HE charge is attenuated by the water and the distance it will be thrown once it reaches the surface is proportional to the depth underwater.

Both blast and shrapnel will be mitigated substantially if the UXO is buried (for the purpose of entering safety tables, "buried" means covered by >2.5 x the EO length. However, the seismic shock created can cause significant damage to unprotected and vulnerable subsurface infrastructure such as pipelines. As a rule, cables are much less vulnerable. On land, a 500kg SC bomb, detonating fully buried (i.e. deeper than 2.5 times its length) will cause a crater of approximately 13.7m (45ft) x 3.7m (12ft). Underwater, the dynamic forces are more complicated but the land figures can be used to give a reasonable approximation of likely crater size (while factoring in the optimum depth calculation for maximum energy transfer).

It follows that exposed soft-skin equipment and personnel are likely to suffer injury or damage from items of UXO that detonate close to or on the surface. The larger the NEQ of the UXO, the greater the severity of the consequence. Personnel under solid cover will also be less likely to be injured that those caught in the open.

5.7 Avoidance (Exclusion Zones) and Safety Distances

5.7.1 Exclusion Zone

An Exclusion Zone is implemented around a geophysical survey anomaly/contact that models as UXO but has not yet been confirmed as such through investigation by diver or ROV. Its purpose is to prevent Project activities from disturbing the as-yet unidentified item sufficiently to cause detonation, if it proves to be UXO.

There is very little reference or research material available for the derivation of exclusion zone distances (unlike "safety distances" where the science is more mature and unknown variables are generally fewer). A close examination of the UK CIRIA maritime UXO guide (Reference I) will demonstrate that exclusion zones are universally applied arbitrarily; usually guided by the advice of EOD professionals (such as *Ordtek's* own specialist who has over 30 years military EOD and Mine Warfare experience).

As an example, a typical exclusion zone radius of 15m is commonly applied within the OWF industry for relative low energy activities such as cable ploughing and this is the figure that *Ordtek* recommends for these operations. The 15m distance is based on the following:

- 10m "avoidance distance" – an arbitrary distance, based on the judgements and experience of an EOD expert, at which the probability of inadvertent detonation of an unknown item of UXO by the envisage Project activity is negligible.
- ± 2.5m navigational error during the geophysical survey.
- ± 2.5m positional error tolerance in the picking of geophysical anomalies during survey data analysis.

15m, therefore, is a distance at which these activities can be conducted safely without "disturbing" potential, as yet unconfirmed, UXO.

The calculation of an exclusion zone for high energy activities, with the potential to cause sympathetic detonation of an item of UXO, such as percussive piling is more complex. These distances are calculated according to the prevailing circumstances. Typically, *Ordtek* would recommend the following avoidance radii, although they may be adjusted to specific circumstances and engineering constraints:

- Surface Cable Lay -10m
- Cable ploughing -15m
- Foundation Piling -30m

5.7.2 Safety Distances

A safety distance is applied to a known item of UXO with the purpose of preventing injury and damage to personnel, vessels and equipment in the event of it detonating. For a given charge weight, the distance chosen depends on the expected effects of detonation – e.g. blast, shock, shrapnel, seismic shock, bubble pulse – and the risk to the receptor that is tolerable. This will depend among other factors on the sensitivity of the receptor – e.g. robustness of the vessel/equipment – and protection (are deck crew below the water line, on deck, under hard cover etc.), range from the UXO, type of weapon (casing, filling type, charge weight, orientation), depth of water, depth of burial, sediment/ground consistency etc. Data from shock trials allows military vessels to determine reasonably accurately the amount of damage that will be sustained from a known size of explosive charge at a range of distances. However, quantifying the precise damage that may occur to civilian vessels and equipment from a specific item of UXO is almost never possible. Consequently, the safety distances applied are usually conservative.

Accordingly, depending on the operational scenario two safety distances can be applied: a "minimum" safety distance that limits disruption to activity but carries a small risk, or a "recommended" safety distance that reduces the risk to almost zero. The first is usually only a *temporary measure.*

6 UXO Risk Assessment

6.1 Key Terms

"Hazard" is a source of potential harm or a situation with the potential to harm or damage. For the purposes of this report the hazard will be termed as "UXO". This is an overarching term which may include all munitions and/or explosive items that have been dumped, fired or unfired.

"Risk" is the calculation of two principal elements:

(1) The likelihood that a hazard may occur (= probability of encountering UXO x probability of detonation);

(2) The consequence (severity) of the hazardous event.

6.2 Risk Assessment Data

Important Data For Risk Assessment Purposes	
Source - Main Hazards	• German ground mines • British ground mines • British and German Buoyant Mines • Allied HE bombs • Projectiles and LSA
Pathway - Classification of Work Activities	• Geotechnical investigation • PLGR • Cable Plough/Excavator/Jetting • Jack-up operations • Anchor handling • Piled foundations
Site conditions	• Dynamic sands and gravel
Receptor - Entities at Risk	• Personnel, equipment, vessels and project program
Tolerability of Risk	• Risk level should be reduced to ALARP
Inherent Risk Controls by the Project	• Follow best practice and Project H&S plan • In-house UXO Risk Management procedure followed and benchmarked against other projects in the region • Specialist UXO risk assessment conducted • All known obstacles to be avoided or investigated

Table 6.1 - Key factors to be used in the risk assessment

6.3 Risk Assessment Matrix

Ordtek uses the following matrix to quantify the risk, each generic UXO hazard is assessed for severity and likelihood of occurrence. This model is generally considered best practice for assessing risk in the construction environment. It has been modified where required to ensure it is UXO centric.

		Hazard Severity				
		1 = Negligible Negligible injury or impact on equipment with no lost work	**2 = Slight** Minor injury or damage requiring treatment or repair	**3 = Moderate** Injury leading to lost time incident	**4 = High** Involving single death and serious damage to equipment	**5 = Very High** Multiple deaths and/or catastrophic damage to major equipment
Likelihood of Occurrence (Encounter *and* Detonation)	**1 = Very Unlikely** A freak combination of factors would be required for a UXO initiation to result	**1 = L**	**2 = L**	**3 = L**	**4 = L/M**	**5 = L/M**
	2 = Unlikely A rare combination of factors would be required for a UXO initiation to result	**2 = L**	**4 = L/M**	**6 = L/M**	**8 = M**	**10 = M/H**
	3 = Possible Could happen if sensitive UXO exists but otherwise unlikely to occur	**3 = L**	**6 = L/M**	**9 = M**	**12 = M/H**	**15 = H**
	4 = Likely Not certain to happen but sensitive UXO may exist and density may be above average resulting in an accident	**4 = L/M**	**8 = M**	**12 = M/H**	**16 = H**	**20 = H**
	5 = Very Likely Almost inevitable that an UXO initiation would result due to the type and density of UXO	**5 = L/M**	**10 = M/H**	**15 = H**	**20 = H**	**25 = H**

Table 6.2 - UXO Risk Assessment Matrix

6.4 Risk Assessment

6.4.1 Overview

Our semi-quantitative risk assessment (SQRA) pre-mitigation is shown at Table 6.3 below. *Ordtek* sees the purpose of the risk calculation table at the pre-mitigation stage of the risk management process mainly to produce a relative order of merit that will inform the Risk Mitigation Strategy. At Table 6.4, we have calculated the risk post-mitigation, assuming that the risk mitigation measures recommended by *Ordtek* are fully implemented. This will allow *Siemens* to use the results as a tool to determine whether ALARP has been achieved (to satisfy H&S requirements) and whether the residual UXO risks are tolerable to the Project.

6.4.2 Important Considerations

In assessing the UXO risk to offshore projects, *Ordtek* uses a SQRA process widely considered as best practice in the offshore industry and in line with the Construction Industry Research and Information Agency's (CIRIA) guidance (Reference I).

We have shown that the risk that UXO poses to any particular Project activity is the product of three key elements:

- The probability of encountering an item of ordnance;
- *If* that encounter happens, the probability of the UXO detonating; and
- *If* the UXO detonates, the severity of the consequence to vulnerable receptors (people, marine life, vessels and equipment) and company reputation.

UXO risk is generally considered a low probability but very high consequence event and it is the latter factor that usually dictates the overarching risk score. The potential consequence of a UXO detonation is by far the dominant factor in the calculation.

