GREEN VOLT

Technical Appendix 5.4

Unexploded Ordnance Risk Mitigation Strategy

Offshore EIA Report: Volume 2

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Unexploded Ordnance Risk Mitigation Strategy

FLOTATION ENERGY

Project: *Green Volt Offshore Wind Farm*

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 risk mitigation strategy is considered a living document. Should the proposed intrusive works change, further evidence of UXO sources be found, or if UXO is 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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1.0	20/05/2022	LH	LH	SC	LG
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Executive Summary

Project Overview

Flotation Energy has commissioned *6 Alpha Associates* to deliver a desk-based Unexploded Ordnance (UXO) Risk Mitigation Strategy (RMS), to support the development of the *Green Volt* Offshore Wind Farm (OWF) and associated cable installations. A Threat and Risk Assessment has already been completed and was delivered on the 5th May 2022.

The proposed location of *Green Volt OWF* array, together with the proposed export cable corridors, has been provided by the Client and is presented at Figure 1.

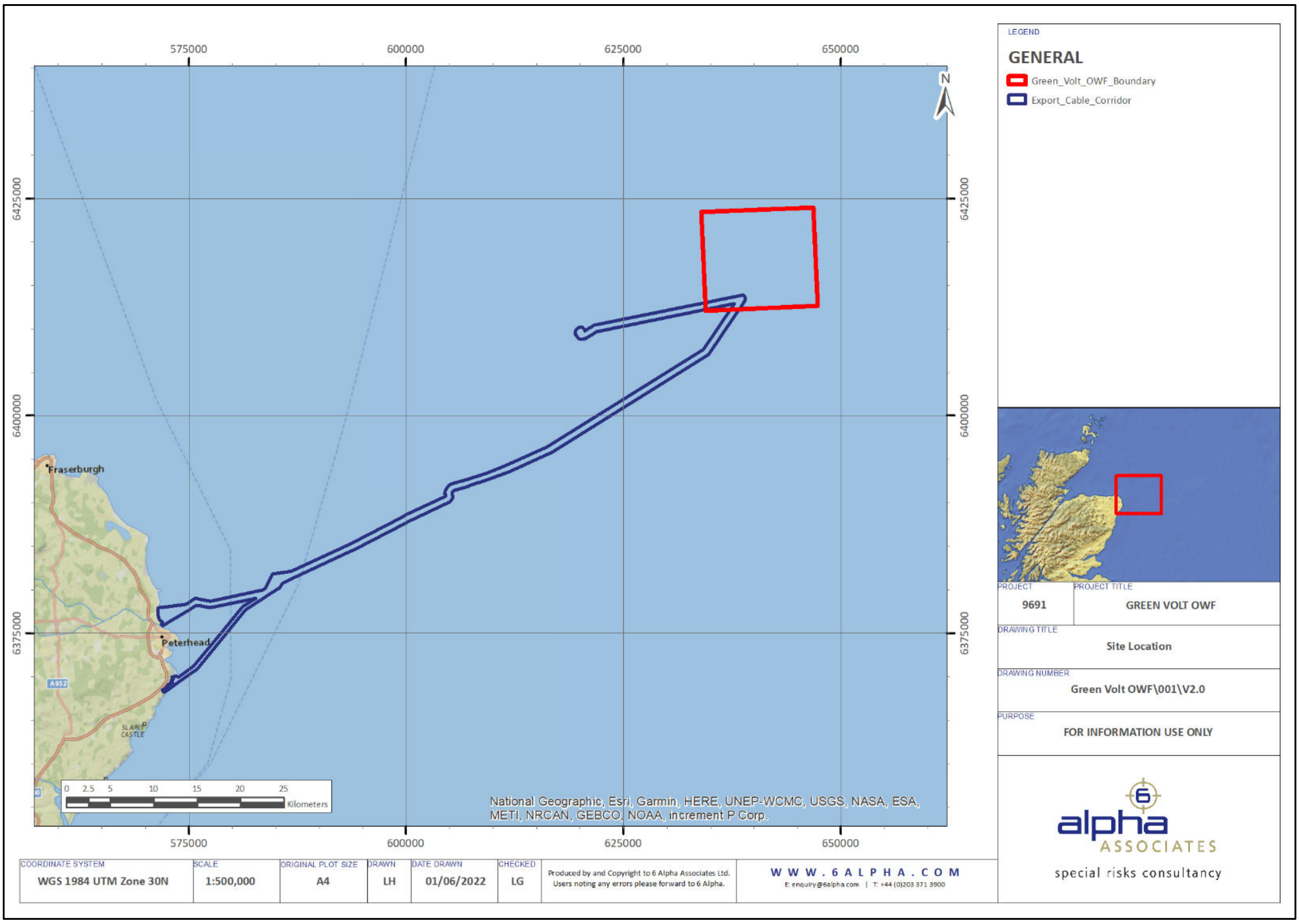

Figure 1: Site Location

UXO Threat and Risk Assessment Summary

A tabulated summary of the findings of the threat and risk assessment is presented in Table 1:

Intrusive Operation	UXO Threat	UXO Risk (Vessels and Personnel Only)				
		Ultra-Nearshore ~10m LAT	Nearshore ~26m LAT	Shallow Offshore ~40m LAT	Offshore ~60m LAT	Deep Offshore ~100m LAT
Wind Turbine Generator Mooring Operations	Aerial Bombs	N/A: Wind turbine generator mooring and offshore substation platform installation operations will not occur at these water depths.				**VERY LOW**
	Torpedoes					**LOW**
	Naval Mines					**MEDIUM**
	Artillery and Naval Projectiles					**VERY LOW**
Offshore Substation Platform Foundation Installation Operations	Aerial Bombs					**VERY LOW**
	Torpedoes					**LOW**
	Naval Mines					**LOW**
	Artillery and Naval Projectiles					**VERY LOW**
Pre-Lay Operations	Aerial Bombs	**HIGH**	**HIGH**	**MEDIUM**	**LOW**	**VERY LOW**
	Torpedoes	**LOW**	**LOW**	**MEDIUM**	**LOW**	**LOW**
	Naval Mines	**LOW**	**MEDIUM**	**MEDIUM**	**LOW**	**MEDIUM**
	Artillery and Naval Projectiles	**HIGH**	**MEDIUM**	**LOW**	**LOW**	**LOW**
Cable Installation	Aerial Bombs	**HIGH**	**HIGH**	**MEDIUM**	**LOW**	**VERY LOW**

Intrusive Operation	UXO Threat	UXO Risk (Vessels and Personnel Only)				
		Ultra-Nearshore ~10m LAT	Nearshore ~26m LAT	Shallow Offshore ~40m LAT	Offshore ~60m LAT	Deep Offshore ~100m LAT
and Burial Operations	Torpedoes	**LOW**	**LOW**	**MEDIUM**	**LOW**	**LOW**
	Naval Mines	**LOW**	**MEDIUM**	**MEDIUM**	**LOW**	**MEDIUM**
	Artillery and Naval Projectiles	**HIGH**	**MEDIUM**	**LOW**	**LOW**	**LOW**
Protection Operations	Aerial Bombs	**HIGH**	**HIGH**	**MEDIUM**	**LOW**	**VERY LOW**
	Torpedoes	**LOW**	**LOW**	**LOW**	**LOW**	**LOW**
	Naval Mines	**LOW**	**LOW**	**LOW**	**LOW**	**MEDIUM**
	Artillery and Naval Projectiles	**MEDIUM**	**LOW**	**LOW**	**VERY LOW**	**VERY LOW**
Enabling Operations	Aerial Bombs	**HIGH**	**HIGH**	**MEDIUM**	**LOW**	**VERY LOW**
	Torpedoes	**LOW**	**LOW**	**LOW**	**LOW**	**LOW**
	Naval Mines	**LOW**	**LOW**	**LOW**	**LOW**	**MEDIUM**
	Artillery and Naval Projectiles	**MEDIUM**	**LOW**	**LOW**	**VERY LOW**	**VERY LOW**

Table 1: Representative UXO Risk Assessment Summary

UXO Risk Zones

The categorisation of UXO risk is not universal throughout the Study Site, and the zoning of UXO risk is based on several factors, including the nature, scope, and location of UXO threat sources within the proposed OWF array and along the export cable corridors, considering the expected water depths. As a result, there are areas of HIGH, MEDIUM and LOW UXO risks throughout the Site as depicted at Figure 2.

