EXECUTIVE SUMMARY

Conclusion	Explosive ordnance (EO) poses a **Low-to-Moderate Risk** to the proposed works.
Recommendation(s)	► **Explosive Ordnance Safety & Awareness Briefing** for all Site personnel conducting ground works (both GI and post-GI development phases). ► **Explosive Ordnance Site Safety Instructions** to be held on Site for the duration of the post-GI development phase works.
The Site	The Site is located on Wrexham Industrial Estate, ~4.5km east of Wrexham city centre in Clwyd County (northeast Wales). It is bound to the north by Bridge Road North, and to the east and west by neighbouring commercial properties. The Site is centred on the approximate National Grid Ref: SJ 38117 49554. The Site is a roughly triangular plot of overgrown mixed vegetation.
Proposed works	The proposed development is for a battery energy storage system with associated access. At this stage the foundation design is unknown. Shallow pad foundations (mechanically excavated up to ~3.0m bgl) may suffice, however poor quality ground could necessitate deeper piled foundations. Prior to redevelopment a GI will be undertaken, comprising 5No. dynamic sampler boreholes to 5.0m bgl. Each location will require a starter pit, hand-dug to 1.20m bgl. The GI locations will be constrained to the northern and central areas where the proposed development is located.
Risk Assessment - Key Findings	
Historic Site occupancy	During WW2, the Site was located within Royal Ordnance Factory (ROF) Wrexham, an explosive-type ROF exclusively manufacturing cordite propellant for the British armed forces. The Site encompassed a small reservoir (for fire-fighting) and maintained grassland.
Likelihood of EO contamination:	**British EO:** ► ROF Wrexham did not manufacture items of EO (i.e. ammunition / munitions and related devices), instead it produced the propellant explosive - cordite - which was packaged and then delivered to filling-type ROFs where it was added to casings to produce cartridges, a form of EO. As the Site was located outside the ROF danger area (where the hazardous materials / compounds and finished cordite were exclusively handled) there is no contamination pathway between the Site and these explosives, which would have been bagged / packaged explosives. ► Although the ROF was fortified against an anticipated German invasion, the local Home Guard (HG) battalion's defence scheme is unlikely to have seen defence measurers of any type built / dug / placed on Site. This is due to the Site's wartime occupancy / use and its central position within the ROF. It is conceivable that the Site was accessed infrequently by HG soldiers during training exercises or routine armed patrols, however neither activity typically would have seen hazardous forms of EO used, i.e. live LSA (e.g. grenades). ► There is also a low likelihood of surplus / unwanted EO being disposed of (buried) on Site by ROF or HG personnel, again due to its occupancy and well-maintained ground cover. Note, the small man-made reservoir is not considered significant in this regard. ► During WW2, a small number of heavy anti-aircraft (AA) and light AA guns within firing range of the Site probably expended ammunition on multiple occasions, however due to the low intensity of local Luftwaffe activity, each engagement will have been short.

	The local unexploded AA shell strike density was low and the Site was small. Consequently, there is a low likelihood of such UXO contamination. **German Unexploded Bomb (UXBs):** ► The official records state that the only air raid to have affected the ROF occurred in Marchwiel Parish. The border of this parish passed ~500m south of the Site at its closest point. Therefore, the resulting bomb strikes may have all occurred beyond the wider study area (500m radius around the Site). That said, as the air raid also mentions the ROF, it is possible that the bombing affected any part of this vast factory site. ► This one raid (a single aircraft sortie attack) occurred in the middle of the night during August 1940. At this time, the ROF was probably in the final stages of construction. The national importance of this wartime facility probably meant that it was to be built as quickly as possible, necessitating a night shift of construction workers. ► As the threat of German invasion and sabotage was very high at this time, HG troops would have been active throughout the night, on the sentry and perimeter patrol duties. Once ROF Wrexham was operational, it was protected by a large team of fire-watchers stationed at multiple fire-watcher posts distributed throughout the ROF. Their job was to quickly extinguish any German 1kg / 2kg incendiary bomb (IBs) before they could take hold and cause an uncontrollable fire. These observers (on night duty throughout the remainder of the conflict) would have also reported any UXB falls they observed. Therefore, it is considered highly likely that the one known air raid (or any other unknown incidents) was witnessed by multiple people as it occurred, with any UXB falls probably observed and reported. ► And even if a high explosive UXB struck the Site, its entry hole (at least 200 / 300mm in diameter) would have been easily recognisable on the maintained grassland that accounted for most of the Site area. Any such strike to the reservoir would have created a clean / recognisable entry hole in the (assumed) concrete base, which would have been reported and investigated when the reservoir was drained during the mid to late 1940s.
Likelihood of EO remaining	Within the Site's undisturbed areas of soft ground, the risk associated with any EO (shallow or deeper buried) remains unmitigated.
Likelihood of EO encounter and initiation	► The Site's undisturbed areas of soft ground represent an area of potential concern. That said, the likelihood of EO remaining in-situ here is neither high nor moderate. As the zone of potential EO contamination (ZPC) exists just below the present-day ground level, all intrusions / excavations of the area of potential concern will be exposed to a potential EO encounter. ► The GI works will disturb a very small volume of soil and geology within the ZPC, significantly limiting the likelihood of encountering anything buried (e.g. EO). There is a greater likelihood of encountering shallow buried EO during the post-GI development phase mechanical excavations. However, this is partly offset by the 'blind' intrusive nature of borehole works, during which there is a greater likelihood of forcefully striking buried EO when compared to 'open' mechanical excavations of the same material.

The executive summary covers the key points only. The main body of this report contains the majority of the Site-specific detail and the limitations of the assessment. Should the proposed works be significantly modified or additional works be considered, IAL should be contacted as a reassessment of EO risk may be required.

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Glossary

AA	Anti-Aircraft
AAA	Anti-Aircraft Artillery
ALARP	As Low As Reasonably Practicable
AP	Anti-Personnel
ARP	Air Raid Precautions
AT	Anti-Tank
AXO	Abandoned Explosive Ordnance
BD	Bomb Disposal
bgl	below ground level
BGS	British Geological Survey
BPD	Bomb Penetration Depth
CIRIA	Construction Industry Research & Information Association
DA	Delayed Action (bomb type)
EO	Explosive Ordnance (UXO and AXO)
EOC	Explosive Ordnance Clearance
EOD	Explosive Ordnance Disposal
FAA	Fleet Air Arm (Royal Navy)
FP	Fire Pot (WW2 German bomb)
GP	General Purpose (bomb type)
ha	hectare(s)
HAA	Heavy Anti-Aircraft (gun)
HC	High Capacity (bomb type)
HE	High Explosive
HMNB	Her/His Majety's Naval Base
HMS	Her/His Majesty's Service (shore establishment)
HO	Home Office
HQ	Headquarters
HSE	Health & Safety Executive
IB	Incendiary Bomb
kg	kilogram(s)
km	kilometre(s)
LAA	Light Anti-Aircraft (gun)
LM	Land Mine
LRRB	Long Range Rocket Bomb (V2 rocket)
LSA	Land Service Ammunition
m	metre(s)
MC	Medium Capacity (bomb type)
mm	millimetre(s)
MOD	Ministry of Defence
MU	Maintenance Unit
NEQ	Net Explosive Quantity
NFF	National Filling Factory
NGR	National Grid Reference
OB	Oil Bomb
OS	Ordnance Survey
PAC	Pilotless Aircraft (V1 missile)
PB	Phosphorus Bomb
PM	Parachute Mine (bomb type)
POW	Prisoner of War
RADAR	Radio Detection And Ranging
RAF	Royal Air Force
RDX	Research Department Explosive
REF	Royal Explosive Factory
RFC	Royal Flying Corps (1912-1918)
RN	Royal Navy
RNAD	Royal Naval Armaments Depot
RNAS	Royal Naval Air Station
ROF	Royal Ordnance Factory
SAA	Small Arms Ammunition
SI	Site Investigation
SIP	Self-Igniting Phosphorus (grenade type)
TA	Territorial Army
TNT	Trinitrotoluene (explosive)
UK	United Kingdom
UN	United Nations
UP	Unrotating Projectile (AA rocket)
USAAF	United States Army Air Force (1941-1947)
USAF	United States Air Force (since 1947)
UX	Unexploded
UX AA	Unexploded Anti-Aircraft (projectile)
UXB	Unexploded Bomb
UXO	Unexploded Ordnance
V1	Vergeltungswaffe 1 (German cruise missile)
V2	Vergeltungswaffe 2 (German ballistic missile)
WAAF	Women's Auxiliary Air Force (1939-1949)
WO	War Office (1857-1964)
WW1	World War One (1914-1918)
WW2	World War Two (1939-1945)

