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special risks consultancy

Unexploded Ordnance Threat and Risk Assessment with Geotechnical Investigation Risk Mitigation Strategy

DNV·GL

Project: ***A04 Normandy***

Meeting the requirements of the UK's Construction Industry Research and Information Association's

UXO Risk Management Framework:

"Assessment and Management of the Unexploded Ordnance Risk in the Marine Environment (C754)"

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This UXO threat and risk assessment is considered a living document. Should the proposed geotechnical investigation, cable installation and/or wind turbine installation methodologies change, further evidence of UXO sources be found, or UXO be found during these or other operations, then this assessment for the Study Site is to be reassessed and updated by 6 Alpha Associates Ltd.

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Executive Summary

Study Site

DNVGL has commissioned *6 Alpha Associates* to deliver a desk-based Unexploded Ordnance (UXO) threat and risk assessment, for Geotechnical Investigation (GI), cable installation and wind turbine installation of the *A04 Normandy Offshore Wind Farm (OWF)*. A risk mitigation strategy for the proposed GI operations has also been commissioned.

The proposed location of the *A04 Normandy OWF* has been provided by the Client and has been geo-referenced and presented at Figure 1.

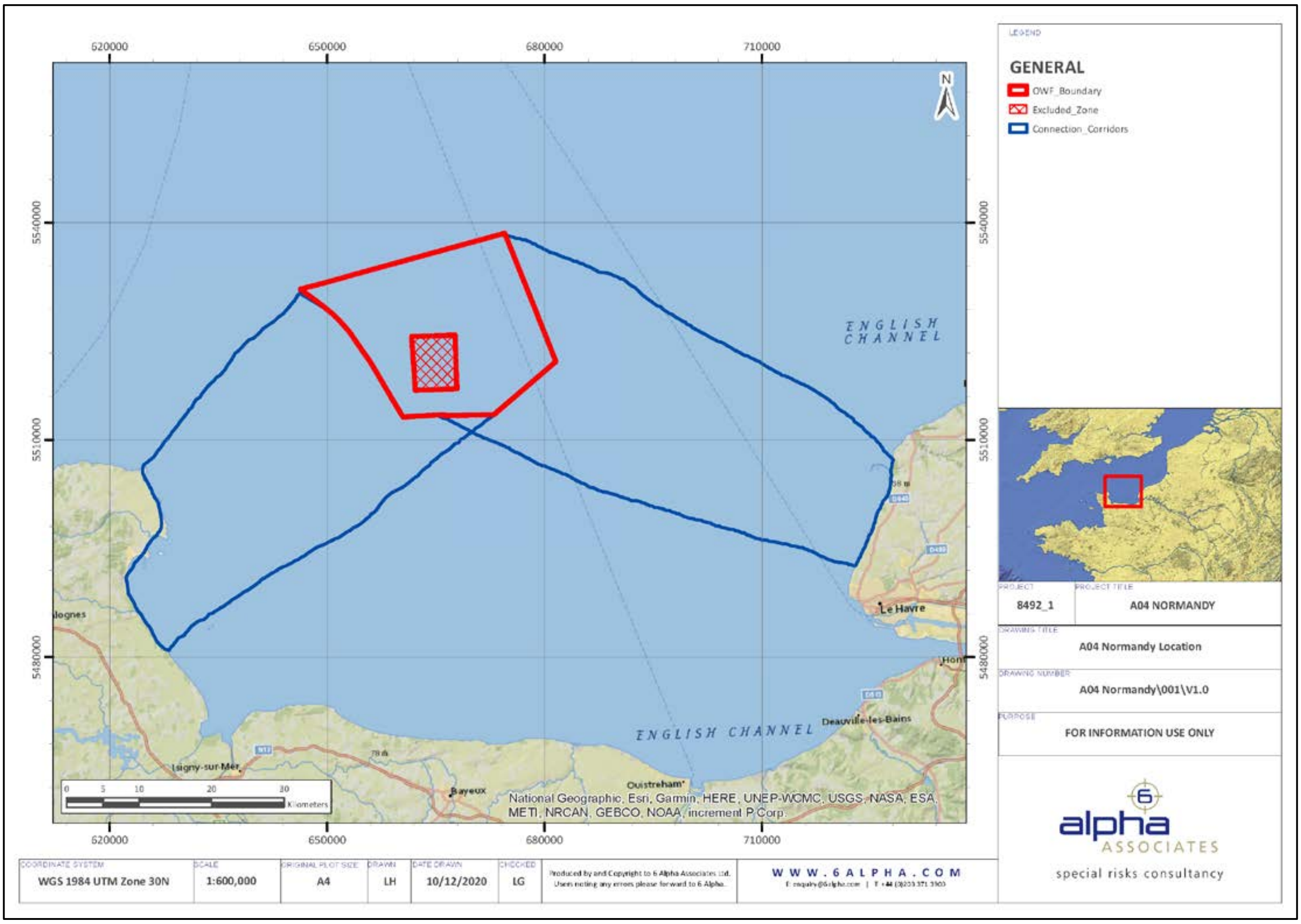

Figure 1 – Site Location

UXO Threat and Risk Assessment Summary

A tabulated summary of the findings of the threat and risk assessment is presented in Figure 2:

Intrusive Operation	UXO	UXO Risk (10m WD)	UXO Risk (26m WD)	UXO Risk (40m WD)
Geotechnical Investigation	Aerial Bombs	HIGH	HIGH	MEDIUM
	Naval Mines	HIGH	HIGH	MEDIUM
	Projectiles	MEDIUM	LOW	LOW
Pre-Lay Operations	Aerial Bombs	VERY HIGH	VERY HIGH	HIGH
	Naval Mines	VERY HIGH	VERY HIGH	HIGH
	Projectiles	HIGH	MEDIUM	LOW
Cable Installation and Burial	Aerial Bombs	VERY HIGH	VERY HIGH	VERY HIGH
	Naval Mines	VERY HIGH	VERY HIGH	HIGH
	Projectiles	HIGH	MEDIUM	LOW
Wind Turbine Installation	Aerial Bombs	HIGH	HIGH	HIGH
	Naval Mines	HIGH	HIGH	HIGH
	Projectiles	HIGH	MEDIUM	LOW
Protection Operations	Aerial Bombs	HIGH	HIGH	HIGH
	Naval Mines	HIGH	HIGH	HIGH
	Projectiles	HIGH	MEDIUM	LOW
Enabling Operations	Aerial Bombs	HIGH	HIGH	HIGH
	Naval Mines	HIGH	HIGH	HIGH
	Projectiles	HIGH	MEDIUM	LOW

Figure 2 – Representative UXO Risk Assessment Summary

The table presented at Figure 2 is intended as an indicative summary. Torpedoes were not included for presentation purposes based on the fact that they were assessed to pose MEDIUM UXO risks at most and do not require bespoke mitigation as such (e.g. associated risk can be mitigated when mitigating more significant UXO risks from HE bombs and naval mines).

UXO Risk Zones

The zoning of UXO risk is based on a number of factors, including the nature, scope and geospatial distances of pertinent UXO threat sources and the expected water depths. Nonetheless, the categorisation of UXO risk is not universal throughout the Study Site, and there are areas of VERY HIGH, HIGH and MEDIUM categories of risk. The high level "worst case scenario" UXO risk zones for all installation and GI operations are depicted at Figure 3.

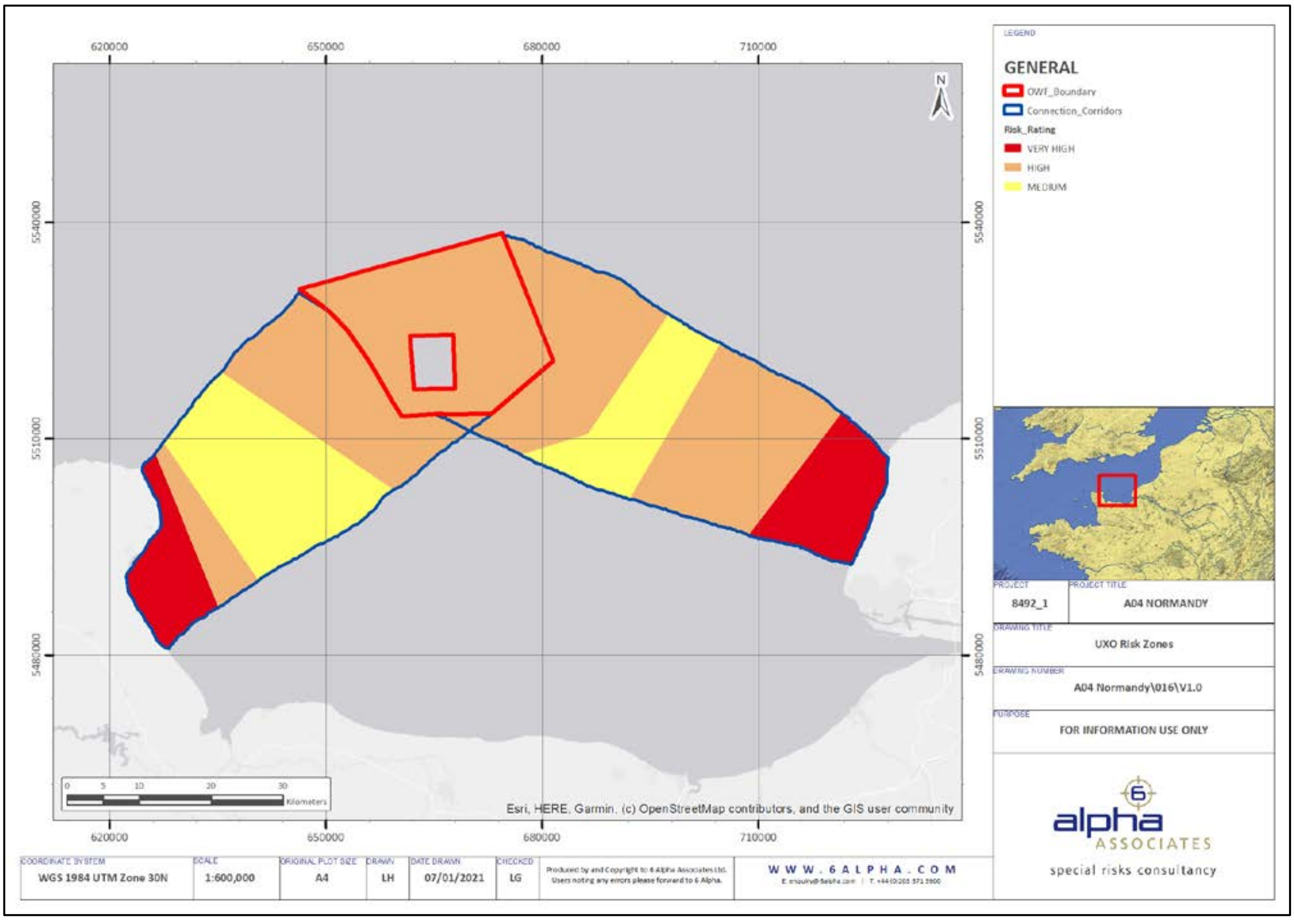

Figure 3 – "Worst Case Scenario" High-Level UXO Risk Zones:

All Operations

6 Alpha have also zoned the UXO risk associated with GI works only, those risk zones are presented at Figure 4.

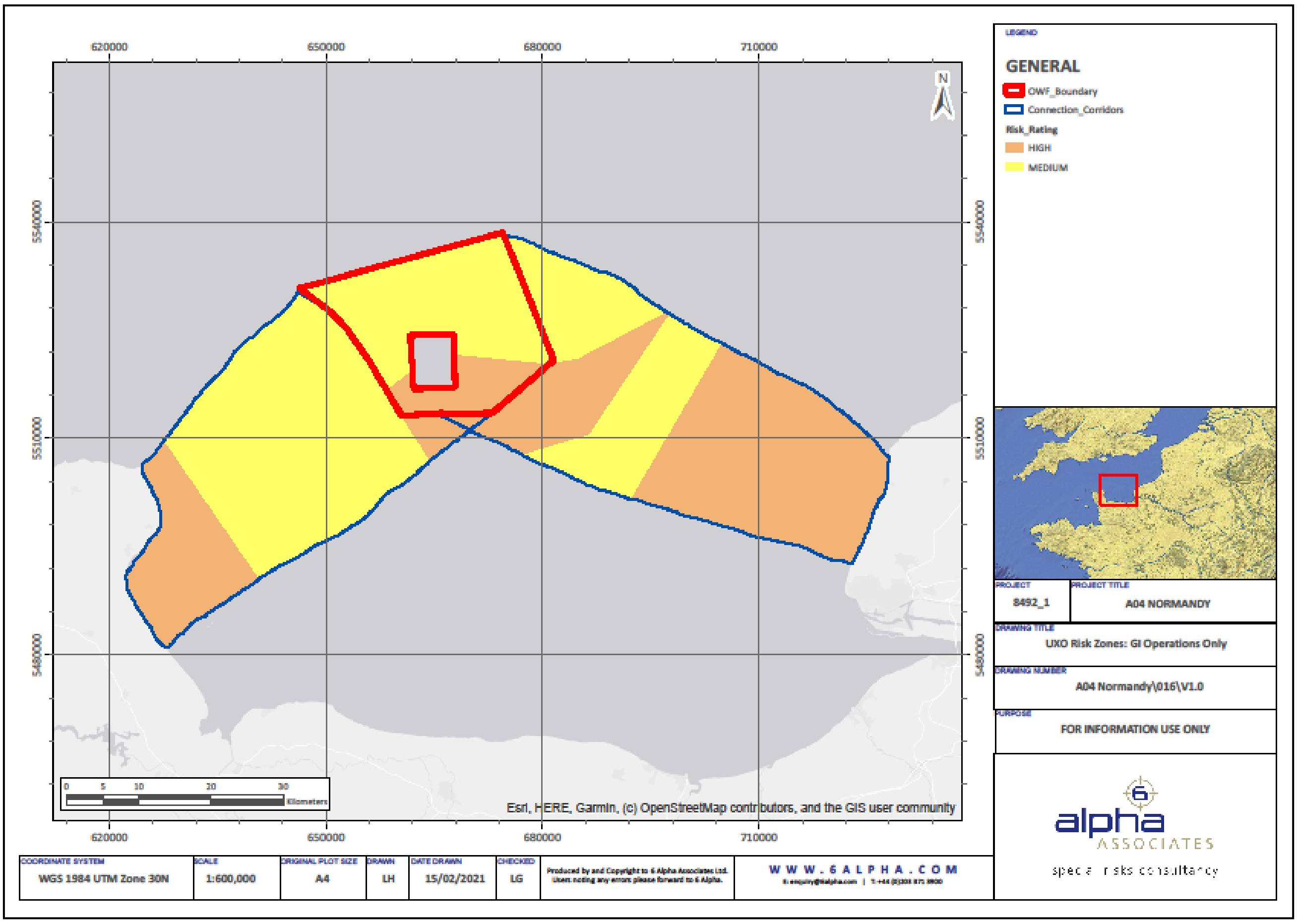

Figure 4 – UXO Risk Zones: GI Only

It is likely that the UXO risk zones could be refined further within the body of a tactical level risk mitigation design document. However, the precise types and locations of any intrusive GI operations would need to be considered, together with the water depths and likely shallow sub seabed conditions, in order to further and better refine the UXO risk zoning, in either the OWF area or in the export cable corridors.

Conclusions

Generally

The nature and scope of the UXO risks vary across the OWF area and each connection corridor, 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 doing so, in particular. The nature and extent of the risks posed are partly predicated by 6 Alpha's assessment the type, extent and aggressiveness of the proposed intrusive operations.

In the offshore environment, the effects of the depth of water upon potential UXO initiation consequences (and *inter alia* the resultant through seabed and through water shock wave), will be partly or wholly risk mitigative with the exception of large Net Explosive Quantity (NEQ) UXO threat items - and in such circumstances where the risk is partly and sufficiently mitigated, the residual risks might well be tolerated.

Nonetheless, some UXO risks posed by proposed operations have been categorised as either VERY HIGH or HIGH and they are generally associated with the unplanned initiation of large NEQ UXO – such as naval mines and aerial bombs during certain sub-seabed operations such as GI, cable installation and wind turbine installation, as well as similar enabling or supporting operations. Such risks are considered intolerable.

MEDIUM category UXO risks are also posed by certain other types of UXO and/or intrusive sub-seabed operations. As a result, *6 Alpha* have zoned such offshore UXO risks into different categories and have defined the requirements for their mitigation, based upon underwater explosive effects modelling and the variable likelihood that UXO may be encountered within different areas of the OWF.

UXO Risks to Surface Vessels and their Crew

UXO risks that are posed to vessels and their crews are most severe in shallow water (defined for the purposes of UXO risk analysis as 26m water depth, or shallower). Although the prospective consequences for surface vessels generally reduces as the depth of water between the vessel and the point of a UXO initiation increases, the water depths throughout the OWF area and the export cable corridors are not expected to be sufficient to wholly mitigate large NEQ UXO risks posed by naval mines and high NEQ aerially delivered High Explosive bombs. Therefore, the level of UXO risk remains high in those zones.

If divers are deployed to facilitate subsea operations, then they may also be exposed to significant UXO risk because divers are especially vulnerable to UXO if it is initiated underwater and fatalities can be generated hundreds of meters from the seat of such an explosion (subject to the NEQ in the UXO).

UXO Risks to Underwater Equipment

The prospective UXO risks posed to underwater equipment - and to any cables or wind turbine foundations – are also significant. Such assets and their installation support vessels are unlikely to be sufficiently robust to withstand the consequences of an initiation of large threat spectrum UXO.

Recommendations

6 Alpha recommends that the UXO risk is mitigated within the bounds of the As Low As Reasonably Practicable (ALARP) risk reduction principal. For example, if project stakeholders are willing and able to tolerate some low NEQ UXO risks associated with subsea equipment, then better value for money solutions may be afforded in terms of UXO risk mitigation by avoiding those costly and time-consuming risk mitigation measures that reduce the risks associated with low NEQ UXO threats in deep water especially. Therefore, *6 Alpha* has recommended that only specific and intolerable risks are mitigated in order to reduce them to ALARP, in accordance with *EU* and national laws.

The following UXO risk mitigation recommendations have therefore been made in order to reduce UXO risks to ALARP:

UXO Risk Mitigation Strategy for GI - Overview

The UXO risk mitigation strategy has been designed for GI operations only, and there are three main options to consider in order to reduce these UXO risks ALARP, based upon the source-pathway-receptor model.

6 Alpha's approach is that UXO risk can effectively be reduced to ALARP, by removing one (or more) element(s) of the model or otherwise mitigating the risks associated with a single element of the model. The UXO risk mitigation strategy will, therefore, consist of UXO risk mitigation measures, that are to be implemented to reduce risks to ALARP. The three main strategic options based upon source-pathway-receptor modelling are, in priority order:

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 by moving the locations of GI operations where necessary, such risks are appropriately and effectively reduced.

Removal of Risk Receptors

A second option is to remove the receptor element (of the source-pathway-receptor model), by moving certain sensitive and vulnerable receptors (typically crews of offshore vessels), to a safe distance from the point of the intrusive activity and thus the pUXO hazard, so that it will diminish sufficiently the prospective blast, fragmentation and/or shock wave consequences to reduce UXO risks to ALARP. Clearly, this is not always achievable and such a course of action is commonly impractical.

Removal of Threat Sources

Where GI operations cannot be moved in order to avoid pUXO, an alternative (but commonly, time consuming and costlier) option, is to verify pUXO by investigation and where it is cUXO, to remove it (effectively removing the source element of the source-pathway-receptor model), by either moving it to a position where it can do no harm (but only when it is safe to do so and wherever permit licencing and consent condition allow such actions), and/or destroying it or otherwise rendering it safe.

Residual Risk Tolerance

Following the implementation of the risk mitigation strategy, UXO risks will not be reduced to "zero". Residual UXO risks will likely remain in the offshore environment due to *inter alia*, the limits of geophysical UXO survey technology, data interpretation limitations and the fact that small scale low NEQ UXO threats might be tolerated which is acceptable under the auspices of the ALARP risk reduction principle. Such residual risks have been tolerated on many other projects, in very similar circumstances. Such an approach therefore, is likely to be deemed acceptable by a wide variety of project stakeholders and regulators and is consistent with all agreed upon risk management standards, practices and frameworks.

UXO Risk Mitigation Measures

- The GI risk mitigation strategy should be enacted through the design and implementation of risk mitigation measures, as follows:
- Proactive Measures:
    - **Geophysical UXO Survey**; a geophysical UXO survey is to be designed (and subsequently undertaken) to detect threat spectrum UXO as follows:
        - **SSS;** high-resolution Side Scan Sonar should be employed (>600kHz frequency);
        - **MBES;** Multi-Beam Echo-Sounder survey is often corroborative and helpful in delivering UXO target discrimination; its outputs should therefore be employed to compliment SSS data;
        - **MAG;** subject to the locations and type of GI being undertaken, the juxtaposition of the GI work vessel(s) and the water depth, geophysical survey by magnetometer of gradiometer may or may not be required. 6 Alpha can better advise when the details of the GI are known;

- **Anomaly Selection**; geophysical UXO survey data (once acquired) is to be employed in order to select those anomalies that model as potential UXO (pUXO). A UXO specialist is usually employed to discriminate pUXO from benign seabed (or sub-seabed) detritus. Our recommendation is that pUXO should be avoided (see below); or, where it cannot be avoided, it may have to be verified by investigation (also see below);
- **pUXO Avoidance**; pUXO is to be avoided either by 15m (the latter is a baseline and *6 Alpha* standard safety distance but may be reduced through the medium of a Technical Advisory Note), measured from the edge of any seabed intrusive GI tool;
- **pUXO Investigation**; where pUXO avoidance criteria cannot be met, then target investigation must be undertaken to verify and classify pUXO as either confirmed UXO (cUXO), or as seabed debris;
- **UXO Disposal**; following the inspection of pUXO, those items of cUXO will require either: movement (e.g. to the edge of the consent corridor – where it is permitted and safe to do so) and/or render safe either by sympathetic detonation (or possibly by a low-order/deflagration technique);

- Reactive Measures:
  - **Emergency Management Plans**; are to be written and distributed to all vessels involved with GI operations;
  - **Tool-Box Briefs**; are to be delivered to all personnel intimately involved in GI activities;
  - **On-Call Service**; an Explosive Ordnance Disposal company may be employed to provide an immediate repose in the event that an item of UXO is discovered - even after proactive risk mitigation measures have been executed - during any and all subsequent activities associated with GI operations.

Minimum UXO Threat Item

The recommendation for the minimum threat items to be detected by geophysical UXO survey is variable throughout the Study Site depending on a number of factors including but not limited to; water depth, likely GI methodology, the nature of the UXO threat, prospective vessel slant range and vessel robustness. It should also be noted that the minimum threat item is based on a UXO threat item's ferrous metal content rather than its physical dimensions or any other factor.

In water depths of up to 10m LAT, the minimum UXO threat item to be detected by geophysical UXO survey is assessed to be:

- *French* 10.5 cm leFH 18 Artillery Projectile with a ferrous mass of 13kg.

In water depths of between 10m and 26m LAT, the minimum UXO threat item for survey is assessed to be the following:

- *German* SC-50 HE Bomb with a ferrous mass of 23kg.

In water depths of between 26m and 40m LAT, the minimum UXO threat item for survey is assessed to be the following:

- *US* AN-M57 250lb HE Bomb with a ferrous mass of 59kg.

Where water depths exceed 40m LAT, the minimum UXO threat item for survey should instead be the following:

- *British* Mark XV/XVII Naval Mine with a ferrous mass of 68kg.

ALARP Safety Sign-Off Certification

If the above criteria are satisfied, then ALARP safety sign-off certification for GI can be readily provided. 6 Alpha recommend that the UXO risk mitigation strategy is subsequently updated and expanded to encompass risk mitigation measures for OWF foundation and all cable installation works, which are expected to be scheduled later in the project cycle.

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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
CPT	Cone Penetration Testing
cUXO	Confirmed Unexploded Ordnance
DP	Dynamically Positioned
EOD	Explosive Ordnance Disposal
EMP	Emergency Management Plan
EU	European Union
GI	Geotechnical Investigation
HE	High Explosive
LAT	Lowest Astronomical Tide
LMB	Luftmine B
LSA	Land Service Ammunition
MBES	Multi-Beam Echo Sounder
MMA	Munitions Migration Assessment
MPa	Mega Pascals
NEQ	Net Explosive Quantity
OSPAR	Oslo-Paris Convention for the Protection of the North-East Atlantic
OWF	Offshore Wind Farm
PEXA	Practice and Exercise Area
PLGR	Pre-Lay Grapnel Run
pUXO	Potential Unexploded Ordnance
RC	Route Clearance
SAA	Small Arms and Ammunition
SQRA	Semi-Quantitative Risk Assessment
SSS	Side Scan Sonar
TBB	Tool Box Brief
TNT	Trinitrotoluene
UK	United Kingdom
UXO	Unexploded Ordnance
WD	Water Depth
WROV	Work-Class Remotely Operated Vehicle

Key Definitions

There are several terms that are used within this UXO threat and risk assessment report, namely:

Key Industry Definitions

- **As Low As Reasonably Practicable (ALARP)** – a term used in the management of safety-critical and safety-involved systems. The ALARP principle is that risks shall be reduced as low as reasonably practicable, which is effectively a (UK) legal minimum requirement;
- **Best Practice –** those standards for controlling risk which have been judged and recognised by a regulatory body as satisfying the law, when those standards are applied in an appropriate manner;
- **Competency –** a person or organisation with sufficient training, experience, and knowledge;
- ***De Minimis*** – an abbreviated form of the Latin maxim *de minimis non curat lex*, "the law cares not for small things". In terms of risk management, risks that are defined as too small to be of concern and exempt from further consideration; the purpose being, to avoid a disproportionate use of finite resources by mitigating a virtually inexhaustible supply of insignificant or low-level risks;
- **Hazard –** anything that has the potential to cause harm or damage;
- **Precautionary Principle –** an action with the potential risk to cause harm or damage without certainty or scientific consensus that the action is not harmful or damaging. The burden of proof that the action is not harmful or damaging falls upon those undertaking risk assessment and taking risk mitigation action;
- **Risk –** the intentional interaction of something of value with the potential for danger, harm, or loss;
- **Risk Assessment** – a systematic process of identifying and evaluating the potential risks of an action or undertaking;
- **Threat –** anything that has the potential to cause harm or damage, but especially UXO;
- **Uncertainty –** an unknown element that is not fully understood to properly inform the decision-making process;
- **Unexploded Ordnance (UXO)** – any **unexploded** munition with an explosive or chemical fill that failed to initiate and poses a risk of causing harm or damage.

Key Historical Definitions

- **Allies (WWI)** – the alliance between the *British Empire*, *France*, *Russia* and the *USA*, though many other "associated powers" are sometimes labelled collectively as the "Allies";
- **Allies (WWII)** – the alliance between the *British Empire*, *France*, the *Soviet Union* and the *USA*, though many other "associated powers" are also sometimes labelled collectively as the "Allies";
- **Axis** – the alliance between *Germany*, *Italy*, and *Japan* during WWII;
- **Central Powers** – the alliance between the *German Empire*, *Austria-Hungary*, the *Ottoman Empire* and *Bulgaria* during WWI;
- **Grand Fleet** – the main *British Royal Navy* fleet of ships during WWI;
- **High Seas Fleet –** The name of the battle fleet of the *German Imperial Navy* that was created in 1907 and saw action in WWI;
- **Luftwaffe** – the official name of the *German* air force between 1933 and 1946;
- **Kriegsmarine** – the name given to the *German* navy between 1935 and 1945.