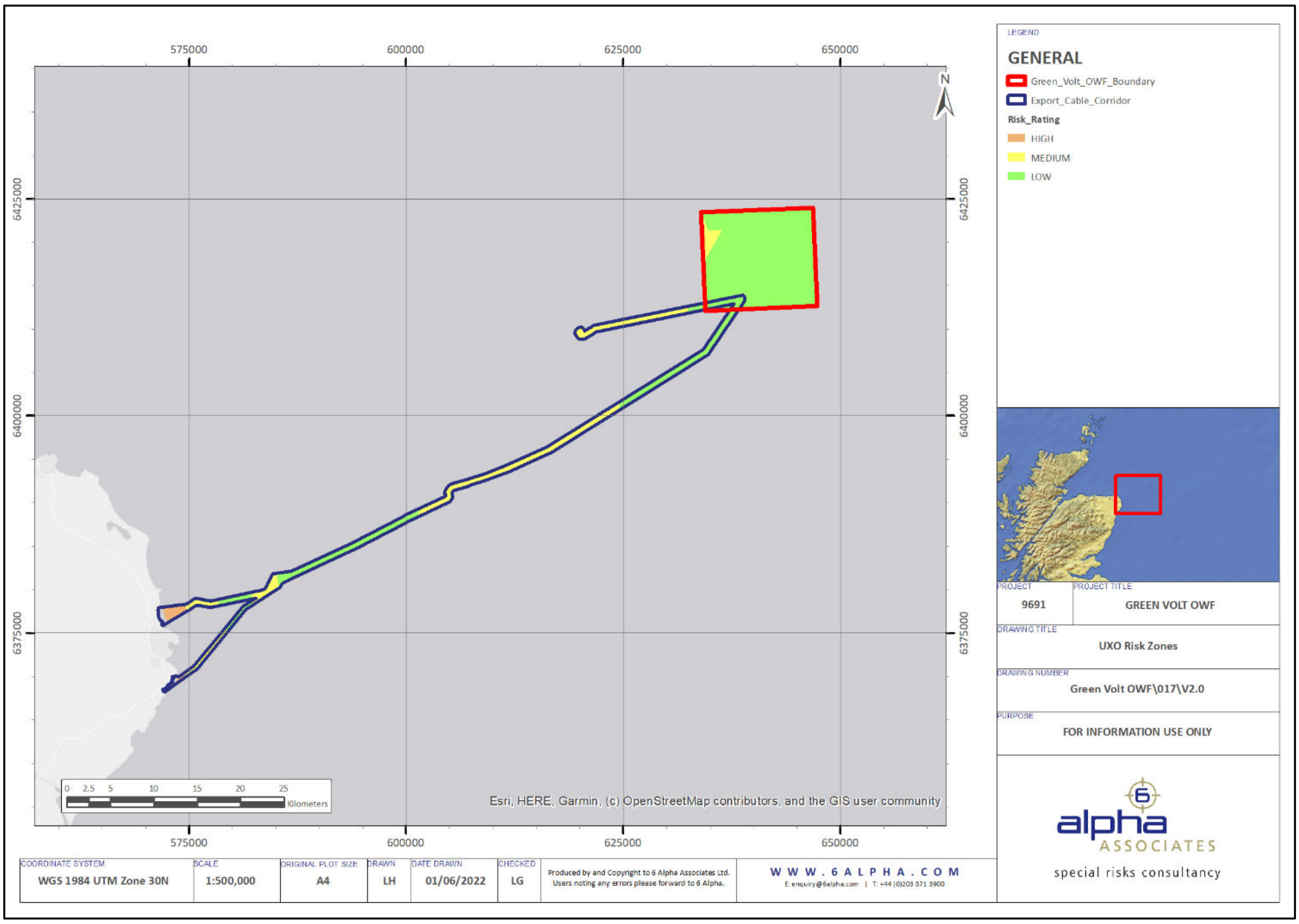

Figure 2: UXO Risk Zones

Risk Mitigation Strategy

6 Alpha recommend that the UXO risks are mitigated within the bounds of the As Low As Reasonably Practicable (ALARP) risk reduction principle and in accordance with national laws through the implementation of a suitable and cost-effective RMS.

There are three main options to consider, to reduce UXO risks ALARP. In priority order they are:

- **Avoidance;** a strategy of potential UXO (pUXO) detection and avoidance is proposed as the most cost effective and efficient method of reducing UXO risks to ALARP. By surveying for and avoiding direct or indirect contact with any pUXO (the source of the risk) and by moving the anchor moorings and cable routes away from such prospective hazards, such risks are appropriately and effectively reduced;

- **Removal of UXO Risk Receptors;** an alternative option is to remove the receptor element (of the source-pathway-receptor model), by moving certain sensitive and vulnerable receptors (typically the crews of offshore vessels), to a safe distance from the point of the intrusive activity and thus the pUXO hazard, so that it will diminish sufficiently the prospective blast, fragmentation (the former and latter are through air effects) and/or shock wave (a through water effect) consequences, in order 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 pUXO cannot be avoided, another alternative (but commonly, time consuming and costlier) option, is to verify pUXO by investigation and where it is confirmed UXO (cUXO), to remove it (effectively removing the source element of the source-pathway-receptor model), either by 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 by destroying it or otherwise rendering it safe.

Risk Mitigation Measures

The UXO RMS ought to be enacted through the implementation of pertinent, proactive and/or reactive UXO risk mitigation measures, as summarised at Table 2:

UXO Risk Mitigation Measures Overview		
Risk Zone	**Recommended Risk Mitigation**	**Final UXO Risk Rating**
HIGH **MEDIUM**	- Bespoke geophysical UXO survey; - Sub-surface and surface pUXO detection; - pUXO avoidance or Target Investigation and cUXO removal; - Emergency Response Plans and Tool Box Briefs; - On-Call Explosive Ordnance Disposal Engineer.	**ALARP**
LOW	- Existing Geophysical Survey Data Analysis; - Surface pUXO Detection; - pUXO avoidance or Target Identification and cUXO removal; - Emergency Response Plans and Tool Box Briefs; - On-Call Explosive Ordnance Disposal Engineer.	
The Risk Mitigation Measures are detailed within Sections 5 and 6 of this document.		

Table 2: UXO Risk Mitigation Measures Overview

Minimum UXO Threat Items

The minimum size of UXO to be detected by geophysical UXO survey within the proposed OWF array and export cable corridors varies, depending on several factors including but not limited to water depth, likely intrusive methodologies, the type(s) of the UXO, prospective vessel slant range to UXO and vessels' robustness. It should also be noted that the minimum size UXO for magnetometer survey purposes especially is based on a UXO threat item's ferrous metal content rather than its physical dimensions or any other factor. Table 3 illustrates the categorisation of minimum UXO threats for detection at a strategic level, with respect to depth of water.

Water Depths	Minimum UXO Threat	Dimensions (L x W)	Ferrous Mass	Explosive Fill
<10m	3.7" Artillery Projectile	360mm x 94mm	11.6kg	0.93kg
10m – 26m	SC-50 HE Bomb	762mm x 200mm	25-30kg	25kg
26m – 40m	SC-250 HE Bomb	1,194mm x 368mm	126kg	130kg
>40m	Mark XVII/XX Mine	1,321mm x 1,016mm	68-236kg	227kg

Table 3: Minimum UXO threats for detection

Residual Risk Tolerance

Following the implementation of a suitable risk mitigation strategy, UXO risks will not usually be reduced to "zero", nor need they be under the auspices of ALARP risk reduction principle. Residual UXO risks may 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 Net Explosive Quantity – NEQ) UXO threats might be tolerated - which might be tolerated under the principles of ALARP risk reduction. Project stakeholders are therefore requested to consider and to formally endorse the assumed risk tolerance recommendations for offshore residual UXO risks, as presented and labelled as Option 2, in Table 4.

UXO Risk Tolerance	Prospective Residual UXO Risk	Project Implications
Option 1 – Very Conservative	Damage to subsea equipment of any kind, will not be tolerated.	Most expensive and time-consuming option but the risk of damaging the subsea equipment is significantly reduced.
Option 2 - Recommended (within ALARP threshold)	Damage/Destruction of subsea equipment will be tolerated – although it remains undesirable. Significant damage to vessels that may injure or endanger personnel (either directly or indirectly), is intolerable and will require proactive risk mitigation.	Time and cost efficient, although carries the risk of repair and/or replacement of equipment in the event of unplanned low NEQ UXO encounter and detonation.

Table 4: Recommended Residual UXO Risk Tolerance

ALARP Safety Sign-Off Certification

ALARP safety sign-off certification provides an independent source of evidence that Clients have followed industry best practice and have successfully managed and reduced UXO risks to ALARP. Following the execution of UXO risk mitigation measures, ALARP safety sign-off certification should be obtained and distributed in advance of proposed operations.

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Acronyms and Abbreviations

ALARP	As Low As Reasonably Practicable
CIRIA	Construction Industry Research and Information Association
cUXO	Confirmed UXO
EOD	Explosive Ordnance Disposal
ERP	Emergency Response Plan
HE	High Explosive
Kg	Kilogram
Km	Kilometre
LAT	Lowest Astronomical Tide
m	Metres
mm	millimetres
NEQ	Net Explosive Quantity
OSP	Offshore Service Platform
OWF	Offshore Wind Farm
pUXO	Potential UXO
RMS	Risk Mitigation Strategy
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance
WGS	World Geodetic System
WTG	Wind Turbine Generator

Key Definitions

There are several terms that are used within this UXO risk mitigation strategy, namely:

- **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.

