FEBRUAR 2023
LILLEBÆLT VIND A/S

LILLEBÆLT SYD VINDMØLLEPARK

MILJØKONSEKVENSRAPPORT FOR VINDMØLLEPARK TIL HAVS

BILAG I UXO-ANALYSE (UNEXPLODED ORDNANCE)

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Bilag 2	ORDTEKS tillæg om Risk Mitigation_V1.0 af 23. februar 2018

1 Indledning

Som en del af grundlaget for miljøkonsekvensvurderingen er der foretaget en undersøgelse af ueksploderet ammunition (Unexploded Ordnance, UXO) på havbunden. UXO-undersøgelsen er udført af firmaet ORDTEK og er afrapporteret i vedhæftede 3Bilag 1 på engelsk. Der er udarbejdet en dansk sammenfatning herunder.

2 Sammenfatning på dansk

ORDTEK vurderer, at UXO-risikoen, for risikoreducerende aktioner, allerede er lav og meget tæt på ALARP (As Low As Reasonably Practicable) for udførelse af de geotekniske forundersøgelser, når der ses bort fra uforudsete omstændigheder.

Den direkte kontakt med havbunden for geotekniske forundersøgelser er normalt meget lille i forhold til det totale areal. I forhold til den relativt lave tæthed af UXO-objekter er sandsynligheden for at støde på et UXO-objekt også meget lav. Dertil følger, at sandsynligheden for en utilsigtet UXO-detonation er endnu lavere.

Den resterende risiko kan reduceres til under ALARP-grænsen ved at indføre reaktive- og proceduremæssige forholdsregler. Omkostningerne ved en fuld geofysisk undersøgelse er normalt uberettigede og urimelige i forhold til grundsætningerne i ALARP-princippet. Risikoen i forhold til udstyret på havbunden er, selvfølgelig, en smule højere, og bygherren må beslutte, om denne meget lave projektrisiko (omkostning, forsinkelser, omdømme) er tolerabel eller kræver yderligere reduktion.

Det er normal praksis at udlevere UXO-undersøgelsen og den geofysiske undersøgelse til dem, der skal udføre den geotekniske undersøgelse forud for alt arbejde med kontakt til havbunden. UXO-analysen blev på den baggrund i februar 2018 udleveret til GEO, der var blevet valgt til at udføre de geotekniske forundersøgelser.

Da GEO valgte at udføre de geotekniske forundersøgelser med en såkaldt jack-up, som står på havbunden og dermed har en lidt større berøring med havbunden end geotekniske undersøgelser udført fra skib med borerig, udarbejdede ORDTEK en tillægsvurdering af fund af UXO ved brug af jack-up (3Bilag 2). Derefter foretog COWI en visuel inspektion af de akustiske geofysiske data fra de geofysiske forundersøgelser (multibeam echosounder og side scan sonar), se kapitel 3.

3 COWIs sign-off ved brug af jack-up

Der blev ikke observeret nogle potentielle UXO-elementer og dermed ikke fundet nogle årsager til at undgå potentielle UXO-områder i nedenstående sign-off.

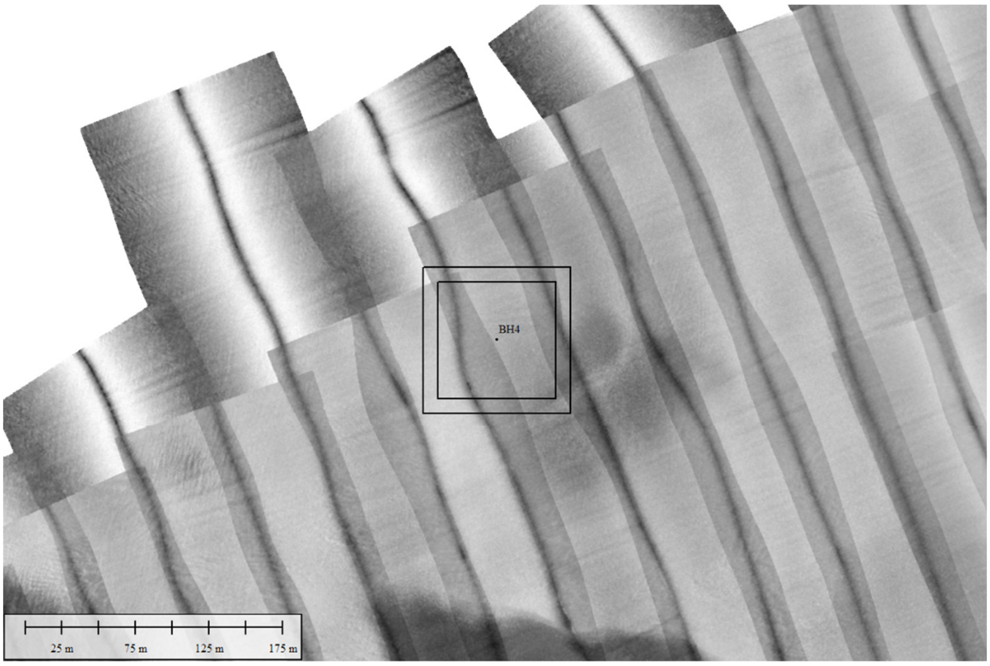
Sign-off er udført omkring fem positioner for borehuller ved hjælp af visuel inspektion af de geofysiske data (Tabel 1). Der er undersøgt for tilstedeværelse af objekter i et kvadrat på 100 m * 100 m omkring borehuller. Positioner for vibracores er ikke undersøgt, da UXO-analysen konkluderer, at det ikke er nødvendigt, når de tages fra skib.

Tabellen viser, at der ikke er fundet nogen potentielle UXO-objekter inden for de undersøgte kvadrater. Der er fundet enkelte objekter, som tydeligt genkendes som store sten. Disse objekter ses der bort fra. For tre af positionerne var der i yderområdet lidt støj (fra bølger o. lign.), men disse områder er dækket af data fra andre positioner, hvor der ikke er konstateret potentielle UXO-objekter.

Tabel 1 Resultat af UXO sign-off ved borehuller. CPT er borehuls ID.

CPT Area	pUXO Findings?	UXO Sign-off?
BH1	No	YES
	No	
	No	
	No	
BH2	No	YES
	No	
	No	
BH3	No	YES
	No	
	No	
	No	
BH4	No	YES
	No	
	No	
BH5	No	YES
	No	
	No	

I nedenstående kan man se, at selv BH4, der ligger på kanten af det undersøgte område, er dækket godt ind af de geofysiske undersøgelser. Der er vist positionen med en hhv. 100 m * 100 m og 80 m x 80 m kasse. Begge kasser ligger helt inden for området, som er dækket af vores data, og der har derfor ikke været nogen problemer med sign-off af denne position.



Figur 1 *Sidescan sonar mosaik (se Bilag D til miljøkonsekvensvurdering) omkring borehul 4 (BH4).*

Bilag 1 ORDTEKS rapport _V3.0 af 14. marts 2018 (konfidentiel)

Unexploded Ordnance (UXO) Hazard and Risk Assessment with Risk Mitigation Strategy

Project: **Lillebaelt Syd Offshore Wind Farm**

Client: **COWI**

Date: **14 March 2018**

Ordtek Project Reference: **JM5376**

Ordtek Report Reference: **JM5376_RA_V3.0**

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Disclaimer

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Quality Assurance

Project Number	Status	Version	Date	Written	Imagery	Reviewed	Released
JM5376	Final	3.0	14/03/2018	AP	RB	HM	LG

Document Revisions and Amends

Version	Page	Section	Amends
V1.0	-	-	Issued as draft.
V2.0	Throughout	Throughout	Amended in line with Client comments.
V3.0	44	5.7.1	Section updated to clarify mitigation required for GI.

Executive Summary

Introduction

Ordtek Limited (*Ordtek*) has been appointed by *COWI A/S (COWI)* to undertake an unexploded ordnance (UXO) threat and risk assessment with risk mitigation strategy in support of the of the Lillebælt Syd offshore wind farm.

The Lillebælt Syd offshore wind farm is located in Danish waters in the Lillebælt, a strait between the island of Funen and the Jutland Peninsula. The project will have a capacity of 100-160 MW produced from an array of up to 44 turbines, spanning an estimated area of approximately 25-33 km².

This UXO risk assessment will cover the main array of the Lillebælt offshore wind farm as well as the export cable running from the OSS to the island of Als (referred to as “export cable 1” in this report) and where the cable re-emerges on the western side of the island of Als to the Danish mainland (referred to as “export cable 2” in this report). The entire wind farm development, main array and export cables, is referred to within this report as the “Project Area” as well as a wider surrounding “Study Area”.

UXO presents a potential risk to the development and continued operation of offshore projects in European waters, principally due to the UXO residue from World War One (WWI) and World War Two (WWII). Explosive Ordnance (EO), both the result of military action and planned post-war dumping, is frequently encountered in the Baltic Sea.

Military History

Within Danish waters, UXO contamination is principally the result of military activity over two World Wars. British air laid ground mine “gardens”, bombing, submarine operations, naval surface conflict, modern military training exercises, aircraft and ship wrecks and munitions dumping have all played a part in potentially contaminating the Project Area.

While the level of UXO contamination in the Danish Kattegat is low when compared with other European waters, nevertheless a UXO legacy remains. The WWII military convoy route running through the wind farm is considered the most likely vector of UXO contamination, via allied bombing raids on vessels in convoy, as shown in the table below:

Probability of Contamination Key	Lillebælt Syd Project Area		
1 Very Unlikely 2 Unlikely 3 Possible 4 Likely 5 Very Likely			
UXO Threat Item	Offshore	Export cable 1	Export cable 2
German Ground Mine	1	1	1
British Ground Mine	2	2	2
British and German WWI Mines	1	1	1
Artillery and Naval Projectiles	2	2	2
Small HE Bombs (250lb)	3	3	2
Large HE Bombs (500lb and greater)	2	2	2
Depth Charges and Torpedoes	2	2	2
British and German WWII Buoyant Mines	2	2	1
Land Service Ammunition	1	1	1

Table ES1 – Probability of UXO Encounter at the Site

The UXO risk at the export cable 2 location, between the island of Als and the mainland of Denmark, is considered to be low risk; there are few vectors in which UXO may contaminate the area when compared with the wind farm, however within the marine environment the risk is never "zero".

UXO Burial

Over a period of several decades, the seabed level within an area can change due to the process of sediment accretion (also sometimes referred to as "deposition") or erosion. It is an important factor that must be taken into consideration when determining the potential for UXO burial. The movement of sandy bedforms (ripples, mega-ripples, sand waves, etc.) also has the potential to bury (or expose) items of UXO over time and therefore the seabed sediment composition, morphology and mobility must also be considered. Most active bedforms are those formed of sand, although where currents are strong, particularly in the nearshore, gravel can also be mobilised; this is particularly prevalent during high-energy storm events.

Within dynamic sediment conditions, UXO items are likely to become buried; the depth of burial at any one location is dependent on a number of variables. It should also be noted however that where seabed conditions are relatively stable (limited or no accretion or bedform movement) or where there is limited or no sand/gravel cover UXO burial is less likely and in some environments does not happen. The main mechanisms for burial at Lillebælt Syd are:

- **Self-burial by scour, sinking and backfill** – within sands and silts,
- **Bedform migration** – within areas of sandwaves and mega ripples

Smallest Threat Item

A 100lb (50kg) HE bomb with an NEQ of ~25kg can present a significant threat to some activities in some circumstances. If brought inadvertently to the surface, the detonation of a 100lb (50kg) bomb would present a considerable hazard to personnel due to shrapnel and serious injury or death could result. However, a 100lb (50kg) bomb laying in water deeper than ~20m presents a relatively low risk to Project equipment and vessel; the likelihood of a detonation is very low and any damage caused by such an event is likely to be relatively minor.

Therefore, *Ordtek* have determined the project may employ two threat items for detection depending on the activity. While the 250lb HE bomb may be a risk to jacking up and piling, due to vessel offset in cable laying and detonation from a 250lb bomb is a lower risk to cabling; therefore *Ordtek* considered that the smallest threat items for ALARP sign-off are:

- Allied 250lb HE Bomb (~114kg) within 50m of a WTG foundation and jack-up zones.
- Allied 500lb HE Bomb (~227kg) for all other areas of the Project.

Allied 250lb HE Bomb

Depending on the variant, the 250lb GP is cylindrical/tear-drop in shape, 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.

Allied 500lb HE Bomb

The 500lb HE Bomb is cylindrical in shape, made of steel and weighs around 227kg. They have an NEQ of ~95kg-105kg of TNT or Amatol depending on the variant. The body diameter is 0.327m and the length (without tail) is ~1.041m, depending on the variant.

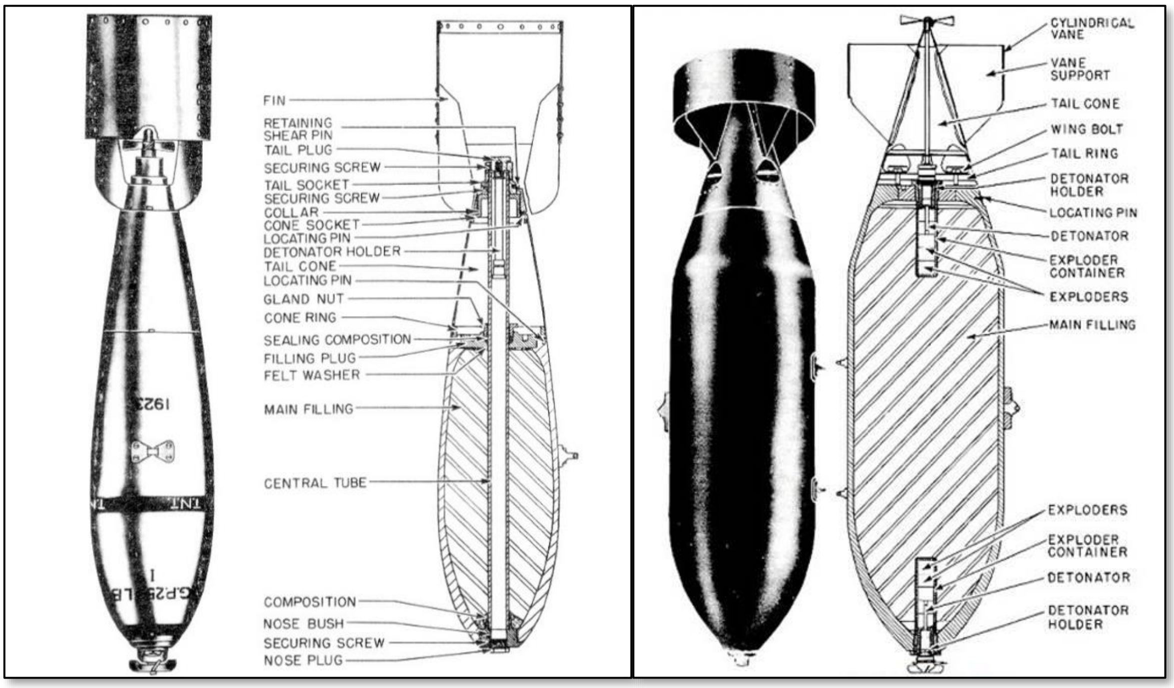

Figure ES1 – Allied 250lb (left) and 500lb (right) HE Bombs

In order to mitigate the risk of encountering these items of UXO during the full scope of Project works, it is recommended that a UXO-specified geophysical survey is undertaken and then interpreted by a UXO consultant.

UXO Risk Mitigation Strategy

Geophysical Survey

Ordtek recommends that the following geophysical survey techniques are deployed to detect and mitigate the main UXO hazard items:

- Magnetometry
- Side Scan Sonar (SSS)
- Multibeam Echo Sounder (MBES)

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.

Residual Risk Mitigation

To conform to best practice, installation contractors should also adopt the following UXO risk management and mitigation actions:

- Geophysical survey to detect smallest threat items (Mag, SSS and MBES).
- Obtain the ALARP sign-off certificate for each installable asset. Input the geophysical contacts to be avoided into the on-board navigation system.

- Establish the location of known wreck sites, especially any highlighted in this desk study. *Ordtek* suggests that non-military related wrecks are also avoided in accordance to the developer's standard protocol.
- Ensure the Project team are aware of their 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.

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Appendix 1 – Semi Quantitative Risk Assessment Table

Annex A – Supplementary Notes on UXO Types

Annex B – Explosive Ordnance Technical Data

Annex C – Potential Detonation Mechanisms for Explosive Ordnance Items

Abbreviations and Acronyms

AA	Anti Aircraft	**M**	Metres
AEZ	Archeological Exclusion Zone	**MBES**	Multibeam Echo Sounder
ALARP	As Low As Reasonably Practicable	**MBD**	Maximum Burial Depth
AOI	Area of Interest	**MCM**	Mine Countermeasures
BL	Breech Loading	**MDD**	Maximum Detection Depth
BSH	Bundesamt für Seeschifffahrt und Hydrographie (German hydrographic office)	**MGS**	Mindestens Gleiche Sicherheit (German legislation)
CDM	Construction Design and Management (UK legislation)	**ML**	Muzzle Loading
CIRIA	Construction Industry Research and Information Association	**mm**	Millimetres
CW	Chemical Weapon	**MoD**	Ministry of Defence
EMC	German moored contact mine Type C	**MTB**	Motor Torpedo Boat
EMG	German moored contact mine Type G	**MW**	Megawatt
EO	Explosive Ordnance	**NEQ**	Net Explosive Quantity
EOD	Explosive Ordnance Disposal	**NM**	Nautical Mile
ERW	Explosive Remnants of War	**OSPAR**	Convention for the Protection of the Marine Environment of the North East Atlantic
EU	European Union	**PLGR**	Pre-Lay Grapnel Run
GAMAB	Globalement Au Moins Aussi Bon	**RMF**	Risk Management Framework
GC	Allied designation for German type LMB mine	**RML**	Rifled Muzzle Loading
GD	Allied designation for German type LMA mine	**RN**	Royal Navy
GG	Allied designation for German type BM1000 mine	**ROV**	Remotely Operated Vehicle
GY	Allied designation for German type EMC/EMG mine	**QA/QC**	Quality Assurance/Quality Control
GZ	Allied designation for German type UMA mine	**SAA**	Small Arms Ammunition
GIS	Geographical Information System	**SBP**	Sub Bottom Profiler
H&S	Health and Safety	**SF**	Shock Factor
HAA	Heavy Anti-Aircraft Artillery	**SOP**	Standard Operating Procedure
HE	High Explosive	**SQRA**	Semi Quantitative Risk Assessment
HSE	Health and Safety Executive	**SSS**	Sidescan Sonar
HSF	Hull Shock Factor	**TNT**	Trinitrotoluene
Kg	Kilogram	**UK**	United Kingdom

KHz	Kilohertz	**UKHO**	United Kingdom Hydrographic Office
Km	Kilometre	**UMA**	German anti-submarine mine Type A
KSF	Keel Shock Factor	**UXB**	Unexploded Bomb
Kv	Kilovolt	**UXO**	Unexploded Ordnance
LMA	Luftmine A (German air-dropped ground mine Type A)	**WWI**	World War One
LMB	Luftmine B (German air-dropped ground mine Type B)	**WWII**	World War Two
LSA	Land Service Ammunition		

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.

1 Introduction

1.1 Background

Ordtek Limited (*Ordtek*) has been appointed by *COWI A/S (COWI)* to undertake an unexploded ordnance (UXO) threat and risk assessment with risk mitigation strategy in support of the Lillebælt Syd offshore wind farm.

UXO presents a potential risk to the development and continued operation of offshore projects in European waters, principally due to the UXO residue from World War One (WWI) and World War Two (WWII). Explosive Ordnance (EO), both the result of military action and planned post-war dumping, is frequently encountered in the Baltic Sea.

1.2 Purpose of this Document

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

This study is structured around five key components:

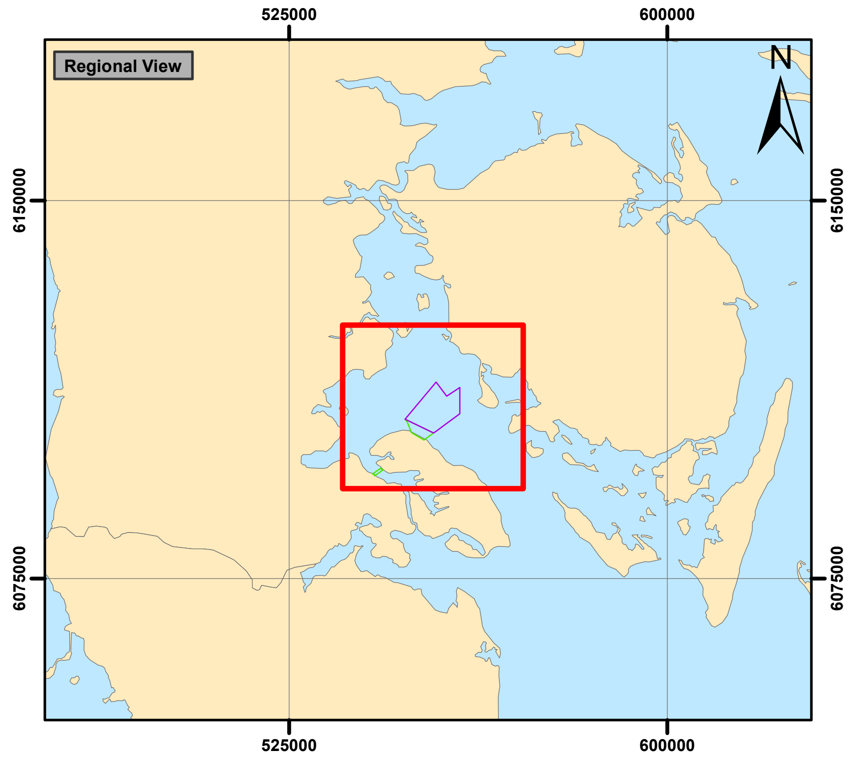
- **Project Description** – Those activities to be risk assessed.
- **UXO Threat Assessment** – A summary of identified UXO threats along the cable route.
- **UXO Interaction in the Natural Environment** – How the threat items are likely to be found within the Study Area.
- **UXO Risk Assessment –** Using the information above *Ordtek* will then assess the risk to the proposed operations.
- **UXO Risk Mitigation Strategy -** Recommendations for mitigation ahead of the proposed operations.