1 Introduction

1.1 Instruction

Geo2 Limited (referred to hereon in as the Client) has commissioned Impartial Assessments Limited (referred to hereon in as IAL) to carry out a Stage 2 Detailed EO Risk Assessment of the proposed works at the Land South of Bridge Road North, Wrexham site (referred to hereon in as the Site).

1.2 Objective

The objective of this report is to assess the likelihood of encountering buried explosive ordnance (EO) during intrusive ground works and to assess the consequences of any such encounter. If an intolerable risk level is identified, risk mitigation measures will be recommended.

1.3 Using This Report

In the UK, EO risk is not always considered or fully understood and is often misunderstood. This report aims to provide a comprehensive and coherent account, including introductory text and details on location-specific types of EO. We believe it is important to provide sufficient information to allow the layman to form a good understanding of the potential EO risks.

However, we also appreciate that some readers will not require the full contextual information and therefore the report is structured with this in mind. From **Chapters 3 to 13**, all Site-specific text that affects the outcome of this risk assessment can be found under the highlighted Site-Specific subheadings.

1.4 Explosive Ordnance Risk in the UK

The term EO describes both unexploded ordnance (UXO) and abandoned explosive ordnance (AXO). The former describes devices and projectiles that have been armed (and in some cases fired, dropped, placed, etc) yet failed to function. The latter describes devices and projectiles that have simply been abandoned (discarded or buried).

Fortunately, inadvertent EO initiations (detonations) in the UK are very rare, however, buried EO can cause significant delays to construction projects with associated increases in costs. The origin of UK EO can be broadly categorised as such:

- **Enemy Action (UXO):** the German air force bombed targets throughout the UK during WW1 and WW2. The German Navy bombarded coastal targets in eastern England during WW1 and German long-range artillery bombarded Kent during WW2.
- **Allied Military Activity (UXO and AXO):** several Allied nations used the UK as a staging area for military action in the European theatre of conflict (most notably the US and Canada) during WW1 and WW2.
- **UK Military Activity (UXO and AXO):** domestic British Army, Royal Air Force (RAF) and Royal Navy (RN) training activities as well as anti-aircraft (AA) weapons used during WW1 and WW2.

1.5 Guidelines for Risk Assessment

1.5.1 CIRIA

This assessment has been designed and written in accordance with the relevant Construction Industry Research and Information Association (CIRIA) guidelines: **C681** 'Unexploded Ordnance - A Guide for the Construction Industry' (published 2009) and **C785** 'Unexploded Ordnance Risk Management Guide for Land-Based Projects' (published 2019). C681 and C785 were written (with the support of the UK Health and Safety Executive) to provide the construction industry with accurate and authoritative information regarding matters of onshore EO risk in the UK.

1.5.2 Legislation

There is no specific UK legislation covering the assessment and management of EO risk. However, there is legislation that more broadly covers the consideration of EO hazards:

- Health & Safety at Work Act (1974) and Management of Health & Safety at Work Regulations 1999
- Construction (Design & Management) Regulations (CDM) 2015
- Corporate Manslaughter and Corporate Homicide Act 2007

1.5.3 MOD

EO finds in the UK are handled by the MOD's Joint Service Explosive Ordnance Disposal Operations Centre (JSEODOC). At any site where an identifiable EO risk was not highlighted at project design stage, JSEODOC will not provide EOD services for frequent callouts to EO encounters. Instead, the client will be required to employ the services of a commercial EO risk management contractor to manage the ongoing EO risk.

The delay caused by retrospectively carrying out a risk assessment can have significant cost implications as site works are halted. Therefore, it is essential that EO risk is considered at the earliest possible stage, ideally through the commissioning of a Stage 1 or Stage 2 EO risk assessment.

1.6 Assessment Methodology

1.6.1 Introduction

This report is based on a traditional source-pathway-receptor-consequence (SPRC) assessment methodology and semi-quantitative risk model. The following subheadings describe how this risk assessment structure is applied to buried EO risk (in the UK).

1.6.2 Source

In the UK there are numerous sources of potential EO contamination. Three main factors govern the likelihood of buried EO being present at a given site today:

- **Contamination:** The likelihood that EO came to be buried at a site.
- **Subsequent Detection:** The likelihood that EO (chiefly UXO) contamination went unobserved and reported.
- **Degree of (any) Risk Mitigation:** Could subsequent earthworks or Explosive Ordnance Clearance (EOC) activities have mitigated the buried EO risk?

1.6.3 Pathway

The activities that could result in the EO hazard reaching sensitive receptors and the specific type of EO hazard.

- **Encounter:** The likelihood of buried EO being encountered during the proposed works depends on the total volume of soil disturbed and the type(s) of intrusion methodology. Note, site-specific bomb penetration depth (BPD) calculations must be conducted where appropriate.
- **Initiation:** The likelihood that an encounter results in the EO initiating.

1.6.4 Receptor

The number and sensitivity of receptors will vary from site to site. In the context of an EO initiation, the receptors present at the time of the event will almost always include the most sensitive category; human health.

1.6.5 Consequence

The consequences of an inadvertent EO initiation event vary from none to catastrophic. However, the likelihood of initiating EO is far lower than that of encountering EO. The negative consequences of an EO encounter are much more likely to be financial, resulting from project delays.

1.6.6 Semi-Quantitative Risk Calculation

Once all project-specific factors have been assessed, a semi-quantitative risk assessment (likelihood versus consequence risk matrix) will be carried out or multiple calculations will be carried out if the factors described above vary considerably across the site. In the latter scenario, a risk map will be drawn to illustrate the differing risk zones.

1.6.7 Recommendations

If a significantly elevated risk level(s) is concluded, industry standard risk mitigation measures (appropriate to the project specific intrusive methodologies) will be recommended to reduce the elevated risk level(s) to as low as reasonably practicable (ALARP) level.

