Hesselø South Offshore Wind Farm

ENERGINET

Unexploded Ordnance Threat and Risk Assessment with Risk Mitigation Strategy

Meeting the requirements of the UK's Construction Industry Research and Information Association's UXO Risk Management Framework: "Assessment and Management of the UXO Risk in the Marine Environment" (C754)

6 Alpha Associates Ltd

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Executive Summary

Project Overview

Energinet has commissioned *6 Alpha Associates Ltd* (hereafter 6 Alpha) to deliver a desk-based Unexploded Ordnance (UXO) threat and risk assessment to support the development of the *Hesselø South Offshore Wind Farm*, as part of the wider *Danish Offshore Wind 2030* project. A risk mitigation strategy for the proposed works has been commissioned and is presented in Part III of this document.

UXO Threat Summary

Significant archive research has unearthed clear evidence of prospective UXO contamination at the Study Site, primarily driven by *Allied* aerial minelaying operations across the *Kattegat* during WWII, including *Minegarden Silverthorn* which overlapped the entire Study Site. This UXO contamination threat has been further evidenced by the discoveries of two *British* A Mark I-IV mines within the OWF array in the past decade, in addition to further such encounters in the Study Site's surrounding area.

Further UXO contamination threats might have been generated as a result of modern naval firing exercises and WWII-era Anti-Aircraft Artillery (AAA) projectiles, as well as munitions dumping activities undertaken following the end of WWII in the *Kattegat*.

Collectively, these activities are likely to have generated a potential UXO contamination threat across the Study Site – as illustrated at Appendix 10. The prospective UXO threats together with their (worst-case) likelihood of encounter scenarios are summarised at Table I.

Likelihood of Encounter	UXO Threat Items
HIGHLY LIKELY	WWII-era Naval Mines
LIKELY	Modern Naval Projectiles
POSSIBLE	WWII-era *German* Aerial Bombs, Depth Charges and AAA Projectiles
UNLIKELY	N/A
HIGHLY UNLIKELY	WWII-era *British* Aerial Bombs and Depth Charges

Table I: UXO Threat Assessment Summary

UXO Risk Assessment Summary

A strategic level semi-quantitative UXO risk assessment has been undertaken and it is standard *6 Alpha* practice to divide the Study Site into multiple UXO risk zones based upon one, or a combination of, the following factors:

- The nature and scope of seabed intrusive activities and the distances from pertinent UXO threat sources;
- The varying water depths (in LAT) across the Study Site;
- The project stakeholders' assumed appetite for the carriage of residual UXO risks.

At a worst-case, assuming that jack-up barges may be used to facilitate the GI campaign, UXO risks to the GI phase of work have been categorised as ***HIGH*** across the majority of the Study Site – driven by the likelihood of encountering and initiating WWII-era *British* naval mines, which were deployed in large quantities from aircraft across the Nonetheless, the likelihood of encountering such munitions in very shallow waters is much reduced, and therefore a small area of ***LOW*** UXO risk has been defined in the nearshore sector of the export cable corridor. The resultant risk zones for the GI phase of works are presented at Figure I.

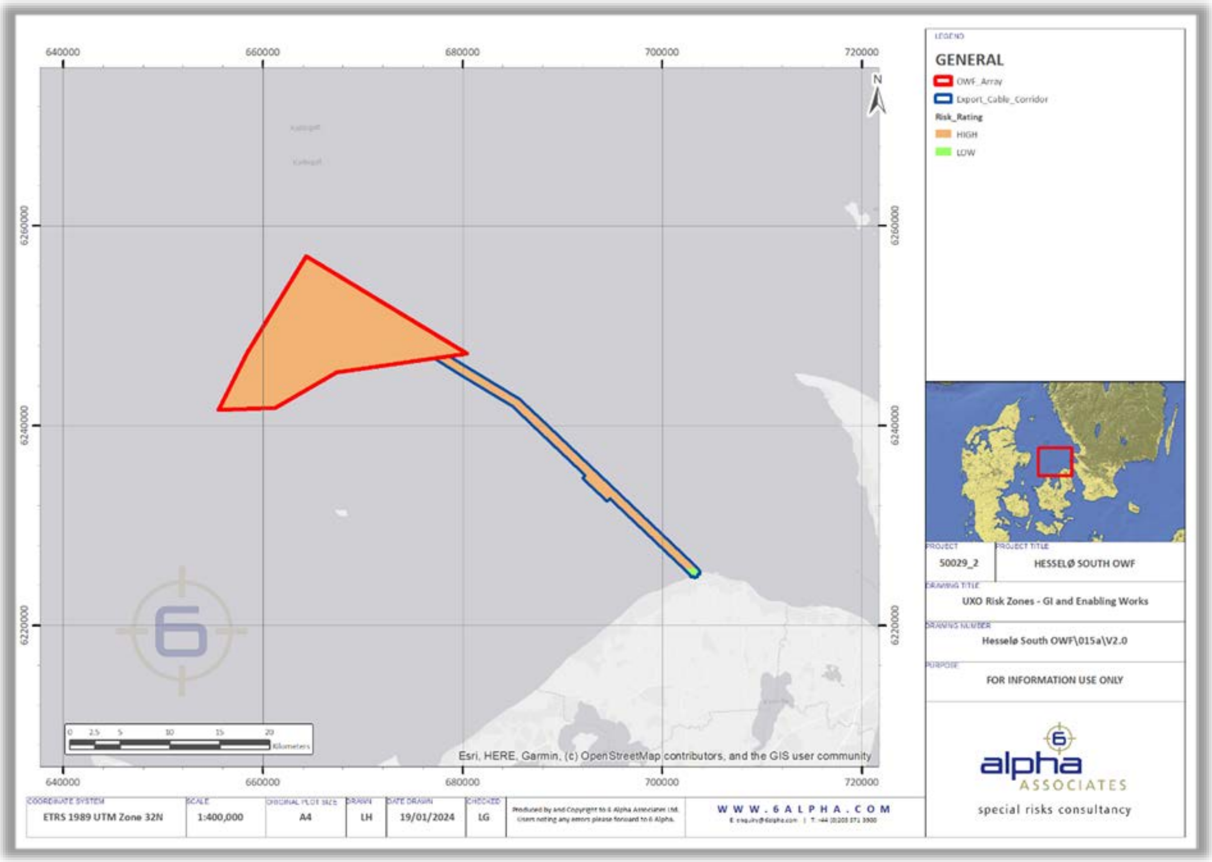

Figure I: UXO Risk Rating – GI and Enabling Operations

Nonetheless, given the elevated probability of encountering WWII-era naval mines across the Study Site during the construction and installation phase of works, at a worst-case scenario, the UXO risks are assessed as ***VERY HIGH*** during this phase of work – near to recent UXO encounters. Figure II presents the UXO risk zoning associated with the construction and installation works.

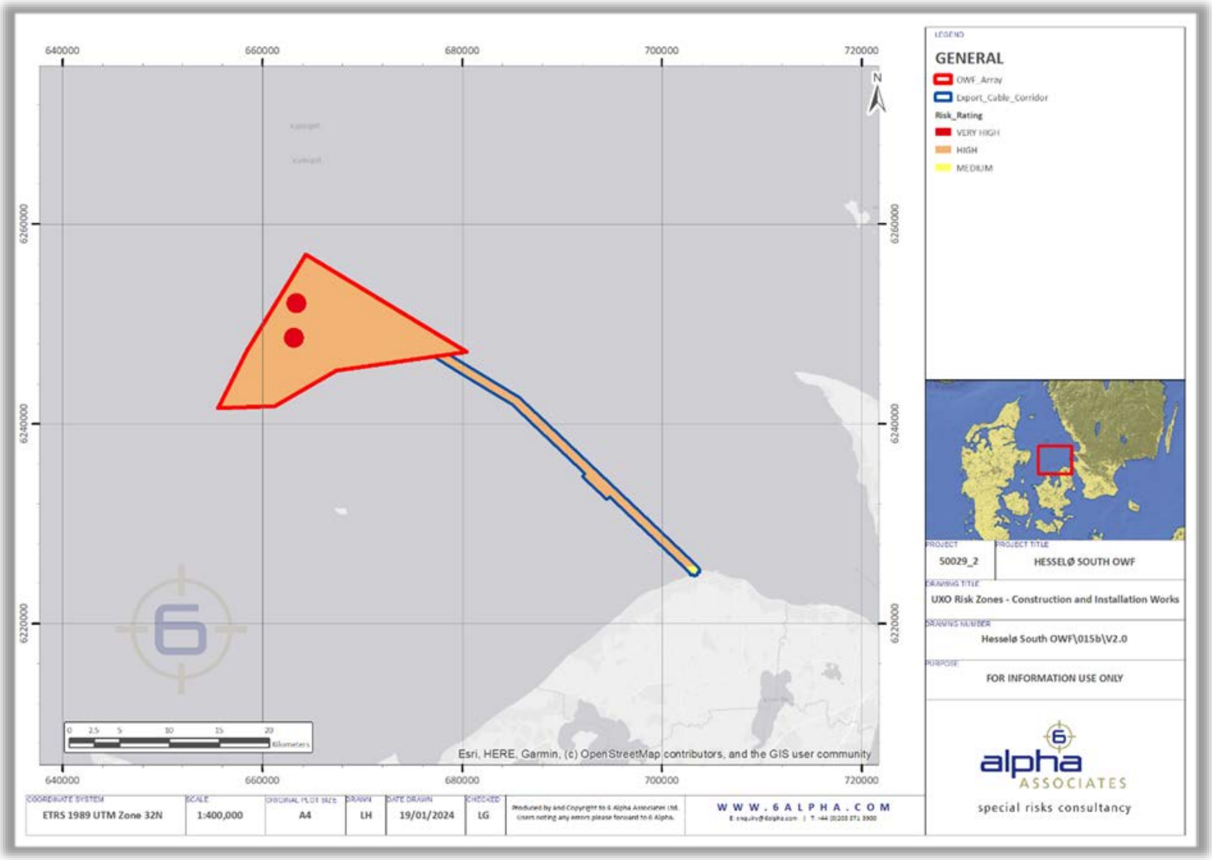

Figure II: UXO Risk Rating – Construction and Installation Operations

Risk Mitigation Strategy

6 Alpha's approach is that there are three main strategic risk mitigation options to reduce the UXO risk ALARP, based upon source-pathway-receptor modelling are, in priority order:

1. Avoidance;
2. Removal of Risk Receptors;
3. Removal of Threat Sources.

The Risk Mitigation Strategy will be enacted through the implementation of proactive and reactive risk mitigation measures.

Proactive UXO Risk Mitigation Measures

A conventional geophysical UXO survey, appropriately designed to detect threat spectrum UXO, is recommended prior to the commencement of the GI and construction operations, to provide a basis for a strategy of pUXO avoidance, or to facilitate its identification and removal.

This survey should include acoustic and magnetic detection methodologies (i.e. side scan sonar, multi-beam echo sounder and magnetometer/gradiometer) and any point intrusive works within this area must also be located along the magnetometer line for safety purposes.

Reactive UXO Risk Mitigation Measures

In all risk zones across the Study Site, "reactive" UXO risk mitigation measures should be put in place, namely:

- Any vessels involved in intrusive works are to be equipped with UXO specific Emergency Response Plan(s);
- All personnel involved with intrusive works are to receive a UXO Safety and Awareness Briefing concerning the identification of relevant UXO and safe actions to be taken in the event of a UXO encounter;
- Safety and Awareness mini-posters concerning the nature of the UXO threat and the key actions to be taken, are to be displayed on operational vessels;
- Shore-side and office-based explosive ordnance disposal engineers may be engaged to provide remote, rapid UXO recognition advice and to provide immediate safety management guidance in the event that UXO is discovered.

UXO Risk Mitigation Measures – Design, Specification and Guidance

Broadly, existing geophysical survey data and/or any newly captured data needs to be able to detect the following type of UXO, as specified at Table II:

Water Depth	Minimum UXO Threat	Dimensions (L x W)	Estimated Ferrous Mass	Explosive Fill
Up to 26m LAT	**SC-50 HE Bomb**	762mm x 200mm	25-30kg	25kg TNT
More than 26m LAT	**Type I Depth Charge**	572mm x 445mm	54.5kg	136kg

Table II: Minimum UXO Threat Items by Water Depth

Further Recommendations

6 Alpha recommend that the Client's next steps are focused upon phase four of the UXO Risk Management Framework namely, that detailed designs and specifications to support the recommended proactive UXO risk mitigation measures are implemented. The specifications are to be delivered and the UXO risk mitigation work is to be executed, in advance of the intrusive works, in order to warrant and to evidence that UXO risks have been mitigated and reduced to ALARP.

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Acronyms and Abbreviations

AAA	Anti-Aircraft Artillery
AHT	Anchor Handling Tugboat
ALARP	As Low As Reasonably Practicable
CIRIA	Construction Industry Research and Information Association
cm	Centimetre
CPT	Cone Penetration Testing
cUXO	Confirmed Unexploded Ordnance
DP	Dynamically Positioned
ETRS	European Terrestrial Reference System
EU	European Union
GI	Geotechnical Investigation
GP	General Purpose
HE	High Explosive
JUB	Jack-Up Barge
JUV	Jack-Up Vessel
kg	Kilogram
kHz	Kilohertz
km	Kilometre
LAT	Lowest Astronomical Tide
m	Metre
MBES	Multi-Beam Echo Sounder
MC	Medium Capacity
mm	Millimetre
MMBA	Munitions Migration and Burial Assessment
MPa	Megapascal
NEQ	Net Explosive Quantity
OSPAR	Oslo-Paris Convention for the Protection of the North-East Atlantic
OSS	Offshore Sub-Station
OWF	Offshore Wind Farm
PEXA	Practice and Exercise Area
PLGR	Pre-Lay Grapnel Run
pUXO	Potential Unexploded Ordnance
RC	Route Clearance
SQRA	Semi-Quantitative Risk Assessment
SSS	Side Scan Sonar
TAN	Technical Advisory Note
TI	Target Investigation
TNT	Trinitrotoluene
UK	United Kingdom
US	United States (of America)
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance
WTG	Wind Turbine Generator
WWI	World War One
WWII	World War Two

Part I – Introduction

1 Project Overview

1.1 Scope of Work

Energinet has commissioned *6 Alpha Associates Ltd* (6 Alpha) to deliver a desk-based Unexploded Ordnance (UXO) threat and risk assessment to support the development of the *Hesselø South Offshore Wind Farm* (OWF), as part of the wider *Danish Offshore Wind 2030* project*.* A risk mitigation strategy for the proposed works has also been commissioned and is presented in Part III of this document.

1.2 Project Location

The proposed OWF is situated in *Danish* waters within the *Kattegat,* approximately 12km to the north of the island of *Hesselø, Denmark*. The Site also features a potential export cable corridor to *Sjælland*, which makes landfall to the west of the town of *Gilleleje*.

The proposed location of the Study Site is presented at Figure 1 below and at Appendix 1.

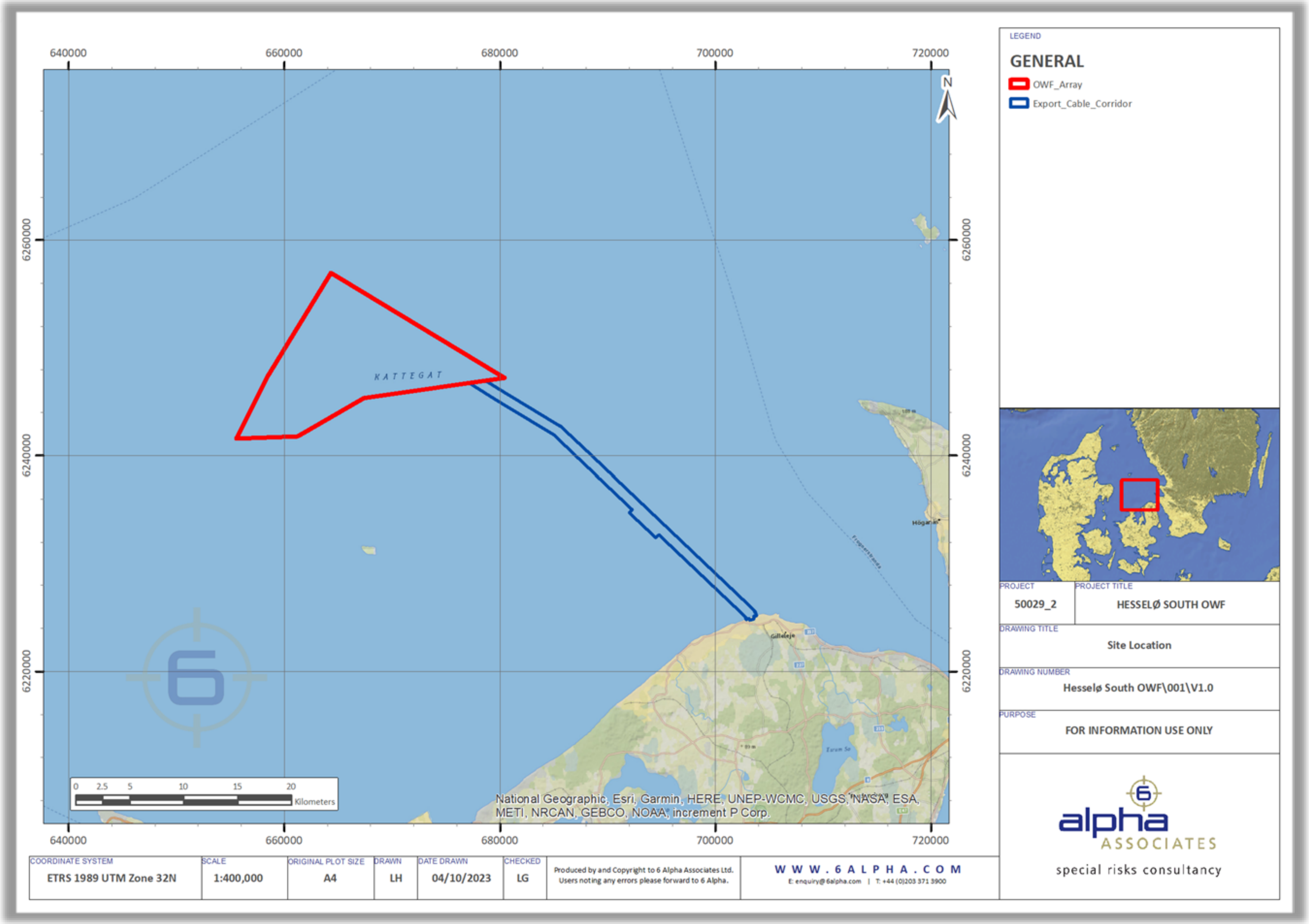


Figure 1: Site Location

2 Introduction to UXO

2.1 UXO in the Marine Environment

All military technology has an inherent base-line failure rate, meaning that not all ordnance functions as the designer intended, either during its training or operational use. Consequently, the military activities and conflicts of the 20th Century have left a legacy of munitions contamination in the marine environment, and it is now a relatively common occurrence to encounter UXO during seabed intrusive activities.

2.1.1 Generic UXO Threats

In the offshore environment, there are multiple factors that may have contributed to the UXO contamination, largely driven by the various conflicts of the 20th Century. For example, it is generally accepted that during WWII approximately 10% of *Axis* aerially delivered bombs failed to explode – *Allied* bomb failure rates are estimated to be slightly higher. Aerial bombing targets were also simply missed, and bombs were sometimes jettisoned from aircraft during evasive manoeuvres and/or when seeking to reduce aircraft weight during a return journey, to deliver a higher safety margin when landing.

During both World Wars, the naval theatre of war played a crucial role with surface vessels and submarines often involved in blockades, skirmishes and covert operations. Sea mines were also deployed in significant quantities in both offensive and defensive naval operations, posing a further UXO contamination threat to intrusive sub-seabed activities in the marine environment.

Wartime training exercises also employed live munitions filled with high explosives (or else other substances including toxic chemicals or ignition/burning agents), which may have remained on the seabed after the training exercises had been completed. Modern military training areas, such as offshore firing ranges, may have also contributed to the background UXO contamination in the offshore environment.

Conventional and chemical munitions dumping was also prevalent throughout this period, particularly following the widescale disarmament post-war, often with little consideration given to future safety implications. Widespread unrecorded dumping of land service ammunition and small arms ammunition was also perceived to be inconsequential, and it was therefore frequently undertaken without regard to munitions dump positional accuracy – resulting in so-called “short dumping”. Some dumped munitions may also have migrated from their original locations because of natural seabed sediment transportation and other forces.

Besides the clearance of naval minefields to open sea lanes, minimal effort was made in the immediate post-war periods to clear the unexploded bombs and projectiles that contaminated the seabed. As such, unexploded munitions relating to previous conflicts, but particularly WWII-era munitions, often pose a considerable contamination threat source in the marine environment.

2.1.2 Generic UXO Risks

The explosive or chemical fill within UXO rarely becomes inert or loses its effectiveness with age, but instead the explosive fill may change or crystallise over time – increasing the high explosive's sensitivity to a physical shock or an impact. Trigger mechanisms and fuses, which may have failed, may corrode and deteriorate in the saltwater environment becoming more sensitive to detonation. It is therefore possible that a significant impact on the UXO case, and the resultant effect upon the fuse, may cause its inadvertent detonation.

Prospective UXO incidents that may result in harm are generally considered low probability-high consequence events, which present a challenge when designing project, public and commercial safety policies. Nonetheless, there are clear safety risks associated with UXO encounters for any subsea operation that interacts with the seabed, which must be managed in order to protect offshore personnel from injury or, in the very worst-case scenario, prospective fatalities. Such risks must also be considered, to fulfil Clients' statutory obligations under the auspices of national laws.

2.2 UXO Industry Best Practice

There is no specific legislation concerning the management of UXO risks during construction, engineering or ground investigation projects in the *European Union* (EU) generally, or in *Denmark* specifically. *6 Alpha* have therefore employed a risk assessment process advocated by the *United Kingdom's (UK*'s*) Construction Industry Research and Information Association* (*CIRIA*).

Whilst the *CIRIA C754* guide is a *British* publication (and is endorsed by the *UK*'s *Health and Safety Executive*), its guidance and risk management principles have generally become the accepted as the industry leading standard globally, for managing UXO risks during marine projects. Consequently, *6 Alpha* have successfully employed *CIRIA* C754 guidance on projects throughout the *UK, Europe* and *Asia* and strongly recommend that its guidance is followed on this project.

CIRIA C754 guidance provides a coherent framework for offshore UXO risk management projects and therefore, in undertaking this assessment *6 Alpha* has ensured compliance with industry best practice and As Low As Reasonably Practicable (ALARP) risk reduction criteria – through continued adherence to the framework, which has been employed on similar projects throughout the *EU*, the project stakeholder's legal obligations will be fulfilled.

Further information regarding national and international legislation within the *EU*, and the management and reduction of UXO risk to ALARP, is presented at Annex A and is indicative of the safety benchmark to which *6 Alpha* adhere.

2.3 UXO Risk Management Strategic Framework

At Section 5 of *CIRIA's* C754 guide, the risk management framework is divided into five key phases that correspond with those employed by *6 Alpha*, as presented at Table 1. A complete overview of *6 Alpha's* UXO Risk Management Framework is presented for completeness, at Appendix 2.

6 Alpha Risk Management Framework	UXO Risk Management Phase	CIRIA C754 Risk Management Framework	Delivered within Report? (✔/✘)
UXO Threat Assessment	**PHASE ONE**	UXO Threat Assessment	✔
UXO Risk Assessment	**PHASE TWO**	UXO Risk Assessment	✔
Strategic Risk Mitigation Options	**PHASE THREE**	UXO Risk Management Strategy	✔
Risk Mitigation Design and Specification	**PHASE FOUR**	UXO Risk Mitigation (Planning)	✘
Implementation	**PHASE FIVE**	UXO Risk Mitigation (Delivery)	✘

Table 1: 6 Alpha and CIRIA UXO Risk Management Frameworks

The purpose of this report is to address Phases One, Two and Three of the above UXO risk management framework. This framework is applied to provide a holistic solution for managing UXO risks to ALARP, as per Appendix 3.

The potential nature and scope of the UXO threat is addressed initially (Phase One), before the potential UXO risk pathways are identified and analysed to assess the UXO risks associated with the proposed operations (Phase Two).

Once the associated UXO risks have been assessed, recommendations are outlined for the completion of a suitable Risk Mitigation Strategy (Phase Three), which has been commissioned and is presented in Part III of this document.

In addition, *6 Alpha* recommend that Phase Four, which typically involves the detailed and more specific scope, design and specification of UXO risk mitigation measures for the project, should be undertaken once designs, plans and schedules are finalised, and before intrusive works commence.

3 Assessment Scope and Structure

3.1 Report Structure

This report comprises a desk-based collation and review of readily available documentation and records (which have been summarised separately in Section 3.2), relating to the types of UXO that might be encountered in order to assess the potential UXO risks at the Study Site.

Therefore, the following aspects will be covered in this assessment:

- The sources of prospective UXO contamination that might be encountered at the Study Site will be summarised;
- An assessment of the water depths (in terms of Lowest Astronomical Tide (LAT)), seabed sediments and other environmental factors across the extent of the site will be considered, in order to assess the prospective UXO detonation consequences and the potential for UXO burial and/or migration;
- The likely UXO risk receptors will be identified;
- A Semi-Quantitative Risk Assessment (SQRA) will be undertaken;
- Conclusions will be drawn, and recommendations made to facilitate reducing UXO risks to ALARP.

3.2 Information Sources

6 Alpha have been provided with the following document by the Client, which was employed in this assessment where appropriate:

- RPS, Report Reference: EES1129; *Desk Study for Potential UXO Contamination Hesselø Export Cable Route*, 29th January 2021.

In addition, *6 Alpha* has also employed the following generic sources of information (amongst others) to inform and to compile this report:

- *European Marine Observation and Data Network*;
- *Forsvaret*;
- *Geodatastyrelsen*;
- *James Martin Centre for Nonproliferation Studies*;
- *National Geospatial-Intelligence Agency*;
- *Naval Historical Centre*;
- *Naval History and Heritage Command*;

- *Oslo-Paris Conventions for the Protection of the North-East Atlantic* (OSPAR) databases;
- *Rigsarkivet*;
- *Royal Navy* (Diving Units);
- *Theatre History of Operations*;
- *UK National Archives*;
- *US National Archives*;
- *UK Hydrographic Office*.

3.2.1 Azimuth© UXO Threat Database

6 Alpha's Azimuth© database also contains digitised historic charts, aerial photographs and other extensive analogue records from an exhaustive range of national, regional and global archives and/or datasets that have also been digitised. This database has been heavily drawn upon to deliver the UXO threat assessment element of this report.

3.3 Constraints and Limitations

This UXO threat and risk assessment is constrained and limited by that information which is reasonably available to *6 Alpha* at the time of writing, as well as that UXO information that is reasonably accessible in a variety of archives, which *6 Alpha* have digitised and georeferenced or have otherwise summarised in written form.

This document may also require updates and changes, especially wherever and whenever the circumstances and factors associated with assessing UXO risk change. For example, if UXO threats are subsequently discovered and they are different from those that have been anticipated, and/or if proposed subsea operations are significantly changed.

In such circumstances, risks may require re-evaluation and any such changes are to be made by *6 Alpha*, to ensure the continued technical veracity and risk management efficacy of this document.

4 Risk Assessment Methodology

4.1 Source – Pathway – Receptor Model

The source-pathway-receptor model is a conceptual risk model employed by *6 Alpha* across all marine projects (as per *CIRIA* guidance and industry best practice), which informs how UXO risks are assessed for the project. The model also helps to explain the link between the separate sections of this report and the UXO risk assessment at Section 8. The components of the model are as follows:

4.1.1 UXO Sources

The source element of the source-pathway-receptor model is comprised of the UXO itself. The nature and scope of the UXO contamination threat at the Study Site and its immediate vicinity is summarised in the threat assessment (at Section 5), which details the activities that might have generated a source of UXO contamination. The specific types of munitions that might be present as a result of these activities are also defined.

4.1.2 UXO Pathways

Marine UXO pathways are likely to be either by direct contact and/or through soil or water energy transfer, via which the resulting shock wave (generated by a UXO source, or sources) may reach potential receptors. Nonetheless, surface events (e.g. if UXO is inadvertently brought back to the vessel and is initiated), may also generate a through-air risk pathway in which blast and fragmentation from the UXO sources might also reach the receptors.

UXO risk pathways may be generated by a variety of operations that interact with the seabed. Therefore, likely operations associated with the project have been assessed and summarised (at Section 6), to demonstrate the potential risk pathway elements of the model.

4.1.3 UXO Receptors

Receptors are defined as anything which might be adversely affected by the consequences of an inadvertent detonation of any UXO source through an identified pathway. The proximity, robustness, and sensitivity of such receptors is essential in determining their capacity to withstand such high explosive effects and defining what degree of UXO risk might be tolerated (if any). For example, risks to underwater equipment might be tolerated by some (or all) stakeholders but risks to personnel, which might generate injuries (in general) and fatalities (in particular), are highly unlikely to be considered tolerable.

Typically, offshore receptors include subsea equipment and infrastructure, underwater equipment and surface vessels, and where appropriate, their crews. Divers are also especially vulnerable to underwater high explosive effects, as are marine mammals and fish.

4.2 Semi-Quantitative Risk Assessment Methodology

The SQRA is specifically designed to assess the probability of an unplanned discovery and initiation of UXO, as well as their prospective consequences upon a range of potential sensitive receptors (e.g. surface vessels and any associated underwater equipment), in order to determine the level of UXO risk for each intrusive activity. A full explanation of *6 Alpha's* SQRA process is presented at Annex B, but most importantly, the SQRA embodies the source-pathway-receptor risk model and is achieved by employing the following formula:

Risk **(R)** = Probability **(P)** x Consequence **(C)**.

For each activity that interacts with the seabed, the probability and consequence of the identified UXO threats has been assessed on a scale of 1 to 5. These ratings are multiplied together (with a maximum of 25) in order to determine a risk rating based on *6 Alpha*'s UXO risk matrix – which is presented at Table 2.

		Consequence of Initiation				
Probability of Encounter and Initiation		**1** Negligible	**2** Minor	**3** Moderate	**4** Major	**5** Severe
	5 Highly Likely	**5** Low	**10** Medium	**15** High	**20** High	**25** Very High
	4 Likely	**4** Low	**8** Medium	**12** High	**16** High	**20** High
	3 Possible	**3** Low	**6** Medium	**9** Medium	**12** High	**15** High
	2 Unlikely	**2** Low	**4** Low	**6** Medium	**8** Medium	**10** Medium
	1 Highly Unlikely	**1** Very Low	**2** Low	**3** Low	**4** Low	**5** Low

Table 2: 6 Alpha Associated UXO Risk Matrix

4.2.1 Probability

Probability is determined by considering the likelihood of both encountering and initiating UXO and is a function of the prospective nature, scope, and extent of the potential UXO contamination at the site and the juxtaposition of all seabed intrusive activities with respect to them. Nonetheless, the prospective UXO threats are difficult to accurately quantify due to the nature of historical records associated with depositional events. This can include unrecorded and abandoned ordnance, Anti-Aircraft Artillery (AAA) gun fire, and/or jettisoned aerial High Explosive (HE) bombs – which cannot be spatially defined with either certainty or accuracy. Such uncertainty is accounted for by employing the (undermentioned) precautionary principle.

4.2.1.1 The Precautionary Principle

Making predictions about the yet unobserved states of UXO generates uncertainties within the risk assessment, especially when determining the probability of UXO initiation. The probability of UXO encounter and initiation is, therefore, steered by the precautionary principle.

The principle concludes that if there is uncertainty about the nature of the risk (e.g. the condition and viability of UXO), then a proportionate, transparent, and consistent approach must be taken during the decision-making process that aligns with industry best practice. Therefore, for risk assessment and precautionary purposes, it is assumed any direct kinetic energy encounter with UXO is likely to cause its initiation and generate a potential UXO risk pathway.

4.2.2 Consequence

The consequences of an unplanned UXO initiation are a function of the mass of high explosives in the UXO, which can be either estimated or accurately modelled, along with their underwater and/or surface effects. Other assessment factors include the prospective position of the UXO on the seabed at the moment of encounter (i.e. on the surface or shallow buried – and in the latter case to what depth), the soil type, the through-soil and through-water/air separation distances between the UXO and the receptor.

The likely through-water and/or through-air effects upon such receptors are dependent upon their juxtaposition with reference to the UXO, as well as their robustness in general and their capacity to withstand such high-explosive events in particular. Generally, personnel are very vulnerable to high explosive fragmentation, as well as underwater shock and to a reduced extent surface-blast. As long as workers are not jeopardised, limited adverse effects upon vessels, barges and subsea equipment might be tolerated.