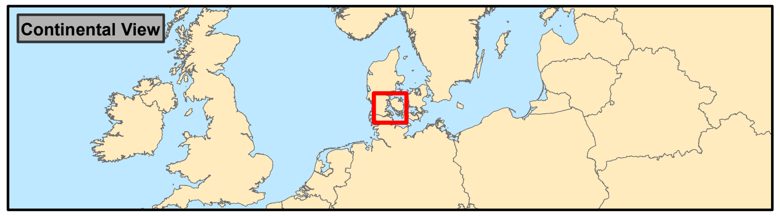
Charts have been embedded within the body of the report and will be referenced by their Chart Number.

1.3 Project Details

1.3.1 Background

The Lillebælt Syd offshore wind farm is located in Danish waters in the Lillebælt, a strait between the island of Funen and the Jutland Peninsula. The project will have a capacity of 100-160 MW produced from an array of up to 44 turbines, spanning an estimated area of approximately 25-33 km². The export cable runs from the OSS to the island of Als, and from Als to Ballebro, Denmark.





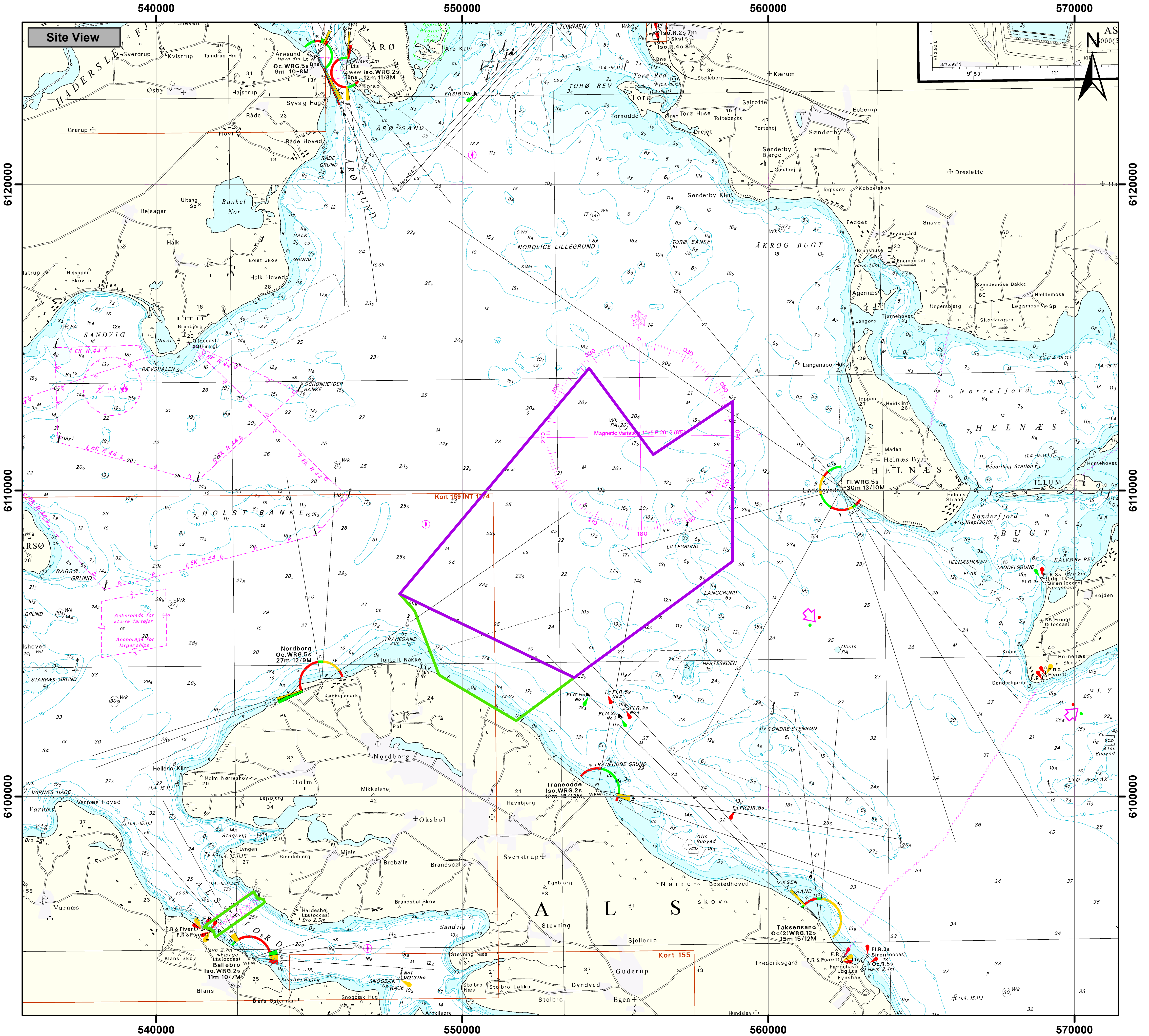
Legend for Site View

- Lillebælt Syd Wind Farm Study Area
- Lillebælt Syd Export Cable Study Area

Horizontal Scale(s)

Kilometers: 0 — 2.5 — 5 — 10

Nautical Miles: 0 — 1.25 — 2.5 — 5



Consultant	Client	Drawing Title	User Notes			
ORDTEK	COWI	Lillebælt Syd Offshore Wind Farm Project Overview	N/A	THE BRITISH ASSESSMENT BUREAU ISO9001	WGS 1984 UTM Zone 32N Projection: Transverse Mercator Datum: WGS 1984 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 Ordtek Limited, Herz House, Unit B21 Owen Road, Diss, Norfolk IP22 4ER, United Kingdom. (+44) 01379 644400

JM5376 - Lillebælt Syd OWF

Date Drawn: 11 December 2017

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Drawing Version: 2.0

1.3.2 Proposed Work for UXO Risk Assessment

Ordtek understanding that the full scope of works and installation methods have not yet been decided and therefore have assumed for the purpose of the Risk Assessment the following broad, generic, scope of works undertaken on similar projects.

The offshore wind farm will consist of wind turbine generators (WTG) and may include one or more offshore substation (OSS) platforms. We have assumed these will be supported on either piled, suction bucket or gravity base foundations and the WTGs connect to one another/OSS via inter-array cables. The wind farm will be connected to the shore via export cables running from the OSS to a shore-based substation.

Ordtek have assumed that cable burial may be accomplished using a cable plough, pre-cut trench plough, jetting Remotely Operated Vehicle (ROV) or vertical injection methods. Pre-Lay Grapnel Runs (PLGR) prior to cable installation is likely to be required. Dynamically Positioned (DP) vessels are likely to be used for offshore cable installation.

UXO mitigation for the installation phase will target the foundations, WTGs/OSS, inter-array cables and export cables with suitable working spaces.

Accordingly*, Ordtek* has assumed the following phases and activities may be undertaken:

- Installation of MetOcean equipment, such as Buoys, Met Mast and Tide Gauge.
- WTG and OSS foundation installation
  - Site preparation: debris removal and/or dredging
  - Jack-up barge operations
  - Dredging
  - CPT and drilling operations
  - Piling (hydraulic hammer, driven/drilled pile)
  - Suction bucket installation
  - Gravity base placement
  - Scour protection: rock/gravel dumping
- Inter-Array and Export Cable Installation
  - PLGR
  - Use of DP vessel
  - Cable burial to ~1.5m-2.0m
  - Cable Protection – rock cover or concrete mattressing
  - Ploughing/Trenching/Vertical Injector (with integral debris clearance)
  - Anchor handling

1.3.3 Risk Assessment Study Area

This UXO risk assessment will cover the main array of the Lillebælt offshore wind farm as well as the export cable running from the OSS to the island of Als (referred to as "export cable 1" in this report) and where the cable re-emerges on the western side of the island of Als to the Danish mainland (referred to as "export cable 2" in this report). The entire wind farm development, main array and export cables, is referred to within this report as the "Project Area" as well as a wider surrounding "Study Area".

1.4 References

Key references used for this study are listed below:

A. CIRIA – C754, Assessment and Management of Unexploded Ordnance (UXO) Risk in the Marine Environment, 2015.

B. GEUS - Vindmøller nord for Als i Lillebælt, dated 2016.

1.5 Construction Industry Duties and Responsibilities

1.5.1 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 12NM 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.”

Both UK and Danish health and safety law are therefore adopted from European Union directives and codified into National law.

1.5.2 Danish UXO-Related Legislation and Guidance

European law has been enshrined in Danish law and our understanding is that the Danish health and safety system is very similar to that of the UK, and revolves around the principle of reducing risk to As Low As Reasonably Practicable (ALARP).

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. The main legislation takes the form of a single framework act covering most work-related activity, with subordinate legislation and advisory documents dealing with specific risks.

The Consolidated Danish Working Environment Act (WEA) (2005) issued by the Danish Ministry of Employment and as subsequently amended is the major framework act covering health and safety at work.

Of note, Clause 12 of the act states “If the employer does not have the necessary expertise to undertake the health and safety work of the enterprise, the employer shall seek external expert assistance with a view to ensuring the continued health and safety of the employees. The Minister for Employment may lay down further rules on this matter.” This relates specifically to external consultancy; for example a UXO consultancy, such as *Ordtek*, commissioned to undertake a UXO Risk Assessment and Risk Management Strategy.

In practice the regulations below impose a responsibility on the construction industry to ensure that they discharge their obligations to protect those engaged in offshore operations from any reasonably foreseeable UXO risk.

As a part of the Danish consent process, *COWI* 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.

1.6 UXO Risk Management Standards and Risk Assessment

Through previous engagement on projects in the Denmark 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 national health and safety legislation and guidance and research provided by the UK Construction Information and Research Agency (CIRIA).

Where limited official guidance exists, *Ordtek* will work within its proprietary framework (see Figure 1.1).

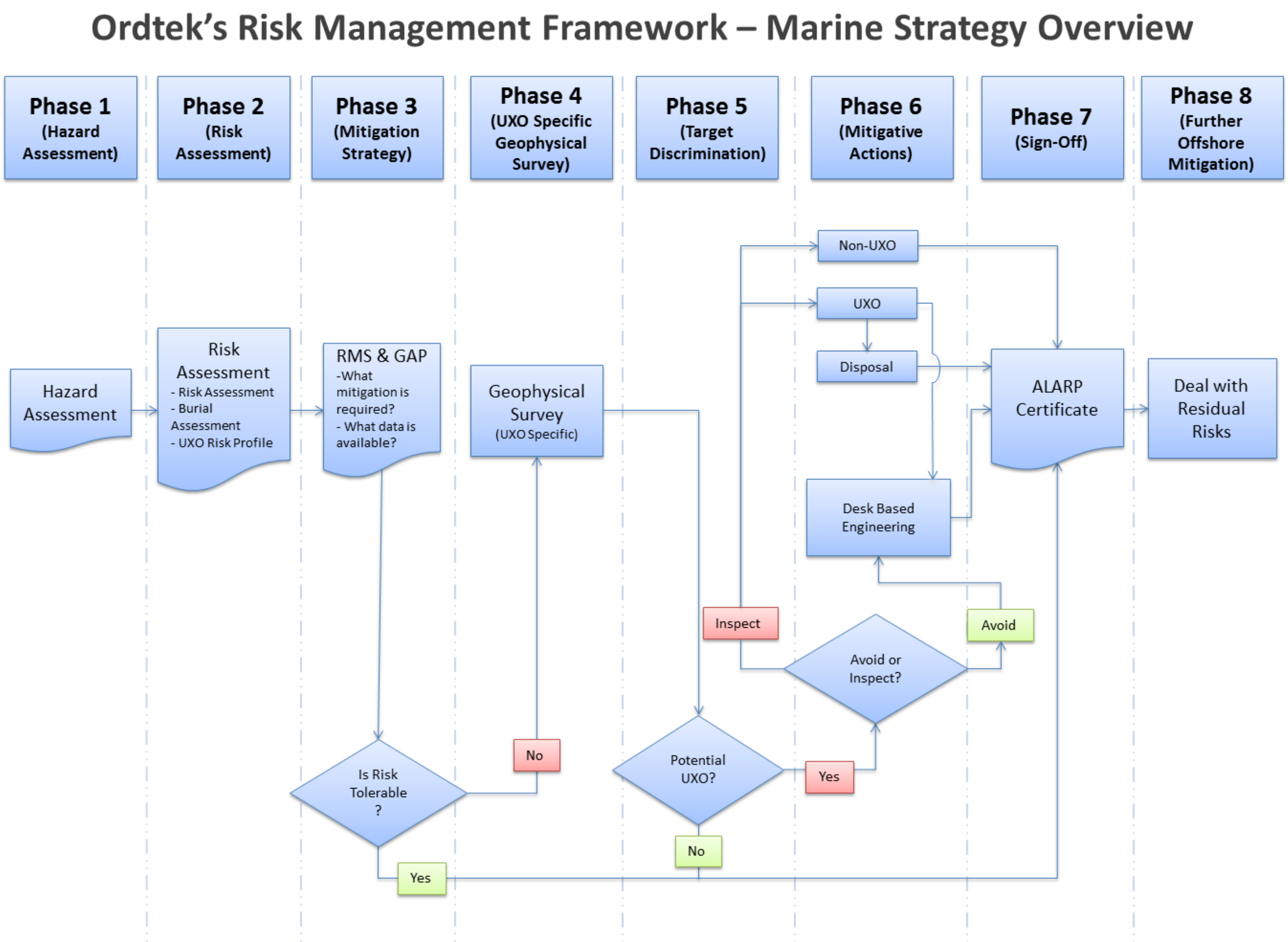


Figure 1.1 – Ordtek's risk management framework for the reduction of UXO risks.

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.

2 UXO Threat Assessment

2.1 Research

In this desk based 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.

Our research has focussed on the following:

- Military history of the area
- Official and unofficial munitions dumping sites
- Current and historical 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 the German and British military forces
- Evidence of aerial warfare, including bombing, depth charge and torpedo deployment
- Bombing raid flight paths
- 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 British Ministry of Defence (MoD)
- Pertinent authoritative publications
- Web based archives
- Ordtek's own comprehensive internal database
- Bundesarchiv-Militaerarchiv Freiburg
- Federal Maritime and Hydrographic Agency (BSH) in Hamburg
- Naval Office of the German Federal Armed Forces, Division Geo 1, Underwater Data Centre, Rostock
- British Ministry of Defence, Air Historical Branch, RAF Northolt

2.2 Overview

Within Danish waters, UXO contamination is principally the result of military activity over two World Wars. British air laid ground mine "gardens", bombing, submarine operations, naval surface conflict, modern military training exercises, aircraft and ship wrecks and munitions dumping have all played a part in potentially contaminating the Project Area. This desk based study has considered all these possible sources of UXO contamination.

While the level of UXO contamination in the Danish Kattegat is low when compared with other European waters, nevertheless a UXO legacy remains. The UXO risk at the export cable 2 location, between the island of Als and the mainland of Denmark, is considered to be low risk; there are few vectors in which UXO may contaminate the area when compared with the wind farm, however within the marine environment the risk is never “zero”.

2.3 WWI Sea Minefields

Both the Danish and German navies were active in the Study Area during WWI, as shown at Figure 2.1.

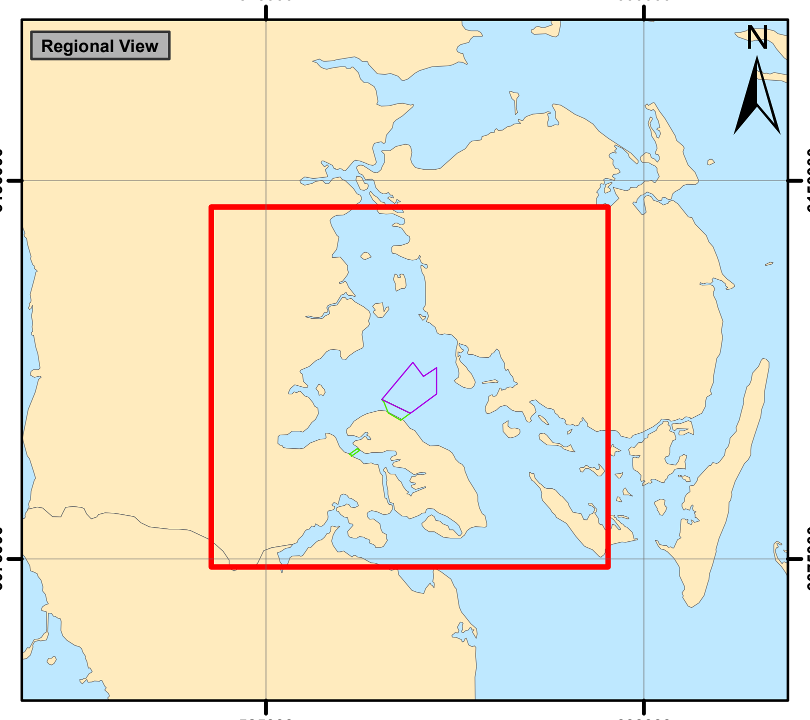
Despite laying much larger fields in the Great Belt and other navigation choke points during WWI, Denmark only mined the Lillebælt in a symbolic way that allowed German navy free passage. A small field of only 6 mines was laid in the eastern channel between Bågø and Funen (˜15km north of the Project Area) and another between Mommark and Ærø (˜20km southwest of the Project Area). These “controlled” mines were attached to the shore by cables and could be turned on and off, as required, to allow passage of friendly ships.

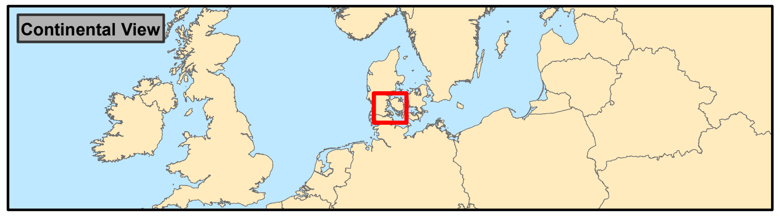
Two German mine lays were positioned between Arø and Assens ˜8km north of the Project Area aimed at preventing British submarine incursions into Baltic. The precise types of mines laid is not known by they were likely to be type “EMA” (commonly known as “egg” mines) moored contact mines with chemical Herz horns and with a charge weight of 160kg block-fitted Hexanite.

Both Danish and German minefields were subject to clearance operations between the end of the war and 1920 however moored mines frequently broke free from their moorings and drifted many tens, sometimes hundreds, of kilometres before sinking; many of mines were later found on Denmark’s beaches. Their presence anywhere within the Project area cannot be discounted, although by now these mines will be severely corroded and the risk they present is low.

Source of Potential UXO Hazard - Findings
A small number of moored minefields were laid in the Lillebælt by the Danish and German navies, the closest being located ˜8km north of the Project Area. These mines were known to have broken free from their moorings and consequently their presence within the Project Area cannot be discounted. Severe corrosion of these mines, however, means that the risk they now present is low.

Table 2.1 – WWI Mine Sources within the Study Area





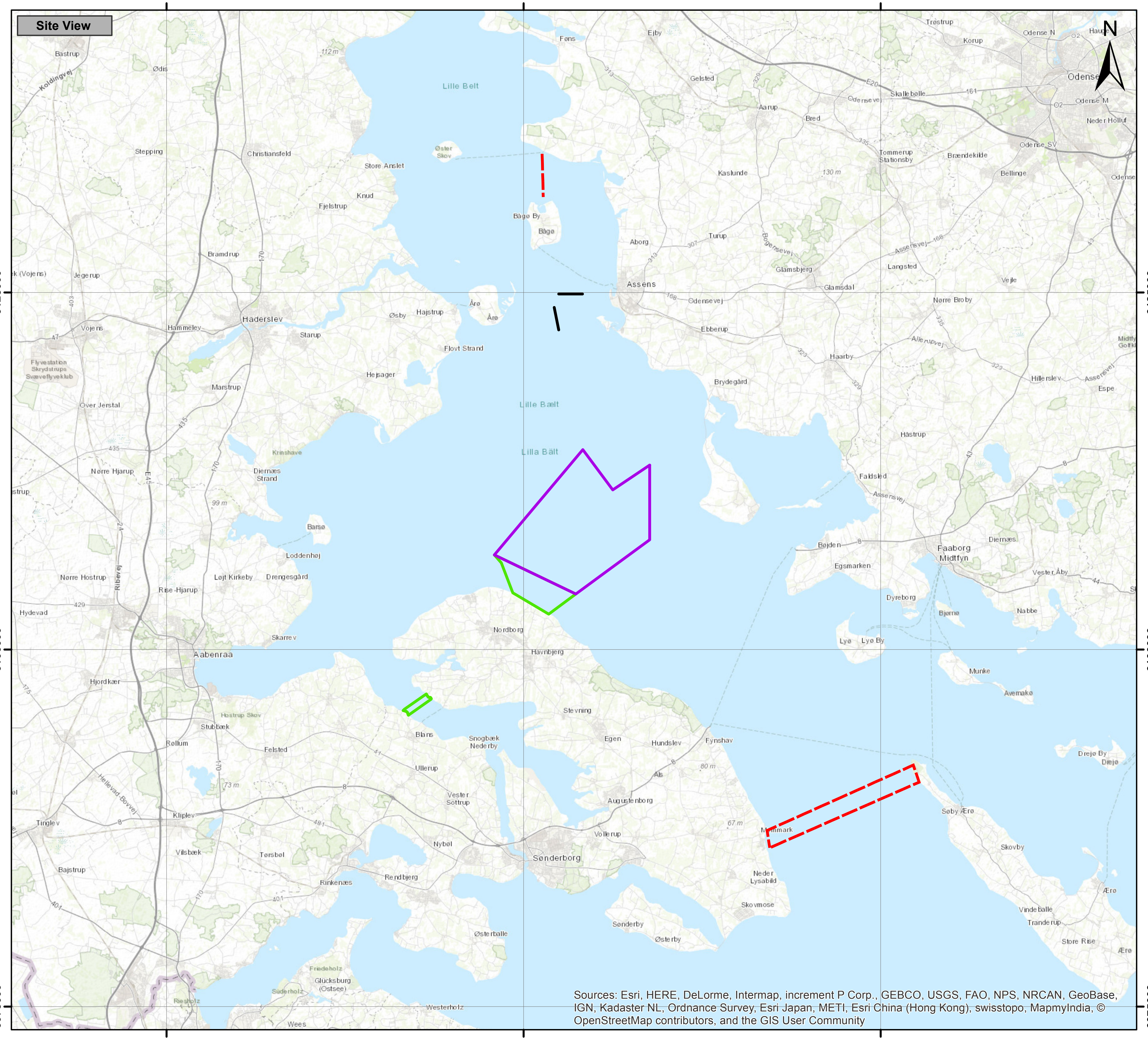
Legend for Site View

- Lillebælt Syd Wind Farm Study Area
- Lillebælt Syd Export Cable Study Area
- WWI Danish Mine Lay
- WWI German Mine Lay