1.7 Information Sources

To guarantee a robust assessment of risk, primary source records form the basis of this report. The following information types and information sources were accessed / contacted during the research process:

- The National Archives (London), Glamorgan Archives, North East Wales Archives, the MoD, Royal Commission on the Ancient and Historical Monuments of Wales, Council for British Archaeology, British Geological Society, the local authority, the Client.
- Historic OS mapping, historic aerial photography and various web resources.
- Our PIEO (potential indicators of explosive ordnance) GIS map and our physical library. Note, PIEO is the result of over fourteen years of research and is constantly growing.

1.8 Reporting Conditions

The accuracy of original records relating to bombing is difficult to verify. Wartime bombing records were only as detailed and accurate as the availability of time, personnel, and ease of access to information would allow. The conditions under which information was gathered in many urban locations, i.e. intense aerial bombardment, will not have been conducive to accurate record keeping. Air raids within sparsely populated locations are less likely to have been witnessed, limiting the accuracy of any corresponding records. Furthermore, such records were often based on unverifiable second-hand eyewitness accounts.

Many records of historic military activity have not survived and some of those that have are only declassified and released into the public domain decades after their creation. Consequently, pertinent records can be inaccessible at the time of requirement. Impartial Assessments cannot accept liability for any missing historic records, inaccuracies or omissions within the available historic records.

It is never possible to accurately determine, through desktop study alone, the precise location, type and condition of buried EO at a given site. Furthermore, some factors (human behavioural) make assessment of EO risk partly subjective.

2 The Site

2.1 Location

The Site is located on Wrexham Industrial Estate, ~4.5km east of Wrexham city centre in Clwyd County (northeast Wales). It is bound to the north by Bridge Road North, and to the east and west by neighbouring commercial properties.

The Site is centred on the approximate National Grid Ref: SJ 38117 49554.

Site location maps and recent aerial photography are displayed at **FIGURE 1**.

2.2 Description

The Site is a roughly triangular plot of overgrown mixed vegetation.

2.2.1 Proposed Works

The proposed development is for a battery energy storage system with associated access. At this stage the foundation design is unknown. Shallow pad foundations (mechanically excavated up to ~3.0m bgl) may suffice, however poor quality ground could necessitate deeper piled foundations.

Prior to redevelopment a GI will be undertaken, comprising 5No. dynamic sampler boreholes to 5.0m bgl. Each location will require a starter pit, hand-dug to 1.20m bgl. The GI locations will be constrained to the northern and central areas where the proposed development is located.

A proposed development plan is displayed at **FIGURE 2**.

3 Site History Assessment

3.1 OS Mapping

3.1.1 Introduction

Bomb damage resulting from German air raids can be identified by comparing historic OS maps. These maps can also help identify examples of historic military activity. Note, 19th / 20th Century military structures had a typical shape and were distributed in typical patterns.

The table below includes a review of the relevant OS maps. Note, the process adopted in generating these maps (mapping intervals, scale, exclusion of some features in the interests of national security, etc), may result in an incomplete account of a site's history.

The earliest available post-WW2 large-scale OS map is displayed at **FIGURE 3**.

3.1.2 Site-Specific

	Date	Scale	Observations	
Pre-WW1	1873	1:2,500	Site occupancy?	Farmland.
			Evidence of local military activity?	No.
	1899	1:2,500	Site occupancy?	Unchanged.
			Evidence of local military activity?	No.

	1911	1:2,500	Site occupancy?	Unchanged.
			Evidence of local military activity?	No.
Pre-WW2	1938	1:10,560	Site occupancy?	Unchanged. Note, this small-scale map lacks detail.
			Evidence of local military activity?	No.
Post-WW2	1954	1:10,560	Site occupancy?	A rectangular demarcation in the north of the Site, a structure or an area. The Site is bound by Bridge Road North. Note, the local area has seen widespread development.
			Evidence of WW2 bombing? ('Ruins', clearance, redevelopment)	No obvious evidence locally.
			Evidence of local military activity?	Yes. The local area (encompassing the Site) has been developed as Royal Ordnance Factory (ROF) Wrexham.
	1961	1:2,500	Site occupancy?	The rectangular demarcation has gone, the Site is featureless. The Site is bound by drainage ditches. A small structure with access path has been built immediately west.
			Evidence of local military activity?	No new evidence.
	1982	1:2,500	Site occupancy?	Unchanged.
			Evidence of local military activity?	No new evidence.
	1994	1:2,500	Site occupancy?	Unchanged.
			Evidence of local military activity?	No new evidence.
	Other significant observations		None.	

TABLE 1: Historical OS Mapping Review

3.2 Government Plans

3.2.1 Introduction

The three branches of the UK armed forces and related government bodies (e.g. the Ministry of Munitions, the Ministry of Supply, etc) all produced various different types of plans of their bases / facilities historically. These plans vary in their scale and level of detail. Most plans are indexed with accompanied keys / legends identifying the various structures. Not all 19th and 20th Century dated plans have however survived to the present-day.

Two original Royal Ordnance plans of ROF Wrexham were accessed. Sections of both are displayed at **FIGURE 4**.

3.2.2 Site-Specific

	Date	Scale	Observations
WW2	1944	1:2,500	The first plan (poor quality) shows the Site as it appears on the 1954 OS map. The plan's schedule of buildings / areas is missing and therefore it is not clear whether the rectangular feature on Site (index No. 13/005) is a building, other type of structure or a plot of demarcated ground.
	1944	1:2,500	The second plan (better quality) uses the same basemap as the first plan. In the northeast corner of the Site 'FH' likely indicates a fire hydrant. Again, the plan's schedule of buildings / areas is missing. An accompanying key is available however it appears to only illustrate the varying ownerships of parts of the wider ROF.

TABLE 2: Historical Government Plan(s) Review

3.3 Aerial Photography

3.3.1 Introduction

Historical aerial photography is often key in identifying temporary wartime activity. As well as clarifying historic site occupancy, aerial photographs can elucidate the degree of bomb damage to structures and show the locations of German high explosive (HE) bomb craters. Note, the latter usually only persisted for a short time.

WW2-era aerial photography is displayed at **FIGURE 5**.

3.3.2 Site-Specific

	Date	Type	Observations	
Post-WW2	2nd May 1946	Vertical. Moderate resolution	Timing?	Approx. one year after the cessation of hostiles (in Europe).
			Site occupancy?	As per the 1954 OS map and 1944 Royal Ordnance plans. The rectangular feature is a reservoir, almost certainly for firefighting.
			Site ground cover type(s)?	Grass, probably subject to maintenance.
			Evidence of WW2 bombing? (ruins, clearance, craters)	No obvious evidence.
			Evidence of local military activity?	No obvious evidence.
			Other observations?	None.

TABLE 3: Historical Aerial Photography Review

Note, vertical and oblique view photographs of the Site dated 30th January 1958 record the removal of the reservoir. The Site was entirely maintained grassland by this date.

3.4 ROF Wrexham

ROF Wrexham was approved for construction in August 1939. The site was chosen due to its likely distance from Luftwaffe bomber bases in Europe, its good rail links and a good supply of local labour.

Wrexham was a Ministry of Supply-operated explosive-type ROF employing several thousand people and was dedicated to the manufacture of explosive compounds for the British armed forces, chiefly the propellant cordite, a solventless propellant used in gun projectiles and rockets.

The complex was spread over a vast area (~700ha). The key buildings were dispersed and earth-bunded with the intention of minimising the effects of an accidental explosion or explosions caused by German bombing raids. Farm buildings were left in situ while the main buildings were camouflaged in an attempt to confuse Luftwaffe planners.