Consequences apply to the specific equipment, vessel or personnel and in the circumstances that may lead to detonation for a particular activity. The SQRA calculation may therefore produce resultant similar risk levels for dissimilar activities that could appear counter-intuitive. For example, although the probability of encounter may be greater for one type of UXO over another, the likelihood of detonation for a particular activity may be less. The values assigned to each factor in the risk calculation are subjective and based on many variables, which themselves are difficult or impossible to quantify. Moreover the data for a statistical analysis is not available. **The risk calculation results must be treated with caution and an understanding of their origin.**

The risk factor values assigned in the *Ordtek* SQRA are determined by our UXO specialist experts and are consequently subjective and open to different interpretation. The values assigned cannot be absolute or based upon statistical data (for example, of previous occurrences) because the data is not generally available and there are a great many permutations of the factors involved. A wholly statistical analysis is not possible and a "pseudo" statistical analysis should be treated with scepticism.

Scoring probability requires a qualitative and informed judgement to be made based upon the limited facts available. It is rarely possible (almost never when dealing with UXO in the offshore environment) to present a purely quantitative and statistically accurate measure of UXO probability factors, simply because the base data is largely qualitative i.e. it is drawn from a variety of different historical and environmental sources. The UXO specialist provides a professionally informed judgement based upon empirical, qualitative and anecdotal evidence employed in a consistent approach.

Nevertheless, despite its limitations, our view is that the risk assessment matrix as currently used is suitable for adequately assessing and grading Health and Safety (H&S) risk, which is generally mandated by legislation as well as individual company policy. It is also a robust tool for assessing Project risk tolerability. In the risk calculation tables below, for risk assessment purposes, a number of generic ordnance classifications have been grouped. This is justifiable as the probability of encounter, potential for initiation and NEQ are sufficiently similar.

Unless otherwise stated, the consequence (hazard severity) level shown is for the typical vessel or equipment used for a particular development stage. The table also contains a separate section that shows the likely consequence of UXO detonation to exposed personnel. This section will always assume the worst case scenario.

6.4.3 Risk Calculation Results

Risk Assessment Results – Nissum Bredning Vind				
Development Stage	**Generic Ordnance Category**	**Likelihood of Occurrence (Encounter *and* Detonation)**	**Severity of Consequence**	**Result**
Geotechnical Investigation (from a DP Vessel) (see below for Jack Up ops)	German ground mines	1	5	5 – Low/Moderate –
	British ground Mines	1	5	5 – Low/Moderate
	British and German Buoyant Mines	1	3	3 – Low
	HE Bombs	1	3	3 – Low
	Land Service Ammunition	1	2	2 – Low
PLGR (severity of consequence is calculated for worst case – detonation close to towing vessel)	German ground mines	1	5	5 – Low/Moderate
	British Ground Mines	1	5	5 – Low/Moderate
	British and German Buoyant Mines	1	3	3 – Low
	HE Bombs	1	3	3 – Low
	Land Service Ammunition	1	2	2 – Low
Cable Ploughing/ Trenching/ Jetting from tracked vehicle	German ground mines	1	5	5 – Low/Moderate
	British Ground Mines	1	5	5 – Low/Moderate
	British and German Buoyant Mines	1	5	5 – Low/Moderate

Risk Assessment Results – Nissum Bredning Vind				
Development Stage	**Generic Ordnance Category**	**Likelihood of Occurrence (Encounter *and* Detonation)**	**Severity of Consequence**	**Result**
Cable Ploughing/ Trenching/ Jetting from tracked vehicle	HE Bombs	1	3	3 - Low
	Land Service Ammunition	1	2	2 – Low
Anchor Deployment & Handling	German ground mines	1	5	5 – Low/Moderate
	British Ground Mines	1	5	5 – Low/Moderate
	British and German Buoyant Mines	1	3	3 – Low
	HE Bombs	1	3	3 – Low
	Land Service Ammunition	1	2	2 – Low
Jack Up Operations	German ground mines	1	5	5 – Low/Moderate
	British Ground Mines	1	5	5 – Low/Moderate
	British and German Buoyant Mines	1	3	3 – Low
	HE Bombs	1	3	3 – Low
	Land Service Ammunition	1	2	2 – Low
Foundation Installation for WTGs (from DP vessel – anchoring assessed separately)	German ground mines	1	5	5 – Low/Moderate
	British Ground Mines	1	5	5 – Low/Moderate
	British and German Buoyant Mines	1	3	3 – Low
	HE Bombs	1	3	3 – Low
	Land Service Ammunition	1	2	2 – Low
Unprotected Personnel (Small items: activities that could recover UXO above the water surface – detonation on or very close to the surface/or in very shallow water. Large items: detonation in >10m water close to vessel)	German ground mines	1	5	5 – Low/Moderate
	British Ground Mines	1	5	5 – Low/Moderate
	British and German Buoyant Mines	1	2	2 – Low
	HE Bombs	1	2	2 – Low
	Land Service Ammunition	1	4	4 – Low/Moderate

Table 6.3 - UXO Risk Assessment Table

7 Recommended UXO Risk Mitigation

7.1 Overview

In strategic terms, the UXO risk on this project can realistically be either:

- Accepted by all parties and no further proactive action is taken.
- Avoided by not undertaking the activities at risk.
- Mitigated with measures to contain, and/or eliminate the UXO risks (by reducing the probability or consequences).
- Carried with the balance of any residual risk transparently exposed to those parties involved with site works.

Although mitigation is generally the most cost effective and efficient option for dealing with UXO risks, a balanced blend of the options is usually required to comply with best practice. This desk based study and risk assessment has shown that UXO risk to the windfarm ranges from Low – Low/Moderate and a degree of mitigation is required to reduce the risk to ALARP. To achieve this standard, it is recommended a geophysical survey be commissioned by *Siemens* to locate large net explosive quantity (NEQ) items of UXO, above the smallest item needed to be detected for ALARP sign-off, and to implement procedural mitigation measures.

Mitigation should not focus solely on the Health and Safety risk UXO presents, it is also important to consider other risks to the project, such as the impact of delay. For example, even if the UXO risk to personnel and equipment was deemed low during offshore work, if a number of suspect UXO items were subsequently found after work had started, the impact to the project could be major. This has been clearly demonstrated on other OWF around Europe. These other risks therefore need to be taken in to consideration when determining the level of risk mitigation required.

However, the risk from UXO can never be considered "zero" in the offshore environment, due to equipment limitations and the potential for UXO migration.

Ordtek has been in contact with the Danish military and they concur with this assessment, however it is advised *Siemens* expose this risk assessment to the consenting stakeholders to ensure that all Danish authorities are content that H&S and Project risk obligations have been fulfilled.

7.2 Risk Tolerance and ALARP

In Denmark, the Health and Safety (H&S) risks that UXO poses to Project personnel and the general public must, by law, be reduced to below a threshold deemed ALARP (in some parts of Europe other measures are used, such as MEM and GAMAB). On the other hand, the level of Project risk (damage to equipment, delay, reputation etc.) that can be carried is not mandated by legislation. In this case, UXO risk tolerance is a matter for the developer and his insurers.

Our view that the two can be considered separately. As long as the standard of ALARP is achieved for H&S risk, the developer has the option of accepting higher (or, indeed, striving for lower) project risk. In the former (H&S risk), it is necessary show that all that is reasonably practicable has been done to reduce UXO risk. The key benchmark, therefore is not the actual *level* of risk but what is seen to be done in its mitigation. If this is judged sufficient, the project can proceed with a *de minimis* risk of a catastrophic UXO event *(De minimis - a residual risk that is deemed to be too trivial or minor to merit consideration, especially in law. In risk assessment, it refers to the level of risk too small to be concerned with or that needs action. There is no legal requirement for further mitigation.)*

On the other hand, when it comes to Project risk, managers are concerned with *actual risk levels*; that is, the probability of a detonation occurring for any particular activity and the cost and severity of the likely consequences.

As we noted earlier, the inadvertent detonation of an item of UXO is generally acknowledged as being a very low probability, high consequence event. Therefore the developer, if he judges it acceptable, may forego the potentially high costs of additional survey, contact investigation etc. in favour of risking the costs of the consequences of a detonation, in the knowledge that such a detonation is highly unlikely to occur. Particularly if the project costs incurred may be reasonable in comparison.