Horizontal Scale(s)

Kilometers: 0 — 12.5 — 25

Nautical Miles: 0 — 2 — 4 — 8 — 12



Consultant	Client	Drawing Title	User Notes			
ORDTEK	COWI	Lillebælt Syd Offshore Wind Farm WWI Mining	N/A	WGS 1984 UTM Zone 32N Projection: Transverse Mercator Datum: WGS 1984 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 Ordtek Limited, Herz House, Unit B21 Owen Road, Diss, Norfolk IP22 4ER, United Kingdom. (+44) 01379 644400	JM5376 - Lillebælt Syd OWF Date Drawn: 11 December 2017 Drawing Reference: JM5376_Lil-Syd_02 Drawing Version: 2.0

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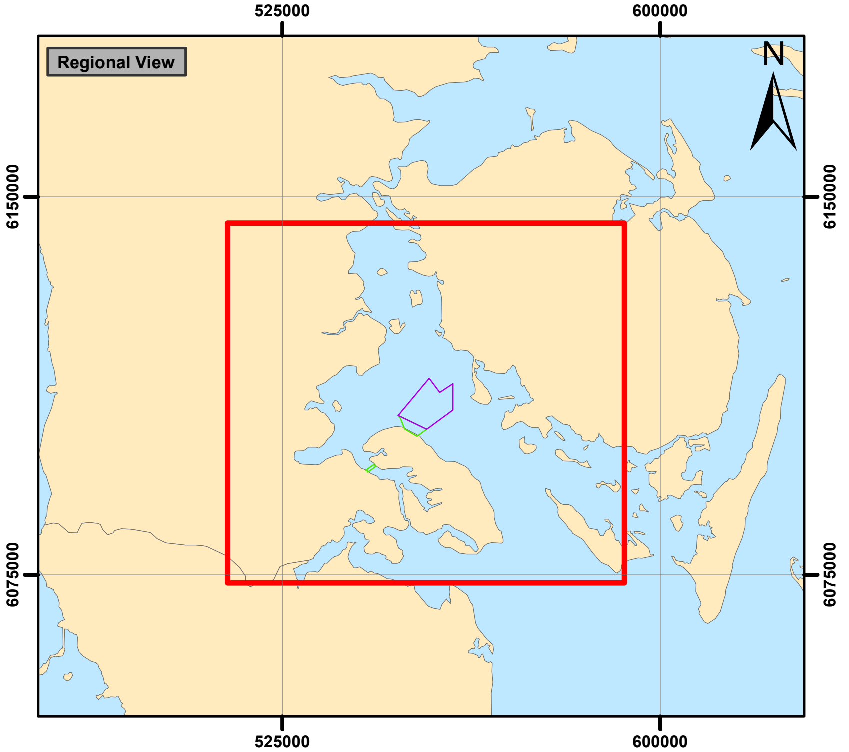
2.4 World War II Sea Minefields

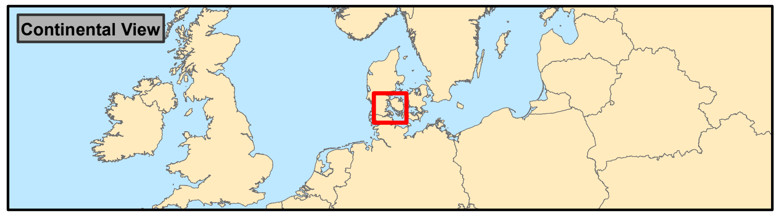
There were 2 British air-laid mine "gardens" sewn by the Royal Air Force (RAF) within the Study Area during WWII; Endives ˜16km north and Wallflower ˜26km southwest of the Project Area. As seen at Figure 2.2, these areas encompass large sections of German convoy routes through the Lillebælt.

Endives contained a total of 207 mines with Wallflower holding ˜1500 mines. These mines were of the ground mine variant with a single or combination of magnetic, acoustic and pressure sensors to detect the influence "signature" of passing target vessels. British ground mine casings were generally made of steel and subject to corrosion over time unless they become buried in hypoxic sediment. The mines relied on batteries to power sensors and firing circuits; these will now be discharged and the mine will not function as designed. Charge weights were between 227kg and 499kg, except for two specialist mines that had much smaller Net Explosive Quantity (NEQ) of 45kg and 91kg. The British continued to develop ground mines throughout the war, starting with A Mks I-IV in the early years, finally progressing to the A Mk IX by 1945.

Source of Potential UXO Hazard - Findings
British air-laid mine "gardens" *Endives* and *Wallflower* were located within the Study Area, ˜16km north and ˜26km southwest of the Project Area respectively. Given these distances from the Project Area, contamination from WWII mines is unlikely.

Table 2.2 – WWII Mine Sources within the Study Area





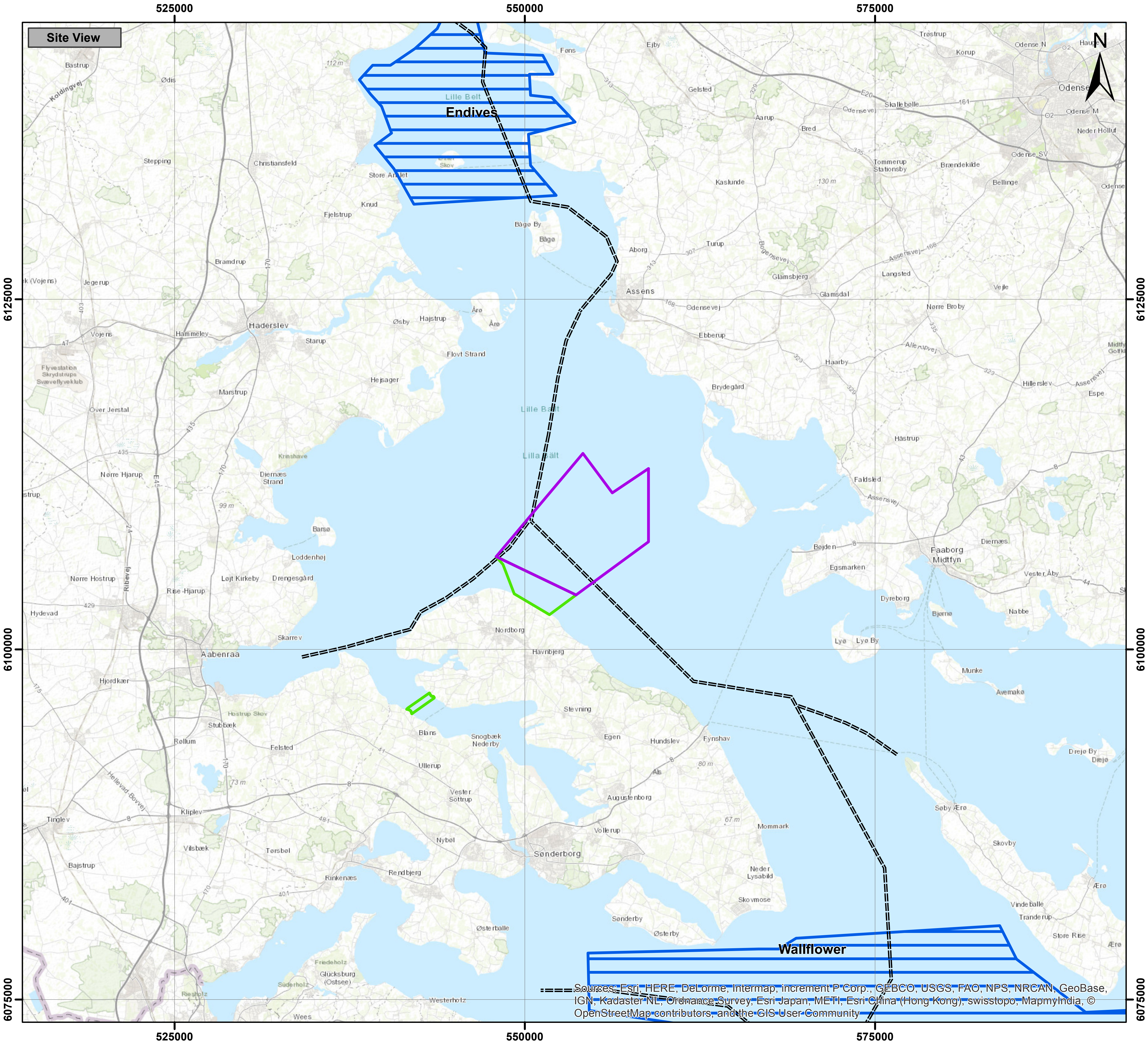
Legend for Site View

- Lillebælt Syd Wind Farm Study Area
- Lillebælt Syd Export Cable Study Area
- WWII British Mine "Garden"
- WWII German Military Convoy Routes

Horizontal Scale(s)

Kilometers: 0 — 12.5 — 25

Nautical Miles: 0 — 2 — 4 — 8 — 12



Consultant	Client	Drawing Title	User Notes
ORDTEK	COWI	Lillebælt Syd Offshore Wind Farm WWII Mining and Convoy Routes	N/A

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WGS 1984 UTM Zone 32N
Projection: Transverse Mercator
Datum: WGS 1984
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
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JM5376 - Lillebælt Syd OWF

Date Drawn: 11 December 2017
Drawing Reference: JM5376_Lil-Syd_03
Drawing Version: 2.0

2.5 Minesweeping and Mine Clearance Operations

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.

A similar effort was put into clearing minefields after WWII. Many reports refer to the "clearance" of barrier minefields after WWI and WWII. 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 (anchors) 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.

2.6 Torpedoes/Depth Charges

During both WWI and WWII most surface ships were fitted with torpedoes and there were many ship to ship torpedo actions in addition to submarine attacks on shipping. In turn, submarines were attacked with depth charges. Consequently, large and small naval projectiles, torpedoes, depth charges and other anti-submarine weapons remain an almost universal threat.

Depth charges (and depth bombs from RAF coastal patrol aircraft) were deployed in huge numbers during WWII, often at spurious targets, as this contemporary diary account illustrates:

> *"Setting sail at 5.45 am on 27 August, Rodney headed west, bound for Plymouth, a sloop and two destroyers as escort.* ***Along the way, there was the usual enthusiastic depth-charging of submarine contacts, which were, as so often was the case, probably wrecks on the seabed****".*

German submarine U-2521 was attacked by rockets from a British Typhoon aircraft (Squadron 184) and sunk in Flensborg Fjord, close to the entrance to the Lillebælt.

Depth charges and depth bombs have an NEQ in the range of 50kg - 200kg. These all would have been thin-cased and consequently subject to severe corrosion in the intervening years. They would have fired by a hydrostatic fuse or perhaps an impact bomb fuse with a delay.

During both WWI and WWII, the Germans developed torpedoes of the "wet heater" type; steam driven, with kerosene as fuel and compressed air providing oxygen for combustion. Warheads of around 250kg were detonated by means of a direct impact or magnetic fuse. WWI torpedo fusing was often unreliable and it is quite possible that attacks took place, unrecorded, when the torpedo failed to function and sank to the seabed. WWII warheads were filled with 280kg of Hexanite and were generally much more reliable.

The standard British airborne torpedo for World War II was the 18-inch, a 450 mm-diameter design that progressed through several Marks through the war. It had an explosive charge of 388 lb (176 kg) of TNT. Later, more powerful versions had a 247kg Torpex warhead.

Source of Potential UXO Hazard - Findings
Whilst the majority of naval battles took place outside of the Lillebælt, the potential presence of torpedoes, depth charges and other anti-submarine EO is a background threat across the Study Area. We cannot completely discount engagements taking place near or within the Project Area as torpedo attacks may have gone unrecorded if the fusing failed to function or missed its target and sank to the seabed.

Table 2.3 – Torpedo/Depth Charge Sources within the Study Area

2.7 Air Dropped Bombs

Air delivered EO is likely to come from the following sources:

- The result of attacks on ships or submarines transiting the convoy routes, where EO missed its target. These weapons are likely to have been armed and will present a UXO risk.
- Bombs dropped in error into the sea during raids on land targets.
- Bombs jettisoned into the water by aircrew in an emergency on the way to or from an inland target. If planes had been badly damaged or were under attack, the crews often jettisoned their bomb loads to aid their evasion attempts. This was a common tactic known as “tip and run”. These bombs may or may not have been armed on release. For risk assessment purposes, it must be assumed that they were armed.

Consequently almost any category of bomb could be present in the area. In addition to bombs, cannon shells are also very likely to be present.

British aircraft carried 250lb General Purpose (GP) and Medium Capacity (MC) HE bombs, routinely attacking German shipping with bombs and torpedoes across the shipping lanes. Nevertheless, it is quite possible that some bombs missed their targets and fell within the study area. German ships using these routes were frequently attacked by British aircraft, using bombs and rockets. 2 British aircraft were wrecked in the Study Area during WWII.

Bombs dropped from Luftwaffe bomber aircraft are likely to be in the region of 50kg - 500kg but in rare cases much larger bombs – up to 1800kg – could also be encountered, particularly any destined for inland raids but jettisoned over the sea. The charge to weight ratio of a general purpose bomb is approximately 50%, giving NEQs for the examples above of 25kg, 250kg. Of interest, approximately 70% of all bombs deployed by the Luftwaffe during WWII were 50kg varieties (we do not have the statistic for attacks on ships alone).

Source of Potential UXO Hazard - Findings
German WWII convoy routes ran through the Project Area, connecting the Lillebælt ports though the Danish straits to the North and Baltic Seas. These routes were vital to the German WWII war effort and consequently, ships and submarines in Danish waters were frequently attacked by Allied aircraft using bombs. There are two military airfields identified in the Study Area as potential targets for bombing raids, however these are unlikely to affect the Site due to their distance from the Site. Air-dropped high explosive (HE) bombs could be present anywhere within the Study Area. These are most likely to be Allied but German bombs cannot be discounted.

Table 2.4 – Air-dropped Bombs Sources within the Study Area

2.8 Naval Projectiles

While WWII saw less big-ship surface to surface action than in WWI, there was much greater use of naval weapons in the Anti-Aircraft (AA) role, particularly in the protection of convoys. Most commonly, the guns used for AA would have been 20mm and 40mm but 4in, 6in and even 8in would also have been employed. German AA picket boats (vorpostenboots) were stationed in the Lillebælt during WWII and there were number coastal AA positions located throughout Denmark.

A wide variety of calibres of guns, up to 16in (40.6cm), were fitted to ships. Depending on their role (armour-piercing, capped, HE etc.), these shells contained between 10kg-50kg of Lyddite or Shellite (HE).

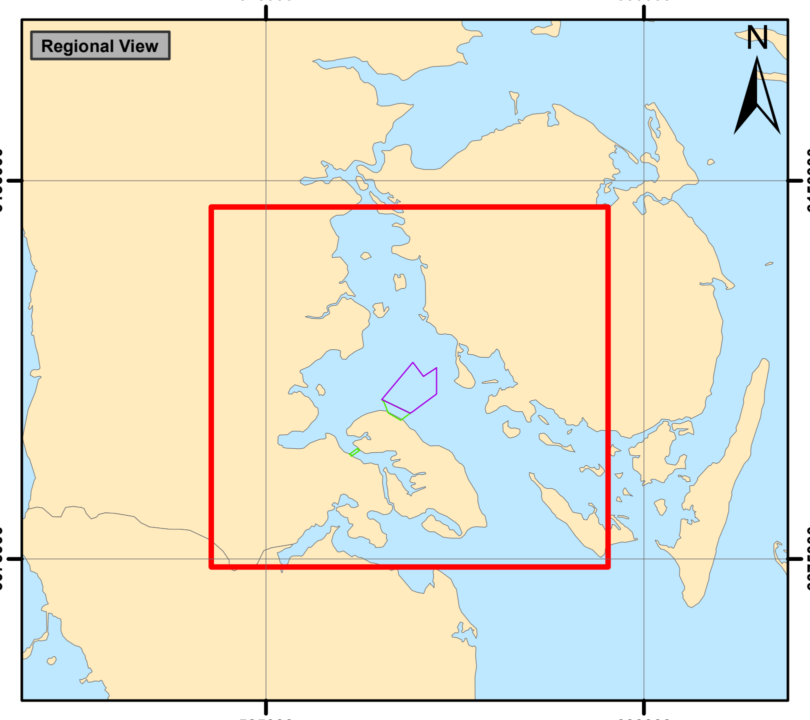
Weapon systems of the day lacked the first time strike accuracy of modern weapons and, in an exchange of fire, projectiles are likely to have missed the target in the first instance and it is entirely feasible that a number of exchanges of fire would have preceded a successful attack, with numerous rounds sinking to the seabed.

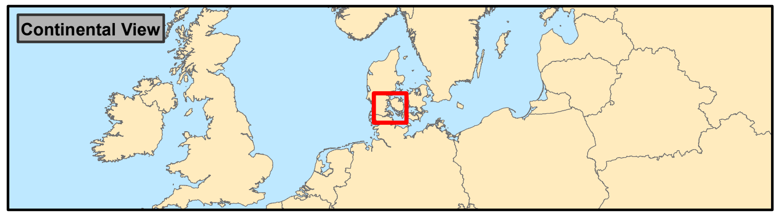
Naval engagements took place in the wider region during both WWI and WWII, but most are recorded as being outside of the Lillebælt, in the Skagerrak, entrance to the Kattegat and in the Baltic Sea. The majority of exchanges of fire with large calibre weapons took place in WWI. We have found no direct evidence of ship to ship naval engagements taking place close to, or within the Project Area however the use of naval projectiles in the AA role means the presence of these items within Project Area cannot be completely discounted.

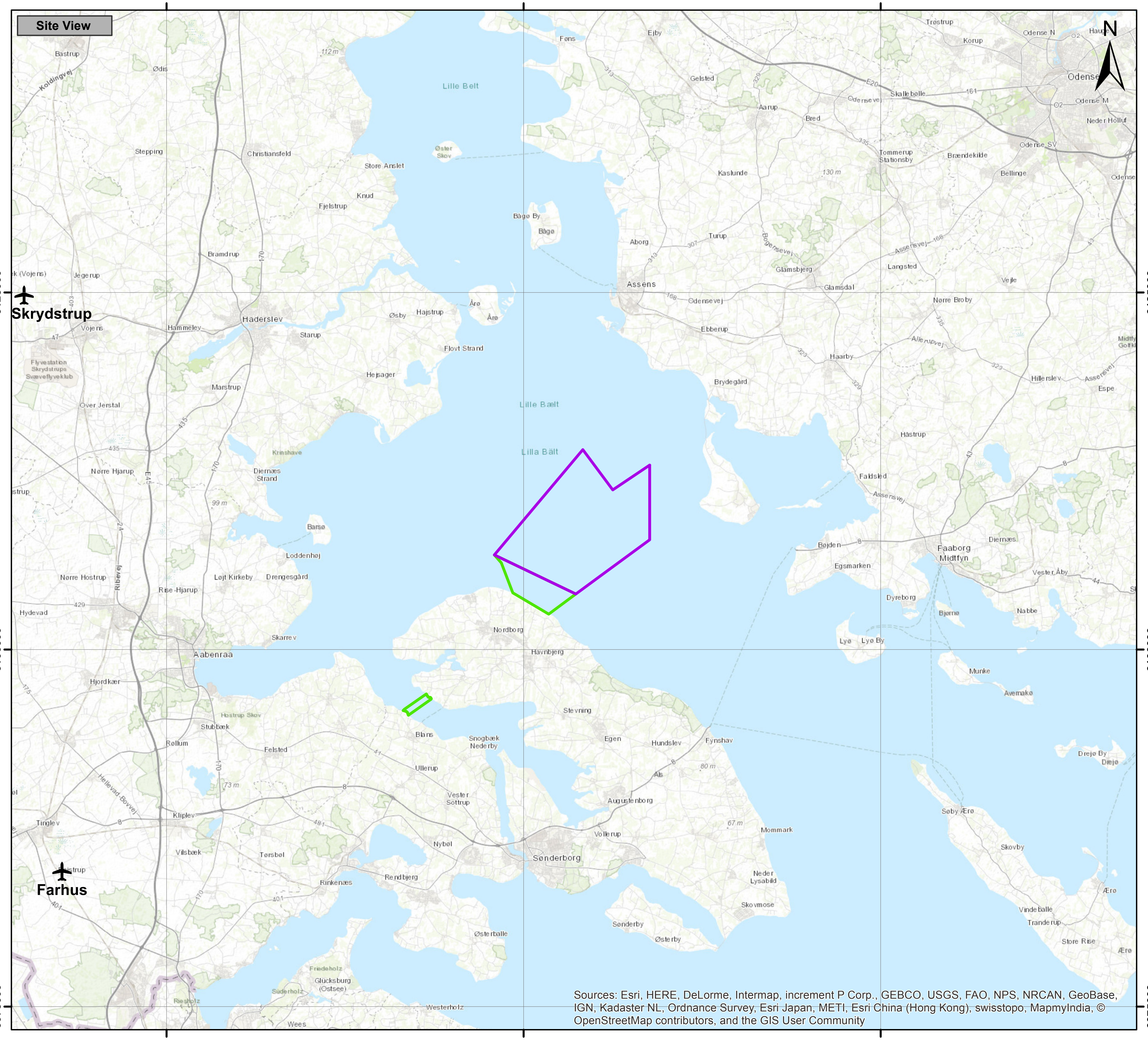
Any projectiles potentially present within the Project Area are most likely to be relatively small calibre shells with an NEQ in the region of 2kg-5kg but larger projectiles could be encountered and with a slightly larger NEQ – up to 25kg of Picric acid based explosives, such as Shellite.

Source of Potential UXO Hazard - Findings
The majority of ship-to-ship naval engagements in the wider region took place outside of the Lillebælt however the use of naval weapons in the AA role during WWII means any size of projectile could be encountered in the Project Area although most are likely to be small, (sub 5kg NEQ).