The ROF, split into Factories 1 and 2, commenced production of propellants in March 1941. The cordite producing section was supplied by three units producing nitrocylcerine and two units producing nitrocellulose. To the southwest of the main factory there were two tetrylnitration plants.

With the end of the war, the government's need for cordite was substantially reduced and the ROF ceased production by August 1945. Most of the buildings were abandoned and a residual group of 200No. staff remained onsite to clear up and for caretaking duty. The factory was decommissioned in 1947 / 1948.

Note, much of the archive material relating to ROF Wrexham has since been destroyed.

4 Domestic Military Activity Assessment

4.1 Sources of Potential Explosive Ordnance Contamination

The table below lists all the modern and historical sites and activities that could have potentially resulted in British / Allied UXO and AXO contamination in the UK.

Source of EO	Examples	Associated EO Hazard Items	Relevance
Military Bases and Installations	Army camps, RAF, RN or USAAF airfields, RN shore establishments, signals or communications installations, military training centres, etc.	Various conventional and chemical EO. The types of EO will depend on the type of site and branch of the military utilising it. Plus AXO (SAA, LSA and AA ammunition) for WW2 site defence, if applicable.	INSIGNIFICANT
Military Training Areas and Weapons Ranges	Inland and costal RAF and USAAF bombing ranges. Army / Royal Marines / RAF Regiment etc weapons ranges.	Various conventional and chemical EO. The types of EO will depend on the type of range / training area and branch of the military utilising it.	INSIGNIFICANT
Munitions and Explosives Factories	Royal Ordnance Factories, National Filling Factories, National Explosives Factories, Royal Naval Cordite Factories, etc.	Various conventional and chemical EO. The types of EO and explosives contamination will depend on the type of factory. Potentially plus AXO (SAA, LSA and AA ammunition) for WW2 defence.	**POTENTIALLY SIGNIFICANT**
Munitions Storage Depots	Royal Naval Armaments Depot, Royal Naval Ordnance Depots, RAF Ammunition Depots, Air Ammunition Parks, Reserve / Forward Ammunition Depots, Central Ammunition Depots, etc	Various conventional and chemical EO. The types of EO potentially present will depend on the branch of the military utilising it. Potentially plus AXO (SAA, LSA and AA ammunition) for WW2 defence.	INSIGNIFICANT

Fortifications and Defence Measures	Pillboxes, fortified houses, various earthworks (e.g. trenches) etc at: Nodal Points, Stop-Lines, VPs, etc.	SAA, regular army LSA, AA ammunition, Flame Fougasse, and Home Guard-specific weapons / ammunition.	**POTENTIALLY SIGNIFICANT**
Military Requisitioned Sites: WW1 and WW2	During WW1 and WW2 many private properties were requisitioned by the War Office for military use, including training.	SAA, regular army LSA and Home Guard specific weapons / ammunition.	INSIGNIFICANT
Pipe Mines and Conventional Minefields: WW2	Pipe mines and improvised mines at military bases. Conventional minefields at beaches and some Nodal Points.	Canadian pipe mines, various British landmines (AT and AP) and IEDs.	INSIGNIFICANT
RAF and USAAF Crash Sites	Numerous British and American aircraft crashed in the UK, chiefly during WW2. Munitions and ammunition not always fully recovered.	Various conventional air-delivered ordnance (bombs and rockets) and machine gun / autocannon ammunition.	INSIGNIFICANT
Home Guard Activity: WW2	Volunteer army tasked with home defence during WW2. An armed branch of the British Army. Battalions were active in all British counties.	SAA, regular army LSA, Home Guard specific ammunition e.g. 29mm Spigot Mortar, 3-inch Smith Gun, No.73, No.74, No.75 and No.76 grenades, etc.	**POTENTIALLY SIGNIFICANT**
Anti-Aircraft Weaponry: WW1 and WW2	Light AA (machine gun and autocannon), Heavy AA (QF guns), and ZAA (rocket projectors).	SAA, autocannon shells (20mm, 37mm, 40mm), QF shells (3, 3.7, 4.5-inch), UP rockets (2 and 3-inch).	**POTENTIALLY SIGNIFICANT**

TABLE 4: Sources of Potential Domestic Explosive Ordnance

4.2 Explosive-Type ROF

4.2.1 Brief Overview

The two factories that made up ROF Wrexham were divided into two distinct zones, the danger areas and the areas encompassing everything else; chemicals storage, workshops, offices etc. The danger areas were divided into sections, devoted to the manufacture of guncotton, nitro-glycerine, and the finished product cordite.

The production and processing of these sensitive and hazardous compounds was undertaken in lightly constructed laboratories surrounded by revetments. If one building was destroyed, the revetments were designed to contain the blast, thereby protecting adjacent buildings. The same revetment design was used for the magazines, where packaged cordite was stored prior to dispatch, although these buildings were more substantial constructions.

The active ingredient of cordite is nitro-glycerine. To make this highly unstable material safe to handle it was absorbed onto the surface of ‘nitro-cotton’ (chemically charred cotton waste) which then became known as ‘gun-cotton’. When extruded and dried, the finished product resembled thin orangey-brown coloured rope or cord, hence the name ‘cordite’.

Once produced, nitro-cotton was transported to the paste making buildings in rubber bags, where it was combined with nitro-glycerine. The raw nitro-glycerine had to be transported via gravity (lead lined troughs) as it was too unstable to pump or move about the site in containers. The cordite paste was then transferred to the press houses in rubber bags. The finished product (bunches of dried, pressed cordite cords) was again bagged up and delivered to the magazines for storage.

Explosive-type ROFs had peripherally located proofing areas where products could be quality tested. Small quantities of live ammunition (utilising the factory’s cordite) were produced and fired on the range to assess the propellant quality. There were also peripheral burning (demolition) grounds where life-expired or sub-standard chemicals / products could be safely destroyed.

4.2.2 EO Contamination at ROFs

Post-closure decommissioning operations at historical explosives / munitions factories have not always resulted in the total clearance of all EO contamination or explosive residues. The soft landscaped access areas that interspersed the laboratory buildings within the danger areas were well maintained and under strict controls to avoid inadvertent explosions.

However, the peripheral ground outside of the danger areas and around the proofing ranges and burning grounds were not always subject to the same strict controls. Indeed, EO finds in recent years indicate that the 'housekeeping' at former explosive and munitions factory burning grounds was poor during WW1 and WW2. Corners were cut and the scope of operations during wartime appears to have been massively increased in some cases, resulting in unanticipated EO contamination of a wider area. Note, EO was often only partially burnt or simply buried instead of being destroyed. Some examples of such incidents:

- The Normanton Explosives Factory (Wakefield) produced and tested detonators during WW2. Since its closure, several army EOC tasks have been required at different times to dispose of large numbers of buried detonators, unearthed on and near the former factory site. The first such EO encounter resulted in the death of a workman during excavations, in January 1988.
- Since its closure, decommissioning and subsequent redevelopment (present day White Lund industrial Estate), construction works at the former WW1 No.13 National Filling Factory (Morecambe) site have encountered items of EO, e.g. an artillery shell in November 2020.
- Between 2007 and 2008, a WW2-era mortar and 60No. projectiles were encountered during construction works at the former WW2-era Royal Ordnance Factory (ROF) Bridgend - Filling Factory No.2 site.
- During January and February of 1990, a 1.35ha area of Risley Moss Country Park was subject to an EOD clearance task; Ref: EOC 252. This resulted in the recovery and disposal of 9,946No. items of expended EO. Between May and July 1994 another area of Risley Moss Country Park was subject to an EOD clearance task; Ref: EOC 3691. This resulted in the recovery and disposal of ~93,000No. further items of expended EO. The country park borders the site of the former ROF Risley (Filling Factory No.6).
- Historically, at munitions related sites, explosive residues (e.g. nitro-glycerine) have been found in drainage systems. It is not clear how such contamination occurred, however today, this would pose a toxic hazard as opposed to a significant explosive hazard. At another filling factory, ROF Bridgend, there were several yellow phosphorus spillages which are thought to have contaminated local water courses.