Part II – UXO Threat and Risk Assessment

5 Sources of UXO Contamination

Significant archive research has been undertaken to corroborate and to highlight, any and all potential sources of UXO contamination as well as to assess their likelihood of encounter. It has revealed that the primary UXO contamination threat is likely to have been generated by aerial minelaying operations during WWII, whilst naval firing exercises and post-war munitions dumping might also have generated contamination threats.

Background information detailing generic military ordnance and UXO classification, as well as their associated high explosive and prospective detonation effects, is presented separately at Annexes C and D, respectively.

5.1 Aerial Bombing

Air dropped bombs may be encountered in areas where conflict and/or air campaigns have occurred, although the precise locations of bombing raids and aerial attacks have not always been accurately documented – especially in the offshore environment. In addition, offshore bombing ranges have also been employed by military air forces, which may also have contributed to the contamination of the marine environment.

Nonetheless, extensive desk-based research of historical records did not uncover any evidence to suggest that historic aerial bombing occurred at the Study Site itself during WWII, nor within 5km of its boundaries. Despite this, *Allied* air patrols were undertaken across the *Kattegat* and targeted *German* naval convoys and submarines in the region – particularly those transiting the *Øresund* south-east of the Study Site. Wartime naval charts indicated that one such convoy route crossed the export cable corridor, near to *Sjælland*, as well as a convoy route leading north-south near the proposed OWF array. It is therefore plausible that vessels might have come under aerial attack when transiting the site. For example, the *German* trawler *FV Helmi Söhle* was sunk during a *British Royal Air Force* air raid in April 1945 whilst operating as an offshore AAA battery – i.e. as a "flak ship" – approximately 8.5km to the north of the OWF array.

Again, however, there is no direct evidence of such engagements occurring in closer proximity of the Study Site and as such, there is only a background contamination threat posed by unexploded bombs and depth charges, which might have been deployed.

Moreover, there is also a residual, but largely unquantifiable, UXO contamination threat posed by prospective bomb-jettisoning activities from military aircraft. The jettisoning of unwanted bombloads occurred relatively frequently during WWII; however, such a threat remains almost impossible to quantify without such instances being recorded (and often, such events were either inaccurately recorded or, more commonly, were not recorded at all).

Likelihood of UXO Contamination	Associated UXO Threat Items
HIGHLY UNLIKELY	WWII-era Aerial Bombs and Depth Charges

Table 3: Historic Aerial Bombing Threat Summary

5.2 Naval Engagements

The combatant navies of the 20th Century commanded fleets that consisted of armed surface craft such as destroyers and battleships, as well as more covert craft such as submarines and motor torpedo boats – all of which were armed with a variety of weapons systems. As with aerial bombardment in the offshore environment, the specific locations of most naval engagements were neither commonly nor accurately recorded in contemporary records.

No such evidence has been uncovered during an analysis of *6 Alpha's* in-house Azimuth database, however, as records have not identified evidence to suggest any naval encounters occurred on-site nor within a 5km radius of the Study Site boundary.

The closest such incident was documented in April 1940, when the *British* submarine *HMS Sealion* torpedoed and sunk the cargo ship *SS August Leonhardt* 8.3km to the north of the proposed OWF array. Although it is therefore plausible that further engagements might have occurred across the region, perhaps not resulting in the sinking of vessels in proximity, such an event is considered highly unlikely to pose a substantial UXO contamination threat at the Study Site.

Likelihood of UXO Contamination	Associated UXO Threat Items
HIGHLY UNLIKELY	N/A

Table 4: Naval Engagements Threat Summary

5.3 Naval Minefields

A naval sea mine is a self-contained high-explosive weapon that is placed in the water to destroy ships and/or submarines and would have been fused to ensure that detonation under appropriate circumstances, either upon impact or otherwise upon a close encounter with a ship. During the conflicts of the 20th Century, naval mines were generally employed either offensively, to hamper enemy shipping and to blockade harbours; or defensively, to protect shipping and by creating safe movement zones through them.

During WWI and WWII, defensive minefields were typically laid by surface craft, whereas offensive minefields were often laid by aircraft or submarines – the latter therefore delivering an element of secrecy to the positions of the minelaying operations. Minefields that were deployed by aircraft or submarines were also less likely to be accurately recorded than those laid by surface vessels and as such, the exact positions of these types of minelaying operations are difficult to corroborate with any degree of certainty.

5.3.1 WWI Minefields

Detailed desk-based research of historical records and charts did not uncover any evidence to suggest that WWI minefields were employed across the Study Site or within a 5km radius of the Study Site boundary. Indeed, *British* military records indicated that a conscious effort was made to not lay naval mines in *Danish* or *Swedish* waters during WWI, given both countries made formal declarations of neutrality during the conflict. The closest documented minefield was in fact laid by *Danish* forces approximately 24km to the south-east of the Site, around the island of *Ven* in the *Øresund.*

Consequently, there is no evidence to indicate that such a UXO contamination threat is likely to have been generated at the Study Site.

Likelihood of UXO Contamination	Associated UXO Threat Items
HIGHLY UNLIKELY	N/A

Table 5: WWI-era Naval Minefields Threat Summary

5.3.2 WWII Minefields

Extensive desk-based research of historical records and charts indicated that the Study Site is located within an extensive *British* minefield, designated as *Minegarden Silverthorn*. Historical records indicated that a total of 4,442 mines were laid in the wider *Kattegat* zone – incorporating several mine gardens – the majority of mines were assigned to the aforementioned *Silverthorn* complex from 1942 onwards. Moreover, an analysis of modern records indicated numerous "mine danger areas" across the *Kattegat* and the wider region. A residual danger from bottom mines was noted in two places around the Study Site: immediately to the north-east of the export cable corridor and 3.4km to the south-west of the OWF array. In addition, a residual danger from surface mines was noted 2.8km to the south-west of the export cable corridor. This is further evidenced by the *OSPAR* database of UXO encounters, which indicated that two *British* A Mark I-IV mines have been discovered within the proposed OWF array in recent years, in June 2011 and October 2019, respectively.

A residual danger from surface mines (that subsequently sunk to the seabed) was also documented 2.5km to the south-west of the export cable corridor. There is no indication as to the provenance of these mines, however, but given that each of the danger areas was located within the larger *Minegarden Silverthorn* it is reasonable to assume that they could represent an ongoing UXO contamination threat from this source.

Documentary records also indicate that *British* aerial minelaying campaigns across the *Kattegat* resulted in the sinking of approximately 189 vessels throughout WWII. Cross-examination of shipwreck records did not identify any resultant wrecks directly within the boundaries of the Study Site, though the *FV Alliance*, *SS Valencia* and *SS Desdemona* were all sunk by naval mines within 5km of the export cable corridor near to the *Øresund*, the latter being the closest and located 3.6km to the north-east.

As a result, it is considered likely that WWII-era aerially delivered mines may present an ongoing residual UXO contamination threat at the Study Site. The locations of *Minegarden Silverthorn* and the mine danger areas, in relation to the Study Site, are presented at Appendix 4.

Likelihood of UXO Contamination	Associated UXO Threat Items
HIGHLY LIKELY	WWII-era *British* aerially delivered mines

Table 6: WWII-era Naval Minefields Threat Summary

5.4 Military Practice and Exercise Areas

The *Danish Coastline*, as well as the *North* and *Baltic Seas*, has been used for much of the 20th and 21st centuries by various national and international military forces to conduct training and weapons' systems testing. These activities may have employed live or practice munitions (the latter being difficult to distinguish from the former once abandoned on the surface of the seabed for many years), which in most cases are likely to have remained in the marine environment, once the training activities have ceased.

5.4.1 Historic Military Training Areas

An examination of relevant historic records and military documents, together with supplementary research, did not identify any historic military training areas situated on-site or else within 5km of its boundary.

Likelihood of UXO Contamination	Associated UXO Threat Items
HIGHLY UNLIKELY	N/A

Table 7: Historic Military Training Areas Threat Summary

5.4.2 Modern Military Practice and Exercise Area

An analysis of available documentation relating to modern military Practice and Exercise Areas (PEXA) in *Denmark* identified the *EK D 352* range across the proposed OWF array, as well as *EK D 353* across the northern portion of the export cable corridor, although both firing ranges have since been decommissioned by the *Danish Navy*.

In addition, the *EK R 22 Hesselø* range directly intersects the export cable corridor. This PEXA extended immediately to the south of the proposed OWF array, together with the neighbouring *EK R 19 MULTEX* range. Although specific details regarding the locations and extent of any military activities within these PEXA was not forthcoming, available *Forsvaret* information indicated that the area is used for naval firing exercises – likely including 35mm, 76mm and 5" (127mm) calibre guns. It is also possible that naval torpedo practice exercises might be undertaken within each PEXA, however, any such exercises would be undertaken without an explosive fill.

Nonetheless, although inert or practice munitions (potentially containing small smoke charges) would not themselves pose a UXO threat, they may be visually in distinguishable from live ordnance, as their markings may have corroded or otherwise deteriorated over time.

The location of these modern military PEXA in relation to the Study Site are presented at Appendix 5.

Likelihood of UXO Contamination	Associated UXO Threat Items
LIKELY	Modern Naval Projectiles

Table 8: Modern Military PEXA Threat Summary

5.5 Coastal Armaments

An assessment of local and national archive sources and databases indicated that numerous WWII-era defensive installations were constructed around the *Danish* coastline during WWII, as part of the larger *German Atlantikwall* fortifications across occupied *Europe* – from *Norway* to the *Atlantic* coastline of *France*.

Historical records indicated that a coastal artillery gun battery was constructed at *Gilleleje* during WWII comprising 7.5cm armaments. In addition, the 12cm guns at *Hornbæk* possessed a likely firing range that would have encompassed the nearshore sector of the export cable route. As a result, it is possible that these guns would have been fired for weapons testing and validation purposes, in addition to being employed during the various *Allied* air raids over the region, potentially being fired across the Study Site.

The locations of these coastal armaments and their maximum firing ranges, in relation to the Study Site, are presented at Appendix 6.

Likelihood of UXO Contamination	Associated UXO Threat Items
POSSIBLE	WWII-era AAA Projectiles

Table 9: Coastal Armaments Threat Summary

5.6 Munitions Dumping

Stockpiles of *Allied*, *Central Powers*, and *Axis* munitions of the conventional variety (i.e. HE filled), and chemical munitions that had been earmarked for wartime use, were disposed of at the end of WWI and WWII. As a cost effective and military expedient, conventional and chemical munitions were often dumped offshore or into other suitable bodies of water, such as lakes.

Whilst the centre of mass of such dumpsites was typically recorded, the logistical accuracy of dumping such munitions was then, less than perfect. Such munitions were commonly short-dumped and although some chemical and conventional munitions were disposed of in small munitions containers, the effects of their break-up and subsequent munitions migration may well have further spread the theoretical extent of such contamination.

An analysis of pertinent naval and admiralty charts, together with relevant marine environment protection agency databases and specific supplementary research, indicated that the *SS Bernlef* was transporting a cargo of up to “1,200 tonnes of depth charges and 250kg of aircraft bombs”. The vessel was loaded with this ordnance at *Copenhagen* in August 1945 and was enroute to dump them at sea when an accidental explosion destroyed and sank the ship, approximately 3.4km to the south-west. In some sources it was recorded that the *SS Bernlef* carried chemical munitions, however, on subsequent investigations this was found to not be the case.

The location of this incident is presented at Appendix 7.

Likelihood of UXO Contamination	Associated UXO Threat Items
POSSIBLE	WWII-era HE Bombs and Depth Charges

Table 10: Munitions Dumping Threat Summary

5.7 Munitions Related Shipwrecks and Aircraft

Merchant and naval vessels that were sunk during 20th Century conflicts may have contained munitions, as armament and/or cargo, and the prospective extent of UXO contamination may vary, depending upon nature and integrity of such wrecks. Wreck investigations have found that munitions can spill from ships as they sink and break up, otherwise their ordnance may remain sealed within their holds and remain immobile. Similarly, military aircraft that were shot down or otherwise had to forcibly crash-land into the sea, may have also carried munitions.

It is also unlikely that any ship would have been sunk in the first exchange of fire due to the relative inaccuracy of naval weapons during these conflicts; and it is therefore likely that many bombs, projectiles, and torpedoes would have initially missed their targets and might remain on the seabed as UXO. Regardless of the type of weapons systems employed to attack ships or aircraft, it is entirely feasible that several exchanges of fire would have preceded a successful attack. Generally, the closer the munitions related wreck is located to the Study Site, the more likely a UXO contamination threat is to have been generated in its vicinity.

Extensive desk-based research, together with corroborative evidence gathered from *6 Alpha's Azimuth©* UXO database, identified four munitions related shipwrecks located within a 5km radius of the Study Site boundary. Three of these were sunk by naval mines during WWII near the *Øresund* (as presented at Section 5.3.2); whilst the fourth was the *SS Bernlef*, which sunk following an explosion as it was carrying a cargo of conventional munitions for dumping in 1945 (as presented at Section 5.6).

The locations of these shipwrecks in relation to the Study Site, together with others in the wider area, are presented at Appendix 8.

5.8 Previous UXO Encounters

An analysis of the OSPAR database indicated that two *British* A Mark I-IV mines have been discovered within the bounds of the proposed OWF array: the first in June 2011 and the second in October 2010. A further five of these mines, as well as one *British* A Mark VI mine, were also documented as being encountered within a 15km radius of the Study Site.

Given that UXO encounters within the marine environment are not always documented in the public domain, the fact that historic munitions were and continue to be found highlights the longevity of the threat that might be posed by UXO in the marine environment. Further information concerning *inter alia*, the longevity of the UXO threat in the marine environment is included at Annex E.

The location of the two mine encounters, in addition to others in the wider area, are presented at Appendix 9.

5.9 UXO Threats – Summary

A georeferenced chart depicting the considered range of prospective UXO contamination sources at the study area is presented at Figure 2 below, as well as at Appendix 10.

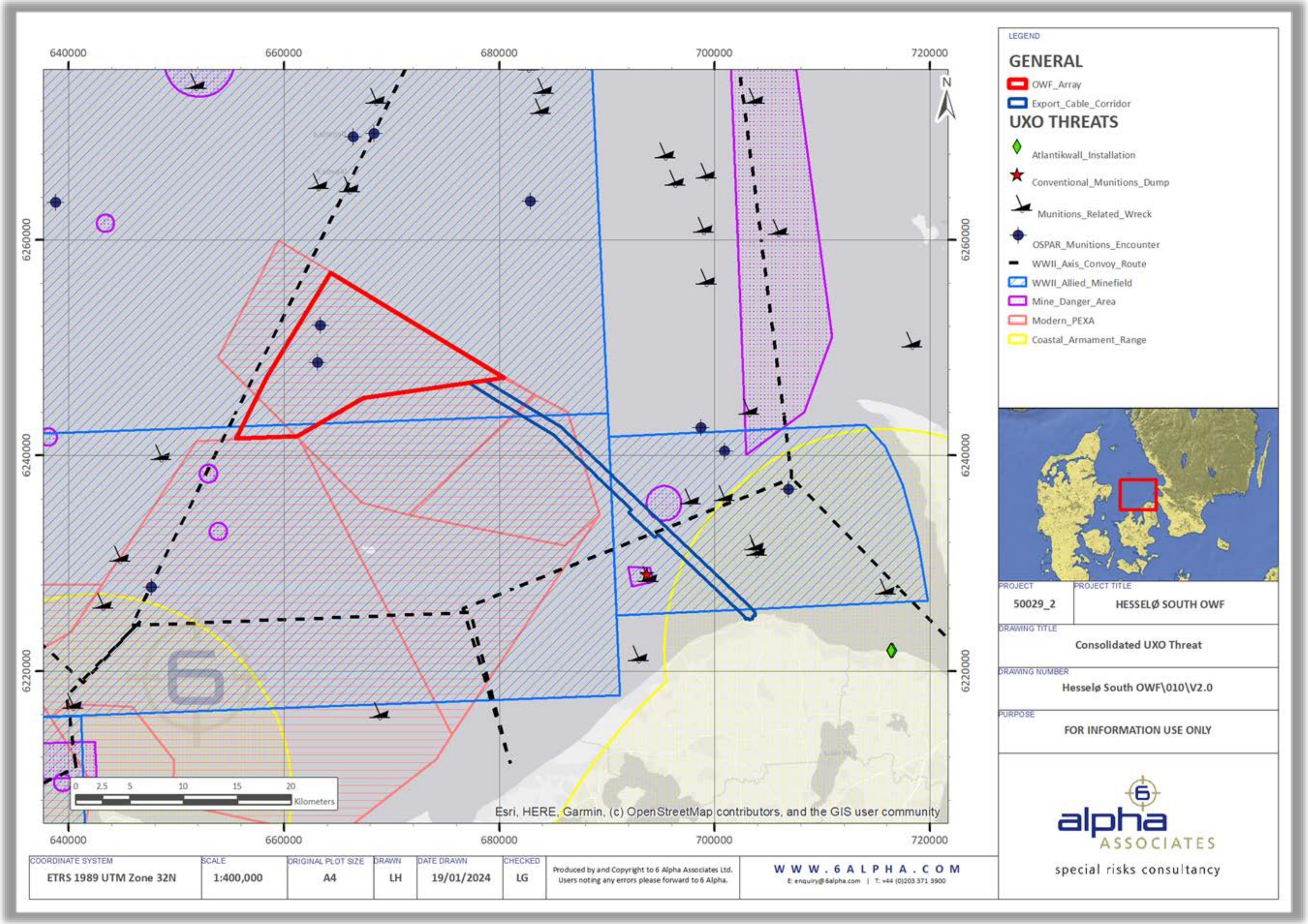


Figure 2: Consolidated UXO Threat

Based upon the threat element of this assessment, the following types of UXO, complete with their measurements, estimated ferrous mass, and expected Net Explosive Quantity (NEQ) (based upon equivalent Trinitrotoluene (TNT) masses), may pose a UXO threat at the Study Site.

5.9.1 Aerial Bombs

Designation	Length x Diameter	Estimated Ferrous Mass	NEQ
1,000lb MC Bomb	1,334mm x 451mm	202-225kg	309kg
SC-500 HE Bomb	1,415mm x 457mm	208kg	220kg
1,000lb GP Bomb	1,334mm x 410mm	315kg	162kg
500lb MC Bomb	1,041mm x 328mm	111-121kg	137kg
SC-250 HE Bomb	1,194mm x 368mm	126kg	130kg
250lb MC Bomb	699mm x 254mm	54kg	68kg
500lb GP Bomb	925mm x 328mm	148kg	66kg
250lb GP Bomb	701mm x 262mm	74kg	30kg
SC-50 HE Bomb	762mm x 200mm	25-30kg	25kg

5.9.2 Depth Charges

Designation	Length x Diameter	Estimated Ferrous Mass	NEQ
Type I Depth Charge	572mm x 445mm	54.5kg	136kg
Mark VII Airbourne Depth Charge	702mm x 444mm	54kg	132kg
Mark VIII Airbourne Depth Charge	701mm x 262mm	35kg	100kg
Tactical Depth Charge	556mm x 457mm	18.1kg	76.7kg

5.9.3 Naval Mines

Designation	Length x Diameter	Estimated Ferrous Mass	NEQ
A Mark VI Mine	2,280mm x 470mm	453kg	454kg
A Mark I-IV	2,280mm x 470mm	340kg	340kg

5.9.4 Artillery and Naval Projectiles

Designation	Length x Diameter	Estimated Ferrous Mass	NEQ
5" Naval Projectile	660mm x 127mm	27.9kg	3.52kg
12cm Artillery Projectile	565mm x 120mm	25.3kg	2kg
76mm Naval Projectile	355mm x 76mm	5.6kg	0.75kg
7.5cm Artillery Projectile	358mm x 75mm	6kg	0.51kg
35mm Naval Projectile	387mm x 35mm	0.44kg	0.11kg

6 UXO Risk Pathways – Planned Operations

An outline of the expected operations that may be employed during the investigation and construction phases of work is presented, in order to evidence the potential UXO risk pathways that may be generated, should such work encounter those threat spectrum UXO that have been identified in Section 5. If the planned methods are changed, then the risk assessment is to be reviewed and updated if necessary.

6.1 Geophysical Survey

Geophysical survey methodologies may include Multi-Beam Echo Sounder (MBES), Side Scan Sonar (SSS), Sub-Bottom Profiler and/or magnetometer/gradiometer survey operations. These methodologies employ remote and direct sensing which use the reflection or refraction of energy sources to generate data that can be interpreted to provide a "picture" of the seabed.

Whilst it might be theoretically possible that some of these energy sources could initiate sensitive marine UXO, it is considered practically impossible to do so. Furthermore, there is no evidence of historic UXO in the marine environment (or elsewhere), being initiated by conventional methods of marine geophysical survey.

However, where equipment is deployed on the seabed to aid in the calibration of the various geophysical survey tools, such as a ferrous target for magnetometer validation, the potential for contact with UXO items on the seabed may be introduced.

6.2 Geotechnical Investigation Operations

A GI campaign will likely then be undertaken in order to gather data on the local seabed's makeup and conditions within the Study Site, in addition to a benthic survey. It is expected that the following GI methodologies could be employed as part of the campaign:

6.2.1 Boreholing

Continuous sampling/coring borehole operations employ kinetic energy to invasively penetrate the seabed. Such techniques are capable of initiating UXO, especially if the leading edge of the borehole equipment comes into contact with it.

6.2.2 Cone Penetration Testing (CPT)

CPT measures the resistance to penetration of the seabed, using a steel rod fitted with a conical tip. Given that this methodology employs kinetic energy to invasively penetrate the seabed, it is possible that if the CPT tool comes into direct contact with UXO, the kinetic energy generated may be sufficient to cause its initiation.

6.2.3 Vibrocoring

Vibrocoring employs the force of gravity, combined with kinetic energy (supplied by a vibrating head), to drive a sampling-core into the seabed, in order to collect sub-seabed samples. Therefore, given the kinetic energy involved in the process, vibrocoring is considered to be capable of initiating UXO, especially if the leading edge of the sampling equipment comes into direct contact with it.

6.2.4 Environmental Grab Sampling

Surface grab sampling can be used as a method of recovering sediments from the seabed during environmental/benthic surveys. The methodology involves a simple grab bucket being lowered to the seafloor, closing upon impact and securing a sediment sample, before being brought back to the surface – usually through the means of a winch. Grab sampling tends to be an aggressive investigative operation which generates kinetic energy as the bucket falls to the seabed and as the sample is taken. In addition, there is a possibility of inadvertently recovering small UXO to the deck of the vessel along with the grabbed sample (though the threat assessment at Section 5 has not identified an elevated hazard associated with such munitions at this Study Site).

6.3 Construction Operations

The development of the *Hesselø South OWF* will involve the construction of Wind Turbine Generators (WTG) installed on fixed platforms on the seabed, in addition to an Offshore Sub-Station (OSS) located within the array boundary.

6.3.1 Monopile Support Structures

A monopile support structure is employed where the tower of the wind turbine is held by a single structure rooted in the seabed and is the most commonly employed foundation type when installing WTG foundations in shallow water (typically, not exceeding 60m deep). A standard method of WTG foundation installation involves driving the piles into the seabed using high energy impact-hammers, powered by either steam or hydraulics, often from by a Jack-Up Barge (JUB) platform. As this method delivers significant kinetic energy as the piles are driven into the seabed, any UXO encountered directly is almost certain to be initiated, with any UXO in the immediate vicinity of such operations being placed at risk of being initiated indirectly by the through seabed shock, generated by such activities.

Drilling may be considered as an alternative methodology, which is most suitable in areas where the seabed is composed of hard sub-seabed strata that has sufficient strength to make the installed structure self-supporting. The probability of UXO encounter remains largely the same as with the employment a high-energy impact hammer due to the intense, invasive force exerted upon and through the seabed.

6.3.2 Jacket Support Structures

Alternatively, the use of jacket support structures is commonly considered for WTG and/or OSS installation. The potential for UXO encounter and initiation is similar to that associated with WTG monopile installation although the piles used are of a much smaller diameter and are generally expected to be emplaced with less energy. Nonetheless, given that the same holistic installation methodologies are usually used for jacket support structures as with monopiles, the likelihood of UXO initiation remains similar.

6.4 Cable Installation and Burial Operations

It is expected that export and inter-array cables could be installed using several different methodologies depending on the geological conditions, although specific methodologies are yet to be defined. Alternatively, the cables may be pre-laid on the seabed and subsequently buried.

An overview of prospective cable installation and burial methodologies is described briefly below, to inform subsequently the risks that UXO might pose to such techniques.

6.4.1 Pre-Lay Operations

Pre-Lay Grapnel Run (PLGR) and Route Clearance (RC) will likely be employed to ensure that the working area is clear of disused communication cables and other seabed debris, which may prove detrimental to the cable lay and post-lay burial equipment.

PLGR operations generally involve towing an array of spear-point grapnels along the surface of the seabed, within the designated cable corridor(s). PLGR is not a UXO risk mitigative method and nor should it be considered as such in other than the most extreme circumstances (and only where no other technique is likely to work – in such conditions it needs careful supervision and risk mitigation). RC operations also typically involve the identification and removal of specific and significant impediments to cable lay and/or burial, such as boulders, anchors, chain, steel-wire rope, disused cables, and obstructions generated by wrecks and suchlike.

It is therefore possible that pre-lay operations could cause a UXO detonation event, should pre-lay equipment come into direct contact with UXO that is very shallow buried or else on the surface of the seabed.

6.4.2 Surface Laid Cable

The export and inter-array cables may be laid on the surface of the seabed and then subsequently buried where necessary. Cables are also typically surface laid where they cross existing infrastructure (such as existing pipelines and other cables), as they cannot be buried at such locations.

The kinetic energy associated with surface laying the cable might be sufficient to initiate UXO, especially if the cable makes direct contact with it. This is subject to several factors including the mass of the cable per linear meter, the water depth, and rate of lay. Even if the cable lay energy is considered insufficient to initiate UXO (e.g. because the cable is relatively low mass and it is laid slowly), it is not considered best practice to deliberately overlay UXO with cables and in such circumstances, post-lay inspection and burial is likely to be both compromised and/or jeopardised.

6.4.3 Jetting

Where soft seabed conditions are encountered, jetting can be employed to bury inter-array cables either concurrently or in a separate operation once it has been laid on the surface of the seabed. Jetting functions by fluidising the seabed to enable burial of the cable, to its target depth of burial.

Jetting procedures are considered a more benign and less aggressive installation methodology (for example, as compared with mechanical cutting) and is therefore, less likely to inadvertently initiate UXO when benchmarked with other methods. Despite this, a risk pathway may still be generated if direct contact is initiated between UXO and the jetting tool itself, or the direct or indirect effects of its high-pressure water jetting system.

6.4.4 Ploughing

Displacement ploughs create an open V-shaped trench into which the export or inter-array cables can be concurrently laid. This process causes significant disturbance to the seabed as the trench can typically be up to 3m wide and 1.5m deep, whilst the plough can have a skid footprint of up to 10m wide, between its support skids. The open trench can be then backfilled using blades mounted to the rear of the plough, thus burying concurrently the cable behind it. The large footprint, significant mass of the machine and the kinetic energy it generates could collectively, encounter and initiate UXO.

Alternatively, a non-displacement plough could be used to cut through the seabed using a thin blade-like shear, through which the cable runs. This method generates a reduced level of disturbance to the seabed, by comparison with a displacement plough and it creates a narrow trench (usually between 0.3m and 1.0m wide). In such circumstances the trench, is normally backfilled as the cable is laid.

The risk considerations associated with plough methodologies are generated by the mass of the shear (and any supports skids) and their velocity, which in combination may be sufficient to initiate UXO either directly or indirectly.

6.5 Protection and Crossing Operations

WTG and OSS foundations may require some form of anti-scour protection. In addition, where offshore cable burial is not possible, and where existing cables or pipelines are crossed, some form of surface cable crossing and protection is likely to be required.

Options that might be considered include the following:

6.5.1 Scour Protection

It is expected that the WTG and OSS foundations may require some form of anti-scour protection, possibly in the form of either static or dynamic rock armour to be emplaced after installation works are complete. The specific type and overall extent of the scour protection depends on the local seabed conditions, as well as the type of foundation that is installed. Nonetheless, the emplacement of rock armour around such foundations may present a UXO risk pathway, should any UXO be encountered directly or in close proximity subject to the kinetic energy associated with such emplacement.

6.5.2 Concrete Mattress and/or Rock Placement

To protect any existing (live and in-use) cable(s), concrete mattresses and/or rock placement may be employed to facilitate cable crossing(s), or else split-piping may be applied to protect the cable. A UXO risk pathway may be generated by the emplacement of mattresses, rock (or rock-bags) or split-pipe, alongside and over the cable. The probability of an inadvertent UXO detonation is dependent upon the resultant kinetic energy generated by the emplacement of the protection method and the juxtaposition, sensitivity and NEQ of such UXO.

The potential risks may well be reduced if direct contact with UXO is avoided. Where there is potential UXO (pUXO) located within close proximity, then the cable protection system(s) are not only to be deployed in a controlled fashion, but also as slowly as is reasonably practicable (to reduce the resultant kinetic energy generated). Minimum pUXO safety avoidance distances are also to be adhered to.

6.5.3 Crossing Design

In consideration of third-party cable crossing and/or the removal of out-of-service cables, it is assumed that such cables would not have been (deliberately) installed on top of UXO, or else in close proximity. Nonetheless, this does not mean that UXO will not be encountered anywhere such routes, and therefore, a risk pathway may still be generated depending on the precise methodology employed to work in areas where third-party or out-of-service cables are located.

6.6 Enabling Operations

The following methodologies may be employed to facilitate the proposed works:

6.6.1 Jack Up Barges/Vessels

A JUB, or other Jack-Up Vessel (JUV), is a type of mobile platform that consists of a buoyant hull fitted with multiple movable legs, capable of lifting it over the surface of the sea, thus affording a stable work platform for operations such as piling. The buoyant hull facilitates relatively easy transportation of the barge between operations and once it is at the desired location, the hull is raised (jacked-up on legs), to the required elevation above the sea and its legs are supported by the seabed.

From a UXO risk perspective, the legs of such barges may be designed to penetrate the seabed and may be fitted with enlarged sections or footings. Generally, JUB/JUVs are not self-propelled and rely on Anchor Handling Tugboats (AHT) for positioning and upon its anchors for stability and movement. Nonetheless, if the JUB/JUV leg or its anchor (deployed by an AHT) encounters UXO, then a significant risk pathway might be generated as any detonation might result in the destabilisation of the surface vessel, any fitted equipment such as cranes, or in an extreme case, result in it capsizing.

6.6.2 Dynamically Positioned (DP) Vessels

DP vessels employ computer-controlled systems to automatically maintain their position and heading by using propellers and thrusters. Position reference sensors and satellite navigation, combined with wind sensors, motion sensors, and gyrocompasses provide information to a computer that maintains vessels' positions, constantly accounting for the magnitude and direction of environmental forces affecting them.

If a DP vessel does not contact the seabed (because it is not anchored and will not ground), then a prospective encounter with UXO from such a work platform does not present a UXO risk pathway. In shallow water, however, a risk might be presented if thrusters disturb UXO in close proximity of the influence (of the thruster), especially if the UXO is located on the surface of the seabed or shallow buried beneath it.

6.6.3 Vessel Anchoring

It is possible that other types of vessels will anchor independently or otherwise employ AHT, to support the proposed works. There is a risk that anchors could initiate UXO if they were to come into direct contact with it, as they are positioned and emplaced. However, the deployment and post-tensioning of anchor catenaries are considered less likely to inadvertently initiate UXO.

In the latter case, this is due to a number of factors, namely: the cable forces are comparatively longer in duration and of lower magnitude; the risk is generally confined to surface UXO only (as the cables may be deployed under tension and may not sweep extensive areas of the seabed). Nonetheless, any cable contact with UXO is likely to be linear (i.e. along the cable/UXO length rather than as a "point".

6.7 Diving Operations

There is no indication that divers are currently being considered to assist or undertake works. Nonetheless, divers are especially vulnerable to the types of underwater shock generated by UXO detonations and, subject to UXOs' NEQ, diver fatalities can easily be generated hundreds of metres from the seat of an underwater high explosive event. Therefore, divers must not be deployed where there is a risk of such a detonation event.

If divers are to be used, then the associated risks must be reassessed by *6 Alpha*.