Table 2.5 – Naval Projectile Sources within the Study Area







Legend for Site View

- Lillebælt Syd Wind Farm Study Area
- Lillebælt Syd Export Cable Study Area
- WWII Luftwaffe Airfields/Bases

Horizontal Scale(s)

Kilometers: 0 — 12.5 — 25

Nautical Miles: 0 — 2 — 4 — 8 — 12

Consultant	Client	Drawing Title	User Notes
ORDTEK	COWI	Lillebælt Syd Offshore Wind Farm WWII Luftwaffe Airfields/Bases	N/A

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WGS 1984 UTM Zone 32N
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
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Central Meridian: 9.0000
Scale Factor: 0.9996
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Units: Meter

Drawn by: RB
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Date Drawn: 12 December 2017
Drawing Reference: JM5376_Lil-Syd_07
Drawing Version: 2.0

2.9 Military Related Shipwrecks

Many merchant as well as naval vessels sunk in WWI and WWII contained munitions. Similarly, aircraft that were shot down, or otherwise had to ditch into the sea, also had unexpended ammunition and other EO. There is evidence that munitions could spill and be thrown clear from a sinking ship or become exposed as the vessel broke-up on the seabed, and in due course migrate away from the original site. But the risk of EO contamination is generally less in the vicinity of wrecks (compared with munitions dump sites) as the ordnance typically remains contained and immobile within the structure of the sunken vessel. From a UXO threat perspective, wrecks of unknown origin should be avoided.

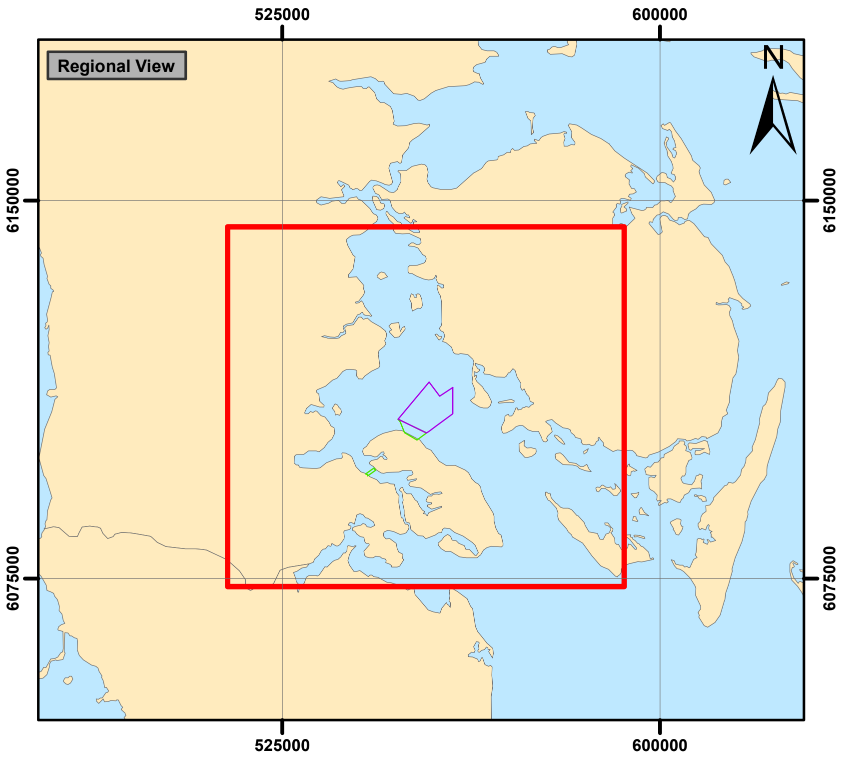
While some wrecks may contain ammunition, they are unlikely to be the source of any direct UXO contamination. However, the wrecks do provide clear evidence of military action and the potential for the presence of UXO from the action preceding the sinking.

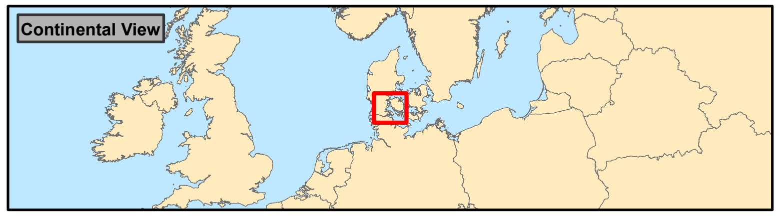
The closest shipwreck of military significance to the Project Area is the *FV Ellen*, a Danish fishing vessel sunk by a mine in 1940. This wreck is ˜8km from the Project Area.

Two aircraft were recorded as wrecked in the Lillebælt however the circumstances of most aircraft losses offshore mean that accurate positional information of such wrecks is very rarely available and consequently other aircraft may have been shot down in the area. Aircraft debris, together with embarked bombs, torpedoes and ammunition, could be present anywhere within the Study Area. Potential UXO contamination from this source is therefore an ever-present background rather than specific threat.

Source of Potential UXO Hazard - Findings
There are a large number of shipwrecks in the Study Area that were sunk due to military action during WWI and WWII. Including: • 4 wrecks sunk by mining • 2 wrecks sunk by scuttling • An unknown British aircraft wreck (3km south of the Site) Some of these wrecks contained ammunition when sunk, such as U-2251, U-1168 and S-103, but these are unlikely to be the source of any direct UXO contamination. However, the wrecks do provide clear evidence of military action and the potential for the presence of UXO from the action preceding the sinking. No wrecks are recorded as sunk within the Project Area.

Table 2.6 – Military Wrecks within the Study Area





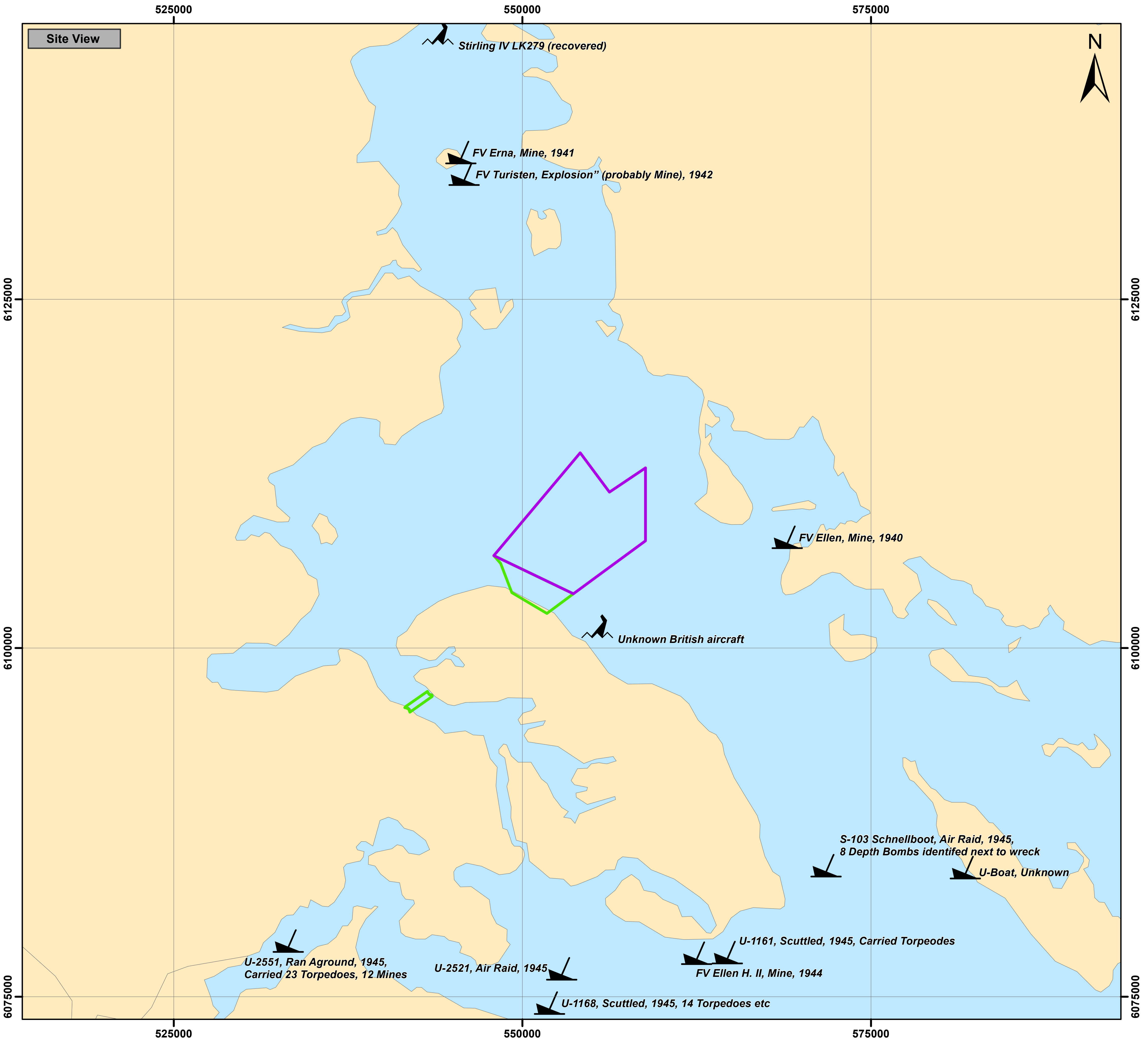
Legend for Site View

- Lillebælt Syd Wind Farm Study Area
- Lillebælt Syd Export Cable Study Area
- Military Aircraft Wreck
- Ship Wrecks of Military Interest

Horizontal Scale(s)

Kilometers: 0 — 12.5 — 25

Nautical Miles: 0 — 2 — 4 — 8 — 12



Consultant	Client	Drawing Title	User Notes
ORDTEK	COWI	Lillebælt Syd Offshore Wind Farm Wrecks of Military Interest	N/A

THE BRITISH ASSESSMENT BUREAU ISO9001

WGS 1984 UTM Zone 32N
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
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JM5376 - Lillebælt Syd OWF

Date Drawn: 12 December 2017
Drawing Reference: JM5376_Lil-Syd_05
Drawing Version: 2.0

2.10 Exercise Areas and Firing Practice / Bombing Ranges

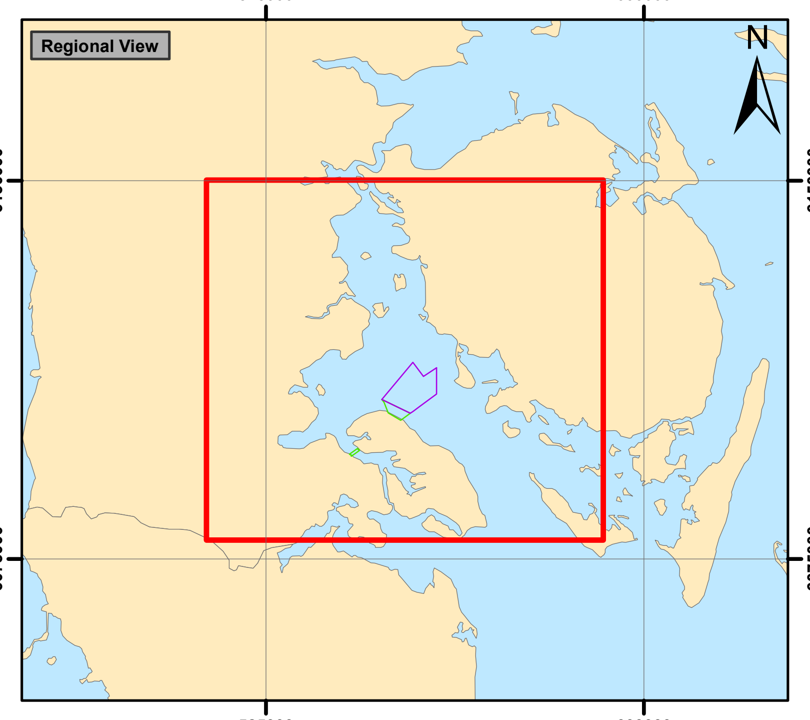
Naval vessels and aircraft carry out exercises, day and night, off all points of the coast and it very probable that some *ad hoc* training evolutions have taken place over a period of several decades outside designated areas, particularly during the war years; including live firing of small arms, naval gunfire (typically up to 105mm) and possibly larger anti-submarine weapons.

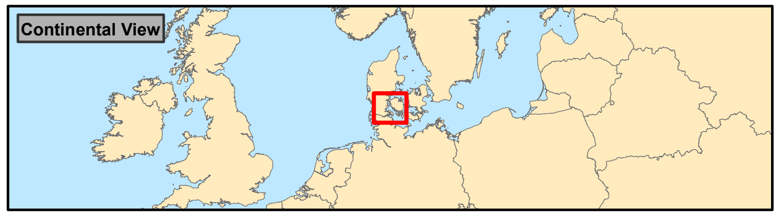
As a rule, live firing of HE munitions for practice is only conducted in designated exercise areas; however, from experience, naval ships and aircraft commonly conduct firings, as convenient, outside formal practice areas using “clear range procedure”.

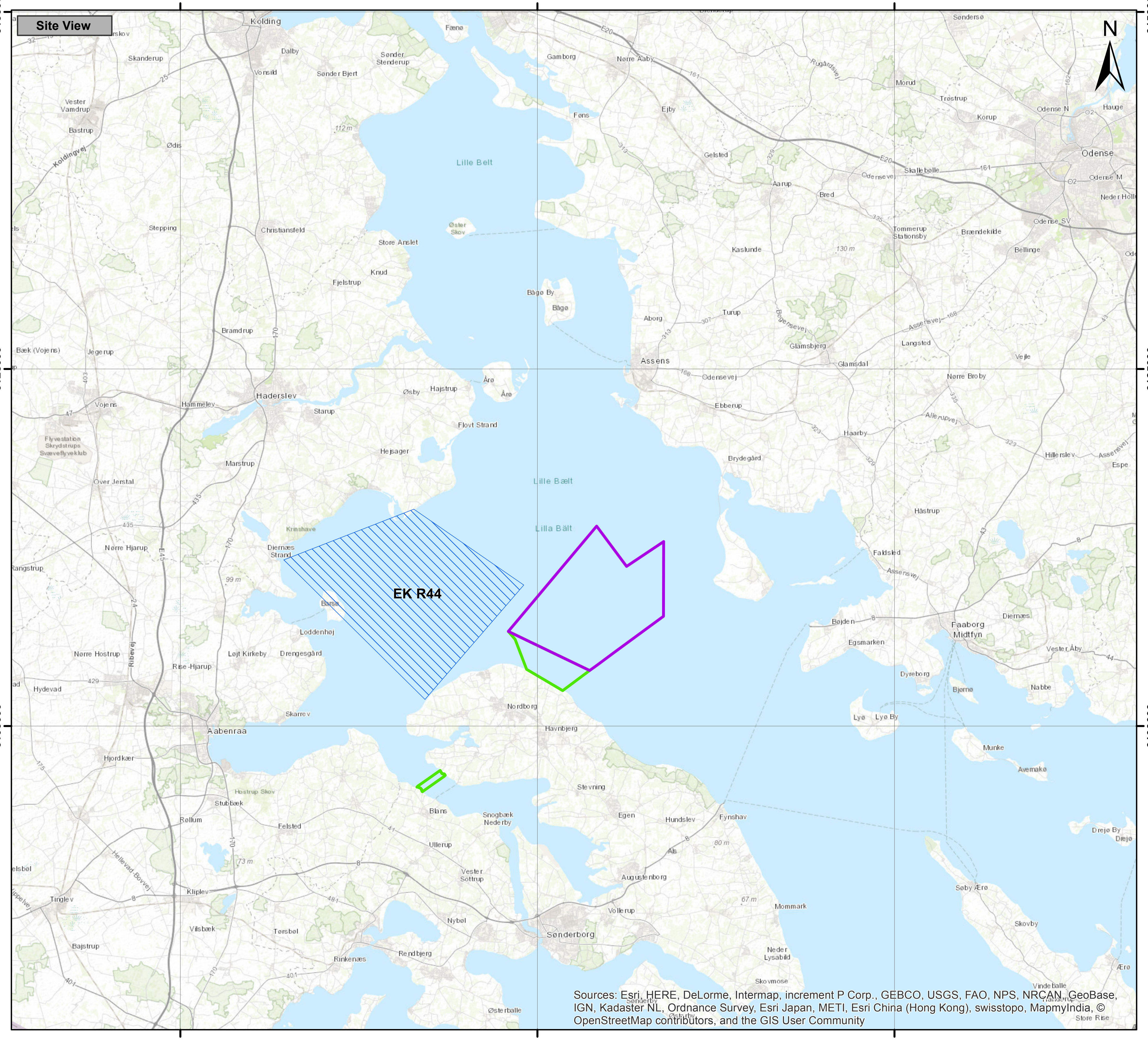
In such exercises, ships, submarines and aircraft would have used a wide variety of munitions, including flares, smoke and starshell. It is impossible to determine the detail of precisely what activities might have been conducted over so many years but it is very possible that a combination of both HE and “practice” ammunition contaminate the area. Practice munitions usually contain a Low Explosive spotting charge and/or a pyrotechnic element. These present a minimal risk to Project activities however, given the corrosion that will have occurred in the intervening years, it is unlikely that practice munitions will be readily distinguish from similarly shaped HE versions. We have seen on other projects that it is usually necessary to dispose of “inert” items of UXO using high-order methods (counter-mining with a HE charge).

Source of Potential UXO Hazard - Findings
A modern military practice and exercise area, EK R44 is located ˜1.5km to the west of the Project Area. EK R 44 is used for small calibre weapons and presents no UXO risk to planned Project activities. Mine countermeasures and other general naval training is routinely conducted all around the Danish coast but live ordnance is only used in the designated exercise areas or further out to sea, well away from the Project Area. 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.

Table 2.7 – Exercise Areas within the Study Area







Legend for Site View

- Lillebælt Syd Wind Farm Study Area
- Lillebælt Syd Export Cable Study Area
- Military Practice and Exercise

Horizontal Scale(s)

Kilometers: 0 — 12.5 — 25

Nautical Miles: 0 — 2 — 4 — 8 — 12

Consultant	Client	Drawing Title	User Notes				
ORDTEK	COWI	Lillebælt Syd Offshore Wind Farm Military Practice and Exercise	N/A	THE BRITISH ASSESSMENT BUREAU ISO9001	WGS 1984 UTM Zone 32N Projection: Transverse Mercator Datum: WGS 1984 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 Ordtek Limited, Herz House, Unit 821 Owen Road, Diss, Norfolk IP22 4ER, United Kingdom. (+44) 01379 644400	JM5376 - Lillebælt Syd OWF Date Drawn: 11 December 2017 Drawing Reference: JM5376_Lil-Syd_06 Drawing Version: 2.0

2.11 Dump Sites

For several decades after the World Wars, large volumes of chemical and conventional munitions were disposed of at sea. At the time, with public safety as a guiding principle, such disposal was considered best practice. The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention, 1972), ratified by many countries, now prohibits the disposal at sea of wastes, including munitions. These discarded munitions can be a significant hazard to offshore projects.

The two World Wars left a legacy of enormous quantities of munitions requiring disposal. The process had to be completed quickly and safely. Given the technical limitations of the time, sea dumping was the only practical method of disposing of the bulk of the munitions. It became the internationally accepted method of munitions disposal. Sea dumping continued until 1972 when the UK and other European nations adopted the London Convention on the Disposal of Wastes at sea.

The Oslo-Paris Convention (OSPAR), a collaborative agreement between European countries for the Protection of the Marine Environment of the North-East Atlantic, was open for signature in Paris in 1992 and entered into force on 25 March 1998. Since the end of the 1990s, the Oslo-Paris (OSPAR) Convention has systematically recorded the munitions dumping sites of the Eastern Atlantic Ocean and the North Sea. Both dumping areas and subsequent EO finds have been recorded and the distribution of activities leading to the discovery of EO plotted. Fishing vessels have found more than 50% of EO.

2.11.1 Condition of Dumped Munitions

It can generally be assumed that most of the munitions deposited at post-war dump sites were packaged robustly and dumped unfused. There is no reason to believe, therefore, that they will become unstable or present a hazard even if accidently disturbed. However, the state of corrosion of all munitions could vary from very little to completely degraded and therefore it is not possible to predict the condition of all types of EO in and around the dumping areas.

Anecdotal evidence has recorded occasional unexplained explosions in the vicinity of dump sites. No definite evidence of spontaneous detonation of dumped conventional munitions exists, but any EO which contained Shellite or Lyddite (highly sensitive picric acid based explosives) is far more likely to spontaneously detonate when disturbed than, for example, TNT filled munitions. This could arise if they were subject to an impact when the structure of a container collapsed or if they were struck by other items of ordnance falling onto them.

Picric acid is known to have an ageing problem through which metal picrates form, e.g. iron picrate. Such metal picrates are extremely sensitive energetic materials that can be initiated very easily. Shellite and Lyddite were a common WWI filling for large shells, including naval projectiles.