7.3 Geophysical Survey across Entire Site - Smallest UXO Item for ALARP Sign Off

Given the low probability of encounter, Ordtek considers that magnetometer survey is not required to reduce the risk to ALARP. While improvement in detection can be achieved utilising magnetometer survey, generally the detection and identification of all magnetic anomalies that could resemble a 250lb bomb in the area is likely to be impractical as well as highly costly, when compared to the risk reduction. Investigating the resultant anomalies that ensued from data interpretation would be unjustified in both time and cost according to Ordtek's understanding of the ALARP principle. Accordingly, a high resolution (HR) acoustic survey is recommended. Geophysical anomalies modelling as UXO in subsequent analysis can be detected and avoided or investigated and removed/destroyed.

The choice of the smallest hazard item that needs to be mitigated for ALARP sign-off is determined, *inter alia*, by the prevailing environment (including likely UXO burial) and the ability to detect the item using available geophysical techniques. It is necessary to weigh up the perceived significance of the hazard to specified Project activities against what is "reasonably practicable" in terms of effort to detect it.

Ordtek considers that **the smallest significant UXO hazard item that needs to be mitigated for an ALARP sign-off is the British 250lb GP or MC bomb.** Depending on the variant, the 250lb GP is made of cast steel with a wall thickness of 0.6in (1.5cm). The body length is ~28in (71cm). The body diameter is ~10.2in (26cm) and the filling consists of 110lb (50kg) of TNT or Amatol. The 250lb MC dimensions are the same, except the body wall thickness is only 0.3in (0.75cm) and the charge weight is greater at ~120lbs (55kg) of Amatol or Pentolite.

Assuming these items can be successfully detected and identified within the geophysical datasets, larger objects will also be detectable. While this will reduce the risk from large UXO, the bulk of risk reduction and risk management will be undertaken via physical and procedural measures, which are outlined below.

Nevertheless, the likelihood of detonation is very low and the overall UXO risk can be reduced satisfactorily to below the ALARP threshold through procedural mitigation measures alone.

7.4 Geophysical Anomaly Management - Design Engineering Stage

Any geophysical anomalies which are classified as "potential UXO" but are not definitively confirmed as such by video or ROV inspection, can be avoided by a suitably safe distance, making the assumption that the item remains stable and will not be disturbed. In accordance with the ALARP principle, the installation could then proceed with a *de minimis* risk of encountering UXO. However the safety exclusion zones around the geophysical contacts must be respected. Unless these contacts are investigated and confirmed as not UXO related, they should be considered a potential hazard.

Based on a review of the methodologies deployed for the installation, the following safety constraints should be adhered to:

- No geotechnical exploratory activity or anchor should interact with the seabed within 10m of a geophysical contact that is potentially UXO.
- No scour protection material is to be placed within 15m of any geophysical contact that is potentially UXO.
- Inter array cable shall not be installed within 15m of any geophysical contact that is potentially UXO.
- No foundation shall be installed with 30m of any geophysical contact that is potentially UXO *(note that if analysis suggests that the anomaly is likely to be a German ground mine, this distance should be expanded to 50m)*.

7.5 Offshore UXO Risk Management

7.5.1 Overview

To conform to best practice, installation contractors should also adopt the following UXO risk management and mitigation actions; these are the procedures and reactive measures that will mitigate the residual risk from UXO that may have been missed during survey and analysis, as well as ensuring any avoidance strategy is implemented effectively and safely.

- Obtain the ALARP sign-off certificate for each installable asset. Input the geophysical contacts to be avoided into the on-board navigation system.
- Ensure the Project team are aware of Project internal UXO policy, including key support numbers.
- Hold a copy of this risk assessment on-site/on-board the vessel.
- Brief all personnel on the potential UXO risk.
- Hold a UXO specialist on-call in the event of a suspect item being discovered unexpectedly.

Expansion on these points is provided below.

7.5.2 UXO Risk Mangement Plan with Safety Instructions

The contractor's/vessel emergency response plan (ERP) should identify management responsibilities in respect of reporting potential UXO items, marking of objects, dealing with potential UXO brought onto the vessel inadvertently, securing the area, ensuring the safety of personnel and informing the UXO specialist, whether embarked offshore or on-call ashore.

Management staff and supervisors, for all phases of development, will be required to attend the normal Explosive Ordnance Safety and Awareness Briefing, in addition to a separate expanded briefing detailing actions to be taken in the event that an item of ordnance or suspicious objects encountered. Key staff should be nominated as part of the vessel/site health and safety protocol with specific responsibility for the implementation and maintenance of the site Explosive Ordnance Site Safety Instructions.

7.5.3 UXO Safety Awareness Briefings

All involved personnel will be required to attend a site safety induction briefing, this will be provided by an appropriately trained person. This formal briefing should include a section on Explosive Ordnance Safety and Awareness and will apply during all work that interacts with the seabed throughout the life of the project. The briefing will be supported by photographs of the range of ordnance that is considered likely to be encountered. The visual material will depict the ordnance in a 'typical' state (e.g. rusting and covered in concretion). A record will be maintained of all personnel who attend the briefing and subsequent update briefings. At the discretion of the principle contractor, all personnel should attend a periodic update briefing, particularly during the seabed engineering phases of the project

7.5.4 UXO Specialist On Call/Offshore

The Project should engage an UXO specialist to be on call in the event of a potential UXO encounter. A procedure can be implemented to ensure the item is viewed and dealt with as quickly as possible.

When on-site, the role of the UXO specialist would be to monitor works, where appropriate advising staff of the need to modify work practices and provide immediate UXO identification and safety advice. If an object was confirmed as UXO, he would help with the vessel/site incident management and provide pertinent specialist advice, which would involve liaison with shore/local authorities, including any requirement to test chemical agents, and the Client's UXO consultant (*Ordtek).*

7.5.5 Anchor Handling

The deployment of anchors may be required outside the surveyed footprint. *Ordtek* has considered this situation carefully and can confirm the deployment of anchors outside the surveyed area is an acceptable risk to be carried by the installation contractor and wider project team. *Ordtek* would consider this to be an ALARP risk based on the fact that anchor deployment is a routine activity within the Limfjord.

On other renewable projects the same stance has been taken on site where the UXO risks are far higher such as in the Thames Estuary. However where geophysical data is available, it should be consulted, and any suspect contacts avoided by at least 10m.

8 Conclusion

8.1 Summary

This desk based study has considered the UXO risk within the Nissum Bredning Vind study area and also within the wider region, in order to assess the potential risk to the project from UXO.

This study has followed a logical process. *Inter alia*, we have:

- Assessed the baseline UXO risk in the study area to likely project activities.
- Developed and recommended a UXO risk mitigation strategy to achieve ALARP for Nissum Bredning Vind project activities.

Our research for this study has identified UXO sources that have the potential to contaminate the area. We have made an assessment of what we consider to be the most likely UXO hazard items in the Area of Interest (AOI) now and, potentially, across the life of the project, including the most likely types that could be encountered, the probability of encountering them as well as the risk and consequences of detonation.

8.2 UXO Hazards

This area of the North Sea has seen a considerable amount of military action over two World wars. There were substantial mine laying operations in both wars involving both German and British buoyant and ground mines, with minefield clearance of only limited effectiveness after each period of conflict. Buoyant mines frequently broke free from their moorings and drifted tens, occasionally hundreds, of kilometres before sinking to the seabed. In addition, Allied bombing and coastal defences have all played a part in potentially contaminating the site.

However, the North of Denmark saw considerably less military activity and the Nissum Bredning Site appears to have been sheltered from much of the conflict.

While military sources consulted have confirmed EOD has taken place within the Limfjord and potentially within the Nissum Bredning site, there are no known UXO finds in the area or within the Site boundary.

Ordtek considers the smallest UXO threat item for ALARP sign-off is the British 250lb GP bomb.

8.3 Risk Calculation

This desk based study and risk assessment has shown that the pre-mitigation risk from UXO within the Nissum Bredning site ranges from *Low* to *Low/Moderate* and mitigation is required to reduce this risk to ALARP. The post-mitigation UXO risk is expected to be *Low*, assuming that *Ordtek's* risk mitigation strategy is adopted. This can be considered as ALARP.