1 Introduction

1.1 Project Overview

DNGVL (the *Client*) has commissioned *6 Alpha Associates* (*6 Alpha*) to deliver a desk based Unexploded Ordnance (UXO) threat and risk assessment study, for Geotechnical Investigation (GI), cable installation and wind turbine installation of the *A04 Normandy Offshore Wind Farm (OWF)*. A Risk Mitigation Strategy has also been commissioned and designed, but as requested as this stage, only for the mitigation of UXO risks associated with GI operations.

The proposed development will be located in the *Baie de Seine*, off the coast of *Normandy* in the *English Channel*.

The location of the OWF and associated connection corridors are presented at Appendix 1.

1.2 UXO in the Marine Environment

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 subsea investigation and installation activities.

1.2.1 Generic UXO Threats

All military technology has an inherent base failure rate, meaning that not all ordnance functions as the designer intended, during either training or operational use. It is generally accepted that during WWII approximately 10% of *German* aerially delivered bombs failed to explode – *Allied* bomb failure rates are estimated to be slightly higher. Offshore and onshore bombing targets were also simply missed, and bombs were also jettisoned from aircraft when evading an adversaries' attacks and/or when seeking to reduce aircraft weight during a return journey and to deliver a higher safety margin when landing.

Wartime training and operations also employed live munitions filled with high explosives (as well as other substances and materials including toxic chemicals or ignition/burning agents in incendiary bombs), which may have remained after the training exercises and operations had been completed. From the outset of WWI, and throughout WWII, sea mines were deployed in significant quantities in both offensive and defensive naval operations and their residue poses a further UXO contamination threat to intrusive activities in the marine environment. Conventional and chemical munitions dumping was also prevalent in these periods with little consideration given to future safety implications. There was also widespread unrecorded dumping of Small Arms Ammunition (SAA) and

Land Service Ammunition (LSA) that was, not only perceived to be inconsequential, but also 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 as a result of natural seabed sediment transport and other forces. Modern military training areas, such as offshore firing ranges, are also likely have also contributed to the background UXO contamination of the offshore environment.

Besides the clearance of naval minefields to open the commercial 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, pose a considerable contamination threat source in the marine environment.

1.2.2 Generic UXO Risks

The explosive or chemical fill within UXO rarely becomes inert or loses its effectiveness with age, but 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 when subjected to an impact or a physical shock. It is therefore possible, that a significant impact on the UXO casing, 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. UXO risks must be considered and managed in order to protect offshore personnel from injury or, in the very worst-case scenario prospective fatalities; as well as to fulfil the Clients’ statutory obligations under the auspices of national and/or *European Union* law.

Further information regarding national and international legislation, and the management and reduction of UXO risk to As Low As Reasonably Practicable (ALARP), is presented at Annex A and is indicative of the safety benchmark to which 6 Alpha adhere.

1.3 UXO Industry Best Practice

The *UK’s Construction Industry Research and Information Association* (CIRIA) has published a best practice guide for the assessment and management of UXO risk in the marine environment (CIRIA, *Assessment and management of unexploded ordnance risk in the marine environment (C754),* February 2016), that not only has significant and wide-reaching offshore industry recognition, but also has been formally endorsed by the *U.K.*'s *Health and Safety Executive*; *6 Alpha* were *CIRIA's* lead technical author for this publication and as such, it guides *6 Alpha's* UXO risk management practices. Whilst this project is being undertaken in *EU* waters and not in the *U.K.*, CIRIA C754 guidance has been successfully employed on similar projects in *French* waters previously.

Therefore, in undertaking this threat and risk assessment, we have not only brought to bear our offshore UXO risk management expertise and technical experience, but we have also benchmarked our delivery of offshore service provision with the CIRIA C754 guide - in order to ensure compliance with industry best practice and to manage UXO risks in accordance with ALARP risk reduction criteria.

Nonetheless, whilst the *CIRIA* guide outlines "what" steps are to be taken to manage the UXO risk, it lacks detail of "how" these steps are to be executed in order to reduce risks to ALARP. Where such finer detail is lacking in the *CIRIA* guidance, *6 Alpha* has filled those gaps through the careful and appropriate application of our UXO risk management strategic framework.

1.4 UXO Risk Management Strategic Framework

To manage and ameliorate the prospective UXO risks, 6 Alpha has developed a detailed UXO risk management strategic framework that is not only in line with CIRIA guidance but also, is in accordance with ALARP risk reduction principles. At Section 5 of CIRIA C754, the risk management framework is divided into five key phases that correspond to those employed by 6 Alpha, as presented at Table 2.3. A full overview of 6 Alpha's UXO Risk Management Framework is presented for completeness at Appendix 2.

Table 2.3: 6 Alpha and CIRIA UXO Risk Management Frameworks

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)	✘

Notwithstanding *CIRIA* guidance, the purpose of this report is to address stages one, two, and three of the UXO risk management framework, for GI only in the latter case. The potential nature and scope of the UXO threat at the Site is addressed initially (at Stage One), before the potential UXO risk pathways are identified and analysed in order to assess the UXO risks associated with the proposed GI, cable installation and wind turbine installation works (at Stage Two). Once the associated UXO risks have been assessed, recommendations for Site-specific UXO risk mitigation measures (at Stage Three) are outlined for GI operations, which (if implemented fully), will ensure and evidence that a suitable and appropriate UXO risk management strategy has been planned and delivered, in order to reduce UXO risks to ALARP.

1.5 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), that informs the way in which UXO risks are assessed for each seabed intrusive activity associated with the project. The model also helps to explain the link between the separate sections of this report and the UXO risk assessment at Section 6. The components of the model are as follows:

1.5.1 UXO Sources

The nature and scope of the UXO threat is summarised in the UXO threat assessment (at Section 3) and it forms the source element of the source-pathway-receptor model.

1.5.2 UXO Pathways

The UXO pathways are the routes by which the sources can reach the receptors. Marine UXO pathways are likely to be either by contact and/or through soil or water, through 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 sources may also reach the receptors.

UXO risk pathways may be generated by a variety of GI, cable installation and wind turbine installation operations that interact with the seabed. Therefore, the Client's intended operations have been assessed and summarised (at Section 4), to demonstrate the potential risk pathway elements of the model.

1.5.3 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 important, not only in determining their capacity to withstand such high explosive effects, but also in defining what degree 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 that might generate injuries (in general) and fatalities (in particular), are highly unlikely to be considered tolerable. Typically, offshore receptors include, but are not limited to, the GI and installation equipment; the cable, wind turbines and their protective systems; as well as underwater (e.g. Work-Class Remotely Operated Vehicle - WROV) and surface vessels, and where appropriate, their crews. Divers are also especially vulnerable to underwater high explosive effects, as are marine mammals.

2 Scope and Structure of the UXO Risk Assessment

2.1 Report Structure

This report comprises a desk-based collation and review of readily available documentation and records (which have been summarised separately in Section 2.2), relating to the types of UXO that might be encountered at the Site in order to assess the potential UXO risks and in light of that, to design a suitable and appropriate risk mitigation strategy to reduce such risks to ALARP.

Therefore, the report has been structured to summarise the relevant data and to present the UXO threat. In light of the proposed GI, cable installation and wind turbine installation activities a risk assessment will be undertaken, and a risk mitigation strategy will be presented for the GI operations. The following aspects will be covered:

- The sources of prospective UXO contamination that are likely to be encountered within the bounds of the Study Site will be summarised;
- Where they are known, the Client's intended GI, cable installation and wind turbine installation activities will be outlined. Where such methodologies have not yet been outlined, a variety of prospective options will be presented;
- An assessment of the water depths (in terms of Lowest Astronomical Tide (LAT)) across the Site will be considered in order to assess the prospective UXO detonation consequences;
- The likely UXO risk receptors will be identified;
- A semi-quantitative risk assessment (SQRA) will be undertaken;
- Conclusions will be drawn, and recommendations made, in order to present a viable and cost-efficient risk mitigation strategy, benchmarked with reducing UXO risks to ALARP.

2.2 Information Sources

6 Alpha has employed the following generic sources of information to inform and to compile this report:

- *European Marine Observation and Data Network*;
- *The General Bathymetric Chart of the Oceans*;
- *James Martin Centre for Nonproliferation Studies*;
- *Naval Historical Centre* at *Portsmouth*;

- *Oslo-Paris Convention for the Protection of the North-East Atlantic (OSPAR) databases*;
- *Royal Navy* (Diving Units);
- *Service Hydrographique et Océanographique de la Marine* (SHOM)*;*
- *Theatre History of Operations;*
- *UK National Archives* at *Kew*;
- *UK Hydrographic Office* at *Taunton*.

6 Alpha's "Azimuth" database also contains digitised historic charts, aerial photographs and other extensive analogue records that have also been digitised. That database has been heavily drawn upon to deliver the UXO threat assessment element of this report.

2.3 Constraints and Limitations

This UXO threat and risk assessment is constrained and limited by the information available to *6 Alpha* at the time of writing, as well as that UXO information which 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 require updates and changes, especially wherever and whenever the circumstances and factors associated with assessing UXO risk change. For example, if UXO threats that might be subsequently discovered are different from those that have been anticipated and/or if GI, cable or wind turbine installation methods are significantly changed.

In such circumstances, risks may require re-evaluation and risk mitigation recommendations may need to be subtly altered. Such changes are to be made by *6 Alpha*, in order to ensure the continued technical veracity and risk management efficacy, of this document.

3 Sources of Unexploded Ordnance Contamination

3.1 UXO Hazard Assessment

Significant archive research associated with the Study Site has been undertaken in order to corroborate and to highlight, any and all potential sources of UXO contamination as well as to assess their likelihood of encounter. This assessment is therefore, based upon UXO defined geospatial threat source positions and the anticipated level of contamination from background UXO threats situated upon, and within 5km of, the OWF boundary and its associated export cable corridors. Where it is deemed appropriate, potential UXO threats that are located further than 5km from the Site, have also be considered for analysis. Such potential sources of UXO are summarised in Table 3.1.

Table 3.1: Summary of Potential UXO Sources within 5km of the Site Boundary.

Potential Sources of UXO (within 5km)	Likelihood of UXO Contamination	Associated UXO Threat Items
Aerial Bombing	**Highly Likely:** There is evidence of aerial bombing in both connection corridors.	HE Bombs
Naval Engagements	**Likely:** There is evidence of naval engagements throughout the OWF site and the connection corridors.	Naval Projectiles and Torpedoes
Naval Minefields	**Highly Likely:** There is evidence of considerable mining operations throughout the OWF site and connection corridors.	Naval Mines
Military Practice and Exercise Areas	**Possible:** There are is evidence of historical and modern firing exercise areas intersecting the Study Site.	Naval and AAA Projectiles
Coastal Armaments	**Likely:** The Study Site was located within the firing template of numerous coastal armaments.	AAA Projectiles
Munitions Related Shipwrecks and Aircraft	**Highly Likely:** There is evidence of numerous munitions related shipwrecks within the Study Site.	Shipwreck Related Munitions
Munitions Dumping (within 10km)	**Highly Likely:** One conventional munitions dump was documented within the western connection corridor.	Conventional Dumped Munitions

The core types of UXO threats that have been summarised in Table 3.1 are discussed in detail subsequently and they will be subjected to a risk assessment, based upon the proposed operations that are outlined at Section 4 of this report. Background information detailing generic military ordnance and UXO classification, is presented separately at Annex B.

3.2 Aerial Bombing

Air dropped bombs may be encountered in areas where conflict and/or an air campaign has occurred, although the precise locations of bombing raids and aerial attacks have not always been accurately documented - especially in the offshore environment. Nonetheless, there is evidence to suggest that aerially delivered High Explosive (HE) iron bombs may pose a potential UXO contamination threat at the Study Site.

For example, the landfall points associated with the export cable corridors are located in *Normandy*, a key zone of conflict during WWII. Consequently, at least seven locations, primarily coastal gun emplacements located within 5km of the western landfall area were documented, as having been targeted by *Allied* aerial bombing raids in 1944, the closest of which are gun emplacements at *Barfleur* (located 185m to the south-west). Further supplementary research also indicated that *Le Havre* harbour (located approximately 10km to the south-east), was heavily bombed during WWII with the city itself largely destroyed. It is therefore possible that bomb strikes may have occurred in closer proximity of the eastern export cable corridor, during air raids on the city.

Aerial bombing raids during WWII were not limited to land-based targets however, as shipping in the *English Channel* and near to the coast of *France* was also targeted. An examination of *6 Alpha's Azimuth* database has identified a total of six vessels confirmed as having been sunk by air raids within the eastern export cable corridor. Of these, two were sunk by *Allied* friendly fire, one by *German* aircraft-launched torpedoes, and three by *German* aerial bombing. The sinking of the *French* cargo ship *SS Niobe* on the 11th June 1940 is particularly significant, as it was carrying a consignment of unspecified ammunition at the time of its sinking within the proposed eastern export cable corridor. Further details regarding this and other munitions related shipwrecks within the area, are presented at Section 3.8.

There is also a residual but largely unquantifiable UXO contamination threat, posed at the Study Site by prospective bomb-jettisoning activities associated with nearby *Luftwaffe* airfields. Nearby operational airfields during WWII included *Barfleur* (situated along the western export cable corridor), *Le Havre Octeville* (located 1.1km to the south-east) and *Le Havre* (located 6.0km to the south-east).

As was common at the time, it is plausible that HE bombs were jettisoned at sea by *Luftwaffe* aircraft that were returning to land at these airfields, to ensure that for safety purposes, aircraft did not attempt to land with live bomb loads onboard. HE bombs may also have been jettisoned at sea by *Allied air*craft before or after air raids in the vicinity, in order to lighten their aircraft for the purposes of either evading their adversaries' attacks or, to reduce their aircrafts' weight for their return journeys. Such a threat is, however, almost impossible to quantify without such instances being recorded (and often, such events were either inaccurately recoded or more commonly were not recorded at all).

A geo-referenced summary of the aerial bombing threat at the Site is presented at Appendix 3.

3.3 Operation Overlord

In the summer of 1944, *Allied* forces launched an invasion of *Occupied Europe*, that involved *inter alia,* numerous amphibious landings in northern *France*; this operation was given the codename *Operation Overlord* and is colloquially known as *D-Day*. The operation involved the transport of over two million *Allied* troops over a period from June to August 1944, with the initial amphibious landings taking place in *Normandy*.

The main naval invasion route passed through the OWF area and the western export cable corridor partially overlaps one of the designated *D-Day* landing areas – *Utah Beach*. Prior to the invasion a large minesweeping campaign code-named *Operation Neptune*, was undertaken through the central route, that was code-named *The Spout*, in order to reduce the risk posed by *German* naval mines on the approaches to the landing beaches. A total of 919 mines were recorded as having been safely swept within the *Baie de Seine*. Nonetheless, empirical evidence strongly suggests that such historic clearance has not guaranteed the removal of all mines because, they were situated beyond the minesweepers effective range and/or may have by then, sunk to the bottom of the seabed. Therefore, mines may remain present and as such they may pose a residual or background level of UXO threat in the area. A full assessment of the mine-related UXO threat is presented at section 3.5 of this report.

In addition to the UXO contamination threats generated by the *Allied* forces, that included associated aerial bombing and naval warfare, there is a significant UXO threat in proximity of the landing beaches, especially near *Utah Beach* located at landing point associated with the western export cable. During *D-Day*, amphibious landings were supported both by naval bombardments and aerial bombing against land targets, including those fortifications and coastal artillery batteries comprising the *Atlantikwall*. In addition, heavy artillery fire was encountered by landing craft from *German* artillery positions located along the *Normandy* coastline, including near western export cable corridor near *Utah Beach*. It is therefore highly likely that aerially delivered iron bombs, Anti-Aircraft Artillery (AAA) and coastal artillery projectiles might be encountered in this part of the Study Site, in particular the nearshore sector of the western export cable corridor, as well as *American* and *German* Land Service Ammunition *(*LSA) and Small Arms Ammunition (SAA), associated with military beach landing operations and shoreline battles.

A geo-referenced summary of the key routes and areas associated with *Operation Overlord* are presented at Appendix 4.

3.4 Naval Engagements

The combatant navies of WWI and WWII possessed 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. This means that the nature and the scope of naval engagments that were fought throughout WWI and WWII varied significantly from encounter-to-encounter and was dependant on the types of vessels involved. As with aerial bombardment in the offshore environment, the specific locations of the majority of naval engagements were not commonly nor accurately recorded. Nevertheless, there is clear evidence to suggest that naval engagements occurred within the Study Site during both WWI and WWII.

Such evidence is readily presented by an analysis of *6 Alpha's* in-house *Azimuth* database which indicates that there are eight shipwrecks located within the OWF area, and a further 34 within the export cable corridors, that were sunk during naval engagements in either WWI or WWII. Of the total 42 wrecks within the proposed OWF array and export cable corridors, 34 shipwrecks were sunk by *German* submarine activity during WWI, having been either scuttled by gunfire; or emplaced high explosive charges; or else sunk by torpedoes, suggesting that *Allied* shipping along the *French* coast near to *Normandy* was regularly and repeatedly targeted. Based on the dates of the vessels sinking and the types of submarines in involved, the torpedoes used are likely to be either 45cm C/06 variant or, 50cm G7 variant torpedoes.

Furthermore, five vessels were sunk by torpedoes within the Study Site during WWII – including those launched from submarines and motor torpedo boats. The *German* submarine *U-390* was sunk by depth charges deployed by the *British* destroyer *HMS Wanderer* and the frigate *HMS Tavy*, in the western connection corridor. Finally, two vessels were sunk by naval gun fire during WWII, within the eastern and western connection corridors, respectively. In February 1942, *German* warships undertook a "*Channel Dash*", from the harbour of *Brest* in *Brittany* to *German* ports, with the route taken crossing both connection corridors. Nonetheless, supplementary research indicated that the vessels were not attacked until they had passed further to the east, and a direct UXO contamination threat is not expected to have been posed by their passing.

Nevertheless, WWI and WWII torpedoes may present a UXO contamination threat within the OWF area and export cable corridors. However, the prospective magnitude of this type of threat is reduced somewhat, by the limited operational capacity of most submarines and the rarity of WWI ordnance encounters in the marine environment. A further UXO contamination threat is presented by the various types of naval guns that would have been employed during such engagements, in addition to the armaments and munitions carried by those military vessels that have been sunk within the area.

The geospatial extent of the contamination threat relating to naval engagements is presented at Appendix 5. Further corroborating evidence of the nature and scope of the naval engagements and the shipwreck's that were generated as a result at the Study Site, are presented at Section 3.8.

3.5 Naval Minefields

A naval sea mine is a self-contained high-explosive weapon that is placed in the water in order to destroy ships and/or submarines. All mines were "fused" so that they detonated either upon impact or otherwise upon a close encounter with a ship. During WWI and WWII, naval mines were generally employed either offensively, in order to hamper enemy shipping and to blockade harbours; or defensively, in order to protect shipping and by creating "safe" movement zones through them.

During WWI and WWII, defensive minefields were often 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 mine laying 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 mine lays are difficult to corroborate with certainty. There is evidence to suggest that naval mines may pose a UXO contamination threat at the Site.

3.5.1 WWI Minefields

Two German minefields had intersected the Study Site during WWI, one at each of the eastern and western export cable corridors, near to the coasts. The western minefield comprised a total of 179 mines, whilst the eastern minefield contained 353 mines. It is unclear as to the proportion of these situated within the connection corridors themselves, however. Despite supplementary research, the type of mine(s) deployed within these minefields was not identified but, it is considered highly likely that the vast majority of mines were the *German* E-variety, as they were the standard *German* contact mine employed during WWI.

An analysis of *6 Alpha's Azimuth* database shows that there were also two shipwrecks caused by WWI naval mines within the eastern export cable corridor: with the *SS Galeka* striking a mine on the 28th

October 1916 and the *HMD Comrades* sinking on the 18th October 1917. In addition, a further six shipwrecks resulting from WWI naval mines were recorded within 5km of the eastern export cable corridor, the closest being the armed merchant ship, the *SS Vanellus*, which struck a submarine laid mine 940m to the south-south-west, which corroborates the evidence for *Central Powers* mines having been deployed in the area. Despite this, WWI era naval mines are only encountered approximately once per decade (in the *English Channel)* and therefore, the likelihood of encountering such ordnance is considered and categorised as, “Unlikely”.

The georeferenced location of the recorded WWI minefields and shipwrecks resulting from WWI mines in relation to the Study Site is presented at Appendix 6.

3.5.2 WWII Minefields

Detailed desk-based research of historical records and plans has noted at least 57 mapped WWII minefields that intersected the Study Site at various points - and together comprised more than 1,500 mines. These minelaying operations were of various natures and significance, but they are, collectively, likely to provide multiple and significant contamination threats across much of the OWF and its export cable corridors. The *Allied* minelaying operations consisted of *British* surface craft deploying a range of mines including *British* Marks XV and XVII, in addition to aerially deployed A Marks I-IV and VI, which pose a direct UXO contamination threat in and around the OWF as well as the nearshore areas of both connection corridors.

The *Axis* minefields that intersected the Study Site comprised primarily, of *German* moored mines (of which the main type used during WWII were EMC mines), although the precise designations of mines used were not specified in the historic data. Although the precise extent of mine deployment in the area was also similarly unclear, several types of WWII *German* influence mines have been discovered in the general vicinity of the Study Site in the past decade (as has been detailed at Section 3.10). Consequently, large Net Explosive Quantity (NEQ) *German* naval mines including BM 1000 and Luftmine B (LMB) should be considered as background UXO threats at the Study Site.

In addition, a detailed analysis of related shipwreck data has also identified eight mine-related shipwrecks within the bounds of the export cable corridor that originate from WWII, another five being within 5km of it. This data corroborates the evidence associated with *Allied* and *Axis* mines having been deployed in large quantities in the area and it further suggests that WWII mines may pose a direct and significant UXO contamination threat over large areas of the Study Site. There is also a high quantity of WWII era mine-related shipwrecks concentrated in near the landfall sector of the western export cable corridor, near to the landing areas of *Utah Beach*. In addition, in February 1988, the

French fishing vessel *MFV Minette* lifted a WWII mine in its nets within the proposed OWF area, the mine then exploded, sinking the vessel.

An assessment of the positions of the minefields and mine-related shipwrecks suggests that WWII mines of different varieties are collectively, likely to pose a significant contamination threat across the majority of the Study Site. It is considered much more likely that WWII naval mines will be encountered (by comparison with WWI mines), as they are estimated to be encountered in the marine environment approximately once a month. Given this comparative encounter ratio, and the nature and scope of the evidenced minelaying operations that intersected the proposed OWF and export cable corridor in multiple areas, the probability that WWII-era naval mines have contaminated the area is assessed as "Highly Likely".

The georeferenced location of the recorded WWII minefields and shipwrecks resulting from WWII mines in relation to the Study Site is presented at Appendix 7.

3.6 Military Practice and Exercise Areas (PEXA)

The waters off the *French* coast have been used for much of the 20th and 21st Century by the *French* military to conduct training and weapons systems testing. These activities may employ 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 been left in the marine environment once the training activities have ceased. There is evidence to suggest that these activities have occurred within the wider area including:

3.6.1 Historic Training Areas

Two historic military training areas intersect the export cable corridor, namely firing ranges from the *Crisbecq Battery* and the *Mont Canisy Battery*. The latter artillery battery was constructed by the *French* military in 1935 and later occupied as part of the *German Atlantikwall* fortifications, whilst the former was constructed by the *German* military in 1941. Several different types of guns were employed at the two firing ranges, including 75mm, 138mm and 210mm cannon. Consequently, it is considered likely that historic AAA projectiles might contribute to the UXO contamination threat, within the bounds of their arcs of fire.

Furthermore, it is quite possible that naval vessels - across the entire bay - and/or coastal artillery batteries at either landfall area, may have fired their weapons systems for validation and/or range finding purposes, and that such events are unlikely to have been recorded. Nonetheless, the likelihood of contamination from this source is considered to be remote and it constitutes a background threat.

The georeferenced location of these historic training areas in relation to the Study Site is presented at Appendix 8.

3.6.2 Modern Military Practice and Exercise Area (PEXA)

One *French* military PEXA intersects much of the eastern connection corridor and is designated as *D82 Baie de Seine*. This area is used by the *Marine nationale* for a variety of practice exercises, including refuelling at sea, tactical manoeuvres and firing exercises. Nonetheless, it is unspecified as to whether live ordnance is or has been used during such naval training and so, modern naval projectiles might be considered as part of the background UXO contamination threat.

The *Baie de Seine* has also previously been used for several *French* minesweeping operations in the shipping channels approaching the ports of *Normandy* and partially intersecting the western connection corridor. Although this minesweeping area overlaps known areas of wartime minefields (as discussed in Section 3.3 of this report), empirical evidence strongly suggests that such historic clearance has not guaranteed the removal of all mines, because they have either been situated beyond the minesweepers effective range and/or, may have sunk to the bottom of the seabed. Therefore, they potentially present as a residual UXO threat in the area.

The georeferenced location of these modern military PEXA in relation to the Study Site is presented at Appendix 9.

3.7 Coastal Armaments

Along the *North Sea* and *North Atlantic* coastline of occupied *Europe*, the German Organisation *Todt*, undertook the construction of thousands of permanent defensive positions facing the sea, that collectively formed the *"Atlantikwall"* – which consisted of concrete bunkers, machine gun positions, military fortifications, and AAA positions (amongst other things). Though the *Atlantikwall* was unfinished by the time of the *Allied* invasion of *Europe,* many of these defensive positions were armed and were fully operational. A total of more than 200 defensive positions related to the *Atlantikwall* were located close to the export cable corridor landfall areas*,* although it is possible that some of the features identified were constructed by the *French* military and simply repurposed by the occupying *German* forces. There is therefore, very likely to be a residual threat posed by LSA and SAA from the probable stationing of troops at some, if not all of these locations.

Nevertheless, the major source of prospective contamination is likely to be posed by AAA projectiles associated with the AAA deployed in this area. Supplementary research also suggests that the majority of the AAA guns were of either 5cm, 8.8cm or 15.5cm calibre, and whilst some larger calibre guns may also have been deployed alongside small calibre AAA and machine guns, and they would almost certainly have been fired in order to defend against *Allied* air raids and landing ships during *Operation Overlord*. The likelihood of AAA contamination from these guns is also considered and classified as “Likely”, up to approximately 29km from the landfall areas (based on the maximum firing ranges of the coastal armaments then in the area). The threat posed by AAA fire is further evidenced by shipwreck data for the area, with the destroyer *USS Glennon* sunk by coastal artillery fire during *Operation Overlord* on the 10th June 1944, located within the western export cable corridor.

A geo-referenced summary of all recorded coastal armaments at the *Atlantikwall* that had a firing range encompassing the Site, is presented at Appendix 10.

3.8 Munitions Related Shipwrecks and Aircraft

Merchant and naval vessels that were sunk in WWI and WWII may have contained munitions - either as armament and/or cargo. The extent of UXO contamination may vary, depending upon the nature and integrity of the wreck. Wreck investigations have found that munitions can spill from ships as they sink and break up, otherwise their ordnance may be sealed within their holds and remain immobile. Similarly, military aircraft that were shot down or otherwise had to ditch into the sea, may have also carried munitions.

It is unlikely that any ship would have been sunk in the first exchange of fire due to the relative inaccuracy of WWI and WWII era weapons and it is likely that many bombs, projectiles, and torpedoes missed their targets. 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. There may, therefore, also be UXO (in the form of iron bombs and/or gun projectiles) situated in the regions of those wrecks that may have been sunk by such exchanges of fire.

Table 3.8 presents a summary of the quantity of shipwrecks with a munitions related history that are located within 5km of the Site together with their cause of sinking.