Part I – Introduction

1 Project Overview

1.1 Scope of Work

Flotation Energy has commissioned *6 Alpha Associates* (6 Alpha) to deliver a desk-based Unexploded Ordnance (UXO) Risk Mitigation Strategy (RMS) associated with the *Green Volt* Offshore Wind Farm (OWF) installation project. This document comprises the recommended risk mitigation measures associated within all intrusive OWF and cable installation works, within the bounds of the OWF array and the potential export cable corridors. A UXO Threat and Risk Assessment has also been commissioned and was delivered by *6 Alpha* on the 5th May 2022.

1.2 Project Location

The project is located in the *North Sea*, with the OWF array situated approximately 75km to the north-east of the *Scottish* coast. Two export cable routes have been defined for the project, the first supplying the nearby *Buzzard Oil Field* and the second making landfall at one of two proposed locations near *Peterhead, Aberdeenshire*. The proposed location of the *Green Volt OWF*, together with these export cable corridors, is presented at Figure 1.2 below, as well as in Appendix 1.

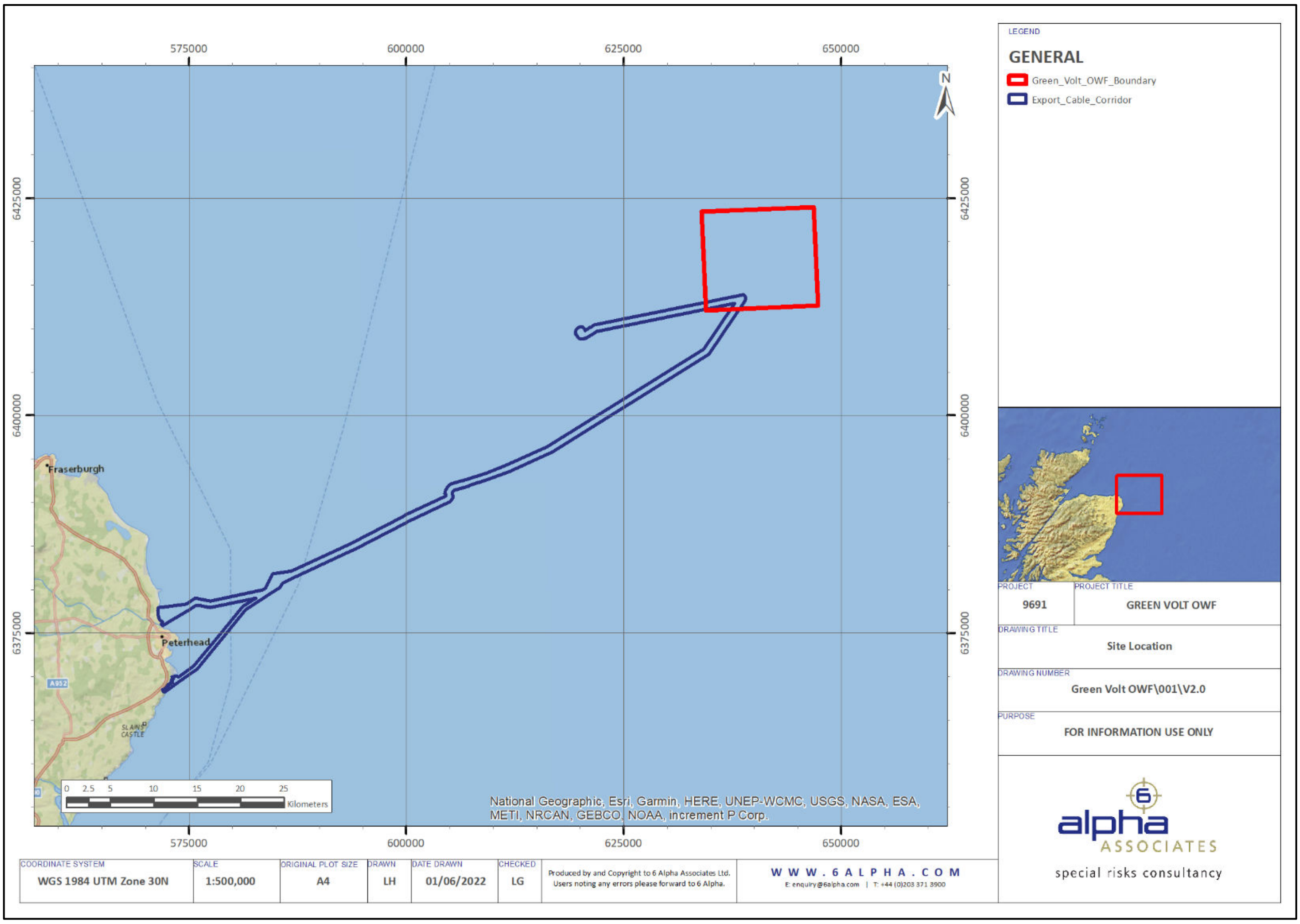


Figure 1.2: Site Location

1.3 UXO Risk Management Strategic Framework

To manage and to ameliorate prospective UXO risks, *6 Alpha* has developed a detailed UXO risk management strategic framework that is not only in line with *Construction Industry Research Information Association* (CIRIA) guidance but also, is in accordance with the As Low As Reasonably Practicable (ALARP) risk reduction principles. At Section 5 of the Health and Safety Executive endorsed *CIRIA* C754 guide, the risk management framework is divided into five key phases that correspond with those employed by *6 Alpha*, as presented at Table 1.3. A complete overview of *6 Alpha's* UXO Risk Management Framework is presented for completeness, at Appendix 2.

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

Table 1.3: *6 Alpha* and *CIRIA* UXO Risk Management Frameworks

Notwithstanding *CIRIA's* guidance, purpose of this report is to address Phase Three of the UXO risk management framework. Phases One and Two have already been addressed by *6 Alpha's* UXO Threat and Risk Assessment, which was delivered on the 5th May 2022. This framework is applied to provide a holistic solution for managing UXO risks to ALARP, in accordance with a recognised UXO risk management process, as per Appendix 3.

This RMS will outline the strategic risk management options and will also make recommendations for the most time-efficient and cost-effective way of mitigating the UXO risk to ALARP (the minimum legal requirement). By outlining the overall RMS at Phase 3, the foundation is laid for Phase 4 of the framework where the specific risk mitigation measures are designed, and specifications are produced. Phase 5 is concerned with the subsequent implementation of those risk mitigation measures.

2 UXO Threat and Risk Assessment Summary

2.1 UXO Threat 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 was considered in greater detail in the Threat and Risk Assessment, and a summary of the potential threat sources identified is presented in Table 3.1. In addition, a georeferenced chart depicting the considered range of prospective UXO contamination sources at the study area is presented at Appendix 4.

Potential Sources of UXO (within 5km)	Likelihood of UXO Contamination	Associated UXO Threat Items
Aerial Bombing	**Likely:** Significant aerial bombing was documented at *Peterhead* during WWII.	HE Bombs
Naval Engagements	**Unlikely:** Although, there is evidence of limited submarine activity across the Study Site.	Naval Projectiles and Torpedoes
Naval Minefields	**Likely:** The Study Site was intersected by three large WWI and WWII-era minefields.	Naval Mines
Military Practice and Exercise Areas	**Highly Unlikely:** Neither historic nor modern military training areas were recorded intersecting the Study Site.	N/A
Coastal Armaments	**Possible:** Several coastal armaments were recorded around *Peterhead*, with firing arcs intersecting the nearshore sector of the Study Site.	Anti-Aircraft Artillery Projectiles
Munitions Related Shipwrecks and Aircraft	**Unlikely:** Although, 11 munitions related shipwrecks were documented within 5km of the Study Site.	Shipwreck Related Munitions
Munitions Dumping (within 10km)	**Highly Unlikely:** No munitions dumps were recorded within 10km of the Study Site.	N/A

Table 3.1: Summary of Potential UXO Sources of UXO Contamination

2.2 Proposed Works

In order to classify the UXO risks, the potential UXO risk pathways must be assessed. *6 Alpha* have been provided with a high-level outline of the proposed scope of works, including the mooring of floating Wind Turbine Generators (WTG), installation of Offshore Substation Platforms (OSP), and the installation and burial of inter-array and export cables.

The aforementioned operations might involve a range of specific methodologies, which could generate varying levels of UXO risk depending on their likelihood of encountering and initiating UXO. It is also likely that Jack-Up Barges and vessel anchoring will be used to enable the proposed works within the Study Site.

2.3 UXO Risk Assessment Findings

The potential sources of UXO contamination were then subject to a Semi-Quantitative Risk Assessment, based on the likely UXO risk pathways described above. Accordingly, an indicative summary of the strategic level risk assessment is presented in Table 3.3.