7 Study Site Characterisation

7.1 Local Seabed Conditions

The Study Site's local seabed conditions are important influencing factors when assessing the potential for UXO burial and/or migration and the potential consequences of an unplanned encounter and initiation of UXO during the proposed operations.

7.1.1 Bathymetry

A body of water will both absorb and transmit energy, generated by either a bomb entering the water and/or a high explosive event of the sort that might be generated by a UXO detonation. In general, the consequences of a through-water UXO detonation will reduce, as the "stand-off" (or separation distance) increases between prospective receptors and the UXO either buried in or lying upon the seabed.

Bathymetric data collected by the Client for the OWF array indicated that the water depths range between 17m and 35m LAT. This was corroborated by an analysis of publicly available bathymetric data, which further showed that water depths are likely to range between 0m LAT (i.e., landfall) and 32m LAT within the export cable corridor.

Given the relatively shallow water depths across the entire Study Site, the potential consequences of threat spectrum UXO initiation are unlikely to be significantly mitigated by such a body of water and the degree of prospective risk mitigation in general (and consequence mitigation in particular) provided by the depth of water, is unlikely to have an effective impact on the results of the SQRA (at Section 8). Small NEQ UXO (such as AAA projectiles), however, are unlikely to cause significant consequences to surface vessels and/or personnel in deeper areas of the Site (as analysed at Section 8).

The water depths across the Study Site (in LAT) are presented at Figure 3 and Appendix 11.

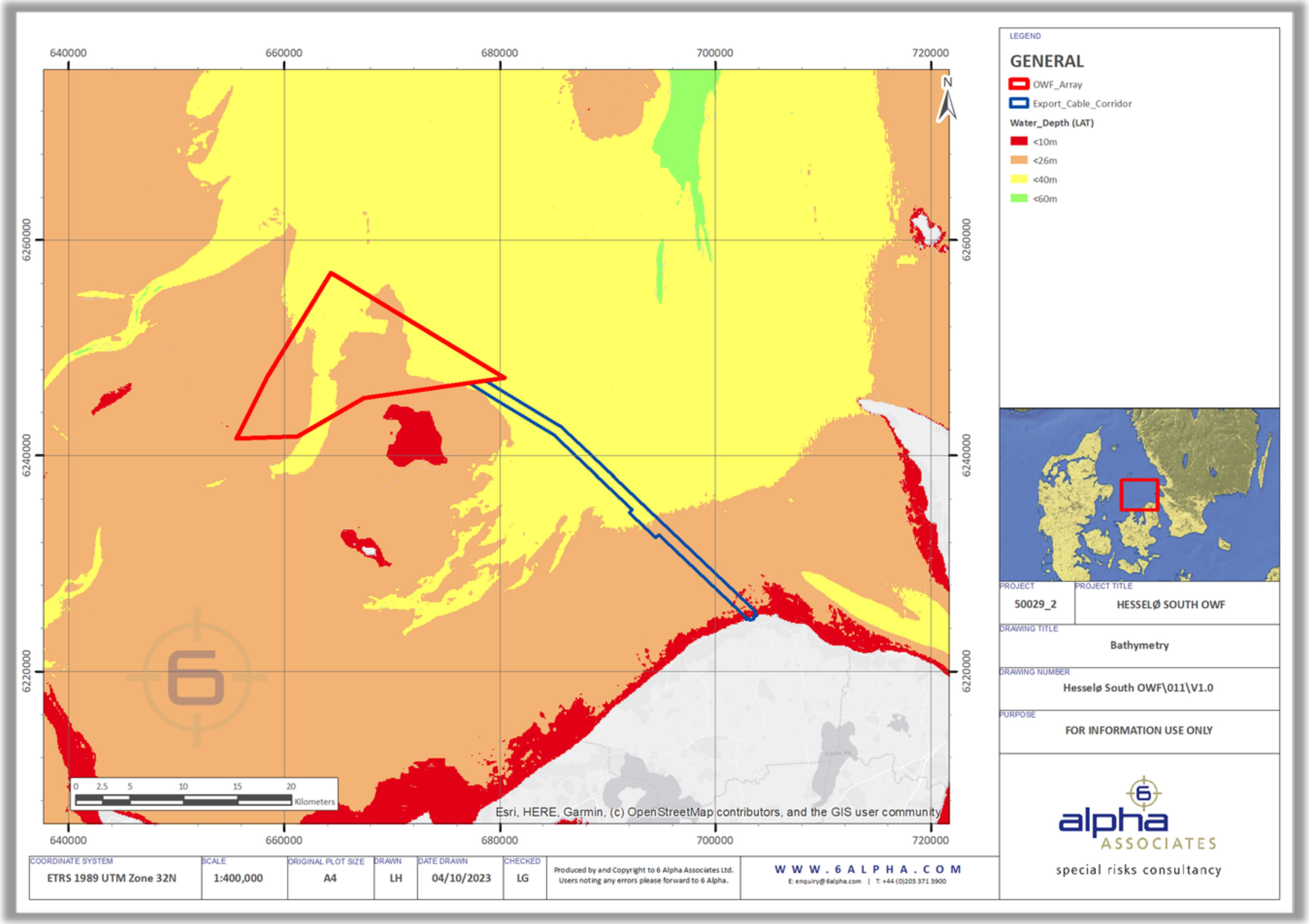


Figure 3: Bathymetry

7.1.2 Seabed Sediments and Shallow Soils

The nature of local seabed sediments and shallow soils also needs to be considered to determine the prospect for UXO burial in general and unexploded bomb burial in particular, upon their initial deployment and/or subsequently by seabed sediment movement. UXO scour and/or migration may also be influenced by seabed sediments.

Detailed shallow soil and seabed sediment information for the OWF array indicated that much of the Study Site comprised sand and muddy sand sediments, though a concentration of gravel and coarse sand was noted in the south-western corner. In addition, till/Diamicton (i.e. mixed sediments) were also widespread across its southern sector.

In addition, an analysis of publicly available data through the *European Marine Observation and Data Network* indicated that seabed sediments within the export cable corridor are likely to comprise predominantly sandy sediments. Areas of mixed sediments, coarse substrata and muddy sand are also likely to be encountered in various areas.

In general, coarse sediments such as mud and gravels are less likely to form a mobile seabed than one comprising solely of sandy sediments. It is still possible that UXO may have become shallow buried (after their initial deployment, having come to rest upon the surface of the seabed), by mobile seabed sediment, particularly in those areas comprising of predominantly sand sediments.

7.2 UXO Burial and Munitions Migration

In the offshore environment, all items of UXO are potentially subject to a variety of environmental and human factors, which may result in their scour and burial, or else their migration across the seabed. Primarily, this is driven by the localised bathymetric conditions including the composition of the seabed sediments, water depth and tidal currents.

7.2.1 Initial Impact Burial

As with impact burial of UXO on land, only those munitions travelling at a high terminal velocity at the point of impact – typically aerially delivered iron bombs or gun/mortar launched projectiles – have the potential to penetrate the seabed upon their initial deployment. Historically, studies of typical bomb penetration depths have been undertaken for the terrestrial environment based upon *inter alia*, the soil type in general and its shear strength in particular, as well as the UXO type, size and mass; and their angle/speed of initial impact.

Such studies are not directly applicable in the offshore environment, however, given the mitigative effects of water in slowing and reducing the impact of munitions on the seabed. Nonetheless and in general, UXO penetration into the seabed beyond 2m below seabed level, is considered highly unlikely in water depths greater than 20m. Potential UXO penetration depths will increase as the water depths decrease in proximity to the shore and an assessment of the seabed sediments present at the export cable route (as per Section 7.1.2) suggests that UXO may be buried as deep as 16m below WWII seabed level in any intertidal areas if muddy sediment is present.

Those areas of the Study Site <20m LAT, where initial impact burial is considered to be more likely, are highlighted at Appendix 12.

7.2.2 Munitions Migration Effects

If geophysical UXO survey data is more than one year old from its date of capture, it may compromise the subsequent longevity of an ALARP safety sign-off certificate in general and the positional accuracy of pUXO (designated for avoidance) in particular, because of the risk of prospective munitions migration effects.

An analysis of the expected UXO threat sources has indicated that near-seabed currents in excess of 1.25 m/s might be expected to move the smallest UXO threat items (i.e. an AAA projectile), as presented at Table 11. If seabed currents at the Site exceed this value, then it is plausible that some UXO might have migrated due to natural conditions. Human activity might also have resulted in the migration of UXO, as survey data collected for the project has indicated that much of the northern and western sectors of the Site show evidence of trawl marks across the seabed.

Munition Type	Length x Diameter	Near-Seabed Critical Current Velocity
A Mark VI Mine	2,280mm x 470mm	3.50 m/s
1,000lb MC Bomb	1,334mm x 451mm	3.48 m/s
250lb MC Bomb	699mm x 254mm	2.71 m/s
12cm Artillery Projectile	565mm x 120mm	1.98 m/s
35mm Naval Projectile	387mm x 35mm	1.25 m/s

Table 11: Near-Seabed Current for Munitions Migration

To address this issue and to extend the longevity of ALARP safety sign-off certification, a Munitions Migration and Burial Assessment (MMBA) can be undertaken to expand upon this indicative summary. An MMBA can be based on appropriate metocean data, which would model the potential for UXO migration based upon seabed geomorphology in general and the Site's seabed characteristics in particular. Such characteristics can typically comprise the seabed sediments, current direction, and strengths.

Further background information regarding UXO scour, burial and migration is presented separately at Annex F.

7.3 Marine Protection Areas

Areas of the offshore marine environment have been designated as requiring protective, conservation, restorative and/or precautionary measures and there is a growing body of regional, national and international legislation supporting offshore environmental conservation. An analysis of national and regional databases noted that the *Gilleleje Flak og Tragten* marine protected area is situated across the nearshore portion of the export cable corridor. in addition, the *Lysegrund* protected area is also located immediately to the south of the proposed OWF array.

Whilst it is unlikely that UXO disposal should be required within the bounds of such areas, it is *6 Alpha's* typical recommendation that techniques such as low-order/low-noise or deflagration might be preferred over other high-order disposal methods regardless of location, although it is of particular pertinence within marine protection areas.

The location of these designated protection areas, as well as those in the wider area, is presented at Appendix 13.

8 UXO Risk Assessment

8.1 Risk Assessment Findings

The results of the strategic level risk assessment at different depth intervals are summarised and presented below and are supported by an unexpurgated project SQRA, which is presented at Appendix 14. The latter presents the complete risk assessment for each individual seabed intrusive activity for each UXO threat group in various water depth intervals.

Nonetheless, as a worst-case scenario, the Study Site has been characterised as posing ***HIGH*** category UXO risks, though this may vary depending on the precise phase and scope of works as detailed below.

8.1.1 GI Operations

The likely GI operations are categorised as posing ***HIGH*** UXO risks to both the vessel and personnel (i.e. vessels' crews) within a limited area of the proposed OWF array; specifically, in proximity of recent encounters with WWII-era naval mines – the worst-case scenario of which is presented at Table 11. In the majority of the Study Site however, the likelihood of encountering such UXO during this phase of works is somewhat reduced given the relatively small point-focal GI operations, which allows for the level of UXO risk to instead be categorised as ***MEDIUM***.

In the nearshore sector of the export cable corridor, the UXO risk has been characterised as ***LOW***, due to the significantly reduced likelihood of encountering WWII-era naval mines in shallow waters.

The risks associated with any operations undertaken to support the GI are assessed separately at Section 8.1.4.

UXO Threat	UXO Risk (Vessels and Personnel Only)		
	~10m LAT	~26m LAT	~40m LAT
Aerial Bombs and Depth Charges	**LOW**		
Naval Mines	**LOW**	**HIGH**	
Artillery and Naval Projectiles	**LOW**		

Table 11: GI Operations SQRA Summary

8.1.2 Construction Operations

Construction operations have been assessed to pose ***HIGH*** category UXO risk as a worst-case scenario– as presented at Table 12. This elevated level of risk is due to the increased likelihood of encountering WWII-era naval mines during these works, within the OWF array boundary. Other threat spectrum UXO, including aerial bombs and projectiles, have been assessed to pose ***MEDIUM*** or ***LOW*** category UXO risks in all depths given the reduced likelihood of encountering such ordnance during potential construction operations, relative to naval mines.

UXO Threat	UXO Risk (Vessels and Personnel Only)		
	~10m LAT	~26m LAT	~40m LAT
Aerial Bombs and Depth Charges	**N/A:** WTG and OSS construction operations will not be undertaken at this depth.	**MEDIUM**	**LOW**
Naval Mines		**HIGH**	
Artillery and Naval Projectiles		**LOW**	

Table 12: Construction Operations SQRA Summary

8.1.3 Cable Installation and Burial Operations

Export and inter-array cable installation operations – including pre-lay and protection operations – may generate ***VERY HIGH*** UXO risks as a worst-case scenario. This is limited, however, to a relatively small area in which WWII-era naval mines have recently been discovered within the proposed OWF array. Elsewhere across the Study Site, UXO risks have been categorised as ***HIGH*** and/or ***MEDIUM***, though this may be reduced should less intrusive methodologies be selected.

This level of UXO risk is largely driven by the likelihood of encountering WWII-era *British* naval mines, which were deployed from aircraft across the *Kattegat* – as has been directly evidenced by entries in the OSPAR database. The water depths at the Study Site are insufficient to provide a significant risk mitigative effect to such munitions and therefore, the categorisation of UXO risk remains elevated across the Site.

The worst-case risk levels for the cable installation phase of the project are summarised and presented at Table 13.

UXO Threat	UXO Risk (Vessels and Personnel Only)		
	~10m LAT	~26m LAT	~40m LAT
Aerial Bombs and Depth Charges	**LOW**	**HIGH**	**LOW**
Naval Mines	**MEDIUM**	**VERY HIGH**	**HIGH**
Artillery and Naval Projectiles	**MEDIUM**	**LOW**	

Table 13: Cable Installation and Burial Operations SQRA Summary

8.1.4 Enabling Operations

The UXO risk associated with the potential enabling operations in support of proposed works is also assessed as potentially generating ***HIGH*** category UXO risks due to the potential likelihood that such operations will encounter and initiate UXO at this Study Site. Even an initiation of relatively small UXO could result in adverse and intolerable consequences should the JUB/JUV become destabilised. Nonetheless, the level of UXO risk is reduced in the nearshore sector given the lower probability of encountering naval mines.

If DP vessels or anchoring are deployed to enable these operations instead, then the associated level of UXO risk can be reduced to ***LOW*** or ***MEDIUM*** – though again in select areas near to recent UXO encounters, the level of risk remains ***HIGH*** during any vessel anchoring operations.

Nonetheless, Table 14 articulates the worst-case scenario associated with the prospective enabling operations.

UXO Threat	UXO Risk (Vessels and Personnel Only)		
	~10m LAT	~26m LAT	~40m LAT
Aerial Bombs and Depth Charges	**LOW**	**MEDIUM**	**LOW**
Naval Mines	**LOW**	**HIGH**	
Artillery and Naval Projectiles	**LOW**	**MEDIUM**	

Table 14: Enabling Operations SQRA Summary

8.2 UXO Receptors

8.2.1 Surface Vessels and Personnel

Although there is evidence to suggest that encountering and initiating UXO is plausible at the Study Site, such an encounter is generally considered a low probability-high consequence event. The consequences of exposing vessels' crews to the kind of forces associated with an underwater initiation of an indicative selection of high, medium, and low NEQ threat spectrum UXO has been carefully modelled and the results are summarised separately at Table 15. These consequences are presented as a "worst-case" scenario, in the event that no risk mitigation measures have previously been enacted to reduce the likelihood of encountering and initiating threat spectrum UXO.

UXO	NEQ	Consequence		
		~10m LAT	~26m LAT	~40m LAT
A Mark VI Mine	454kg	Vessel Sinking / Fatalities		Serious Structural Damage
Type I Depth Charge	136kg	Vessel Sinking / Fatalities	Serious Structural Damage	Mechanism Damage / Minor Injuries
SC-50 HE Bomb	25kg	Vessel Sinking / Fatalities	Slight Damage	

Table 15: Consequences of UXO Initiation

Table 15 has been compiled using *6 Alpha's* in-house shock wave calculator. This tool employs algorithms based on a variety of open-source academic and military studies concerning military ordnance detonations underwater, the peak pressures generated, and the effects of through water shock waves on the vessels' hulls directly as well as the indirect effects upon their crew.

Although the probability of initiating UXO varies with the types of subsea operations, the consequences of an initiation of each type of UXO is not driven by how such an initiation event might be caused. The calculations presented within Table 15 are also employed to inform *6 Alpha's* SQRA (at Appendix 14) to assess and grade potential UXO detonation consequences based upon the shock wave effects.

8.2.2 Underwater Equipment

If UXO is inadvertently encountered and initiated, it is likely that underwater equipment or tools employed in their close proximity are likely to be significantly damaged and/or completely destroyed.

Such risks are presented in the full SQRA (at Appendix 14) but are highly likely to be considered tolerable, under the auspices of the ALARP principle, as long as they are unlikely to also pose a concurrent risk of harm to surface vessels and their crew.

8.2.3 Vessel and Diver Safety Distances

The SQRA assesses the risk of an unplanned initiation of UXO with reference to relevant sensitive receptors (e.g. vessels and their crews and/or underwater equipment), resulting from underwater explosive shock waves and to a reduced extent, localised underwater, high velocity fragmentation effects.

Such underwater detonation effects are determined by the energy that might be generated by detonating high explosive UXO. TNT is employed as a representative baseline high explosive for the likely type of UXO that might be encountered within the Study Site (regardless of the precise nature of their high explosive fill), as well as estimating the distances separating the source (UXO) and the sensitive receptors (equipment/vessels).

The following formula has been applied to calculate peak pressure in megapascals (MPa), of the resultant shock wave output (Reid, 1996):

$$Peak\ Pressure\ (MPa) = 52.4.\left(\frac{M^{\frac{1}{3}}}{R}\right)^{1.18}$$

For SQRA calculations, R is the separation distance in metres between the source and the receptor (typically based on the water depth in LAT), and M is the mass of TNT explosive equivalent in kilograms.

Using this formula, Table 16 summarises the distances at which point the prospective consequences of an underwater encounter and initiation of a selection of threat spectrum UXO to the vessel(s) and their crew(s) becomes intolerable (e.g. where injuries are sustained from exposure to more than 4MPa of peak pressure). In addition, Table 16 also summarises the minimum safety distance for divers – if they are to be employed (these distances have been calculated by *6 Alpha's* UXO experts).

UXO	NEQ	SQRA Consequence Score Peak Pressure Exposure (MPa) and Vessel Safety Distance		Swimmers and Divers Safety Distance
		1 0 – 2 (MPa)	**2** 2 – 4 (MPa)	Burst on seabed with diver on seabed
A Mark VI Mine	454kg	125m	70m	1,830m
Type I Depth Charge	136kg	85m	50m	1,475m
SC-50 HE Bomb	25kg	50m	30m	1,085m

Table 16: Underwater Explosion Safety Distances

For the consequences of an initiation of high NEQ UXO to be completely ameliorated, in terms of its effects upon the vessel (<2 MPa and see consequence column 1), the minimum vessel safety stand-off distance must be not less than 125m.

Consequence column 2 articulates the depths of water at which superficial damage to the vessel may be caused. The exposure of the vessel and its crew to intolerable and dangerous high-explosive effects is likely to occur at depths of less than 70m, if a large NEQ UXO is initiated. If the vessel(s) and its crew(s) are exposed to greater than 4MPa of pressure, the likely effects include damage to electronics, injuring crew and partial loss of vessel steering and control. Vessel damage becomes more severe as the peak pressure exposure increases, with fatalities highly likely to be caused at 8MPa pressure and greater. These consequences have been calculated without accounting for the vessels' age/condition nor their specific design characteristics in general or their robustness, in particular. Therefore, the precise consequence modelling and minimum safe stand-off distances are subject to change, especially as additional factors such as vessel draught are introduced.

In addition, divers are highly vulnerable if they are exposed to the kind of underwater shock generated by UXO initiation. As Table 16 evidences, swimmers and divers must be located at least 1,830m from the seat of a seabed initiation of threat spectrum UXO, to be considered safe, which further evidences the risks involved with deploying divers during sub-seabed operations, wherever UXO contamination might be expected.

8.3 UXO Risk Zones

It is standard *6 Alpha* practice to divide the Study Site into multiple UXO risk zones based upon one, or a combination of, the following factors:

- The nature and scope of seabed intrusive activities and the distances from pertinent UXO threat sources;
- The varying water depths (in LAT) across the Study Site;
- The project stakeholders' assumed appetite for the carriage of residual UXO risks.

Given the distribution of UXO threat sources (identified in Section 5) and their various NEQ, it is possible to split the Study Site into UXO risk zones at a high-level depending on the phase of work being undertaken, as presented at Appendix 15 and as follows:

8.3.1 UXO Risk Zones: GI and Enabling Operations

At a worst-case, assuming that JUB/JUVs may be used to facilitate the GI campaign, UXO risks to the GI phase of work have been categorised as ***HIGH*** across the majority of the Study Site. Specifically, the ***HIGH*** category of UXO risk has been driven by the likelihood of encountering and initiating WWII-era *British* naval mines, which were deployed in large quantities from aircraft across the *Kattegat* (see Section 5.3.2). That such munitions have been discovered at the Site within the past decade, serves to reinforce the continuing contamination threat posed by such ordnance. Nonetheless, the likelihood of encountering such munitions in very shallow waters is much reduced, and therefore a small area of ***LOW*** UXO risk has been defined in the nearshore sector of the export cable corridor.

Moreover, should alternative enabling methodologies be used (i.e. vessel anchoring or DP vessels), then the risk rating may be lowered, given the reduced likelihood of encountering and initiating UXO during these works.

Figure 4 displays the worst-case UXO risk zoning for GI and enabling operations at the Study Site.

8.3.2 UXO Risk Zones: Construction and Installation Operations

Given the high probability of encountering threat spectrum UXO (identified in Section 5) across the Study Site during the construction and installation phase of works, at a worst-case scenario, the UXO risks to construction and cable installation works are assessed as ***HIGH*** across most of the Study Site. Moreover, a small area of ***VERY HIGH*** category UXO risk has been defined around two locations within the OWF array, where WWII-era A Mark I-IV mines were encountered in 2011 and 2019, respectively.

The contamination threat generated by wartime minelaying is extant across the entire Study Site and is the primary driver of the elevated UXO risk rating, though additional risks were generated by wartime coastal artillery batteries on *Sjaelland* and the explosion of the *SS Bernlef* whilst enroute to dispose of live munitions in August 1945, near to the export cable corridor. Despite this, an area of ***MEDIUM*** category risk has been defined in the Site's nearshore sector, given the reduced probability of encountering WWII-era naval mines in the shallow waters.

The resultant UXO risk zones for construction and installation operations are presented at Figure 5 and is elevated compared to the UXO risk zones for GI and enabling works, due to the increased probability of encountering and initiating UXO during inter-array cable installation operations when mines have recently been encountered.

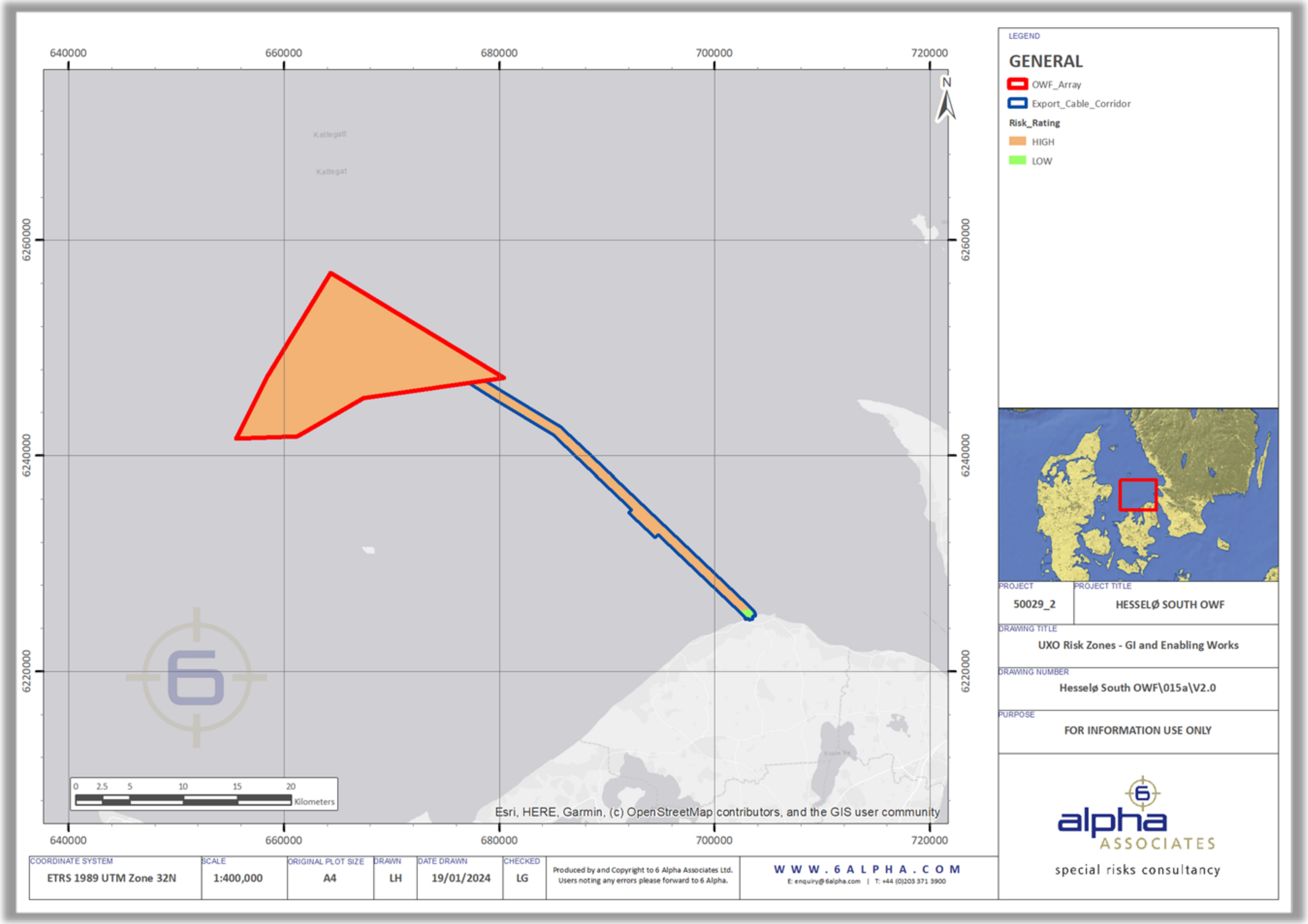


Figure 4: UXO Risk Zones – GI and Enabling Operations (Assuming JUB Deployment)

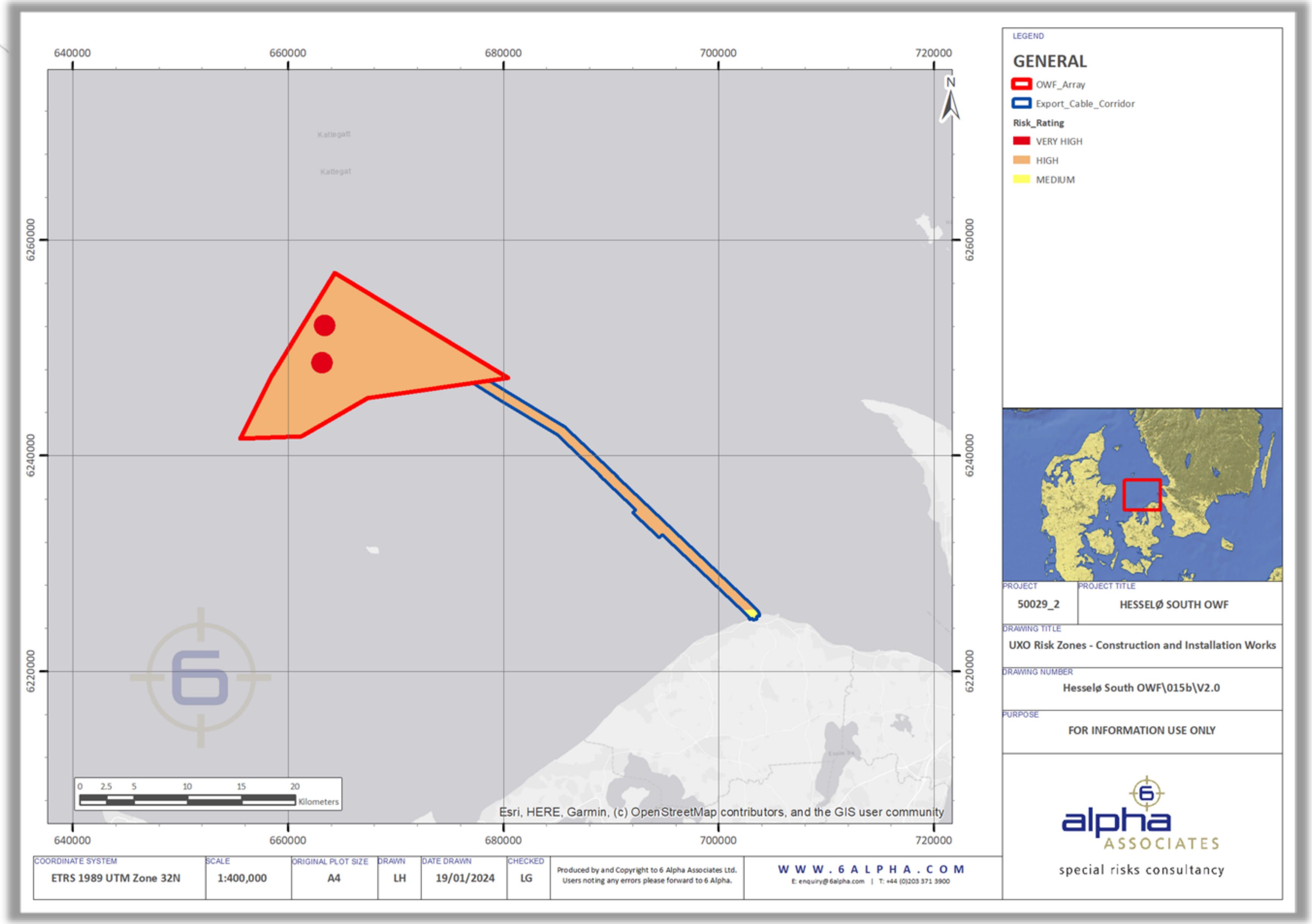


Figure 5: UXO Risk Zones – Construction and Installation Operations

9 Risk Assessment Conclusions and Recommendations

9.1 Conclusions

The nature and scope of the UXO risk has been categorised based upon a source-pathway-receptor review in general, as well as an analysis of the probability of encountering and of initiating UXO and the prospective consequences of initiating UXO, in particular.

9.1.1 UXO Risks to Surface Vessels and Crews

After an extensive desk-based analysis of historical and military records, UXO risks to vessels and vessels' crews have been zoned into areas of ***VERY HIGH*** and ***HIGH*** category UXO risks, depending on the phase of work being undertaken. In addition, a limited area of the nearshore export cable corridor has been defined as posing only ***MEDIUM*** or ***LOW*** UXO risk, due to the reduced likelihood of encountering WWII-era naval mines in shallow waters.

Specifically, the UXO risk associated with the GI work and any enabling operations has been assessed as ***HIGH*** across the majority of the Study Site, predominantly driven by the likelihood of encountering WWII-era naval mines within the extensive *Minegarden Silverthorn*. This assumes that JUB/JUVs be used to facilitate the GI works – if other enabling methodologies are used then UXO risks may instead be categorised as ***MEDIUM*** and ***LOW***, with the exception of areas in which such UXO has been discovered in recent years.

The UXO risk to surface vessels and personnel during construction and installation activities has been assessed as posing near-ubiquitous ***HIGH*** risks across nearly the entire Study Site, with the exception of two areas of ***VERY HIGH*** category UXO risk where WWII-era naval mines have been encountered in the past decade, as well as ***MEDIUM*** category UXO risk in the nearshore sector of the Site. This elevated level of UXO risk is driven by the increased likelihood of encountering WWII-era *British* naval mines, together with the relatively shallow water depths that are insufficient to wholly mitigate the consequences posed by such UXO.

9.1.2 UXO Risks to Underwater Equipment

Underwater equipment is unlikely to be robust enough to withstand the consequences of a nearby initiation of most large NEQ, threat spectrum UXO (such as WWII-era naval mines). Therefore, the prospective UXO risks posed to underwater equipment are also classified as ***HIGH*** in all depths of water.