8.4 Risk Mitigation

This desk based study and risk assessment has shown that the UXO risk is low for the whole site. However, it is likely that mitigation is required to reduce the risk to ALARP. To achieve this standard a geophysical survey should be commissioned by *Siemens* to locate large net explosive quantity (NEQ) items of UXO, above the smallest item needed to be detected for ALARP sign-off. Geophysical anomalies modelling as UXO in subsequent analysis can be and avoided or investigated and removed/destroyed.

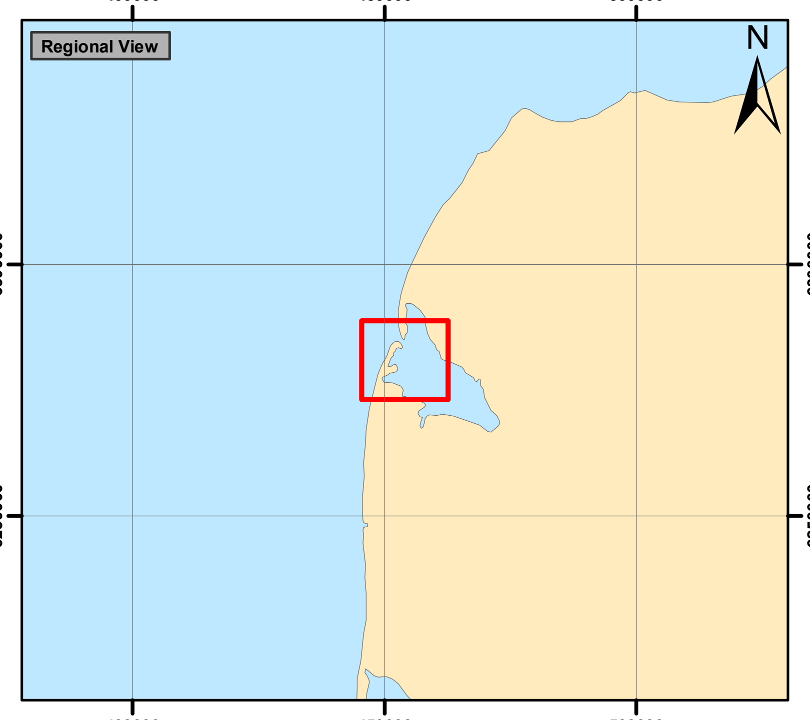
While the geophysical survey will reduce the risk from large UXO, the bulk of risk reduction and risk management will be undertaken via physical and procedural measures, which are outlined below.

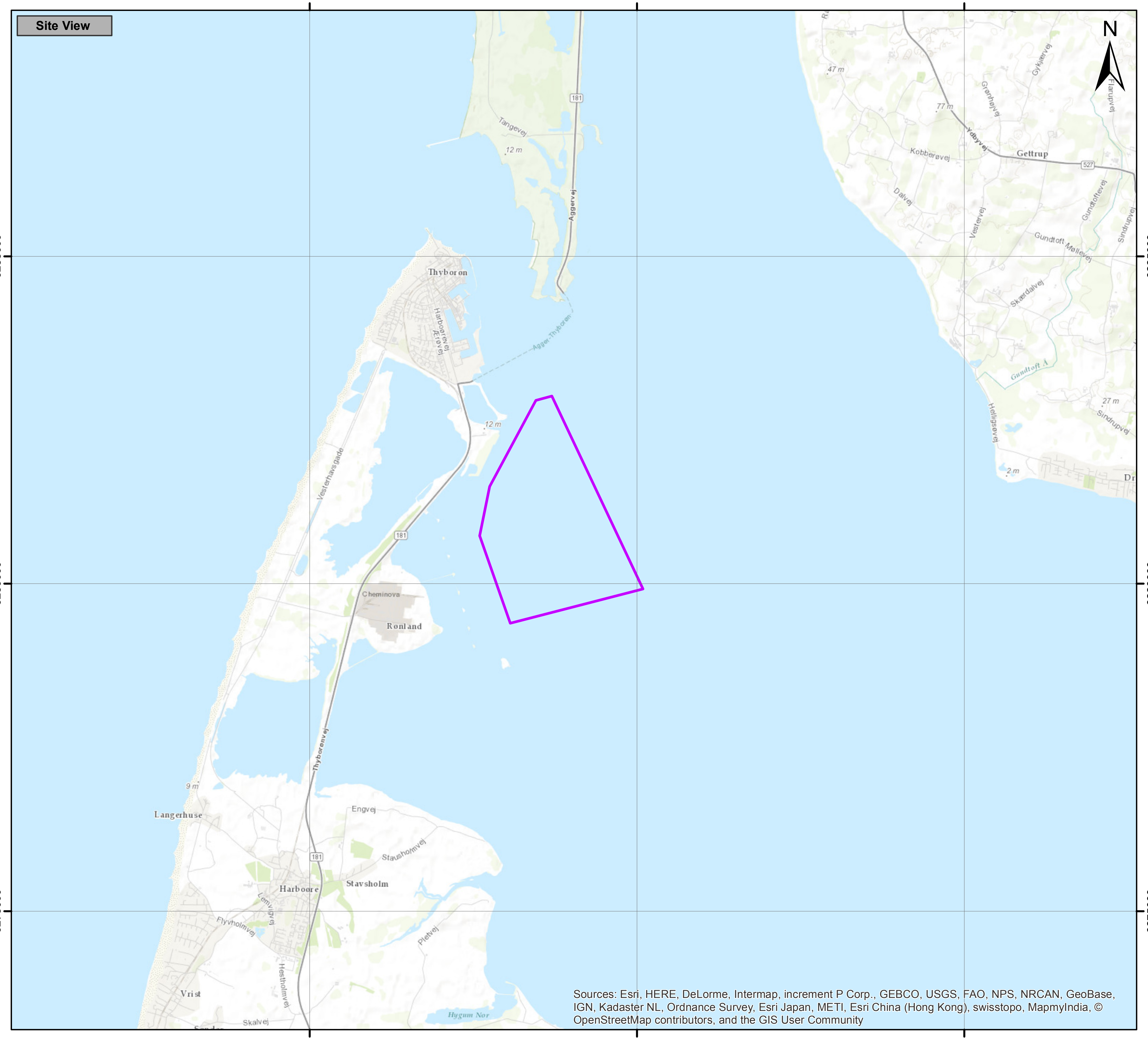
To conform to best practice, installation contractors should also adopt the following UXO risk management and mitigation actions; these are the procedures and reactive measures that will mitigate the residual risk from UXO that may have been missed during survey and analysis, as well as ensuring any avoidance strategy is implemented effectively and safely.

- Obtain the ALARP sign-off certificate for each installable asset. Input the geophysical contacts to be avoided into the on-board navigation system.
- Ensure the Project team are aware of Project internal UXO policy, including key support numbers.
- Hold a copy of this risk assessment on-site/on-board the vessel.
- Brief all personnel on the potential UXO risk.
- Hold a UXO specialist on-call in the event of a suspect item being discovered unexpectedly.