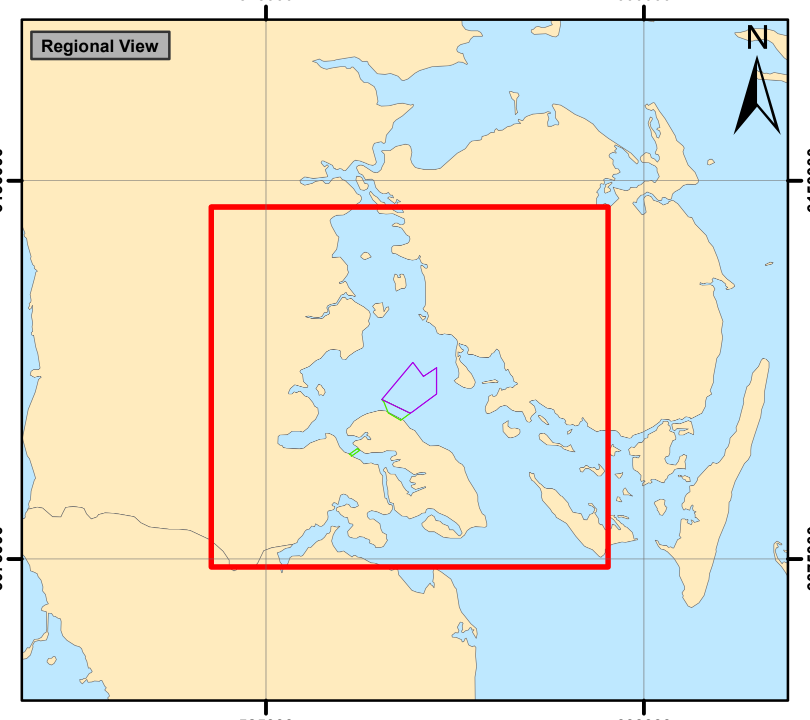
2.11.2 Chemical Weapons Dump Site

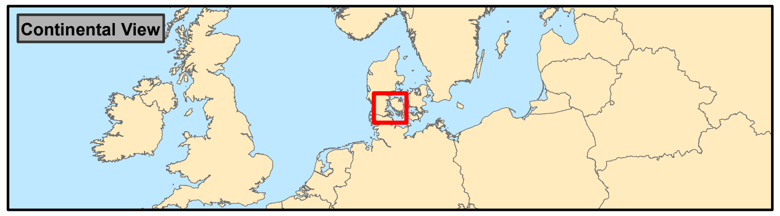
A chemical munition dumping site is located ˜40km southeast of the Project Area and is believed to contain 750T of chemical weapon (CW) agents. It is believed that German vessels loaded with nerve agent projectiles (tabun) and other types of chemical and conventional munitions were dumped at a water depth of approximately 30m. It is expected that these munitions sunk into seabed mud in the area.

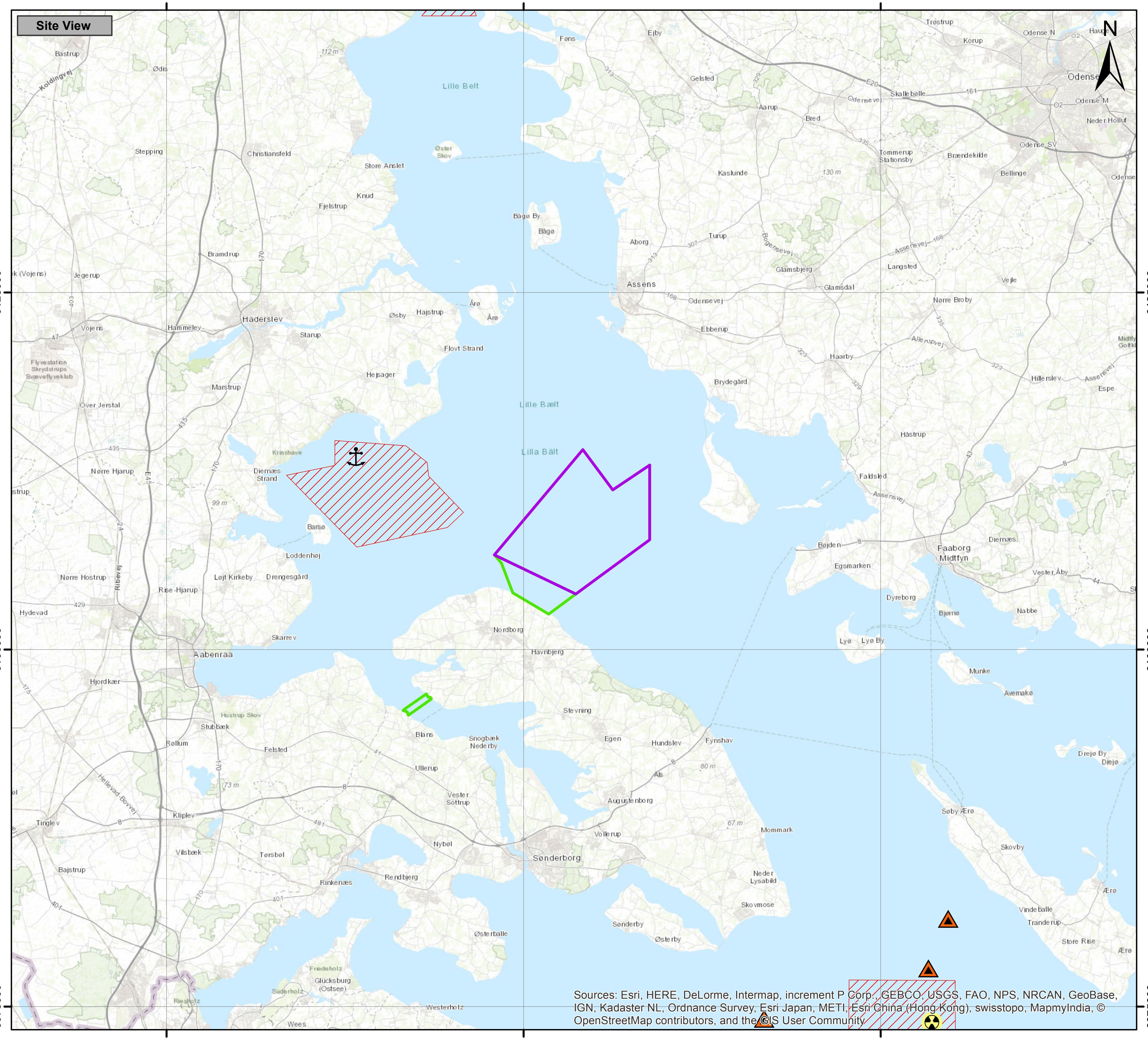
Once the weapons containing chemical agents have corroded sufficiently, most CW agents are rapidly neutralised by seawater. The exception, however, is mustard gas thickened with plasticiser, known as Thickened Mustard Gas (TMG) which is very long-lived and accumulates in solid clumps.

Source of Potential UXO Hazard - Findings
The closest known chemical munition dumping site is located ˜40km southeast of the Project Area, as shown at the chart below. This site is believed to contain 750T of chemical weapon (CW) agents and is marked as a danger area on navigational charts. Given the distance from the Project Area, this dump site is unlikely to be a direct source of UXO contamination. A prohibited development area is located ˜3km west of the Project Area and is designated to indicate a residual danger from bottom mines or other objects containing explosives on the seabed. While navigational charts mark this area for caution against fishing, anchoring and seabed activities, it does not directly affect the Project Area. While the locations of most dumps are well known, there are problems with the accuracy of both type and quantity dumped. The cause of this imprecision is due to a combination of factors, including inadequate record keeping, the dumping of items outside designated official dumping areas. As a result, while it is considered unlikely, it is possible that dumped munitions are located within the Project Area.

Table 2.8 – Sources of Munitions Dumping within the Study Area







Legend for Site View

- Lillebælt Syd Wind Farm Study Area
- Lillebælt Syd Export Cable Study Area
- Warning Against Anchoring
- Chemical Weapon Dump
- Munition Dump Site
- Prohibited Development Area

Horizontal Scale(s)

Kilometers: 0 — 12.5 — 25

Nautical Miles: 0 — 2 — 4 — 8 — 12

Consultant	Client	Drawing Title	User Notes			
ORDTEK	COWI	Lillebælt Syd Offshore Wind Farm Prohibited Development Areas and Munition Dump Sites	N/A	THE BRITISH ASSESSMENT BUREAU ISO9001	WGS 1984 UTM Zone 32N; Projection: Transverse Mercator; Datum: WGS 1984; 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. JM5376 - Lillebælt Syd OWF. Date Drawn: 12 December 2017; Drawing Reference: JM5376_Lil-Syd_04; Drawing Version: 2.0

2.12 Probability of UXO Contamination

The UXO items we consider most likely to be *present* within the Project Area are shown in Table 2.9 below. Note that this table shows the probable *encounter* of generic UXO types within the Project Area based on the evidence we have gathered about potential UXO sources.

It is important to recognise that the probability of *encounter* (i.e. a positive interaction with the UXO during a specific Project activity) will generally be less than the probability of items of that particular UXO type being *present* across the whole Project Area; given that the actual Project activity footprint will be significantly less than the total Project Area. Among other factors, the probability of *encounter* will depend on the Project activity being undertaken and the potential for burial.

Probability of Contamination Key	
1	Very Unlikely
2	Unlikely
3	Possible
4	Likely
5	Very Likely

	Lillebælt Syd Project Area		
UXO Threat Item	Offshore	Export cable 1	Export cable 2
German Ground Mine	1	1	1
British Ground Mine	2	2	2
British and German WWI Mines	1	1	1
Artillery and Naval Projectiles	2	2	2
Small HE Bombs (250lb)	3	3	2
Large HE Bombs (500lb and greater)	2	2	2
Depth Charges and Torpedoes	2	2	2
British and German WWII Buoyant Mines	2	2	1
Land Service Ammunition	1	1	1

Table 2.9 – Likelihood of UXO encounter at Lillebælt Syd

3 UXO and Interaction in the Natural Environment

3.1 Overview

Over a period of several decades, the seabed level within an area can change due to the process of sediment accretion (also sometimes referred to as "deposition") or erosion. It is an important factor that must be taken into consideration when determining the potential for UXO burial. The movement of sandy bedforms (ripples, mega-ripples, sand waves, etc.) also has the potential to bury (or expose) items of UXO over time and therefore the seabed sediment composition, morphology and mobility must also be considered. Bedforms in shallow water migrate and change shape due to forcing by tides and currents. Most active bedforms are those formed of sand, although where currents are strong, particularly in the nearshore, gravel can also be mobilised; this is particularly prevalent during high-energy storm events.

3.2 Lillebælt Syd Seabed Characteristics

The surficial geology of the southern Lillebælt reflects the glacial deformation episodes during the end of the last glaciation. In many areas, the glacial deposits are overlain by late glacial clayey and fine sandy deposits, which again can be overlain by early Holocene freshwater deposits often interlayered with organic deposits and peat (Bennike & Jensen, 2011). Marine Holocene sediments gradually cover these freshwater deposits. During the Holocene transgression, muddy sediments were deposited in the area, mostly connected to the deep basins, the fjords and the troughs in the deepest part. Between these basins, the seabed is partly influenced by areas of Holocene sand and gravel deposits with shallow areas of glacial deposits of moraine ridges and boulder reefs outcropping in between.

Seabed levels vary across the site, with water depth ranging between 5m and 40m (LAT) (Reference B).

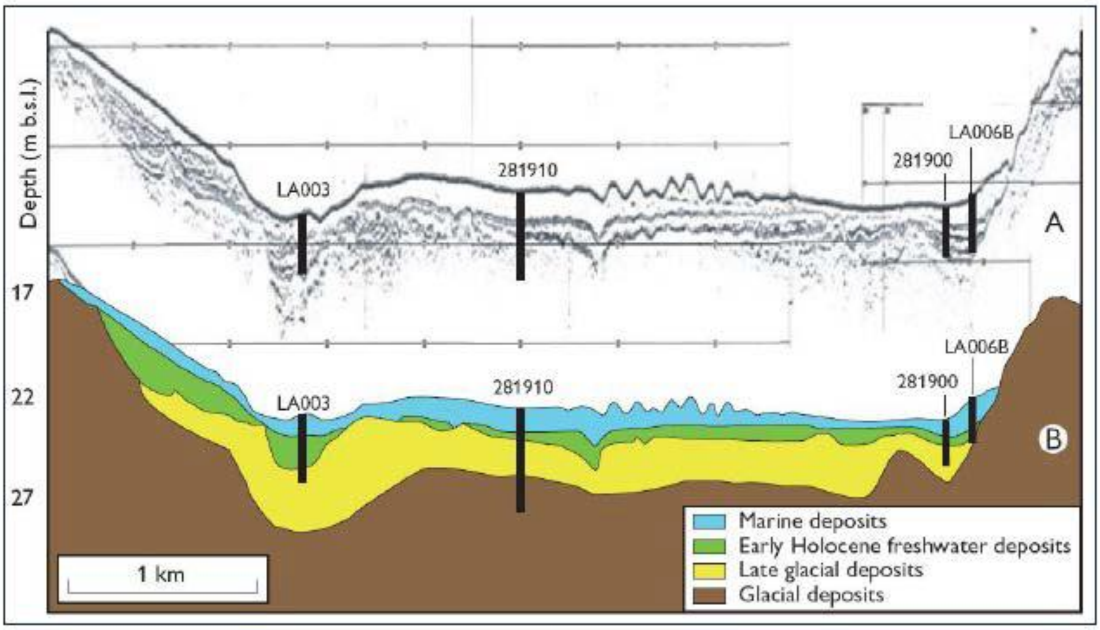


Figure 3.1 – Location map and seismic section showing the general stratigraphy of the southern Lillebælt region (Bennike & Jensen, 2011).

3.3 UXO Burial

Within dynamic sediment conditions, UXO items are likely to become buried; the depth of burial at any one location is dependent on a number of variables that will be explored below. It should also be noted however that where seabed conditions are relatively stable (limited or no accretion or bedform movement) or where there is limited or no sand/gravel cover UXO burial is less likely and in some environments does not happen.

- **Initial impact** – within water depth <5m LAT
- **Liquefaction** – within shallow and nearshore sands/silts
- **Self-burial by scour, sinking and backfill** – within sands and silts,
- **Bedform migration** – within areas of sandwaves and mega ripples

Figure 3.1 below shows an example of how the combination of self-burial, sediment accretion and sand wave migration might lead to deeply buried UXO.

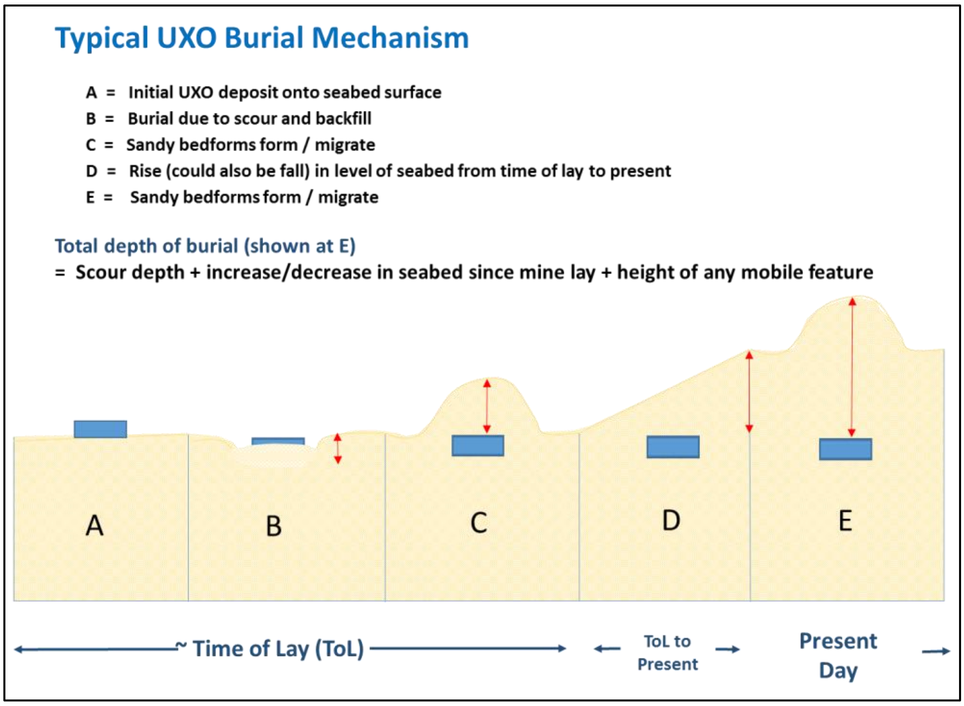


Figure 3.2 – Typical UXO burial mechanisms

3.3.1 Self-Burial by Scour, Sinking and Backfill

The self-burial process by scour, sinking and backfill depends upon sediment grain size; as this becomes coarser, and approaches gravel size, seabed burial will reduce and instead a settling effect will occur working the UXO partially into the seabed. UXO self-burial on hard consolidated surfaces such as clay or chalk will not occur. Where the required conditions, sediment grain size and tidal flow, are met UXO burial by scour, sinking and backfill will occur.

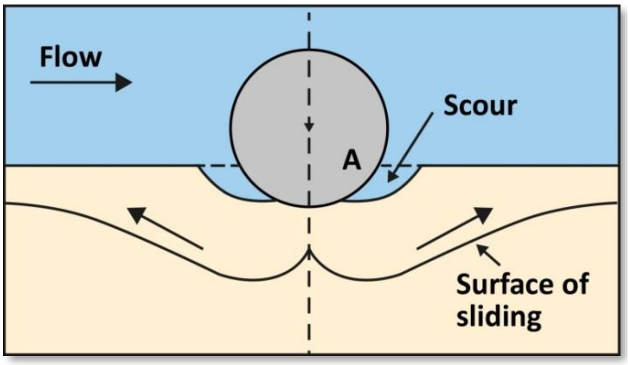


Figure 3.3 – Scour mechanism

When an item of UXO is situated on an unconsolidated sediment bed in the tidal flow, wave motion and currents of a marine environment, scour will develop in its immediate vicinity. The local change in the flow will generally cause an increase in the bed shear stress and in the turbulence level, resulting in an increased sediment transport close to the structure and thus leading to scour. After the onset of scour, the scour occurs in the form of tunnel erosion, which is followed by lee wake erosion. The scour depth approaches a steady state through a transitional period.

The type and transitional phase of the self-burial, before equilibrium is reached, will depend among other factors on the shape and weight of the UXO item and sediment grain size. However, the mechanism is essentially the same in all cases. 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 will stop only when the UXO sinks to such depths that it will be protected against scour. When the scour stops, the repeated failure of the bed will stop, and consequently the sinking of the sphere will come to an end (*Truelson* et *al.,* 2005). In the final stage, the space between the UXO and the scour hole is gradually filled with sand, this is known as backfilling.

Within test conditions self-burial of a sphere in sand (0.18mm) has been seen to reach equilibrium at 0.5 x the diameter (*Truelson* et *al.,* 2005). For a bomb shaped cylinder, it will vary on precise shape and circumstances but will be similar to the sphere, and around 0.6 x the diameter.

In finer sediment (silts and sands), self-burial is likely to be greater becoming closer to complete burial of the item (0.6<1 x UXO diameter), however where the sediment is coarser, or consists of gravel or pebbles, the maximum scour depth will be less; varying with the granularity from 0<0.6 x UXO diameter.

3.3.2 Bedforms and Accretion

UXO burial (and exposure) is also caused by the formation and migration of bedforms such as sand banks, sandwaves, ripples and mega ripples. The presence and size of these features are a function of grain size and seabed current orbital velocity. It is also dependent on the turbulence, the velocity profile and the grain density.

The characteristics of the sediments and distribution of grain sizes, coupled with the wind, wave and current conditions dictate the characteristics that can cause sandwaves to occur. Sandwaves form within cohesive sediments because the sand grains have a roughness which creates turbulence as water flows over the surface and are an expression of a minimum energy loss system. 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.

When added to self-burial by scour, the resultant maximum UXO depth in the sediment will be the height of the feature plus the self-burial.

3.4 General Burial Assessment Conclusions

The conclusions on the potential for UXO burial are presented below:

- Given the water depths at the site, burial by initial impact is unlikely.
- UXO may be completely buried in ripple and sand wave areas, up to the full height of the bedform, which could be several metres.
- In areas of sand and gravelly sand areas where there are no bedforms, UXO is likely to be partially exposed; showing around 0.4 diameter above the sediment.
- In areas of gravel, burial due to scour will be substantially less than in sandy areas and may not have occurred.
- In areas of outcropping bedrock UXO will be exposed on the seafloor.
- Where burial is likely to be negligible, depending on size and orientation, large items of UXO should be visible to SSS. However, these areas often coincide with concentrations of boulders, which will complicate SSS data analysis.

4 UXO Risk Assessment (Baseline Pre-Mitigation)

4.1 General

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).

4.2 Likelihood of Encounter

4.2.1 General

Likelihood of encounter, the first element, is a function of the density of UXO items and the total area of intrusive engineering interaction of as a proportion of the total area of the site (to be accurate: by volume to the maximum intrusive depth). It is rarely possible to know precisely how many items of UXO are potentially present within the site boundary (if any) 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 Project Area in relation to each other are:

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

Drilling will intrude into the sediment well below the likely maximum burial depth of all types of EO and any of the UXO items articulated in Section 2 could be encountered during geotechnical or installation operations.

4.3 Likelihood of UXO Detonation

4.3.1 Factors Affecting Likelihood of Detonation

The second element, *Likelihood 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. plough)
- 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 fuze (the part of the weapon that initiates function), a safety and arming mechanism/unit (often contained within the fuze), a detonator and a main charge. Additionally, most EO has a booster charge (also variously 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 safety and arming 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.

4.3.2 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 buckets 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 friction or excessive heat. The movement of vessels and implementation of non-intrusive surveys will not result in the initiation of ordnance through influence alone.

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

- Crushing of the casing, leading to the detonation of the EO's detonator (the main filling is unlikely to be initiated independently).
- A blow with sufficient energy by heavy equipment or, perhaps, a drill bit 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.
- Vibration or disturbance that initiates an item of UXO that is in a particularly sensitive state (e.g. cocked striker hung up, firing pin in contact with the detonator HE filling, exudation of sensitive metallic salts).

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.

The following are typical activities that may cause inadvertent UXO detonation during offshore developments (*Ordtek* recognises that not all are relevant to the project: they are shown for illustrative purposes only).

- Jack-Up barge leg deployment – crushing.
- Percussive piling (monopile installation) – sympathetic detonation, vibration, kinetic blow.
- Rock dumping/Concrete mattress installation – crushing, high kinetic energy blow.
- Borehole/Horizontal drilling – high kinetic energy blow, vibration (in contact with sensitive UXO).
- Anchor deployment – crushing, blow.
- PLGR – dragging (with UXO striking hard object on seabed, e.g. boulder).
- Cable Plough – crushing (unlikely but possible).
- Cable jetting – disturbance of a sensitive item of UXO.
- Cable surface lay-down – disturbance of sensitive item of UXO.

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 equipment and then 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 fuze 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. The potential detonation mechanisms for a range of ordnance items are discussed at Annex C.

4.4 Effects and Consequences of UXO Detonation

4.4.1 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.

4.4.2 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.

4.4.3 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 it 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:

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

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

4.4.4 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.

4.4.5 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's 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 Ɵ will tend to zero and, in theory, the SF received by the cable will be =

$$\frac{\sqrt{C}}{2R}$$

However, we have found no experimental or wartime empirical data to support this assumption and it should be applied with great caution.