Table 3.8: Munitions related shipwrecks within 5km of the Site.

Distance from Site	Cause of Sinking					Total
	Air Raid	Mined	Naval Skirmish	Coastal Artillery	Other	
On-Site	6	11	42	1	1	61
<500m	0	2	2	1	0	5
500m - 1km	0	1	3	0	1	5
1km – 2km	0	1	5	0	0	6
2km – 5km	1	6	8	0	2	17

An analysis of the data presented in Table 3.8 and together with corroborative evidence gathered from *6 Alpha's Azimuth* UXO database, highlights the scale of historical warfighting activities within the OWF and its export cable corridor, which may have led to a UXO contamination threat, evidenced by not less than 61 munitions related shipwrecks documented within its boundaries. A further 33 munitions related shipwrecks were also recorded within 5km of the export cable corridor. Generally, the closer the munitions related shipwreck to the Study Site, the more likely a UXO contamination threat is to have been generated within it.

The majority of the munitions related shipwrecks within the Study Site can be traced to naval engagements occurring within WWI, particularly the actions of *German* submarines in torpedoing and scuttling *Allied* merchant vessels off the coast of *Normandy*. Nonetheless, a considerable number of shipwrecks date from WWII, including those sunk by aerial bombing, coastal artillery, during naval engagements and significantly, to naval mines.

Several vessels sunk within the Study Site are highly likely to have carried military munitions of their own which, following their sinking, would likely remain either within the body of the shipwreck or else on the seabed in close proximity to it. Nonetheless, any shipwrecks or aircraft identified within the Study Site, regardless of their munitions related history are nevertheless, to be treated with caution and may anyway be the subject of routine avoidance.

A georeferenced summary of the proximity of all 94 munitions-related shipwrecks located within 5km of the Site is presented at Appendix 11.

3.9 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 both World Wars. As a cost effective and military expedient, conventional and chemical munitions were often dumped offshore or into suitable bodies of water inland, such as lakes.

Whilst the centre of mass of such dumpsites were 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 dumped 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 international naval and admiralty charts and marine environment protection agency databases has identified one conventional munitions dump within the western export cable corridor, near to *Saint Vaast La Hougue*. The exact types of conventional munitions dumped at this location is not known however and therefore, it is not possible to assess the specific type of UXO that may be encountered.

The georeferenced locations of nearby recorded munitions dumps are presented at Appendix 12.

3.10 Previous UXO Encounters

An analysis of the OSPAR database, combined with further supplementary research, indicates that munitions have been encountered within the wider area and likely within the Study Site itself, namely:

- On the 21st February 1988, the *French* fishing vessel *MFV Minette* lifted a WWII mine in its nets within the proposed OWF area, the mine subsequently exploded, sinking the vessel;
- In March 2009, the minehunter vessel *Percée* discovered and neutralised a *German* LMB mine found 2.2km off the coast near *Saint Vaast la Hougue* (likely within the western connection corridor);
- In September 2012, a fisherman found a 90mm unexploded shell on the beach near *Saint Vaast la Hougue* (likely along the western export cable corridor), which was subsequently destroyed by the *French* navy;
- In December 2013, amateur divers discovered six unexploded artillery shells approximately 5km off the coast of *Saint Vaast la Hougue* (likely along the western export cable corridor), which were subsequently destroyed in situ;

- In July 2013, one 15.5cm artillery shell was neutralised at *Cauville-sur-Mer* (located approximately 700m to the south-east of the eastern export cable corridor);
- In October 2009, one 250lb HE bomb was discovered and removed from *Octeville-sur-Mer* (located approximately 1.5km to the south-east of the eastern export cable corridor);
- In November 2010, an anti-tank mine and two artillery shells were discovered at *Tilluel Beach* (located approximately 2.5km to the north-east of the eastern export cable corridor);
- In May 2010, one 15cm artillery shell was discovered at *Mont Gaillard, Octeville-sur-Mer* (located approximately 3.1km to the south-east of the eastern export cable corridor);
- In November 2010, one *American* 250lb HE bomb was discovered on the beach near *Saint-Martin-de-Varreville* (located approximately 3.2km to the south-east of the western export cable corridor);
- In May 2010, two 8cm artillery shells were discovered on the beach at *Néville-sur-Mer* (located approximately 4.3km to the west of the western export cable corridor);
- The relocation and destruction of a *German* LMB mine on the 30th August 2014 by the *French* naval minehunter *Croix du Sud* in the *Baie de Seine*, after it had been encountered by a fishing trawler. Given its precise location was not documented, it is possible that the mine was encountered in close proximity of the OWF area or the adjacent export cable corridors;
- On the 20th and 21st April 2020, the *French* minehunter *La Cassiopée* countermined and destroyed one 250lb *US* HE bomb and one *German* BM 1000 naval mine. Both of these items were encountered near *Le Havre*, potentially in the vicinity of the eastern export cable corridor.

Such encounters serve to highlight the longevity of the threat that might be posed by UXO in the marine environment in general. And further information on *inter alia*, the longevity of the UXO threat in the marine environment is included at Annex C.

3.11 UXO Threats – Summary

Based upon the threat assessment the following items, complete with their measurements, estimated ferrous mass, and expected NEQ based on equivalent Trinitrotoluene (TNT) masses, are considered to pose a specific UXO threat at the Site:

3.11.1 Aerial Bombs

Designation	Body Length x Diameter	Ferrous Mass	NEQ
American AN-M66 HE Bomb	1,778mm x 592mm	448kg	507kg
American AN-M65 HE Bomb	1,349mm x 478mm	196kg	253kg
German SC-500 HE Bomb	1,417/1485mm x 457mm	280kg	220kg
German SC-250 HE Bomb	1,486mm x 503mm	126kg	130kg
American AN-M64 HE Bomb	1,143mm x 361mm	127kg	121kg
British 500lb GP Bomb	925/945mm x 328mm	148kg	65.5kg
American AN-M57 HE Bomb	914mm x 277mm	59kg	59kg
British 250lb GP Bomb	650/701mm x 259mm	82kg	30kg
American AN-M30 HE Bomb	737mm x 208mm	26kg	26kg
German SC-50 HE Bomb	765/671mm x 203mm	23/30kg	25kg

3.11.2 Naval Mines

Designation	Length x Diameter	Ferrous Mass	NEQ
German BM 1000 Mine	31213mm x 660mm	261kg	943.5kg
German LMB Mine	2,640mm x 660mm	>10kg	916.5kg
British A Mark VI Mine	2,280mm x 470mm	453kg	454kg
German LMA Mine	1,730mm x 660mm	>10kg	390kg
German EMC Mine	1,232mm x 1,168mm	331kg	389.2kg
British A Mark I-IV Mine	2,280mm x 470mm	340kg	340kg
British Mark XV/XVII Mine	1,219mm x 1,020mm	68kg	227kg
German E-Mine	1168mm x 864mm	208kg	165kg

3.11.3 Torpedoes

Designation	Length x Diameter	Ferrous Mass	NEQ
German 53.3cm G7a Torpedo	7,200mm x 533mm	1,248kg	366kg
British 21" Mark VIII Torpedo	6,604mm x 533mm	1,239kg	327kg
German 50cm G7 Torpedo	7,000mm x 500mm	1,170kg	253.5kg
German 45cm C/06 Torpedo	5,689mm x 450mm	751kg	122.6kg

3.11.4 Artillery Projectiles and LSA

Designation	Body Length x Diameter	Ferrous Mass	NEQ
German 21cm Artillery Projectile	748/905mm x 210mm	98-120kg	21.7kg
American 5" Artillery Projectile	527mm x 127mm	22kg	5.44kg
German 15.5cm Artillery Projectile	580mm x 155mm	41kg	4.16kg
French 138.6mm Artillery Projectile	587mm x 139mm	29kg	2.66kg
German 10.5cm Artillery Projectile	391/489mm x 105mm	13kg	1.845kg
German 8cm Heavy Mortar	325mm x 81mm	3kg	0.533kg
American 3" Artillery Projectile	308mm x 76mm	5.6kg	0.34kg
German 5cm Artillery Projectile	165/208mm x 50mm	2.1kg	0.17kg
Allied 40mm Artillery Projectile	184mm x 40mm	0.83kg	0.068kg

A geo-referenced chart depicting the range of UXO contamination sources across the Study Site is presented at Appendix 13.

4 UXO Risk Pathways - Planned Site Operations

The Client has informed *6 Alpha* that a variety of GI works (undermentioned), are likely to be undertaken at the Site. These planned works are summarised to evidence the potential UXO risk pathways that may be generated, should such works encounter the threat spectrum UXO - as identified in Section 3. The proposed scope of works associated with cable installation and wind turbine installation has yet to be confirmed and therefore, *6 Alpha* have presented a range of typical methodologies that might be employed.

4.1 Geotechnical Investigation (GI)

The Client has stated that the following GI works are planned in advance of cable installation and wind turbine installation operations are expected to be carried out across the Study Area; and significantly, some of them in shallow waters (<5m). In general, a risk pathway may be generated if there is direct contact between the leading edge of the GI equipment and an item of UXO. The following methodologies are expected to be employed as part of the GI campaign:

4.1.1 Boreholing

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 UXO.

4.1.2 Cone Pentration Testing (CPT)

CPT measures the resistance to penetration of the seabed, using a steel rod with a conical tip. This methodology also employs kinetic energy to invasively penetrate the seabed and therefore, it is possible that if the CPT tool comes into direct contact with an item of UXO, that the kinetic energy generated may be enough to cause its initiation.

4.1.3 Vibrocoring

Vibrocoring employs the force of gravity, combined with kinetic energy (supplied by a vibrating head), to drive a core into the seabed in order to collect samples from the sub-strata sediments. 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 tool comes into direct contact with it.

4.2 Pre-Lay Operations

Pre-Lay Grapnel Run (PLGR) and Route Clearance (RC) will likely be employed to ensure that the cable route is clear of *inter alia*, disused communication cables and other seabed debris, that 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 along the designated cable Route Position List (RPL). Such operations may encounter and initiate UXO that is either very shallow buried or, that is located on the surface of the seabed. 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 circumstances 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 and obstructions generated by wrecks.

It is possible that pre-lay operations could cause a UXO detonation event, if pre-lay equipment comes into direct contact with it.

4.3 Cable Installation

An overview of potential cable installation methodologies is described briefly below, in order to inform subsequently the risks that UXO might pose to such techniques. The methodologies described below are not exhaustive, nor are they specific to this project however, they serve to illustrate the risks associated with a variety of commonly employed cable installation and burial methodologies.

4.3.1 Surface Laid Cable

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

The kinetic energy associated with surface laying the cable, subject to amongst other factors the mass of the cable per liner meter, the water depth and rate of lay, might be sufficient to initiate UXO - especially if the cable makes direct contact with it. Even if the cable lay energy is considered insufficient to initiate UXO (because e.g., 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 (PLIB) is likely to be both compromised and/or jeopardised.

4.3.2 Jetting

Where soft seabed conditions are encountered, jetting seabed sediments can be employed to bury cables either concurrently or in a sperate operation once it has been laid on the surface of the seabed. Jetting fluidises 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 (as compared with e.g., mechanical cutting) and it 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 its high-pressure water jetting system.

4.3.3 Ploughing

Displacement ploughs create an open V-shaped trench into which the cable can be concurrently laid. This process causes significant disturbance to the seabed as the trench can be up to 3m wide, whilst the plough can have a skid footprint of up to 10m. The open trench can be then backfilled using blades mounted to the rear of the plough, thus burying 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 causes comparatively low disturbance to the seabed in comparison to displacement ploughing and creates a narrow trench (usually between 0.3m and 1.0m wide). The trench in such circumstances, 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.

4.3.4 Open Cut Trenching

Open cut trenching is typically utilised to bury and thus protect the cable, at the cable landing point onshore. Trenching can be undertaken by a terrestrial-based excavator during low tide and during these operations, a transition or joint-pit may also be excavated.

There are several risk factors to consider for trenching and excavation operations; firstly, the mass of the excavator bucket and is operating velocity may be sufficient to initiate any UXO that might be encountered directly and/or indirectly, if it is in close very close proximity. Second, the excavated material is expected be used to back-fill the trench once the cable has been emplaced within it. If the excavated material is contaminated with UXO, the back-filling operation may also present a risk pathway in that UXO might then be inadvertently initiated.

Nonetheless, the risks that might be presented on “land” (defined for the purposes of this report, as above the high-water mark), are beyond the scope of this document. *6 Alpha* can consider the risks associated with trenching and excavation operations separately, together with those that might otherwise be presented at the landing point, in line with CIRIA guidance for UXO in the onshore environment – which differs from the guidance for offshore cable installation projects.

4.4 Cable Protection and Crossing Operations

Where offshore cable burial is not possible and also where existing cables or pipelines are crossed, some form of surface cable protection is likely to be required. Options that might be considered include but are not limited to the following:

4.4.1 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 split-piping may be applied to the cable itself. A UXO risk pathway may be generated by the emplacement of rock (or rock-bags), alongside and over the cable, although the probability of an inadvertent UXO detonation is dependent upon the resultant kinetic energy generated by the emplacement of the rock/rock-bags, and the juxtaposition, sensitivity and NEQ, of such UXO.

The potential risks may reduce if direct contact with UXO is avoided. And where there is potential UXO (pUXO) in close proximity, then the rocks/rock bags are not only to deployed in a controlled fashion and as slowly as is practicable (because the resultant kinetic energy generated is reduced), but also, that minimum safety avoidance distances are adhered to.

4.4.2 Third Party and Out-of-Service Cables

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, or in very close proximity to UXO. Nonetheless, this does not mean that UXO will not be encountered anywhere within the export cable corridors, nor the OWF area and therefore a risk pathway may still be generated depending on the precise methodology employed to install the cable in areas where third-party or out-of-service cables are located.

4.5 Wind Turbine Installation Operations

The following piling techniques have been considered for WTG foundation and offshore platform installation:

4.5.1 Monopile Support Structures

A monopile support structure is employed where the tower of the wind turbine is supported 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 typical method of WTG foundation installation involves driving the piles into the seabed using large-impact hammers powered by either steam or hydraulics, often from by a jack-up barge. As this method involves significant kinetic energy as the piles are driven into the seabed, any UXO encountered directly is almost certain to be initiated, with any in the immediate vicinity 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 sediments, strong enough to make the structure self-supporting. The probability of UXO encounter remains largely the same as with using a large-impact hammer due to the intense, invasive force exerted upon the seabed.

4.5.2 Jacket Support Structures

Alternatively, the use of jacket support structures is commonly considered for offshore converter platform 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 will be emplaced with less force. 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.

4.5.3 Scour Protection Systems

It is expected that the wind turbine foundations may require some form of anti-scour protection, which is usually provided in the form of either static or dynamic rock armour which is emplaced after the installation operations are complete. The type and extent of anti-scour protection depends upon the soil and seabed conditions as well as the type of foundations employed.

If rock or scour protection systems are employed, the UXO risk is dependent upon the resultant kinetic energy generated during their installation, which may be considered sufficient to initiate a variety of different types of UXO.

4.6 Enabling Operations

The following methodologies may be employed to facilitate the planned GI works and/or cable installation and wind turbine installation operations:

4.6.1 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 the computer pertaining to the vessel's position and the magnitude and direction of environmental forces affecting its position. DP vessels are commonly used to support a wide variety of sub-seabed operations, such as foundation and cable installation.

If the DP vessel has no contact with the seabed (because it is not anchored and will not ground) then a prospective encounter with UXO from such a work platform presents no UXO pathway and thus no risk.

4.6.2 Anchoring

In the nearshore environment it is possible that other types of vessels, including anchor-handling tugboats (AHT), will be deployed to support the proposed operations. There is a risk that anchors could initiate UXO if they were to come into direct contact with it, as they are positioned and especially emplaced. However, the deployment and post-tensioning of anchor catenaries are considered much 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 will generally sweep the surface of the seabed); cable contact with UXO is likely to be linear (i.e., along the cable/UXO length rather than as a “point” force) which is considered less aggressive.

4.6.3 Jack-Up Barges

A jack-up barge is a type of mobile platform that consists of a buoyant hull fitted with a number of movable legs, capable of raising its hull over the surface of the sea, thus affording a stable work platform for *inter alia*, the installation of WTG foundations. 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), 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/or may be fitted with enlarged sections or footings. Generally, jack-up barges are not self-propelled and rely on AHT for propulsion and positioning. If the jack-up barge leg or its anchor (deployed by an AHT) encountered UXO, then a risk pathway might be generated.

4.6.4 Diving Operations

There is no indication that divers are currently being considered to assist or undertake GI, or installation operations.

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 should not be deployed where there is a risk of occurrence of such a detonation event.

If diver operations change and divers are to be used, then the risks associated with diving operations must be reassessed by *6 Alpha*.

5 Study Site Characterisation

5.1 Local Sea Bed 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 GI, cable installation and wind turbine installation operations.

5.1.1 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 the prospective receptors and the UXO buried in, or lying upon, the surface of the seabed.

The water depths reported in the *Baie de Seine*, within the bounds of the connection corridors, range from landfall (i.e., 0m LAT) up to approximately 60m LAT. Within the OWF area itself, the water depths range from approximately 30m to 50m LAT. Due to the relatively shallow water depths throughout much of the Study Site the consequences of a potential UXO initiation are unlikely to be significantly mitigated by such water depths across the Site.

5.1.2 Seabed Sediments and Shallow Soils

The nature of local seabed sediments and shallow soils also need to be considered to determine the prospect for UXB burial upon initial deployment and/or subsequently. UXO scouring and/or migration may also be influenced by the seabed sediments at the Study Site.

Although shallow soil and seabed sediment information for the Study Site has not yet been collected, an analysis of *European Marine Observation and Data Network* data records coarse substrate sediments, within the majority of the Study Site. At both export cable corridors, the seabed sediments comprise principally of sand in the nearshore environment together with areas of muddy sand. Gravel and mud are less likely to form a mobile seabed than one comprising solely of sandy sediments, but it is still possible that UXO may have become shallow buried (after its initial deployment and having come to rest upon the surface of the seabed), by mobile seabed sediment particularly within sandy areas.

5.2 UXO Burial and Munitions Migration

5.2.1 Initial Burial

Historically, studies of typical bomb penetration depths have been undertaken for the terrestrial environment based on, *inter alia*, the soil type and strength, bomb type, size and mass and the angle/speed of initial impact. Such studies are not directly applicable in the offshore environment, given the mitigative effects of water (e.g. in slowing and reducing the impact of munitions on the seabed). Nonetheless and in general, UXO penetration into the seabed of greater than 2m is considered highly unlikely in water depths of more than 20m, with initial impact burial in deeper water considered highly unlikely. As with the case of impact burial of UXO on land, only those munitions travelling at a high terminal velocity at the point of impact (e.g. aerially delivered iron bombs and gun launched projectiles) have the potential to penetrate the seabed.

5.2.2 Munitions Migration

If geophysical UXO survey data is more than a year old from its date of capture, in order to assess whether munitions migration is a potential factor anywhere within the Study Site, then a Munitions Migrations and Burial Assessment (MMBA) might be considered beneficial, because it will extend the longevity of any 6 Alpha delivered ALARP safety sign-off certification by at least another year. MMBA is a highly specific tactical-level assessment that models the potential for UXO migration along the connection corridors and OWF area, based on detailed information such as the local seabed characteristics (e.g. the seabed sediments, current direction, strength and tide conditions).

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

6 UXO Risk Assessment

6.1 Overarching Methdology

The SQRA (which has been undertaken and is presented at Appendix 14), is specifically designed to assess the probability of an unplanned discovery and initiation of UXO, as well as its prospective consequences upon potential sensitive receptors (e.g. installation vessels and any associated underwater equipment), in order to determine the level of UXO risk for GI, cable installation and wind turbine installation methodology. This assessment is achieved by employing the following formula: Risk **(R)** = Probability **(P)** x Consequence **(C)**. The core elements of this formula are further described at paragraph 6.3.

It is also important to note that the risk assessment for the project has been conducted for all types of operations, irrespective of the prospective risk mitigative effect of any prior operations which by then, may have preceded them.

However, the assessment not only evaluates the level of UXO risks generated but also highlights the effect of the recommended risk mitigation measures - benchmarked with reducing risks ALARP. A full explanation of *6 Alpha's* SQRA process is presented at Annex E.

6.2 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 of initiation is therefore steered by the precautionary principle that, for risk assessment and mitigation purposes, informs risk-mitigating actions in such circumstances.

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.

6.3 Risk Assessment Variables

The UXO risk level at the Study Site has been determined by calculating of the following factors:

6.3.1 Probability

Probability is determined by considering the likelihood of both encountering and initiating UXO.

The probability of encountering UXO is a function of the prospective nature and scope of UXO contamination sources within the Site (which have been evidenced separately at Section 3) and the juxtaposition of any and all sub seabed, intrusive activities with respect to any UXO that might be present within the Site. Nonetheless, the numbers, extent and locations of all prospective UXO threats are difficult to accurately quantify due to the lack of detailed historical records associated with depositional events (such as, and especially; unrecorded and abandoned ordnance; or AAA fire; or jettisoned aerial HE bombs that cannot be spatially defined with either certainty or accuracy). Such uncertainty is accounted for by employing the precautionary principle (and see paragraph 6.2).

The likelihood of initiating underwater UXO is generally, but not exclusively, dependent upon kinetic energy; therefore, the planned operations that might generate it have been considered within Section 4, in order to determine if the kinetic energy associated with such activities might generate a viable UXO risk pathway.

6.3.2 Consequence

The consequences of an unplanned UXO initiation are a function of the mass of high explosives in the UXO and their proximity to and robustness of sensitive receptors - including the support vessels, their crews as well as ground investigation, cable installation and wind turbine installation equipment/tools.

The mass of high explosives and their underwater and/or surface effects can generally be either estimated or accurately modelled. Other assessment factors include but are not limited to; the prospective position of the UXO on the seabed at the moment of encounter (i.e., on the surface or partially/completely 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 robustness of such receptors.

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 capacity to withstand such a high-explosive event in particular. Generally, personnel are very vulnerable to high explosive fragmentation, as well as underwater shock and surface-blast. As long as people are not jeopardised, limited adverse effects upon vessels, barges and GI, cable installation and/or wind turbine installation equipment, might be tolerated.

Further detailed information, detailing both the effects of high explosive detonation events in the marine environment and the way in which these are modelled by *6 Alpha*, is included at Annex F.

6.4 Risk Assessment Key Findings

The findings of the risk assessment are presented at Table 6.4:

Table 6.4: Representative UXO Risk Assessment Summary

Intrusive Operation	UXO	UXO Risk (10m WD)	UXO Risk (26m WD)	UXO Risk (40m WD)
Geotechnical Investigation	Aerial Bombs	HIGH	HIGH	MEDIUM
	Naval Mines	HIGH	HIGH	MEDIUM
	Projectiles	MEDIUM	LOW	LOW
Pre-Lay Operations	Aerial Bombs	VERY HIGH	VERY HIGH	HIGH
	Naval Mines	VERY HIGH	VERY HIGH	HIGH
	Projectiles	HIGH	MEDIUM	LOW
Cable Installation and Burial	Aerial Bombs	VERY HIGH	VERY HIGH	VERY HIGH
	Naval Mines	VERY HIGH	VERY HIGH	HIGH
	Projectiles	HIGH	MEDIUM	LOW
Wind Turbine Installation	Aerial Bombs	HIGH	HIGH	HIGH
	Naval Mines	HIGH	HIGH	HIGH
	Projectiles	HIGH	MEDIUM	LOW
Protection Operations	Aerial Bombs	HIGH	HIGH	HIGH
	Naval Mines	HIGH	HIGH	HIGH
	Projectiles	HIGH	MEDIUM	LOW
Enabling Operations	Aerial Bombs	HIGH	HIGH	HIGH
	Naval Mines	HIGH	HIGH	HIGH
	Projectiles	HIGH	MEDIUM	LOW

The unexpurgated SQRA has been included at Appendix 14, which presents the complete risk assessment for each individual seabed intrusive activity and UXO threat group.

In addition, Table 6.4 is intended as an indicative summary. Torpedoes were not included for presentation purposes based on the fact that they were assessed to pose MEDIUM UXO risks at most and do not require bespoke mitigation as such (e.g. associated risk can be mitigated when mitigating more significant UXO risks from HE bombs and naval mines).

6.4.1 GI Operations

GI operations (including bore holing, CPT and vibro coring) are considered less likely to directly encounter UXO contamination threats (benchmarked with other activities), given the spatial extent of the methodologies employed and the likely disturbance of the seabed. GI operations are considered a HIGH UXO risk in general, although this risk is reduced to MEDIUM in deeper waters (>26m), due partially to the concentration and scope of the UXO contamination threats across the Study Site and the amelioration effect of the deep water, upon a high explosive UXO detonation event.

6.4.2 Pre-Lay Operations

Any PLGR and/or RC operations that are undertaken along the export cable corridor routes and in advance of cable installation, is likely to generate significant UXO risks. This is because PLGR is considered quite likely to encounter UXO contamination as it covers a significant linear extent, and the grapnels have prolonged contact with the seabed. Therefore, unmitigated UXO risks associated with pre-lay operations are considered to pose VERY HIGH UXO risks across the extent of the Study Site in general and in areas associated with WWII mine deployment and aerial bombing in particular.

6.4.3 Cable Installation and Burial Operations

The surface lay and subsequent burial of the cables are likely to generate different categories of UXO risks owing to the amount of seabed interaction involved with the various installation and burial methodologies under consideration.

Where cables are laid on the surface of the seabed and they are not subsequently buried, then the UXO risk is assessed as HIGH, although this risk may be reduced to MEDIUM in deeper waters (>26m) – assuming that the cable will be lowered onto the seabed in a controlled fashion.

Where either jetting or ploughing are employed, then the UXO risk is assessed as being VERY HIGH due to the comparatively large footprint of such installation tools (especially a subsea cable plough) and the significant forces exerted by the tools into the seabed, in order to bury the cable.

6.4.4 Wind Turbine Installation Operations

The installation of wind turbine foundations is assessed to pose HIGH UXO risks in all water depths. This is because the common installation methodologies employ significant levels of kinetic energy to drive monopiles into the seabed. Any UXO encountered directly or in their close proximity is highly likely to be initiated.

6.4.5 Protection Operations

The emplacement of rock to protect unburied cables or to prevent scour at wind turbine foundations may also generate HIGH UXO risks. Dumping rock either over the side of a rock dumping support vessel or through a pipe-fall system, may result in significant kinetic energy being transferred (in comparison with a more controlled method), which may cause a UXO initiation event should the rock come into direct contact with it or if rocks impact the seabed in its close proximity.

6.4.6 Enabling Operations

Anchoring is considered unlikely to directly encounter UXO, given the spatial extent of the work and the likely point-disturbance of the seabed. Nonetheless, anchoring is considered a HIGH UXO risk, although this is reduced to MEDIUM in deeper waters (>26m), due partially to the concentration and scope of the UXO contamination threats across the Study Site and the amelioration effect of the deep water upon a high explosive UXO detonation event.

Jack-up barge operations also pose a HIGH UXO risk in all water jack-up operational depths, as a result of the kinetic energy and penetration of the seabed, associated with the deployment of their legs.

6.4.7 Surface Vessels and Personnel

Although there is evidence to suggest that a UXO encounter could occur across significant swaths of the OWF area and its export cable corridors, such an encounter is generally considered a low probability-high consequence event. Therefore, the consequences of exposing the vessel and its crew to the kind of peak pressure associated with an underwater initiation of an indicative selection of high, medium and low NEQ threat spectrum UXO has been modelled and is presented separately at Table 6.4.7.