The UXO risk to underwater equipment is likely to be considered tolerable (as compared with the effects associated with vessels and their crews) under the auspices of the ALARP risk reduction, as long as the latter risks do not also pose a hazard to the former.

9.2 Recommendations

6 Alpha recommend that the prospective UXO risks posed to the project are mitigated, within the bounds of the ALARP risk reduction principle and in accordance with national laws. Specifically, risk reduction can be achieved through the holistic implementation of the subsequent phases of the *CIRIA C754* derived risk management framework, including a suitable and cost-effective risk mitigation strategy – which is presented at Part III of this document.

Part III – UXO Risk Mitigation Strategy

10 UXO Risk Mitigation Strategy

10.1 Risk Mitigation Strategy Options

6 Alpha's approach is that the UXO risk to the intrusive operations can effectively be reduced to ALARP, by removing one (or more) element(s) of the source-pathway-receptor risk model, or otherwise mitigating the risks associated with a single element of the model.

The three main strategic risk mitigation options based upon source-pathway-receptor modelling are, in priority order:

10.1.1 Avoidance

A strategy of pUXO detection and avoidance is proposed as the most cost effective and efficient method of reducing UXO risks to ALARP. By surveying for and avoiding direct or indirect contact with any pUXO (the source of the risk), and by moving any intrusive activity away from such prospective hazards (wherever this is practicable), such risks are appropriately and effectively reduced. This strategy may prove more practical for the GI operations than for subsequent construction and cable installation operations.

10.1.2 Removal of Risk Receptors

An alternative option is to remove the receptor element (of the source-pathway-receptor model), by moving certain sensitive and vulnerable receptors (typically the crews of offshore vessels) to a safe distance from the point of the intrusive activity and thus, the pUXO hazard. Clearly, this is not always achievable and such a course of action is commonly impractical.

10.1.3 Removal of Threat Sources

Where pUXO cannot be avoided, another alternative option (but commonly, one that is more time consuming and costly), is to verify pUXO by investigation. Where it is classified as confirmed UXO (cUXO), then to either move it (to a position where it cannot reasonably be initiated by project operations), and/or then rendering it safe (effectively removing the source element of the source-pathway-receptor model).

10.2 Risk Mitigation Measures Overview

The UXO risk mitigation strategy ought to be enacted through the implementation of pertinent proactive and reactive UXO risk mitigation measures, based upon whether they are to be implemented before or concurrently with the proposed operations, tailored to the specific level of risk across each area of the Study Site.

A summary of the recommended UXO risk mitigation measures for proposed works is presented at Table 17.

Risk Mitigation Measure	VERY HIGH, HIGH and MEDIUM Risk Zones	LOW Risk Zones
UXO Emergency Response Plan	✔	✔
UXO Safety and Awareness Briefing	✔	✔
Existing Geophysical Survey Analysis	✘ (Not Critical)	✔
Bespoke Geophysical UXO Survey	✔	✘ (Not Critical)
Acoustic UXO Survey	✔	✔
Magnetic UXO Survey	✔	✘ (Not Critical)
Residual UXO Risk Rating	ALARP	

Table 17: UXO Risk Mitigation Measures Overview

Detailed advice concerning the specific nature of the recommended risk mitigation measures is given at Sections 11, 12 and 13 of this document.

11 Proactive Risk Mitigation Measures

The following risk mitigation measures are categorised as "proactive" measures and are recommended in advance of all planned operations:

11.1 Bespoke Geophysical UXO Survey

A conventional geophysical UXO survey, appropriately designed to detect threat spectrum UXO, is recommended prior to the commencement of the GI and construction phases of work in the ***VERY HIGH***, ***HIGH*** and ***MEDIUM*** risk zones, to provide a basis for a strategy of pUXO avoidance, or to facilitate its identification and removal.

Specifically, geophysical survey data (newly collected and any existing datasets that are otherwise available) will be analysed to identify pUXO and a Master Target List will be generated. Those pUXO that require avoidance will be identified and avoidance distances can be safely established through the medium of any Technical Advisory Notes (TAN), which can be produced for specific activities. Those pUXO that cannot be avoided may need to be verified and where they are then classified as cUXO, they will need to be moved and/or disposed of.

An overview of geophysical UXO survey methods that might be employed is presented at Annex G, but the survey must consist of acoustic and magnetic survey methods.

11.1.1 Acoustic UXO Detection

Acoustic detection for threat spectrum UXO should consist of suitably specified SSS and MBES over the area of the proposed intrusive phases of work. There is no evidence to suggest that non-ferrous UXO threats are expected at the Study Site, so a bespoke survey for such UXO will not be required. Such pUXO is to be avoided by an appropriate safety avoidance distance. Further guidance on the implementation of such survey methods is given at Section 13.

11.1.2 Magnetic UXO Detection

Magnetic detection for threat spectrum UXO should also be undertaken ahead of GI, WTG/OSS construction and/or cable installation works across the Study Site.

6 Alpha also recommend that any point intrusive works must be relocated upon a magnetometer line and that pUXO are avoided by a suitable and appropriate safety distance.

11.2 Existing Survey Data Analysis

Ahead of any intrusive operations within the ***LOW*** risk zones, the undertaking of a bespoke geophysical UXO survey may not be warranted <u>**if a suitable alternative can be implemented**</u>. Specifically, it is highly likely that some form of general engineering geophysical survey data will be or has been collected, for other (non-UXO related) purposes. Therefore, any existing and suitable geophysical survey data is to be employed for the purposes of pUXO identification and avoidance and/or further/investigation.

Any existing and suitable geophysical survey data will be analysed to identify pUXO and a Master Target List will be generated. If suitable data is not available, then additional survey data suitable for the purposes of pUXO avoidance may need to be acquired.

Those pUXO that require avoidance will be identified and avoidance distances can be safely established and evidenced by not only an MMBA but also subsequently, through the medium of any TANs, which can be produced for specific activities. Those pUXO that cannot be avoided may need to be verified and where they are then classified as cUXO, they will need to be moved and/or disposed of.

12 Reactive Risk Mitigation Measures

Reactive risk mitigation measures are recommended across the entire site regardless of UXO risk rating, not only to reduce intolerable risks to ALARP but also, to mitigate any residual risks that may remain once any proactive risk mitigation measures have been implemented. They are:

12.1 Operational UXO Emergency Response Plan

Any vessels involved in intrusive works should be equipped with UXO specific emergency response plans, so that in the event of an unplanned UXO discovery the vessel Master and/or the offshore superintendent/party chief (or similar) are informed in advance about what safety actions must be taken.

12.2 UXO Safety and Awareness Briefings

Safety briefings are considered as an essential reactive risk mitigation measure, to be implemented whenever there is a possibility of UXO encounter and as such, they are considered a vital part of the general UXO safety requirement.

Therefore, it is crucial that all personnel involved with seabed intrusive works, operational support staff working on vessels and/or any other relevant workers are to receive a safety briefing concerning the identification of relevant UXO and safe actions to take in the event of a potential UXO encounter, in advance of undertaking GI, construction and enabling operations.

Safety and awareness mini-posters concerning the nature of the UXO threat and key actions to be taken, are to be displayed on operational vessels for general information and on notice boards, both for reference and as a UXO safety reminder for offshore crew.

12.3 On-Call Explosive Ordnance Disposal Engineers

Following the implementation of proactive UXO risk mitigation measures, shore-side and office-based explosive ordnance disposal engineers may be engaged to provide remote, rapid UXO recognition advice and to provide immediate safety management guidance in the event that UXO is discovered. Such a service provides UXO risk management expertise as and when it is required on a just-in-time basis and not only affords safety, but also avoids prospective project delays that might otherwise be caused by the discovery of misidentified UXO, that might prove to be benign, non-UXO debris.

13 Risk Mitigation Measures – Design, Specification and Guidance

The specific designs and specifications of the recommended UXO risk mitigation measures are part of the next phase of the UXO risk management framework. Nonetheless, it is important to evidence that the risk mitigation measures are consistent with an overarching risk mitigation strategy and therefore, the following strategic level guidance ought to underpin any subsequent detailed designs and specifications for risk mitigation.

13.1 Geophysical Survey Specifications

In accordance with the risk management recommendations contained within *CIRIA*'s C754 guide, the survey contractor will need to provide evidence that their proposed survey methodology and equipment is fit for the purpose of identifying threat spectrum UXO. It is expected that acoustic UXO surveys should consist of suitably specified SSS survey (with MBES to provide positional confidence), with magnetometry survey employed where appropriate.

A suitable SSS set-up could comprise:

- ≥540kHz high-frequency of better;
- ≤50m range;
- 200% coverage (excluding nadirs).

A recommended magnetometer specification could include:

- A maximum flying altitude of 4m (assuming 2m burial of threat spectrum munitions);
- A target altitude of 3m, not less than 5m between the magnetometer sensors;
- 100% coverage achieved through dynamic coverage.

Accordingly, a detailed geophysical survey specification should be drafted for each proposed survey method – outlining the required survey parameters, equipment and calibrations – to ensure that the survey is fit for the purpose of threat spectrum UXO detection. When approaching the shoreline a shallow-draft vessel would typically be used to get as close as possible, which can tow SSS and magnetometers. Depending on the local topography, this can be achieved in only a few metres of water, though a non-vessel based solution of magnetometry may be employed in the intertidal/very shallow water zone as necessary.

In addition, a Survey Verification Test is to precede the main survey acquisition work itself, to validate and prove the efficacy of the survey equipment.

13.2 Minimum Size UXO Threats

The minimum size of UXO to be detected by geophysical UXO survey depend on a number of factors including water depth, likely intrusive methodologies, the type(s) of the UXO, prospective vessel slant range to UXO and vessels' robustness.

The minimum size UXO threat for the purposes of detection by *inter alia* magnetometer/gradiometer survey is based on UXO threats' ferrous metal contents rather than its physical dimensions, or any other factor. Figure 6 illustrates the general categorisation of minimum UXO threats for detection (and thus ALARP safety provision), at different water depths but also provides their physical dimensions.

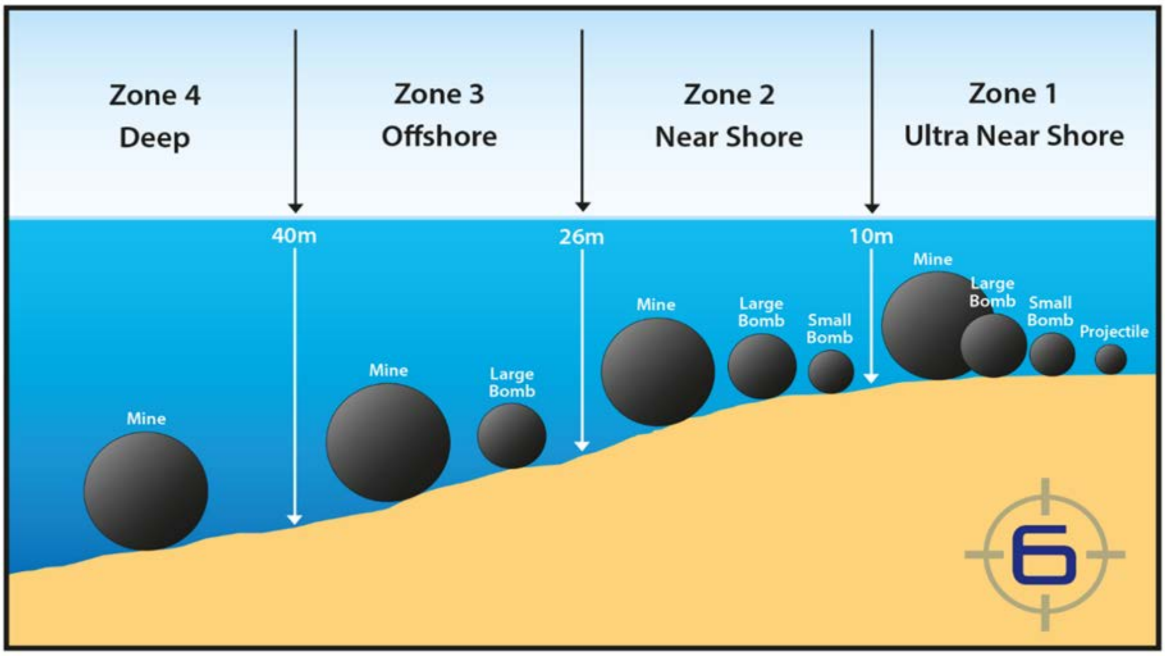


Figure 6: UXO Detection Requirement with Respect to Water Depths (in LAT)

The diagram presented at Figure 6 is intended as a general guide to minimum threat detection at those specified depths that is generally correct across all types of offshore projects but is not project specific. At the strategic level it is possible to broadly refine the minimum UXO threats that require detection for this project, as presented in Table 18.

Water Depth	Minimum UXO Threat	Dimensions (L x W)	Estimated Ferrous Mass	Explosive Fill
Up to 26m LAT	**SC-50 HE Bomb**	762mm x 200mm	25-30kg	25kg TNT
More than 26m LAT	**Type I Depth Charge**	572mm x 445mm	54.5kg	136kg

Table 18: Minimum Size of UXO Threats by Water Depth

13.3 Geophysical Survey Data Longevity

In accordance with *CIRIA* C754 UXO guidance (pp 91-92 and 149), geophysical survey data is generally employed for up to 12 months (from the time of its final capture), for UXO risk management and mitigation purposes. Once the survey data is more than 12 months old and subject to *inter alia* environmental conditions, additional risk mitigation measures may need to account for the potential changes in position of the pUXO, especially in highly mobile seabed circumstances.

In such circumstances, an MMBA can be undertaken to gain a better understanding of the type of UXO that might move, as well as the magnitude and direction of its likely migration path.

13.4 pUXO Avoidance Radii

Any geophysical UXO survey anomaly that is classified as pUXO is to be avoided, by the following distances:

- By not less than 10m from the leading edge of any underwater GI equipment,
- By not less than 15m from any construction or installation activities.

These avoidance distances are to be followed wherever possible, provided the survey data positional accuracy is demonstrated to be suitably accurate. Such safety avoidance is designed to ensure that if non-verified pUXO is in fact cUXO, it will neither be encountered nor initiated (directly or indirectly). Thus, safety is afforded.

If such a safety avoidance distance proves problematic to implement (for example, because there is a profusion of pUXO anomalies), such avoidance might be safely reduced through the medium of a TAN. A TAN can consider, *inter alia*: the kinetic energy generated by the type and nature of the intrusive activity; high-level and shallow sub-seabed geotechnical considerations, and the prospective detonation sensitivity of those types of UXO that might be encountered. Typically, such (*6 Alpha* produced) TAN can reduce safety avoidance distances by about one third.

13.5 pUXO Verification by Investigation

In the unlikely event that pUXO cannot be avoided, they might instead be verified by a campaign of Target Investigation (TI) to classify them as cUXO, or otherwise as benign debris. Such TI operations require professional quality control and independent oversight, to ensure that its outputs can properly inform and support the subsequent production of ALARP safety sign-off certification.

Nonetheless, it is the *Royal Danish Navy (Søværnet)* that is responsible for the investigation and removal of any pUXO identified at the project, within *Danish* waters. Therefore, a master target list should be supplied to *Søværnet*, which can then be investigated – typically via a remotely operated vehicle.

13.6 cUXO Disposal

Where pUXO is investigated and classified as cUXO, it will require safe disposal either in situ or, if it is considered safe to do so, through it being removed and subsequently rendered safe. For safety reporting and third-party avoidance purposes, the relevant local and national *Coast Guard* authorities - amongst a variety of other stakeholders - will also require notification upon discovery of cUXO.

It is important to note that the disposal of cUXO within *Danish* waters is in the purview of *Søværnet*, rather than the direct responsibility of a private contractor. Typically, naval divers will be mobilised to oversee such operations.

14 Residual Risk Tolerance

Following the implementation of suitable risk mitigation measures, UXO risks will not usually be reduced to "zero", nor need they be under the auspices of ALARP risk reduction principle. Residual UXO risks may remain in the offshore environment due to *inter alia*, the limits of geophysical UXO survey technology, data interpretation limitations and the fact that low NEQ UXO threats might be tolerated - which is acceptable under the principles of ALARP risk reduction.

Project stakeholders are therefore, requested to consider and to formally endorse *6 Alpha*'s assumed level of Client risk tolerance and thus our residual UXO risk recommendations, as presented and labelled as Option 2, in Table 19.

UXO Risk Tolerance	Prospective Residual UXO Risk	Project Implications
Option 1: Conservative	Damage to subsea equipment, of any kind, will not be tolerated.	Most expensive and time-consuming option but the risk of damaging the subsea equipment is significantly reduced.
Option 2: Recommended (within ALARP threshold)	An initiation of low-NEQ UXO resulting in the damage/destruction of subsea equipment will be tolerated – although it remains undesirable – as long as surface vessels and personnel are not harmed.	Time and cost efficient, although carries the risk of repair and/or replacement of equipment in the event of unplanned low NEQ UXO encounter and detonation.

Table 19: Residual UXO Risk Tolerance Levels

14.1 ALARP Safety Sign-Off Certification

ALARP safety sign-off certification provides an independent source of evidence that a Client has followed industry best practice and has successfully managed and reduced UXO risks to ALARP. Following the execution of appropriate and proportional UXO risk mitigation measures, ALARP safety sign-off certification can be delivered, in advance of the proposed operations.

In such circumstances the project will be able to certify for the benefit of all of its stakeholders, that all reasonably practicable measures have been taken to protect contractors from UXO hazards and that the commissioning Client will have acted in compliance with industry best practice as well as the national safety legislation.

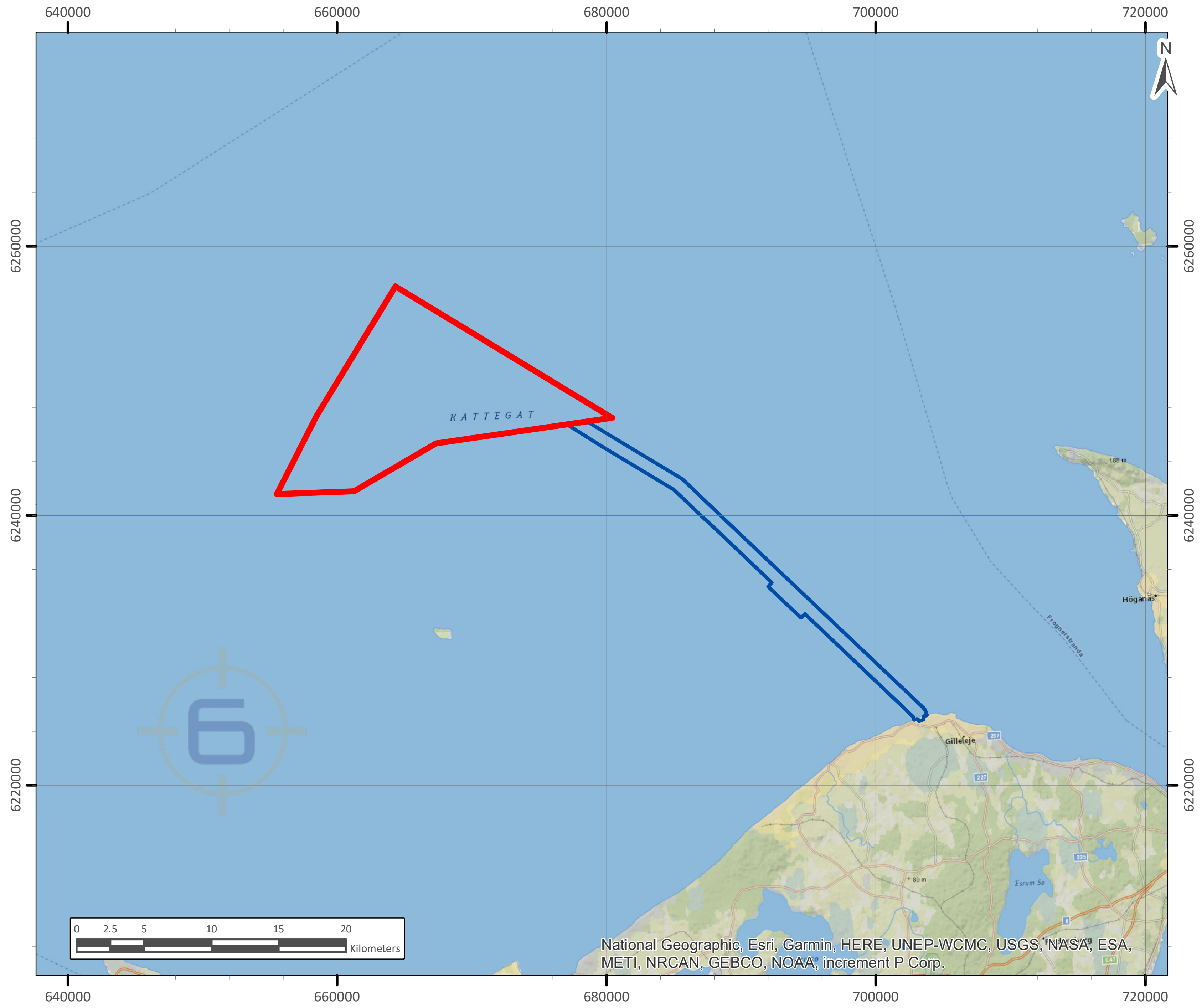
14.2 Next Steps

We recommend that the Client's next steps are focused upon phase four of the UXO Risk Management Framework namely, that detailed designs and specifications to support the recommended proactive UXO risk mitigation measures as outlined at Section 11 of this report are implemented. The specifications are to be delivered and the UXO risk mitigation work is to be executed, in advance of the intrusive investigative works, in order to warrant and to evidence that UXO risks have been mitigated and reduced to ALARP.

Appendices

Appendix 1

Site Location



LEGEND

GENERAL

- OWF_Array
- Export_Cable_Corridor

PROJECT	PROJECT TITLE
50029_2	HESSELØ SOUTH OWF

DRAWING TITLE: Site Location

DRAWING NUMBER: Hesselø South OWF\001\V1.0

PURPOSE: FOR INFORMATION USE ONLY

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special risks consultancy

COORDINATE SYSTEM	SCALE	ORIGINAL PLOT SIZE	DRAWN	DATE DRAWN	CHECKED
ETRS 1989 UTM Zone 32N	1:400,000	A4	LH	04/10/2023	LG

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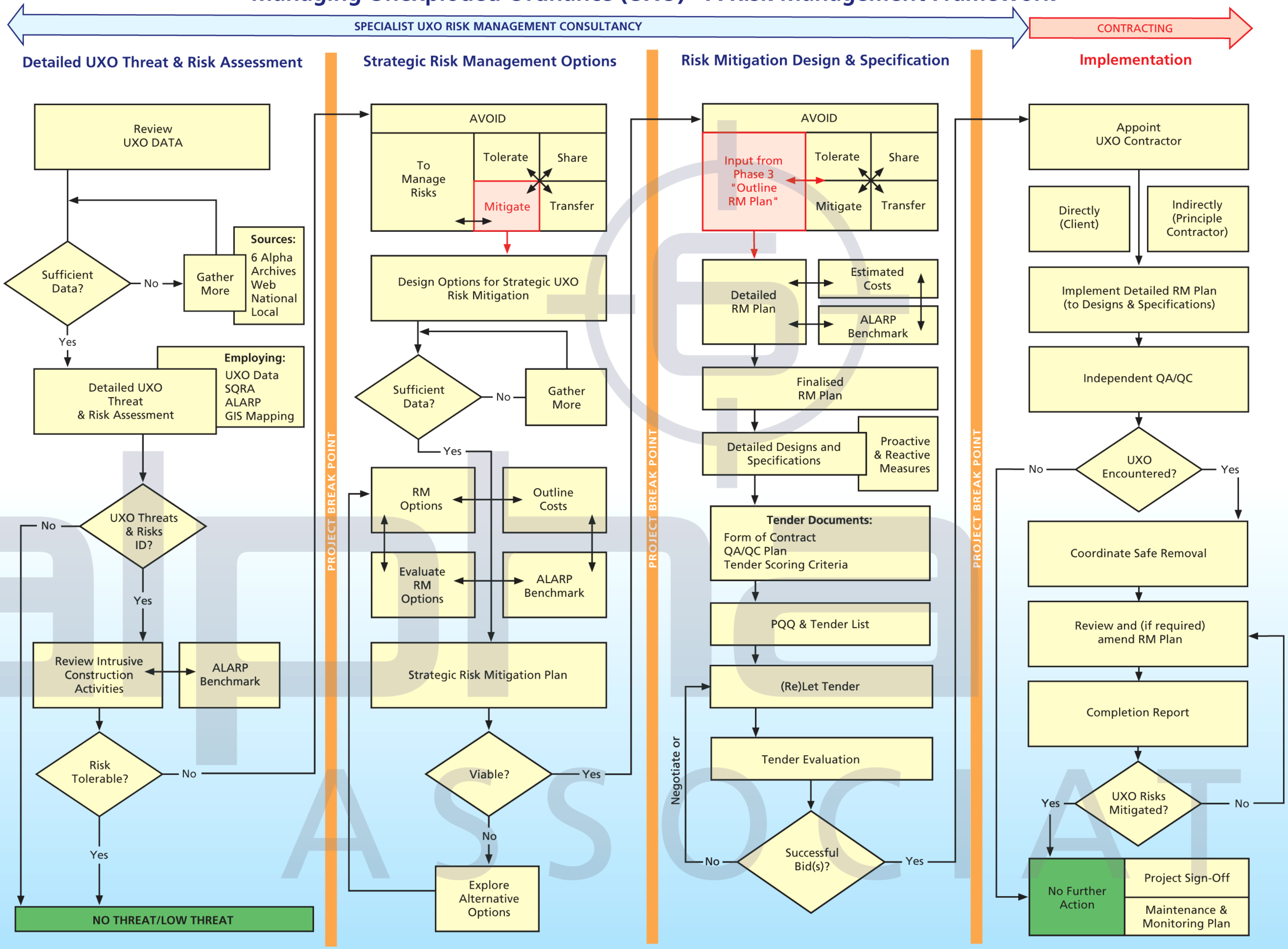
Appendix 2

Marine Risk Management Framework

Managing Unexploded Ordnance (UXO) - A Risk Management Framework



Expected Outputs

Detailed UXO Risk Assessment
Expected Consultancy Outputs:
UXO Threat Assessment employing:
Comprehensive UXO Data Sources
Semi-Quantitative Risk Assessment (SQRA) & ALARP
GIS Mapping
Independent/Robust/Transparent Assessment
Comprehensive & Informative Report

Expected Outputs

Strategic Risk Management Options
Expected Consultancy Outputs:
Strategic Risk Mitigation (RM) options
Criteria for selection of mix of options
Selection of best mix of options
Benchmark with Client's Tolerance of UXO Risk
Strategic Risk Mitigation Plan

Expected Outputs

Risk Mitigation Design & Specification
Expected Consultancy Outputs:
Detailed Risk Mitigation Design
Accompanying Risk Mitigation Specifications
Sufficient for Incorporation into Tender Documents

Expected Outputs

Implementation
Expected Consultancy & Contractor Outputs:
Safe Removal of UXO
Independent QA/QC on Contractor
Completion Reposts
Independent Consultancy Sign-off
Post Construction Maintenance/Monitoring Plan

Appendix 3

Holistic UXO Risk Management Process

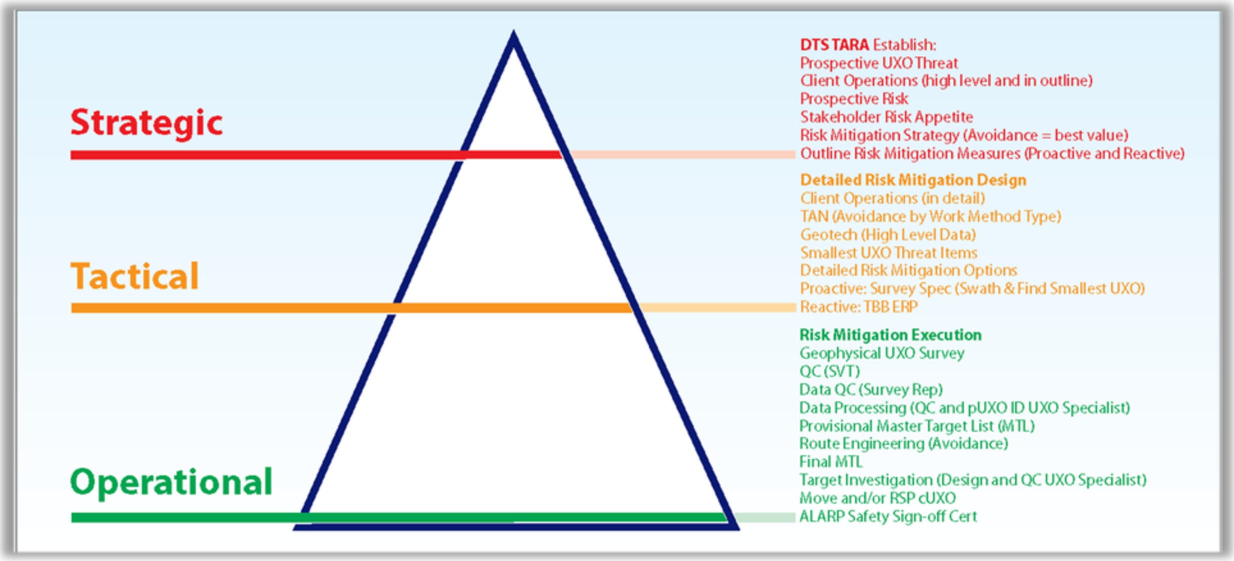
Holistic UXO Risk Management Process

1.1 Concept

There are generally, three sequential strands of Unexploded Ordnance (UXO) risk management work to consider in order to reduce risks ALARP and they have been depicted (at Figure 1) and grouped together, at the Strategic, Tactical and Operational levels.

Figure 1: 6 Alpha UXO Risk Management – Concept

1.2 Strategic Level – A Holistic Perspective of UXO Threat, Risk and Risk Management



A UXO Desk Top Study (DTS) will establish the prospective UXO threat and risk in sequence, as follows:

- **Operations**; it will establish the nature of prospective Client operations (at high level and in outline) for example and typically:
    - Geotechnical Investigation (GI);
    - Cable Installation;
    - OWF Installation;
- **Risk**; establish prospective UXO risk by examining (using Semi Quantitative Risk Assessment), two key factors:
    - **Probability**; of UXO encounter and of its initiation (the former is driven by UXO/civil engineering juxtaposition; the latter by kinetic energy);

        - **Consequence**; of UXO initiation, which is driven by the Net (High) Explosive Quantity (NEQ) in each type of UXO. And (critically); the proximity and robustness of sensitive receptors (e.g. people, GI and/or installation equipment);
- **Stakeholder Risk Appetite**; what risks can stakeholders reasonably and legally tolerate? What cannot be tolerated (e.g. risk of injury to personnel)?;
- **Risk Mitigation Strategy**; e.g. UXO avoidance which delivers the best value for money solution;
- **Risk Mitigation Measures**; divided typically into proactive and reactive categories.

1.3 Tactical Level – Detailed Risk Mitigation Design

Following GI and/or installation solution has been designed (or concurrent with it), 6 Alpha then deliver a "Detailed UXO Risk Mitigation Design", considering the following factors, in sequence:

- The Client's and Principal Contractor's installation operations (in detail);
- Technical Advisory Notes (TAN) that deliver potential UXO (pUXO) avoidance by work method type. Benefits: reduced pUXO avoidance (initially 15m radius, but typically ~10m radii, post TAN); therefore, more freedom of manoeuvre, micro-routing and micro siting, in advance of installation; fewer pUXO to be avoided; less investigation; thus save time, reduce schedule and save money;
- Geotech input in the form of high level data on soil types and shear strengths. Detailed geotech will enable more accurate and better focussed TAN;
- Smallest UXO threat items for detection v stakeholder appetite for risk?
- Therefore, outline risk mitigation measures are typically sub-divided into the following categories:
    - **Proactive Measures** e.g.:
        - Geophysical UXO survey (accounting for the smallest UXO threat) and its avoidance
        - If pUXO cannot be avoided, then verify it by investigation;
        - If it is confirmed UXO (cUXO) then move it (if it both safe and practical to do so) and/or destroy it;
    - **Reactive Measures** e.g.:
        - Site Emergency Response Plans (ERP);
        - Tool Box Briefs (TBB) for site workers.