Intrusive Operation	UXO Threat	UXO Risk (Vessels and Personnel Only)				
		Ultra-Nearshore ~10m LAT	Nearshore ~26m LAT	Shallow Offshore ~40m LAT	Offshore ~60m LAT	Deep Offshore ~100m LAT
WTG Mooring Operations	Aerial Bombs	**N/A:** WTG mooring and OSP installation operations will not occur at these water depths.				**VERY LOW**
	Torpedoes					**LOW**
	Naval Mines					**MEDIUM**
	Artillery and Naval Projectiles					**VERY LOW**
OSP Foundation Installation Operations	Aerial Bombs					**VERY LOW**
	Torpedoes					**LOW**
	Naval Mines					**LOW**
	Artillery and Naval Projectiles					**VERY LOW**
Pre-Lay Operations	Aerial Bombs	**HIGH**	**HIGH**	**MEDIUM**	**LOW**	**VERY LOW**
	Torpedoes	**LOW**	**LOW**	**MEDIUM**	**LOW**	**LOW**
	Naval Mines	**LOW**	**MEDIUM**	**MEDIUM**	**LOW**	**MEDIUM**
	Artillery and Naval Projectiles	**HIGH**	**MEDIUM**	**LOW**	**LOW**	**LOW**

Intrusive Operation	UXO Threat	UXO Risk (Vessels and Personnel Only)				
		Ultra-Nearshore ~10m LAT	Nearshore ~26m LAT	Shallow Offshore ~40m LAT	Offshore ~60m LAT	Deep Offshore ~100m LAT
Cable Installation and Burial Operations	Aerial Bombs	HIGH	HIGH	MEDIUM	LOW	VERY LOW
	Torpedoes	LOW	LOW	MEDIUM	LOW	LOW
	Naval Mines	LOW	MEDIUM	MEDIUM	LOW	MEDIUM
	Artillery and Naval Projectiles	HIGH	MEDIUM	LOW	LOW	LOW
Protection Operations	Aerial Bombs	HIGH	HIGH	MEDIUM	LOW	VERY LOW
	Torpedoes	LOW	LOW	LOW	LOW	LOW
	Naval Mines	LOW	LOW	LOW	LOW	MEDIUM
	Artillery and Naval Projectiles	MEDIUM	LOW	LOW	VERY LOW	VERY LOW
Enabling Operations	Aerial Bombs	HIGH	HIGH	MEDIUM	LOW	VERY LOW
	Torpedoes	LOW	LOW	LOW	LOW	LOW
	Naval Mines	LOW	LOW	LOW	LOW	MEDIUM
	Artillery and Naval Projectiles	MEDIUM	LOW	LOW	VERY LOW	VERY LOW

Table 3.3: Offshore UXO Threat and Risk Assessment Summary

2.4 Threat and Risk Assessment Conclusions

The majority of the Site is assessed as LOW risk due to either the ameliorative effects of the significant water depths present offshore on the potential consequences of a UXO initiation or because of a comparatively low likelihood of encountering UXO in some areas.

Nonetheless, certain UXO risks posed by the proposed operations have been categorised as HIGH or MEDIUM, because they are generally associated with the unplanned initiation of threat spectrum UXO - including High Explosive (HE) bombs, naval mines and anti-aircraft artillery projectiles in various areas of the Study Site, some of which are also very shallow water areas; such risks are considered intolerable.

The UXO risk zones across the *Green Volt OWF* are presented in Figure 3.4 and at Appendix 5.

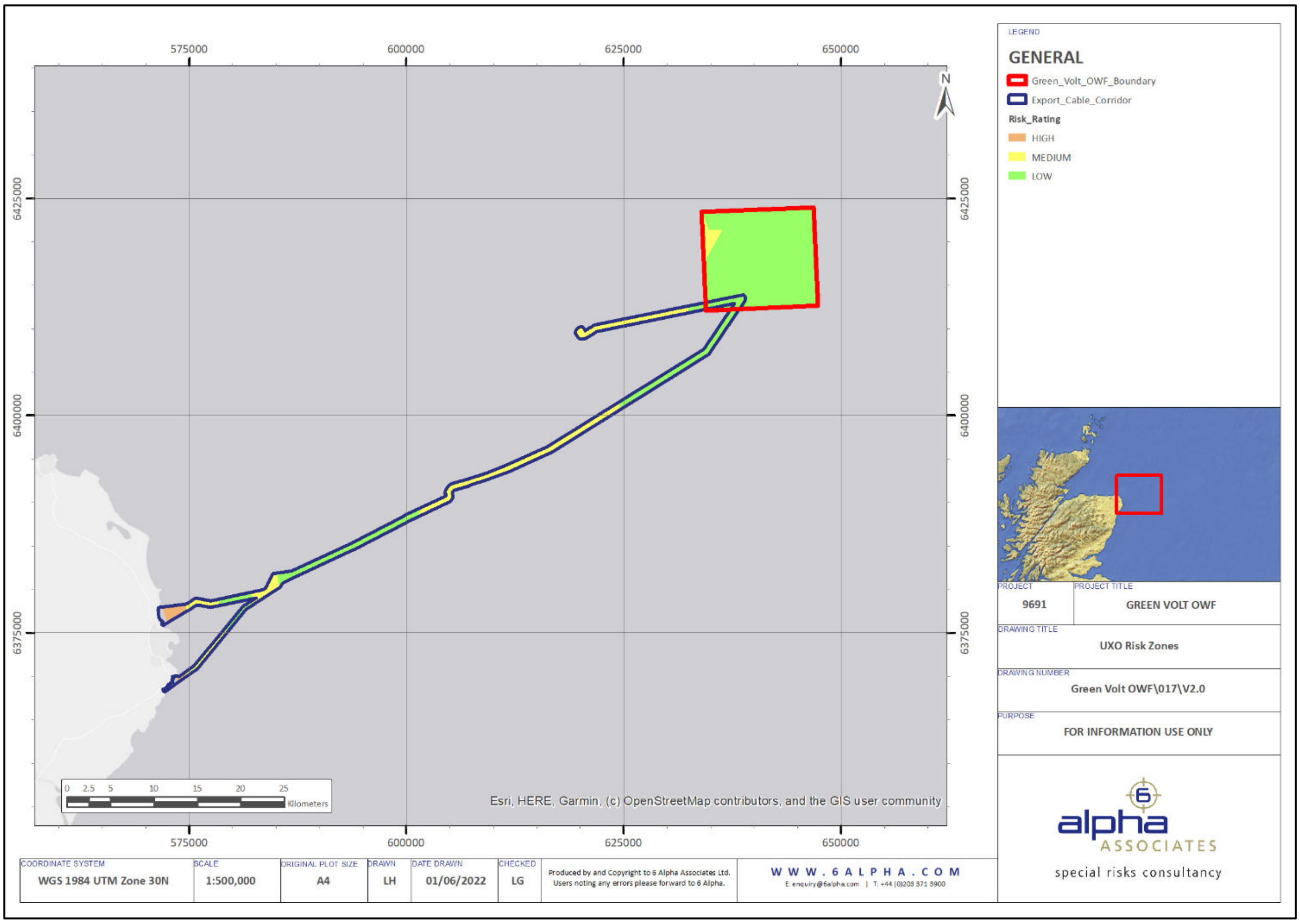


Figure 3.4: UXO Risk Zones

Part II – UXO Risk Mitigation Strategy

3 UXO Risk Mitigation Strategy

3.1 Risk Mitigation Strategy Options

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

3.1.1 Avoidance

A strategy of potential UXO (pUXO) detection and avoidance is proposed as the most cost effective and efficient method of reducing UXO risks to ALARP. By surveying for and avoiding direct or indirect contact with any pUXO (the source of the risk) and by moving any intrusive activity away from such prospective hazards (where practicable), such risks are appropriately and effectively reduced.

3.1.2 Removal of Risk Receptors

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

3.1.3 Removal of Threat Sources

Where pUXO cannot be avoided, another alternative (but commonly, time consuming and costlier) option, is to verify pUXO by investigation and where it is confirmed UXO (cUXO), to remove it (effectively removing the source element of the source-pathway-receptor model), either by 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 by destroying it or otherwise rendering it safe.

3.2 Risk Mitigation Measures Overview

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

4 Proactive Risk Mitigation Measures

The following risk mitigation measures are categorised as 'proactive' measures and are recommended in advance of proposed intrusive works at the *Green Volt OWF*:

4.1 Bespoke Geophysical UXO Survey – HIGH and MEDIUM Risk Zones

A geophysical UXO survey, appropriately designed to detect threat spectrum UXO, is recommended prior to the commencement operations that are planned within the boundaries of the Study Site, in order to provide the basis for a strategy of pUXO avoidance, or for its identification and removal. An overview of geophysical UXO survey methods that might be employed is presented at Annex B.

4.1.1 Surface UXO Detection

Surface detection for threat spectrum UXO should consist of either Side Scan Sonar, Multi Beam Echo Sounder and/or Work Class Remotely Operated Vehicle camera search (subject to visibility and resolution, especially in areas where shallow water operations are planned), over the area of proposed operations and prior to their commencement.