4.2.3 Site-Specific

Original WW2-era Ministry of Supply records relating to the decommissioning of the ROF state that before transfer of the ROF to the Board of Trade, the ROF's buildings and land (within the danger area fence) will be decontaminated and certified free from explosives by the officer-in-charge, by September 1946. In certain areas however, especially the gun cotton plants, there may be small quantities of explosives in the drains and possibly in the floors of buildings. These locations will be highlighted by the officer-in-charge who will provide a safety inspector to supervise all subsequent excavations near and alterations to said buildings.

A separate record (dated 1946) states that the buildings in the danger areas of Factories 1 and 2 should be burnt to eliminate traces of explosives mixtures, the weeds should be eradicated and the areas held on a temporary care and maintenance basis.

An accompanying plan (displayed at **FIGURE 6**) shows the Site to be situated within the area proposed as a future industrial estate ('conversion for industry'). The Site lies between two of the factory's former danger areas (to the north and south) which are marked as requiring decontamination before conversion to other uses.

ROF Wrexham did not produce finished items of ammunition / munitions, i.e. EO. So, there is no direct EO contamination pathway relating to the ROF's main manufacturing function. The only pathway for hazardous manufacture-related contaminates (packaged or unpackaged explosives) to have ended up buried on Site is

intentional unauthorised burial by individuals.

However, as the Site was situated outside the danger areas, bags of gun-cotton or cordite in transit would not have passed close to the Site and therefore the likelihood of such a scenario occurring is very low. Furthermore, the Site's open maintained grassland (lacking tall / dense vegetation) would have deterred anyone looking to carry out unauthorised disposal.

The location of the ROF's burning ground is unknown, however as it will have been peripherally sited, the centrally located Site will not have been situated close by.

The location of the ROF's proofing range is unknown, however past research at other ROFs indicates that this would also have been peripherally sited. Furthermore, the available ROF plans and historic aerial photography do not record any structures / ground typical of such a facility near the Site.

4.3 Anti-Invasion Defence Activity

4.3.1 Brief Overview - WW2

From mid-1940, the threat of imminent German invasion resulted in the fortification of many coastlines, cities and towns in Britain. Army units were concentrated in the most vulnerable / most likely invasion areas and local Home Guard (HG) battalions were raised throughout the country.

At first, the strategy called for largely static defences focused on the coastline (the coastal crust) and a series of inland anti-tank (AT) stop-lines. The stop-lines varied in their length, strength and complexity with the General Headquarters Line (GHQ Line) being the most important. Stop-lines mostly comprised pillbox fortifications and AT trenches, where possible built / dug along natural barriers to armoured vehicles, for example rivers. Similarly, major cities (including London) were ringed with inner and outer stop-lines.

By July 1940 however, the plan had changed. Coastal crust defences and 'nodal points' were prioritised over stop-lines. Nodal points (also known as AT islands or fortress towns), were strategic focal points expected to hold out against attack for up to seven days.

Military bases / installations and crucial factories / depots were also prepared. Defence schemes were devised, defence measures were established, onsite personnel were trained and infantry units from around the country were detached to military installations to bolster the local defence force.

The HG comprised men either too old or young, or in reserved occupations. Almost all populated areas in Britain stood up a HG battalion and some organisations (infrastructure organisations and large industrial works) created their own private units. HG platoons were sometimes detached to military related sites for training and to provide guards for sentry duty.

By mid-1940, over one million had signed up to the HG. Initially, only basic and improvised weapons were available, however by mid WW2, weapons specifically designed for the HG (e.g. SIP grenades and the Blacker Bombard spigot mortar) as well as conventional weapons, were widely deployed.

Historically, an 'out of sight out of mind' culture (with regards to ammunition disposal) has been widespread in the British armed forces. This is evidenced by numerous post-war AXO finds in the UK. Troops appear to have discarded unwanted or faulty items (including surplus ammunition) on civilian land, most likely when the threat from invasion had passed or when the HG was disbanded in 1944. Ammunition caches are also believed to have been buried at defended positions, for quick / easy access in the event of an invasion. Inevitably some were forgotten and can therefore remain in-situ today.

Small and large-scale invasion defence exercises were frequent at military sites and in civilian areas throughout Britain. However, such exercises usually involved the use of blank ammunition and relatively unhazardous training aids (smoke canisters and pyrotechnics). For obvious reasons, live ammunition was rarely used for mock battles between defenders and a group posing as the enemy.

4.3.2 Site-Specific

Original WW2 British Army records relating to invasion defence activities in the region were accessed, however no original operational records relating to the relevant HG unit - the 10th Denbighshire (Marchwiel) HG battalion - were held by the relevant archives. Note, this battalion was dedicated to the defence of ROF Wrexham, the most important Vital Point (VP) in the region. As this battalion's ROF defence scheme is unavailable, commentary on invasion defence activities relating to the study area is very limited.

Secondary source research (OS mapping, aerial photography, archaeological records, relevant publications, etc) has highlighted evidence of 12No. pillboxes (hardened gun positions) in and around the ROF, none of which are situated close to the Site. Note however, there were probably similar fortifications which have since been destroyed to make way for post-war development. That said, the Site's wartime occupancy and position within the ROF indicate a very low likelihood that any fortifications or defensive earthworks (e.g. trenches and weapons pits) were built / dug on or adjacent to the Site.

It is conceivable however that HG soldiers accessed parts of the Site whilst on night patrols or during training exercises. Either activity almost certainly would not have involved live land service ammutnion (e.g. grenades) however. ROF defence training exercises would have involved blank small arms ammunition (SAA) and battle simulants (e.g. smoke grenades and pyrotechnics), neither of which pose a significant EO hazard. Armed patrols of the ROF will have only required live SAA (a low hazard EO variant) for rifles and sidearms.

Recent UXO finds in the UK suggest that bodies of water provided an ideal location for the quick / hassle-free disposal of unwanted hazardous items (including live ammunition) during WW2. There appears to have been a culture in the HG (and armed forces more generally) of unauthorised disposal of surplus equipment and ammunition on civilian land, most likely towards the end of the war, e.g. when the HG disbanded in 1944. However, as the reservoir on Site was a temporary wartime structure (presumably with a concrete base), the likelihood of such activity affecting the Site is considered to be low. Furthermore, when the reservoir was drained / decommissioned post-war, any hazardous objects therein would have been removed from the Site.

4.4 Anti-Aircraft Artillery - UXO Strikes

4.4.1 WW1

AA artillery was in its infancy during WW1 and therefore British AA gun deployments were on a far smaller scale than during WW2. Initial activity saw guns installed on top of some buildings and at other key facilities in London and Kent during 1914.