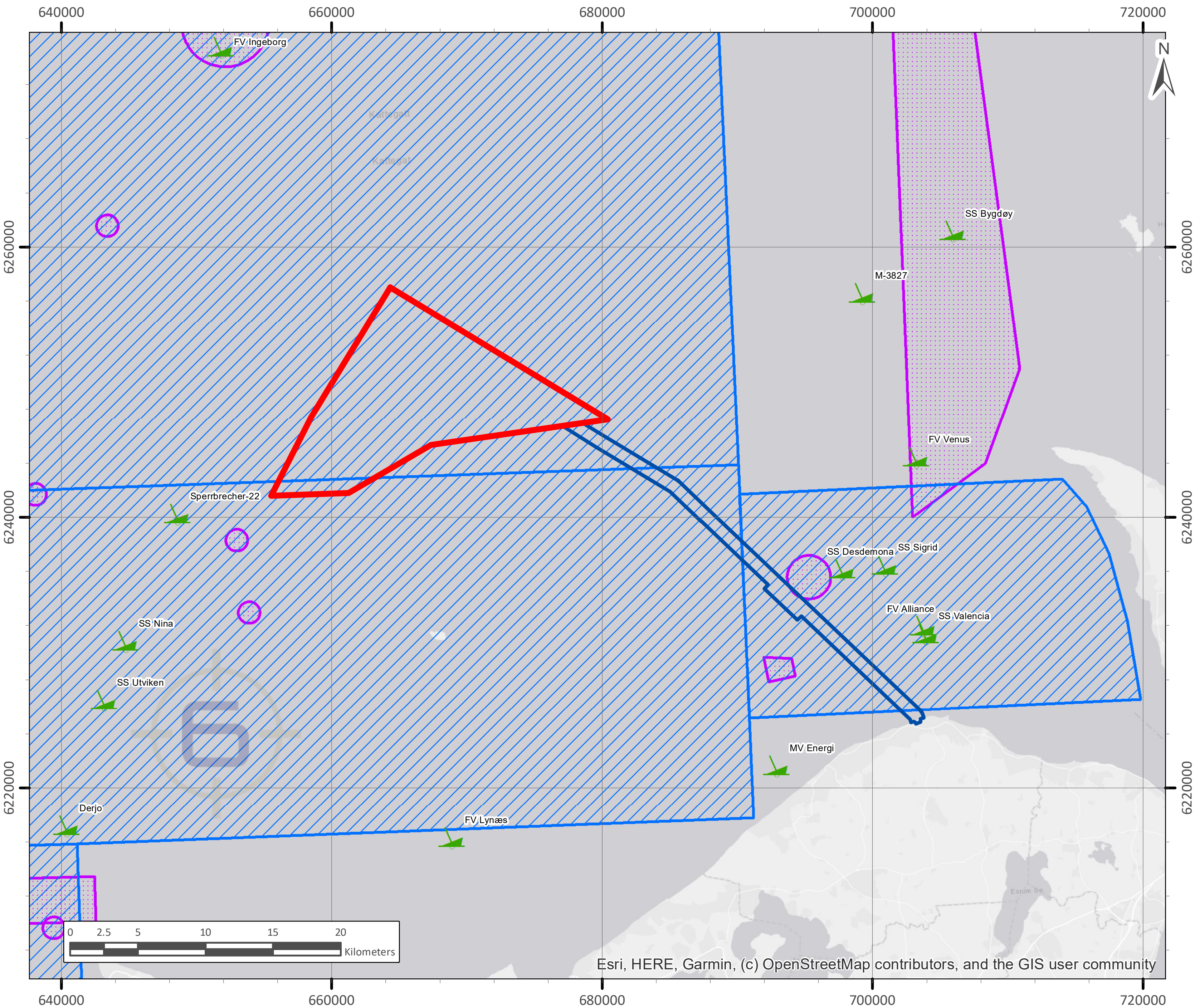
1.4 Operational Level – Delivery of UXO Risk Managements and Mitigation Solutions

UXO risk mitigation execution might typically include, sequentially:

- Geophysical UXO Survey pre-installation;
- Survey Quality Control (QC) via a Survey Verification Test (SVT);
- Data QC;
- Data Processing (QC and pUXO ID - by a UXO Specialist, such as 6 Alpha), concurrent with survey operations;
- Provisional Master Target List (MTL) generated by UXO Specialist consisting of all pUXO;
- Micro-siting and/or route engineering (thus avoidance) is undertaken (benefit - saves time and money);
- Final MTL produced, which ensured that the following activities are reduced to the minimum in order to reduce risk ALARP and to save time and money:
    - Target Investigation (designed, and QC'd by a UXO Specialist such as 6 Alpha);
    - Move and/or Redner Safe Procedure (RSP) on confirmed UXO (cUXO);
    - ALARP Safety Sign-off Certs delivered for all installation methods.

Appendix 4

WWII Minefields



LEGEND

GENERAL

- OWF_Array
- Export_Cable_Corridor

UXO THREATS

- WWII_Mined_Wreck
- WWII_Allied_Minefield
- Mine_Danger_Area

PROJECT	PROJECT TITLE
50029_2	HESSELØ SOUTH OWF

DRAWING TITLE

WWII Minefields

DRAWING NUMBER

Hesselø South OWF\004\V2.0

PURPOSE

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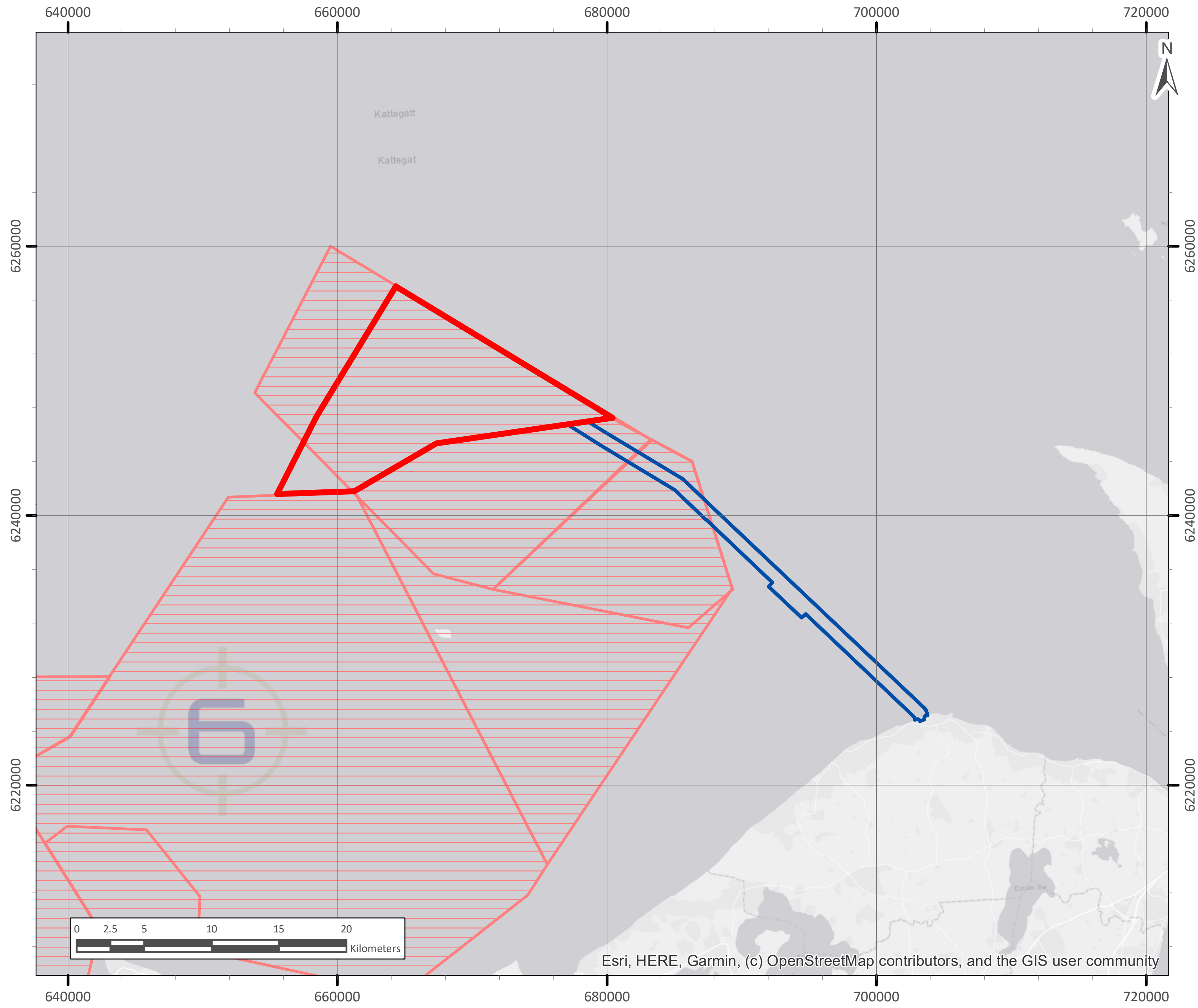
Modern Military PEXA



LEGEND

GENERAL

- OWF_Array
- Export_Cable_Corridor

UXO THREATS

- Modern_PEXA

PROJECT	PROJECT TITLE
50029_2	HESSELØ SOUTH OWF

DRAWING TITLE
Modern Military PEXA

DRAWING NUMBER
Hesselø South OWF\005\V2.0

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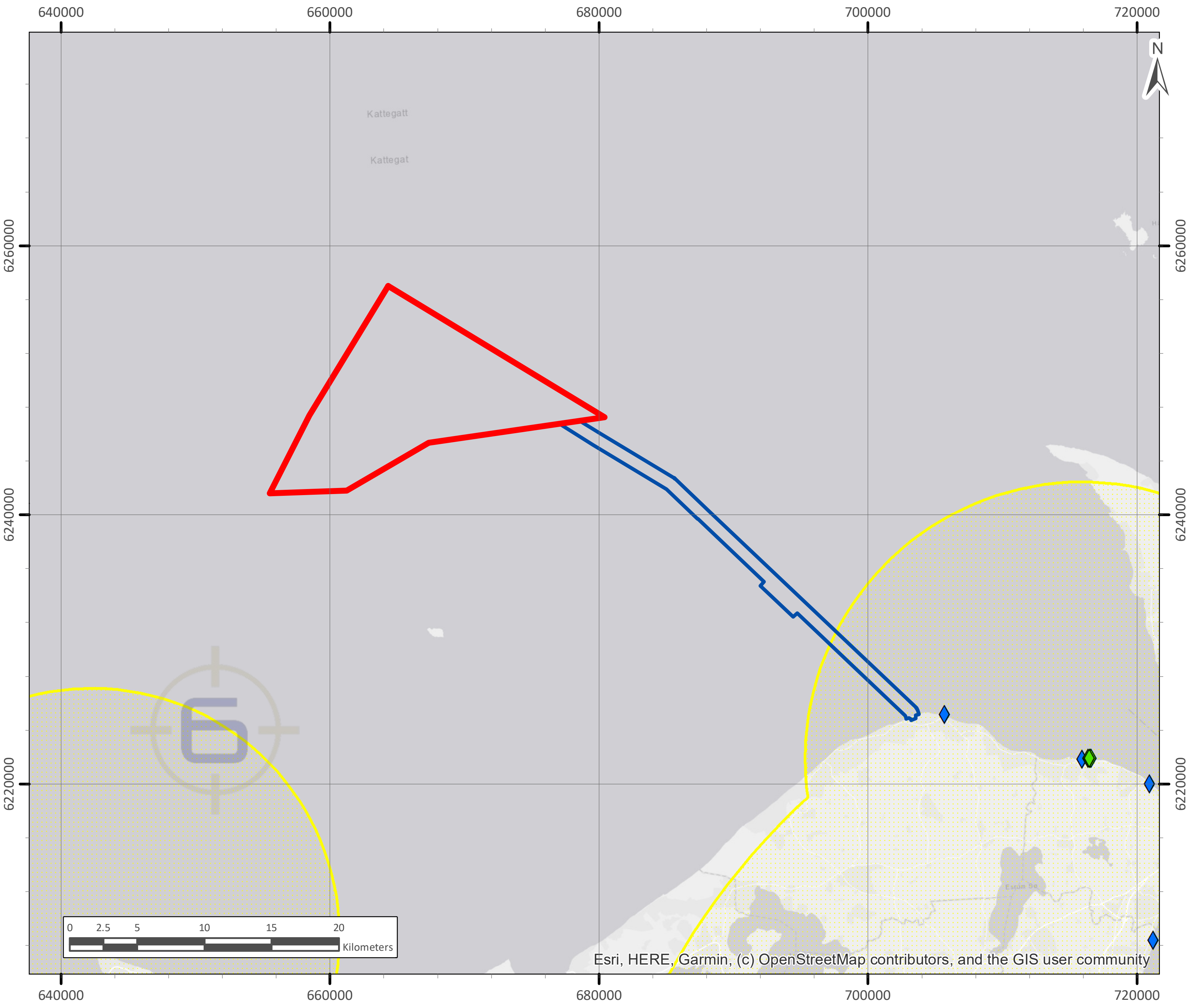
Coastal Armaments



LEGEND

GENERAL

- OWF_Array
- Export_Cable_Corridor

UXO THREATS

- Atlantikwall_Installation
- Coastal_Armament
- Coastal_Armament_Range

PROJECT	PROJECT TITLE
50029_2	HESSELØ SOUTH OWF

DRAWING TITLE
Coastal Armaments

DRAWING NUMBER
Hesselø South OWF\006\V1.0

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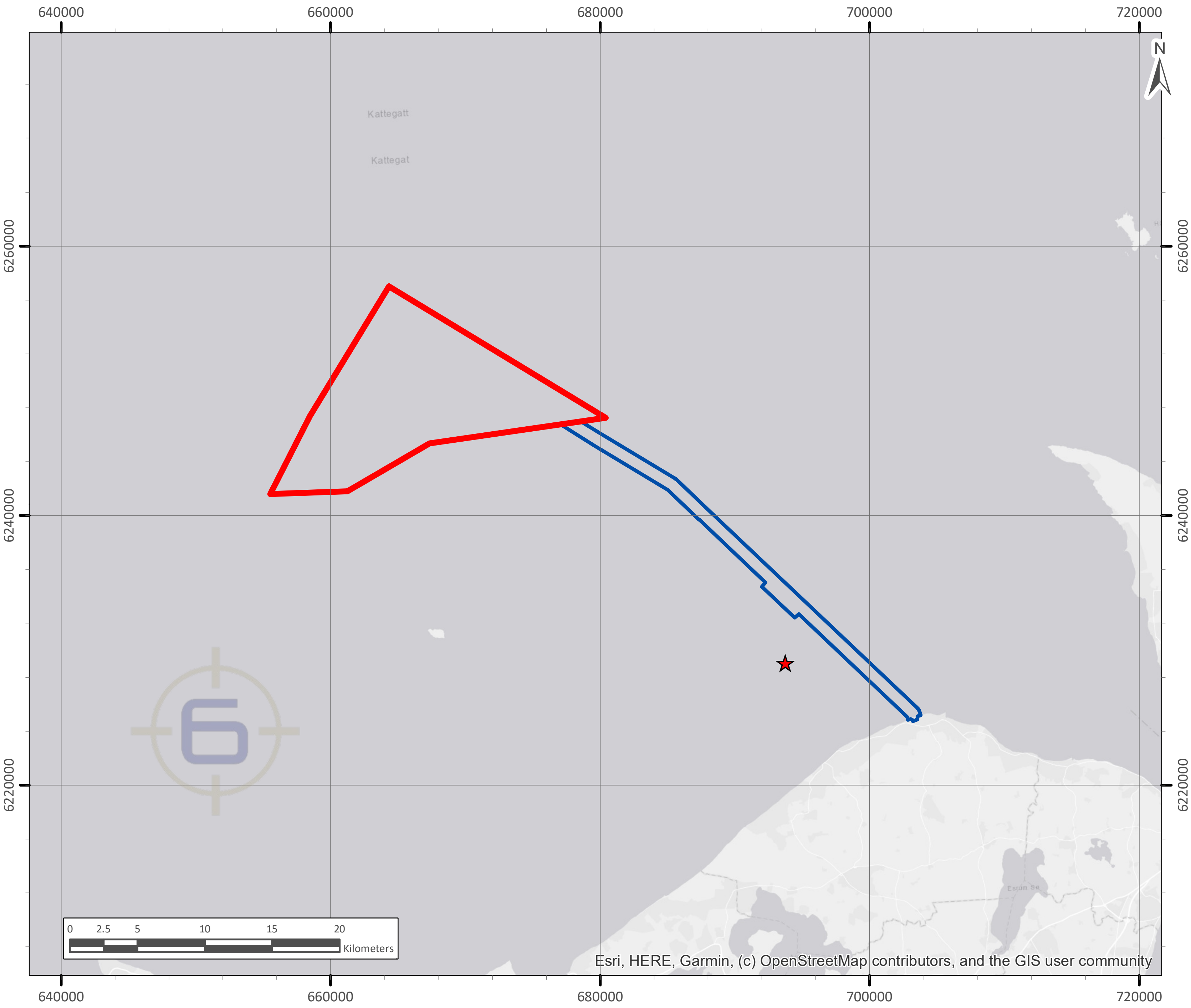
Appendix 7

Munitions Dumping



LEGEND

GENERAL

OWF_Array

Export_Cable_Corridor

UXO THREATS

Conventional_Munitions_Dump

PROJECT	PROJECT TITLE
50029_2	HESSELØ SOUTH OWF

DRAWING TITLE
Munitions Dumping

DRAWING NUMBER
Hesselø South OWF\007\V1.0

PURPOSE
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COORDINATE SYSTEM	SCALE	ORIGINAL PLOT SIZE	DRAWN	DATE DRAWN	CHECKED
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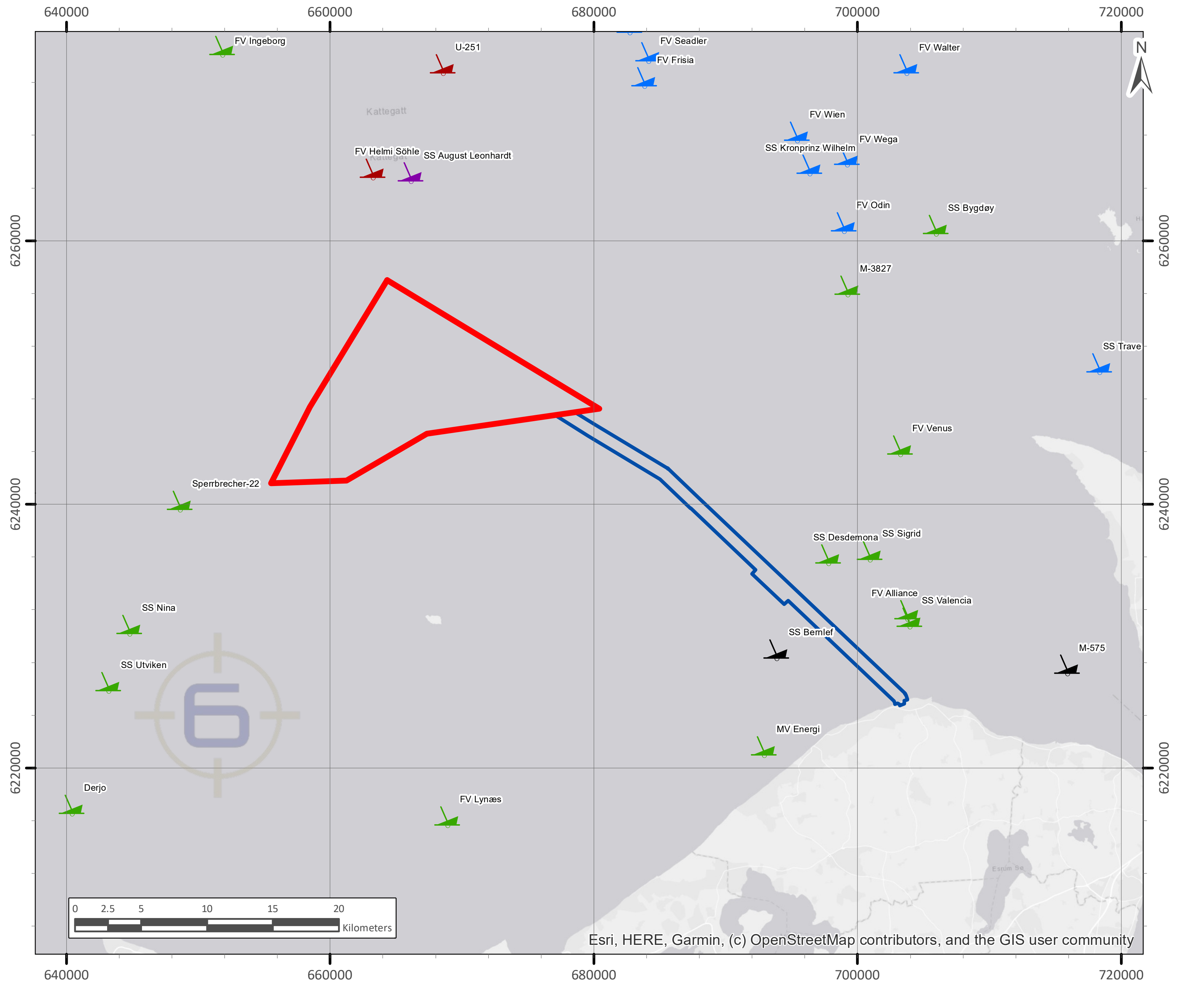
Munitions Related Shipwrecks



LEGEND

GENERAL

- OWF_Array
- Export_Cable_Corridor

UXO THREATS

- WWII_Air-Raid_Wreck
- WWI_Naval_Wreck
- WWII_Naval_Wreck
- WWII_Mined_Wreck
- Other_Munitions_Wreck

PROJECT	PROJECT TITLE
50029_2	HESSELØ SOUTH OWF

DRAWING TITLE
Munitions Related Shipwrecks

DRAWING NUMBER
Hesselø South OWF\008\V1.0

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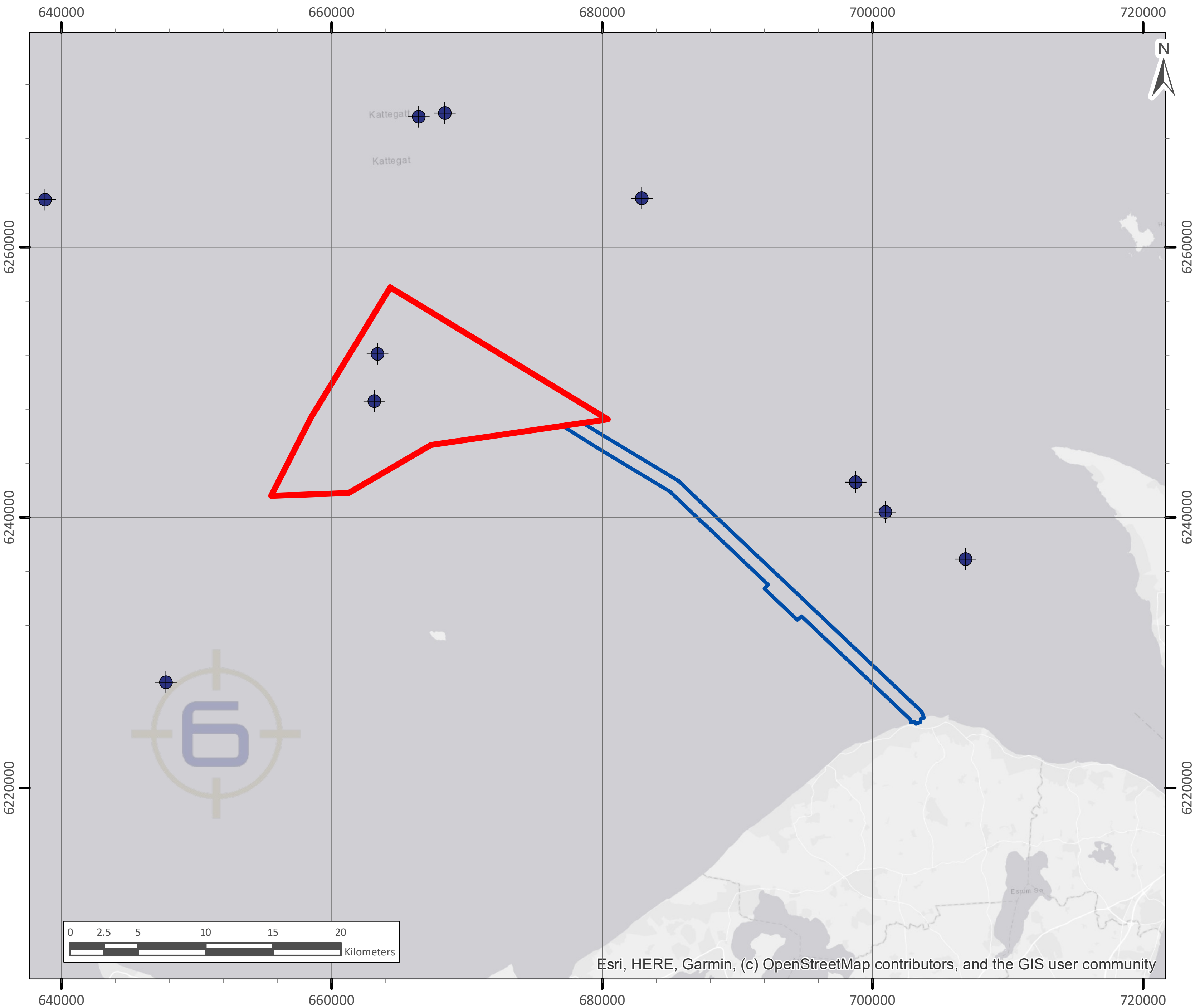
Appendix 9

Munitions Encounters



LEGEND

GENERAL

OWF_Array

Export_Cable_Corridor

UXO THREATS

OSPAR_Munitions_Encounter

PROJECT	PROJECT TITLE
50029_2	HESSELØ SOUTH OWF

DRAWING TITLE
Munitions Encounters

DRAWING NUMBER
Hesselø South OWF\009\V1.0

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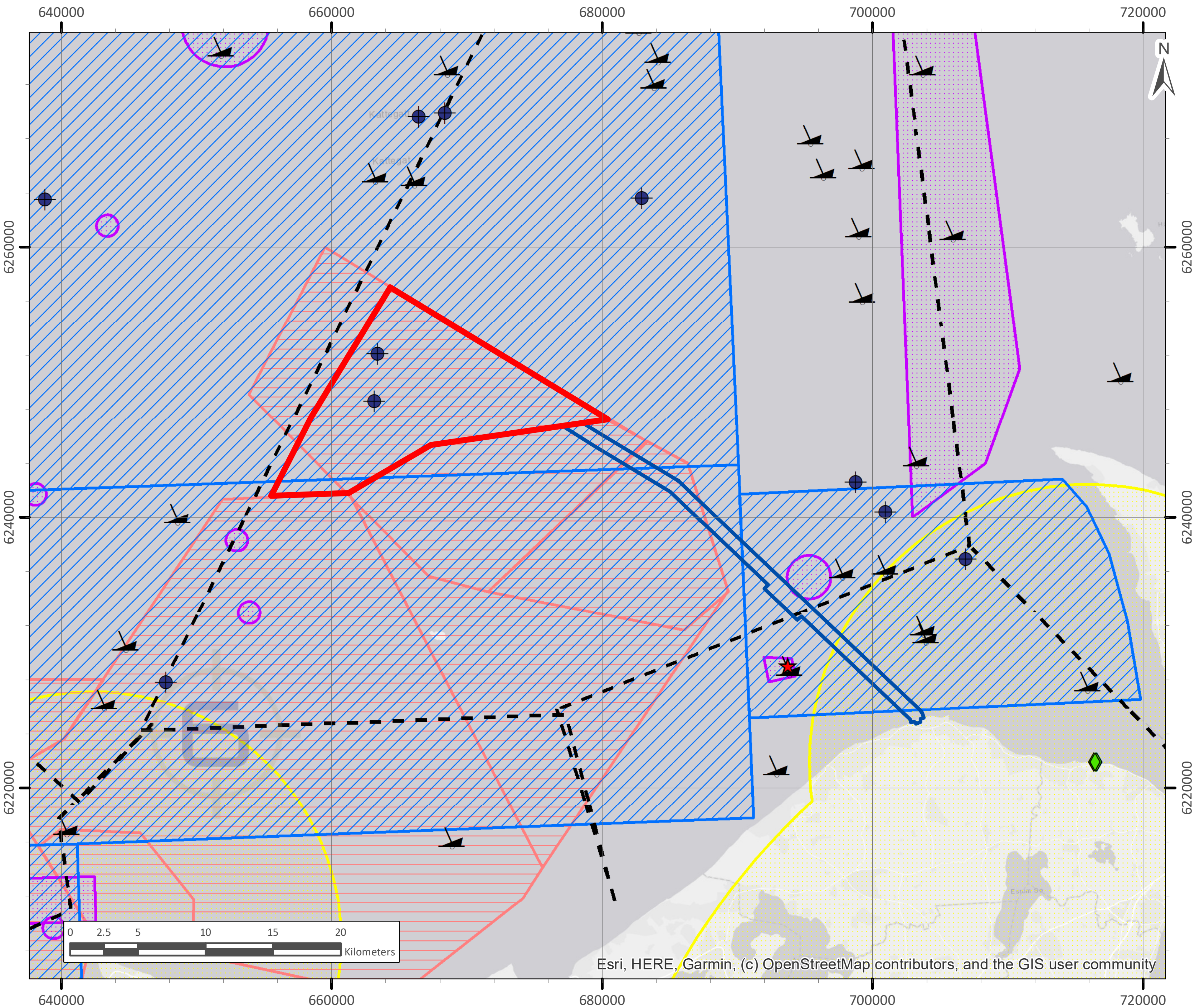
Consolidated UXO Threat



LEGEND

GENERAL

- OWF_Array
- Export_Cable_Corridor

UXO THREATS

- Atlantikwall_Installation
- Conventional_Munitions_Dump
- Munitions_Related_Wreck
- OSPAR_Munitions_Encounter
- WWII_Axis_Convoy_Route
- WWII_Allied_Minefield
- Mine_Danger_Area
- Modern_PEXA
- Coastal_Armament_Range

PROJECT	PROJECT TITLE
50029_2	HESSELØ SOUTH OWF

DRAWING TITLE
Consolidated UXO Threat

DRAWING NUMBER
Hesselø South OWF\010\V2.0

PURPOSE
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COORDINATE SYSTEM	SCALE	ORIGINAL PLOT SIZE	DRAWN	DATE DRAWN	CHECKED
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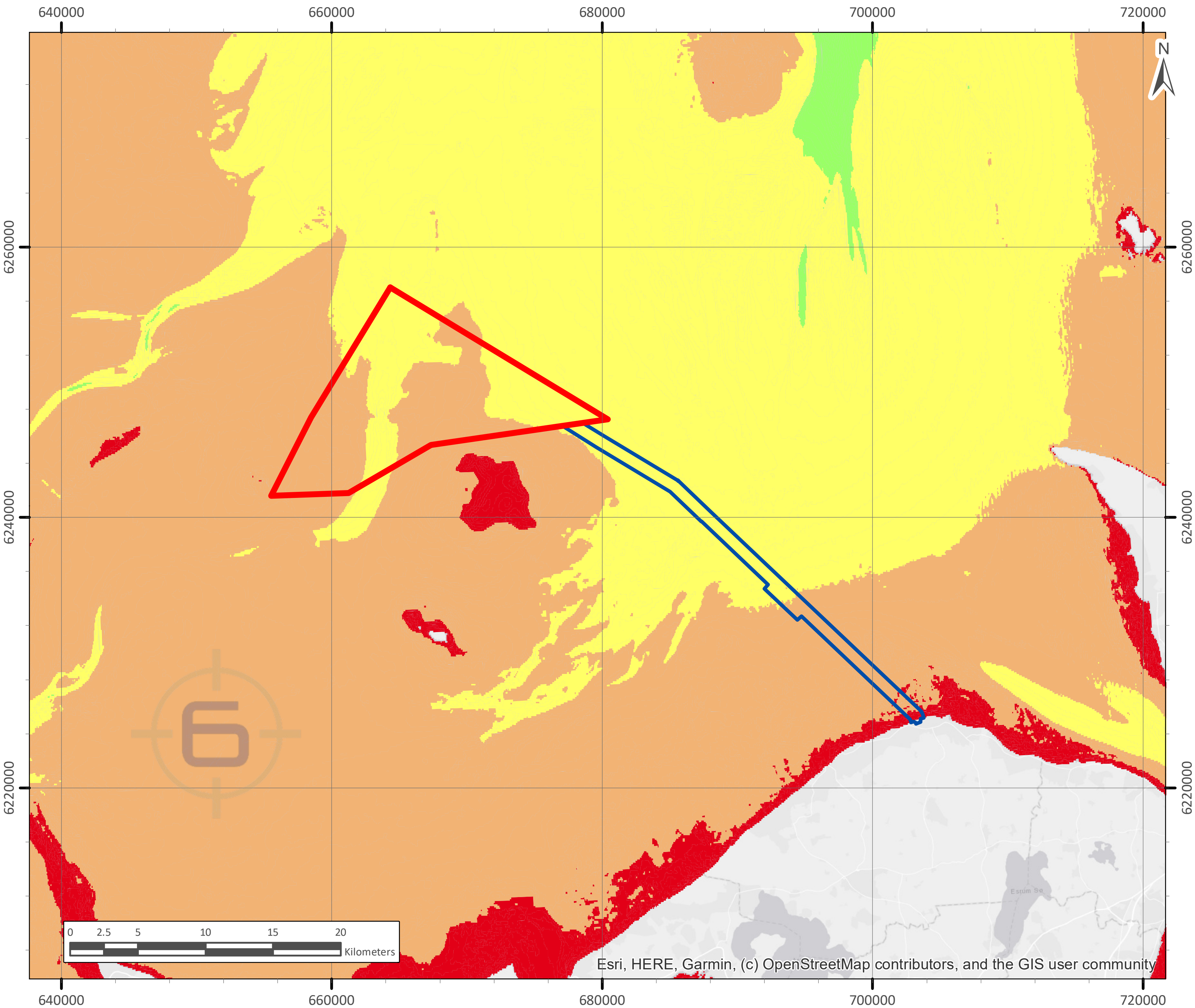
Appendix 11