Table 6.4.7: Consequences of UXO Initiation

UXO	Estimated Ferrous Mass	NEQ	Consequence at 10m	Consequence at 26m	Consequence at 40m
BM 1000 Mine	261kg	943.5kg	Vessel Sinking / Fatalities	Vessel Sinking / Fatalities	Serious Structural Damage / Fatalities
Mark XV/XVII Mine	68kg	227kg	Vessel Sinking / Fatalities	Vessel Sinking / Fatalities	Mechanism Damage / Minor Injuries
SC-50 HE Bomb	30kg	25kg	Vessel Sinking / Fatalities	Minor Damage	Minor Damage
15.5cm Projectile	40kg	3.9kg	Mechanism Damage / Light Injury	Minor Damage	Minor Damage

Table 6.4.7 has been compiled using 6 Alpha's in-house shockwave calculator, which is based on a variety of open source academic and military studies concerning military ordnance detonations underwater, the peak pressure generated, and the effects of pressure (MPa) on vessels and indirectly, their crews. Although the probability of initiating UXO varies between the types of GI and installation operations, the consequences of an initiation of each type of UXO in the table is not driven by how that initiation event was caused. Therefore, the table remains applicable to GI as well as installation operations. The calculations made within Table 6.4.7 are also employed within the SQRA (at Appendix 14) in order to assess and grade potential UXO detonation consequences based upon the peak pressure exposure of the vessel and its crews. Further explanation of the methodology for calculating UXO detonation consequences is presented at Annex E.

6.4.8 Underwater Equipment

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

6.4.9 Vessel and Diver Safety Distances

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 shock wave and to a reduced extent, 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 capacity of vessels in general and divers in particular, has been carefully calculated from a number of open-source research publications.

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

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

Using this formula, Table 6.4.9 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 its crew(s) become intolerable (e.g. where injuries are sustained from exposure to above 4MPa of peak pressure). In addition, the table also summarises the minimum safety distance for divers should they be employed (these distances have been calculated by 6 Alpha’s UXO experts).

Table 6.4.9: Underwater Explosion Consequences

UXO Type	UXO NEQ	TARA Consequence Score Peak Pressure Exposure (MPa) and Vessel Safety Distance		Swimmers and Divers Safety Distance
		1 **0.4 – 2 (MPa)**	**2** **2 – 4 (MPa)**	Burst on seabed with diver on seabed
BM 1000 Mine	943.5	611m	87m	2,086m
SC-50 HE Bomb	25kg	182m	26m	1,085m
15.5cm Projectile	3.9kg	99m	14m	777m

For the consequences of an initiation of high NEQ UXO to be considered negligible, in terms of its effects upon the vessel and its crew, the minimum stand-off distance must be not less than 611m (this is reduced to 182m and 99m for medium and low NEQ items, respectively). The exposure of the vessel and its crew to intolerable and dangerous high-explosive effects at 87m if a large NEQ UXO is initiated. If the vessel(s) and its crew(s) are exposed to 4MPa pressure, the likely effects are damage to electronics, minor injuries sustained by crew members and partial loss of vessel steering and control. Vessel damage becomes more severe as the peak pressure exposure increases, with fatalities very likely to be caused at 8MPa pressure.

Divers are highly vulnerable if they are exposed to the kind of underwater shock generated by UXO initiation. As Table 6.4.9 evidences, divers are required to be between 777m and 2,086m from the seat of a seabed initiation of threat spectrum UXO to be considered safe, which further reinforces the risks involved with deploying divers during subsea bed operations where UXO contamination might be expected.

6.5 UXO Risk Zones

6 Alpha have zoned the whole of the study area according to the level of risk generated by a variety of sub seabed activities and sources of UXO. UXO risk have therefore been zoned on the basis of one or a combination of the following factors:

- The nature and scope of sub seabed activities and the distances from pertinent UXO threat sources;
- The varying water depths (LAT) throughout the OWF area and connection corridors;
- The project stakeholder's appetite for the carriage of residual UXO risks.

Given the distribution of UXO threat sources (identified in Section 3) and their various NEQ, juxtaposed with the expected water depths, it is possible to split the Study Site into UXO risk zones at a high level, as presented at Figure 5 and Appendix 15.

VERY HIGH UXO risks have been evidenced in the nearshore sectors associated with both export cable corridors, based upon *inter alia* but not limited to; the historical evidence of military activities, munitions dumping, naval mining and aerial bombing; in conjunction with the relatively shallow water depths in certain areas.

Furthermore, HIGH UXO risks are posed in significant swaths of the site and around the OWF area itself as well as much of the eastern export cable corridor. Such risks are primarily driven by WWII-era naval mines and large NEQ HE bombs.

The remainder of the Study Site presents MEDIUM UXO risks where a combination of deeper water depth and the absence of evidence to suggest large NEQ UXO items may be present, which reduces the overall level of risk.

The UXO risk zones are presented at Figure 5.

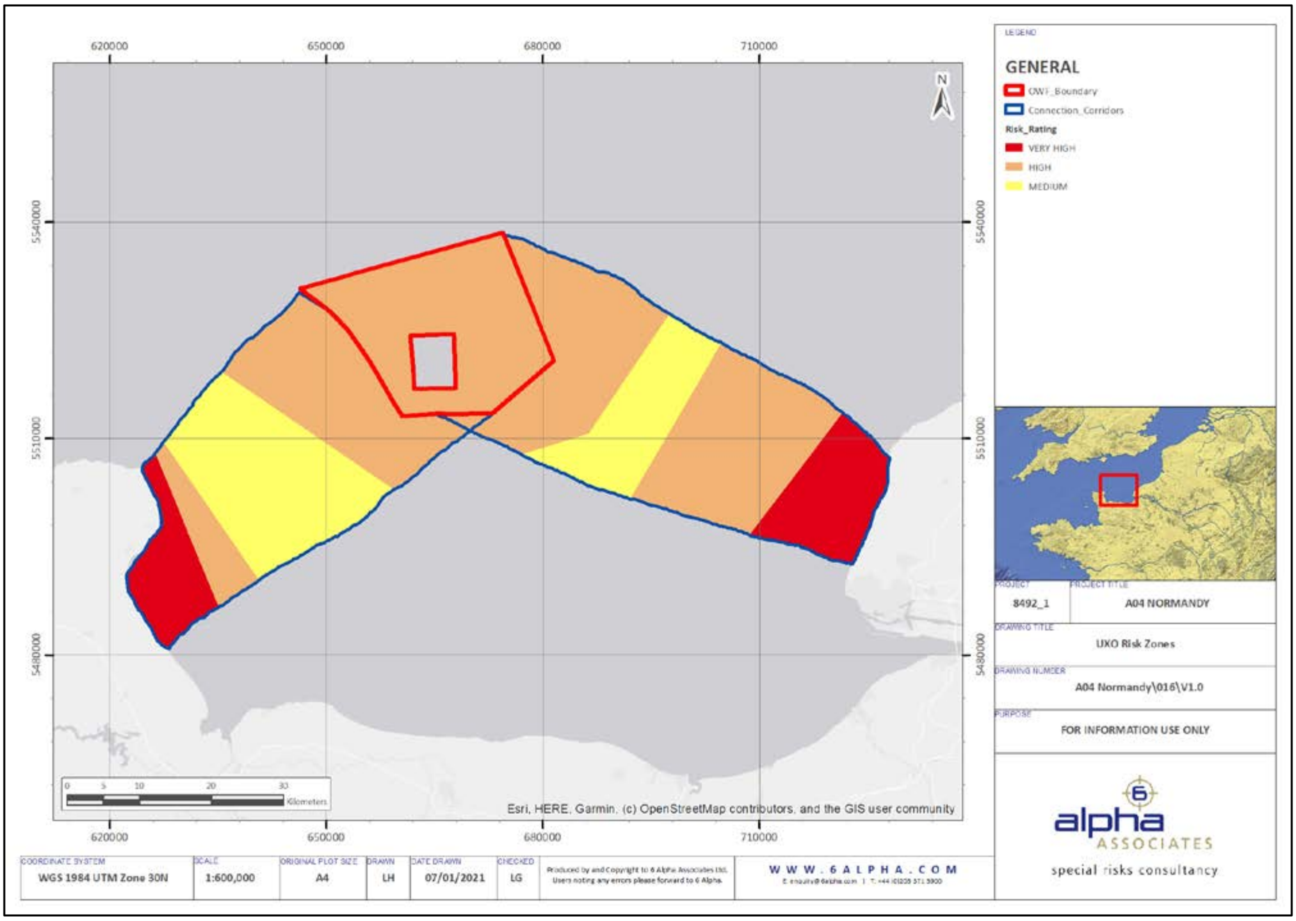


Figure 5 –UXO Risk Zones: All Operations

6 Alpha have also zoned the UXO risk associated with GI works only, those risk zones are presented at Figure 6.

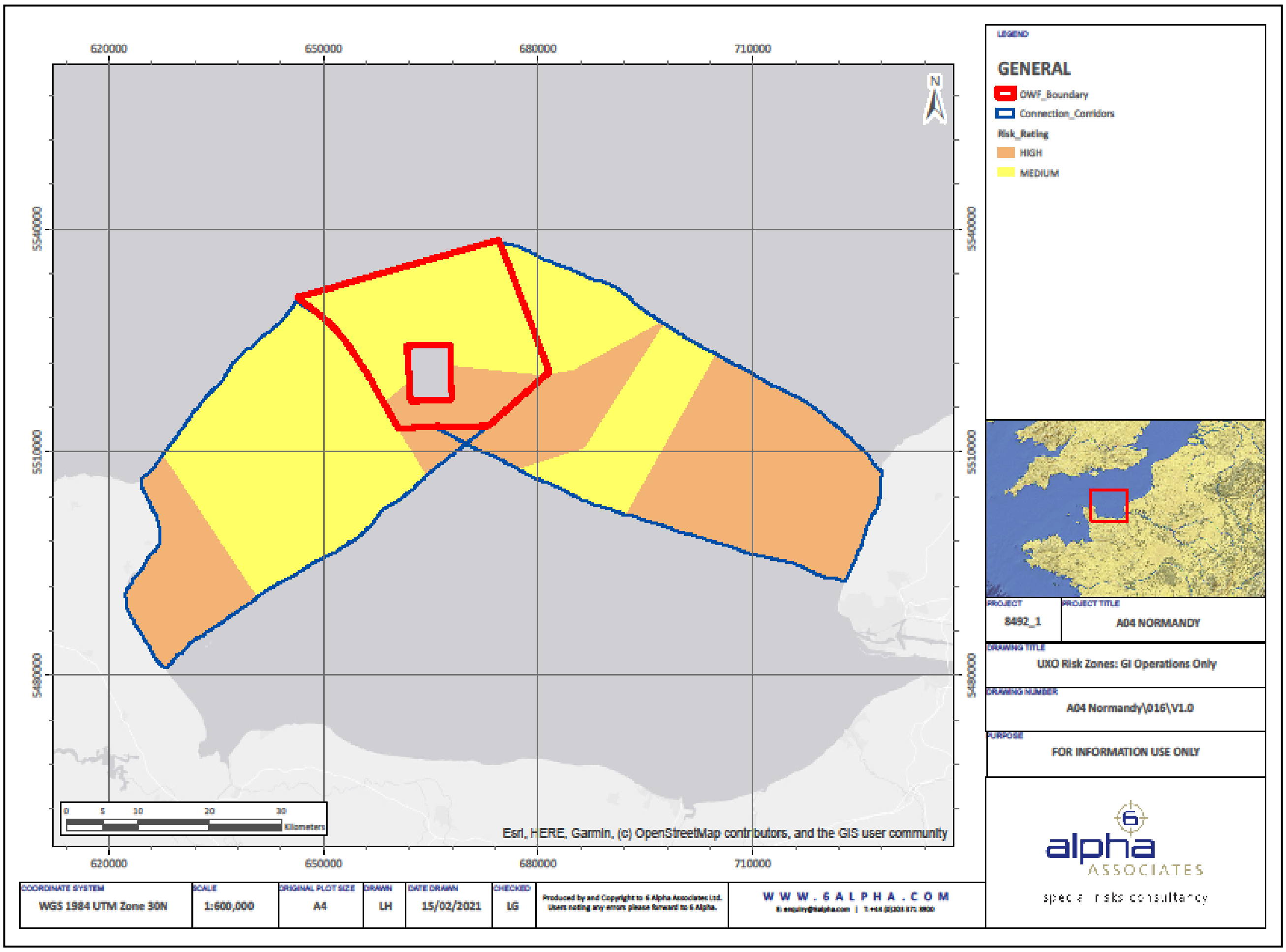


Figure 6 – UXO Risk Zones: GI Only

It is likely that the UXO risk zones could be refined further within the body of a tactical level risk mitigation design document. However, the precise types and locations of any intrusive GI operations would need to be considered, together with the water depths and likely shallow sub seabed conditions, in order to further and better refine the UXO risk zoning, in either the OWF area or in the export cable corridors.

7 Conclusions and Recommendations

7.1 Conclusions

7.1.1 Generally

The nature and scope of the UXO risks vary across the OWF area and each connection corridor, 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 doing so, in particular. The nature and extent of the risks posed are partly predicated by 6 Alpha's assessment the type, extent and aggressiveness of the proposed intrusive operations.

In the offshore environment, the effects of the depth of water upon potential UXO initiation consequences (and *inter alia* the resultant through seabed and through water shock wave), will be partly or wholly risk mitigative with the exception of large Net Explosive Quantity (NEQ) UXO threat items - and in such circumstances where the risk is partly and sufficiently mitigated, the residual risks might well be tolerated.

Nonetheless, some UXO risks posed by proposed operations have been categorised as either VERY HIGH or HIGH and they are generally associated with the unplanned initiation of large NEQ UXO – such as naval mines and aerial bombs during sub-seabed operations such as GI, cable installation and wind turbine installation, as well as similar enabling or supporting operations. Such risks are considered intolerable.

MEDIUM category UXO risks are also posed by certain other types of UXO and/or intrusive sub-seabed operations. As a result, *6 Alpha* have zoned such offshore UXO risks into different categories and have defined the requirements for their mitigation, based upon underwater explosive effects modelling and the variable likelihood that UXO may be encountered within different areas of the OWF.

7.1.2 UXO Risks to Surface Vessels and their Crew

UXO risks that are posed to vessels and their crew are most severe in shallow water (defined for the purposes of UXO risk analysis as 26m water depth, or shallower). Although the UXO risk is generally greater during prospective installation operations than it is during point-focal GI operations.

In addition, the prospective consequences for surface vessels generally reduces as the depth of water between the vessel and the point of a UXO initiation increases, the water depths throughout the OWF area and the export cable corridors are not expected to be sufficient to wholly mitigate large NEQ UXO risks posed by naval mines and high NEQ HE bombs – especially during windfarm installation operations, and therefore, the level of UXO risk remains high in those zones. Nonetheless, the UXO risk to point-focal GI operations is reduced, particularly in deeper water. For example, the UXO risk during GI operations in water depths of 40m LAT is categorised as MEDIUM, whereas installation operations at the same depth may still generate HIGH level of UXO risk.

If divers are deployed to facilitate subsea operations, then they may also be exposed to significant UXO risk because divers are especially vulnerable to UXO if it is initiated underwater and fatalities can be generated hundreds of meters from the seat of such an explosion (subject to the NEQ in the UXO).

7.1.3 UXO Risks to Underwater Equipment

The prospective UXO risks posed to underwater equipment - and to any cables or wind turbine foundations – are also significant. Such assets and their installation support vessels are unlikely to be sufficiently robust to withstand the consequences of an initiation of large threat spectrum UXO.

7.2 Recommendations

6 Alpha recommends that the UXO risk is mitigated within the bounds of the As Low As Reasonably Practicable (ALARP) risk reduction principal. For example, if project stakeholders are willing and able to tolerate some low NEQ UXO risks associated with subsea equipment, then better value for money solutions may be afforded in terms of UXO risk mitigation by avoiding those costly and time-consuming risk mitigation measures that reduce the risks associated with low NEQ UXO threats in deep water especially. Therefore, *6 Alpha* has recommended that only specific and intolerable risks are mitigated in order to reduce them to ALARP, in accordance with *EU* and national laws.

The following UXO risk mitigation recommendations have therefore been made in order to reduce UXO risks to ALARP:

7.2.1 UXO Risk Mitigation Strategy for GI - Overview

The UXO risk mitigation strategy has been designed for GI operations only, and there are three main options to consider in order to reduce these UXO risks ALARP, based upon the source-pathway-receptor model.

6 Alpha's approach is that UXO risk can effectively be reduced to ALARP, by removing one (or more) element(s) of the model or otherwise mitigating the risks associated with a single element of the model. The UXO risk mitigation strategy will, therefore, consist of UXO risk mitigation measures, that are to be implemented to reduce risks to ALARP. The three main strategic options based upon source-pathway-receptor modelling are, in priority order:

7.2.1.1 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 by moving the locations of GI operations where necessary, such risks are appropriately and effectively reduced.

7.2.1.2 Removal of Risk Receptors

A second option is to remove the receptor element (of the source-pathway-receptor model), by moving certain sensitive and vulnerable receptors (typically crews of offshore vessels), to a safe distance from the point of the intrusive activity and thus the pUXO hazard, so that it will diminish sufficiently the prospective blast, fragmentation and/or shock wave consequences to reduce UXO risks to ALARP. Clearly, this is not always achievable and such a course of action is commonly impractical.

7.2.1.3 Removal of Threat Sources

Where GI operations cannot be moved in order to avoid pUXO, an alternative (but commonly, time consuming and costlier) option, is to verify pUXO by investigation and where it is cUXO, to remove it (effectively removing the source element of the source-pathway-receptor model), by either moving it to a position where it can do no harm (but only when it is safe to do so and wherever permit licencing and consent condition allow such actions), and/or destroying it or otherwise rendering it safe.

7.2.1.4 Residual Risk Tolerance

Following the implementation of the risk mitigation strategy, UXO risks will not be reduced to “zero”. Residual UXO risks will likely remain in the offshore environment due to *inter alia*, the limits of geophysical UXO survey technology, data interpretation limitations and the fact that small scale low NEQ UXO threats might be tolerated which is acceptable under the auspices of the ALARP risk reduction principle. Such residual risks have been tolerated on many other projects, in very similar circumstances. Such an approach therefore, is likely to be deemed acceptable by a wide variety of project stakeholders and regulators and is consistent with all agreed upon risk management standards, practices and frameworks.

7.2.2 UXO Risk Mitigation Measures

- The GI risk mitigation strategy should be enacted through the design and implementation of risk mitigation measures, as follows:
- Proactive Measures:
  - **Geophysical UXO Survey**; a geophysical UXO survey is to be designed (and subsequently undertaken) to detect threat spectrum UXO as follows:
    - **SSS**; high-resolution Side Scan Sonar should be employed (>600kHz frequency);
    - **MBES**; Multi-Beam Echo-Sounder survey is often corroborative and helpful in delivering UXO target discrimination; its outputs should therefore be employed to compliment SSS data;
    - **MAG**; subject to the locations and type of GI being undertaken, the juxtaposition of the GI work vessel(s) and the water depth, geophysical survey by magnetometer of gradiometer may or may not be required. 6 Alpha can better advise when the details of the GI are known;
  - **Anomaly Selection**; geophysical UXO survey data (once acquired) is to be employed in order to select those anomalies that model as potential UXO (pUXO). A UXO specialist is usually employed to discriminate pUXO from benign seabed (or sub-seabed) detritus. Our recommendation is that pUXO should be avoided (see below); or, where it cannot be avoided, it may have to be verified by investigation (also see below);
  - **pUXO Avoidance**; pUXO is to be avoided either by 15m (the latter is a baseline and *6 Alpha* standard safety distance but may be reduced through the medium of a Technical Advisory Note), measured from the edge of any seabed intrusive GI tool;
  - **pUXO Investigation**; where pUXO avoidance criteria cannot be met, then target investigation must be undertaken to verify and classify pUXO as either confirmed UXO (cUXO), or as seabed debris;
  - **UXO Disposal**; following the inspection of pUXO, those items of cUXO will require either: movement (e.g. to the edge of the consent corridor – where it is permitted and safe to do so) and/or render safe either by sympathetic detonation (or possibly by a low-order/deflagration technique);

- Reactive Measures:
    - **Emergency Management Plans;** are to be written and distributed to all vessels involved with GI operations;
    - **Tool-Box Briefs**; are to be delivered to all personnel intimately involved in GI activities;
    - **On-Call Service**; an Explosive Ordnance Disposal company may be employed to provide an immediate repose in the event that an item of UXO is discovered - even after proactive risk mitigation measures have been executed - during any and all subsequent activities associated with GI operations.

7.2.3 Minimum UXO Threat Item

The recommendation for the minimum threat items to be detected by geophysical UXO survey is variable throughout the Study Site depending on a number of factors including but not limited to; water depth, likely GI methodology, the nature of the UXO threat, prospective vessel slant range and vessel robustness. It should also be noted that the minimum threat item is based on a UXO threat item's ferrous metal content rather than its physical dimensions or any other factor.

In water depths of up to 10m LAT, the minimum UXO threat item to be detected by geophysical UXO survey is assessed to be:

- 10.5 cm leFH 18 Artillery Projectile with a ferrous mass of 13kg.

In water depths of between 10m and 26m LAT, the minimum UXO threat item for survey is assessed to be the following:

- *German* SC-50 HE Bomb with a ferrous mass of 23kg.

In water depths of between 26m and 40m LAT, the minimum UXO threat item for survey is assessed to be the following:

- *US* AN-M57 250lb HE Bomb with a ferrous mass of 59kg.

Where water depths exceed 40m LAT, the minimum UXO threat item for survey should instead be the following:

- *British* Mark XV/XVII Naval Mine with a ferrous mass of 68kg.

In general, the types of UXO threat spectrum items that need to be detected (and either: avoided by a minimum approved safety distance, or else verified by target investigation) in a variety of water depths, is presented in Figure 7. However, this figure is presented as an indicative guide and the precise detection requirements at each water depth may vary following based on the site-specific UXO threat assessment.

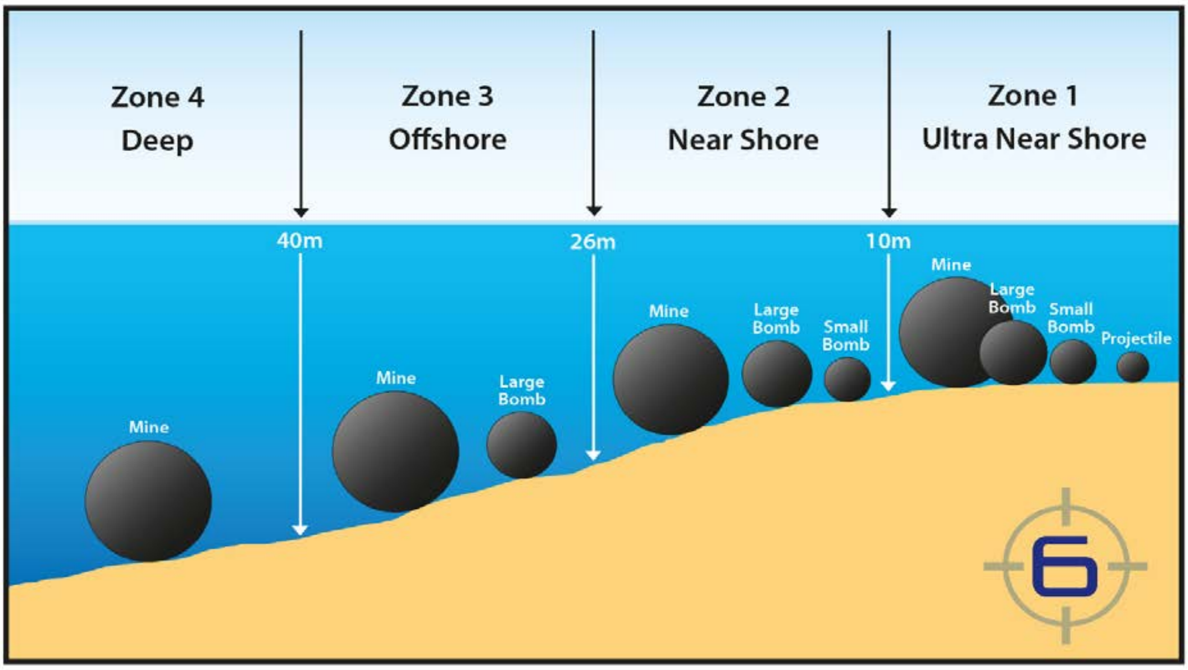


Figure 7 – UXO Detection Requirement with Respect to Water Depths (LAT)

7.2.4 Minimum UXO Threat Item Selection Methodology

The diagram presented at Figure 7 is intended as a general guide to minimum threat detection at those specified depths that is generally correct across all types of projects. However, as a general guide it is not bespoke to this project as the specific ferrous masses, NEQs and potential detonation consequences associated with project specific UXO threats, as identified and evidenced within the threat assessment element at Section 3 of this report, may vary from the general guidance on UXO threat item detection presented at Figure 7.

For example, in water depths up to 10m LAT, the minimum UXO threat item to be detected by UXO geophysical survey is a 10.5cm artillery projectile with a ferrous mass of 13kg. Whilst table 3.11.4 shows that other projectiles with a smaller ferrous mass may be encountered, the selection of the minimum UXO threat item has taken into account the likelihood of encountering each item, the UXO's NEQ in order to assess detonation consequences, the limitations of geophysical survey techniques and the recommended UXO risk tolerance in order to select the UXO with the lowest ferrous mass that ought to be detected by geophysical UXO survey in order to reduce the UXO risk to the vessels and its crews to ALARP.

In addition, whilst Figure 7 suggests that generally, small and medium HE bombs are unlikely to require detecting by geophysical UXO survey in depths above 26m LAT, on this project an *American* 250lb HE bomb with a ferrous mass of 59kg has been selected as the minimum UXO threat item for detection in depths of between 26m LAT and 40m LAT because its NEQ is sufficient to cause prospective damage to the vessel and its crews if it were to be inadvertently initiated in depths up to 40m LAT.

Where water depths exceed 40m LAT, a *British* Mk XV/XVII Naval Mine has been selected as the minimum UXO threat to be detected by geophysical UXO survey. Whilst other mines may pose a UXO threat, the Mk XV/XVII naval mine has been selected as the minimum threat to be detected by geophysical UXO survey because it is the UXO threat item with the lowest ferrous mass that is likely to be encountered during GI activities that contains sufficient NEQ to potentially cause damage to the vessel and harm to vessel crews. Whilst LMA/LMB mines may pose a residual threat, they are highly unlikely to be encountered during GI operations and cannot be mitigated effectively using conventional risk mitigation measures in any areas where they may be partially or completely buried. As such, the UXO risk associated with their deployment to GI operations is considered to be reduced to ALARP without bespoke mitigation measures in place.

7.2.5 UXO Risk Tolerance and Residual Risks

6 Alpha's risk mitigation strategy is based around the principle that whilst damage/destruction to the any underwater GI equipment is undesirable, in certain circumstances it could be tolerated - where the vessel and any personnel are not endangered - as a residual UXO risk, under the auspices of the ALARP principle. Such a recommendation is common for offshore GI projects of this nature.

Specifically, *6 Alpha* also recommends that the UXO risks associated with a prospective initiation of low NEQ UXO risks in deeper waters, such as the risks associated with anti-aircraft artillery or small naval gun projectiles only, in water depths greater than 30mLAT, need not to be reduced with proactive risk mitigation measures ahead of GI operations. This recommendation is driven by the fact that attempting to mitigate low NEQ UXO risks in deep water through UXO geophysical survey is especially challenging, time consuming and costly without the benefit of corresponding risk mitigation reduction.