Appendix 1

Offshore Windfarm Location





Legend for Site View

Project Area

Horizontal Scale(s)

Kilometers: 0, 0.5, 1, 2, 3, 4, 5

Nautical Miles: 0, 0.25, 0.5, 1, 1.5, 2, 2.5

Consultant	Client	Drawing Title	User Notes
ORDTEK	SIEMENS	Nissum Bredning Offshore Wind Farm Project Overview	N/A

THE BRITISH ASSESSMENT BUREAU ISO9001

ETRS 1989 UTM Zone 32N
Projection: Transverse Mercator
Datum: ETRS 1989
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: 9.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter

Drawn by: RB
Checked by: LG

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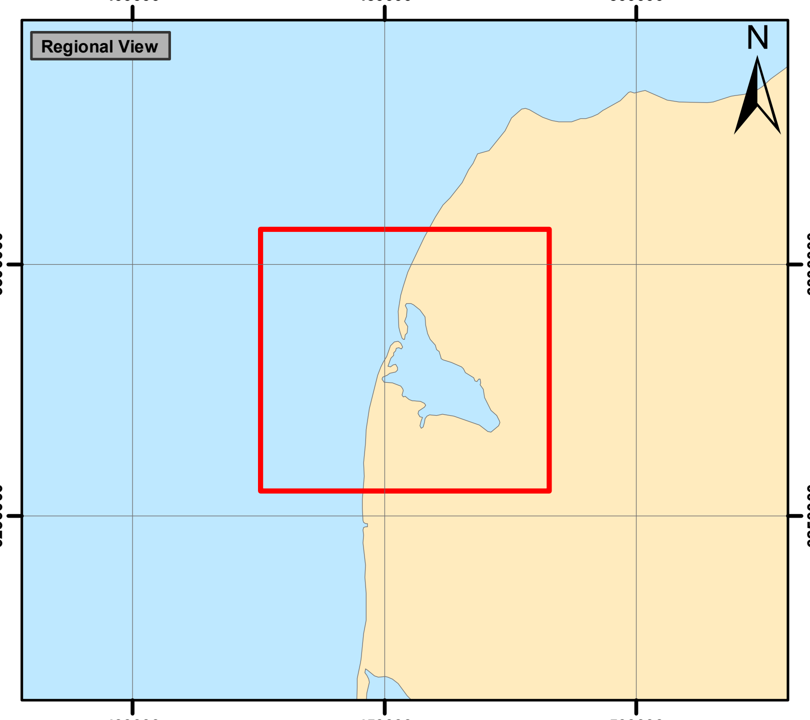
JM5303 - Nissum Bredning OWF

Date Drawn: 03 November 2016
Drawing Reference: JM5303_DTS_01
Drawing Version: 1.0

Appendix 2

Prohibited Areas



Legend for Site View

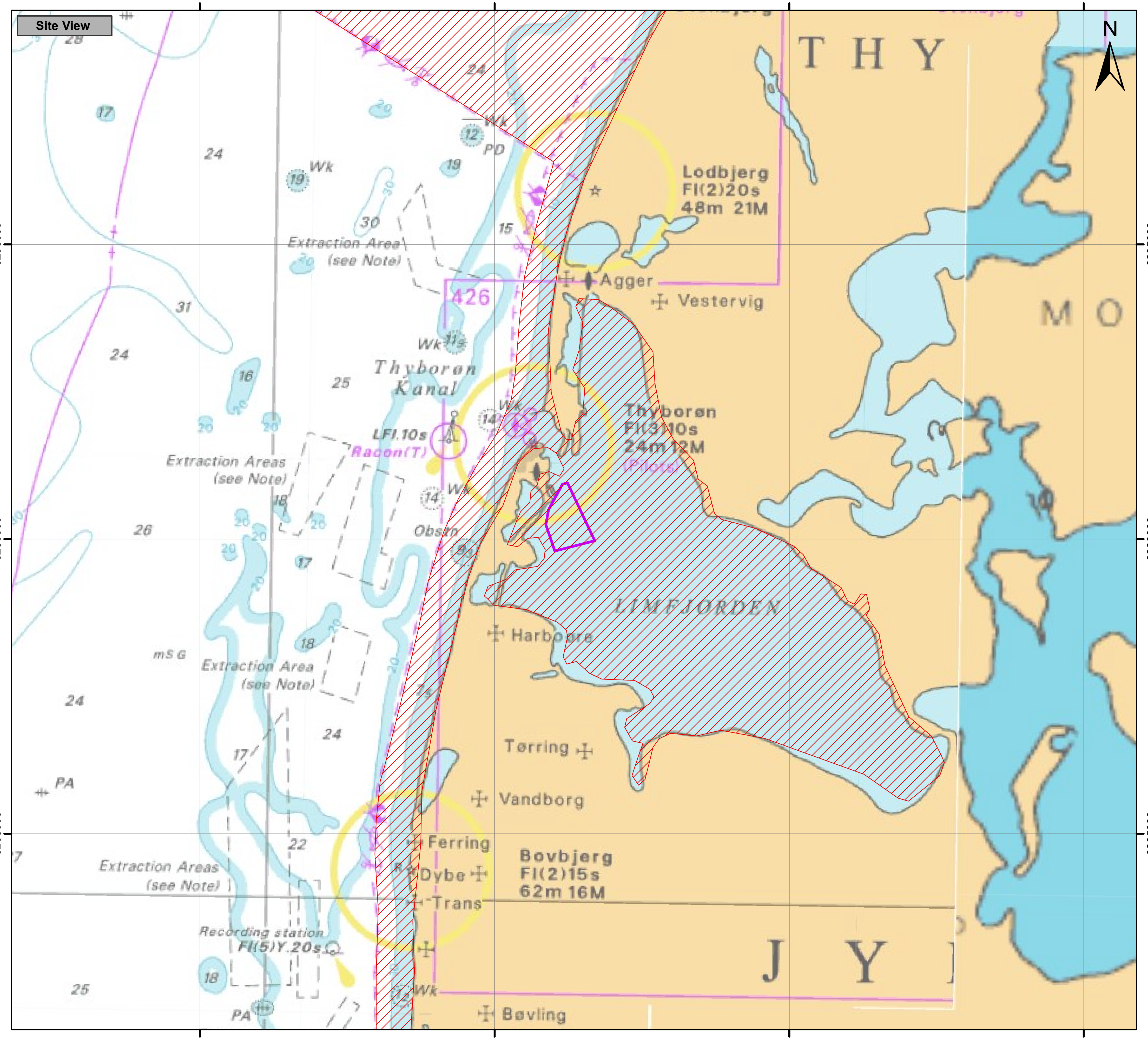
Project Area

Prohibited Area

Horizontal Scale(s)

Kilometers: 0, 2.5, 5, 10, 15

Nautical Miles: 0, 1.25, 2.5, 5, 7.5



Consultant: ORDTEK

Client: SIEMENS

Drawing Title: **Nissum Bredning Offshore Wind Farm Prohibited Areas**

User Notes: N/A

THE BRITISH ASSESSMENT BUREAU ISO9001

ETRS 1989 UTM Zone 32N
Projection: Transverse Mercator
Datum: ETRS 1989
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False Northing: 0.0000
Central Meridian: 9.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter

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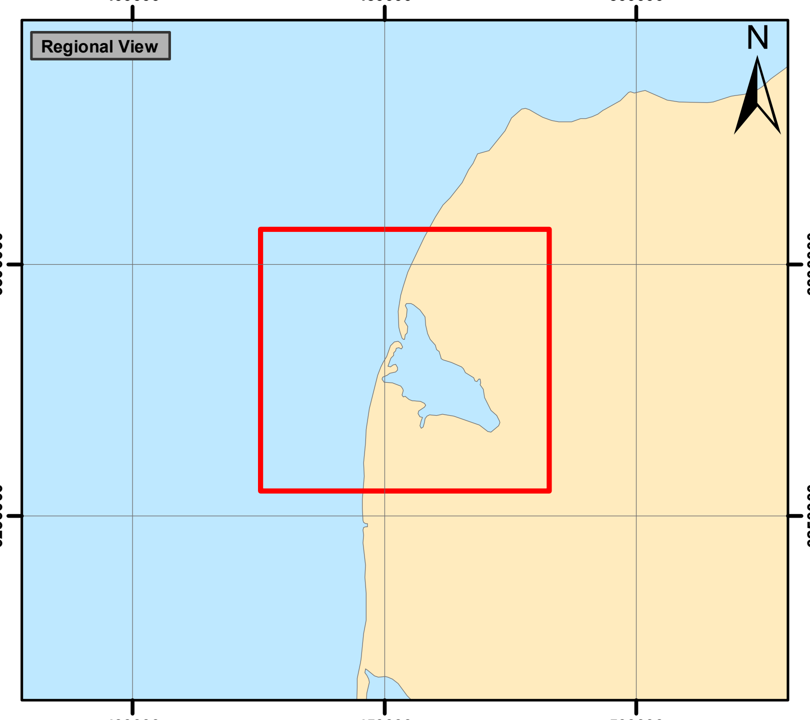
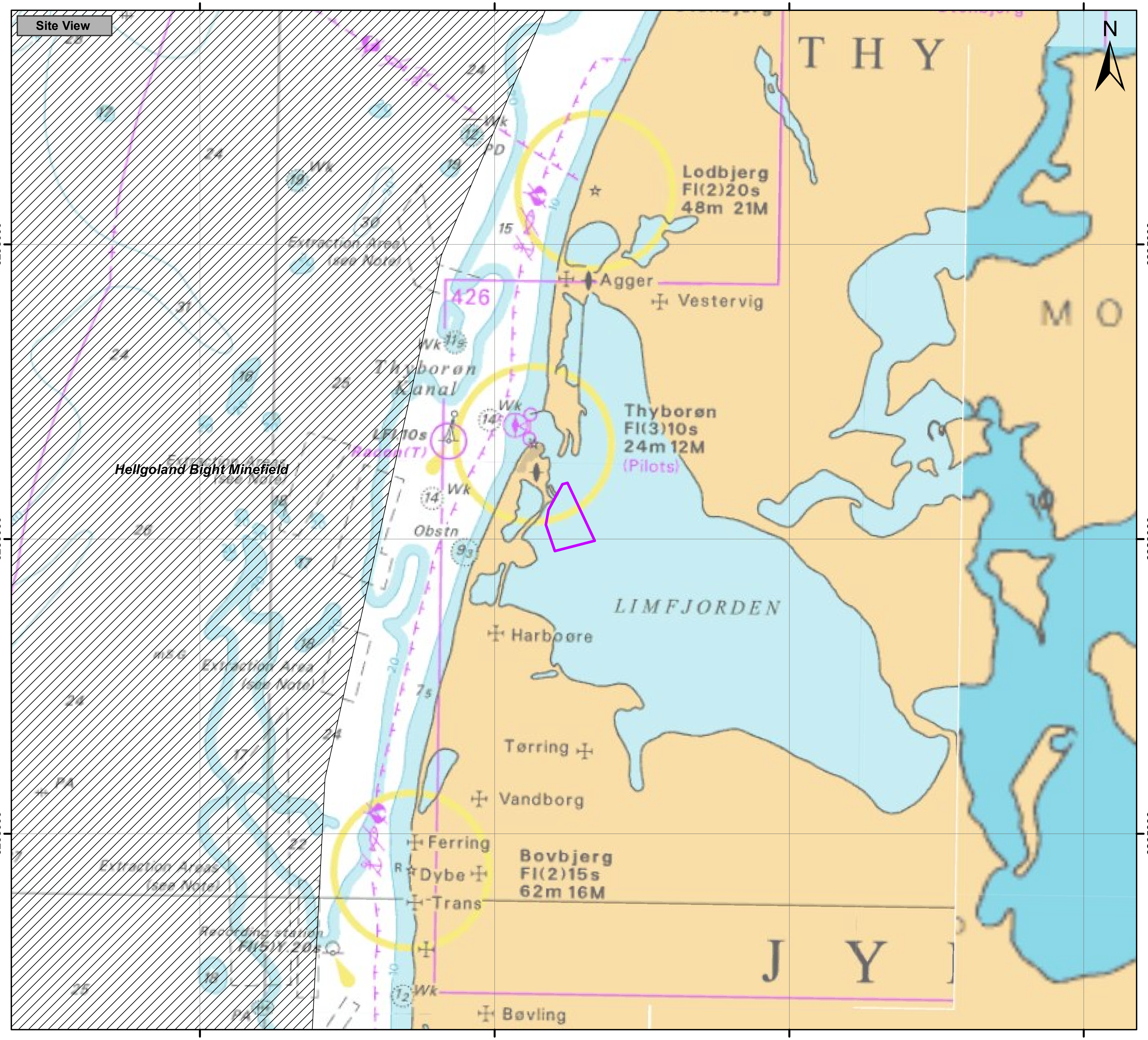
JM5303 - Nissum Bredning OWF

Date Drawn: 15 November 2016
Drawing Reference: JM5303_DTS_06
Drawing Version: 1.0

Appendix 3

British WWI Buoyant Minefields





Legend for Site View

- Project Area
- WWI British Minefield

Horizontal Scale(s)

Kilometers: 0 2.5 5 10 15

Nautical Miles: 0 1.25 2.5 5 7.5

Consultant	Client	Drawing Title	User Notes				
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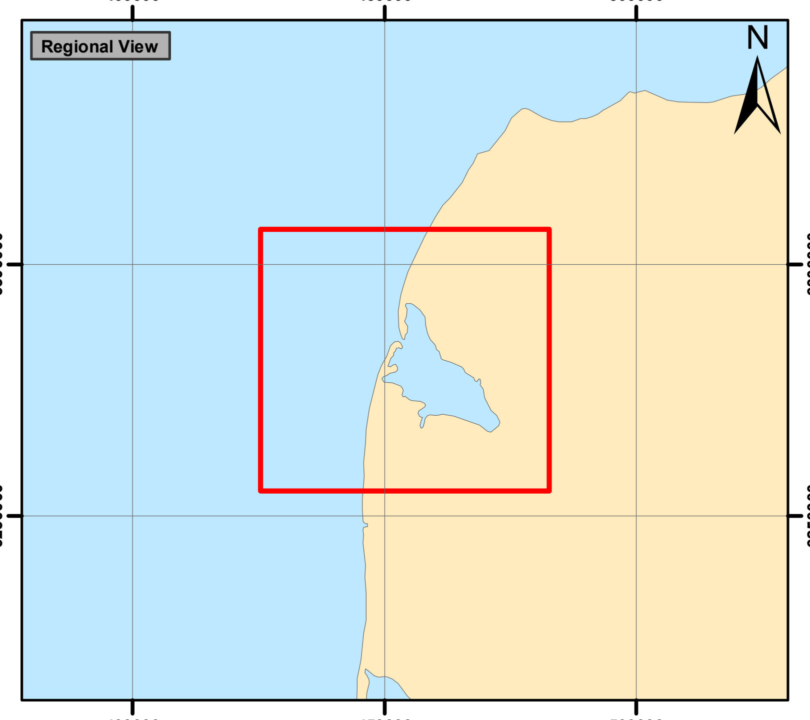
Appendix 4