London was the most heavily defended region. Other cities and towns throughout Britain were defended, however Kent had the most AA batteries outside of the capital. Note, many of Britain's AA guns were not static. Single guns were mounted on trucks and moved around. RN installations also received protection. At the beginning of the conflict, 58No. guns were distributed between naval facilities at Dover, Harwich, Liverpool, the Tyne and the Humber.

The 3-inch QF gun was the mainstay of British AA artillery. UX 3-inch shells typically landed between 8km and 10km away. The smaller calibre 1-Pounder QF autocannon was also used in the LAA role, however it proved to be ineffective.

4.4.2 WW2

During WW2, the British Army's AA Command utilised three types of AA weapon for home defence: heavy AA (HAA) guns, light AA (LAA) guns, and Unrotated Projectile (UP) rocket projectors. From 1940 to 1945, BD units dealt with approximately 7,000No. UXAA projectiles in the UK, however such UXO is still unearthed today.

- **HAA Guns:** The vast majority of HAA guns (3.7 and 4.5-inch calibre) were deployed in static batteries of between four and eight guns. HAA batteries were used to engage bombers at high altitudes and were the main constituent of most city's (and some town's) Gun Defence Area (GDA). Mobile gun mounts were also available

for temporary deployments to key military and civilian targets. Note, a very small number of British 5.25-inch guns were deployed from 1942 onwards, as well as batteries of US Army 90mm guns during 1944.

Some 2,000No. of these guns were available during the 1940 / 1941 Blitz. GDAs could expend vast quantities of ammunition during each engagement. The most numerous 3.7-inch gun variant had a firing ceiling of approximately 9km. Although a number of factors will have affected the range of falling UX shells, most typically landed 10km to 15km away. Note, greater distances were achievable.

- **LAA Guns:** Smaller calibre guns (machine guns, 20mm and 40mm autocannon) were used for point (individual target) defence of strategic targets / vulnerable points (VPs). At the time, government policy mandated that (where possible) every VP should be protected, however in reality, a chronic shortage of effective LAA guns (autocannon) during the early years meant that only priority VPs received adequate protection. These smaller guns were easily transportable, and LAA regiment deployments were often temporary. British WW2 40mm guns had a firing ceiling of approximately 7.1km. Although a number of factors will have affected the range of falling UX shells, most typically landed <10km away.
- **ZAA Rockets:** A ZAA battery comprised a grid of typically 64No. UP rocket projectors firing single and (later) multiple 2-inch (UP-2) and 3-inch (UP-3) rockets in a volley, creating a 'box of effect' at preselected altitudes. Although a number of factors will have affected the range of falling UX rockets, they typically landed within 10km of the battery.

  Prototype ZAA weapons were fielded in late 1940 and deployed in cities around Britain from 1941. However, they were only deployed in significant numbers after the initial nine-month Blitz campaign had ended. Consequently, ZAA batteries saw far less action than AA guns. By the end of the war, >50No. ZAA batteries were operational across Britain.

4.4.3 Site-Specific

- No static AA batteries were established within firing range of the Site during WW1. Many WW1 AA guns did not occupy fixed batteries, they were instead mobile, mounted on vehicles. However, such guns would have been prioritised for the defence of key targets, chiefly Royal Navy establishments, and therefore mobile AA guns are highly unlikely to have been active within firing range of the Site during WW1.
- Two static HAA batteries (totalling at least 8No. gun emplacements) were built within firing range of the Site during WW2.
- Seven LAA gun sites were active within firing range of the Site during WW2, all sited to defend the nearby fighter airfield RAF Wrexham. Note, although the ROF was a VP, it was not itself protected by LAA autocannons.
- No U.P rocket projector (ZAA) batteries were active within firing range of the Site during WW2.
- Luftwaffe activity in the wider area was infrequent and low intensity during WW2. Therefore, these guns are highly unlikely to have expended a significant quantity of ammunition. When combined with the small size of the Site, it is considered highly unlikely that a UX AA shell fell within the Site boundary.

4.5 Explosive Ordnance Hazards Overview

4.5.1 Introduction

The following subheadings detail the EO hazards most likely to be relevant to the study area. Note, this is not an exhaustive list of potential EO contaminates.

4.5.2 Artillery Projectiles: Anti-Armour and Anti-Aircraft

AT guns, AA guns, and howitzers have been in use with the British Army for over a hundred years and from 1942 / 1943, many HG units were armed with a variety of small calibre AT guns. AT gun calibres ranged from the Ordnance QF 2 Pounder (40mm) to the Ordnance QF 17 Pounder (76mm). Howitzers ranged from the Ordnance QF 25 Pounder (87.6mm) to the BL 60 Pounder (127mm). HAA gun calibres were medium.

A wide variety of artillery projectiles have been deployed in the UK historically, by British and allied nation armies. In general, projectiles fall into two categories; shot and shell. The former are inert; solid metal projectiles containing no hazardous element, whereas the latter are hollow (like bombs), containing a variety of potentially hazardous fills.

Solid shot falls into four categories, mainly for gun proofing, target practice, and AT use, however as they are inert they are relatively irrelevant with regards to present day UXO risk. Historically, there were three types of WW2-era British artillery shell:

- **Bursting Type** - The filling (or part of it) caused the shell to burst. The most common filling was HE where the shell caused damage to material by the force of the burst or to personnel and aircraft by fragmentation of the shell casing producing shrapnel. WW2 HAA shells were of the bursting type. Note, bursting shells were also used with chemical fillings.
- **Shrapnel Type** - These usually burst in the air and projected their 'payload' forwards acting like a shotgun. The usual payload was shrapnel bullets however Thermite 'pots' were used during WW1. By the start of WW2 shrapnel shells were obsolete for field artillery.
- **Carrier Type** - These also burst in the air, however ejected their payload backwards after blowing the base plate off the shell. The most common fills used were smoke, star and flare shells. The latter two being designed to illuminate an area or target. Smoke shells were used to produce smoke screens and used various fillings (the most common being white Phosphorus).

Artillery projectiles were always painted, this protected the steel from rust but was also used to indicate the nature of the ammunition. The basic body colours for artillery were; Yellow (HE), Light Green (smoke), Black (Flare / Star) and Grey (chemical). Note, artillery shell fuzes found on their own can also represent a hazard. Although small, such items can contain enough HE to cause serious injury if mishandled.

With regards to HAA shells, British mechanical time-delay and barometric pressure fuzes of WW2 were poorly designed, resulting in high HAA ammunition failure rates (around 30%) during 1940 and 1941. By 1944 however, new fuzes had reduced the rate to approximately 2%.

Unlike bombs, AA shells were not designed to strike the ground nose first and therefore UX AA shell strikes on soft ground did not always create recognisable circular entry holes. This, combined with their lower mass (compared to a UXB) resulted in shallower ground penetration depths, typically <1.0m bgl in soil. Although, in very soft / saturated ground, UX HAA shells were observed to penetrate to >1.5m bgl.

Data sheets detailing examples of field gun and AA projectiles are displayed at **APPENDICES 1** and **2**.

4.5.3 Grenades

Grenades are the most commonly encountered type of WW2-era British LSA in the UK. Other types of LSA include mortars, artillery projectiles (e.g. AT guns), infantry rocket systems and mines (AP and AT).