With this in mind, *6 Alpha* would encourage the Client and their stakeholders to consider and confirm our assumed tolerance for UXO risks with respect to the risk mitigation strategy in general and with reference to the recommended level of GI UXO risk tolerance that is outlined and presented at Option 2 in Table 7.2.5, in particular.

Table 7.2.5: UXO Risk Tolerance Options

UXO Risk Tolerance	Prospective Residual UXO Risk	Cost Implications
Option 1 – Very Conservative	Damage to subsea GI equipment of any kind will not be tolerated.	Very expensive and time-consuming option but the risk of damaging the GI equipment is reduced. There is also a significantly reduced risk of project delay due to UXO initiation but, project delay due to the difficulties of ameliorating low ferrous-low NEQ UXO risks in deep water will increase.
Option 2 – 6 Alpha Recommended (within ALARP threshold)	Damage/Destruction of subsea GI equipment is tolerable – if undesirable. Damage to the vessel that endangers personnel (either directly or indirectly) is intolerable and will require proactive UXO risk mitigation.	Time and cost efficient, although such tolerance carries the risk of repair and/or replacement of the subsea GI equipment in the event of unplanned low NEQ UXO detonation.

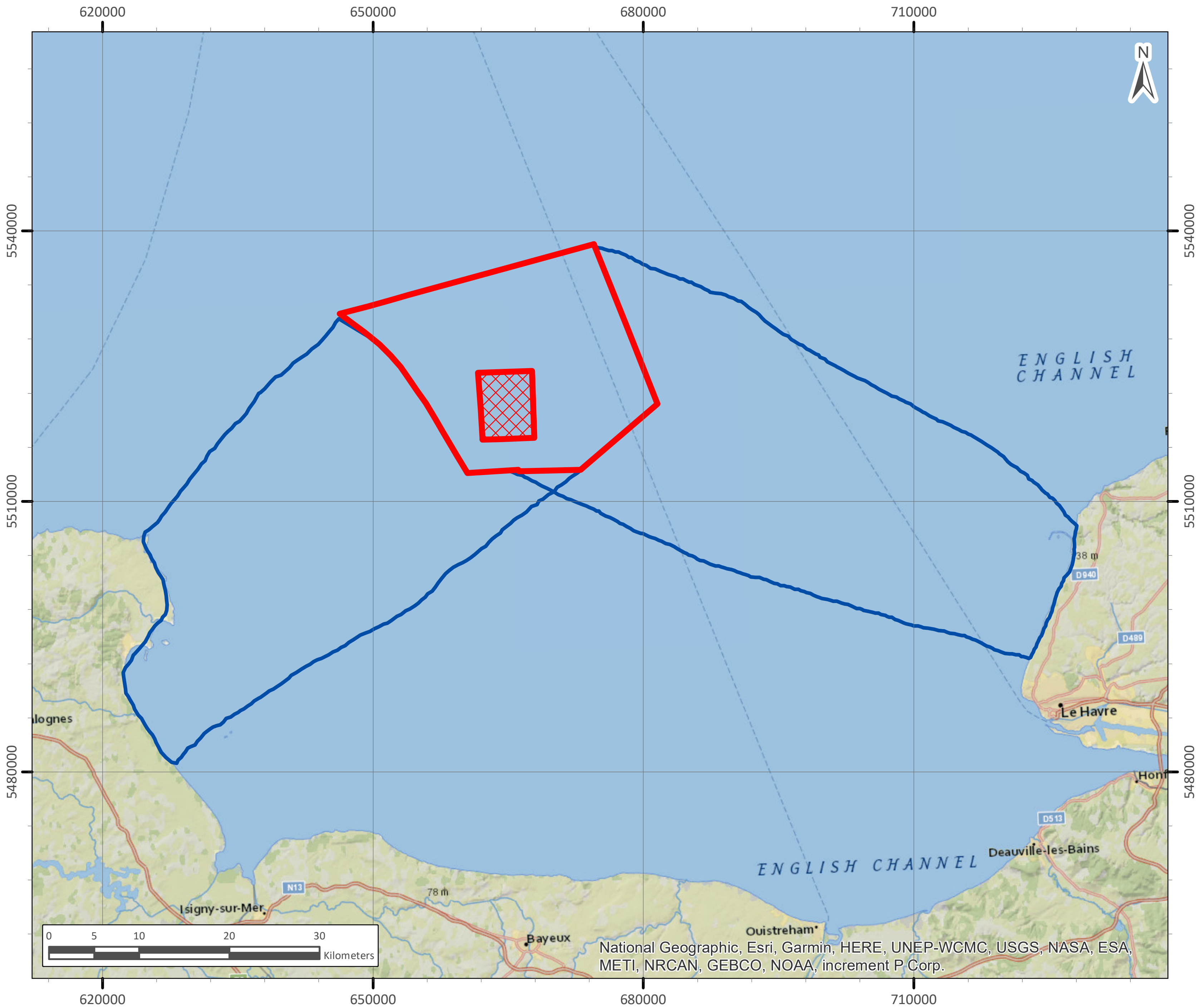
7.2.6 ALARP Safety Sign-Off Certification

If the above criteria are satisfied, then ALARP safety sign-off certification for GI can be readily provided. 6 Alpha recommend that the UXO risk mitigation strategy is subsequently updated and expanded to encompass risk mitigation measures for OWF foundation and all cable installation works, which are expected to be scheduled later in the project cycle.

Appendices

Appendix 1

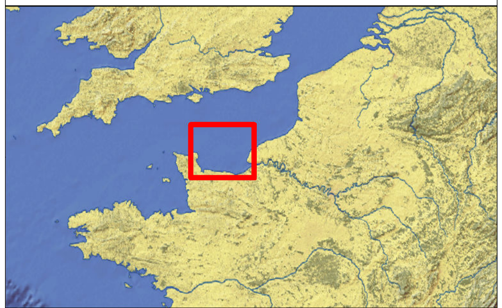
A04 Normandy Location



LEGEND

GENERAL

- OWF_Boundary
- Excluded_Zone
- Connection_Corridors



PROJECT	PROJECT TITLE
8492_1	A04 NORMANDY

DRAWING TITLE
A04 Normandy Location

DRAWING NUMBER
A04 Normandy\001\V1.0

PURPOSE
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Appendix 2

Marine Risk Management Framework

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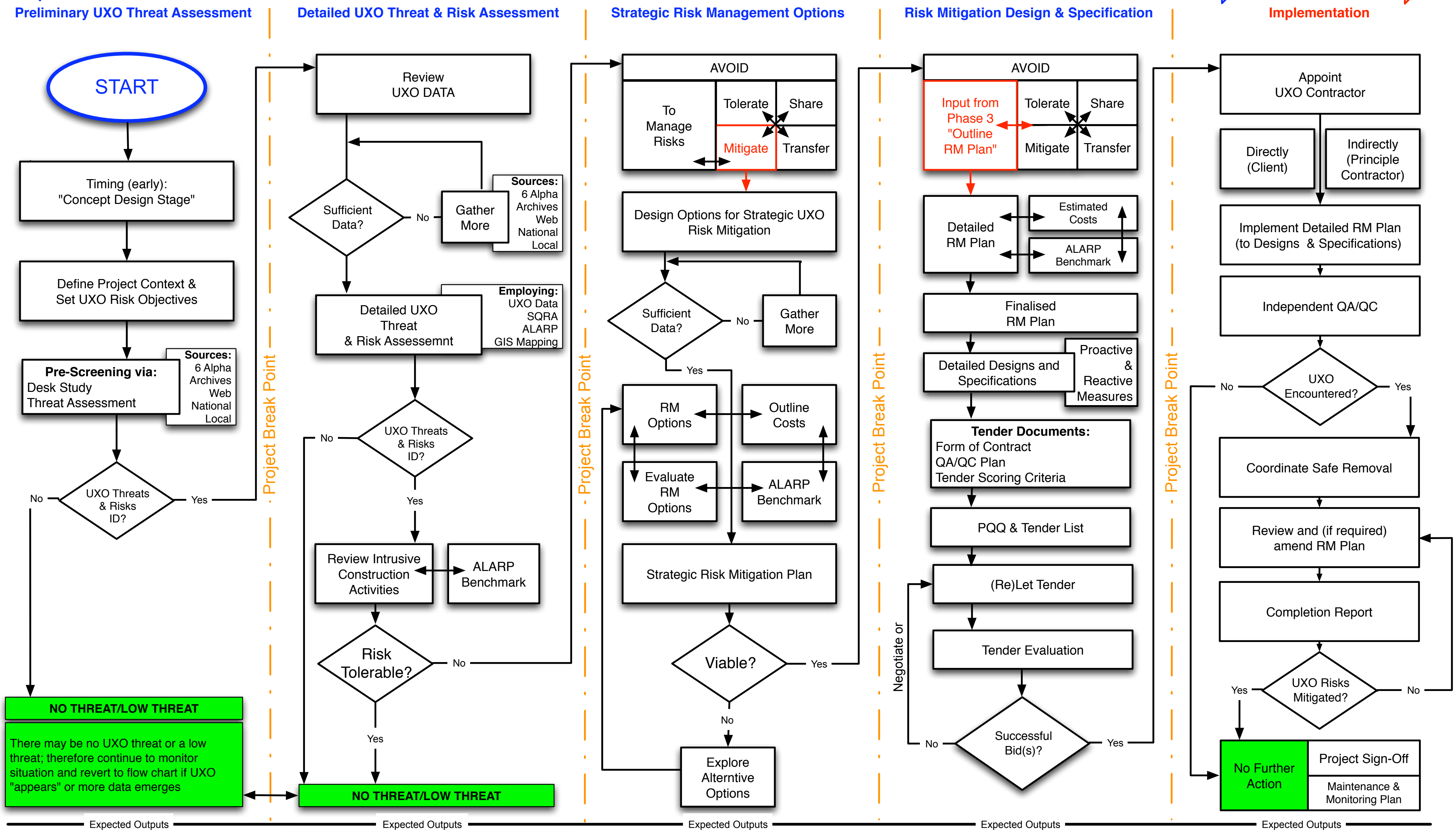
MANAGING UNEXPLODED ORDNANCE (UXO) - A RISK MANAGEMENT FRAMEWORK FOR THE MARINE INDUSTRY

SPECIALIST UXO RISK MANAGEMENT CONSULTANCY

CONTRACTING



Preliminary UXO Threat Assessment
Expected Consultancy Outputs:
Concise Report
Supported by:
GIS Mapping &
Research Data
Conclusions
Recommendations - move to next step (or not)?

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

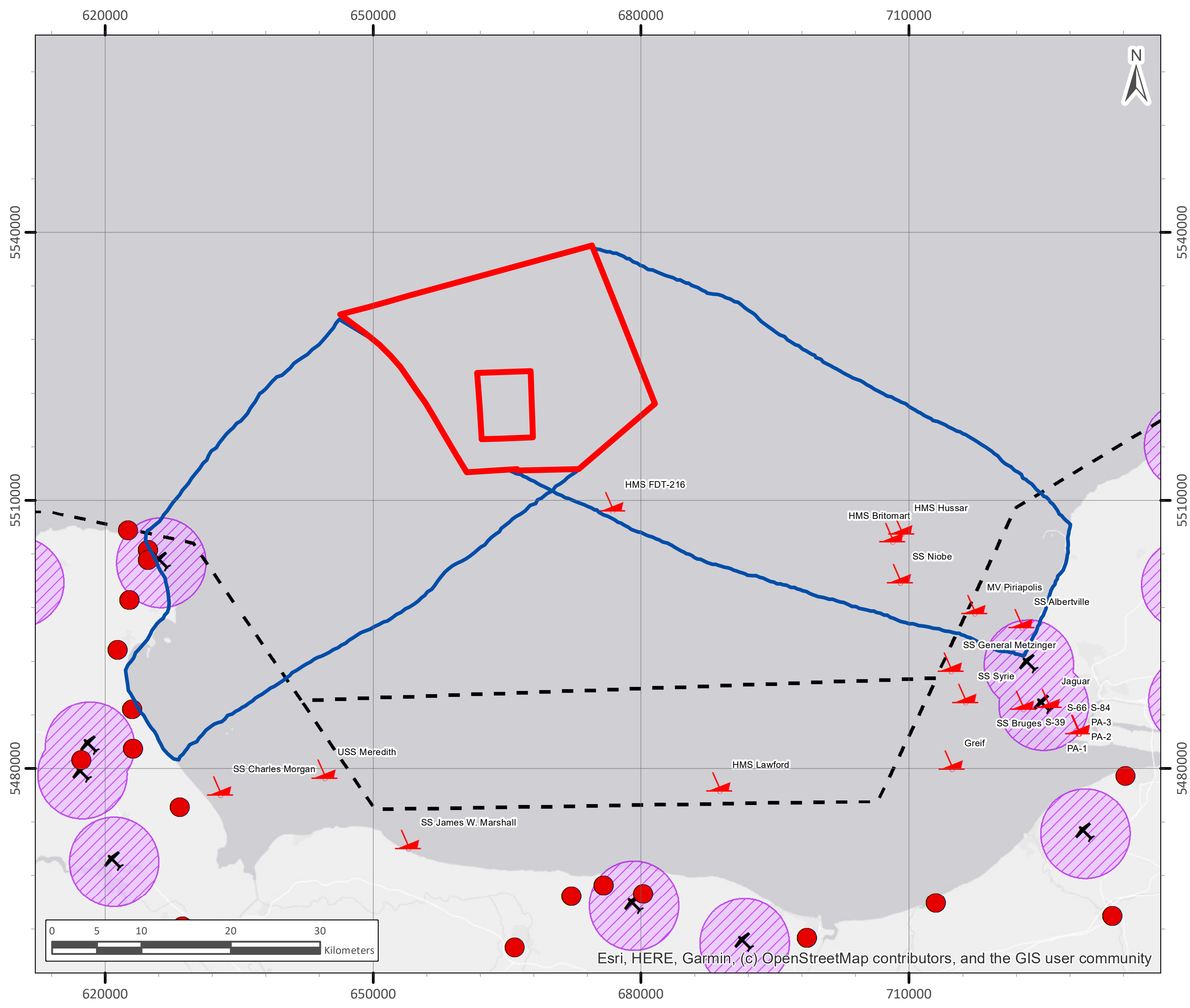
Strategic Risk Management Options
Expected Consultancy Outputs:
Strategic Risk Mitigation (RM) options
Criteria for selection of mix of options
Selection of best mix of options
Benchmark with Client's Tolerance of UXO Risk
Strategic Risk Mitigation Plan

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

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

Aerial Bombing Threat



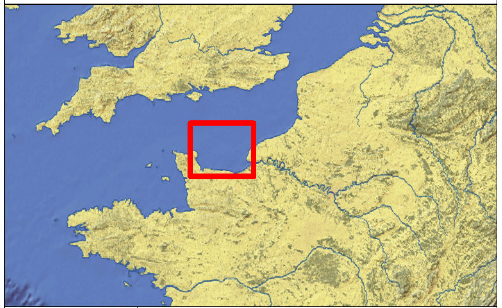
LEGEND

GENERAL

OWF_Boundary
Connection_Corridors

UXO THREATS

WWII_Allied_Targets
WWII_Air_Raid_Wrecks
WWII_German_ROSA_Route
Luftwaffe_Airfields
Airfields_5km_Buffer



PROJECT	PROJECT TITLE
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DRAWING TITLE
Aerial Bombing Threat

DRAWING NUMBER
A04 Normandy\003\V1.0

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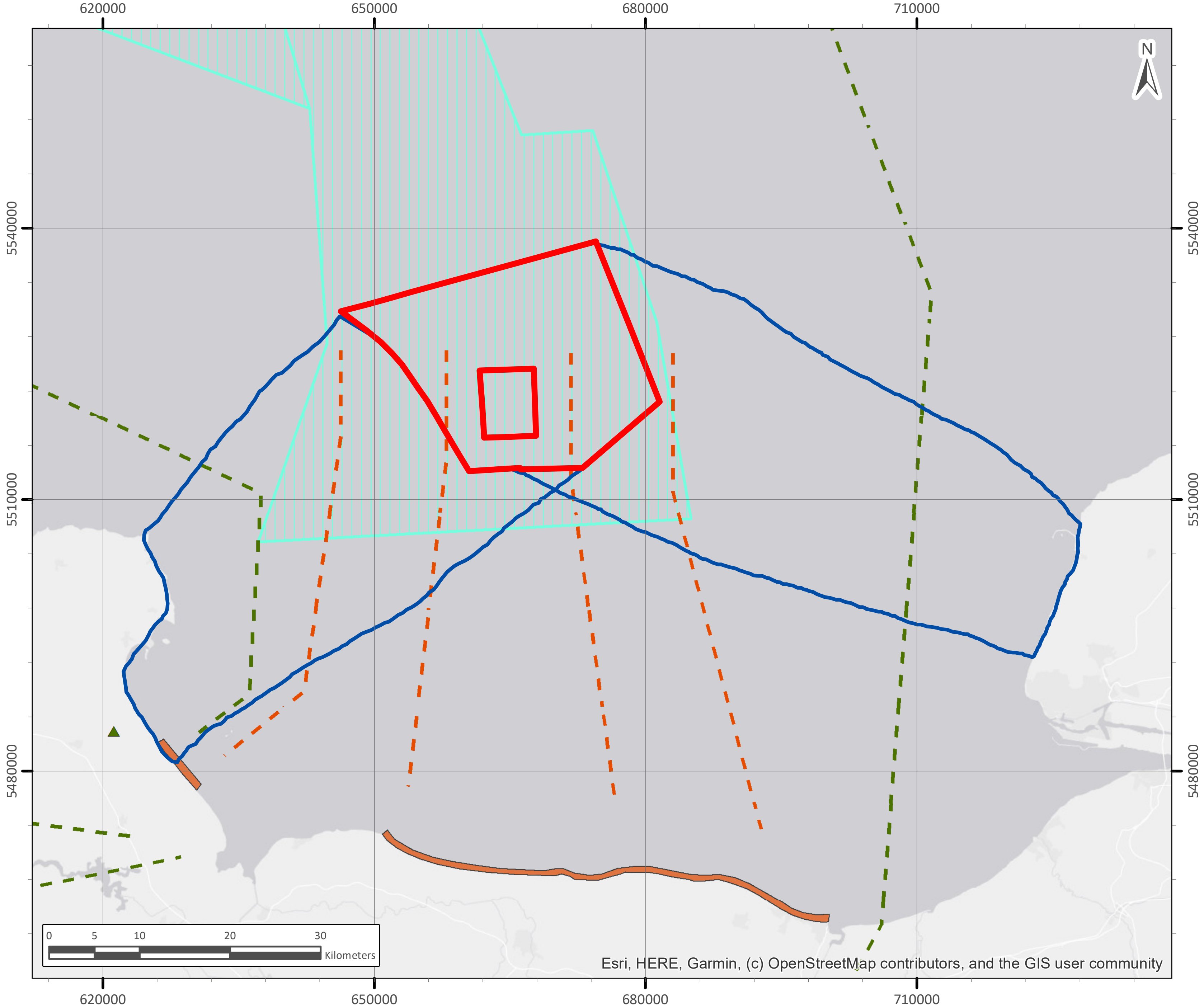
Appendix 4

Operation Overlord



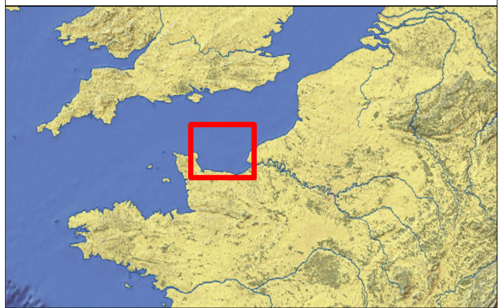
LEGEND

GENERAL

- OWF_Boundary
- Connection_Corridors

UXO THREATS

- Overlord_Allied_Airdrops
- Overlord_Glider_Routes
- Overlord_Sea_Routes
- Overlord_Landing_Beaches
- Overlord_The_Spout



PROJECT	PROJECT TITLE
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DRAWING TITLE
Operation Overlord

DRAWING NUMBER
A04 Normandy\004\V1.0

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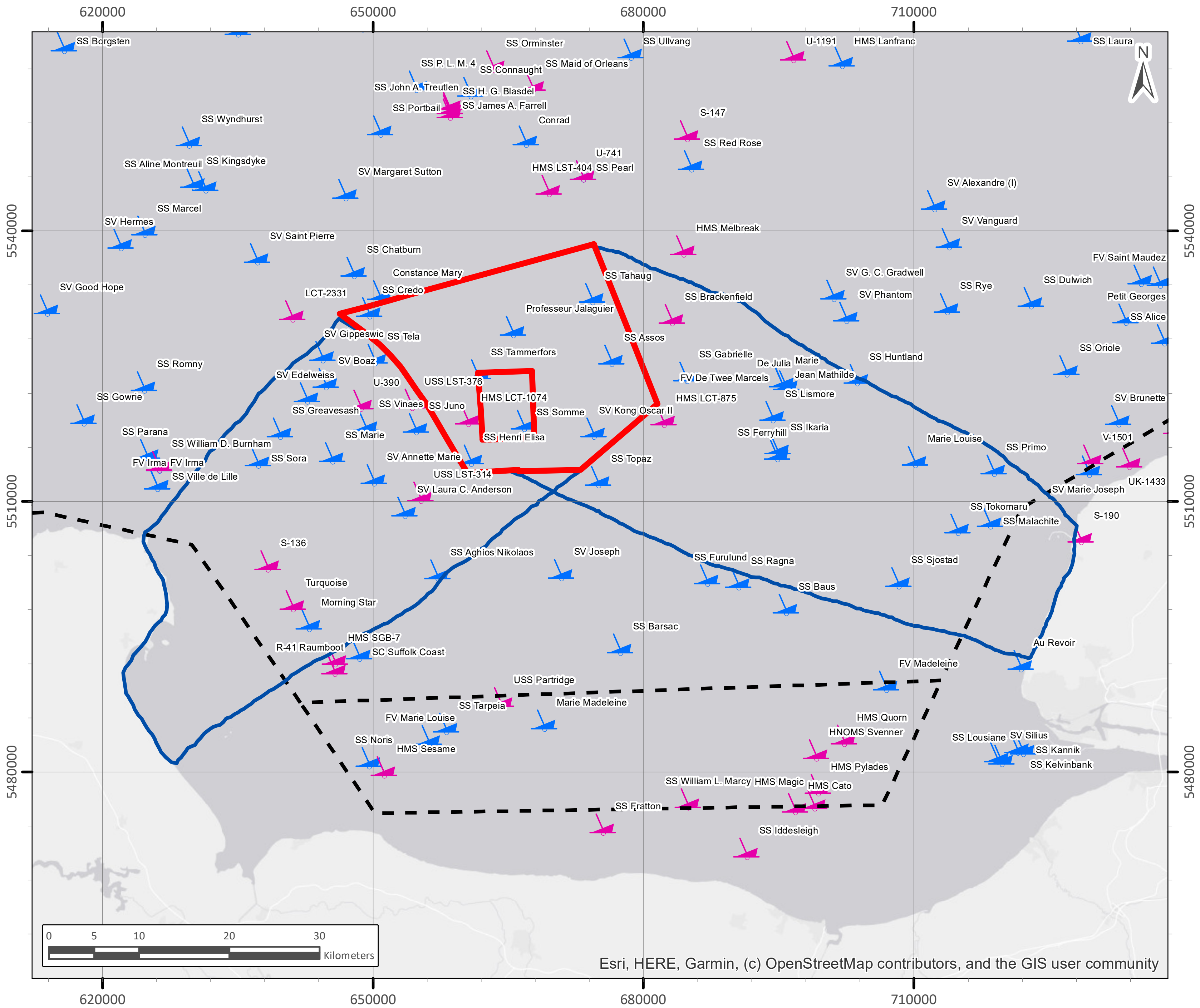
Appendix 5

Naval Engagements



LEGEND

GENERAL

OWF_Boundary

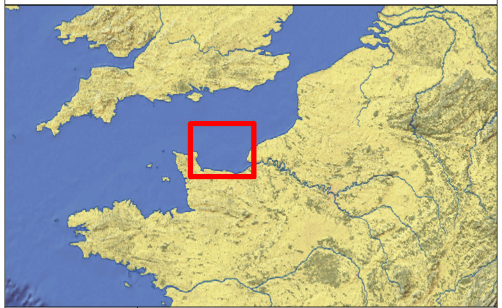
Connection_Corridors

UXO THREATS

WWII_German_ROSA_Route

WWII_Naval_Wrecks

WWI_Naval_Wrecks



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DRAWING TITLE

Naval Engagements

DRAWING NUMBER

A04 Normandy\005\V1.0

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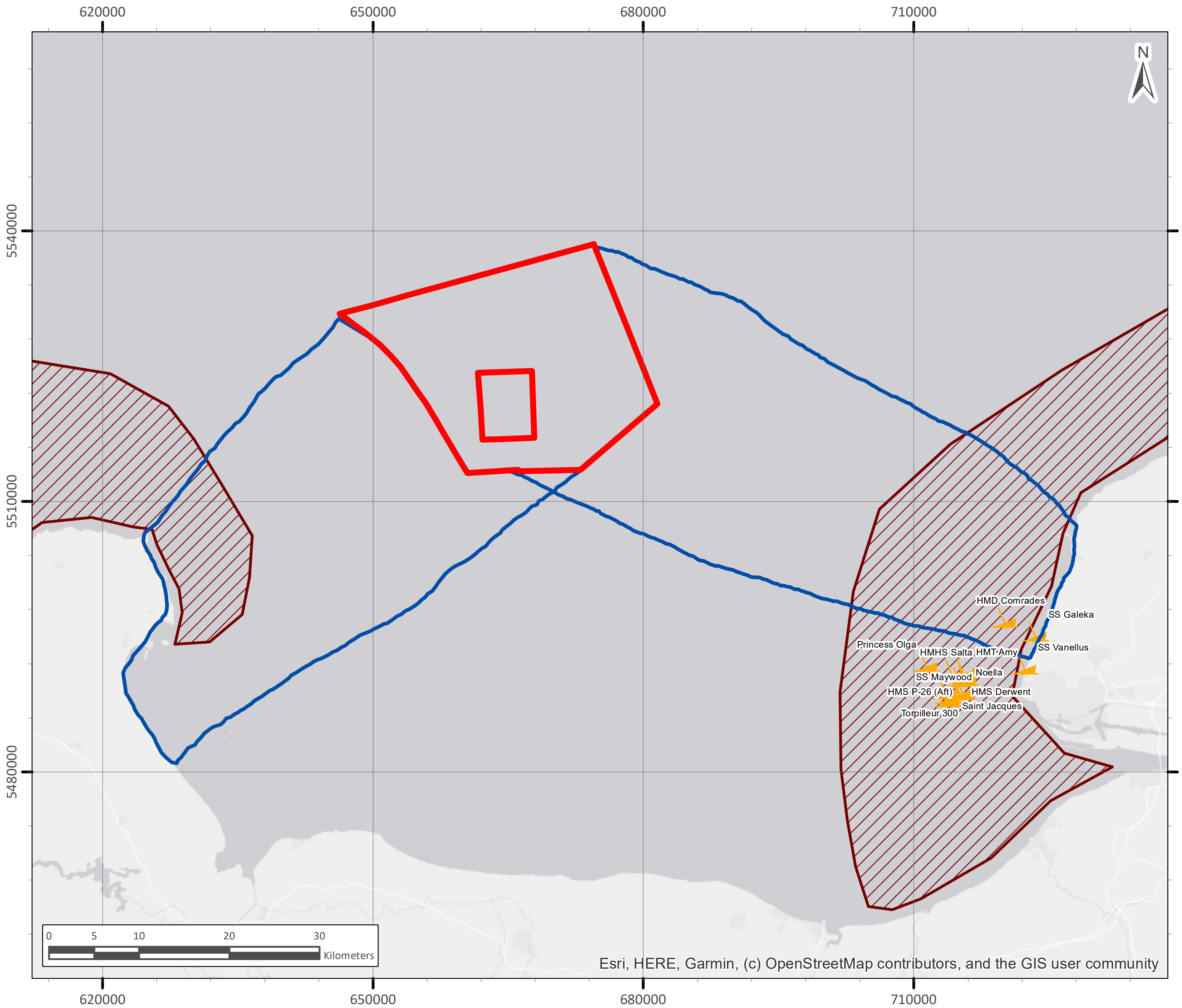
Appendix 6