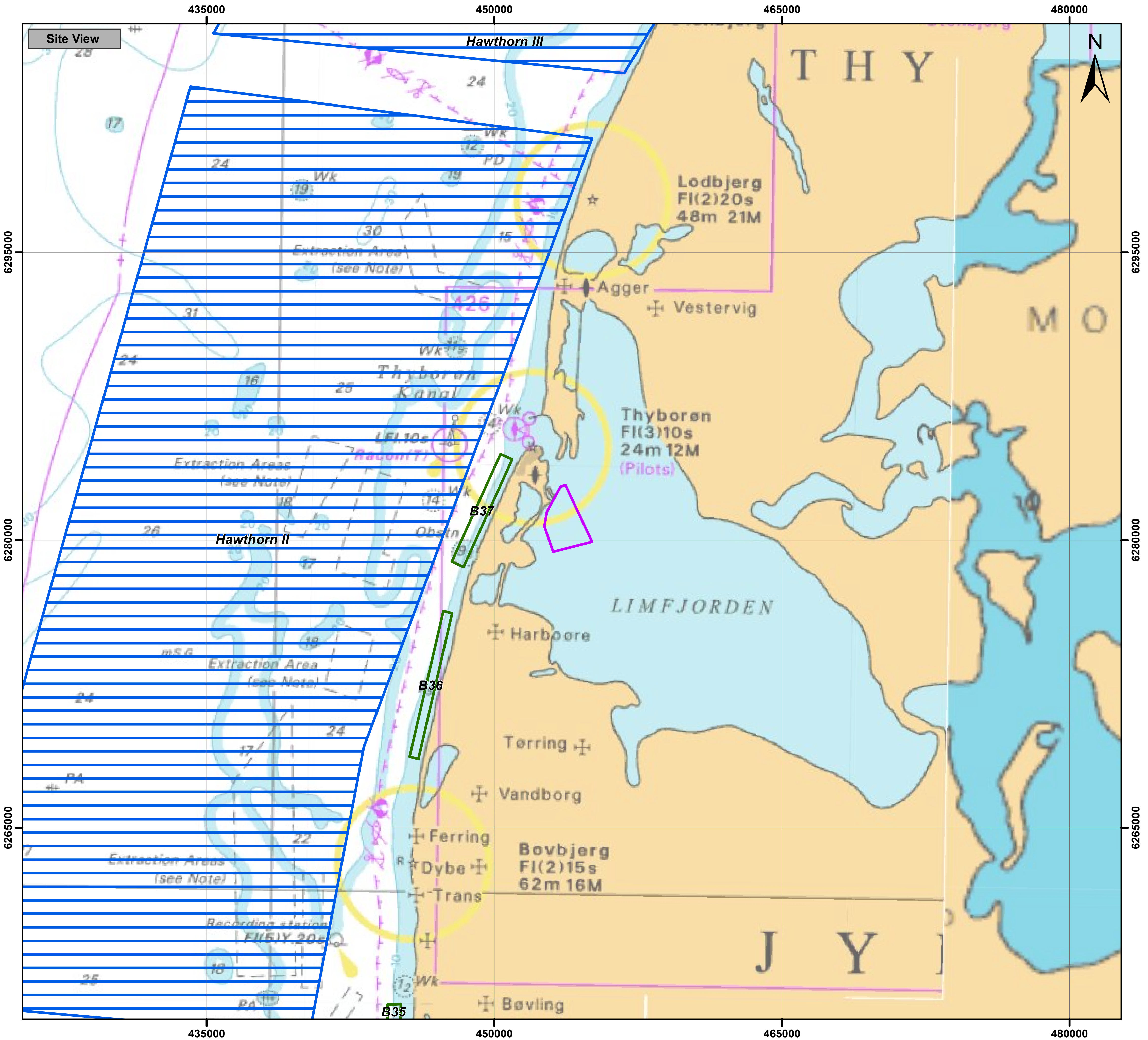
British and German WWII Mining

Regional View



Continental View

Site View



Legend for Site View

- Project Area
- WWII British Mine "Garden"
- WWII German Minefield

Horizontal Scale(s)

Kilometers: 0, 2.5, 5, 10, 15

Nautical Miles: 0, 1.25, 2.5, 5, 7.5

Consultant	Client	Drawing Title	User Notes
ORDTEK	SIEMENS	Nissum Bredning Offshore Wind Farm British and German WWII Mining	N/A

THE BRITISH ASSESSMENT BUREAU ISO9001

ETRS 1989 UTM Zone 32N
Projection: Transverse Mercator
Datum: ETRS 1989
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False Northing: 0.0000
Central Meridian: 9.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter

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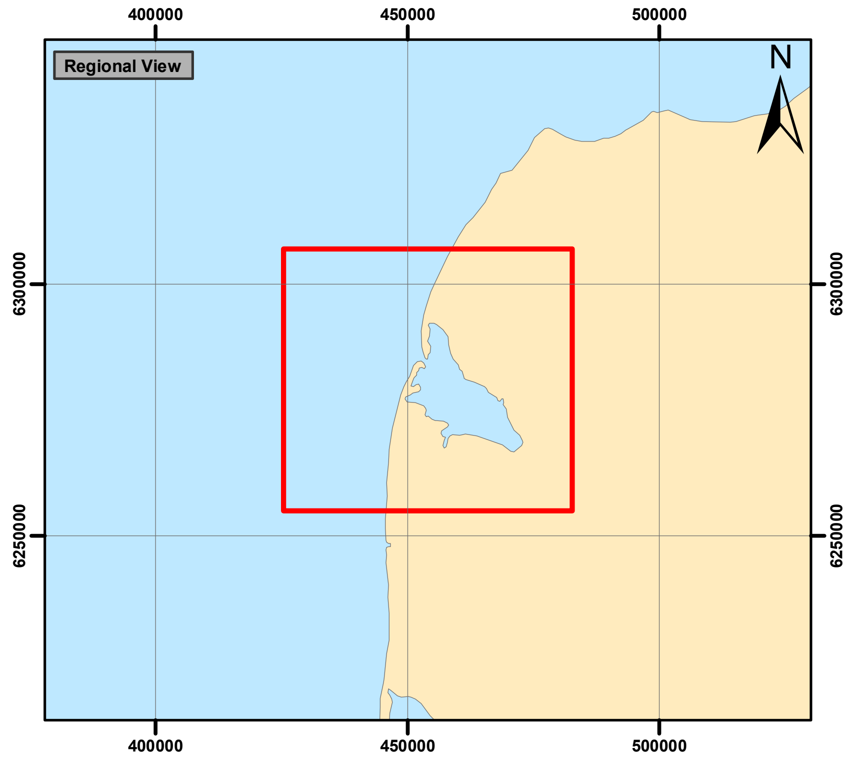
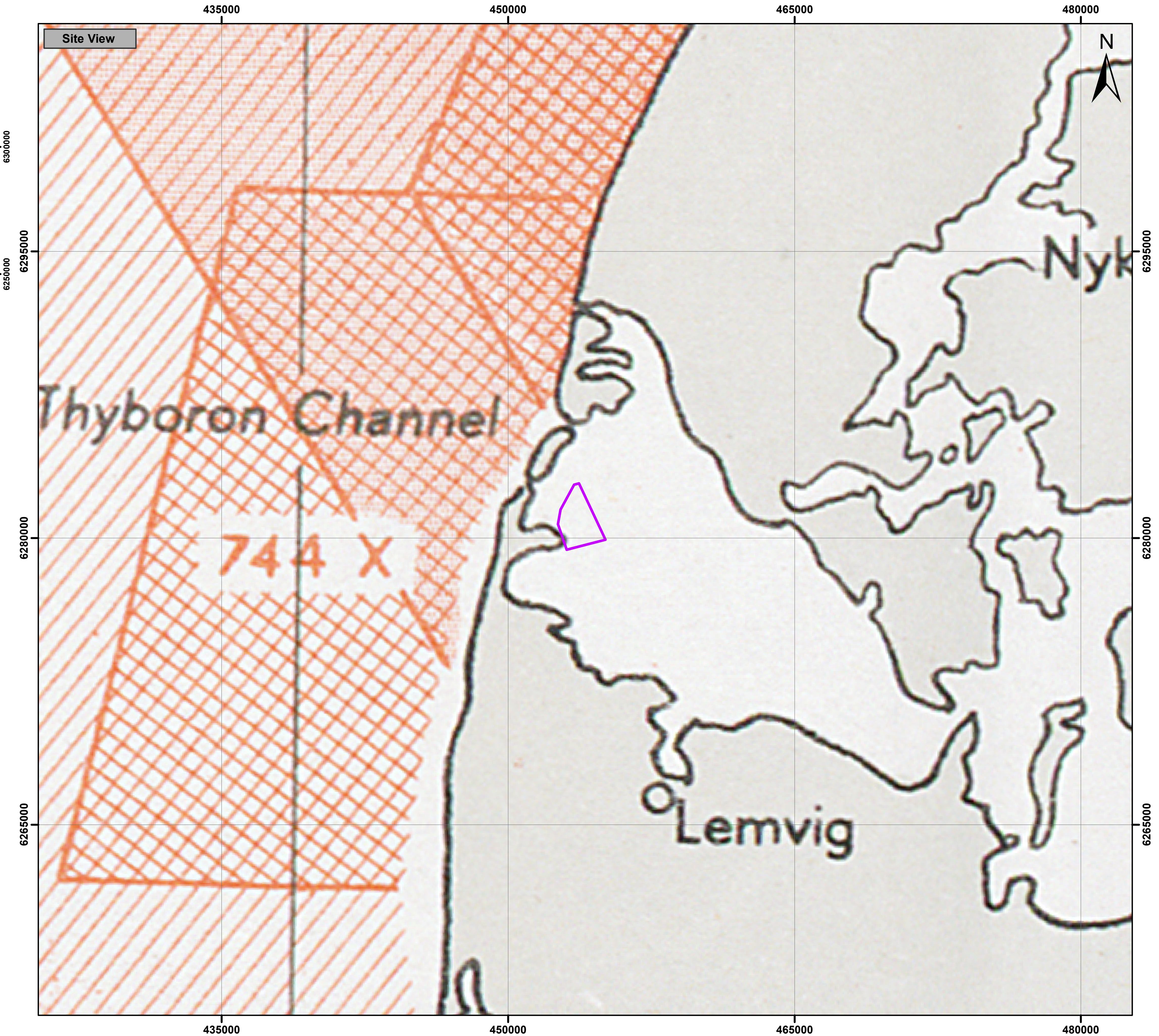
Date Drawn: 03 November 2016
Drawing Reference: JM5303_DTS_03
Drawing Version: 1.0