Hand grenades and rifle (projected) grenades are small devices with a delay fuze that detonates three to five seconds after initiation / launch. They are divided into two categories, explosive (fragmentation or blast) and carrier. The latter are used for signalling (smoke) and incendiary (chiefly white phosphorus for AP and AT use).

A wide variety of grenades have been deployed in the UK historically. The first modern British fragmentation grenade (the Mills Bomb) was used from 1915 onwards, with later models used well into the post-WW2 period. Consequently, this model accounts for the majority of UX grenade finds in Britain. A Mills Bomb (the No.36 grenade in British service) is approximately 95mm x 61mm and contains approximately 71g of HE.

Another common UK grenade find is the No.76 Self-Igniting Phosphorus (SIP) grenade. These cheap and simple devices comprised a glass bottle (152mm x 63mm) containing a composition that reacts with air (when broken) creating an intense white phosphorus incendiary effect (burns hazard). They equipped most HG units during WW2.

A data sheet detailing some of the grenades (and other LSA items) most commonly deployed in the UK historically is displayed at **APPENDIX 2**.

4.5.4 Mortars

A mortar is a compact infantry support weapon that fires a projectile (mortar bomb) in a high-arcing ballistic trajectory, at low velocity. The first British mortars were used during WW1.

A mortar bomb / round is usually tear-drop shaped or cylindrical, nosed-fused and fitted with its own propelling charge. A small tail fin assembly stabilises the round in flight and a 'spigot tube' containing the propellant charge is screwed or welded to the base of the round.

During WW2, the 2-inch and 3-inch calibre mortars were the most commonly used by the British Army. These systems utilised several different types of ammunition (HE, smoke, illumination, signal, chemical and drill). The most commonly deployed round (the 2-inch HE variant) weighed approximately 1kg, 200g of which was the HE bursting charge. As such, mortars pose a hazard similar to grenades.

Data sheets detailing examples of this EO type are displayed at **APPENDIX 2**.

4.5.5 Autocannon (LAA) Shells

In Britain, two types of autocannons were used in the LAA home defence role by the Royal Artillery and later the RAF Regiment, the Hispano (20mm calibre) and Bofors (40mm calibre). These guns are similar to machine guns, however fire larger calibre rounds at a lower rate of fire (<750 rounds / min and 120 rounds / min, respectively).

Although cannon ammunition looks similar to SAA, these larger projectiles incorporate a small, simple impact fuse and hazardous charge. 20mm projectiles were typically 41mm in length and included a 6g - 11g HE and / or incendiary composition charge. 40mm projectiles were typically 130mm in length and included a 70g HE charge. Although small, when compared to artillery shells, each projectile still has the potential to cause serious injury.

Most WW2 autocannon ammunition incorporated a self-destruct mechanism, detonating the projectile after five seconds if no impact occurred. This resulted in less collateral damage and far less unexploded shells falling back to earth. If this mechanism failed, a UXO strike would occur at ground level.

Data sheets detailing examples of this EO type are displayed at **APPENDIX 1**.

4.5.6 Small Arms Ammunition

SAA (or bullets colloquially) is primarily cartridge-type ammunition with a calibre of <20mm. Each 'round' comprises a cartridge case, projectile (bullet), propellant and primer. Side arms (pistols), rifles and light to heavy machine guns utilise SAA.

Generally, SAA poses a relatively low EO hazard due to the small amount of explosive contained within the cartridge case and the low sensitivity / stable nature of the complete round. Although a cache of unspent rounds subjected to high temperatures (e.g. fire) could function and create a hazard.

Expended SAA (the projectile) is almost always solid shot, i.e. inert. Note, During WW1, experimental incendiary and explosive .303-inch SAA saw limited use with the Royal Flying Core and the RAF. Consequently, such SAA encounters today are very rare.

In the UK, the most commonly encountered historic SAA is .303-inch calibre. This was the standard cartridge used by British and Commonwealth armed forces from 1889 until the 1950s. However, many other calibres have been deployed in the UK by British and Allied forces.

4.5.7 Miscellaneous

Aside from live ammunition / munitions, a wide variety of potentially hazardous devices and components of munitions were handled at WW2-era military-related sites.

- **Battle simulants / Training Aids**: during the 20th Century the British armed forces utilised a variety of devices during training exercises to simulate battle conditions. One of the first such devices, the WW2 'Thunder Flash' was designed to mimic a grenade detonation and therefore is akin to a loud firework. Battle simulants are not lethal, however they do contain a small charge or hazardous fill (smoke). As such, they have the potential to cause injury if mishandled.
- **Fuzes and Detonators**: Detonators and fuzes are small components of individual rounds of ammunition / munitions. All detonators and some fuzes contain primary explosive, in relatively small quantities. These devices can be very small and are therefore more likely to persist at a site, long after military activity has ceased.
- **Drill / Training Ammunition**: Drill versions of numerous live ammunition types have been utilised by the British armed forces over the years. However, as drill ammunition / devices do not contain a hazardous fill element, they are inert (harmless). Drill devices are the same size, shape and often weight as their live counterparts, chiefly because they must be fired from the same weapon. They are also very similar in appearance to their live counterparts, although usually painted grey or blue and marked 'drill' or 'inert'. It should be noted however that examples of historic drill ammunition found today are usually so heavily corroded, they are indistinguishable from their live counterparts.

5 WW2 Enemy Action Assessment: Aerial Bombing

5.1 German bombing during WW2

Between 1939 and 1945, the German air force (the Luftwaffe) dropped approximately 75,000 tonnes of HE bombs and over two million incendiary bombs (IBs) on the four nations of the UK. Almost all counties were affected to some degree.

At the time, bombing was still in its infancy. Testing showed that the accuracy of daylight, level flight bombardment would put 50% of the bombload within 91m of the centre of the target from an altitude of 3,000m. At double this altitude the error exceeded 400m. In poor visibility and at night, the error could increase by >250%.

Furthermore, these tests were conducted within an uncontested environment. The various British AA defences and navigational countermeasures greatly hindered bombing. Luftwaffe aircraft frequently abandoned their intended target and jettisoned their bombloads indiscriminately. Consequently, numerous bombing incidents occurred in open countryside throughout the UK, many miles from intended targets.

Bombs were only rarely dropped individually. The normal procedure was to drop an internally carried bombload in a single sequence, with release spacings pre-set from 10m to 100m. 20No. 50kg bombs (the most numerous HE bombload) could thus extend in a line (called a bomb-stick) varying between 200m and 2km in length. These patterns (when accurately plotted) can aid in locating unreported UXBs. It should be noted however that externally carried bombs could be released individually, creating uneven bomb-stick patterns or solitary bomb strikes.

For other types of commonly deployed ordnance, inaccuracy was inherent. 1kg / 2kg IBs and parachute retarded mines (high-capacity blast bombs) were easily blown off course by the wind.

5.2 Explosive Ordnance Hazards Overview

5.2.1 Introduction

During WW2 the Luftwaffe deployed a variety of ordnance against the UK. The most frequently deployed large bombs achieved significant ground penetration due to their 'thick-skinned' steel construction and are therefore more likely to remain buried in the ground today. These HE (and some incendiary type) bombs are termed 'iron' bombs. The 50kg and 250kg 'iron' bombs accounted for approximately 93% of 'iron' bombs dropped on the UK.

Descriptions of these different bomb types are presented below. Data sheets detailing those bombs most likely to be encountered today are displayed at **APPENDIX 3**.