Sufficient working space to provide a margin for safety should be incorporated in the survey area (with pUXO avoidance initially set at 15m), to ensure that proposed activities will not initiate pUXO that might be at the very periphery of the surveyed area.

4.1.2 Subsurface UXO Detection

Sub-surface detection for threat spectrum UXO should also be undertaken ahead of seabed intrusive operations should consist of magnetometer/gradiometer survey over the area of the proposed operations. Again, sufficient working space to provide a margin for safety should be incorporated in the survey area (with pUXO avoidance initially set at 15m).

4.2 Geophysical UXO Survey – LOW Risk Zones

In the LOW risk zones, the prospective level of UXO risk does not warrant undertaking bespoke geophysical UXO survey. However, it is highly likely that some form of general engineering geophysical survey data will be collected for other (non-UXO related) purposes. Therefore, any existing surface data covering the LOW risk zone is to be employed for the purposes of surface pUXO identification and avoidance and/or further investigation.

Alternatively, as a bespoke geophysical UXO survey will already be mobilised across areas of the Study Site categorised as posing elevated levels of UXO risk, the recommended geophysical UXO survey could also be extended across the LOW risk zones, as this will provide a significant risk mitigation benefit for relatively small time and money costs.

5 Reactive Risk Mitigation Measures

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

5.1 Operational UXO Emergency Response Plan (ERP)

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

5.2 UXO Safety and Awareness Briefings

Safety briefings (or Tool Box Briefs) are considered as an essential reactive risk mitigation measure, whenever there is a possibility of explosive ordnance encounter and as such, they are considered a vital part of the general UXO safety requirement. All personnel involved with intrusive sub seabed works, operational support staff working on vessels and/or any other relevant workers are to receive a safety briefing concerning the identification of relevant UXO, what actions are to be taken to keep people and equipment away from such a hazard or otherwise safe and to alert site management.

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

5.3 On-Call EOD Engineers

Following the implementation of proactive UXO risk mitigation measures, shore-side and office-based Explosive Ordnance Disposal (EOD) Engineers may be engaged to provide remote, rapid UXO recognition advice and to provide immediate safety management guidance in the event that UXO is discovered. Such a service provides UXO risk management expertise as and when it is required on a just-in-time basis and not only affords safety but also avoids prospective project delays, which might otherwise be caused by the discovery of inert or non-UXO debris.

6 Risk Mitigation Measures - Design, Specification and Guidance

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

6.1 Geophysical Survey Specifications

In accordance with the risk management recommendations contained within *CIRIA*'s C754 guide, the survey contractor will need to provide evidence that their proposed survey methodology and equipment is fit for the purpose of identifying threat spectrum UXO. Accordingly, geophysical survey specifications should be drafted for each type of survey methodology, outlining the required survey parameters, equipment and calibrations to ensure that the survey is fit for the purpose of threat spectrum, UXO detection – such survey specifications are to be delivered separately and subsequently by *6 Alpha*.

In addition, a Survey Verification Test is to precede the main survey acquisition work itself, in order to validate and prove the efficacy of the survey equipment in it being able to detect the minimum sized UXO threats.

6.2 Minimum UXO Threats

The minimum size of UXO to be detected by geophysical UXO survey within the proposed OWF array and export cable corridors varies, depending on a number of factors including but not limited to; water depth, likely intrusive methodologies, the type(s) of the UXO, prospective vessel slant range to UXO and vessels' robustness. It should also be noted that the minimum size UXO for magnetometer survey purposes especially is based on a UXO threat item's ferrous metal content rather than its physical dimensions or any other factor. Figure 6.2 illustrates the general categorisation of minimum UXO threat items for detection and thus ALARP safety provision, at different water depths.

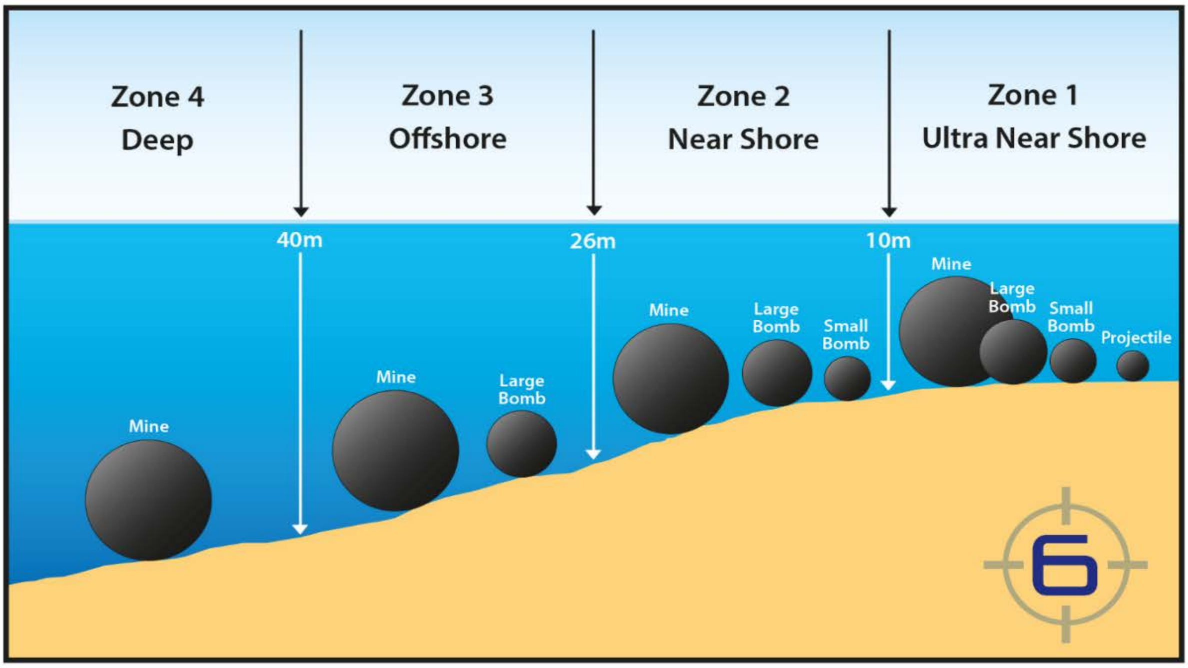


Figure 6.2: UXO Detection Requirement with Respect to Water Depths

The diagram presented at Figure 6.2 is intended as a general guide to minimum threat detection at those specified depths that is generally correct across all types of offshore projects but is not project specific. At the strategic level it is possible to broadly refine the minimum UXO threats that require detection - according to the water depth mitigation criteria, as presented in Table 6.2.

Water Depths	Minimum UXO Threat	Dimensions (L x W)	Ferrous Mass	Explosive Fill
<10m	3.7" Artillery Projectile	360mm x 94mm	11.6kg	0.93kg
10m – 26m	SC-50 HE Bomb	762mm x 200mm	25-30kg	25kg
26m – 40m	SC-250 HE Bomb	1,194mm x 368mm	126kg	130kg
>40m	Mark XVII/XX Mine	1,321mm x 1,016mm	68-236kg	227kg

Table 6.2: Minimum UXO Threat Items by Water Depth (LAT)

6.3 Geophysical Survey Data Longevity

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

6.3.1 Munitions Migration

Theoretically, whilst large UXO are less likely to migrate, survey data might be considered out-of-date within a relatively short time following its acquisition (that is typically, 12 months), especially if UXO migration is likely in highly mobile seabed zones. In such circumstances, a Munitions Migration and Burial Assessment can be undertaken to gain a better understanding of the type of UXO that might move as well as the magnitude and direction of its likely migration path.

6.4 pUXO Avoidance radii

Any geophysical UXO survey anomaly that is classified as pUXO is to be avoided, wherever possible, by not less than 15m from the leading edge of any underwater equipment or platform. Such safety avoidance is designed to ensure that if non-verified pUXO is in fact cUXO, it will not be encountered nor initiated (directly or indirectly). Thus, safety is afforded. If such a safety avoidance distance proves problematic to implement (for example, because there is a profusion of pUXO anomalies), such avoidance might be safely reduced through the medium of a Technical Advisory Note, by considering inter alia: the kinetic energy generated by type and nature of the intrusive activity; high level and sallow sub seabed, geotechnical considerations; and the prospective detonation sensitivity of those type of UXO that might be encountered. Typically, such (*6 Alpha* produced) TAN can reduce safety avoidance distances by about one third.

6.5 pUXO Verification by Investigation

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

6.6 cUXO Disposal

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

Necessary cUXO render safe (typically by UXO destruction) may subsequently be undertaken by a suitable and appropriate specialist, although permitting licensing and consent will need to be sought in advance which can take a number of weeks to acquire. Details of the planned disposal methodology and accompanying risk assessments will usually be required prior to consent being given and the award of a licence/permit/consent.