WWI Minefields



LEGEND

GENERAL

OWF_Boundary

Connection_Corridors

UXO THREATS

WWI_Mined_Wrecks

WWI_Central_Powers_Minefields

PROJECT	PROJECT TITLE
8492_1	A04 NORMANDY

DRAWING TITLE
WWI Minefields

DRAWING NUMBER
A04 Normandy\006\V1.0

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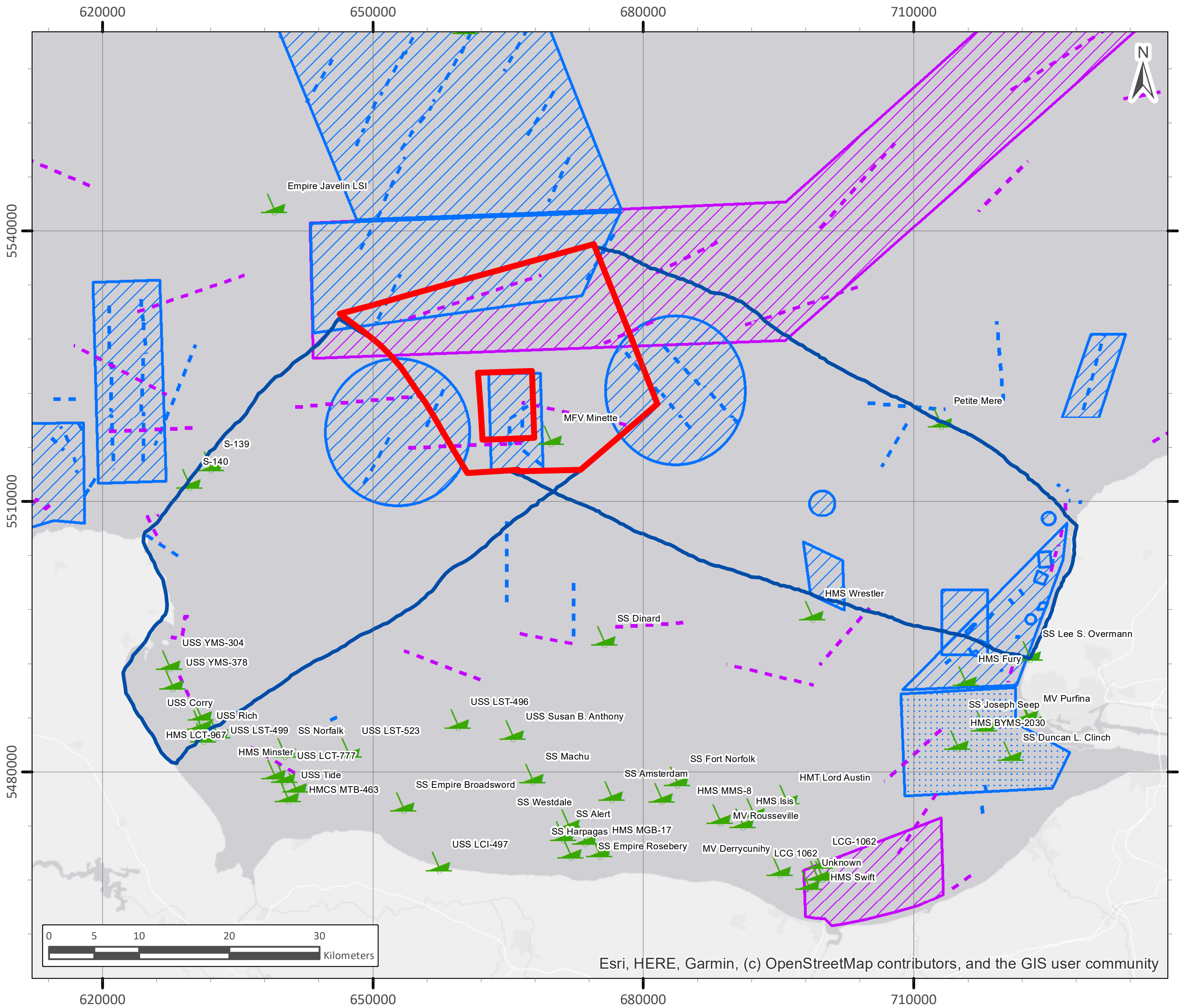
Appendix 7

WWII Minefields



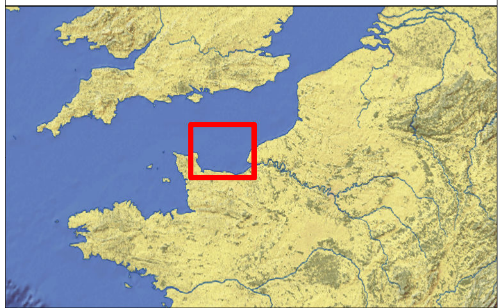
LEGEND

GENERAL

- OWF_Boundary
- Connection_Corridors

UXO THREATS

- WWII_Mined_Wrecks
- WWII_Axis_Minelays
- WWII_Allied_Minelays
- WWII_Allied_Aerial_Minefields
- WWII_Allied_Minefields
- WWII_Axis_Minefields



PROJECT	PROJECT TITLE
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DRAWING TITLE	WWII Minefields
DRAWING NUMBER	A04 Normandy\007\V1.0
PURPOSE	FOR INFORMATION USE ONLY

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Appendix 8

Historic PEXA

LEGEND

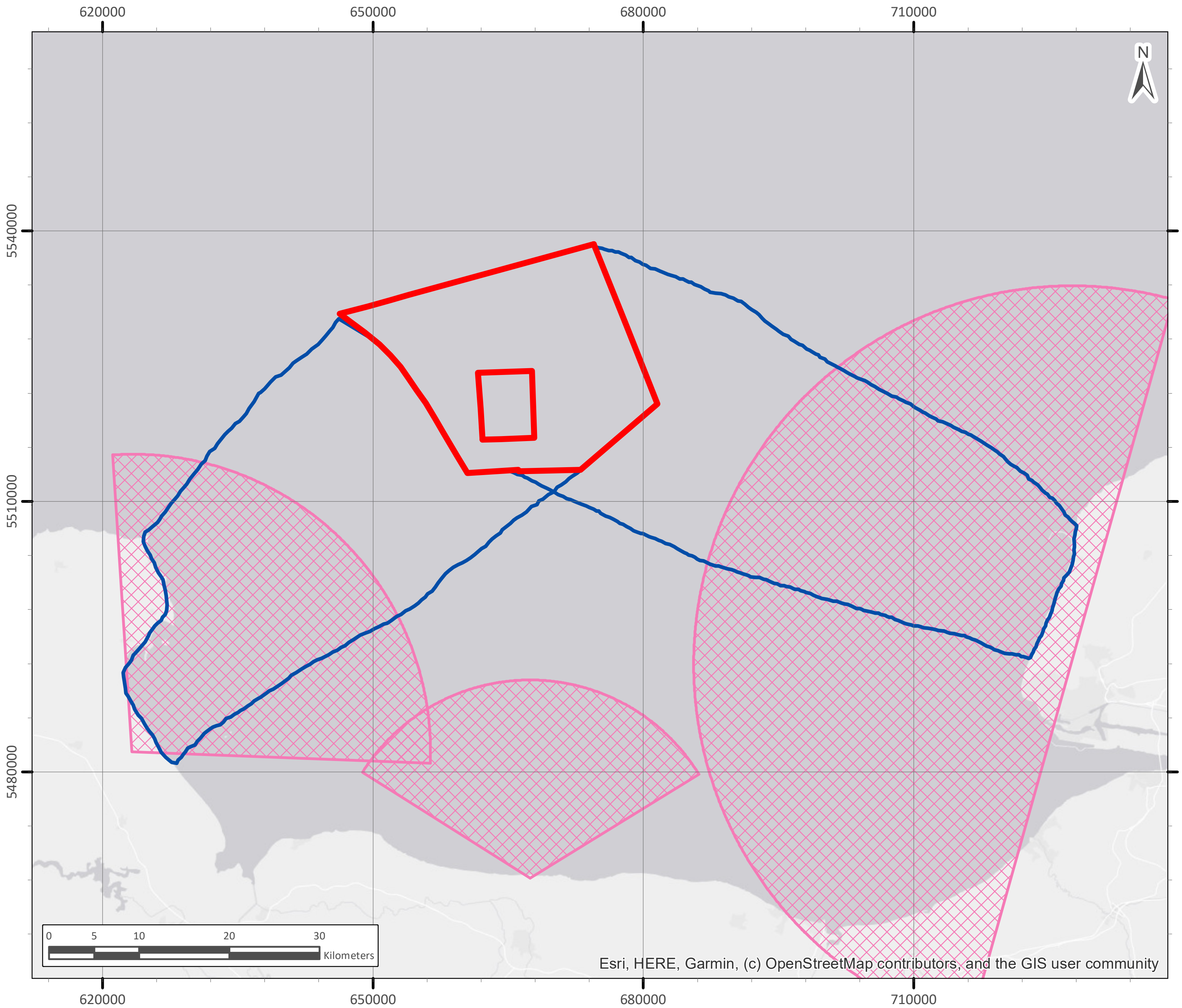
GENERAL

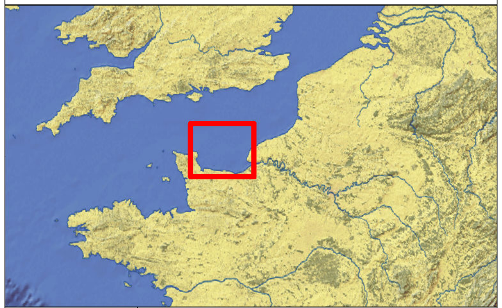
OWF_Boundary

Connection_Corridors

UXO THREATS

Historic_Firing_Ranges





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DRAWING TITLE
Historic PEXA

DRAWING NUMBER
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WGS 1984 UTM Zone 30N	1:600,000	A4	LH	22/12/2020	LG

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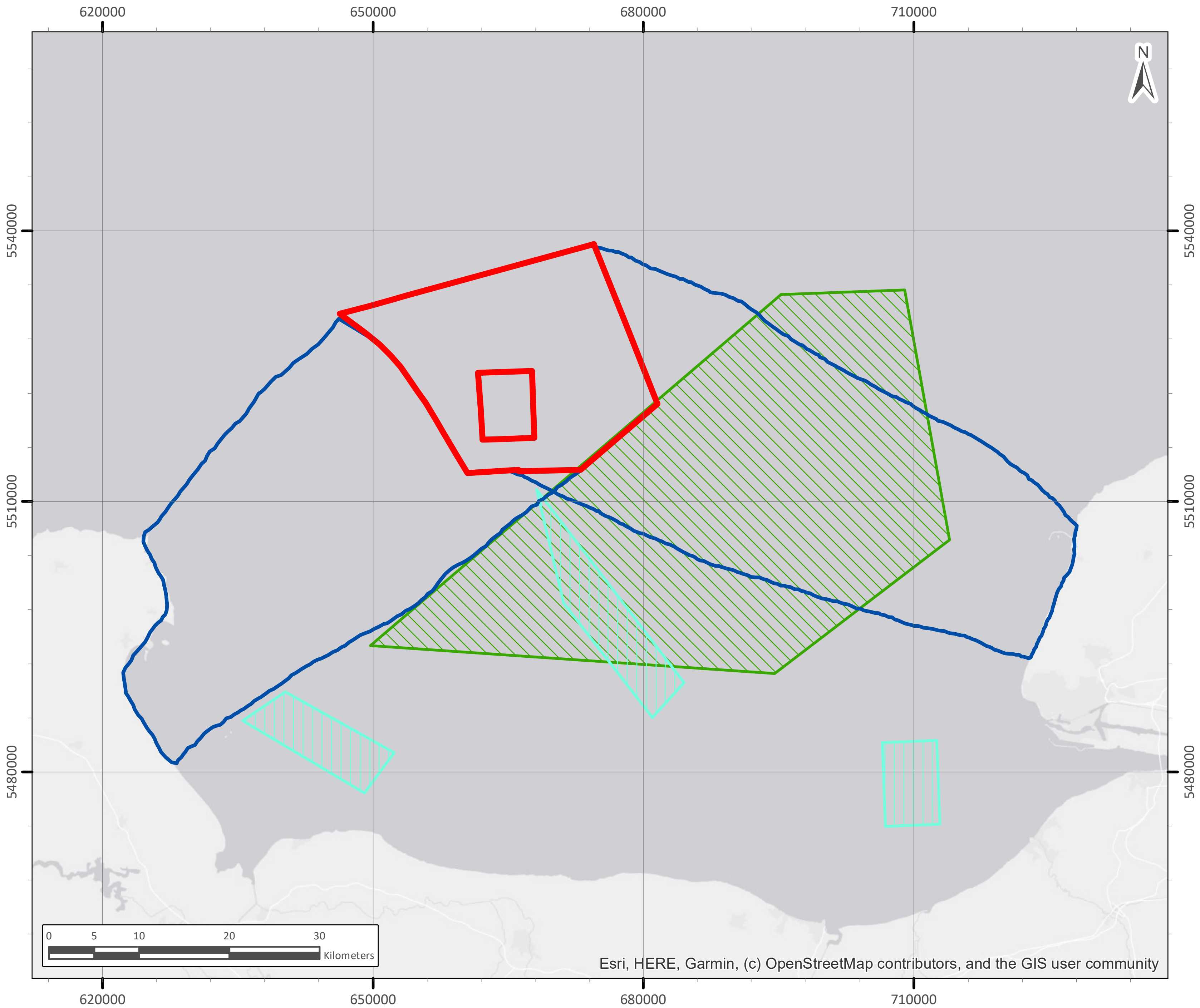
Appendix 9

Modern PEXA



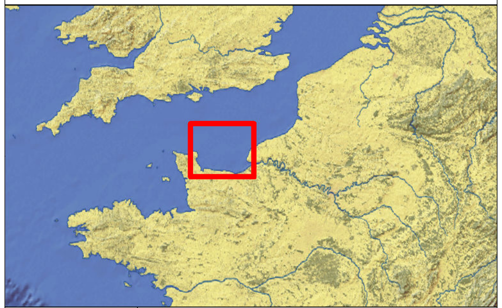
LEGEND

GENERAL

- OWF_Boundary
- Connection_Corridors

UXO THREATS

- Minesweeping_Operations
- Firing_Exercise_Areas



PROJECT	PROJECT TITLE
8492_1	A04 NORMANDY

DRAWING TITLE	Modern PEXA
DRAWING NUMBER	A04 Normandy\009\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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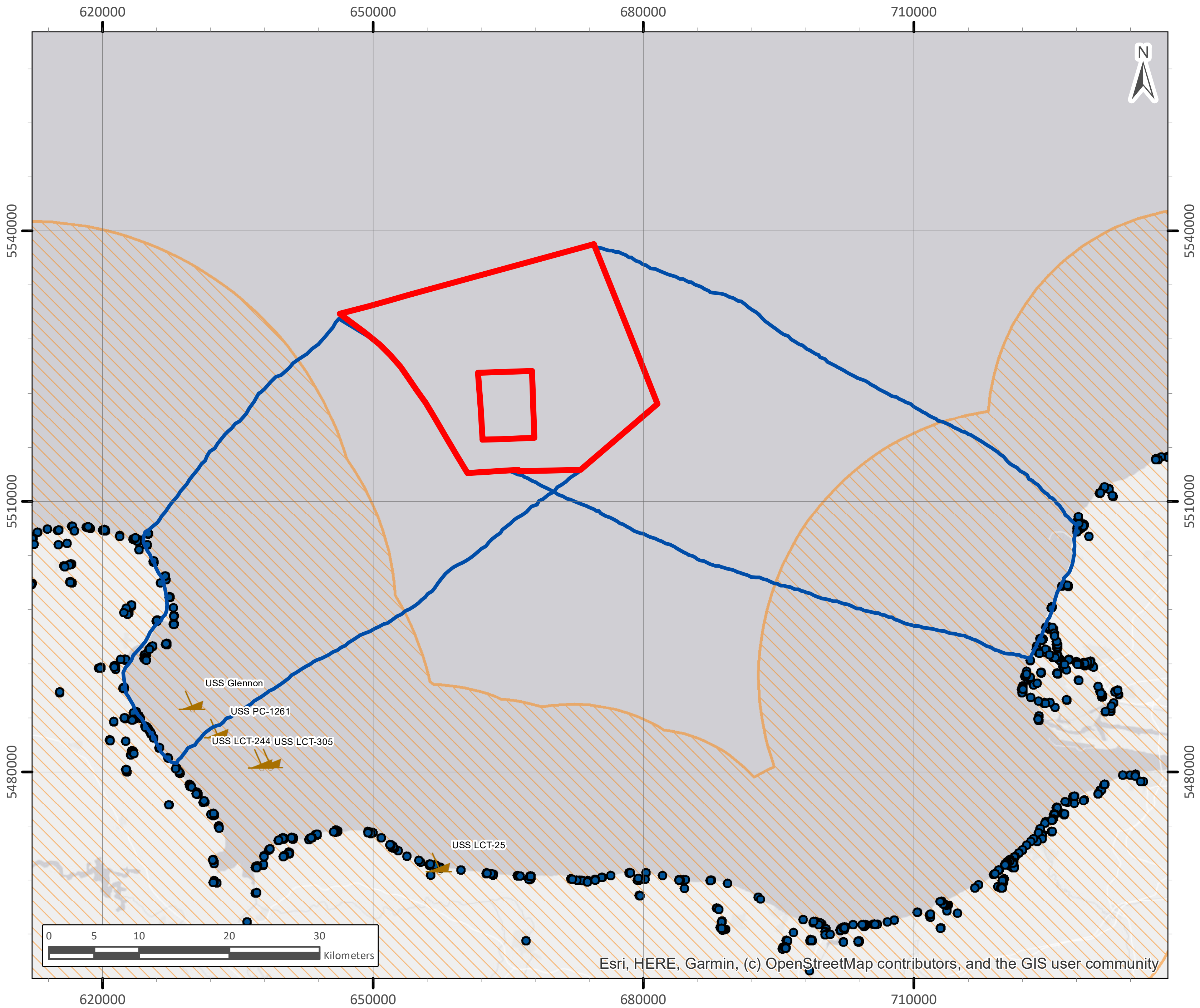
Appendix 10

Atlantikwall



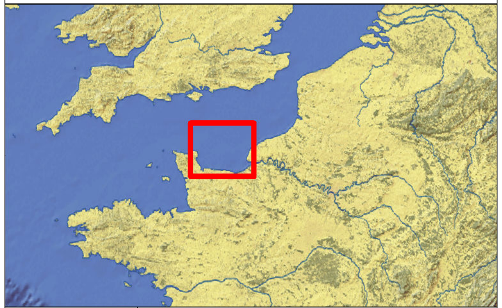
LEGEND

GENERAL

- OWF_Boundary
- Connection_Corridors

UXO THREATS

- WWII_Coastal_Artillery_Wrecks
- Atlantikwall_Features
- Atlantikwall_Range



PROJECT	PROJECT TITLE
8492_1	A04 NORMANDY

DRAWING TITLE
Atlantikwall

DRAWING NUMBER
A04 Normandy\010\V1.0

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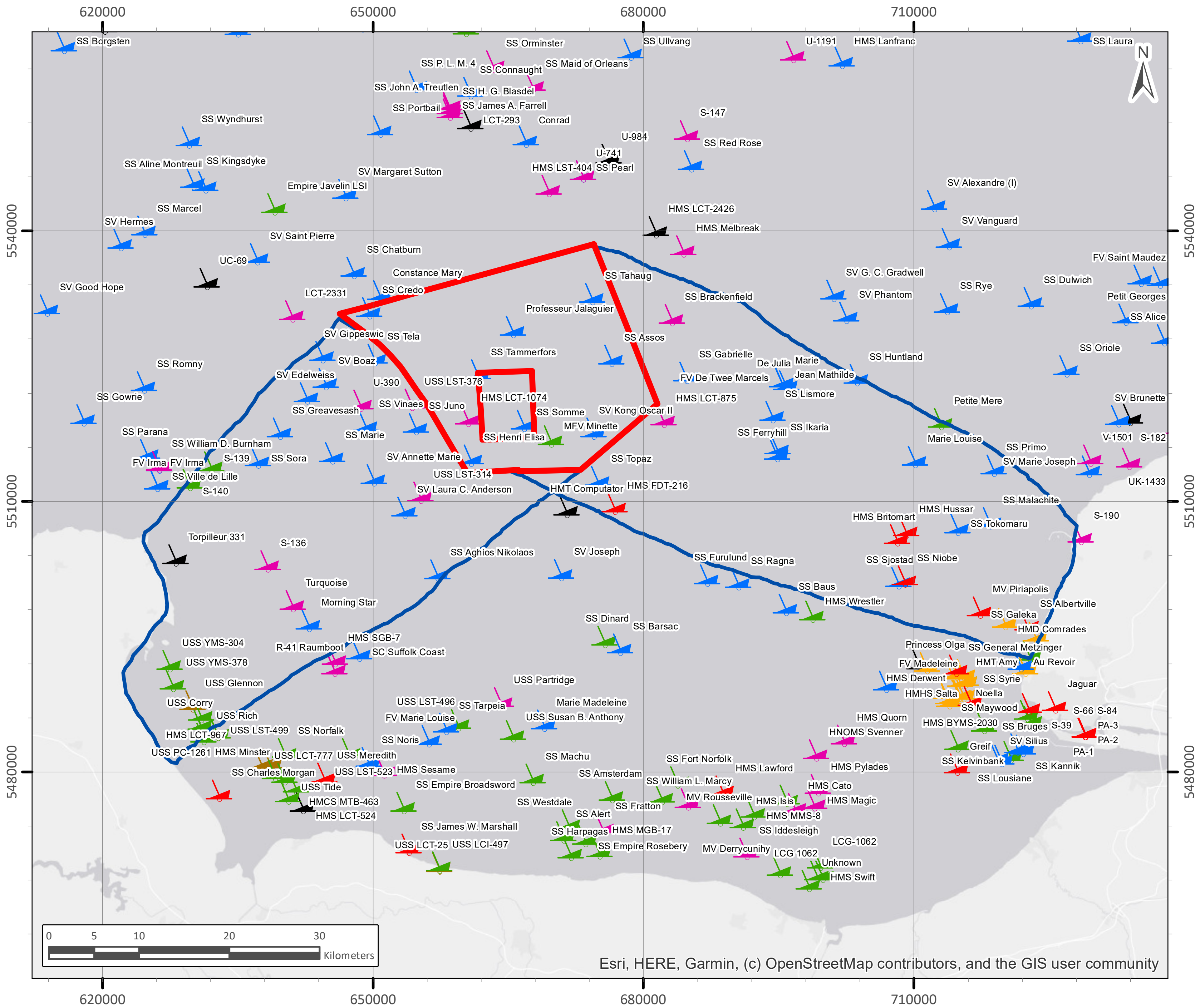
Appendix 11

Munitions Related Shipwrecks



LEGEND

GENERAL

OWF_Boundary

Connection_Corridors

UXO THREATS

WWI_Naval_Wrecks

WWI_Mined_Wrecks

WWII_Air-Raid_Wrecks

WWII_Naval_Wrecks

WWII_Mined_Wrecks

WWII_Coastal_Artillery_Wrecks

Other_Munitions_Wrecks

PROJECT	PROJECT TITLE
8492_1	A04 NORMANDY

DRAWING TITLE

Munitions Related Shipwrecks

DRAWING NUMBER

A04 Normandy\011\V1.0

PURPOSE

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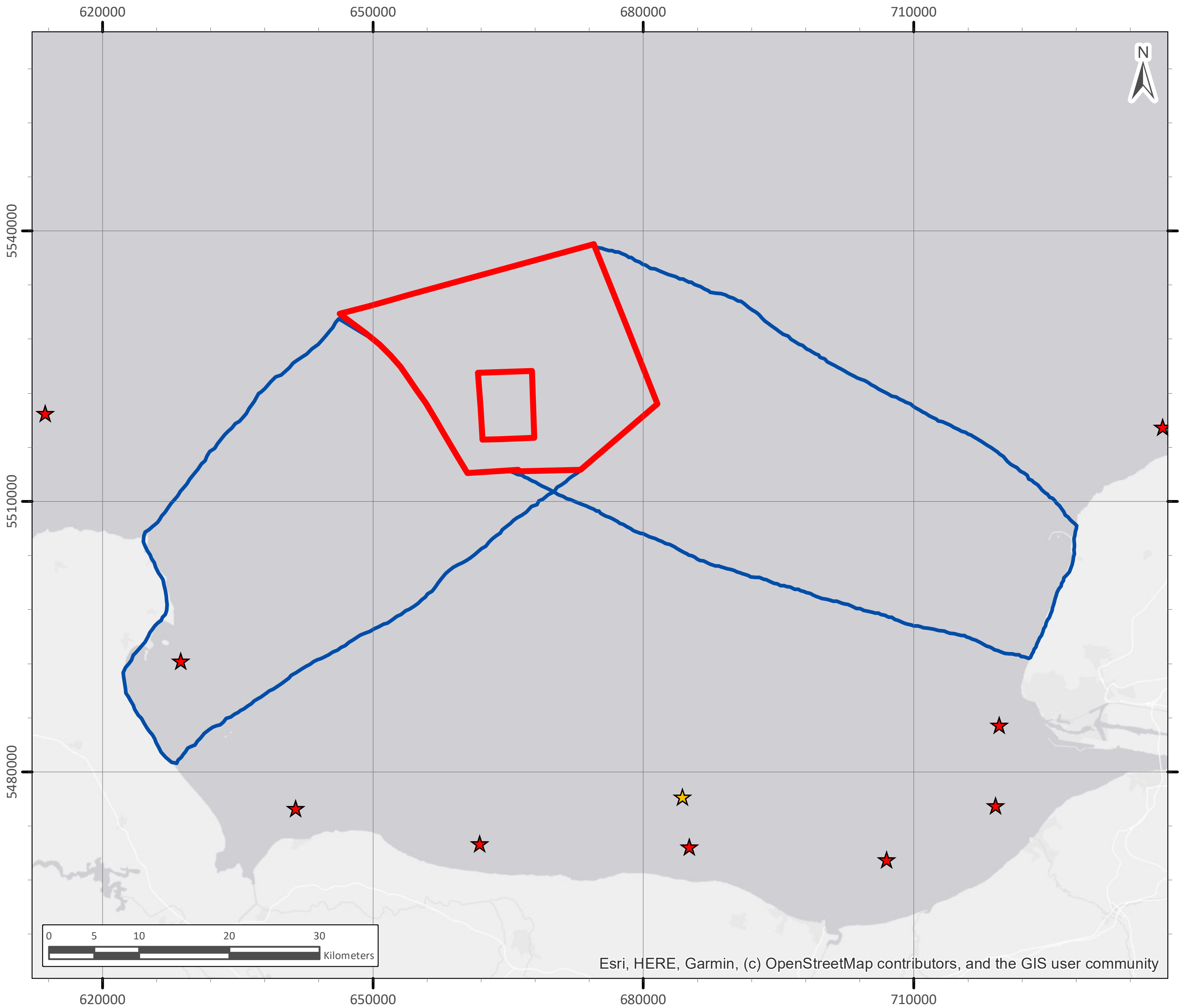
COORDINATE SYSTEM	SCALE	ORIGINAL PLOT SIZE	DRAWN	DATE DRAWN	CHECKED		
WGS 1984 UTM Zone 30N	1:600,000	A4	LH	08/01/2021	LG	Produced by and Copyright to 6 Alpha Associates Ltd. Users noticing any errors please forward to 6 Alpha.	W W W . 6 A L P H A . C O M E: enquiry@6alpha.com | T: +44 (0)203 371 3900