Appendix 5

WWII Mine Danger Areas





Legend for Site View

- Project Area
- British Declared Danger Areas
- British Declared Minefields
- German Minefields
- Searched Channels

Horizontal Scale(s)

Kilometers: 0, 2.5, 5, 10, 15

Nautical Miles: 0, 1.25, 2.5, 5, 7.5

Consultant	Client	Drawing Title	User Notes
ORDTEK	SIEMENS	Nissum Bredning Offshore Wind Farm WWII Mine Danger Areas	N/A

THE BRITISH ASSESSMENT BUREAU ISO9001

ETRS 1989 UTM Zone 32N
Projection: Transverse Mercator
Datum: ETRS 1989
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: 9.0000
Scale Factor: 0.9996
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Units: Meter

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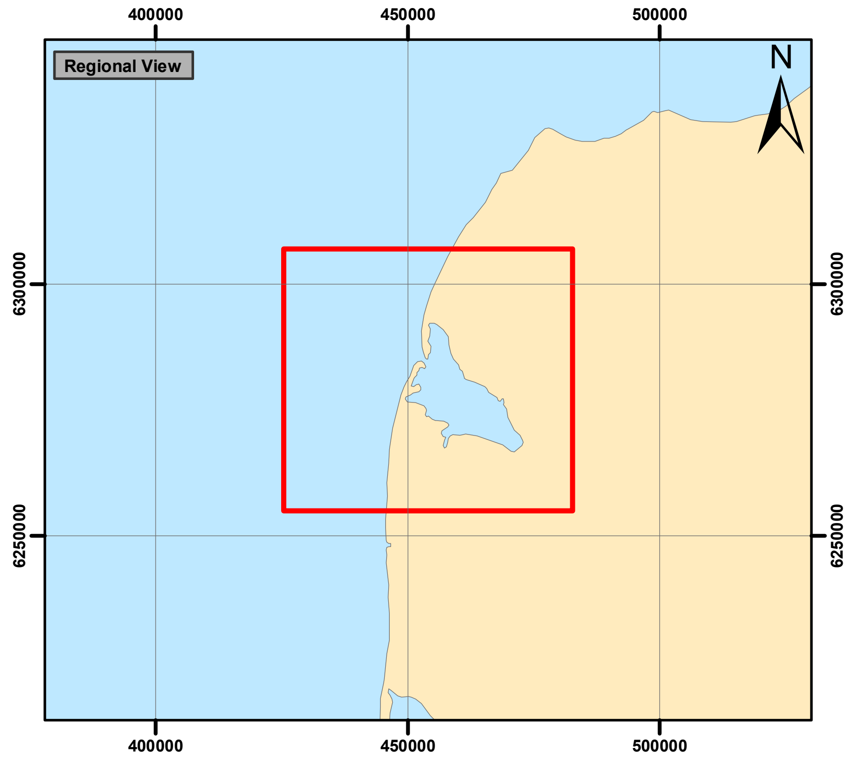
JM5303 - Nissum Bredning OWF

Date Drawn: 03 November 2016
Drawing Reference: JM5303_DTS_04
Drawing Version: 1.0

Appendix 6

Modern Military Practice and Exercise Areas



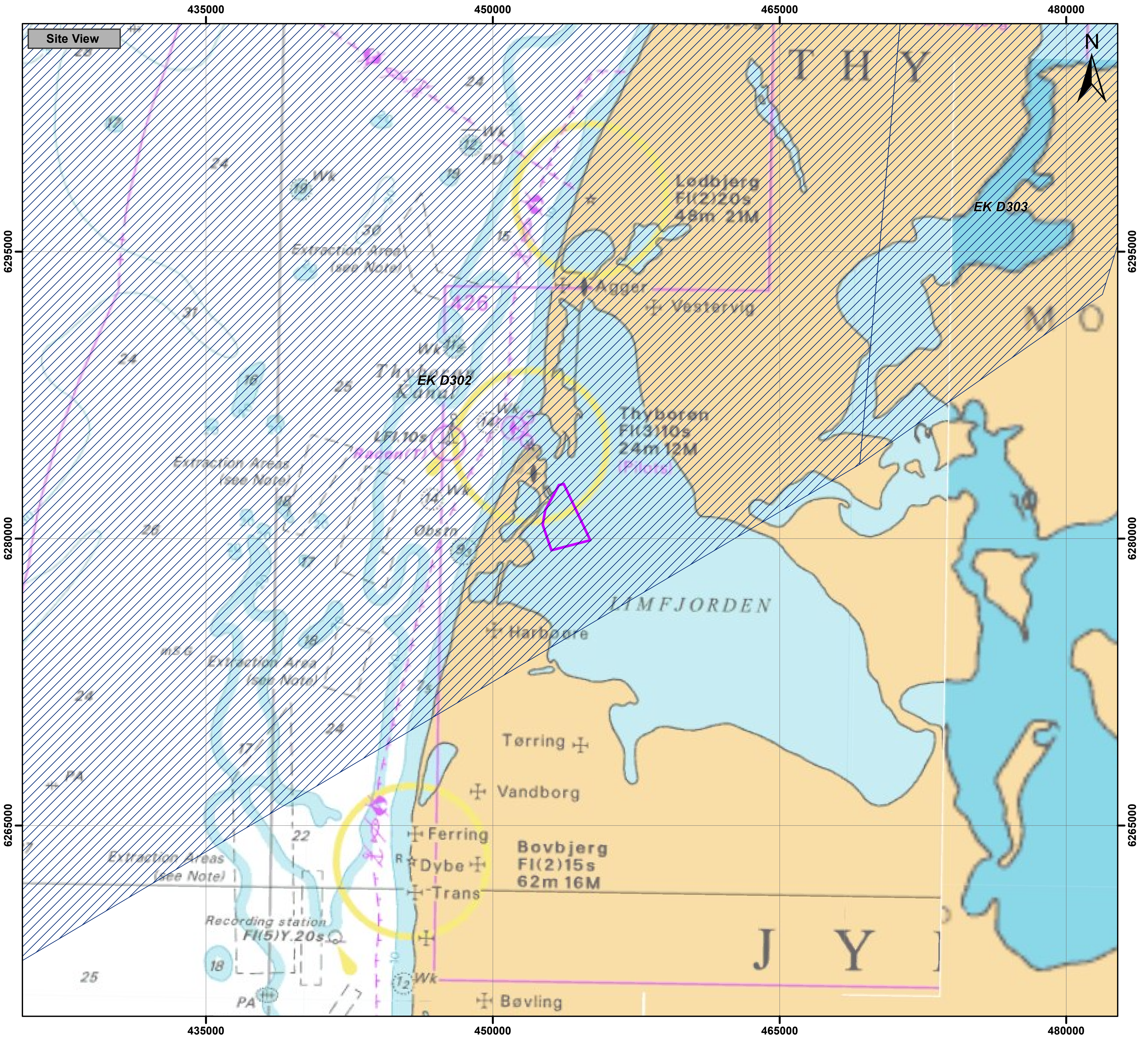
Legend for Site View

- Project Area
- Air Force Practice and Exercise

Horizontal Scale(s)

Kilometers: 0, 2.5, 5, 10, 15

Nautical Miles: 0, 1.25, 2.5, 5, 7.5



Consultant: ORDTEK

Client: SIEMENS

Drawing Title: **Nissum Bredning Offshore Wind Farm Modern Practice and Exercise**

User Notes: N/A

THE BRITISH ASSESSMENT BUREAU ISO9001

ETRS 1989 UTM Zone 32N
Projection: Transverse Mercator
Datum: ETRS 1989
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: 9.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter

Drawn by: RB
Checked by: LG

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JM5303 - Nissum Bredning OWF

Date Drawn: 03 November 2016
Drawing Reference: JM5303_DTS_05
Drawing Version: 1.0