Table 4.1, 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. The SF values, which were originally calculated in imperial values, have been converted by *Ordtek* to metric.

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

4.4.6 Representative Values of Peak Pressure and Shock Factor

The table below shows typical representative calculations for various UXO for Peak Pressure, Shock Factor and possible damage for a vessel at 50m and 200m range from the detonation and where the UXO is situated on the surface of the seabed in 15m depth of water.

UXO Type	~NEQ	Water Depth					
		15m	30m	50m	70m	100m	130m
LMB (GC)	700kg	0.84	0.42	0.25	0.18	0.13	0.10
Torpedo	300kg	0.52	0.26	0.16	0.11	0.08	0.06
1000kg Bomb	500kg	0.67	0.34	0.20	0.14	0.10	0.08
250kg Bomb	120kg	0.33	0.17	0.10	0.07	0.05	0.04
250lb Bomb	55kg	0.22	0.11	0.07	0.05	0.03	0.03
100lb Bomb	25kg	0.15	0.08	0.05	0.03	0.02	0.02
5in Shell	5Kg	0.07	0.03	0.02	0.01	0.01	0.01

Table 4.2 – Representative calculations for Hull Shock Factor at varying depths of water

Underwater, 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. As described earlier, fragmentation can generally be ignored for all but the largest UXO in water depths > 10 m.

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 than those caught in the open.

4.5 Semi-Quantitative Risk Assessment

4.5.1 Important Considerations

The UXO risk calculation table is located at Appendix 1. *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.

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 Association (CIRIA) guidance (Reference A).

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 caution.

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 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 at Appendix 1, 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 tables also contain a separate section that shows the likely consequence of UXO detonation to exposed personnel. This section will always assume the worst case scenario.

It is also important to note that the severity of consequence figures in the tables are predicated on the assumption that there is a reasonable degree of separation (water) between the UXO and receptor on detonation. The figure, therefore, primarily considers the effect of a detonation on vessels afloat and embarked personnel. The exception to this is the calculation for Jack-Up barge operations, where detonation of a relatively small NEQ UXO has the potential to initiate collapse of a spud leg, resulting in the vessel capsizing *(note, we have no trials data to support this view but we consider it prudent to take a cautious approach)*.

Equipment in direct contact or immediately adjacent to the detonation may receive substantial, or even catastrophic, damage from even a small item of UXO (e.g. 3.7in projectile). However, (apart from jack-up) we consider this a Project risk, while the tables are predominantly concerned with presenting H&S risk.

4.5.2 Risk Assessment Matrix

"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.

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 marine environment, although it has been modified where required to ensure it is UXO centric.

Likelihood of Occurrence (Encounter *and* Detonation)		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 and moderate damage to equipment	**4 = High** Involving single death and serious damage to equipment	**5 = Very High** Multiple deaths and/or sunk vessel, equipment totally destroyed beyond repair
	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 4.3 - UXO Risk Assessment Matrix

5 Recommended Risk Mitigation Strategy and Measures

5.1 Risk Tolerance

Although both 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 marine environment, the level of risk can statistically never be "zero". The number of hazard items in a typical offshore development area are 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.

Many European regulatory authorities, including the UK Health & Safety Executive (HSE), require that operational risks should be within acceptable limits and As Low as Reasonably Practicable (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 5.1 demonstrates how ALARP is measured. The principle of ALARP is commonly applied across most of the European offshore renewables industry.

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.

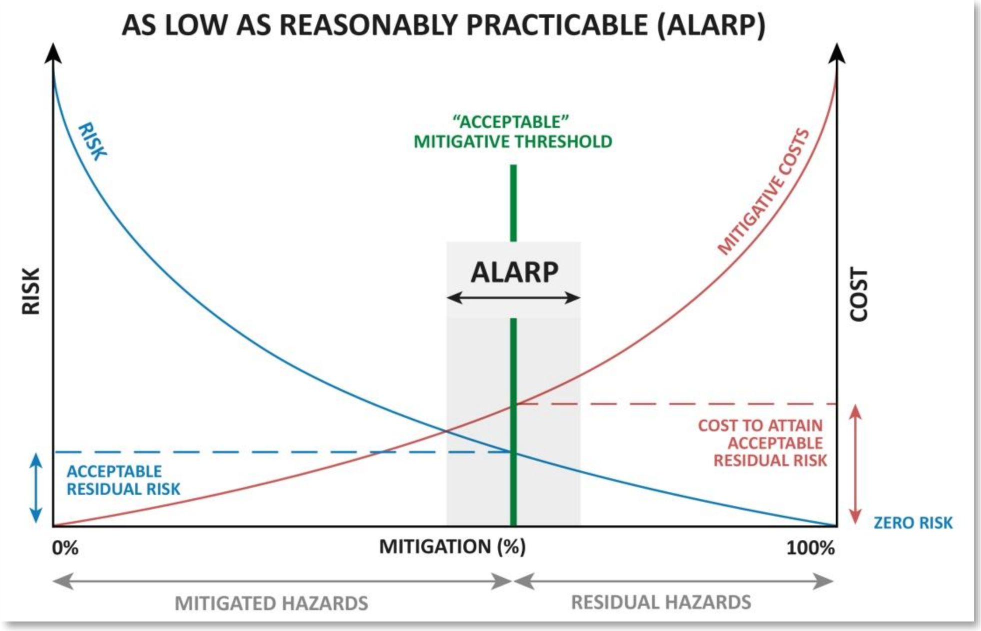


Figure 5.1 - Determining risk are ALARP by measuring Cost versus Effort

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 they judge 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 unreasonable in comparison.

5.1.1 Risk Assessment Results

In can be seen from a Health & Safety risk assessment perspective that in general the risk to the Project is Low to Moderate (Appendix 1) and very much depends upon the project activities. Based upon this, *Ordtek* then uses the following risk tolerability thresholds to determine the level of mitigation required.

Risk	Category	Action
1 – 3	Tolerable – No mitigation required	Nominal risk. A UXO action plan for contractors would be prudent
4 – 6	Partly Tolerable – Procedural mitigation required	Some risk. Control measures MUST be maintained and monitored. Inexpensive reasonably practical risk mitigation measures should still be implemented. (Use existing survey data if available)
7 – 8	Intolerable – Active mitigation required	Intermediate risk. Any control measures MUST be maintained and monitored and on-going actions completed. UXO specified survey is likely to be required.
9 – 12	Intolerable – Active mitigation required	Risk MUST be reduced. Any control measures MUST be maintained and monitored. Risk mitigation required or Company (management) approval needed.
13 – 25	Intolerable – Active, bespoke mitigation required	Substantial risk. MUST NOT BE ALLOWED. Risk MUST be reduced. Any control measures MUST be maintained and monitored. Bespoke, comprehensive mitigation is likely required.

Table 5.1 - UXO Risk Tolerability

5.2 Strategic Risk Management

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 the risk from UXO to the proposed development ranges from Low to Moderate and that mitigation is required to reduce the risk to ALARP.

Moreover, 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 offshore Projects around the UK. These other risks therefore need to be taken in to consideration when determining the level of risk mitigation required.

5.3 Strategy Objectives

In designing a mitigation strategy, *Ordtek* has the following objectives, to:

- Ensure it is technically robust within the bounds of available technology.
- Ensure it is in line with best practice in the offshore renewable industry.
- Reduce the risks to ALARP.
- Take account of the potential for buried UXO.
- Provide a solution that has a high weather tolerance.

5.4 *Ordtek* Methodology

In developing a risk mitigation strategy and protocol for the Lillebælt Syd Project, *Ordtek's* assumption is that UXO risk above the ALARP threshold is not tolerable to *COWI* or any appointed sub-contractors.

Within *Ordtek's* Risk Management Framework (RMF) (shown earlier at Figure 1.1), the risk from UXO is first identified, assessed in relation to the proposed Project activities and then a strategy formulated to mitigate that risk to below the ALARP threshold (this document). These activities correspond to Phases 1, 2 and 3 of the risk management process. Mitigation of the UXO risk then consists of three principal stages, which correspond to Phases 4, 5 and 6.

- Survey (Phase 4)

- Data analysis: discriminate anomalies as potential UXO items (Phase 5)
- Avoidance or removal of UXO hazard items (Phase 6)

For Phase 4, choice of the appropriate search (survey) techniques will be determined by:

- Smallest significant UXO threat for ALARP sign-off
- Maximum detection depth (MDD) of the smallest threat item
- UXO maximum burial depth (MBD)
- Maximum depth of intrusion into the seabed for each Project activity
- Probability of detection for a particular survey technique in the prevailing environment – this will be governed by seabed characteristics, such as rocks, boulders and pebbles, and ambient geological ferro-magnetic noise.

Ordtek will then identify and select the geophysical techniques, or combination of techniques, with the performance that best matches the Lillebælt Syd environmental conditions with respect to MBD, probability of detection, other relevant factors and at best value to *COWI*.

5.5 UXO Threat Items for ALARP Sign-Off

The choice of the hazard items that need 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.

For example, a 100lb (45kg) HE bomb with an NEQ of ~25kg can present a significant threat to some activities in some circumstances. If brought inadvertently to the surface, the detonation of a 100lb bomb would present a considerable hazard to personnel due to shrapnel and serious injury or death could result. However, the same 100lb bomb lying in water deeper than ~20m presents a relatively low risk; the likelihood of a detonation is very low and any damage caused by such an event is likely to be relatively minor to people, vessels and equipment on the surface. (However, equipment immediately in immediate contact, or very close to, the bomb on the seabed are obviously much more likely to suffer more severe damage).

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

Even though some improvement in detection can be achieved by reducing magnetometer survey line spacing (for example from typically 5m to 3m), generally the detection and identification of all magnetic anomalies that could resemble a small bomb in an area is likely to be impossible, particularly in areas of high ferro-magnetic noise. Investigating the many thousands of resultant anomalies that ensued from data interpretation would be prohibitive in both time and cost. This effort required, in *Ordtek's* opinion, would not be reasonable and not within our understanding of the ALARP principle.

Therefore, *Ordtek* have determined the project may employ two threat items for detection depending on the activity. While the 250lb HE bomb may be a risk to jacking up and piling, due to vessel offset in cable laying and detonation from a 250lb bomb is a lower risk to cabling; therefore *Ordtek* considered that the smallest threat items for ALARP sign-off are:

- Allied 250lb HE Bomb (~114kg) within 50m of a WTG foundation and jack-up zones.
- Allied 500lb HE Bomb (~227kg) for all other areas of the Project.

5.5.1 Allied 250lb HE Bomb

Depending on the variant, the 250lb GP is cylindrical/tear-drop in shape, 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.

5.5.2 Allied 500lb HE Bomb

The 500lb HE Bomb is cylindrical in shape, made of steel and weighs around 227kg. They have an NEQ of ~95kg-105kg of TNT or Amatol depending on the variant. The body diameter is 0.327m and the length (without tail) is ~1.041m, depending on the variant.

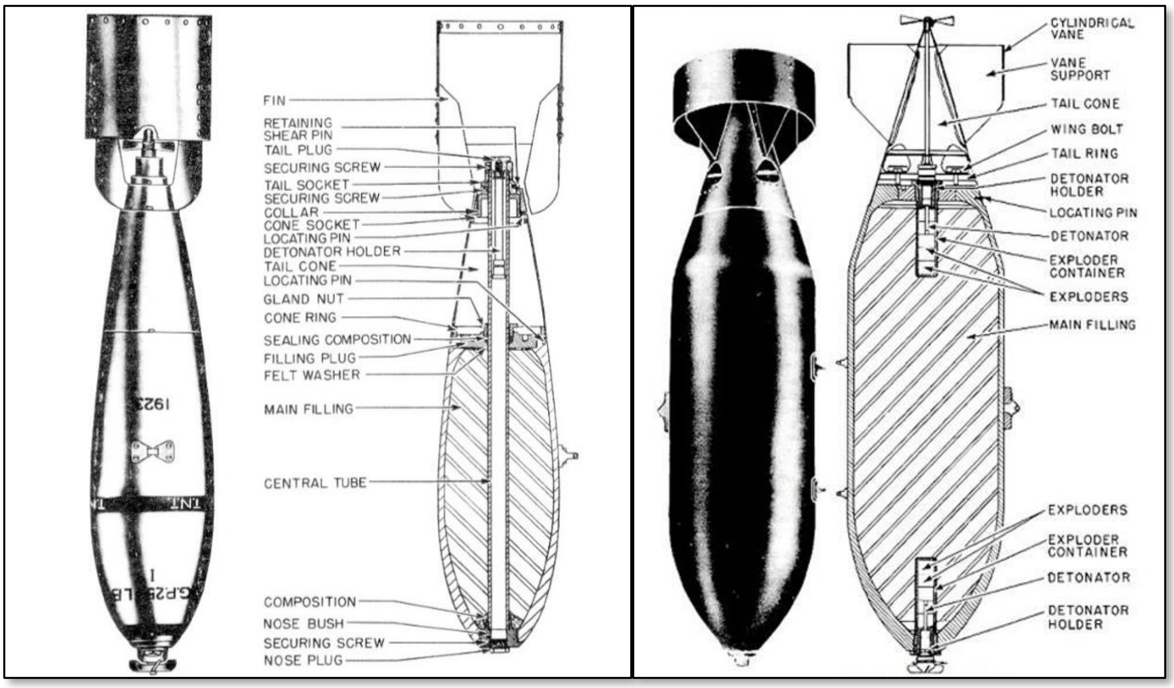


Figure 5.2 – Allied 250lb (left) and 500lb (right) HE Bombs

Assuming these items can be successfully detected and identified within the geophysical datasets, larger objects will also be detectable. It is also likely that there will be smaller items of UXO present within the Project Area. The relatively small risk that these present can be mitigated by physical and procedural measures, which are outlined below.

5.6 Chemical Weapons and Agents

The mitigation recommendations outlined below – both survey and reactive/procedural – will also satisfactorily mitigate the risk from CW and agents. CW hazards and characteristics must be included in UXO safety and awareness briefings and any EOD contractor engaged to investigate and/or dispose of/remove UXO must include the potential of an encounter with CW in his risk assessment and method statement (RAMS).

5.7 Mitigation Required to Reduce the Risk ALARP – Geophysical Survey

5.7.1 Geotechnical Investigation Campaign

The use of acoustic data only (Side Scan Sonar and Multibeam Echosounder) is deemed acceptable for the geotechnical investigation (GI) phase of the project. Ordtek understand the GI campaign will comprise the collection of boreholes and vibrocores, in addition jack-up vessels will be deployed as part of the GI campaign. Therefore, the following strategy is recommended:

Ahead of jack-up operations and the undertaking of boreholes:

- Assess acoustic geophysical data. The resolution and specification should be sufficient to identify UXO within the threat spectrum. Select seabed features that have the potential to be UXO by comparing the threats from Section 5.5.
- Avoid any targets that model as potential UXO by 10m radius (detailed in Section 5.7.3).
- Implement residual risk management (detailed in Section 5.8):
    - UXO risk management plan with safety instructions.
    - UXO safety and awareness briefing.

Ahead of all GI works, including undertaking vibrocores:

- Implement residual risk management (detailed in Section 5.8):
    - UXO risk management plan with safety instructions.
    - UXO safety and awareness briefing.

5.7.2 Pre-Construction

To attain the ALARP criteria, a bounded UXO-specified geophysical survey should be undertaken to locate (Phase 4), identify (Phase 5), investigate and avoid or remove (if necessary) large NEQ items of UXO (Phase 6, Phase 7), while the smaller UXO may be dealt with by physical and procedural mitigative measures adopted during the subsequent phases of the Project (Phase 8). Geophysical anomalies modelling as potential UXO, where possible, should be avoided by route engineering; those that cannot be avoided should be investigated and items of UXO confirmed by inspection should either be removed by demolition or physical relocation, depending on the circumstances.

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

5.7.3 Geophysical Anomaly Management

Any geophysical anomalies that are not definitively confirmed as UXO, can be avoided by a suitably safe distance. The typical exclusion zone radius of 15m is commonly applied within the offshore renewables industry for relative low energy activities such as cable ploughing. The 15m refers to the proximity of the cable installation device rather than the as laid cable position and 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 radius, therefore, is a distance at which typical activities can be conducted safely without "disturbing" potential, as yet unconfirmed, UXO. The 15m exclusion zone has generally become an industry standard exclusion zone for "cable installation", but it does not necessarily consider all project specific elements that make up that distance. 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. Exclusion zones should be applied consistently regardless of the water depth. The basis of the avoidance principle is to ensure that the item is not disturbed therefore the depth of water does not sufficiently influence the decision making.

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

- No foundation installation activity should interact with the seabed within 30m of a geophysical contact modelling as UXO.
- No jack-up leg should interact with the seabed within 15m of a geophysical contact modelling as UXO.
- No cable installation activity should interact with the seabed within 15m of a geophysical contact modelling as UXO.
- No cable or foundation protection material/mattressing is to be placed within 15m of any geophysical contact modelling as UXO.
- No geotechnical activity should interact with the seabed within 10m of a geophysical contact modelling as UXO.
- No anchor should interact with the seabed within 10m of a geophysical contact modelling as UXO.

5.8 Residual UXO Risk Management

5.8.1 Installation and Construction Phase

To conform to best practice, installation contractors should also adopt the following UXO risk management and mitigation actions:

- Obtain the ALARP sign-off certificate for each installable asset. Input the geophysical contacts to be avoided into the on-board navigation system.
- Establish the location of known wreck sites, especially any highlighted in this desk study. *Ordtek* suggests that non-military related wrecks are also avoided in accordance to the developer's standard protocol.
- Ensure the Project team are aware of their 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. *(Note that given the expected level of UXO contamination on the site, Ordtek recommends that a UXO specialist is deployed offshore permanently during any geophysical anomaly investigation phase).*

Expansion on these points is provided below.

5.8.2 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.

5.8.3 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 should include the hazards and characteristics of CW. 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.

5.8.4 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 and the Client's UXO consultant.

Note that we consider the requirement to test CW agents as highly unlikely. With the exception of thickened mustard gas, once free of the container/carrier weapon and following exposure to salt water, all other threat agents hydrolyse to much less toxic compounds. The standard procedure advised by our UXO specialists for any UXO item, including potential complete CW (which is unlikely to be readily identifiable immediately), inadvertently brought to the surface will be to return it to the seabed as soon as possible. This will also be the case for mustard gas accumulations.

5.9 Anchor Handling

Anchors may be required to be deployed outside the surveyed footprint. *Ordtek* has reflected on this situation carefully and considers that the deployment of anchors outside the surveyed area is an acceptable risk that falls below the ALARP threshold.

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

Appendix 1

Risk Assessment Results

ORDTEK

Detailed Risk Assessment Results Lillebaelt Syd OWF Pre-Mitigation		Main Array			Export Cable Area 1			Export Cable Area 2		
Development Stage	Generic Ordnance Category	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result
Geotechnical Investigation from DP vessel with no leg or anchor placement (Intrusive)	**German Ground Mines**	1	5	5	1	5	5	1	5	5
	British Ground Mines	1	4	4	1	4	4	1	4	4
	British WWI mines	1	3	3	1	3	3	1	3	3
	German WWI mines	1	3	3	1	3	3	1	3	3
	Artillery & Naval Projectiles	1	3	3	1	3	3	1	3	3
	HE Bombs	1	4	4	1	4	4	1	4	4
	Depth Charges and Torpedoes	1	4	4	1	4	4	1	4	4
	British WWII Buoyant Mines	1	4	4	1	4	4	1	4	4
	German WWII Buoyant Mines	1	4	4	1	4	4	1	4	4
	LSA	1	2	2	1	2	2	1	2	2
Foundation Installation: Percussive Piling	**German Ground Mines**	1	5	5	N/A	N/A	N/A	N/A	N/A	N/A
	British Ground Mines	1	4	4	N/A	N/A	N/A	N/A	N/A	N/A
	British WWI mines	1	3	3	N/A	N/A	N/A	N/A	N/A	N/A
	German WWI mines	1	3	3	N/A	N/A	N/A	N/A	N/A	N/A
	Artillery & Naval Projectiles	1	3	3	N/A	N/A	N/A	N/A	N/A	N/A
	HE Bombs	2	4	8	N/A	N/A	N/A	N/A	N/A	N/A

Detailed Risk Assessment Results Lillebaelt Syd OWF Pre-Mitigation		Main Array			Export Cable Area 1			Export Cable Area 2		
Development Stage	Generic Ordnance Category	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result
Foundation Installation: Percussive Piling	**Depth Charges and Torpedoes**	1	4	4	N/A	N/A	N/A	N/A	N/A	N/A
	British WWII Buoyant Mines	1	4	4	N/A	N/A	N/A	N/A	N/A	N/A
	German WWII Buoyant Mines	1	4	4	N/A	N/A	N/A	N/A	N/A	N/A
	LSA	1	2	2	N/A	N/A	N/A	N/A	N/A	N/A
Foundation Installation: Gravity Base	**German Ground Mines**	1	5	5	N/A	N/A	N/A	N/A	N/A	N/A
	British Ground Mines	1	4	4	N/A	N/A	N/A	N/A	N/A	N/A
	British WWI mines	1	3	3	N/A	N/A	N/A	N/A	N/A	N/A
	German WWI mines	1	3	3	N/A	N/A	N/A	N/A	N/A	N/A
	Artillery & Naval Projectiles	1	3	3	N/A	N/A	N/A	N/A	N/A	N/A
	HE Bombs	2	4	8	N/A	N/A	N/A	N/A	N/A	N/A
	Depth Charges and Torpedoes	1	4	4	N/A	N/A	N/A	N/A	N/A	N/A
	British WWII Buoyant Mines	1	4	4	N/A	N/A	N/A	N/A	N/A	N/A
	German WWII Buoyant Mines	1	4	4	N/A	N/A	N/A	N/A	N/A	N/A
	LSA	1	2	2	N/A	N/A	N/A	N/A	N/A	N/A
Foundation Installation: Suction Bucket	**German Ground Mines**	1	5	5	N/A	N/A	N/A	N/A	N/A	N/A
	British Ground Mines	1	4	4	N/A	N/A	N/A	N/A	N/A	N/A