6.7 Residual Risk Tolerance

Following the implementation of a suitable RMS, UXO risks will not usually be reduced to "zero", nor need they be under the auspices of ALARP risk reduction principle. Residual UXO risks may 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 Net Explosive Quantity (NEQ) UXO threats might be tolerated - which is acceptable under the principles of ALARP risk reduction. Therefore, the recommended levels of UXO risk tolerance are outlined at Table 6.7.

UXO Risk Tolerance	Prospective Residual UXO Risk	Project Implications
Option 1 – Very Conservative	Damage to subsea equipment of any kind, will not be tolerated.	Most expensive and time-consuming option but the risk of damaging the subsea equipment is significantly reduced.
Option 2 - Recommended (within ALARP threshold)	Damage/Destruction of subsea equipment will be tolerated – although it remains undesirable. Significant damage to vessels that may injure or endanger personnel (either directly or indirectly), is intolerable and will require proactive risk mitigation.	Time and cost efficient, although carries the risk of repair and/or replacement of equipment in the event of unplanned low NEQ UXO encounter and detonation.

Table 6.7: Recommended Residual UXO Risk Tolerance

6.8 ALARP Safety Sign-Off Certification

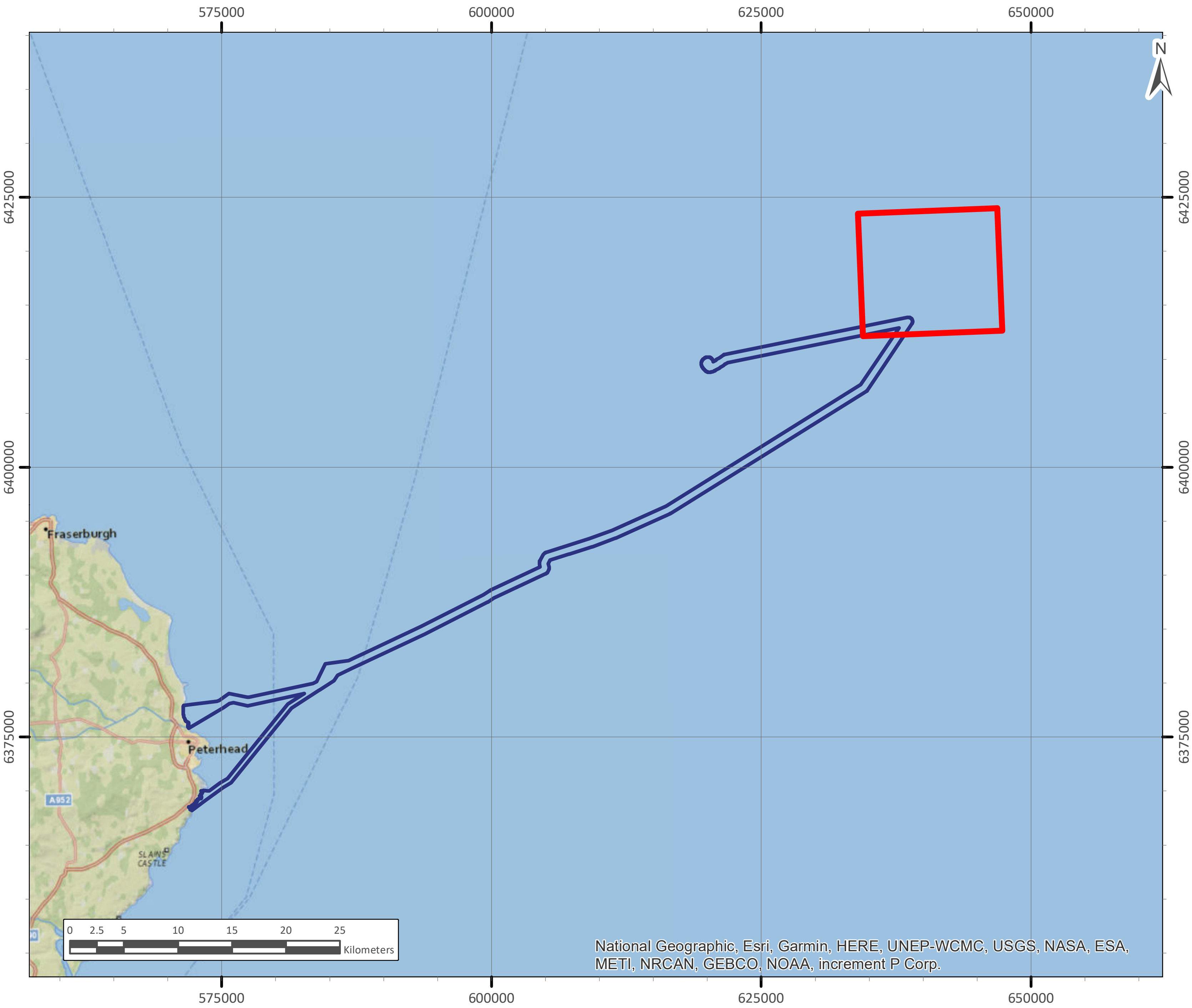
ALARP safety sign-off certification provides an independent source of evidence that a Client has followed industry best practice and has successfully managed and reduced UXO risks to ALARP. Following the execution of UXO risk mitigation measures, ALARP safety sign-off certification should be obtained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

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

Appendices

Appendix 1

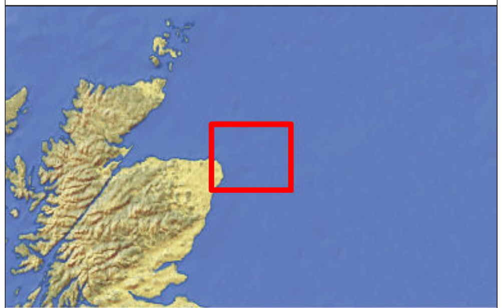
Site Location



LEGEND

GENERAL

- Green_Volt_OWF_Boundary
- Export_Cable_Corridor



PROJECT	PROJECT TITLE
9691	GREEN VOLT OWF

DRAWING TITLE: Site Location

DRAWING NUMBER: Green Volt OWF\001\V2.0

PURPOSE: FOR INFORMATION USE ONLY

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COORDINATE SYSTEM	SCALE	ORIGINAL PLOT SIZE	DRAWN	DATE DRAWN	CHECKED
WGS 1984 UTM Zone 30N	1:500,000	A4	LH	01/06/2022	LG

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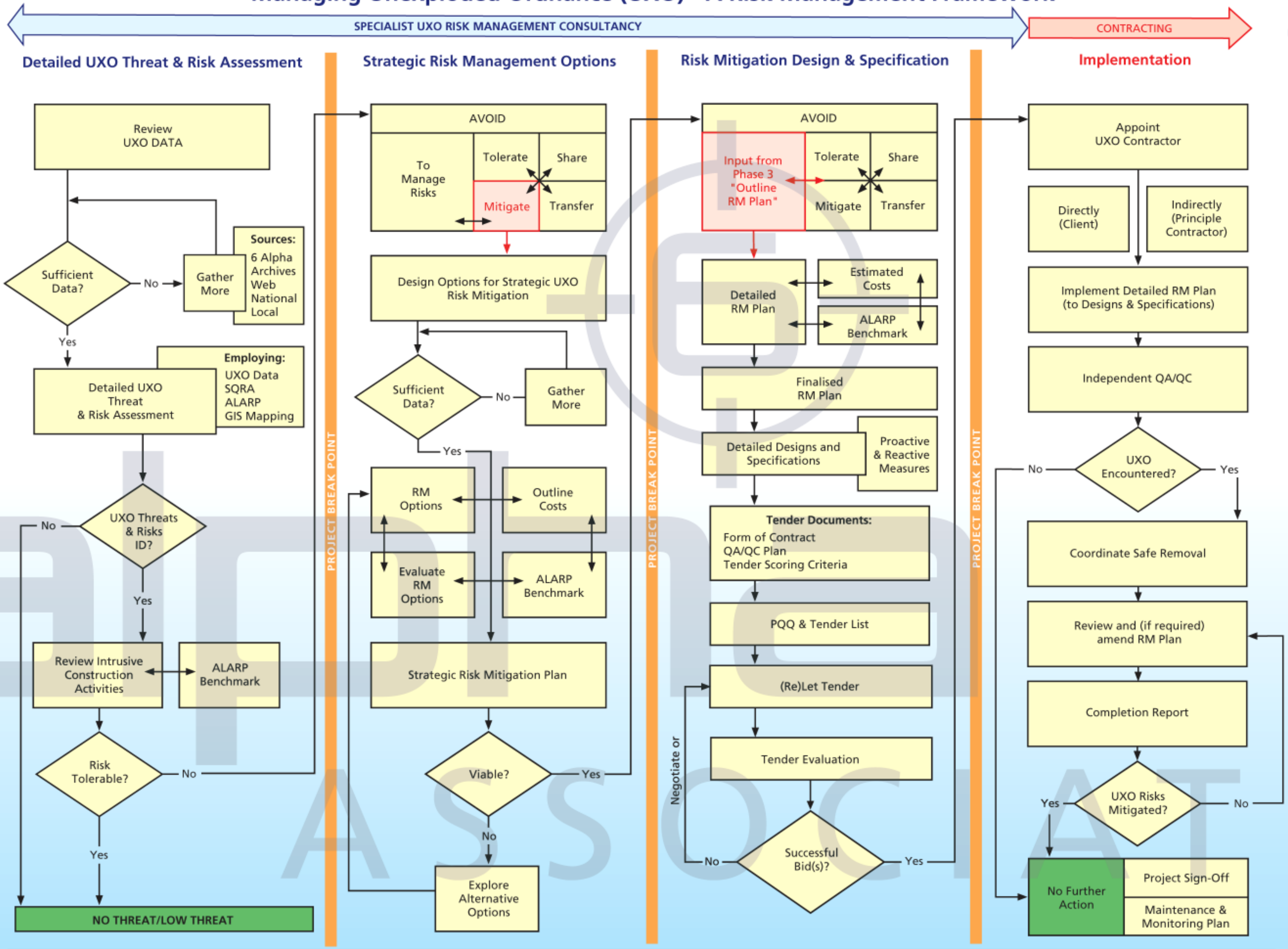
Appendix 2