Appendix 12

Munitions Dumping



LEGEND

GENERAL

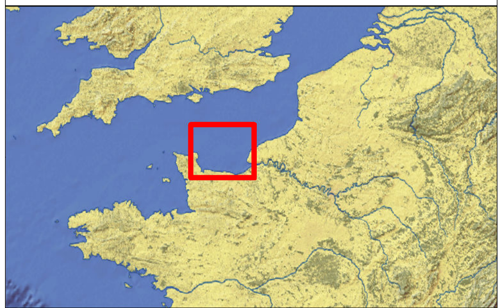
OWF_Boundary

Connection_Corridors

UXO THREATS

Chemical_Munitions_Dump

Conventional_Munitions_Dump



PROJECT	PROJECT TITLE
8492_1	A04 NORMANDY

DRAWING TITLE
Munitions Dumping

DRAWING NUMBER
A04 Normandy\012\V1.0

PURPOSE
FOR INFORMATION USE ONLY

COORDINATE SYSTEM	SCALE	ORIGINAL PLOT SIZE	DRAWN	DATE DRAWN	CHECKED
WGS 1984 UTM Zone 30N	1:600,000	A4	LH	22/12/2020	LG

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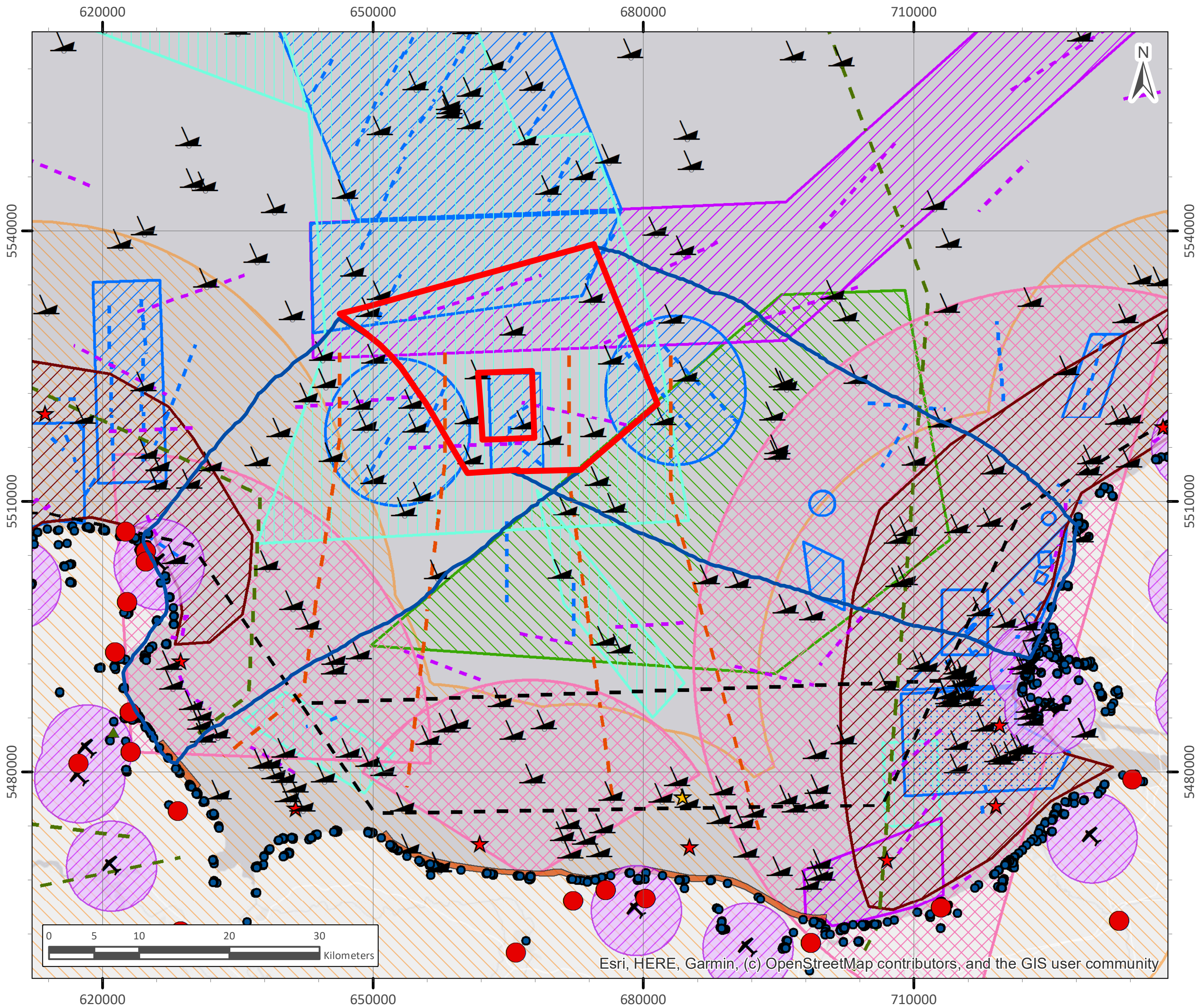
Appendix 13

Consolidated UXO Threat



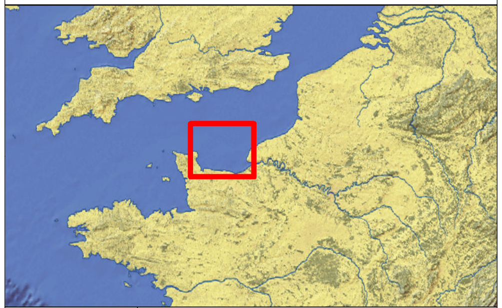
LEGEND

GENERAL

- OWF_Boundary
- Connection_Corridors

UXO THREATS

- WWII_Allied_Targets
- WWII_German_ROSA_Route
- Luftwaffe_Airfields
- Airfields_5km_Buffer
- Overlord_Allied_Airdrops
- Overlord_Glider_Routes
- Overlord_Sea_Routes
- Overlord_Landing_Beaches
- WWI_Central_Powers_Minefields
- WWII_Axis_Minelays
- WWII_Allied_Minelays
- WWII_Allied_Aerial_Minefields
- WWII_Allied_Minefields
- WWII_Axis_Minefields
- Historic_Firing_Ranges
- Minesweeping_Operations
- Firing_Exercise_Areas
- Atlantikwall_Features
- Atlantikwall_Range
- Munitions_Related_Shipwrecks
- Chemical_Munitions_Dump
- Conventional_Munitions_Dump



PROJECT	PROJECT TITLE
8492_1	A04 NORMANDY

DRAWING TITLE
Consolidated UXO Threat

DRAWING NUMBER
A04 Normandy\013\V1.0

PURPOSE
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Appendix 14

Semi-Quantitative Risk Assessment Tables

The tables produced on the following pages outline and display the numeric scored assessment for the project as well as the initial and residual UXO risk to each specific operation after mitigation measures have been appropriately applied. It is also important to note that the risk assessment for the GI, cable installation and wind turbine installation operations is conducted for each individual activity, irrespective of prior operations which may have taken place.

An explanation of the SQRA process and Azimuth risk matrix used by 6 Alpha Associates is presented at Annex E.

Risk (R) is calculated as a function of probability of encounter and initiation (P) and consequence of initiation (C), where R = P x C.

Geotechnical Investigation Operations

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
All GI (10m)	Large HE Bombs	253	3	5	15	1	5	5	3	5	15	1	5	5
	Medium WWII Naval Mines	227	3	5	15	1	5	5	3	5	15	1	5	5
	Medium HE Bombs	130	3	5	15	1	5	5	3	5	15	1	5	5
	Small HE Bombs	25	3	5	15	1	5	5	3	5	15	1	5	5
	Large WWII Naval Mines	943.5	1	5	5	1	5	5	1	5	5	1	5	5
	Large AAA Projectiles	5.44	2	4	8	1	4	4	2	4	8	1	4	4
	Small AAA Projectiles	0.34	2	2	4	1	2	2	2	3	6	1	3	3
	WWII Torpedoes	364	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Naval Mines	165	1	5	5	1	5	5	1	5	5	1	5	5

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Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
All GI (26m)	Large HE Bombs	253	3	5	15	1	5	5	3	5	15	1	5	5
	Medium WWII Naval Mines	227	3	5	15	1	5	5	3	5	15	1	5	5
	Medium HE Bombs	130	3	4	12	1	4	4	3	5	15	1	5	5
	Small HE Bombs	25	3	2	6	1	2	2	3	5	15	1	5	5
	Large WWII Naval Mines	943.5	1	5	5	1	5	5	1	5	5	1	5	5
	Large AAA Projectiles	5.44	2	2	4	1	2	2	2	4	8	1	4	4
	Small AAA Projectiles	0.34	2	1	2	1	1	1	2	3	6	1	3	3
	WWII Torpedoes	364	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Naval Mines	165	1	5	5	1	5	5	1	5	5	1	5	5

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Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
All GI (40m)	Large HE Bombs	253	3	3	9	1	3	3	3	5	15	1	5	5
	Medium WWII Naval Mines	227	3	3	9	1	3	3	3	5	15	1	5	5
	Medium HE Bombs	130	3	3	9	1	3	3	3	5	15	1	5	5
	Small HE Bombs	25	3	2	6	1	2	2	3	5	15	1	5	5
	Large WWII Naval Mines	943.5	1	5	5	1	5	5	1	5	5	1	5	5
	Large AAA Projectiles	5.44	2	1	2	1	1	1	2	4	8	1	4	4
	Small AAA Projectiles	0.34	2	1	2	1	1	1	2	3	6	1	3	3
	WWII Torpedoes	364	1	4	4	1	4	4	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	3	3	1	3	3	1	5	5	1	5	5
	WWI Naval Mines	165	1	3	3	1	3	3	1	5	5	1	5	5

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Pre-Lay Operations

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
PLGR + RC (10m)	Large HE Bombs	253	5	5	25	1	5	5	5	5	25	1	5	5
	Medium WWII Naval Mines	227	5	5	25	1	5	5	5	5	25	1	5	5
	Medium HE Bombs	130	5	5	25	1	5	5	5	5	25	1	5	5
	Small HE Bombs	25	5	5	25	1	5	5	5	5	25	1	5	5
	Large WWII Naval Mines	943.5	4	5	20	1	5	5	4	5	20	1	5	5
	Large AAA Projectiles	5.44	4	4	16	1	4	4	4	4	16	1	4	4
	Small AAA Projectiles	0.34	4	2	8	1	2	2	4	3	12	1	3	3
	WWII Torpedoes	364	2	5	10	1	5	5	2	5	10	1	5	5
	WWI Torpedoes	253.5	2	5	10	1	5	5	2	5	10	1	5	5
	WWI Naval Mines	165	2	5	10	1	5	5	2	5	10	1	5	5

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Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
PLGR + RC (26m)	Large HE Bombs	253	5	5	25	1	5	5	5	5	25	1	5	5
	Medium WWII Naval Mines	227	5	5	25	1	5	5	5	5	25	1	5	5
	Medium HE Bombs	130	5	4	20	1	4	4	5	5	25	1	5	5
	Small HE Bombs	25	5	2	10	1	2	2	5	5	25	1	5	5
	Large WWII Naval Mines	943.5	4	5	20	1	5	5	4	5	20	1	5	5
	Large AAA Projectiles	5.44	4	2	8	1	2	2	4	4	16	1	4	4
	Small AAA Projectiles	0.34	4	1	4	1	1	1	4	3	12	1	3	3
	WWII Torpedoes	364	2	5	10	1	5	5	2	5	10	1	5	5
	WWI Torpedoes	253.5	2	5	10	1	5	5	2	5	10	1	5	5
	WWI Naval Mines	165	2	5	10	1	5	5	2	5	10	1	5	5

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Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
PLGR + RC (40m)	Large HE Bombs	253	5	3	15	1	3	3	5	5	25	1	5	5
	Medium WWII Naval Mines	227	5	3	15	1	3	3	5	5	25	1	5	5
	Medium HE Bombs	130	5	3	15	1	3	3	5	5	25	1	5	5
	Small HE Bombs	25	5	2	10	1	2	2	5	5	25	1	5	5
	Large WWII Naval Mines	943.5	4	5	20	1	5	5	4	5	20	1	5	5
	Large AAA Projectiles	5.44	4	1	4	1	1	1	4	4	16	1	4	4
	Small AAA Projectiles	0.34	4	1	4	1	1	1	4	3	12	1	3	3
	WWII Torpedoes	364	2	4	8	1	4	4	2	5	10	1	5	5
	WWI Torpedoes	253.5	2	3	6	1	3	3	2	5	10	1	5	5
	WWI Naval Mines	165	2	3	6	1	3	3	2	5	10	1	5	5

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Cable Installation and Burial Operations

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Surface Lay (10m)	Large HE Bombs	253	3	5	15	1	5	5	3	5	15	1	5	5
	Medium WWII Naval Mines	227	3	5	15	1	5	5	3	5	15	1	5	5
	Medium HE Bombs	130	3	5	15	1	5	5	3	5	15	1	5	5
	Small HE Bombs	25	3	5	15	1	5	5	3	5	15	1	5	5
	Large WWII Naval Mines	943.5	2	5	10	1	5	5	2	5	10	1	5	5
	Large AAA Projectiles	5.44	2	4	8	1	4	4	2	4	8	1	4	4
	Small AAA Projectiles	0.34	2	2	4	1	2	2	2	3	6	1	3	3
	WWII Torpedoes	364	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Naval Mines	165	1	5	5	1	5	5	1	5	5	1	5	5

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Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Surface Lay (26m)	Large HE Bombs	253	3	5	15	1	5	5	3	5	15	1	5	5
	Medium WWII Naval Mines	227	3	5	15	1	5	5	3	5	15	1	5	5
	Medium HE Bombs	130	3	4	12	1	4	4	3	5	15	1	5	5
	Small HE Bombs	25	3	2	6	1	2	2	3	5	15	1	5	5
	Large WWII Naval Mines	943.5	2	5	10	1	5	5	2	5	10	1	5	5
	Large AAA Projectiles	5.44	2	2	4	1	2	2	2	4	8	1	4	4
	Small AAA Projectiles	0.34	2	1	2	1	1	1	2	3	6	1	3	3
	WWII Torpedoes	364	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Naval Mines	165	1	5	5	1	5	5	1	5	5	1	5	5

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Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Surface Lay (40m)	Large HE Bombs	253	3	3	9	1	3	3	3	5	15	1	5	5
	Medium WWII Naval Mines	227	3	3	9	1	3	3	3	5	15	1	5	5
	Medium HE Bombs	130	3	3	9	1	3	3	3	5	15	1	5	5
	Small HE Bombs	25	3	2	6	1	2	2	3	5	15	1	5	5
	Large WWII Naval Mines	943.5	2	5	10	1	5	5	2	5	10	1	5	5
	Large AAA Projectiles	5.44	2	1	2	1	1	1	2	4	8	1	4	4
	Small AAA Projectiles	0.34	2	1	2	1	1	1	2	3	6	1	3	3
	WWII Torpedoes	364	1	4	4	1	4	4	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	3	3	1	3	3	1	5	5	1	5	5
	WWI Naval Mines	165	1	3	3	1	3	3	1	5	5	1	5	5

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Jetting (10m)	Large HE Bombs	253	4	5	20	1	5	5	4	5	20	1	5	5
	Medium WWII Naval Mines	227	4	5	20	1	5	5	4	5	20	1	5	5
	Medium HE Bombs	130	4	5	20	1	5	5	4	5	20	1	5	5
	Small HE Bombs	25	4	5	20	1	5	5	4	5	20	1	5	5
	Large WWII Naval Mines	943.5	3	5	15	1	5	5	3	5	15	1	5	5
	Large AAA Projectiles	5.44	3	4	12	1	4	4	3	4	12	1	4	4
	Small AAA Projectiles	0.34	3	2	6	1	2	2	3	3	9	1	3	3
	WWII Torpedoes	364	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Naval Mines	165	1	5	5	1	5	5	1	5	5	1	5	5

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Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Jetting (26m)	Large HE Bombs	253	4	5	20	1	5	5	4	5	20	1	5	5
	Medium WWII Naval Mines	227	4	5	20	1	5	5	4	5	20	1	5	5
	Medium HE Bombs	130	4	4	16	1	4	4	4	5	20	1	5	5
	Small HE Bombs	25	4	2	8	1	2	2	4	5	20	1	5	5
	Large WWII Naval Mines	943.5	3	5	15	1	5	5	3	5	15	1	5	5
	Large AAA Projectiles	5.44	3	2	6	1	2	2	3	4	12	1	4	4
	Small AAA Projectiles	0.34	3	1	3	1	1	1	3	3	9	1	3	3
	WWII Torpedoes	364	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Naval Mines	165	1	5	5	1	5	5	1	5	5	1	5	5

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Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Jetting (40m)	Large HE Bombs	253	4	3	12	1	3	3	4	5	20	1	5	5
	Medium WWII Naval Mines	227	4	3	12	1	3	3	4	5	20	1	5	5
	Medium HE Bombs	130	4	3	12	1	3	3	4	5	20	1	5	5
	Small HE Bombs	25	4	2	8	1	2	2	4	5	20	1	5	5
	Large WWII Naval Mines	943.5	3	5	15	1	5	5	3	5	15	1	5	5
	Large AAA Projectiles	5.44	3	1	3	1	1	1	3	4	12	1	4	4
	Small AAA Projectiles	0.34	3	1	3	1	1	1	3	3	9	1	3	3
	WWII Torpedoes	364	1	4	4	1	4	4	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	3	3	1	3	3	1	5	5	1	5	5
	WWI Naval Mines	165	1	3	3	1	3	3	1	5	5	1	5	5

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Ploughing (10m)	Large HE Bombs	253	5	5	25	1	5	5	5	5	25	1	5	5
	Medium WWII Naval Mines	227	5	5	25	1	5	5	5	5	25	1	5	5
	Medium HE Bombs	130	5	5	25	1	5	5	5	5	25	1	5	5
	Small HE Bombs	25	5	5	25	1	5	5	5	5	25	1	5	5
	Large WWII Naval Mines	943.5	4	5	20	1	5	5	4	5	20	1	5	5
	Large AAA Projectiles	5.44	4	4	16	1	4	4	4	4	16	1	4	4
	Small AAA Projectiles	0.34	4	2	8	1	2	2	4	3	12	1	3	3
	WWII Torpedoes	364	2	5	10	1	5	5	2	5	10	1	5	5
	WWI Torpedoes	253.5	2	5	10	1	5	5	2	5	10	1	5	5
	WWI Naval Mines	165	2	5	10	1	5	5	2	5	10	1	5	5

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Ploughing (26m)	Large HE Bombs	253	5	5	25	1	5	5	5	5	25	1	5	5
	Medium WWII Naval Mines	227	5	5	25	1	5	5	5	5	25	1	5	5
	Medium HE Bombs	130	5	4	20	1	4	4	5	5	25	1	5	5
	Small HE Bombs	25	5	2	10	1	2	2	5	5	25	1	5	5
	Large WWII Naval Mines	943.5	4	5	20	1	5	5	4	5	20	1	5	5
	Large AAA Projectiles	5.44	4	2	8	1	2	2	4	4	16	1	4	4
	Small AAA Projectiles	0.34	4	1	4	1	1	1	4	3	12	1	3	3
	WWII Torpedoes	364	2	5	10	1	5	5	2	5	10	1	5	5
	WWI Torpedoes	253.5	2	5	10	1	5	5	2	5	10	1	5	5
	WWI Naval Mines	165	2	5	10	1	5	5	2	5	10	1	5	5

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Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Ploughing (40m)	Large HE Bombs	253	5	3	15	1	3	3	5	5	25	1	5	5
	Medium WWII Naval Mines	227	5	3	15	1	3	3	5	5	25	1	5	5
	Medium HE Bombs	130	5	3	15	1	3	3	5	5	25	1	5	5
	Small HE Bombs	25	5	2	10	1	2	2	5	5	25	1	5	5
	Large WWII Naval Mines	943.5	4	5	20	1	5	5	4	5	20	1	5	5
	Large AAA Projectiles	5.44	4	1	4	1	1	1	4	4	16	1	4	4
	Small AAA Projectiles	0.34	4	1	4	1	1	1	4	3	12	1	3	3
	WWII Torpedoes	364	2	4	8	1	4	4	2	5	10	1	5	5
	WWI Torpedoes	253.5	2	3	6	1	3	3	2	5	10	1	5	5
	WWI Naval Mines	165	2	3	6	1	3	3	2	5	10	1	5	5

Wind Turbine Installation Operations

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Piling (10m)	Large HE Bombs	253	4	5	20	1	5	5	4	5	20	1	5	5
	Medium WWII Naval Mines	227	4	5	20	1	5	5	4	5	20	1	5	5
	Medium HE Bombs	130	4	5	20	1	5	5	4	5	20	1	5	5
	Small HE Bombs	25	4	5	20	1	5	5	4	5	20	1	5	5
	Large WWII Naval Mines	943.5	3	5	15	1	5	5	3	5	15	1	5	5
	Large AAA Projectiles	5.44	3	4	12	1	4	4	3	4	12	1	4	4
	Small AAA Projectiles	0.34	3	2	6	1	2	2	3	3	9	1	3	3
	WWII Torpedoes	364	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Naval Mines	165	1	5	5	1	5	5	1	5	5	1	5	5

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Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Piling (26m)	Large HE Bombs	253	4	5	20	1	5	5	4	5	20	1	5	5
	Medium WWII Naval Mines	227	4	5	20	1	5	5	4	5	20	1	5	5
	Medium HE Bombs	130	4	4	16	1	4	4	4	5	20	1	5	5
	Small HE Bombs	25	4	2	8	1	2	2	4	5	20	1	5	5
	Large WWII Naval Mines	943.5	3	5	15	1	5	5	3	5	15	1	5	5
	Large AAA Projectiles	5.44	3	2	6	1	2	2	3	4	12	1	4	4
	Small AAA Projectiles	0.34	3	1	3	1	1	1	3	3	9	1	3	3
	WWII Torpedoes	364	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Naval Mines	165	1	5	5	1	5	5	1	5	5	1	5	5

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Piling (40m)	Large HE Bombs	253	4	3	12	1	3	3	4	5	20	1	5	5
	Medium WWII Naval Mines	227	4	3	12	1	3	3	4	5	20	1	5	5
	Medium HE Bombs	130	4	3	12	1	3	3	4	5	20	1	5	5
	Small HE Bombs	25	4	2	8	1	2	2	4	5	20	1	5	5
	Large WWII Naval Mines	943.5	3	5	15	1	5	5	3	5	15	1	5	5
	Large AAA Projectiles	5.44	3	1	3	1	1	1	3	4	12	1	4	4
	Small AAA Projectiles	0.34	3	1	3	1	1	1	3	3	9	1	3	3
	WWII Torpedoes	364	1	4	4	1	4	4	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	3	3	1	3	3	1	5	5	1	5	5
	WWI Naval Mines	165	1	3	3	1	3	3	1	5	5	1	5	5

Cable and Wind Turbine Protection Operations

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Rock Emplacement (10m)	Large HE Bombs	253	4	5	20	1	5	5	4	5	20	1	5	5
	Medium WWII Naval Mines	227	4	5	20	1	5	5	4	5	20	1	5	5
	Medium HE Bombs	130	4	5	20	1	5	5	4	5	20	1	5	5
	Small HE Bombs	25	4	5	20	1	5	5	4	5	20	1	5	5
	Large WWII Naval Mines	943.5	3	5	15	1	5	5	3	5	15	1	5	5
	Large AAA Projectiles	5.44	3	4	12	1	4	4	3	4	12	1	4	4
	Small AAA Projectiles	0.34	3	2	6	1	2	2	3	3	9	1	3	3
	WWII Torpedoes	364	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Naval Mines	165	1	5	5	1	5	5	1	5	5	1	5	5

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Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Rock Emplacement (26m)	Large HE Bombs	253	4	5	20	1	5	5	4	5	20	1	5	5
	Medium WWII Naval Mines	227	4	5	20	1	5	5	4	5	20	1	5	5
	Medium HE Bombs	130	4	4	16	1	4	4	4	5	20	1	5	5
	Small HE Bombs	25	4	2	8	1	2	2	4	5	20	1	5	5
	Large WWII Naval Mines	943.5	3	5	15	1	5	5	3	5	15	1	5	5
	Large AAA Projectiles	5.44	3	2	6	1	2	2	3	4	12	1	4	4
	Small AAA Projectiles	0.34	3	1	3	1	1	1	3	3	9	1	3	3
	WWII Torpedoes	364	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Naval Mines	165	1	5	5	1	5	5	1	5	5	1	5	5

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Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Rock Emplacement (40m)	Large HE Bombs	253	4	3	12	1	3	3	4	5	20	1	5	5
	Medium WWII Naval Mines	227	4	3	12	1	3	3	4	5	20	1	5	5
	Medium HE Bombs	130	4	3	12	1	3	3	4	5	20	1	5	5
	Small HE Bombs	25	4	2	8	1	2	2	4	5	20	1	5	5
	Large WWII Naval Mines	943.5	3	5	15	1	5	5	3	5	15	1	5	5
	Large AAA Projectiles	5.44	3	1	3	1	1	1	3	4	12	1	4	4
	Small AAA Projectiles	0.34	3	1	3	1	1	1	3	3	9	1	3	3
	WWII Torpedoes	364	1	4	4	1	4	4	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	3	3	1	3	3	1	5	5	1	5	5
	WWI Naval Mines	165	1	3	3	1	3	3	1	5	5	1	5	5

Enabling Operations

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Anchoring (10m)	Large HE Bombs	253	3	5	15	1	5	5	3	5	15	1	5	5
	Medium WWII Naval Mines	227	3	5	15	1	5	5	3	5	15	1	5	5
	Medium HE Bombs	130	3	5	15	1	5	5	3	5	15	1	5	5
	Small HE Bombs	25	3	5	15	1	5	5	3	5	15	1	5	5
	Large WWII Naval Mines	943.5	2	5	10	1	5	5	2	5	10	1	5	5
	Large AAA Projectiles	5.44	2	4	8	1	4	4	2	4	8	1	4	4
	Small AAA Projectiles	0.34	2	2	4	1	2	2	2	3	6	1	3	3
	WWII Torpedoes	364	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Naval Mines	165	1	5	5	1	5	5	1	5	5	1	5	5

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Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Anchoring (26m)	Large HE Bombs	253	3	5	15	1	5	5	3	5	15	1	5	5
	Medium WWII Naval Mines	227	3	5	15	1	5	5	3	5	15	1	5	5
	Medium HE Bombs	130	3	4	12	1	4	4	3	5	15	1	5	5
	Small HE Bombs	25	3	2	6	1	2	2	3	5	15	1	5	5
	Large WWII Naval Mines	943.5	2	5	10	1	5	5	2	5	10	1	5	5
	Large AAA Projectiles	5.44	2	2	4	1	2	2	2	4	8	1	4	4
	Small AAA Projectiles	0.34	2	1	2	1	1	1	2	3	6	1	3	3
	WWII Torpedoes	364	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Naval Mines	165	1	5	5	1	5	5	1	5	5	1	5	5