Detailed Risk Assessment Results Lillebaelt Syd OWF Pre-Mitigation		Main Array			Export Cable Area 1			Export Cable Area 2		
Development Stage	Generic Ordnance Category	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result
Foundation Installation: Suction Bucket	**British WWI mines**	1	3	3	N/A	N/A	N/A	N/A	N/A	N/A
	German WWI mines	1	3	3	N/A	N/A	N/A	N/A	N/A	N/A
	Artillery & Naval Projectiles	1	3	3	N/A	N/A	N/A	N/A	N/A	N/A
	HE Bombs	2	4	8	N/A	N/A	N/A	N/A	N/A	N/A
	Depth Charges and Torpedoes	1	4	4	N/A	N/A	N/A	N/A	N/A	N/A
	British WWII Buoyant Mines	1	4	4	N/A	N/A	N/A	N/A	N/A	N/A
	German WWII Buoyant Mines	1	4	4	N/A	N/A	N/A	N/A	N/A	N/A
	LSA	1	2	2	N/A	N/A	N/A	N/A	N/A	N/A
PLGR / Cable Recovery (this assumes detonation is at full extent of tow; severity will increase if it occurs closer to the towing vessel)	**German Ground Mines**	1	5	5	1	5	5	1	5	5
	British Ground Mines	1	4	4	1	4	4	1	4	4
	British WWI mines	1	3	3	1	3	3	1	3	3
	German WWI mines	1	3	3	1	3	3	1	3	3
	Artillery & Naval Projectiles	1	3	3	1	3	3	1	3	3
	HE Bombs	2	4	8	2	4	8	1	4	4
	Depth Charges and Torpedoes	1	4	4	1	4	4	1	4	4
	British WWII Buoyant Mines	1	4	4	1	4	4	1	4	4

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Detailed Risk Assessment Results Lillebaelt Syd OWF Pre-Mitigation		Main Array			Export Cable Area 1			Export Cable Area 2		
Development Stage	Generic Ordnance Category	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result
PLGR / Cable Recovery	**German WWII Buoyant Mines**	1	4	4	1	4	4	1	4	4
	LSA	1	2	2	1	2	2	1	2	2
Dredging (TSHD)	**German Ground Mines**	1	5	5	1	5	5	1	5	5
	British Ground Mines	1	4	4	1	4	4	1	4	4
	British WWI mines	1	3	3	1	3	3	1	3	3
	German WWI mines	1	3	3	1	3	3	1	3	3
	Artillery & Naval Projectiles	1	3	3	1	3	3	1	3	3
	HE Bombs	2	4	8	2	4	8	1	4	4
	Depth Charges and Torpedoes	1	4	4	1	4	4	1	4	4
	British WWII Buoyant Mines	1	4	4	1	4	4	1	4	4
	German WWII Buoyant Mines	1	4	4	1	4	4	1	4	4
	LSA	1	2	2	1	2	2	1	2	2
Ploughing / Jetting from tracked vehicle	**German Ground Mines**	1	5	5	1	5	5	1	5	5
	British Ground Mines	1	4	4	1	4	4	1	4	4
	British WWI mines	1	3	3	1	3	3	1	3	3
	German WWI mines	1	3	3	1	3	3	1	3	3

Detailed Risk Assessment Results Lillebaelt Syd OWF Pre-Mitigation		Main Array			Export Cable Area 1			Export Cable Area 2		
Development Stage	Generic Ordnance Category	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result
Ploughing / Jetting from tracked vehicle	**Artillery & Naval Projectiles**	1	3	3	1	3	3	1	3	3
	HE Bombs	2	4	8	2	4	8	1	4	4
	Depth Charges and Torpedoes	1	4	4	1	4	4	1	4	4
	British WWII Buoyant Mines	1	4	4	1	4	4	1	4	4
	German WWII Buoyant Mines	1	4	4	1	4	4	1	4	4
	LSA	1	2	2	1	2	2	1	2	2
Cable Surface Lay	**German Ground Mines**	1	5	5	1	5	5	1	5	5
	British Ground Mines	1	4	4	1	4	4	1	4	4
	British WWI mines	1	3	3	1	3	3	1	3	3
	German WWI mines	1	3	3	1	3	3	1	3	3
	Artillery & Naval Projectiles	1	3	3	1	3	3	1	3	3
	HE Bombs	1	4	4	1	4	4	1	4	4
	Depth Charges and Torpedoes	1	4	4	1	4	4	1	4	4
	British WWII Buoyant Mines	1	4	4	1	4	4	1	4	4
	German WWII Buoyant Mines	1	4	4	1	4	4	1	4	4
	LSA	1	2	2	1	2	2	1	2	2

Detailed Risk Assessment Results Lillebaelt Syd OWF Pre-Mitigation		Main Array			Export Cable Area 1			Export Cable Area 2		
Development Stage	Generic Ordnance Category	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result
Jack-up Leg Placement	**German Ground Mines**	1	5	5	N/A	N/A	N/A	N/A	N/A	N/A
	British Ground Mines	1	4	4	N/A	N/A	N/A	N/A	N/A	N/A
	British WWI mines	1	3	3	N/A	N/A	N/A	N/A	N/A	N/A
	German WWI mines	1	3	3	N/A	N/A	N/A	N/A	N/A	N/A
	Artillery & Naval Projectiles	1	3	3	N/A	N/A	N/A	N/A	N/A	N/A
	HE Bombs	1	4	4	N/A	N/A	N/A	N/A	N/A	N/A
	Depth Charges and Torpedoes	1	4	4	N/A	N/A	N/A	N/A	N/A	N/A
	British WWII Buoyant Mines	1	4	4	N/A	N/A	N/A	N/A	N/A	N/A
	German WWII Buoyant Mines	1	4	4	N/A	N/A	N/A	N/A	N/A	N/A
	LSA	1	2	2	N/A	N/A	N/A	N/A	N/A	N/A
Anchor Deployment & Handling	**German Ground Mines**	1	5	5	1	5	5	1	5	5
	British Ground Mines	1	4	4	1	4	4	1	4	4
	British WWI mines	1	3	3	1	3	3	1	3	3
	German WWI mines	1	3	3	1	3	3	1	3	3
	Artillery & Naval Projectiles	1	3	3	1	3	3	1	3	3
	HE Bombs	1	4	4	1	4	4	1	4	4

Detailed Risk Assessment Results Lillebaelt Syd OWF Pre-Mitigation		Main Array			Export Cable Area 1			Export Cable Area 2		
Development Stage	Generic Ordnance Category	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result	Likelihood of Occurrence (Encounter *and* Detonation)	Severity of Consequence	Result
Anchor Deployment & Handling	**Depth Charges and Torpedoes**	1	4	4	1	4	4	1	4	4
	British WWII Buoyant Mines	1	4	4	1	4	4	1	4	4
	German WWII Buoyant Mines	1	4	4	1	4	4	1	4	4
	LSA	1	2	2	1	2	2	1	2	2
Unprotected Personnel (considering activities that may potentially recover small items above the water surface – detonation on or very close to the surface; detonation <10m)	**German Ground Mines**	1	5	5	1	5	5	1	5	5
	British Ground Mines	1	5	5	1	5	5	1	5	5
	British WWI mines	1	5	5	1	5	5	1	5	5
	German WWI mines	1	5	5	1	5	5	1	5	5
	Artillery & Naval Projectiles	1	5	5	1	5	5	1	5	5
	HE Bombs	1	5	5	1	5	5	1	5	5
	Depth Charges and Torpedoes	1	5	5	1	5	5	1	5	5
	British WWII Buoyant Mines	1	5	5	1	5	5	1	5	5
	German WWII Buoyant Mines	1	5	5	1	5	5	1	5	5
	LSA	1	4	4	1	4	4	1	4	4

Annex A

Supplementary Notes on UXO Types

SUPPLEMENTARY NOTES ON UNEXPLODED ORDNANCE TYPES

High Explosive Bombs and Rockets

The charge weight (commonly referred to as the NEQ - Net Explosive Quantity) of a bomb depends on its purpose. Bombs intended to cause damage principally by blast are relatively thin cased and contain around 75% by weight of HE. Those that are designed to fragment and cause damage to thin-skinned buildings, people and equipment through shrapnel have thicker casings and around 30% HE. “General Purpose” (GP) and “Medium Capacity” (MC) bombs have a charge weight of around 50% of the total weight of the weapon. The German designations for these types of bombs were SB, SD and SC respectively. For example an SC-250 would be a general purpose “Minenbombe” weighing 250kg, with an NEQ of around 125kg of HE. An SD-500 would be a fragmentation “Splitterbombe” weighing 500kg and with a charge weight of around 150kg, depending on the variant.

Allied bombs dropped from medium/heavy bombers could vary from 50lb (~25kg) to 4000lb (~1800kg) or more but, predominantly, the majority were likely to be British General Purpose (GP) or US Medium Capacity (MC) bombs in the order of 100lb-1000lb (~50kg - ~450kg). These are more likely to be present on the inter-tidal zone or the inner Wash.

Bombs employed by the Germans varied from 50kg to 4000kg. However, less than 4% of all bombs dropped on Britain in WWII were of the larger variety; the majority were 500kg or less, with 50kg and 70kg bombs predominating (around 80%). The German HE bombs most likely to be encountered on this project therefore are medium capacity, ranging from the SC 50kg to SC 500kg.

High Capacity Blast Bombs (up to 80% explosives) and “Parachute” mines were also used. When laid by air, these German sea mines were usually fitted with bomb fuses that would function either on impact or with a delay, if they fell on land and did not receive the hydrostatic pressure required to disarm the bomb fuse and activate the mine influence sensors and firing circuits.

German bombs are readily identified by the shape of the tail (if still fitted) and, particularly, by their transverse fusing. Both 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, some could be in an extremely sensitive state.

A typical rocket was the RP-3. These 3 inch rockets had a 60lb (27 kg) warhead in the HE variant.

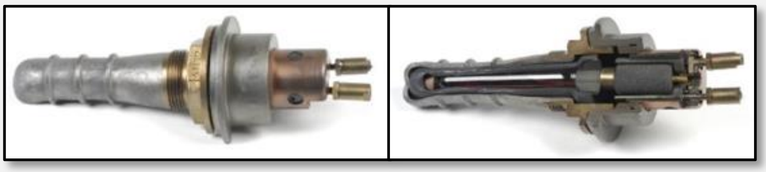
German (R) and British (L) HE bombs as UXO (note typical absence of tail)

Sea Mines

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

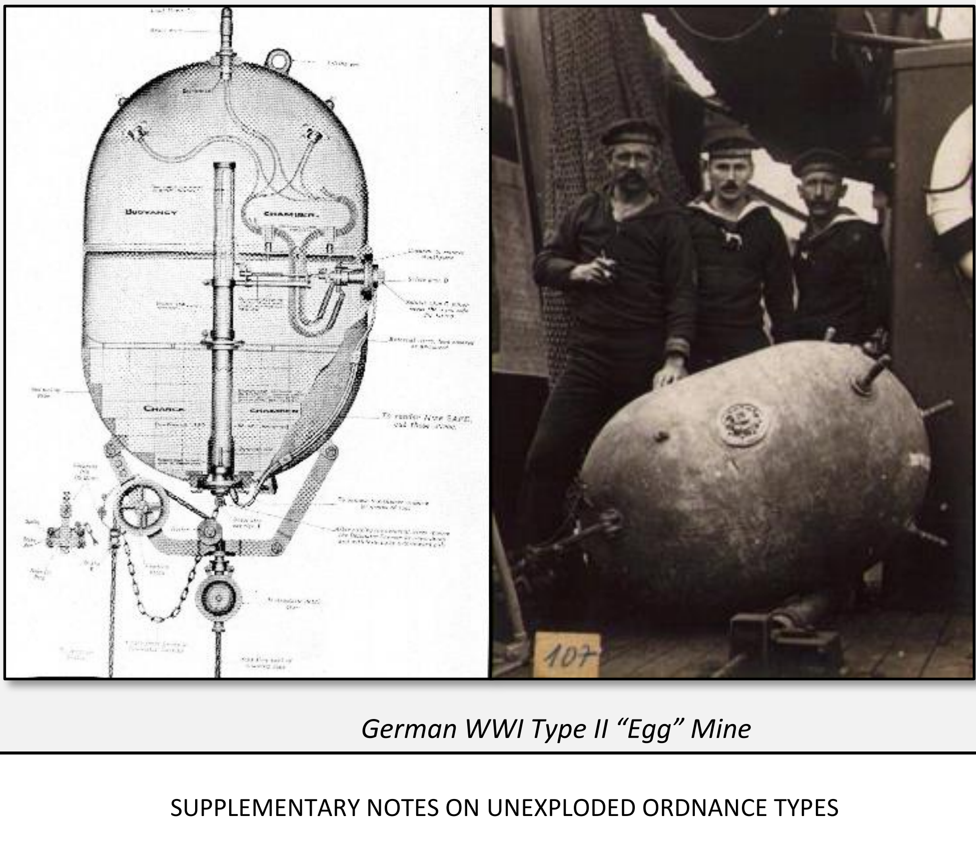
Buoyant Mines

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 “Herz” horns. The latter are also known as “Chemical Horns”. A Herz 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 Herz 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.



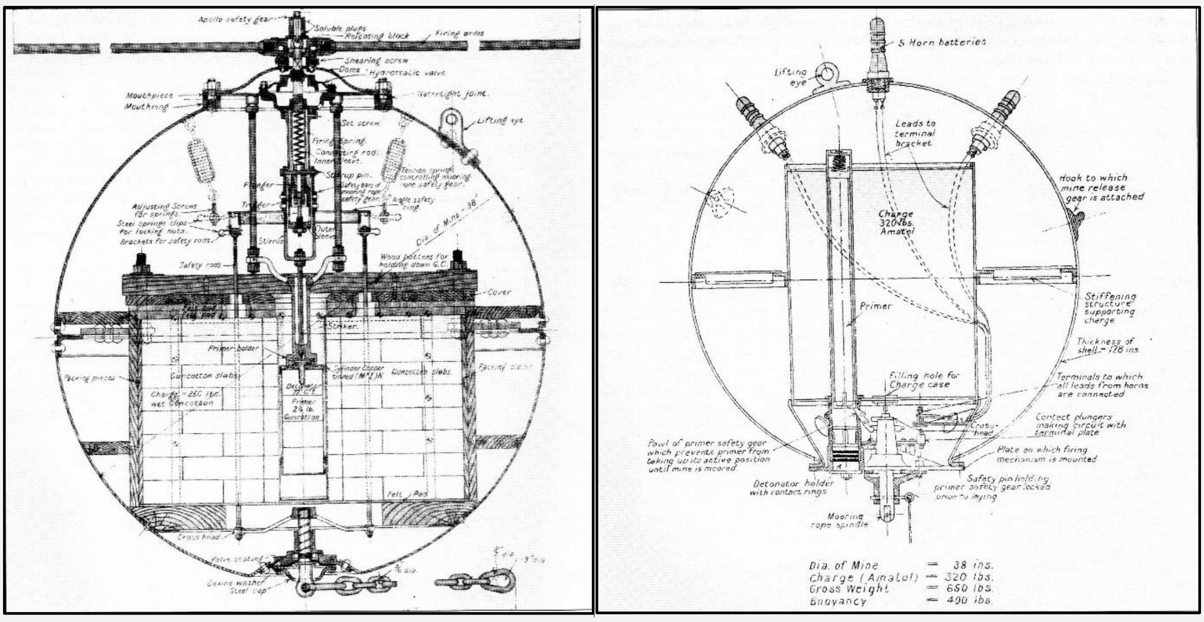
Herz (Chemical) Horn

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.

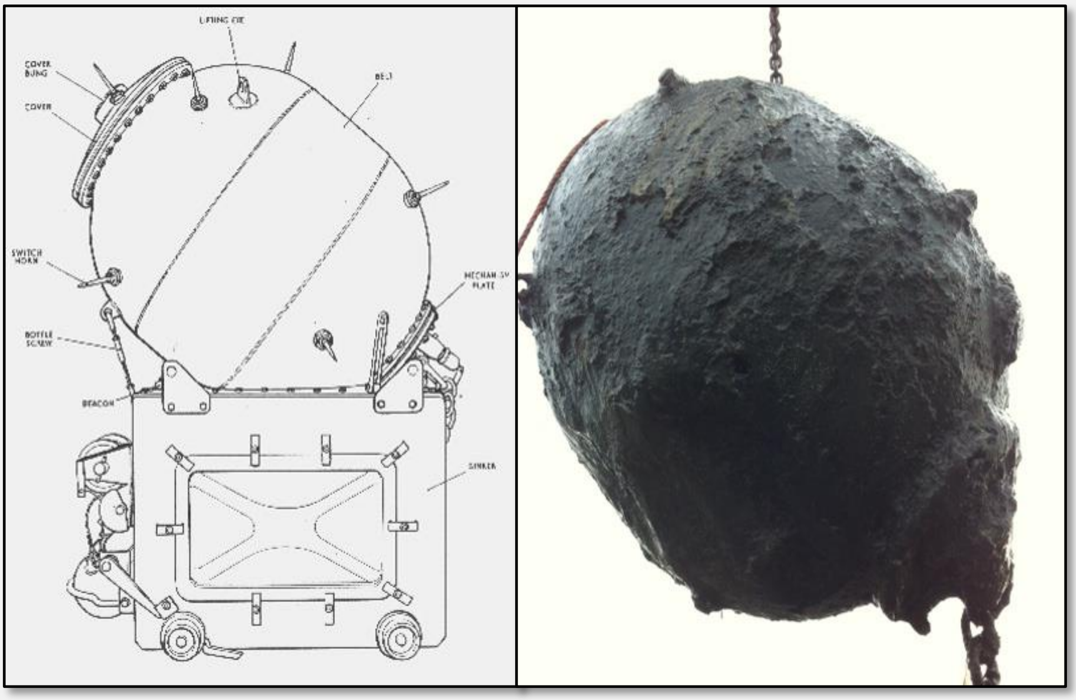


German WWI Type II “Egg” Mine

Mines specifically designed to drift mines are not particularly effective as an anti-ship weapon – their value lays in the fear and disruption they cause – and they 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 1907, 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 off the coast of Northern Europe.



British WWI "Naval Spherical" (L) and "H2" (R) buoyant mines



British WWII Buoyant mine in typical condition as found today

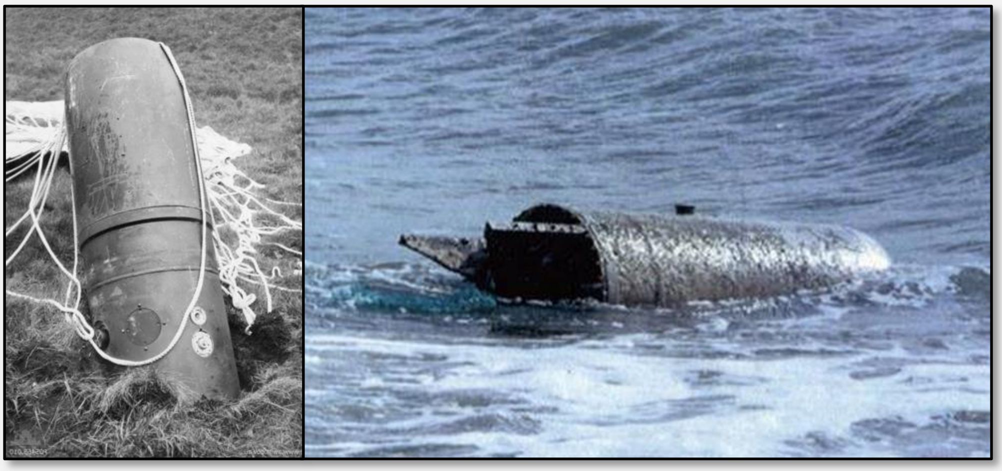
Other variants of moored mines, but used in much less numbers, were the Antenna Mine, an anti-submarine contact mine that used the current generated by two dissimilar metals rubbing together to fire, and the Magnetic mine, an "influence" mine that was actuated by the small electro-magnetic current generated when a target vessel's moving magnetic field cut the mine's internal coiled rod sensor or influenced the dip needle mechanism as, for example, in the German aluminium SMA (GO) buoyant mine shown below.

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. Later in WWII, the German's developed the "Oyster" mine; this had a pressure sensor that was either fitted in combination with an acoustic or magnetic sensor circuit.

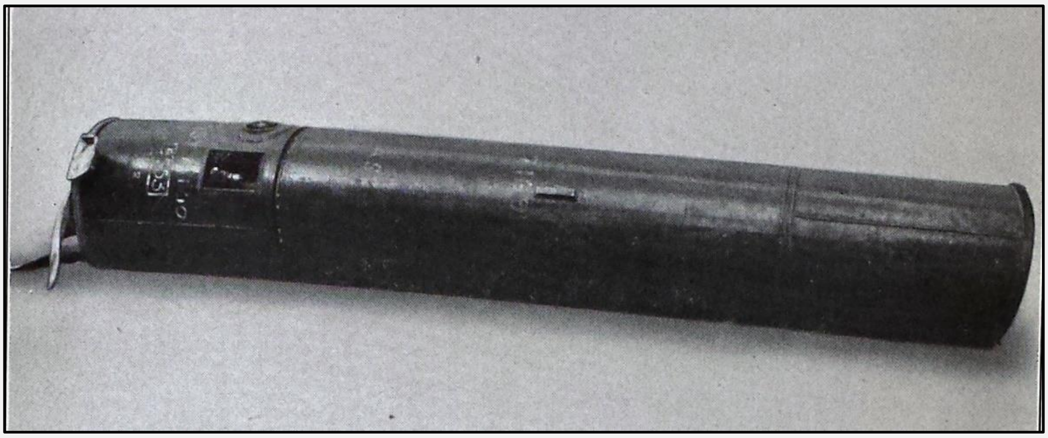
WWII German ground mines were made of aluminium with reliable *Rheinmetal* fuses and superbly engineered and consequently are frequently found in excellent condition after decades in the water. These German air dropped "parachute" mines are likely to be found intact and could probably function as designed if sufficient battery power was available. However, their batteries will now 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, some had clockwork delay mechanisms and others relied on human intervention; all could be in a very sensitive condition and could function if disturbed.