Marine Risk Management Framework

Managing Unexploded Ordnance (UXO) - A Risk Management Framework



Expected Outputs

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

Expected Outputs

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

Expected Outputs

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

Expected Outputs

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

Appendix 3

Holistic UXO Risk Management Process

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.

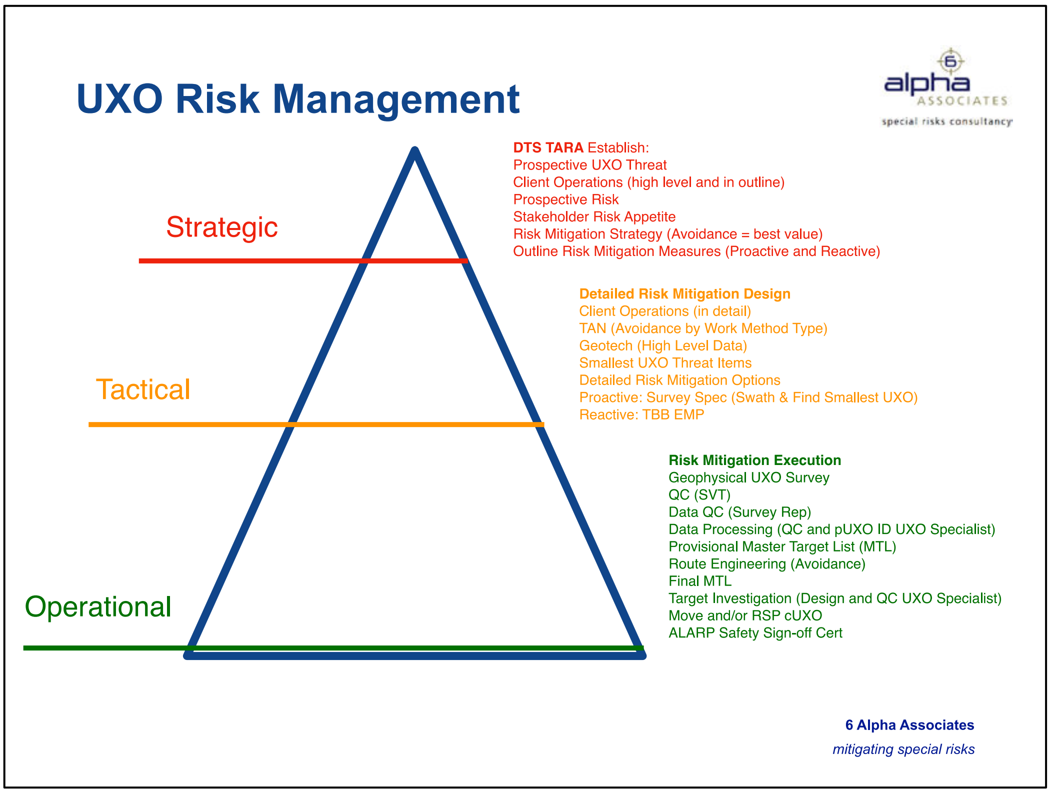


Figure 1: 6 Alpha UXO Risk Management - Concept

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.

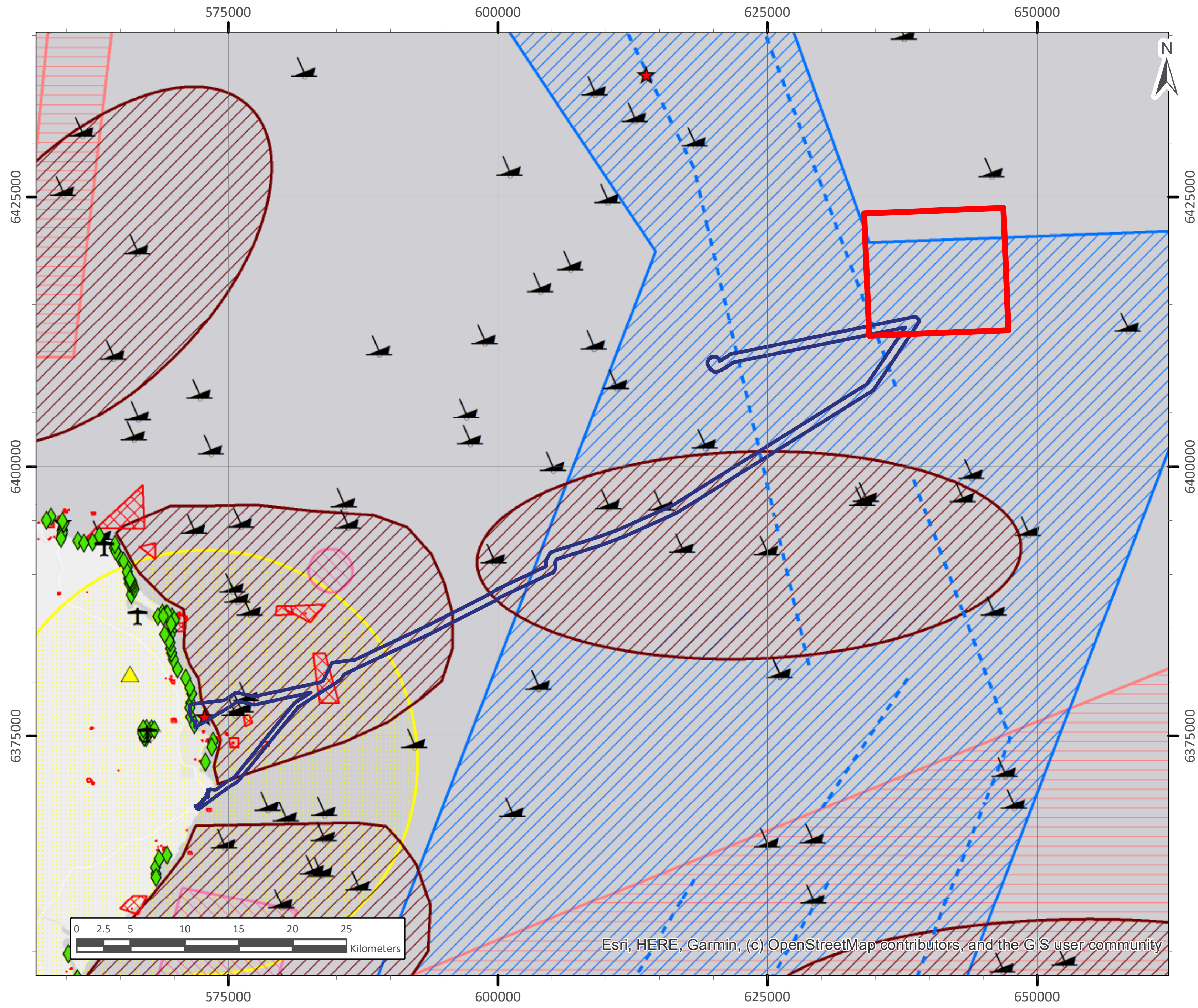
Operational Level - Delivery of UXO Risk Management and Mitigation Solutions

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.