Bathymetry



LEGEND

GENERAL

- OWF_Array
- Export_Cable_Corridor

Water_Depth (LAT)

- <10m
- <26m
- <40m
- <60m

PROJECT	PROJECT TITLE
50029_2	HESSELØ SOUTH OWF

DRAWING TITLE

Bathymetry

DRAWING NUMBER

Hesselø South OWF\011\V1.0

PURPOSE

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COORDINATE SYSTEM	SCALE	ORIGINAL PLOT SIZE	DRAWN	DATE DRAWN	CHECKED
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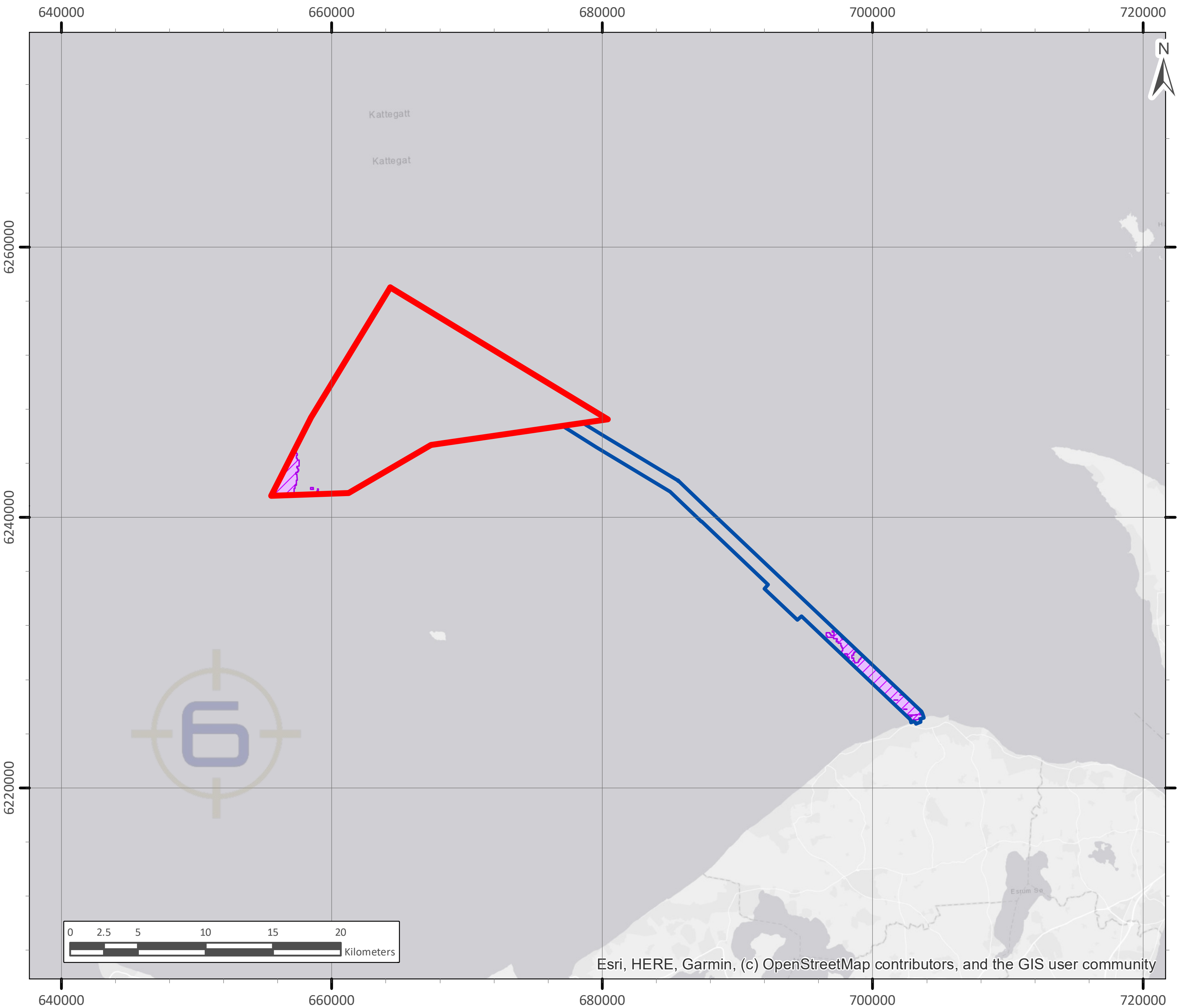
Appendix 12

Initial Impact Burial



LEGEND

GENERAL

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- Export_Cable_Corridor
- Areas_Of_Potential_Initial_Impact_Burial

PROJECT	PROJECT TITLE
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DRAWING TITLE: **Initial Impact Burial**

DRAWING NUMBER: **Hesselø South OWF\012\V1.0**

PURPOSE: **FOR INFORMATION USE ONLY**

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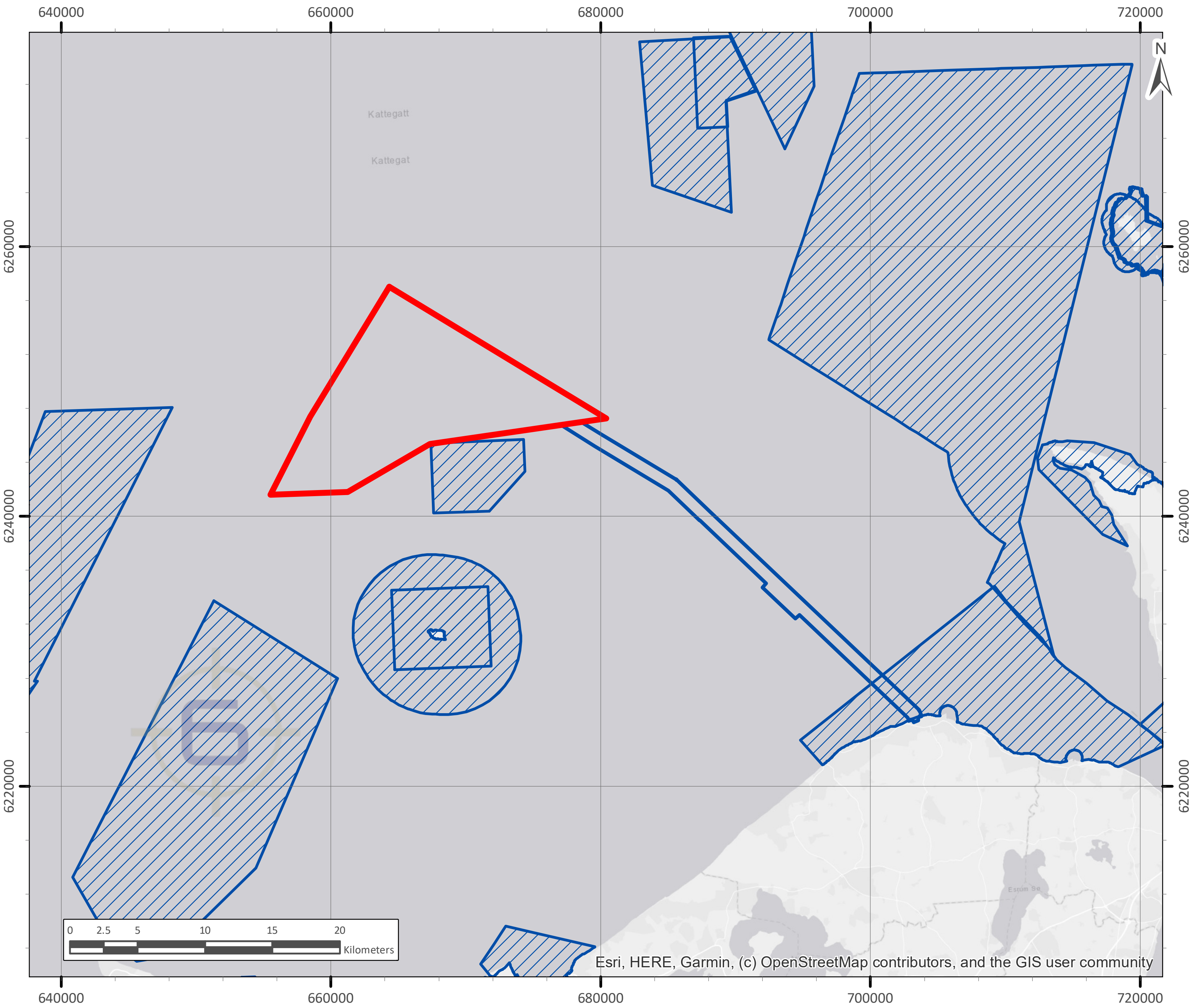
Appendix 13

Marine Protection Areas



LEGEND

GENERAL

- OWF_Array
- Export_Cable_Corridor
- Marine_Protected_Area

PROJECT	PROJECT TITLE
50029_2	HESSELØ SOUTH OWF

DRAWING TITLE: **Marine Protection Areas**

DRAWING NUMBER: **Hesselø South OWF\013\V1.0**

PURPOSE: **FOR INFORMATION USE ONLY**

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COORDINATE SYSTEM	SCALE	ORIGINAL PLOT SIZE	DRAWN	DATE DRAWN	CHECKED
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Semi-Quantitative Risk Assessment Tables

GI Operations

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel			UXO Risk to Underwater Equipment		
			P	C	R	P	C	R
GI ~10m LAT	WWII Naval Mine	454	1	5	**5**	1	5	**5**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	1	5	**5**	1	5	**5**
	German WWII Depth Charge	136	1	5	**5**	1	5	**5**
	British WWII Depth Charge	132	1	5	**5**	1	5	**5**
	Modern Naval Projectile	3.52	1	2	**2**	1	2	**2**
	WWII Artillery Projectile	2	1	2	**2**	1	2	**2**
GI ~26m LAT	WWII Naval Mine	454	3	5	**15**	3	5	**15**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	1	5	**5**	1	5	**5**
	German WWII Depth Charge	136	1	4	**4**	1	5	**5**
	British WWII Depth Charge	132	1	4	**4**	1	5	**5**
	Modern Naval Projectile	3.52	2	1	**2**	2	2	**4**
	WWII Artillery Projectile	2	1	1	**1**	1	2	**2**

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel			UXO Risk to Underwater Equipment		
			P	C	R	P	C	R
GI ~40m LAT	WWII Naval Mine	454	3	4	**12**	3	5	**15**
	British WWII HE Bomb	309	1	4	**4**	1	5	**5**
	German WWII HE Bomb	220	1	3	**3**	1	5	**5**
	German WWII Depth Charge	136	1	3	**3**	1	5	**5**
	British WWII Depth Charge	132	1	3	**3**	1	5	**5**
	Modern Naval Projectile	3.52	2	1	**2**	2	2	**4**
	WWII Artillery Projectile	2	1	1	**1**	1	2	**2**

WTG and OSS Construction Operations

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel			UXO Risk to Underwater Equipment		
			P	C	R	P	C	R
Piling ~26m LAT	WWII Naval Mine	454	4	5	**20**	4	5	**20**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	2	5	**10**	2	5	**10**
	German WWII Depth Charge	136	2	4	**8**	2	5	**10**
	British WWII Depth Charge	132	1	4	**4**	1	5	**5**
	Modern Naval Projectile	3.52	3	1	**3**	3	2	**6**
	WWII Artillery Projectile	2	2	1	**2**	2	2	**4**
Piling ~40m LAT	WWII Naval Mine	454	3	4	**12**	3	5	**15**
	British WWII HE Bomb	309	1	4	**4**	1	5	**5**
	German WWII HE Bomb	220	1	3	**3**	1	5	**5**
	German WWII Depth Charge	136	1	3	**3**	1	5	**5**
	British WWII Depth Charge	132	1	3	**3**	1	5	**5**
	Modern Naval Projectile	3.52	3	1	**3**	3	2	**6**
	WWII Artillery Projectile	2	1	1	**1**	1	2	**2**

Cable Installation and Burial Operations

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel			UXO Risk to Underwater Equipment		
			P	C	R	P	C	R
PLGR + RC ~10m LAT	WWII Naval Mine	454	2	5	**10**	2	5	**10**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	1	5	**5**	1	5	**5**
	German WWII Depth Charge	136	1	5	**5**	1	5	**5**
	British WWII Depth Charge	132	1	5	**5**	1	5	**5**
	Modern Naval Projectile	3.52	1	2	**2**	1	2	**2**
	WWII Artillery Projectile	2	3	2	**6**	3	2	**6**
PLGR + RC ~26m LAT	WWII Naval Mine	454	5	5	**25**	5	5	**25**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	3	5	**15**	3	5	**15**
	German WWII Depth Charge	136	3	4	**12**	3	5	**15**
	British WWII Depth Charge	132	1	4	**4**	1	5	**5**
	Modern Naval Projectile	3.52	4	1	**4**	4	2	**8**
	WWII Artillery Projectile	2	3	1	**3**	3	2	**6**

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel			UXO Risk to Underwater Equipment		
			P	C	R	P	C	R
PLGR + RC ~40m LAT	WWII Naval Mine	454	5	4	**20**	5	5	**25**
	British WWII HE Bomb	309	1	4	**4**	1	5	**5**
	German WWII HE Bomb	220	1	3	**3**	1	5	**5**
	German WWII Depth Charge	136	1	3	**3**	1	5	**5**
	British WWII Depth Charge	132	1	3	**3**	1	5	**5**
	Modern Naval Projectile	3.52	4	1	**4**	4	2	**8**
	WWII Artillery Projectile	2	1	1	**1**	1	2	**2**

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel			UXO Risk to Underwater Equipment		
			P	C	R	P	C	R
Surface Lay ~10m LAT	WWII Naval Mine	454	1	5	**5**	1	5	**5**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	1	5	**5**	1	5	**5**
	German WWII Depth Charge	136	1	5	**5**	1	5	**5**
	British WWII Depth Charge	132	1	5	**5**	1	5	**5**
	Modern Naval Projectile	3.52	1	2	**2**	1	2	**2**
	WWII Artillery Projectile	2	1	2	**2**	1	2	**2**
Surface Lay ~26m LAT	WWII Naval Mine	454	3	5	**15**	3	5	**15**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	1	5	**5**	1	5	**5**
	German WWII Depth Charge	136	1	4	**4**	1	5	**5**
	British WWII Depth Charge	132	1	4	**4**	1	5	**5**
	Modern Naval Projectile	3.52	2	1	**2**	2	2	**4**
	WWII Artillery Projectile	2	1	1	**1**	1	2	**2**

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel			UXO Risk to Underwater Equipment		
			P	C	R	P	C	R
Surface Lay ~40m LAT	WWII Naval Mine	454	3	4	**12**	3	5	**15**
	British WWII HE Bomb	309	1	4	**4**	1	5	**5**
	German WWII HE Bomb	220	1	3	**3**	1	5	**5**
	German WWII Depth Charge	136	1	3	**3**	1	5	**5**
	British WWII Depth Charge	132	1	3	**3**	1	5	**5**
	Modern Naval Projectile	3.52	2	1	**2**	2	2	**4**
	WWII Artillery Projectile	2	1	1	**1**	1	2	**2**

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel			UXO Risk to Underwater Equipment		
			P	C	R	P	C	R
Jetting ~10m LAT	WWII Naval Mine	454	1	5	**5**	1	5	**5**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	1	5	**5**	1	5	**5**
	German WWII Depth Charge	136	1	5	**5**	1	5	**5**
	British WWII Depth Charge	132	1	5	**5**	1	5	**5**
	Modern Naval Projectile	3.52	1	2	**2**	1	2	**2**
	WWII Artillery Projectile	2	2	2	**4**	2	2	**4**
Jetting ~26m LAT	WWII Naval Mine	454	4	5	**20**	4	5	**20**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	2	5	**10**	2	5	**10**
	German WWII Depth Charge	136	2	4	**8**	2	5	**10**
	British WWII Depth Charge	132	1	4	**4**	1	5	**5**
	Modern Naval Projectile	3.52	3	1	**3**	3	2	**6**
	WWII Artillery Projectile	2	2	1	**2**	2	2	**4**

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel			UXO Risk to Underwater Equipment		
			P	C	R	P	C	R
Jetting ~40m LAT	WWII Naval Mine	454	4	4	**16**	4	5	**20**
	British WWII HE Bomb	309	1	4	**4**	1	5	**5**
	German WWII HE Bomb	220	1	3	**3**	1	5	**5**
	German WWII Depth Charge	136	1	3	**3**	1	5	**5**
	British WWII Depth Charge	132	1	3	**3**	1	5	**5**
	Modern Naval Projectile	3.52	3	1	**3**	3	2	**6**
	WWII Artillery Projectile	2	1	1	**1**	1	2	**2**

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel			UXO Risk to Underwater Equipment		
			P	C	R	P	C	R
Ploughing ~10m LAT	WWII Naval Mine	454	2	5	**10**	2	5	**10**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	1	5	**5**	1	5	**5**
	German WWII Depth Charge	136	1	5	**5**	1	5	**5**
	British WWII Depth Charge	132	1	5	**5**	1	5	**5**
	Modern Naval Projectile	3.52	1	2	**2**	1	2	**2**
	WWII Artillery Projectile	2	3	2	**6**	3	2	**6**
Ploughing ~26m LAT	WWII Naval Mine	454	5	5	**25**	5	5	**25**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	3	5	**15**	3	5	**15**
	German WWII Depth Charge	136	3	4	**12**	3	5	**15**
	British WWII Depth Charge	132	1	4	**4**	1	5	**5**
	Modern Naval Projectile	3.52	4	1	**4**	4	2	**8**
	WWII Artillery Projectile	2	3	1	**3**	3	2	**6**

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel			UXO Risk to Underwater Equipment		
			P	C	R	P	C	R
Ploughing ~40m LAT	WWII Naval Mine	454	5	4	**20**	5	5	**25**
	British WWII HE Bomb	309	1	4	**4**	1	5	**5**
	German WWII HE Bomb	220	1	3	**3**	1	5	**5**
	German WWII Depth Charge	136	1	3	**3**	1	5	**5**
	British WWII Depth Charge	132	1	3	**3**	1	5	**5**
	Modern Naval Projectile	3.52	4	1	**4**	4	2	**8**
	WWII Artillery Projectile	2	1	1	**1**	1	2	**2**

Protection and Crossing Operations

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel			UXO Risk to Underwater Equipment		
			P	C	R	P	C	R
Rock Emplacement ~10m LAT	WWII Naval Mine	454	1	5	**5**	1	5	**5**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	1	5	**5**	1	5	**5**
	German WWII Depth Charge	136	1	5	**5**	1	5	**5**
	British WWII Depth Charge	132	1	5	**5**	1	5	**5**
	Modern Naval Projectile	3.52	1	2	**2**	1	2	**2**
	WWII Artillery Projectile	2	2	2	**4**	2	2	**4**
Rock Emplacement ~26m LAT	WWII Naval Mine	454	4	5	**20**	4	5	**20**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	2	5	**10**	2	5	**10**
	German WWII Depth Charge	136	2	4	**8**	2	5	**10**
	British WWII Depth Charge	132	1	4	**4**	1	5	**5**
	Modern Naval Projectile	3.52	3	1	**3**	3	2	**6**
	WWII Artillery Projectile	2	2	1	**2**	2	2	**4**

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel			UXO Risk to Underwater Equipment		
			P	C	R	P	C	R
Rock Emplacement ~40m LAT	WWII Naval Mine	454	4	4	**16**	4	5	**20**
	British WWII HE Bomb	309	1	4	**4**	1	5	**5**
	German WWII HE Bomb	220	1	3	**3**	1	5	**5**
	German WWII Depth Charge	136	1	3	**3**	1	5	**5**
	British WWII Depth Charge	132	1	3	**3**	1	5	**5**
	Modern Naval Projectile	3.52	3	1	**3**	3	2	**6**
	WWII Artillery Projectile	2	1	1	**1**	1	2	**2**

Enabling Operations

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel			UXO Risk to Underwater Equipment		
			P	C	R	P	C	R
DP Vessels ~10m LAT	WWII Naval Mine	454	1	5	**5**	1	5	**5**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	1	5	**5**	1	5	**5**
	German WWII Depth Charge	136	1	5	**5**	1	5	**5**
	British WWII Depth Charge	132	1	5	**5**	1	5	**5**
	Modern Naval Projectile	3.52	1	2	**2**	1	2	**2**
	WWII Artillery Projectile	2	1	2	**2**	1	2	**2**
DP Vessels ~26m LAT	WWII Naval Mine	454	1	5	**5**	1	5	**5**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	1	5	**5**	1	5	**5**
	German WWII Depth Charge	136	1	4	**4**	1	5	**5**
	British WWII Depth Charge	132	1	4	**4**	1	5	**5**
	Modern Naval Projectile	3.52	1	1	**1**	1	2	**2**
	WWII Artillery Projectile	2	1	1	**1**	1	2	**2**

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel			UXO Risk to Underwater Equipment		
			P	C	R	P	C	R
DP Vessels ~40m LAT	WWII Naval Mine	454	1	4	**4**	1	5	**5**
	British WWII HE Bomb	309	1	4	**4**	1	5	**5**
	German WWII HE Bomb	220	1	3	**3**	1	5	**5**
	German WWII Depth Charge	136	1	3	**3**	1	5	**5**
	British WWII Depth Charge	132	1	3	**3**	1	5	**5**
	Modern Naval Projectile	3.52	1	1	**1**	1	2	**2**
	WWII Artillery Projectile	2	1	1	**1**	1	2	**2**

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel			UXO Risk to Underwater Equipment		
			P	C	R	P	C	R
Vessel Anchoring ~10m LAT	WWII Naval Mine	454	1	5	**5**	1	5	**5**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	1	5	**5**	1	5	**5**
	German WWII Depth Charge	136	1	5	**5**	1	5	**5**
	British WWII Depth Charge	132	1	5	**5**	1	5	**5**
	Modern Naval Projectile	3.52	1	2	**2**	1	2	**2**
	WWII Artillery Projectile	2	1	2	**2**	1	2	**2**
Vessel Anchoring ~26m LAT	WWII Naval Mine	454	3	5	**15**	3	5	**15**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	1	5	**5**	1	5	**5**
	German WWII Depth Charge	136	1	4	**4**	1	5	**5**
	British WWII Depth Charge	132	1	4	**4**	1	5	**5**
	Modern Naval Projectile	3.52	2	1	**2**	2	2	**4**
	WWII Artillery Projectile	2	1	1	**1**	1	2	**2**

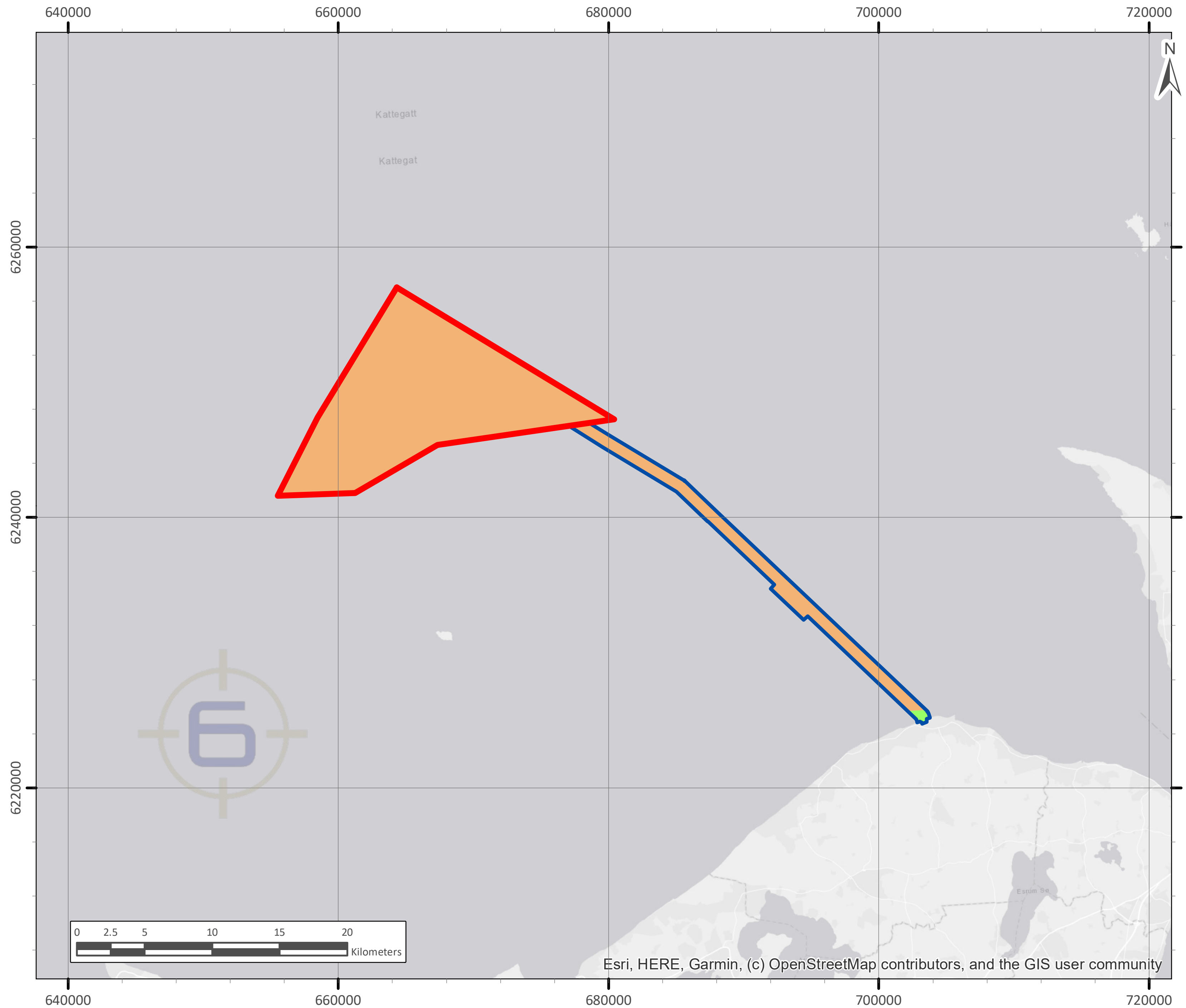
Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel			UXO Risk to Underwater Equipment		
			P	C	R	P	C	R
Vessel Anchoring ~40m LAT	WWII Naval Mine	454	3	4	**12**	3	5	**15**
	British WWII HE Bomb	309	1	4	**4**	1	5	**5**
	German WWII HE Bomb	220	1	3	**3**	1	5	**5**
	German WWII Depth Charge	136	1	3	**3**	1	5	**5**
	British WWII Depth Charge	132	1	3	**3**	1	5	**5**
	Modern Naval Projectile	3.52	2	1	**2**	2	2	**4**
	WWII Artillery Projectile	2	1	1	**1**	1	2	**2**

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel			UXO Risk to Underwater Equipment		
			P	C	R	P	C	R
JUB/JUV Deployment ~10m LAT	WWII Naval Mine	454	1	5	**5**	1	5	**5**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	1	5	**5**	1	5	**5**
	German WWII Depth Charge	136	1	5	**5**	1	5	**5**
	British WWII Depth Charge	132	1	5	**5**	1	5	**5**
	Modern Naval Projectile	3.52	1	2	**2**	1	2	**2**
	WWII Artillery Projectile	2	2	2	**4**	2	2	**4**
JUB/JUV Deployment ~26m LAT	WWII Naval Mine	454	4	5	**20**	4	5	**20**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	2	5	**10**	2	5	**10**
	German WWII Depth Charge	136	2	5	**10**	2	5	**10**
	British WWII Depth Charge	132	1	5	**5**	1	5	**5**
	Modern Naval Projectile	3.52	3	2	**6**	3	2	**6**
	WWII Artillery Projectile	2	2	2	**4**	2	2	**4**

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel			UXO Risk to Underwater Equipment		
			P	C	R	P	C	R
JUB/JUV Deployment ~40m LAT	WWII Naval Mine	454	4	5	**20**	4	5	**20**
	British WWII HE Bomb	309	1	5	**5**	1	5	**5**
	German WWII HE Bomb	220	1	5	**5**	1	5	**5**
	German WWII Depth Charge	136	1	5	**5**	1	5	**5**
	British WWII Depth Charge	132	1	5	**5**	1	5	**5**
	Modern Naval Projectile	3.52	3	2	**6**	3	2	**6**
	WWII Artillery Projectile	2	1	2	**2**	1	2	**2**

Appendix 15

UXO Risk Zones



LEGEND

GENERAL

- OWF_Array
- Export_Cable_Corridor

Risk_Rating

- HIGH
- LOW

PROJECT	PROJECT TITLE
50029_2	HESSELØ SOUTH OWF

DRAWING TITLE
UXO Risk Zones - GI and Enabling Works

DRAWING NUMBER
Hesselø South OWF\015a\V2.0

PURPOSE
FOR INFORMATION USE ONLY

COORDINATE SYSTEM	SCALE	ORIGINAL PLOT SIZE	DRAWN	DATE DRAWN	CHECKED
ETRS 1989 UTM Zone 32N	1:400,000	A4	LH	19/01/2024	LG

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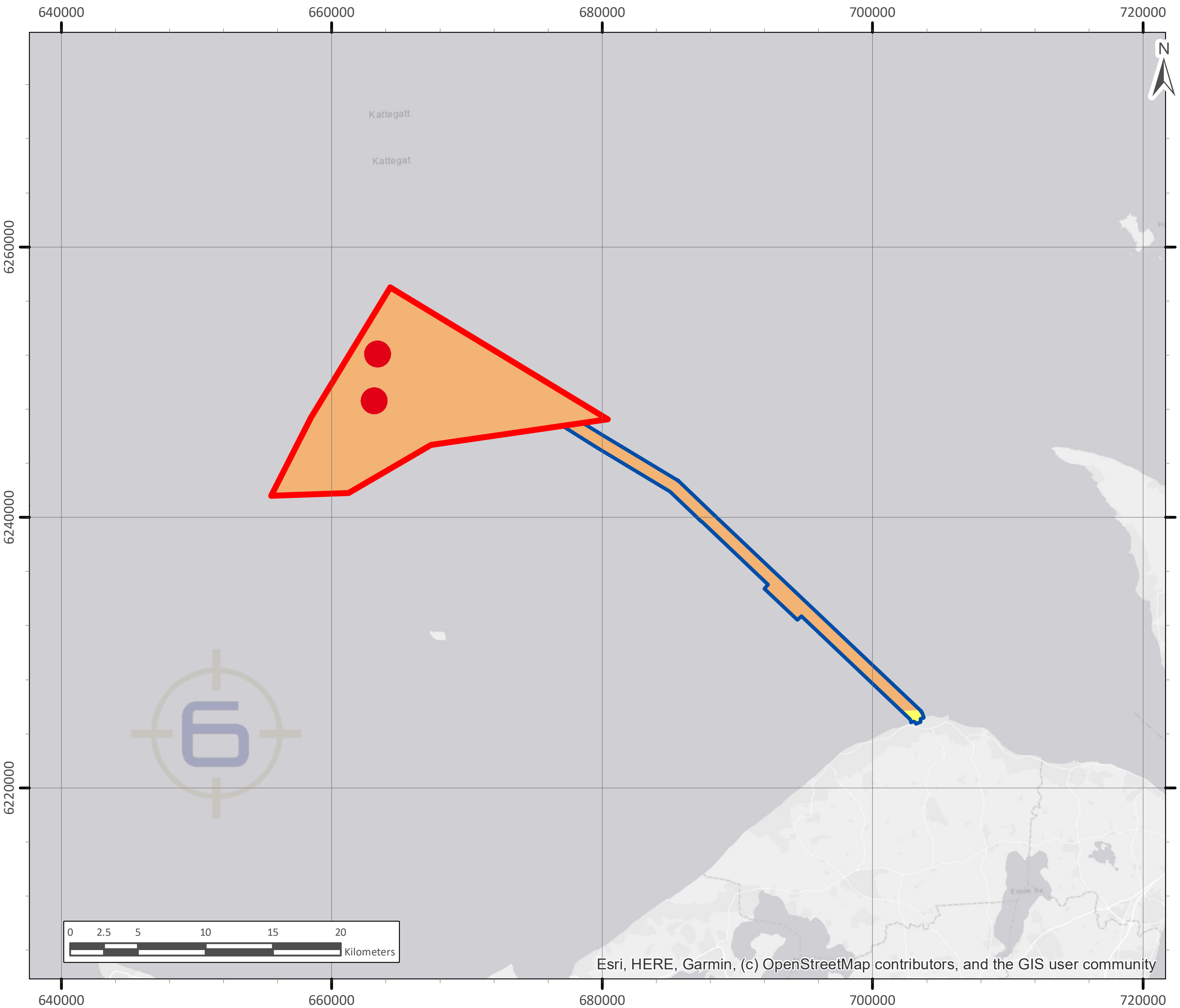
alpha ASSOCIATES
special risks consultancy



LEGEND

GENERAL

- OWF_Array
- Export_Cable_Corridor

Risk_Rating

- VERY HIGH
- HIGH
- MEDIUM

PROJECT	PROJECT TITLE
50029_2	HESSELØ SOUTH OWF

DRAWING TITLE

UXO Risk Zones - Construction and Installation Works

DRAWING NUMBER

Hesselø South OWF\015b\V2.0

PURPOSE

FOR INFORMATION USE ONLY

alpha ASSOCIATES

special risks consultancy

COORDINATE SYSTEM	SCALE	ORIGINAL PLOT SIZE	DRAWN	DATE DRAWN	CHECKED
ETRS 1989 UTM Zone 32N	1:400,000	A4	LH	19/01/2024	LG

W W W . 6 A L P H A . C O M
E: enquiry@6alpha.com | T: +44 (0)203 371 3900

Annexes

Annex A – Legislation and UXO Risk Management

1.1 Introduction

The law requires that the client fulfils both their statutory and legal duties to protect those that may be exposed to harm. In the event of an UXO incident that causes harm, failure to adequately manage the UXO risk may lead to the prosecution and imprisonment of those deemed responsible for breaching their duty of care. The following sections outline national legislation, industry good practice, the ALARP principle, the assumptions made of the client's risk tolerance, as well as the expected behavioural responses of the project stakeholders when confronted with the UXO risk.