German WWII GC (LMB) mine used both as sea mine and blast bomb

The LMB mine casing is made of aluminium and its ferrous content depends on the sensors fitted but is commonly limited to the dip needle sensor arrangement, which contains magnets, and a few other small ferrous components, mainly within the mechanism section. The BM1000 casing is made of manganese steel and presents a very low magnetic target. The ferrous content of a BM1000 is similar to that of a LMB mine. The

LMB casing is 1.74m long (without any additional fittings) and has a diameter of 0.66m. The overall weight is 988kg (NEQ is 698kg Hexanite). The BM1000 casing is 1.52m long and the diameter 0.66m. The overall weight is 986kg (NEQ is 727kg Hexanite).



British AMIII ground mine

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 net explosive quantities (NEQs) of 45kg and 91kg. The British continued to develop ground mines throughout WWII, starting with A Mks I-IV in the early years, finally progressing to the A Mk IX by 1945. The AMks I-IV, which outwardly looked very similar, were the most common mine used by the British for offensive operations.

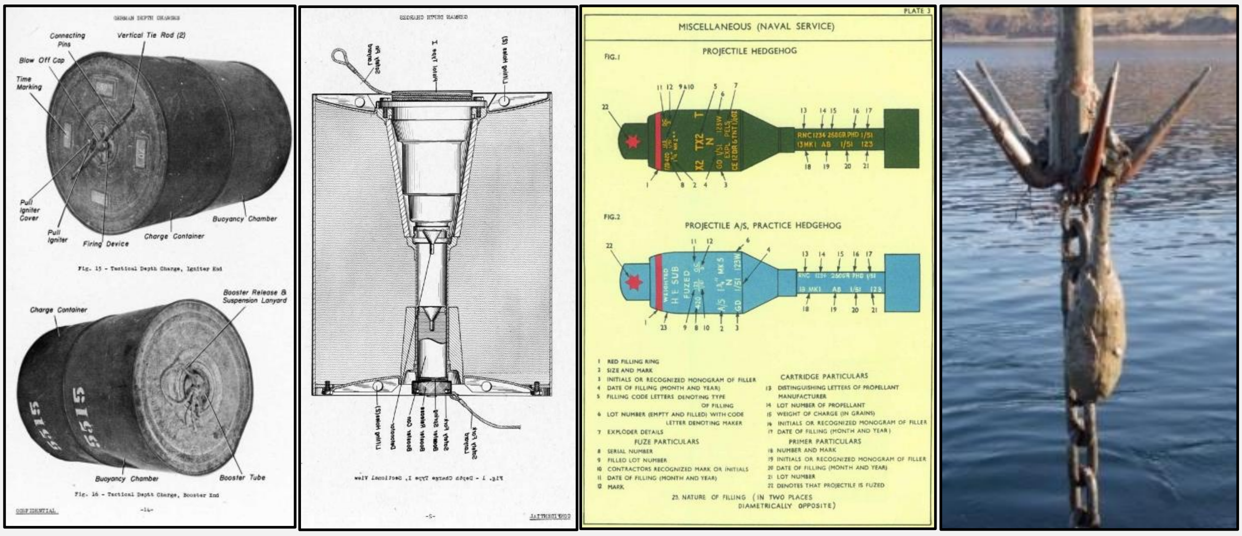
Naval and Artillery Projectiles

Most projectiles encountered in the study area likely to be relatively small calibre shells with an NEQ in the region of 2kg-5kg but larger WWI projectiles could be encountered and these have a slightly larger NEQ – up to 25kg of Picric acid based explosives, such as Shellite. Over time this explosive filling can react with the metal of the shell casing and create sensitive crystals of metal picrates, such as iron picrate. These are extremely sensitive, particularly if they are allowed to dry out and could easily be caused to detonate with sufficient power to initiate the main bursting charge. However, on balance, the risk they pose to Project activities is small. The hazard may reduce when the shells become corroded enough to admit seawater as these materials are water soluble.

An artillery projectile in typical condition on the seabed

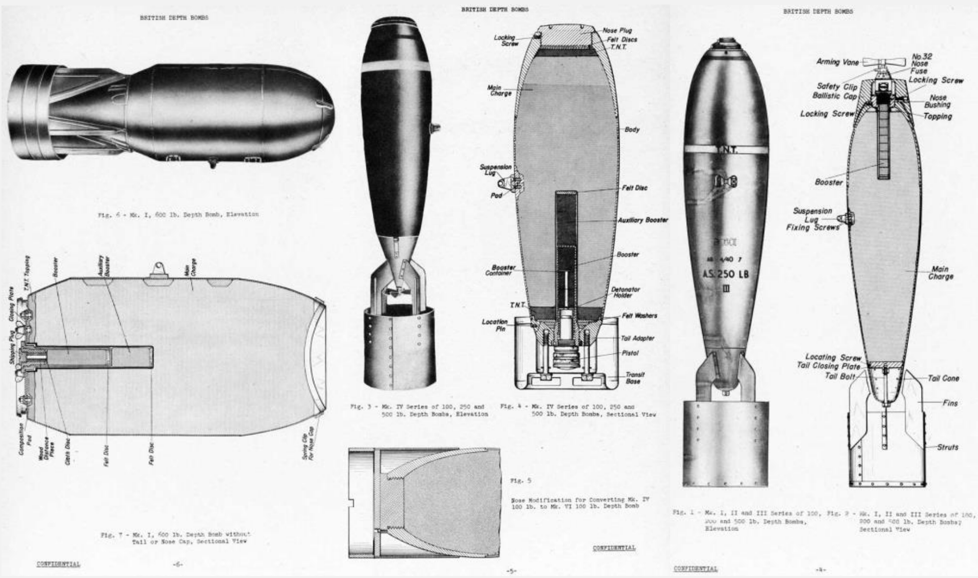
Depth Charges/Depth Bombs

A number of different types of depth charges and depth bombs could have been used to attack submarines, with an NEQ in the range of 50kg-200kg. They would have been caused to detonate by a hydrostatic pistol releasing a cocked striker or perhaps an impact bomb fuse with a delay.



Examples of German Depth Charge (L) and British Anti-Submarine "Hedgehog"

As anti-submarine "blast" weapons, all are thin-cased and consequently subject to severe corrosion in the intervening years, unless deeply buried in hypoxic sediment. Consequently, the firing mechanism is highly unlikely to operate as designed. Nevertheless, the firing train will very probably be complete (i.e. the detonator is in intimate contact with the primer and main charge) and this type of EO could present a significant UXO risk, given the relatively large NEQ. A depth charge could still detonate, for example, if crushed by the leg of a jack-up barge.



British Anti-Submarine Depth Bombs: L-R Mk I 600lb, Mk IV Series, Mk I-III Series

Torpedoes

Any torpedoes present within study area are likely to be of the “wet heater” or “burner cycle” types. During both WWI and WWII, the Germans developed torpedoes of the “wet heater” type; steam driven, with kerosene as fuel and compressed air providing oxygen for combustion. Warheads of around 250kg were detonated by means of a direct impact or magnetic fuse. WWI torpedo fusing was often unreliable and it is quite possible that attacks took place, unrecorded, when the torpedo failed to function and sank to the seabed. German WWII warheads were filled with 280kg of Hexanite and were generally much more reliable. In WWII, the Germans also developed an effective series of battery-driven torpedoes with similar sized warheads.

The standard British airborne torpedo for World War II was the 18-inch, a 450 mm-diameter design that progressed through several Marks through the war. It had an explosive charge of 388 lb (176 kg) of TNT. Later, more powerful versions had a 247kg Torpex warhead. As well as submarines, most ships of any size were fitted with torpedo launchers. The main British 21in heavyweight torpedo in use during WWII was the “improved” Mk VIII. It was used on ships, submarines and motor torpedo boats from 1927 and was the first British burner-cycle design torpedo. Depending on the variant, the warhead consisted of 325kg – 365kg Torpex.

Typical examples of heavyweight (21in/53cm) torpedoes

Annex B

Explosive Ordnance Technical Data

EXPLOSIVE ORDNANCE TECHNICAL DATA

MILITARY DESIGNATION	NATIONALITY	SHAPE	TYPE	FEATURES	NEQ	DIMENSIONS
			MINES			
GD (LMA)	German	Cylindrical	Ground Influence	Air Dropped with parachute/ also Surface Vessel	300kg	Diameter 66cm Length 2.0m (depending on configuration)
GC (LMB)	German	Cylindrical	Ground Influence	Air Dropped with parachute/ also Surface Vessel	700kg	Diameter 66cm Length 3.0m (depending on configuration)
GG (BM1000)	German	Cylindrical	Ground Influence	Air Dropped with parachute/ also Surface Vessel	730kg	Diameter 66cm Length 3.2m (depending on configuration)
TMC (GN)	German	Cylindrical	Ground Influence	Laid by submarine	907kg	Diameter 53.3cm Length 3.36m
EMA and EMB (GU)	German	Ovoid	Moored Contact	Equipped with five Hz Horns. Deployed with base mooring unit. Surface or submarine laid.	163kg or 220kg	Both had similar casing 1.17 m long x 0.863 m in diameter
EMC (GY, GV*)	German	Spherical	Moored Contact	Equipped with seven Hz Horns. Deployed with base mooring unit. Surface laid.	300kg	1.2 m in diameter
EMF (GO)	German	Spherical	Moored Influence	Magnetic influence mine, particularly sensitive in rough sea.	340kg	1.16 m in diameter 1.42m length
UMA (GZ)	German	Spherical	Moored Contact	Five Hz and three switch horns.	30kg	0.81 m in diameter
UMB (GR)	German	Spherical	Moored Contact	Improved moored contact mine with five Hz and three switch horns.	41kg	0.84 m in diameter
A Mk 1 – 4	British	Cylindrical	Ground Influence	Air Dropped with parachute	340-352kg	Diameter 45 cm Length 2.87 m

MILITARY DESIGNATION	NATIONALITY	SHAPE	TYPE	FEATURES	NEQ	DIMENSIONS
A Mk 5	British	Cylindrical	Ground Influence	Air Dropped with parachute	284-306kg	Diameter 40 cm Length 2.057 m
A Mk 6	British	Cylindrical	Ground Influence	Air Dropped with parachute	431kg	Diameter 49.4 cm Length 2.565 m
A Mk 7	British	Cylindrical	Ground Influence	Air Dropped with parachute	281kg	Diameter 42.6 cm Length 2.108 m
A Mk 8	British	Cylindrical	Ground Influence	Air Dropped with parachute	89kg	Diameter 34.3 cm Length 1.448 m
A Mk 9	British	Cylindrical	Ground Influence	Air Dropped with parachute	499kg	Diameter 9.4 cm Length 2.59 m
Naval Spherical Mk III (Service)	British	Spherical	Moored Impact Inertia	Unreliable mine used in the early years of WWI	113kg (wet gun cotton)	~0.8 m diameter
H2	British	Spherical	Moored Contact	5 Herz horns	320lbs (145kg) Amatol	0.97m diameter
Mk XIV	British	Ovoid	Moored Contact	Equipped with 11 mainly Hertz Horns. Used in both WWI and WII.	145kg or 227kg	1.02 m in diameter
Mk XV	British	Ovoid	Moored Contact	Equipped with 11 mainly Hertz Horns. Used in both WWI and WWII.	145kg or 227kg	1.02 m in diameter
Mk XVII	British	Ovoid	Moored Contact	Equipped with 11 switch Horns. Used in WWII.	145kg	1.02 m in diameter
TORPEDOES						
G7a Naval Torpedo (multiple combinations of warhead and fusing)	German	Cylindrical	Impact or Magnetic	Some fitted with Whiskers, Wet Heater propulsion	235kg-295kg	21 inch diameter (533 mm) Length 7.162 m

MILITARY DESIGNATION	NATIONALITY	SHAPE	TYPE	FEATURES	NEQ	DIMENSIONS
G7e	German	Cylindrical	Impact or Magnetic	Electric	280kg	21 inch diameter (533 mm) Length 7.186 m
Luftwaffe Torpedo (F5)	German	Cylindrical	Impact or Magnetic	Wet Heater	200kg	45 cm diameter Length 4.8 m – 5.16 m
Torpedo Mk VIII	British	Cylindrical	Impact or Magnetic	Air/Steam powered	340kg or 365kg	21 inch (533 mm) diameter Length 6.579 m
Torpedo Mk XII	British	Cylindrical	Impact	Air/steam powered	176kg	45 cm diameter Length 4.95 m
DEPTH CHARGES						
DC Type I	German	Cylindrical	Hydrostatic Pistol (cocked striker)	Preset depth set by hand. 5 pistol types	136kg	44.5 cm diameter Length 57.0cm
Mk7 Series	British	Cylindrical	Hydrostatic Pistol (cocked striker)	Preset depth set by hand. 3 versions, depending on depth range	147kg	44.4 cm diameter Length 70.2cm
Mk11	British	Cylindrical	Hydrostatic Pistol (cocked striker)	Dropped by aircraft. Length with tail 1.39m	82kg	27.9 cm diameter Length 94.4cm
BOMBS						
250lb GP Bomb	British	Streamlined sides with ogival nose	Impact/delay	Tail or Nose pistol or fuse	95kg, 100kg, 105kg	Diameter 26 cm Body Length 0.72 m
500lb MC Bomb	British	Parallel sides with ogival nose	Impact/delay	Tail or Nose pistol or fuse	95kg, 100kg, 105kg	Diameter 32.7cm Body Length 1.041 m
1000lb MC Bomb	British	Parallel sides with ogival nose	Impact/delay	Tail or Nose pistol or fuse	215kg, 226kg, 238kg	Diameter 45 cm Body Length 1.33 m

MILITARY DESIGNATION	NATIONALITY	SHAPE	TYPE	FEATURES	NEQ	DIMENSIONS
12000lb HC bomb	British	Parallel sides with convex nose	Impact/ Delay	3 nose pistols, sectional construction (each section ~1.23m	5425 kg	Diameter 0.97m Body Length 3.7m
500lb MC	US	Parallel sides with ogival nose	Impact/delay	Tail or Nose pistol or fuse	126kg	Diameter 0.36 m Body length 1.2 m
1000lb MC	US	Parallel sides with ogival nose	Impact/delay	Tail or Nose pistol or fuse	260kg	Diameter 0.48 m Body length 1.37 m
2000lb MC	US	Parallel sides with ogival nose	Impact/delay	Tail or Nose pistol or fuse	525kg	Diameter 59.2 cm Body Length 1.824 m
50kg SC	German	Parallel sides with ogival nose	Impact/delay	Transverse fusing	25kg	Diameter 0.20m Body length ~0.67 m
250kg SC	German	Parallel sides with ogival nose	Impact/delay	Transverse fusing	130kg/145kg	Diameter 0.368 m Body length 1.2 m
500kg SC	German	Parallel sides with ogival nose	Impact/delay	Transverse fusing	220kg	Diameter 0.46 m Body length 1.45 m

Annex C

Potential Detonation Mechanisms for Explosive Ordnance Items

POTENTIAL DETONATION MECHANISMS FOR EXPLOSIVE ORDNANCE ITEMS

Air Dropped Bombs

Statistics compiled after the war showed that approximately 8.5% of the bombs dropped failed to explode. Subsequent Home Office analysis came up with figure of between 9%-11%. The reasons for failure were several, the main ones were:

Not armed correctly on release from the aircraft

- Deliberately dropped “safe” (if being jettisoned)
- Failure/jamming of a clockwork delay mechanism
- Impact fuse malfunction on striking the ground
- Failure of the detonator or gaine (booster)

Today, in the marine environment, pistols and fuses are likely to be corroded and unlikely to function as intended, although they may be in a sensitive state through the exudation of sensitive salts (this is much less likely underwater than on land). However, a blow with sufficient kinetic energy directly onto a fuse or fuse pocket could be enough to detonate the EO. Small bombs could be lifted inadvertently in the flukes of an anchor; this is unlikely in itself to cause the UXO to detonate but if allowed to dry out, it may become much more sensitive to knocks and friction. Most bombs are relatively thick-cased and therefore not easy to crush; they are more likely to be pushed further into the sediment or moved aside.

Incendiary bombs containing phosphorous pose a particular danger in certain scenarios. If exposed to the air, phosphorous will spontaneously ignite and, while not detonating, will burn fiercely, thereby presenting a threat to exposed personnel and inflammable equipment.

Buoyant Mines

Today, if encountered both WWI and WWII buoyant mines will be found situated on the seabed, often partially buried in the sediment. The mine casings will be heavily corroded. Chemical (Hertz) horns may still be capable of functioning but internal wiring and firing mechanisms are unlikely to be effective. Switch horn mines require power from an internal battery and these will no longer function. The explosive filling is likely to be stable if undisturbed but the mine may still detonate if appropriate criteria are met. If wiring is intact on Hertz horn variants, crushing or deforming the horn could trigger the mine. Charge weights are between 145 - 227kg.

British Ground Mines

WWII British ground mines were made of steel. If encountered, they could be partially or completely buried. Significant corrosion to the casing may have taken place, depending on the depth of burial. Internal batteries, required to power internal influence sensors and the firing mechanism, will have discharged. These mines will not function as intended but have a large charge weight (300kg - 450kg) that could still detonate if the right conditions are met. The detonator is placed in line with the booster by hydrostatic pressure. Once the correct depth of water is reached the detonator is locked into place and cannot easily be withdrawn. It is not possible to see on a cursory external visual inspection (e.g. by diver or ROV) whether the mine is armed or not. It must be assumed that the mine is fully armed and the firing train is complete.

German Ground Mines

WWII German ground mines were very well engineered, with casings of corrosion-resistant aluminium or manganese steel and fuses made by Rheinmetal. They are very liable to be found intact and in excellent condition. The mines could still function as designed if sufficient battery power was available. However, the batteries will have discharged. Many variants were fitted with booby traps and anti-disturbance devices. Charge weights are likely to be in the region of 700kg of HE. Common German ground mine variants, GC & GD, are relatively thin-cased and therefore susceptible to crushing.

Projectiles

HE Naval and artillery projectiles typically will be around 5kg NEQ, but less than 50kg, and consequently present minimal threat to vessels and equipment. Any fusing will be corroded and unlikely to function as designed. However, as relatively small items, they could become wedged in the flukes of an anchor and be brought to the surface, presenting a blast and fragmentation hazard to exposed deck-hands. WWI projectiles were filled with Picric Acid, and derivatives that could be in an extremely sensitive state, particularly if allowed to dry out.

Torpedoes and Depth Charges

As with most UXO, torpedo warheads are liable to be stable if undisturbed but remain a potential hazard, particularly if after launch from the torpedo tube, safety détentes have been removed and the firing train is complete; that is, the detonator is married to the booster and main charge within the warhead. Any depth charges encountered, unless they have been completely buried in hypoxic sediment, are likely to be severely corroded and decomposed to the point of presenting minimal hazard. The firing mechanism is highly unlikely to operate as designed. Nevertheless, the firing train will very probably be complete (i.e. the detonator is in intimate contact with the primer and main charge) and this type of EO could present a significant UXO risk, given the relatively large NEQ. A depth charge could still detonate, for example, if crushed by the leg of a jack-up barge or a vessel grounding.

Land Service Ammunition

A mortar relies on a striker hitting a detonator for detonation to occur. If a mortar failed to function as designed, it is possible that the striker may already be in contact with the detonator and that only a slight increase in pressure would be required for initiation. Similarly, a grenade striker may either be in contact with the detonator or still be retained by a spring under tension and therefore shock may cause it to function. In addition to HE, these items of LSA may be filled with "pyrotechnics" which come in a variety of flares and smoke generating compounds and can include magnesium, thermite and phosphorus.

Small Arms Ammunition

Small arms ammunition (SAA), even if it functioned, is not contained within a barrel and consequently detonation would only result in local overpressure and very minor fragmentation from the cartridge case. SAA cartridges are frequently discovered in military practice areas. These are likely to have been dropped inadvertently during training or deliberately discarded by soldiers. Although technically explosive ordnance, they pose little risk unless they are caused to function by a deliberate act. Moreover it is illegal for an unlicensed person to be in possession of SAA, therefore all finds no matter how minor should be reported in accordance to the appropriate procedure.

Practice Munitions

Most modern practice munitions are painted light blue and/or have fluorescent orange markings. Older practice weapons were often painted white. Generally these are inert but may have small smoke and flash components, which could present a small hazard to personnel close by if these have not been expended. Many practice bombs are readily distinguished as “practice” by their shape and size. However, most practice ordnance items use the same casings, filled with inert material, as the HE versions. Older practice ordnance that has been immersed in sea water for some time will not easily be distinguished from the live, HE-filled, version, even by an EOD expert. If encountered, usually these items will have to be treated as if live.

Bilag 2 ORDTEKS tillæg om Risk Mitigation_V1.0 af 23. februar 2018

Unexploded Ordnance (UXO) Risk Management Technical Note

Title	Lillebaelt Syd Offshore Wind Farm – Defining the UXO Risk Mitigation Strategy for the Geotechnical Campaign
Client	COWI
Project	Lillebaelt Syd Offshore Wind Farm
Project Number	JM5376
Document Version	1.0
Author	Henry McPartland
Reviewed By	Lee Gooderham
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References	A. Ordtek - JM5376_Lillebaelt Syd OWF_COWI_UXO_Risk_Assessment_Mitigation_Strategy_V2.0, dated 2017

1. Background

The aim of this document is to set out the UXO risk mitigation strategy ahead of the confirmed geotechnical investigation campaign, in particular providing clarity on the level of mitigation prior to jack-up operations. In addition, Ordtek will advise on the required separation between jack-up legs and any geophysical anomalies modelling as potential UXO (pUXO).

The geotechnical campaign is proposed to comprise 10 vibrocores from a DP vessel and 5 CPTs from a jack-up barge (15 positions in total).

2. UXO Risk Mitigation Strategy for Geotechnical Operations

2.1 Available Geophysical Data

The following datasets are available for UXO risk mitigation:

- Multibeam Echosounder (MBES) – Reson T20-P with 400 kHz
- Side Scan Sonar (SSS) – Edgetech 4200 with 100/400 kHz

2.2 Mitigation Strategy for Jack-up Leg Operations and Boreholes

- Assess existing acoustic geophysical data. The resolution and specification should be sufficient to identify UXO within the threat spectrum. Select seabed features that have the potential to be UXO by comparing the threats from Reference A.
- Avoid any targets that model as potential UXO by 10m (radius).

2.3 Mitigation Strategy for All Works including Vibrocore from a DP Vessel

2.3.1 UXO Risk Management 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.

2.3.2 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 should include the hazards and characteristics of CW. 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.