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Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Anchoring (40m)	Large HE Bombs	253	3	3	9	1	3	3	3	5	15	1	5	5
	Medium WWII Naval Mines	227	3	3	9	1	3	3	3	5	15	1	5	5
	Medium HE Bombs	130	3	3	9	1	3	3	3	5	15	1	5	5
	Small HE Bombs	25	3	2	6	1	2	2	3	5	15	1	5	5
	Large WWII Naval Mines	943.5	2	5	10	1	5	5	2	5	10	1	5	5
	Large AAA Projectiles	5.44	2	1	2	1	1	1	2	4	8	1	4	4
	Small AAA Projectiles	0.34	2	1	2	1	1	1	2	3	6	1	3	3
	WWII Torpedoes	364	1	4	4	1	4	4	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	3	3	1	3	3	1	5	5	1	5	5
	WWI Naval Mines	165	1	3	3	1	3	3	1	5	5	1	5	5

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Jack-Up Barge (10m)	Large HE Bombs	253	4	5	20	1	5	5	4	5	20	1	5	5
	Medium WWII Naval Mines	227	4	5	20	1	5	5	4	5	20	1	5	5
	Medium HE Bombs	130	4	5	20	1	5	5	4	5	20	1	5	5
	Small HE Bombs	25	4	5	20	1	5	5	4	5	20	1	5	5
	Large WWII Naval Mines	943.5	3	5	15	1	5	5	3	5	15	1	5	5
	Large AAA Projectiles	5.44	3	4	12	1	4	4	3	4	12	1	4	4
	Small AAA Projectiles	0.34	3	2	6	1	2	2	3	3	9	1	3	3
	WWII Torpedoes	364	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Naval Mines	165	1	5	5	1	5	5	1	5	5	1	5	5

Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Jack-Up Barge (26m)	Large HE Bombs	253	4	5	20	1	5	5	4	5	20	1	5	5
	Medium WWII Naval Mines	227	4	5	20	1	5	5	4	5	20	1	5	5
	Medium HE Bombs	130	4	4	16	1	4	4	4	5	20	1	5	5
	Small HE Bombs	25	4	2	8	1	2	2	4	5	20	1	5	5
	Large WWII Naval Mines	943.5	3	5	15	1	5	5	3	5	15	1	5	5
	Large AAA Projectiles	5.44	3	2	6	1	2	2	3	4	12	1	4	4
	Small AAA Projectiles	0.34	3	1	3	1	1	1	3	3	9	1	3	3
	WWII Torpedoes	364	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	5	5	1	5	5	1	5	5	1	5	5
	WWI Naval Mines	165	1	5	5	1	5	5	1	5	5	1	5	5

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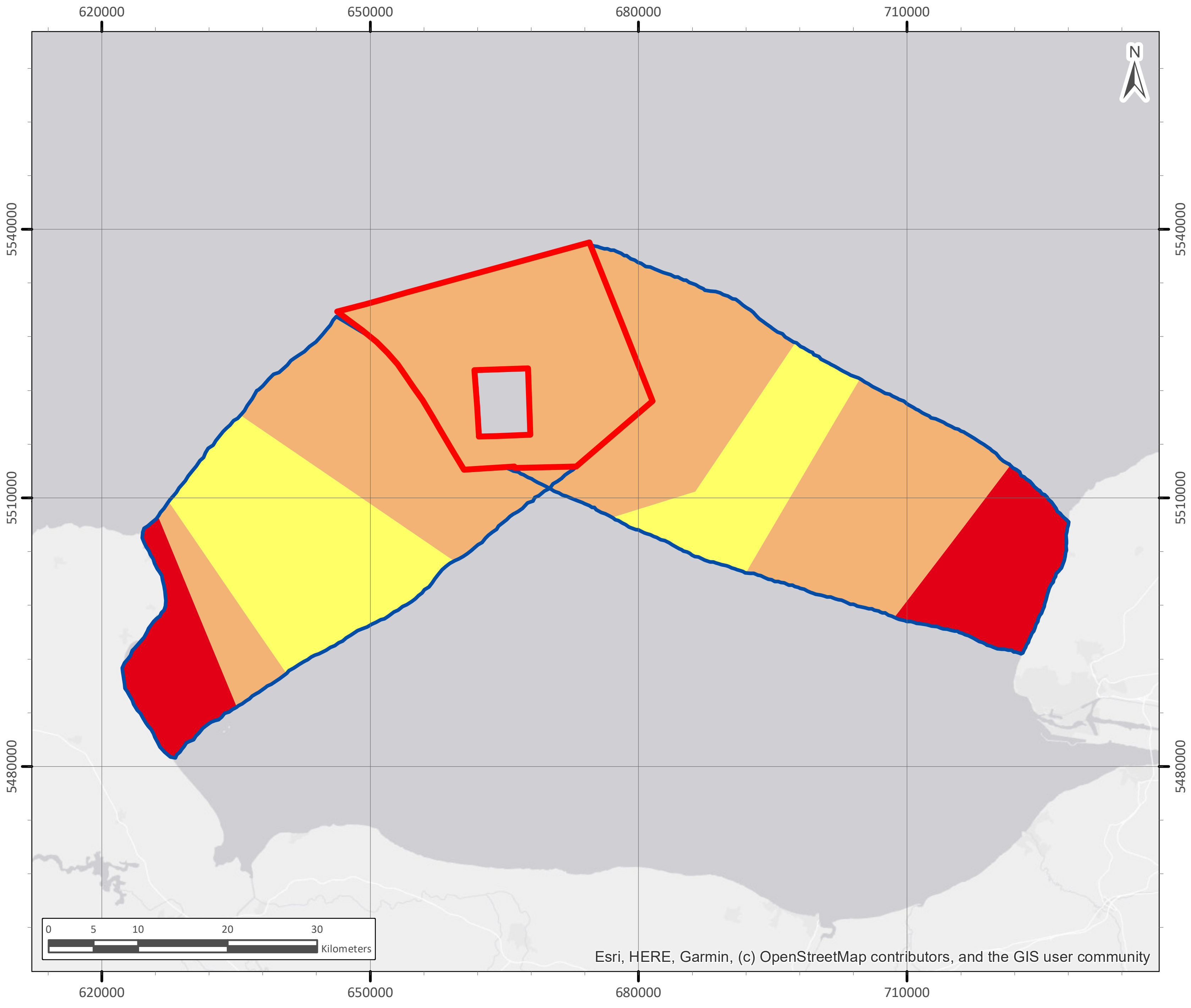
Activity	UXO Threat Item	Assessed NEQ (kg TNT)	UXO Risk to Vessel/Personnel						UXO Risk to Underwater Equipment					
			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level			Initial UXO Risk Level			Recommended Mitigated UXO Risk Level		
			P	C	R	P	C	R	P	C	R	P	C	R
Jack-Up Barge (40m)	Large HE Bombs	253	4	3	12	1	3	3	4	5	20	1	5	5
	Medium WWII Naval Mines	227	4	3	12	1	3	3	4	5	20	1	5	5
	Medium HE Bombs	130	4	3	12	1	3	3	4	5	20	1	5	5
	Small HE Bombs	25	4	2	8	1	2	2	4	5	20	1	5	5
	Large WWII Naval Mines	943.5	3	5	15	1	5	5	3	5	15	1	5	5
	Large AAA Projectiles	5.44	3	1	3	1	1	1	3	4	12	1	4	4
	Small AAA Projectiles	0.34	3	1	3	1	1	1	3	3	9	1	3	3
	WWII Torpedoes	364	1	4	4	1	4	4	1	5	5	1	5	5
	WWI Torpedoes	253.5	1	3	3	1	3	3	1	5	5	1	5	5
	WWI Naval Mines	165	1	3	3	1	3	3	1	5	5	1	5	5

Appendix 15

UXO Risk Zones: All Operations



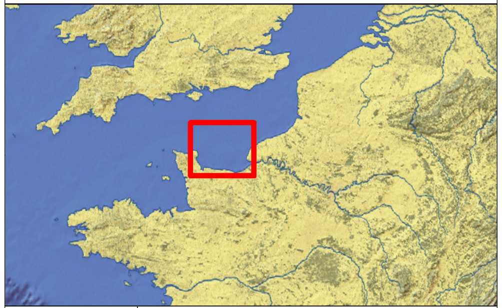
LEGEND

GENERAL

- OWF_Boundary
- Connection_Corridors

Risk_Rating

- VERY HIGH
- HIGH
- MEDIUM



PROJECT	PROJECT TITLE
8492_1	A04 NORMANDY

DRAWING TITLE
UXO Risk Zones: GI and Installation Operations

DRAWING NUMBER
A04 Normandy\015\V1.0

PURPOSE
FOR INFORMATION USE ONLY

alpha ASSOCIATES
special risks consultancy

COORDINATE SYSTEM	SCALE	ORIGINAL PLOT SIZE	DRAWN	DATE DRAWN	CHECKED
WGS 1984 UTM Zone 30N	1:600,000	A4	LH	15/02/2021	LG

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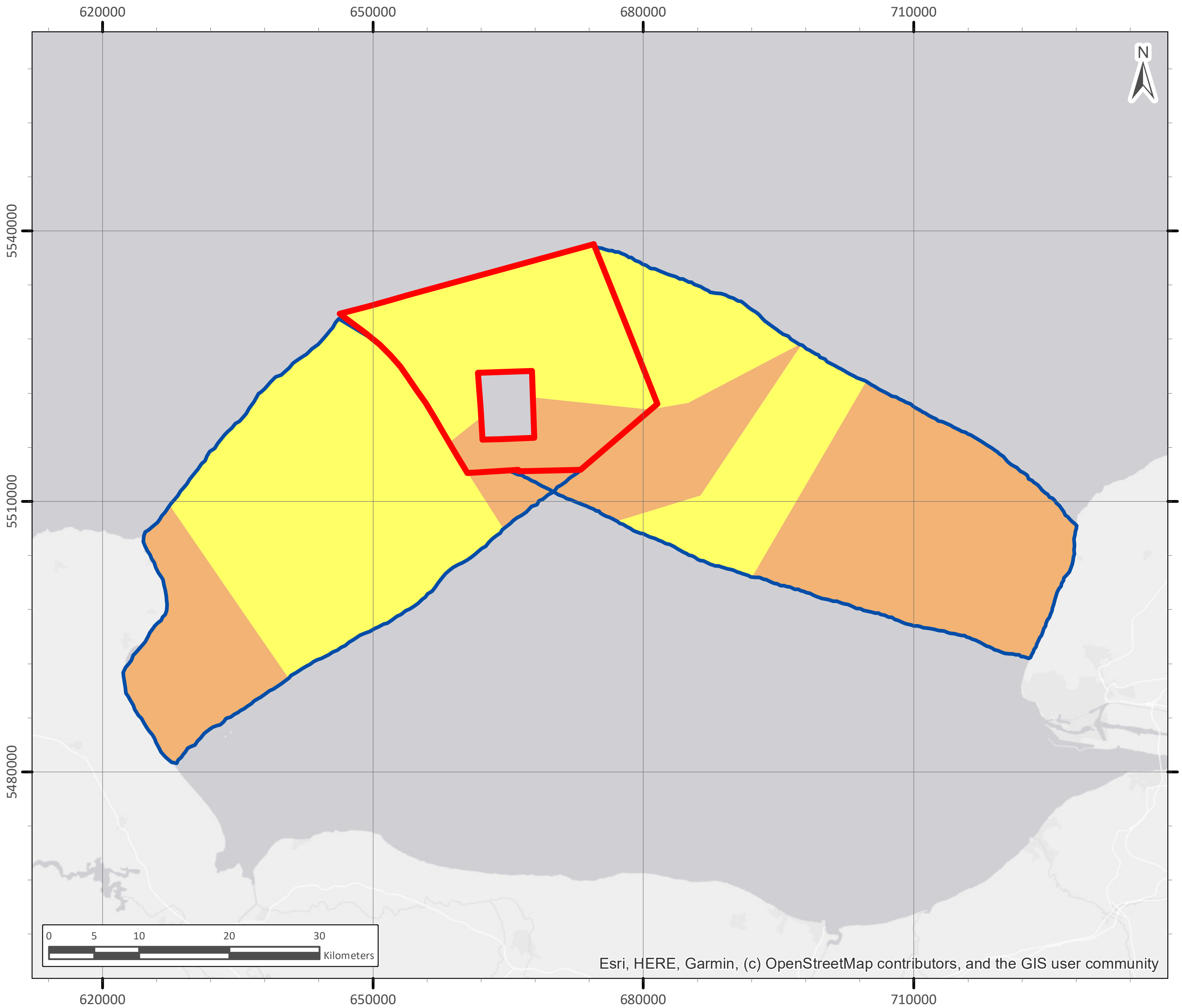
Appendix 16

UXO Risk Zones: GI Only



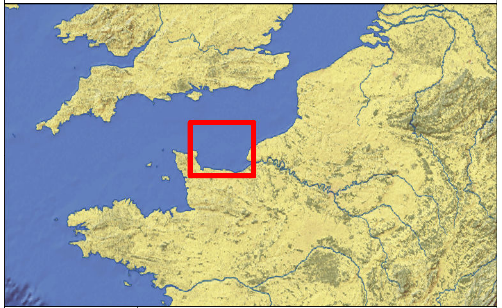
LEGEND

GENERAL

- OWF_Boundary
- Connection_Corridors

Risk_Rating

- HIGH
- MEDIUM



PROJECT	PROJECT TITLE
8492_1	A04 NORMANDY

DRAWING TITLE
UXO Risk Zones: GI Operations Only

DRAWING NUMBER
A04 Normandy\016\V1.0

PURPOSE
FOR INFORMATION USE ONLY

alpha ASSOCIATES
special risks consultancy

COORDINATE SYSTEM	SCALE	ORIGINAL PLOT SIZE	DRAWN	DATE DRAWN	CHECKED
WGS 1984 UTM Zone 30N	1:600,000	A4	LH	15/02/2021	LG

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Appendix 17

Holistic Risk Management Process

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.

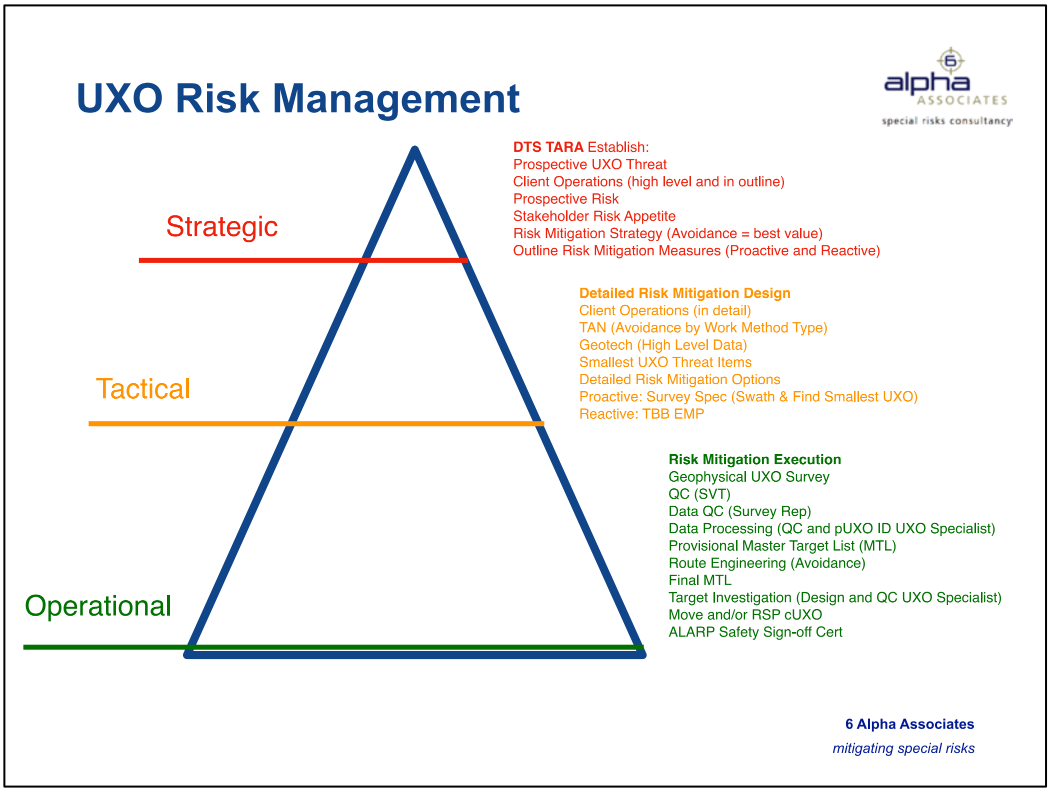

Figure 1: 6 Alpha UXO Risk Management - Concept

DETAIL

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.

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 pipeline 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** eg:
        - Site Emergency Management Plans (EMP);
        - Tool Box Briefs (TBB) for site workers.

Operational Level - Delivery of UXO Risk Management 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.

Annex A

Legislation and UXO Risk Management

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Contents

1 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 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).

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.

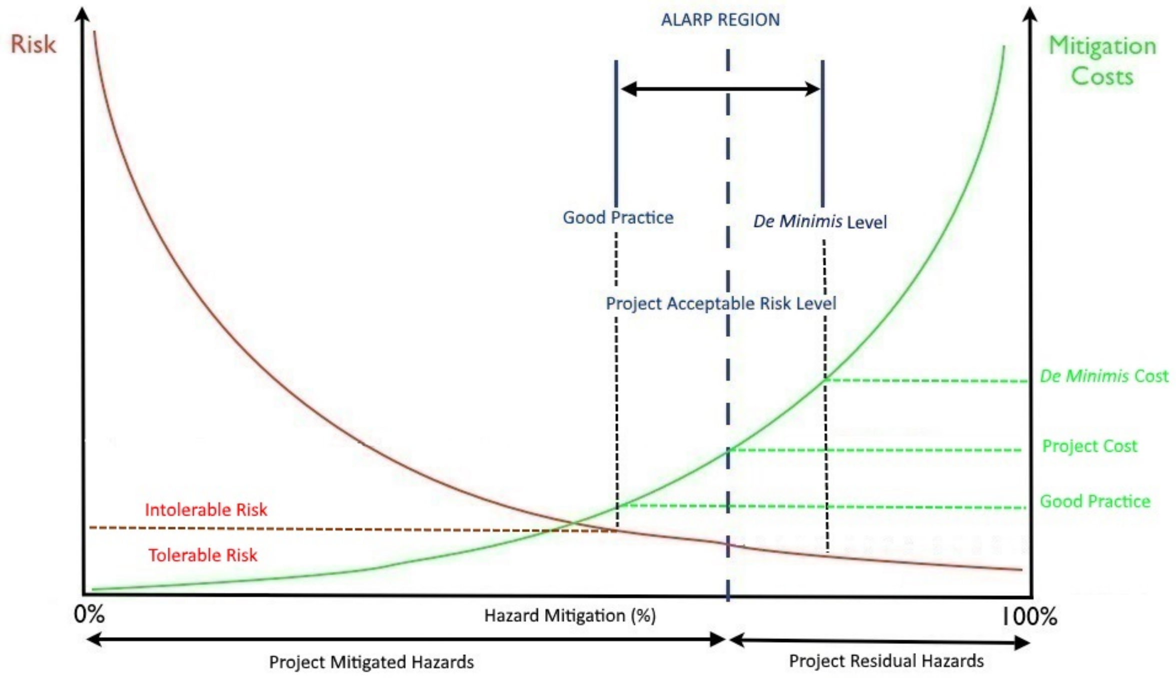

Figure 1: The ALARP principle of managing risk.

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 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

Classification of UXO

Contents

1 Classification of Unexploded Ordnance

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

Unexploded ordnance 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 Charge

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 Torpedo

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 C

UXO Discovery, Detonation and Sympathetic Detonation Risks

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1 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 *English Channel* and the *Baie de Seine* proved to be a crucial naval theatre of war in both WWI and WWII. Numerous naval 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, the *English Channel* also lay under the flight path of fighter and bomber aircraft during WWII, in addition to the *D-Day Landings* across the beaches of *Normandy*. This 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 *North Sea* 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 the *English Channel* to this day, as demonstrated by the following publicly accessible news article summarising encounters with historic munitions.

NEUTRALISATION D'UNE MINE D'UNE TONNE EN BAIE DE SEINE

Neutralisation d'une mine d'une tonne en Baie de Seine

Chasseur de mines Croix du Sud

La mine de type LMB (Luft Mine Bomb) contenant l'équivalent de 850 kg de TNT avait été chalutée par un navire de pêche et remise à l'eau.

Le 30 août, le chasseur de mines de la marine nationale Croix du Sud a procédé à sa relocalisation et à sa destruction.

Préfecture maritime de la Manche et de la mer du Nord, *Neutralisation d'une mine d'une tonne en Baie de Seine*, 30th August 2014.
https://www.premar-manche.gouv.fr/galerie/videos/neutralisation-d-une-mine-d-une-tonne-en-baie-de-seine

French homes evacuated as bomb defused

August 14, 2009 – 7.12pm

Save Share A A A

Two thousand people have been evacuated from their homes in the French port of Le Havre as mine clearance experts made safe a 500kg British bomb from World War II.

The bomb was dealt with on Friday after being uncovered earlier this month during construction work in the northern city, where unexploded ordnance is frequently found from the Allied blitz when it was occupied by the Germans during the war.

In the northwestern port of Brest, 1,500 people were due to be temporarily moved out of their homes this weekend during an operation to rid the city of World War II ordnance.

About 16,000 residents of Brest were evacuated from the city on August 2 for an earlier stage of the same operation.

The Sydney Morning Herald, *French homes evacuated as bomb defused*, 14th August 2009.
https://www.smh.com.au/world/french-homes-evacuated-as-bomb-defused-20090814-el3c.html

Une bombe américaine et une mine allemande neutralisées par la Marine nationale au large du Havre

Vendredi 24 avril 2020 à 16:34 - Par Bénédicte Courret, France Bleu Normandie (Seine-Maritime - Eure), France Bleu Cotentin, France Bleu Normandie (Calvados - Orne), France Bleu

Un navire "chasseur de mines" de la Marine nationale a repéré et neutralisé cette semaine une bombe américaine et une mine allemande au large du Havre.

Les deux munitions ont été "contreminées" le 22 avril par les plongeurs démineurs de la Cassiopée pour un équivalent de 126 kg concernant la bombe US et 837 kg pour la mine allemande, soit 963 kg d'équivalent TNT au total. - Marine nationale

On apprend ce vendredi qu'un navire chasseur de mines de la Marine nationale, la *Cassiopée*, a découvert en début de semaine, les 20 et 21 avril 2020, **une bombe américaine de 500 livres et une mine allemande BM 1000 au large du Havre.** Les deux munitions ont été "contreminées" le 22 avril par les plongeurs démineurs de la *Cassiopée* pour un équivalent de 126 kg concernant la bombe US et 837 kg pour la mine allemande, soit **963 kg d'équivalent TNT au total.**

Des sous-marins filoguidés pour identifier les engins explosifs

La *Cassiopée* utilise ce qui s'appelle **des poissons auto-propulsés** (PAP) pour rechercher les engins explosifs disparus le plus souvent pendant la Seconde Guerre mondiale. Les PAP sont de petits sous-marins filoguidés. Ils permettent d'identifier et si nécessaire de neutraliser une mine par dépose d'engins explosifs jusqu'à 150 mètres de profondeur.

Les plongeurs du Cassiopée ont mené les opérations de déminage ce mercredi. - Marine nationale

Bénédicte Courret, *Une bombe américaine et une mine allemande neutralisées par la Marine nationale au large du Havre*, 24th April 2020.
https://www.francebleu.fr/infos/faits-divers-justice/une-bombe-americaine-et-une-mine-allemande-neutralisees-par-la-marine-nationale-au-large-du-havre-1587738757

Annex D

Ordnance Burial, Scour and Migration

1 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 ALARP sign-off certificate, as well as the expansion size of the avoidance radii.

1.2 Physical Environment

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.

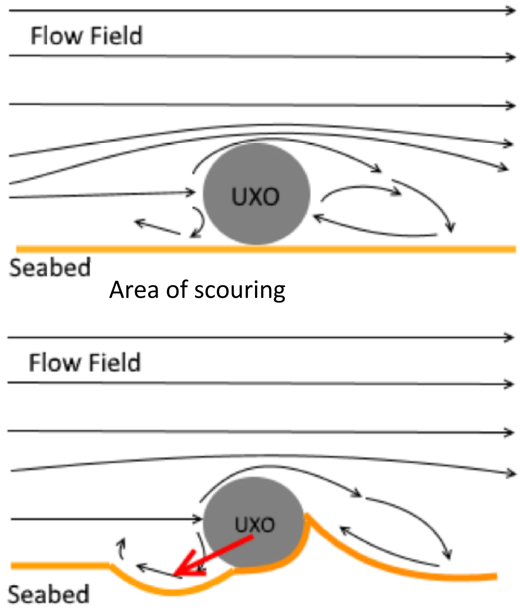
UXO can become buried, either by penetrating the seabed upon its initial deployment (subject to its residual energy upon impact with the seabed) or subsequently, over time, because of scour. UXO items that do become partially or fully buried are unlikely to migrate any further, due to requiring a significantly 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.

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: 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 E

Semi-Quantitative Risk Assessment Methodology

Contents

1 Semi-Quantitative Risk Assessment

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:

$$\mathbf{R = P \times C}.$$

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.

Likelihood		Consequences – 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 Remote	1 Very Low	2 Low	3 Low	4 Low	5 Low

Table 1: *6 Alpha Associates*' UXO Risk Matrix

The numerical values assigned to the UXO risk are compared to Table 2, 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 to Achieve UXO Risks ALARP
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	Tolerable	
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.
12-16	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.
20-25	Very High Risk		

Table 2: *6 Alpha Associates*' Project Risk Tolerability

1.3 Calculating the Project's Probability of Encounter and Initation

At the strategic level, and for risk assessment purposes, *6 Alpha Associates* 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 3 below.

Probability of UXO Contamination	Likelihood Score	Description (Based on a 5km Assessment Distance)
Remote	1	There is no indication of historical or modern ordnance activity or discovered ordnance **5km from the Study Site's boundary.** Potential ordnance 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 an ordnance dump) from 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 an ordnance dump) from 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 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 Projects 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 5, which provides the final consequence calculation for entry into the risk matrix (Szturomski, 2015).

Peak Pressure (MPa)	Consequence Rating	Consequence Score	Description
0 – 2.0	Negligible	1	Likely to be safe for all vessels. Damage to underwater equipment will be influenced by the robustness of such equipment and its internal mechanisms.
2.0 – 4.0	Minor	2	There may be minor damage to weak or brittle materials but serious damage and injuries to any personnel are highly unlikely. Damage to underwater equipment will be influenced by the robustness of such equipment and its internal mechanisms.
4.0 – 6.0	Moderate	3	Light vessel damage and light injuries to personnel may occur. There is also the prospect of light damage to underwater equipment.
6.0 – 8.0	Major	4	Serious vessel damage and serious injuries to personnel aboard. Serious damage to underwater equipment is also likely.
More than 8.0	Severe	5	Catastrophic vessel damage, multiple injuries and fatalities to personnel aboard. Catastrophic damage to underwater equipment is likely.

Table 5: Consequence Rating of an unplanned UXO 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 F

Explosives and Detonation Effects

Contents

1 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 World War One and Two (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

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.

UXO Detection Methods

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Contents

1 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 (ROX) 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

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 Methods

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 $1/r^6$ compared to a total magnetic field falloff rate of $1/r^3$ (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 insonify and 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.