1.2 European Union Directives and National Legislation

The primary regulation, and minimum standard requirement for all *European Union* (EU) countries and businesses, residing in and/or working within the *EU*, is the *Council Directive 89/391/EEC – OSH* "Framework Directive" of 12th June 1989, on the introduction of measures to encourage improvements in the safety and health of workers at work. This framework directive contains basic obligations for employers and workers, with emphasis on the employer's obligation to ensure the safety and health of workers in every aspect related to work, without imposing financial costs on the worker to achieve this aim. From this legally binding *EU* directive, the minimum standards and fundamental principles (such as risk assessment) were passed into national law and enforced by the *EU* member states.

By contracting a UXO risk management consultant, the client has drawn upon help from a competent person to perform a risk assessment and to assess and advise upon the UXO risk posed to the client's employees and contractors. In doing so, the client has acted in compliance with the legal duties required as dictated in the above legislation. *6 Alpha Associates* has acted based on the guidance of industry good practice, professional risk management, Explosive Ordnance Disposal (EOD) experience, and its interpretation of the law.

In the end, it is for both national and *EU* courts to decide whether the client has acted in compliance with the law, and to determine if sufficient risk management and mitigation measures were undertaken and effectively applied.

1.3 UXO Industry Guidance and Good Practice

The *UK's Construction Industry Research and Information Association* (CIRIA) has published guidance on the assessment and management of unexploded ordnance risk in the marine environment (*CIRIA C754*, published 2016, *London*). *CIRIA* is a neutral, non-government, non-profit body linking organisations with common interests, that collaborate with the aim of improving and setting an agreed level of minimum industry standards.

The *CIRIA* C754 guide therefore represents an industry agreed standard for the assessment and management of UXO risk, which has been judged and recognised by the *Health and Safety Executive* (HSE) of the *UK* as a minimum standard or source of good practice, that satisfies the law when applied in an appropriate manner.

For UXO assessment and risk management, *6 Alpha Associates* assesses itself against the *CIRIA C754* guide to ensure compliance with the minimum legal requirements of industry good practice to manage UXO risks to as low as reasonably practicable (ALARP). The guidance outlined in *CIRIA C754* has been implemented by *6 Alpha* successfully throughout the *EU* previously.

1.4 Reducing Risks to ALARP

Reducing risks to ALARP is the concept of weighing a risk against the resources (effort, time, and money) required to a level that adequately control the risks. The law sets this level of what is reasonably practicable, whilst stakeholders determine what is considered tolerable to the project, whilst also fulfilling their legal obligations.

Industry good practice in the form of *CIRIA C754* guide, offers the direction as to assessing both ALARP and the risk tolerance, so that an agreement amongst the stakeholders can be reached as to what the ALARP level is, and what resources are required to achieve it. ALARP therefore describes the level to which risks are controlled, as determined by good practice.

Confirming that the UXO risks have been reduced to ALARP involves weighing the residual risk against the resources to further reduce it. If it can be demonstrated that the resource requirement is grossly disproportional to the benefits of further risk reduction, then risks have been reduced to ALARP. Consequently, the principle of reducing risks to a reasonably practicable level will usually result in a residual level of risk, as well as de minimis risks that must be either shared, transferred, mitigated, and/or tolerated.

A diagrammatic representation for meeting with ALARP is presented at Figure 1.4.

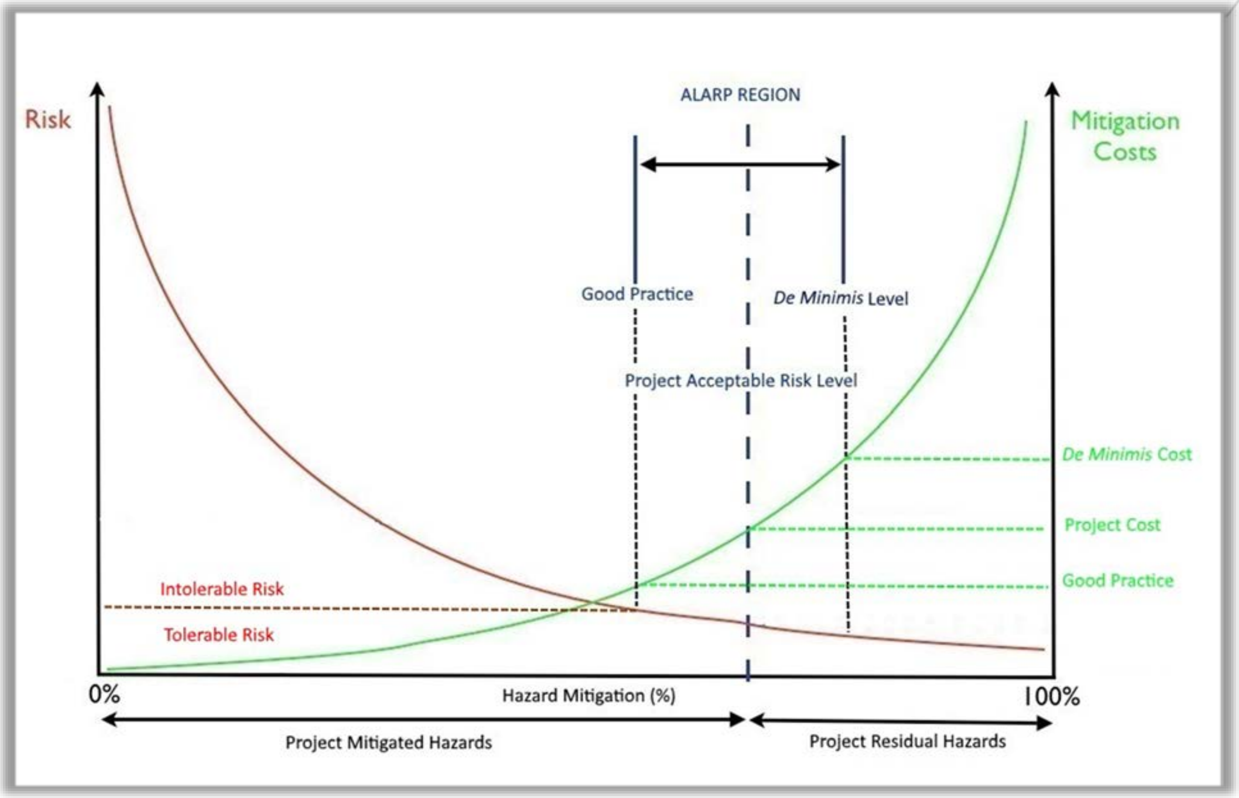


Figure 1.4: The ALARP Principle of managing risk.

1.5 UXO Risk Tolerance

6 Alpha Associates have made certain assumptions about the client's tolerance of UXO risk. Our assumptions include that the following interrelated elements are to be considered when determining the projects UXO risk tolerances:

- **Corporate Governance** – is the system of rules, practices, and processes by which companies are managed and controlled. It is assumed that the client will wish to adhere to the highest international standards of corporate governance. Discharge of corporate responsibility is expected to be on risk-based criteria and it is expected that the client will have in place a framework for managing risk for good governance. It is anticipated that safety and risk management are integrated in the client's business culture and be actively applied throughout the project;
- **Risk Management** – the client will expect the highest standard of risk and safety management to be applied to this project and will have a risk management system in place for responding to business, programme, and project risks. The client will rely upon help from a competent person to identify UXO risks, but also to design appropriate UXO risk management solutions in accordance with industry good practice. Any risks posed by UXO must be assessed based upon probability and consequence criteria. Potential UXO targets must be avoided or

otherwise mitigated not only in accordance with the law, but also with CIRIA C754 industry guidelines. A competent person will oversee the UXO geophysical survey and the UXO risk mitigation contractors who are responsible for the subsequent execution of those works, ensuring they are performed to appropriate quality and meet good practice standards;

- **Safety** – personnel safety will assume the highest priority for the project. The protection and preservation of equipment, property, and the environment, although important, will remain a secondary priority to that of the prevention of harm to personnel involved with the project.

1.6 UXO Risk Behaviour

UXO incidents that result in harm to construction personnel, are generally termed an extreme, or a Low Probability-High Consequence (LP-HC) event. Given the ambiguity and uncertainty surrounding such events, project stakeholders may respond to the risk in an extreme manner and demand a disproportionate level of risk mitigation. The Client should be aware of the following common responses and attitudes to LP-HC risks, to manage stakeholder expectations of the UXO risk throughout the project's life cycle. There are three general behavioural patterns for dealing with LP-HC events (Kunreuther, 1995):

1. Individuals do not think probabilistically and demand zero risk when costs do not need to be absorbed. Alternatively, when individuals do need to absorb the cost themselves, they are more likely to tolerate very high probability risks;
2. Risk is a multidimensional problem which cannot be simply measured quantitively, such as the number of fatalities per year. Risk tends to be influenced by people's attitudes to catastrophic situations, fear, lack of familiarity, or situations they perceive to be beyond their control. By nature, humans are risk averse when exposed to uncertainty and will enhance the level of risk accordingly;
3. Given the lack of knowledge over the probability of these event, people are more likely to use simple decision-making measures, such as threshold values. The general perception is, that the probability of LP-HC risks is too low to possibly occur, and as a result do not take adequate steps to protect themselves.

Such behaviour patterns typically lead to one or more of the following common responses from project stakeholders:

- A desire for zero risk;
- A concern for future generations;
- Denial that the event can ever happen to them;
- A perception that the situation is under their control and therefore can never happen;

- That the hazard is perceived to be benign after a certain amount of time;
- Short sighted behaviour and an aversion to spend today to reap the potential benefits later.

1.7 References

1. Kunreuther, H., 1995, Protection against low probability high consequence events.

Annex B – Semi-Quantitative Risk Assessment Methodology

1.1 Overview

6 Alpha Associates use a Semi-Quantitative Risk Assessment (SQRA) approach to assess the prospective Unexploded Ordnance (UXO) risk for each of the project's intrusive investigation, installation and/or construction operations that interacts with the seabed. The SQRA process relies upon *6 Alpha*'s risk matrix, which is used to provide guidance on the required risk mitigation measures to be implemented, in order to manage the UXO risk to As Low As Reasonably Practicable (ALARP).

The following sections transparently outline *6 Alpha*'s SQRA methodology. The risk assessment tables for each of the project's investigation, installation and/or construction operations are presented separately within the report appendices.

1.2 Risk Matrix

For the purposes of this report, **Risk (R)** is calculated as a function of **Probability (P)** of encounter and initiation of UXO and **Consequence (C)** of initiation:

$$R = P \times C.$$

For each investigation, installation and/or construction activity that interacts with the seabed, the probability and consequence of the identified UXO threats has been assessed on a scale of 1 to 5. (Where 1 = Very Low, & 5 = Very High). These ratings are multiplied together (with a maximum of twenty-five) in order to determine a risk rating based on *6 Alpha*'s UXO risk matrix. Not only does this allow relative weighting and comparison of UXO risk across the project's seabed intrusive operations, but it also ensures that *6 Alpha* assesses UXO risk in a way that is consistent across projects which is a key responsibility of a UXO consultant. *6 Alpha*'s risk matrix is shown below in Table 1.2a.

Probability of Encounter and Initiation	Consequence of Initiation					
		1 Negligible	**2** Minor	**3** Moderate	**4** Major	**5** Severe
	5 Highly Likely	**5** Low	**10** Medium	**15** High	**20** High	**25** Very High
	4 Likely	**4** Low	**8** Medium	**12** High	**16** High	**20** High
	3 Possible	**3** Low	**6** Medium	**9** Medium	**12** High	**15** High
	2 Unlikely	**2** Low	**4** Low	**6** Medium	**8** Medium	**10** Medium
	1 Highly Unlikely	**1** Very Low	**2** Low	**3** Low	**4** Low	**5** Low

Table 1.2a: *6 Alpha Associates*' UXO Risk Matrix

The numerical values assigned to the UXO risk are compared to Table 1.2b, which shows *6 Alpha*'s risk grading and describes the recommended best practice strategic risk mitigation measures required in order to satisfactorily manage the UXO risk to ALARP.

Whilst this risk matrix is aligned with *6 Alpha*'s standards in providing a UXO risk mitigation strategy, we also recognise that other UXO risk management consultancies may differ in their own assessment of the UXO risk and their recommended UXO risk mitigation measures.

Risk Rating (P x C)	Grading	Risk Tolerance	Action Required
1	Very Low Risk	Tolerable	The risk is at, or below the *de minimis* level with no further action required to reduce the UXO risk to ALARP. Operations may proceed without proactive UXO risk mitigation measures in place. Nonetheless, reactive mitigation measures might be recommended in order to mitigate residual UXO risks and to align with industry best practice. Risks will be reviewed periodically to ensure risk mitigation controls remain effective.
2-5	Low Risk		
6-10	Medium Risk	Potentially Tolerable	The UXO risk may be tolerable depending on the specific nature of the UXO risk and the potential consequences of a UXO initiation and the project stakeholder's risk tolerance. Where vessel crews and/or other personnel may be exposed to harm, then the UXO risk is intolerable.
12-20	High Risk	Intolerable	Operations may not proceed without proactive risk mitigation measures being implemented prior to intrusive investigation, installation and/or construction works. Reactive risk mitigation measures must also be implemented.
25	Very High Risk		

Table 1.2b: *6 Alpha Associates*' Risk Tolerability

1.3 Calculating the Project's Probability of Encounter and Initiation

At the strategic level, and for risk assessment purposes, *6 Alpha* applies the precautionary principle to all prospective UXO encounters within a Study Site. For example, the probability of initiating an item of UXO upon an encounter is considered certain, whereas in practice factors such as the kinetic energy transfer and UXO sensitivity will impact whether direct or indirect contact with UXO will cause an initiation event. Therefore, the probability of encountering and initiating UXO is primarily influenced by the likely level of UXO contamination within the Study Site, but also subsequently through the application of a methodology modifier (the value of which is determined by the spatial extent of the soil intrusion). Further details of 6 Alpha's guidance on the scoring of the probability of UXO contamination can be found in Table 1.3 below.

Probability of UXO Contamination	Likelihood Score	Description (based on a 5km Assessment Distance)
Highly Unlikely	**1**	There is no indication of historical or modern ordnance activity or discovered ordnance **within 5km of the Study Site**. Potential UXO discoveries are, therefore, likely to be from unquantifiable sources and/or from subsequent UXO migration.
Unlikely	**2**	There is evidence of historical or modern ordnance activity or discovered ordnance **within 2km to 5km** (or 4km to 10km for a munitions dump) of the Study Site's boundary.
Possible	**3**	There is evidence of historical or modern ordnance activity **within 1km to 2km** (or 2km to 4km for a munitions dump) of the Study Site's boundary.
Likely	**4**	There is evidence of historical or modern ordnance activity or discovered ordnance **either on-site or within 1km of it**. If the prospective UXO threat source intersects the Study Site, then the precise nature of the threat source and/or the proximity and concentration of any previous UXO encounters may influence whether the assessment concludes a "Likely" or "Highly Likely" probability of contamination.
Highly Likely	**5**	There is significant evidence of historical or modern ordnance activity, **within the Study Site** that is corroborated with evidence that **UXO has been encountered previously** either on-site or in the immediate vicinity.

Table 1.3: *6 Alpha Associates*' Probability of UXO Contamination Assessment Criteria

The categorisation of UXO threats may not always be straightforward, and multiple additional factors might also be considered that result in a potential threat source being classified as a higher or lower threat than indicated by Table 3. For example, WWI-era ordnance is rarely encountered in the marine environment in the 21st Century and therefore, the likelihood of encountering such ordnance may be reduced.

Additionally, the categorisation of potential threat sources such as Anti-Aircraft Artillery projectiles (or similar) might also be influenced by the total number of artillery batteries in any given area that possess a firing arc template that encompasses a Study Site and/or the likelihood that they were fired for training or operational purposes (amongst other things).

In order to calculate the overall probability of encounter, the probability of UXO contamination at the Site is modified based upon the likely spatial extent of the seabed disturbance, caused by the proposed investigation, installation or construction activity. This provides the final calculation for the probability of encounter and initiation, which is used for the risk assessment.

1.4 Calculating the Project Consequences

The risk assessment performed by *6 Alpha* assesses the risk of an unplanned initiation of UXO to the relevant sensitive receptors (e.g. human life, the vessel(s) and/or underwater equipment), resulting from explosive shockwave and/or fragmentation effects.

This is achieved by calculating the resulting peak pressure for an equivalent mass of trinitrotoluene (TNT) representative of the likely UXO threat items within the Site, as well as estimating the distances separating the source (UXO) and the sensitive receptors.

The following formula is applied to calculate peak pressure in megapascals (MPa), of the resultant shockwave (Reid, 1996):

$$Peak\ Pressure\ (MPa) = 52.4.\left(\frac{M^{\frac{1}{3}}}{R}\right)^{1.18}$$

For SQRA calculations, R is the separation distance in metres between the source and the receptor and M is the mass of TNT explosive equivalent in kilograms.

The resulting peak pressure calculated is compared to Table 1.4, which provides the final consequence calculation for entry into the risk matrix (Szturomski, 2015).

Peak Pressure (MPa)	Consequence Rating	Consequence Score	Description
0 – 2	**Negligible**	**1**	Damage to the vessel is likely to be negligible and vessel crews are highly unlikely to be hurt. Damage to underwater equipment will be influenced by the robustness of such equipment and its internal mechanisms.
2 – 4	**Minor**	**2**	There may be minor damage to brittle materials and to the sensitive electronics. The vessel crews are unlikely to be injured. Damage to underwater equipment will be influenced by the robustness of such equipment and its internal mechanisms.
4 – 6	**Moderate**	**3**	More significant damage to vessel is likely and may impact vessel steering and control and light injuries might be sustained by the crew. There is also the prospect of light damage to underwater equipment.
6 – 8	**Major**	**4**	Serious damage to the vessels electronics, generators and control systems is likely and serious injuries and/or fatalities amongst the vessel crew are possible. Serious damage to underwater equipment is also likely.
More than 8	**Severe**	**5**	Catastrophic structural vessel damage is likely and it is also likely that there will be multiple injuries and fatalities to personnel aboard. Catastrophic damage to underwater equipment is likely.

Table 1.4: Consequence Rating of an unplanned initiation based on shockwave peak pressure.

1.5 References

1. Reid, W.D., 1996, The response of surface ships to underwater explosions;
2. Szturomski, B., 2015, The effect of an underwater explosion on a ship. Scientific Journal of Polish Naval Academy.

Annex C – Classification of UXO

1.1 General

Unexploded Ordnance (UXO) is any munition, weapon delivery system or ordnance item that contains explosives, propellants, or chemical agents, after they are either:

- Armed and prepared for action;
- Launched, placed, fired, thrown, or released in a way that they cause a hazard;
- Remain unexploded either through malfunction or through design.

1.2 Classification of Unexploded Ordnance

UXO items can be classified into 11 broad categories which are detailed below:

1.2.1 Small Arms Ammunitions (SAA)

Small Arms Ammunition (SAA) is a generic catchall term for projectiles that are generally less than 13mm in diameter and less than 100mm in length. SAA is fired from various sizes of weapon, such as pistols, shotguns, rifles, machine guns. Generally, the outer casings comprise either brass or steel. As UXO, they present a minimal risk compared to other high Net Explosive Quantity (NEQ) UXO, although SAA may explode if subjected to extreme heat, or if struck with a sharp object.

1.2.2 Hand Grenades

Hand grenades are small bombs thrown by hand and come in various sizes and shapes. Typical types of hand grenades include fragmentation, smoke, incendiary, chemical, training, and illumination. As UXO, they present a risk if mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed to extreme heat.

1.2.3 Projectiles

Projectiles are munitions generally ranging in diameter from 20mm to 406mm and can vary in length from 50mm to 1,219mm. All projectiles are fired from some type of launcher or gun barrel and may comprise either an explosive, chemical, smoke, illumination, or inert/training fill. Projectiles may also be fitted with stabilising fins and their fuzes are typically located either in the nose or located at the base. As UXO, they present a risk if mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed to extreme heat.

1.2.4 Mortar Bombs

Mortar bombs come in a range of shapes, sizes, and types, typically ranging between 25mm to 280mm in diameter and typically fired from a mortar; a short smooth barrelled tube. Mortar bomb types and functions can vary to include fragmentation, smoke, incendiary, chemical, training, and illumination. Mortar bombs may be found with or without stabilising fins and they present a risk if mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed extreme heat.

1.2.5 Landmines

Landmines are an explosive device typically shallow buried or concealed on the ground and used to defend vulnerable areas or to deny the area completely for any use. After WWII, the defensive minefields around the coastlines were swept clear and the munitions either buried or dumped at sea. Landmines come in various sizes, shapes and types including fragmentation, incendiary, chemical, training and illumination. The cases of landmines are typically made of metal but can comprise any non-magnetic material such as wood, clay, glass, concrete, or plastic so that they are harder to detect. As UXO, they present a risk if mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed extreme heat.

1.2.6 Bombs

Bombs come in a range of size and types, generally weighing from 0.5kg to 10,000kg with typical components of a metal casing, a mechanical or electrical fuze, a main charge, a booster charge, and stabilising fins. The metal casing contains the explosive or chemical fill and may be compartmentalised. Bomb types include high explosive, incendiary, chemical, training, and concrete. As UXO, they present a risk if mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed extreme heat.

1.2.7 Sea Mines

Sea mines are self-contained explosive devices either placed on the seabed or moored in the water column to damage or destroy surface ships or submarines. Like land mines, they are typically used to defend vulnerable areas or to deny the area completely for any use. After WWI and WWII, sea minefields were swept, with surface vessels working in tandem to cut the mooring tether so that the sea mine would float to the surface. The sea mine was then shot with SAA so that it either exploded or flooded and sank to the seabed. Some sea mines were also simply lost or were not recovered and remain unaccounted for. Sea mines come in all shapes and sizes and as UXO, they present a risk mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed extreme heat.

1.2.8 Rockets

Rockets are self-propelled unguided munitions that generally vary in diameter from 37mm to more than 380mm and can vary in length from 300mm to 2,743mm. All rockets comprise a warhead, fuze and motor section, with the warhead typically containing either an explosive or chemical fill. As UXO, they may or may not be present with tail fins and present a risk if mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed extreme heat.

1.2.9 Depth Charges

A depth charge is a container, typically barrel or drum shaped, of high explosive fitted with a hydrostatic pistol, designed to trigger at a pre-programmed depth. As UXO, they present a risk if mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed extreme heat.

1.2.10 Torpedoes

Torpedoes are guided or unguided, underwater, self-propelled weapons typically fitted with a high explosive warhead. The dimensions of complete torpedoes vary but are generally between 400mm to 600mm in diameter and between 4,500mm to 7,500mm in length. As UXO, torpedoes are they are rarely found completely intact with the warhead and propulsion stages often discovered separated. Both the warhead and propulsion stages of the torpedo present a hazard if mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed extreme heat.

1.2.11 Guided Missiles

Guided missiles are similar in design to rockets, with the exception being that they are guided to their targets by some form of guidance system and can be either self-adjusting or operator controlled. Guided missiles can be found in a variety of size, shape and colour and may be found with or without stabilising fins attached. As UXO, they present a hazard if mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed extreme heat.

Annex D – Explosives and Detonation Effects

1.1 Introduction

Explosives can be categorised into two broad categories, namely: those designed to be detonating (or high explosives) and those designed to be deflagrating (or low explosives). In the case of Unexploded Ordnance (UXO) risk management in the marine environment, the primary concern is associated with ordnance comprising high explosive content.

Due to the infrequency of UXO initiation events that cause harm, it is a commonly held notion that WWI and WWII ordnance devices may have deteriorated and no longer function as designed, presenting a false sense of tolerable risk to project stakeholders. The precautionary principle of risk management prevents this misplaced assumption from being carried throughout the risk assessment and project life cycle. Ordnance must, for the purposes of risk management, be assumed to be fully functional until determined safe by an Explosive Ordnance Disposal (EOD) operative.

This annex describes the classification of explosives, the generic design of the explosives train and the effects of a detonation in the marine environment.

1.2 Classification of Explosives

Explosives can be classified into two broad categories, which are detailed below:

1.2.1 Detonating or High Explosives

Detonating or High Explosive (HE) compounds are characterised by their very rapid decomposition and development of a high-pressure shock wave. These explosives detonate at velocities ranging from 1,000m/s to 9,000m/s and may be subdivided into two explosives classes, differentiated by their respective sensitivity or ease with which an explosive may be ignited or initiated:

- **Primary Explosives** – are extremely sensitive to impact, friction, sparks, flames or other methods of generating heat to which they will respond by burning rapidly or detonating. Examples include mercury fulminate and lead azide. This high sensitivity to initiation makes them unsuitable to use as a base explosive (i.e. main-fill explosive in military ordnance).
- **Secondary Explosives** – are relatively insensitive to impact, friction, sparks, flame or other methods of producing heat. They may burn when exposed to heat in small-unconfined quantities, although the risk of initiation is always present especially when they are confined and/or burnt in bulk. Dynamite, trinitrotoluene (TNT), RDX and HMX are classed as secondary high explosives, which are commonly used as base explosives in military ordnance. Pentaerythritol tetranitrate (PETN) is the benchmark compound for comparative purposes,

with those explosives that are more sensitive to initiation than PETN classified as primary explosives.

1.2.2 Deflagrating or Low Explosives

A low explosive is usually a mixture of a combustible substance and an oxidant that decomposes rapidly, a process known as deflagration which produces a relatively low pressure, shock wave. Under normal conditions, low explosives undergo deflagration at rates that vary from a few centimetres per second to approximately 400m/s, yet when concentrated and confined may be caused to detonate and produce a relatively high-pressure shock wave.

Deflagration processes of low explosives are easier to control than the detonations of high explosive, that they are typically used as ballistic propellants for rockets, artillery projectiles and bullets. Typical ballistic propellants include the family of smokeless propellants known as cordite which was used extensively during WWII.

1.3 Generic Design of Ordnance

In general, explosive ordnance items, such as bombs or sea mines tend to have the following basic components:

- **Case** – the casing or body of the ordnance item is typically manufactured from a ferrous metal such as steel. The *German Luftmine A* and *B* (LMA and LMB respectively) parachute mines used during WWII, were however manufactured from aluminium. The case shatters during detonation of the high explosive fill, fragmenting at high velocity to increase the potential damage and harm;
- **Main Charge** – the main charge makes up most of the explosive mass of the ordnance item comprising a high explosive fill with a relatively low sensitivity to initiation;
- **Booster** – a secondary high explosive booster charge is used to ignite the main charge component and comprises a more sensitive, albeit smaller quantity of high explosive;
- **Fuze** – a small quantity, high explosive charge is usually incorporated into the device which is sensitive to initiation. The fuze acts as the primary explosive which is used to ignite the booster. The fuze is relatively small when compared to the booster and housed with a fuze pocket within the casing of the ordnance item, located immediately adjacent to the booster charge;
- **Trigger** – a mechanical, electrical, or chemical mechanism is used to initiate the fuze at the appropriate time, such as upon impact, hydrostatic depth, magnetic field distortion or time. The trigger is the most sensitive component to the firing train and the primary method of ignition, that if interfered with may cause an inadvertent detonation.

An explosive chain reaction is therefore started when the sufficient energy (kinetic, electrical, or chemical) is generated to initiate the explosive content of the fuze, which in turn detonates the booster and finally the main charge. These components form the explosive train of the ordnance device.

1.4 Underwater High Explosive Detonations

An explosion underwater differs from that within air due to the formation of a gas bubble within the water in addition to the fragmentation and shockwave effects. Upon detonation, the ordnance case will fragment and cause damage to proximal receptors such as underwater equipment, with the main hazard to the surface vessel, personnel aboard, and underwater equipment being from the resulting gas bubble and shockwave.

An underwater explosion results in the change of solid matter (the main charge) into a gas of high temperature and pressure (the gas bubble) as well as a spherical shockwave. The pressure acting outwards from the gas bubble is opposed by the hydrostatic pressure of the surrounding water, which causes an oscillating effect of expansion and contraction as the gas bubble moves towards the water surface.

Each expansion of the gas bubble causes a shockwave that is propagated outwards throughout the water in all directions. Although these shockwaves gradually become weaker as the gas bubble rises through the water column, it may close with nearby receptors such as surface vessels, situated offset or directly above the gas bubble causing damage. When the gas bubble reaches the surface, a columnar plume is formed from the sudden release of the gas into the atmosphere as well as carrying water. Should a vessel be directly in the path of the gas bubble as it contracts, the vessel may be subjected to bubble jetting loads; a high-energy jet of water capable of rupturing the vessel's hull.

The shockwave from an underwater explosion propagates radially outwards from the source location. Possessing an initial high velocity, the shock wave decelerates over distance from the source location, eventually decreasing to the underwater speed of sound. As the distance from the source location increases, the peak pressure of the shockwave decreases reducing the damage potential of the shockwave.

A surface vessel must therefore be kept a safe distance away from a source of an explosion so that resultant shockwave causes no damage.

If a nearby surface vessel is struck by the shockwave, the vessel can experience significant vibrations resulting in the damage to underwater hull mounted equipment and the dislodgment of loose objects, machinery, and power cables on board the vessel. Both the initial vibrations and secondary effects resulting from the vessel damage, have the capacity to cause disabling injuries to personnel aboard, from being struck by loose objects, trips and falls, and joint damage (ankles, knees, hips, spine, and neck) from a sudden acceleration.