Appendix 4

Consolidated UXO Threat



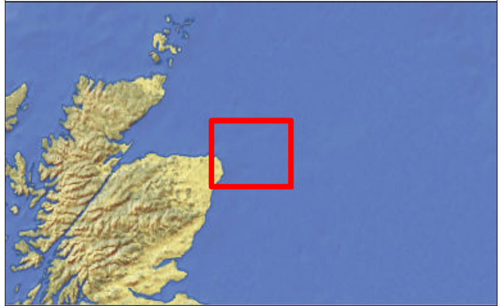
LEGEND

GENERAL

- Green_Volt_OWF_Boundary
- Export_Cable_Corridor

UXO THREATS

- Military_Airfield
- Bombing_Decoy
- Defensive_Installation
- Munitions_Related_Wreck
- OSPAR_Munitions_Encounter
- WWII_Allied_Minelay
- WWII_Bomb_Strikes
- WWII_Bombing_Target
- WWI_Central_Powers_Minefield
- WWII_Allied_Minefield
- Historic_PEXA
- Air_Force_PEXA
- Coastal_Armament_Range



PROJECT	PROJECT TITLE
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DRAWING TITLE
Consolidated UXO Threat

DRAWING NUMBER
Green Volt OWF\013\V2.0

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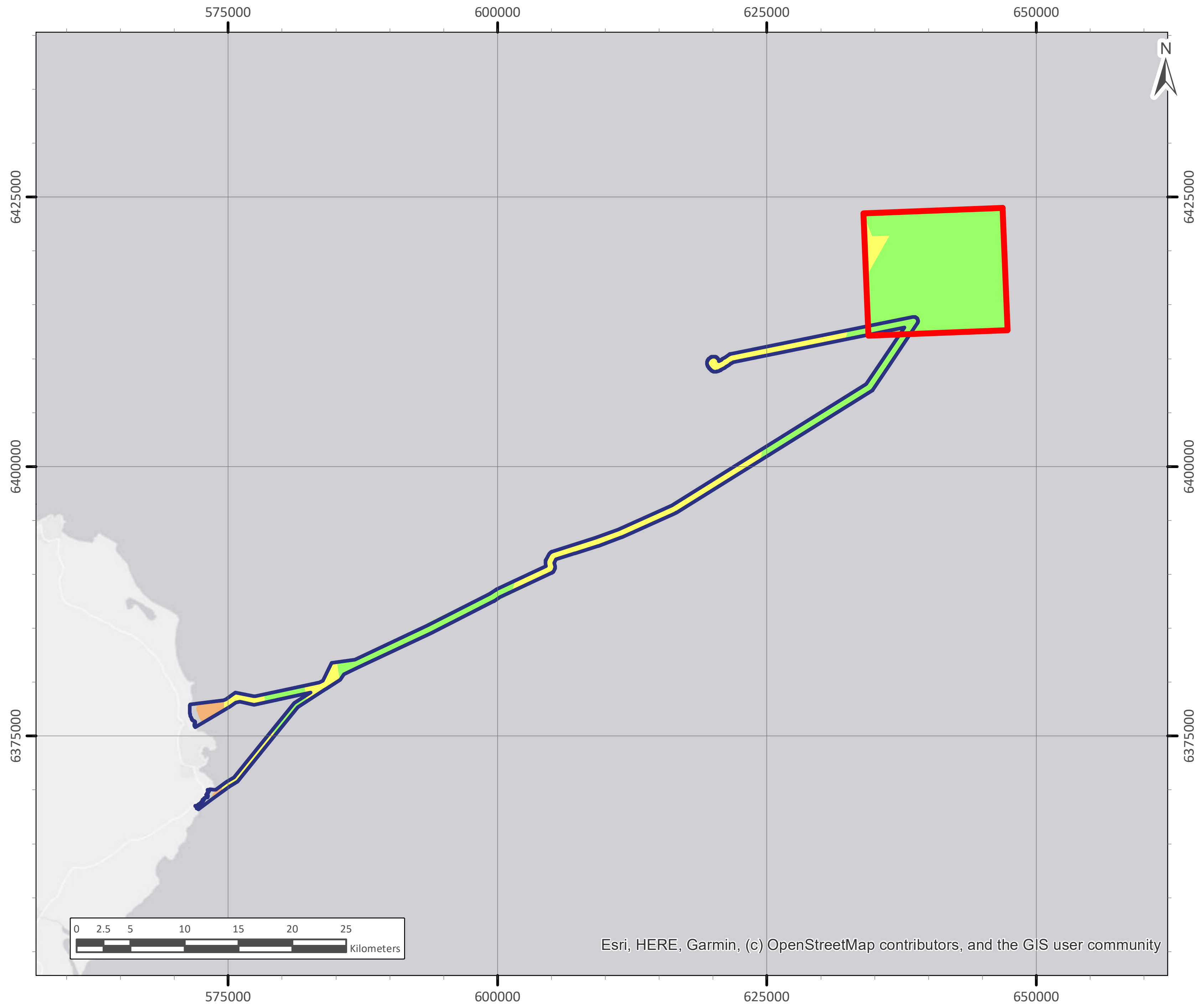
Appendix 5

UXO Risk Zones



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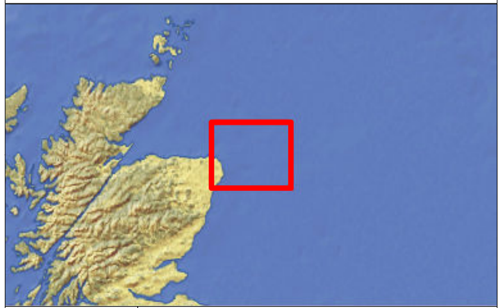

PROJECT	PROJECT TITLE
9691	GREEN VOLT OWF

DRAWING TITLE
UXO Risk Zones

DRAWING NUMBER
Green Volt OWF\017\V2.0

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Annexes

Annex A

Legislation and UXO Risk Management

Annex A – Legislation and UXO Risk Management

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 best 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.

National Legislation

The primary regulation, and minimum standard requirement for businesses residing in and/or working within the *UK*, is enforced within the *UK* by the following legislation:

- Health and Safety at Work Act 1974;
- Management of Health and Safety at Work Regulations 1999;
- CDM Regulations 2015.

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, EOD experience, and its interpretation of the law.

In the end, it is for national 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.

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UXO Industry Guidance and Good Practice

CIRIA has published guidance on the assessment and management of unexploded ordnance risk in the marine environment (*CIRIA* C681 and CIRIA C754). 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.

CIRIA guidance, 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* assesses itself against the *CIRIA* C754 guide to ensure compliance with the minimum legal requirements of industry best practice to manage UXO risks to ALARP.

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 best practice 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.

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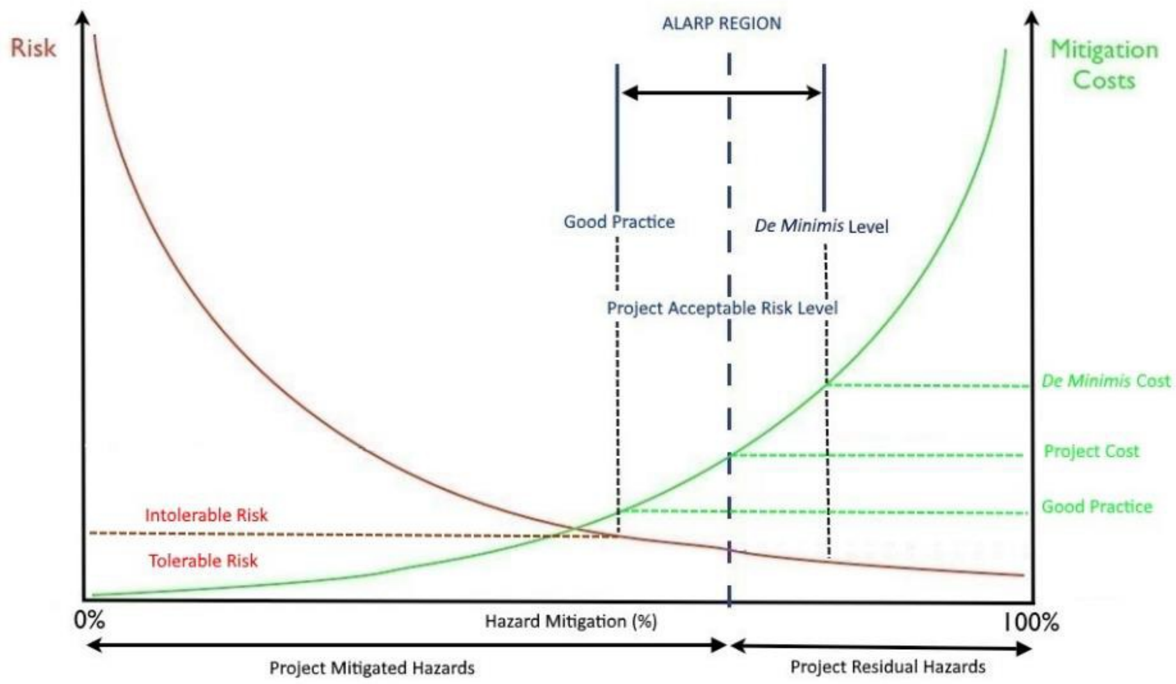

Figure 1: The ALARP principle of managing risk.

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 industry guidelines. A

competent person will oversee the UXO geophysical survey and UXO risk mitigation contractors 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.

UXO Risk Behaviour

UXO incidents that result in harm to construction personnel, are generally termed an extreme, or a low probability, high consequence 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.

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References

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

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Annex B

UXO Detection Methods

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.

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