A second damage mechanism may arise from the whipping effect. The whipping effect occurs when the frequency of the expansion and contraction of the gas bubble matches the vessels natural oscillating frequency. The vessel's hull will be driven to vibrate at its natural resonating frequency, vibrating at a greater amplitude than that of the initial pressure wave from the expanding gas bubble.

A badly affected ship usually sinks quickly due to cracking and deformation of the hull, resulting in flooding across the length of the ship and eventual sinking.

Divers, as well as marine mammals, are especially vulnerable to underwater shockwave effects and can be seriously injured or killed by the detonation of relatively small, high explosive charges.

Annex E – UXO Discovery, Detonation and Sympathetic Detonation Risks

1.1 Introduction

A host of theoretical and empirical studies have provided strong evidence that Unexploded Ordnance (UXO) becomes more sensitive to trigger events that transfer kinetic energy (such as a physical impact or shock) and/or chemical energy (such as heat) as they age. Theoretically, a spontaneous detonation of UXO may occur but such instances are exceptionally rare. Therefore, UXO risk management focuses on the avoidance of known trigger events, even those of small magnitude, that may cause UXO to detonate.

Subject to its size and Net Explosive Quantity (NEQ), significant risks may be present by the discovery and accidental detonation of a singular item of UXO. Additionally, it is not uncommon for UXO to be discovered in close proximity to one another, in the offshore environment especially. For example, UXO might be found in very close proximity in munitions dumps, within the body of a shipwreck, or clustered together due to underwater topography. These circumstances are not unusual, with numerous 20th century shipwrecks and munitions dumps having been discovered around the world. Given that UXO becomes more sensitive to trigger events as they age, it is reasonably foreseeable that one detonation may trigger others in close proximity to explode in a chain reaction, a process known as sympathetic detonation.

1.2 Objectives

The objective of this annex is to present open-source examples of UXO discovery in individual and group circumstances that evidences the longevity and severity of UXO threats in the marine environment. Secondly, this annex aims also to highlight the potential hazards associated with a prospective UXO detonation and/or a sympathetic detonation event and the emergency reaction of the authorities to such discoveries.

1.3 Open-Source Examples

The *Kattegat* was a significant a naval theatre of war in both WWI and WWII, given its location between the *North Sea* and the *Baltic Sea* and its proximity to various airbases throughout continental *Europe* and *Britain*. Numerous submarine engagements and offensive and defensive mine campaigns have specifically involved the deployment of munitions across the region. With the advances in aircraft technology and understanding in the mid-20th century, naval convoys and the coastline of *Denmark* were also in range of bomber aircraft during WWII, which also resulted in deliberate air-to-surface vessel attacks, air mining and bomb jettisoning at sea.

As such, both WWI and WWII have left a legacy of unexploded munitions in the *Kattegat* which are still encountered to the present day. Although almost 75 years have passed since the end of the WWII, associated UXO are still located and discovered within the coastline and offshore environments of *Denmark* to this day, as demonstrated by the following publicly accessible news article summarising encounters with historic munitions.

Denmark: Fishing boat catches WW2 mustard gas bomb

29 January 2015

Fishing around the Danish island of Bornholm can be a risky business

By News from Elsewhere...

...media reports from around the world, found by BBC Monitoring

Danish fishermen reeled in a particularly dangerous catch during an trawl in the Baltic Sea - a mustard gas bomb from World War Two.

The fishing cutter caught the unexploded German ordnance in the sea around the island of Bornholm, which lies just south of Sweden, **the Bornholm Tidende news website reports**. A navy bomb disposal team met the boat as it docked in the harbour in the town of Nexo, after the crew called ahead to report what it had aboard. It was then given a thorough cleaning by the Danish Emergency Management Agency (DEMA), in case any of the mustard gas had escaped, the website says. "The bomb was well preserved," says DEMA spokesman Michael Gronbech-Dam, adding that it is about 90cm long. Mr Gronbech-Dam say it's unlikely the gas has leaked, but officials aren't taking any chances.

The Baltic Sea is a well-known burial ground for unexploded WW2 bombs. In 2013, **Spiegel Online reported** that tens of millions of leftover munitions - including detonators and shells - lie on the North and Baltic Sea beds, and high-risk areas are marked on nautical charts. But it's a lucrative fishing area, and in the past fishermen have been injured after coming into contact with mustard gas from corroding bombs. In 1984, **more than 30 fishing boats were contaminated** in the space of three months, and a dozen fishermen suffered burns.

BBC News, *Denmark: Fishing boat catches WW2 mustard gas bomb*, 29th January 2015.

https://www.bbc.co.uk/news/blogs-news-from-elsewhere-31037151

UXO on Fehmarnbelt tunnel route cleared in controlled explosion

31 OCTOBER, 2022 | BY THAMES MENTETH

An anti-submarine warfare weapon from the Second World War that was found near the alignment of the Fehmarnbelt Tunnel has been diffused.

A controlled explosion of the bomb known as a depth charge was carried out earlier this month (17 October).

It was on the Danish side of the Fehmarnbelt and was defused after intensive preparations and close coordination with the relevant Danish and German authorities.

The depth charge was discovered in the spring of 2021 during the thorough investigations of the seabed in and around the tunnel alignment. The investigations were carried out for safety reasons prior to the start of dredging operations for the Fehmarnbelt tunnel.

Seabed investigations revealed unexploded munitions in the Danish and German sides of the Fehmarnbelt. All finds were salvaged and rendered safe, apart from the 125kg depth charger.

The controlled explosion involved using a "bubble curtain" to keep underwater noise to a minimum. Meanwhile, pingers and "seal scarers" were used as acoustic deterrents to keep marine mammals, such as porpoises and seals, away from the affected area. The area was also monitored by whale watchers.

The remaining bomb has now been defused by the successful detonation carried out under the highest safety measures.

Femern A/S undertook to make the "bubble curtain" available for any potential detonations in the project area during negotiations at the German Administrative Court in the autumn of 202. This was consequently deployed during the controlled explosion.

Commenting on the operation Femern A/S technical director Jens Ole Kaslund said: "We're pleased that the depth charge was defused in a controlled way today. Due to the proximity to the nature protection area and the German border, we coordinated the operation very carefully with the relevant Danish and German authorities. An important prerequisite for the commencement of the immersion of the tunnel elements from 2024 has therefore now been achieved."

The Fehmarnbelt link will connect Rødby on the island of Lolland in Denmark and Puttgarden in northern Germany. It will be the world's longest immersed tunnel when completed.

Main contractor Femern Link Contractors (FLC) is building the tunnel on behalf of the sate-owned developer Femern A/S. The FLC joint venture includes Aarsleff, Max Bögl, Bam Infra, Bam International, Wayss & Freytag Ingenieurbau, Vinci Construction Grands Projets, Soletanche Bachy, CFE and Dredging International.

It started construction work on the tunnel in January 2021. A groundbreaking ceremony was held on the German side of the tunnel in December 2021.

Thames Menteth, *UXO on Fehmarnbelt tunnel route cleared in controlled explosion*, 31st October 2022.

https://www.geplus.co.uk/news/uxo-on-fehmarnbelt-tunnel-route-cleared-in-controlled-explosion-31-10-2022/

13 DECEMBER 2022

CONTROLLED EXPLOSION USED TO DISPOSE OF BOMBS FOUND AT DANISH HALIFAX CRASH SITE

Following the disturbance by a local amateur historical group of a Second World War crash site, Danish Military authorities have carried out an operation to destroy unexploded ordnance.

The bomb crater left after the controlled explosion. (Photos: courtesy Rune Dyrholm and Forsvaret (Danish Defence Command))

The crash site in Kær Hestehave, Als, belonged to Halifax II HR940, RAF 51 Squadron, RAF Snaith, Yorkshire lost on the night of the 24/25 July 1943, shot down by a German night fighter. Its crew were Sgt. William J. Murray (pilot), Sgt. Douglas C. Ford (Fl/Eng), Sgt. Thomas McLaughlin (Nav), Sgt. Ronald A. Fleming (Air/Bmr), Sgt. Reginald E. Livermore (W/Op/Air/Gnr), Sgt. Harry Cousin (Air/Gnr), Sgt Bernard T. Walsh (Air/Gnr). All are buried in CWGC graves at Aabenraa Cemetery, Denmark. A local memorial to the crew was also established by the Danish people in the area.

The bomb load was recorded as 5 x 1000 lb (454 kg) General Purpose and 2 x 1000lb (454kg) Medium Capacity high explosive.

The area cordoned off during the operation. (Photos: courtesy Rune Dyrholm and Forsvaret (Danish Defence Command))

The Danish military operation involved a large area being cordoned off and patrolled by the Danish Home Guard during the search for any additional unexploded ordnance or items from the aircrew found in the process. Due to the unstable nature of the munitions that they found, a large safety zone was established and local people evacuated. A controlled explosion took place on the morning of 16 November 2022, before residents were able to return home.

Dr Stephan Naji, Head of CWGC's Recovery Unit said: *"In this case the Danish authorities were able to respond quickly and professionally to deal with the danger presented by the disturbance of the crash site. We're glad that the people of Kær Hestehave are safe and have been able to return home. It's a reminder to everyone of the dangers of unauthorized excavations on sites which haven't been searched by de-mining teams before works start."*

Halifax Mk.II (Photo: IWM (CH 011324))

Commonwealth War Graves Commission, *Controlled explosion used to dispose of bombs found at Danish Halifax crash site*, 13th December 2022.

https://www.cwgc.org/our-work/news/controlled-explosion-used-to-dispose-of-bombs-found-at-danish-halifax-crash-site/

ACCIDENT REPORT

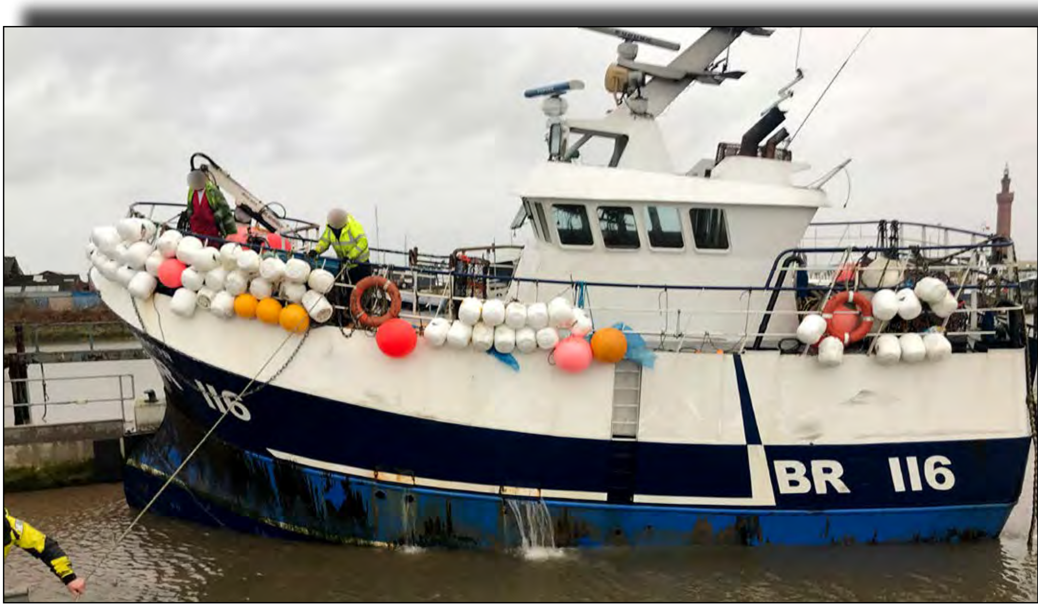
MAIB

MARINE ACCIDENT INVESTIGATION BRANCH

Report on the investigation of a subsea explosion resulting in crew injuries and vessel damage to the crab potting vessel *Galwad-Y-Mor* (BRD 116)

22 nautical miles north of Cromer, England

on 15 December 2020



SERIOUS MARINE CASUALTY | REPORT NO 1/2022 | JANUARY 2022

The United Kingdom Merchant Shipping

(Accident Reporting and Investigation)

Regulations 2012 – Regulation 5:

"The sole objective of the investigation of an accident under the Merchant Shipping (Accident Reporting and Investigation) Regulations 2012 shall be the prevention of future accidents through the ascertainment of its causes and circumstances. It shall not be the purpose of an investigation to determine liability nor, except so far as is necessary to achieve its objective, to apportion blame."

NOTE

This report is not written with litigation in mind and, pursuant to Regulation 14(14) of the Merchant Shipping (Accident Reporting and Investigation) Regulations 2012, shall be inadmissible in any judicial proceedings whose purpose, or one of whose purposes is to attribute or apportion liability or blame.

Front Cover image courtesy of Andrew Oliver

All MAIB publications can be found on our website: www.gov.uk/maib

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SYNOPSIS

On 15 December 2020, the 14.95m crab potting vessel, *Galwad-Y-Mor*, disturbed a piece of unexploded ordnance on the seabed while recovering crab pots in the North Sea, approximately 22 nautical miles off Cromer, England. The ordnance detonated and the ensuing explosion threw *Galwad-Y-Mor* up from the surface of the sea, causing significant crew injuries and damage to the vessel. The crew were rescued and evacuated to local hospitals and *Galwad-Y-Mor* was later towed to Grimsby.

The MAIB investigation found that:

- The ordnance was an air-dropped bomb that had remained intact on the seabed since The Second World War.

- The bomb detonated on the seabed and the shock wave and gas bubble from the explosion hit *Galwad-Y-Mor*.

- The position of most seabed unexploded ordnance is unknown and *Galwad-Y-Mor*'s crew could not have anticipated the fouling of a bomb in the crab potting string.

- *Galwad-Y-Mor*'s crew training, experience, length of service together and emergency preparedness improved their survival chances.

- *Galwad-Y-Mor*'s hull was well constructed and able to withstand the force of the nearby seabed explosion.

Based on this accident's circumstances, no action has been taken by external stakeholders and no recommendations made.

The aim of this report is to highlight the dangers that still exist with unexploded ordnance in the seas around the UK, and the actions to take should fisherman encounter any. In this case, the skipper and crew could not have foreseen the explosion and their level of preparedness to deal with such an emergency saved lives.

SECTION 1 – FACTUAL INFORMATION

1.1 PARTICULARS OF *GALWAD-Y-MOR* AND ACCIDENT

SHIP PARTICULARS	
Vessel's name	*Galwad-Y-Mor*
Flag	United Kingdom
IMO number/fishing numbers	BRD 116
Type	Crab potting vessel
Registered owner	The *Galwad-Y-Mor* Shellfish Company
Manager(s)	Not applicable
Construction	2007
Year of build	Steel
Length overall	14.95m
Registered length	12.90m
Gross tonnage	63.23

VOYAGE PARTICULARS	
Port of departure	Grimsby
Port of arrival	Grimsby
Type of voyage	Commercial
Cargo information	Shellfish
Manning	7

MARINE CASUALTY INFORMATION	
Date and time	15 December 2020 at 1122
Type of marine casualty or accident	Serious Marine Casualty
Location of accident	53°18.59'N 001°15.46'E
Place on board	Hull and all compartments
Injuries/fatalities	Significant injuries to crew members
Damage/environmental impact	Extensive deformation to hull plating, engine room flooded and severe shock damage in all internal compartments
Ship operation	Fishing, recovering pots
External & internal environment	Wind, south-westerly force 3-4, sea state slight/moderate, visibility good
Persons on board	7

Reproduced from Admiralty Chart 0002 by permission of HMSO and the UK Hydrographic Office

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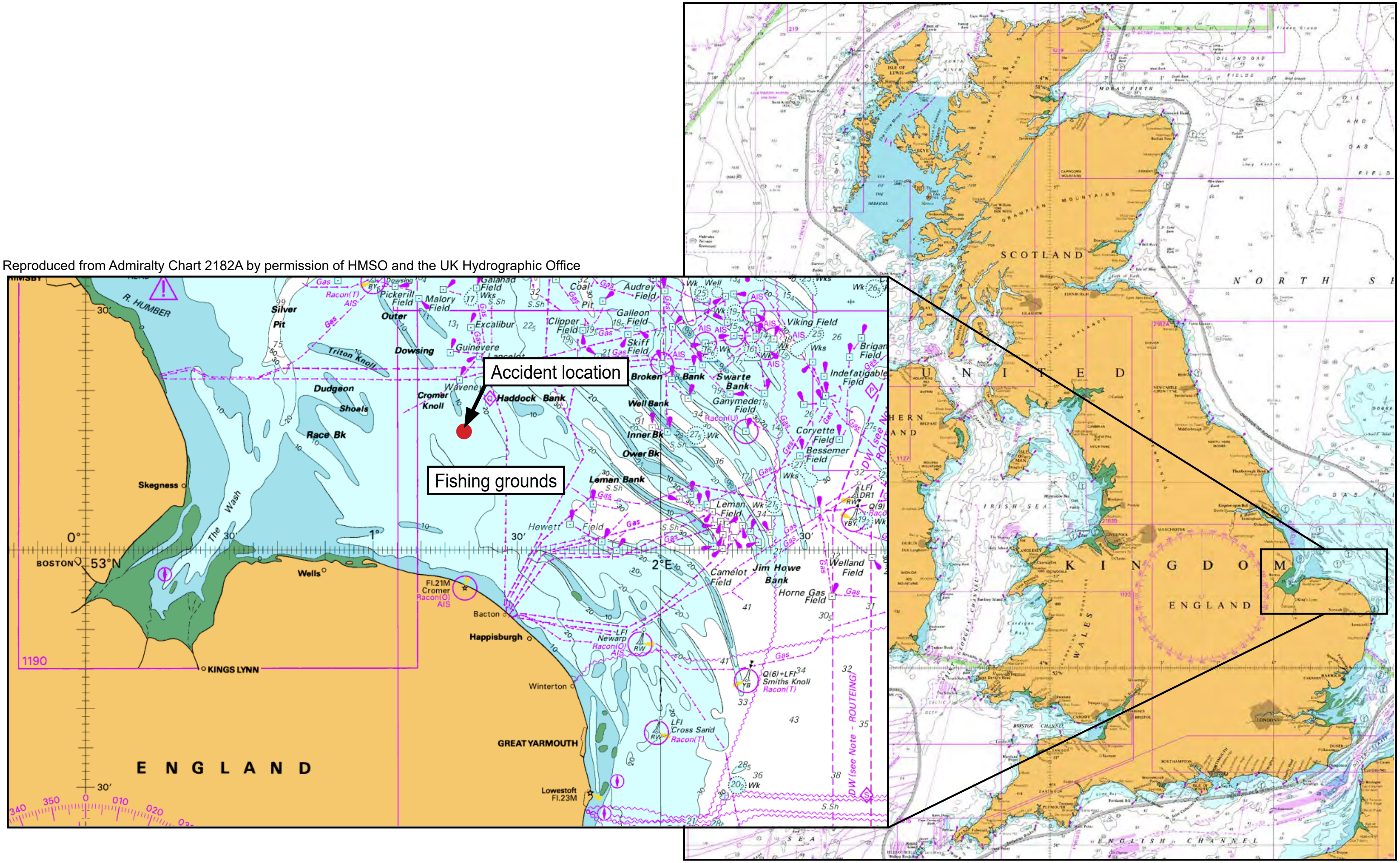

Figure 1: Location of the accident

Marine Accident Report

INVESTORS IN PEOPLE

Annex F – Ordnance Scour, Burial and Migration

1.1 Overview

Unexploded Ordnance (UXO) is typically found washed up on the coastlines, typically during severe weather periods, that strongly suggests movement from their originally deployed position. Consequently, any item of UXO detected during the geophysical UXO survey will be subjected to similar forces and processes and may therefore migrate and change position over time. The following annex provides an overview of the forces and processes to be considered for the assessment of UXO migration, to inform the UXO consultant of the longevity of the UXO risk As Low As Reasonably Practicable (ALARP) sign-off certificate, as well as the expansion size of the avoidance radii.

1.2 Physical Environment

There are several environmental factors that can influence munitions migration and burial on the seabed, namely:

1.2.1 Bathymetry

Both the local bathymetry and the seabed morphology have a significant influence on where munitions are likely to be situated, as well as their prospective mobility. For instance, ordnance located in shallower water depths will be exposed to higher wave generated forces than in deeper water depths. High seabed gradients will also promote migration downslope under the force of gravity.

Whilst it may take relatively little force for an item of UXO to roll or slide downslope into a topographic low, such as a depression or a channel, an increased amount of force will be required to transport the UXO item back upslope. It is widely accepted that any UXO items found in such areas will effectively become trapped and is highly unlikely to move any further.

1.2.2 Tidal Currents

The force generated at the seabed by the tidal current flow will determine the rate and direction of movement of mobile sediments and hence bedform features, but also any debris on the seabed including UXO items.

Tides may be semi-diurnal (generating two low and two high tides within a 24-hour period) or diurnal (generating one high and one low tide during a 24-hour period). Localised tidal variations vary by the alignment of the Sun and Moon, by the pattern of tides in the deep ocean, by the amphidromic systems of the oceans and by the shape of the coastline and near-shore bathymetry. Analysis of metocean data is necessary to fully understand the localised tides and currents which operate within a region to understand the potential for UXO migration.

Depending on the local region, a tidal system will generate either a stronger ebb or flood tide and, dependent on the tidal current vector (magnitude and direction), will influence the predominant direction and rate of movement of an item of UXO.

1.2.3 Wind Generated Surface Waves and Storm Events

Long periods of high wind speeds associated with storm events, which can generate large surface waves, have the highest potential to mobilise items of UXO on the seabed.

The frequency, direction and duration of these storm events is difficult to predict, and therefore there is no proven way to accurately predict the net rate of mobility of UXO on-site without direct observation. Nonetheless, if a 1:50 year storm was to take place on the site after a geophysical UXO survey had already been undertaken, then some form of confirmatory geophysical survey (and investigation) may be required to evidence that the potential UXO targets have not moved, or to scope the magnitude and direction of any such movement.

1.2.4 Seabed Sediments

The nature of the sediments on any site is important for understanding the prospective movement of UXO. The ability of sediments to allow for either full or partial burial of such objects, is key to understanding the potential for scour, burial and the future mobility of the UXO item.

UXO can become buried, either by penetrating the seabed upon its initial deployment (subject to its residual energy upon impact with the seabed) or subsequently, over time, because of scour. UXO items that do become partially or fully buried are unlikely to migrate any further, due to requiring a significantly greater force to mobilise them from their partially buried position. If a UXO item is situated above the mean seabed level and covered by mobile bedforms, such as megaripples or sand waves, they may potentially become uncovered if the bedform position migrates over time.

UXO items are likely to be found on the surface of the seabed of consolidated cohesive sediments as well as bedrock. In comparison, UXO items located on granular soils or unconsolidated cohesive soils may be subjected to greater a potential of scouring and subsequent burial.

The disturbance of the water flow across the UXO item itself causes scouring. Vortices are generated in front of the UXO item, which in turn exerts a shear force at the seabed and mobilise the seabed sediments away from the UXO item. This process is periodic, accelerating with energetic wave and tidal current conditions, and will continue until the UXO item is of a similar roughness to the surrounding seabed. Eventually, the UXO item will be undermined by the scouring action and fall into its own scour pit as shown in Figure 1.2.4.

1. Vortices are produced in the front of the UXO scouring sediment away;
2. The UXO is eventually undermined by the scouring action and rolls/slides into the scour pit;
3. Scour – burial cycle begins again until vortices are too weak to transport the seabed sediments

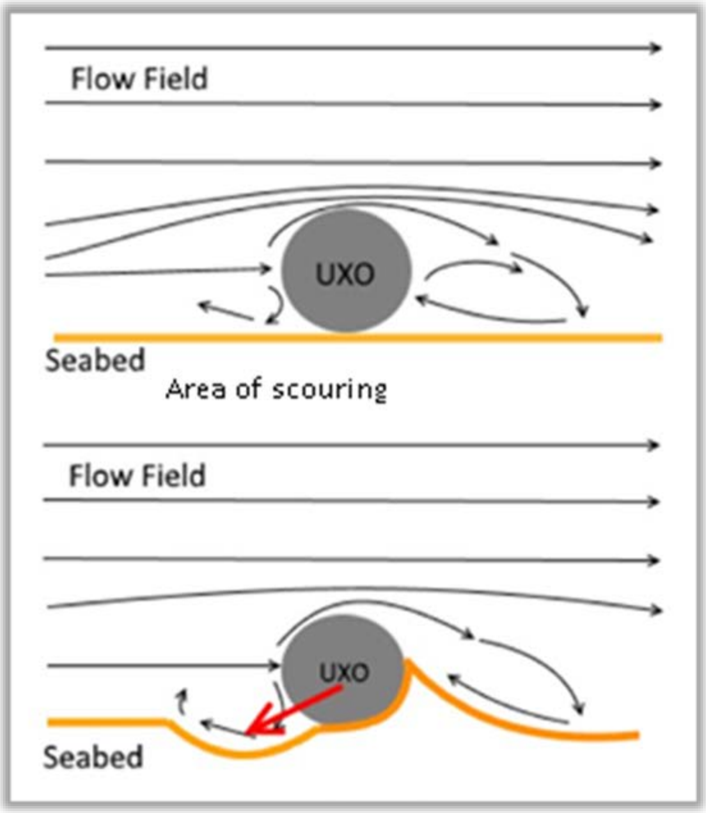

Figure 1.2.4: Vortex scouring and burial mechanism for UXO.

1.3 Human Factors – Fishing

Commercial fishing activities have the capability to inadvertently snag and move items of UXO, particularly in areas where dredging, beam and pair trawling is prevalent and nets are in contact with the seabed. These snagged UXO items may have been transported with the movements of the vessel's nets for considerable distances before they are returned to the seabed or recovered to the vessel.

Fishing boats which accidentally recover items of UXO have also been known to dispose of them/cut them free once they have been brought up to the surface, rather than inform the authorities (which involves considerable delay, but reduced risk).

1.4 Munitions Properties – Size, Shape and Density

The density, which is dependent on the mass and volume of the ordnance item, the cross-sectional area presented to the residual flow direction, and the hydrodynamic shape are primary factors considering an ordnance item's propensity to migrate.

In general, the denser and smaller an item of UXO is, the less likely it is to migrate. A large cross-sectional area will experience a higher hydrodynamic drag force than a smaller cross-sectional area, and a more streamlined body will experience a lower hydrodynamic drag force than a non-streamlined body.

Items of UXO, particularly high explosive bombs, are effectively hollow cases filled with an explosive fill. A large proportion of the bomb's volume is therefore dedicated to this low-density explosive fill. In comparison, a heavy anti-aircraft artillery projectile is significantly smaller and lighter, but is also denser, with a larger proportion of the volume dedicated to the casing to maximise the fragmentation effect. The projectile will also have a much smaller area exposed to the water flow. Given these circumstances, it is likely that the heavy anti-aircraft projectile will have a lower propensity to migrate than the high explosive bomb.

Annex G – UXO Detection Methods

1.1 Overview

There are several systems and underwater tools available on the commercial market for detecting Unexploded Ordnance (UXO). Generally, UXO detection methods rely on either one or more of the following ordnance properties: the known physical dimensions of the threat items likely to be encountered upon the site, whether the ordnance casing is metallic, and/or whether the ordnance casing comprises a ferrous metal for most ordnance types. The other property that an item of UXO has which classifies it from benign debris, is the explosive content. However, marine explosive detectors are still at the experimental stage and currently not widely utilised.

UXO detection is accomplished by utilising one or more of the following methods:

- Visual detection methods;
- Magnetic methods;
- Electromagnetic methods;
- Acoustic methods.

1.2 Visual Detection

A visual inspection typically employs a Remotely Operated Vehicle (ROV) or diver, to inspect the seabed at the site of the intrusive investigation, installation or construction operation and detect any UXO present. The classification of any potential UXO targets found is performed simultaneously during the visual inspection. An ROV or diver is typically equipped with a pulse induction metal detector, to detect any shallow buried potential UXO targets, or to search for and relocate any marked potential UXO targets. The costs of performing a visual inspection across an extensive area of the seabed makes visual detection of UXO a more appropriate method for small specific locations.

1.3 Magnetic Methods

Th Magnetic methods for UXO detection, relies on the ferrous metal content of the UXO item producing a local magnetic distortion/anomaly of the *Earth*'s magnetic field. This magnetic distortion will occur even when the ferrous source is buried under the seabed. Magnetometer sensors are typically employed to provide a scalar or vector measurement of the *Earth*'s magnetic field. A suitably qualified interpreter may then record the positions of these anomalies for further target classification.

Magnetometers for UXO detection are generally regarded as the main detection methods for UXO and allow flexibility in the towing arrangement for rapid geophysical acquisition of extensive survey areas. Diurnal fluctuations of the *Earth*'s magnetic field may be eliminated by towing two or more magnetometers in a gradiometer arrangement. As a gradiometer, the magnetometers measure the rate of change of the magnetic field distortion in one or more axial planes and have the benefit over a conventional single magnetometer of an improved signal to noise ratio, permitting the detection of smaller ferrous sources. Geology with a high susceptibility to magnetisation, will act as a source of magnetic noise potentially masking potential UXO targets from detection. Ordnance casing made from non-ferrous metals, such as aluminium, are undetectable by magnetometers as are any other non-ferrous debris occurring upon the site.

1.4 Electromagnetic Currents

UXO detection using electromagnetic methods classifies UXO targets by their electrical conductivity and will detect both ferrous and non-ferrous metallic targets. Pulse induction is an electromagnetic method, commonly employed for the detection of UXO, although the system is generally mounted upon an ROV during relocation of potential UXO targets.

Pulse induction works by generating a pulse of electrical current, within a few microseconds through a coil of wire. Each pulse produces a brief magnetic field which collapses with the stoppage of the current resulting in a large voltage spike across the coil and a second current or reflected pulse flowing through the coil. If there is a conductor present, the pulsing magnetic field induces eddy currents. These eddy currents produce a second magnetic field which propagates back to the detector inducing a small voltage within the coil. The eddy currents generated by a conductor are scaled with the item's inherent conductivity, which is dependent on the item's material, thickness, and length.

If a target is purely magnetic and non-conductive (e.g. a boulder), no eddy current would be generated and nothing would be detected on the sensor. One of the advantages of electromagnetic methods over magnetic methods is that geology is not detected, removing a potential source of false positive potential UXO targets to be investigated.

However, the range of detection is inferior to that of magnetic methods with EM methods possessing a faster signal falloff rate proportional to 1/r6 compared to a total magnetic field falloff rate of 1/r3 (r being the separation distance between the detector and the target). Boat towed metal detectors are commercially available; however, they are required to be flown very close to the seabed which may prove difficult. For increased control, pulse induction detectors are generally mounted on an ROV, making this method suitable for potential UXO target relocation, and to limited survey areas where there is a threat of non-ferrous UXO.

1.5 Acoustic Methods

Acoustic methods for UXO detection rely on the distinguishable contrasts in reflected acoustic energy between a UXO item and the surrounding seabed.

Sound navigation and ranging (sonar) is a method of using acoustic energy to determine distance and direction. Single and Multi-Beam Echo Sounders (MBES) use this method to determine distance to the seabed. Side Scan Sonars (SSS) are used to produce an image of the seafloor. SSS is generally used during geophysical surveys for the locating of boulders and debris, as well as mapping the boundaries of sediment types and bedforms. Classification of potential UXO targets from non-UXO targets is typically based on matching the SSS contacts' dimensions to the physical dimensions of possible UXO threat items.

Although SSS is used to detect potential UXO (pUXO) items on the seabed, sonar methods are unable to detect fully buried targets. Instead, seismic reflection methods are used, specifically 3D chirp and other high-resolution seismic systems, which rely on variations of density and therefore acoustic impedance, to detect buried contacts.

Acoustic methods of UXO detection are susceptible to error during the classification of contacts, particularly when using SSS and/or MBES. Partial burial of the UXO within the seabed may reduce the dimensions of targets (length and width), resulting in pUXO targets being incorrectly graded as benign debris. Further errors may also be introduced via human error during the measuring process of the contacts' dimensions, leading to false classifications of targets.

For UXO detection, acoustic methods are ideally combined with either magnetic or electromagnetic methods to provide a further method of target classification. Without a second method to classify between targets, the client may be overwhelmed by the sheer number of SSS contacts that have dimensions like that of UXO, which are subsequently graded by the UXO consultant as pUXO targets and would require either avoiding or further target investigation.