Note, the Italian Air Force participated in a small number of air raids in Essex and Kent during 1940. The Italian bombs were comparable to German general purpose 'iron' bombs, however any UXB find would be extremely rare.

5.2.2 More Likely to be Unearthed in the UK Today

- **High Explosive 'iron' bombs - General Purpose:** The SC series accounted for the majority of HE bombs dropped on the UK. This design had a moderate charge to weight ratio, approximately 50% charge. The most common weights were 50kg (SC50), 250kg (SC250) and 500kg (SC500). 6No. additional models (1,000kg, 1,200kg, 1,400kg, 1,800kg, 2,000kg and 2,500kg) were deployed in much smaller numbers.
- **High Explosive 'iron' bombs - Semi Armour Piercing:** The SD series were very similar in appearance to the SC bombs but had lower charge to weight ratios, approximately 30% charge. The casing was thicker, allowing for greater penetration through structures. There were six 'iron' bombs models ranging from 50kg to 1,700kg.
- **Incendiary 'iron' bombs:** The Brand C50A used a SC50 type casing but contained a mixture of incendiary liquids (including phosphorus) that ignited on contact with the air. The C50B was the same size but mostly phosphorus filled. The Sprengbrand C50 (Firepot) also utilised a thick 'iron' bomb casing, however contained both Thermite incendiary containers and a 7kg HE charge. These bombs weighed approximately 41kg and 50kg respectively and were introduced later in the war.
- **Incendiary Sub-Munitions:** The 1kg B1E IB was the most frequently dropped German bomb. Up to 620No. B1Es could be packed into a sub-munition canister, which opened at a pre-determined height, scattering the IBs over a wide area. The Thermite fill burns at extremely high temperature. The longer 2kg B2E model incorporated a small HE charge with delay fuze. The B2E is therefore more hazardous than the B1E, however was dropped in smaller numbers. Although light weight, both had the potential to fully penetrate soft ground.

5.2.3 Less Likely to be Unearthed in the UK Today

- **High Explosive 'iron' bombs - Armour Piercing:** The PC series (four models between 500kg and 1,600kg) were used against reinforced military structures and warships. Consequently, they were not commonly used against the UK mainland. Charge to weight ratios were low, approximately 15% charge.
- **High Explosive Blast Bombs - Parachute Mines:** Converted naval influence mines were dropped on urban targets. Their thin steel bodies allowed for very high charge to weight ratios, approximately 73% charge. Luftmine A (LMA) and Luftmine B (LMB) weighed 500kg and 1,000kg respectively. Each was parachute retarded, enabling detonation at ground level and therefore no ground penetration. Consequently, the only unexploded parachute mines found today, wash up along the coastline or remain on river or lake beds.
- **Oil Incendiary Bombs:** The Flam 250 and Flam 500 bombs contained a mixture of benzine and petroleum, ignited by a small HE charge. They were constructed of thin metal which broke up on impact, spreading the incendiary mixture across an area. As such they are unlikely to remain buried in the UK today. The bombs proved unreliable, often failing to ignite, and consequently were withdrawn from service in 1941.

- **Anti-Personnel (AP) Sub-Munitions:** The 2kg SD2 'Butterfly' AP bomb was dropped on several British cities and towns. It was a nuisance weapon incorporating both time-delay and anti-handling fuzes. It contained a small 225g HE charge, however had no ground penetration ability. A sub-munition canister could hold up to 108No. SD2s. The SD10 was a larger (10kg) AP bomb. It could achieve full penetration, however this model was dropped in very small numbers on the UK. A sub-munition canister could hold 17No. SD10s.
- **Miscellaneous:** The Luftwaffe dropped various other devices on the UK. Flares (for target illumination) were by far the most numerous, however had no ground penetration potential. Photoflash bombs (to aid reconnaissance photography) are similar in appearance to 50kg bombs. Inert concrete-filled bombs were dropped to cause disruption and unnecessarily tie up bomb disposal (BD) resources.

5.2.4 'Iron' Bomb Penetration Depths

The Research & Experiments Department of the Ministry of Home Security used BD records to study German HE UXB penetration depths, publishing their findings in 1949. The British Army's BD headquarters provided details of 1,304 UXB recoveries. In addition, the ministry carried out their own tests, involving 24No. bombs dropped into Chalk under controlled conditions.

The average penetration depth of 430No. 50kg bombs (the most commonly dropped HE bomb) in London Clay was 4.6m and 6.1m for the 250kg model. Note, these bombs landed in open ground and were therefore unaffected by structures or hardstanding. Once the distribution of bomb weights against penetration depths was plotted, the mean line was extrapolated for each bomb weight to produce probable maximum depth figures.

For each bomb weight, the mean average of all observed penetration depths was calculated for each geology. The resulting figures, plus the observed minimum penetration depths, are presented in the table below. Note, bombs weighing >1,000kg have been omitted from the table as only several such UXBs were recovered during WW2.

	Clay			Chalk			Gravel			Sand			Sandstone		
Bomb (Kg)	Min (m)	Average (m)	Max (m)	Min (m)	Average (m)	Max (m)	Min (m)	Average (m)	Max (m)	Min (m)	Average (m)	Max (m)	Min (m)	Average (m)	Max (m)
50	0.7	4.0	9.1	1.0	3.5	7.7	1.0	2.8	7.8	1.0	2.8	7.8	1.8	2.7	6.0
250	1.5	6.8	15.8	1.0	6.0	13.1	0.7	4.8	13.7	1.8	4.8	13.7	2.5	4.6	10.3
500	3.8	8.7	19.8	4.0	7.6	16.4	2.5	6.0	17.3	3.0	6.0	17.3	-	5.8	13.1
1,000	4.8	10.9	24.9	4.2	9.6	20.7	2.0	7.6	21.9	6.8	7.6	21.9	-	7.3	16.4

TABLE 5: WW2 German UXB Penetration Depths Data

Although most German HE UXBs came to rest after several metres travel through the ground, these weapons can be encountered at any depth between just below WW2 ground level and the maximum BPD. There are three reasons why heavy bombs might be found at surprisingly shallow depths:

- **Low Altitude Release:** Some Luftwaffe raids (particularly those involving fast fighter-bombers) were executed at very low altitudes, to avoid RADAR detection. Bombs released over soft ground from very low altitude would impact at a shallower angle, resulting in extreme J-Curve Effect (see below).
- **Deflection:** 'iron' bombs had conical nosecones and were therefore susceptible to deflection. A bomb striking a structure (above or below ground), could deflect and come to rest at a shallower depth.
- **Aircraft Crash Site:** For several reasons, a pilot may not have been able to dump his bombload before impacting the ground. Any internally or externally fitted bombs could have become shallow buried on impact.

5.2.5 'Iron' Bomb J-Curve Effect

WW2 BD units reported that most deep buried German HE UXBs were observed in a horizontal or up-turned orientation. As a HE UXB penetrates the ground at an angle slightly offset from the vertical, it begins to turn, creating a curved passage through the soil.

This phenomenon can be significant when assessing the risk of UXO as the J-Curve Effect results in a horizontal offset from the point of UXB entry. A HE UXB could impact soft ground adjacent to a building and then come to rest beneath that building. The degree of lateral offset is typically one third (approximately) of the bomb's ultimate penetration depth. Therefore, for locations which experienced high-altitude bombing raids, J-Curve offsets will typically be between 2.0m and 4.0m. In extreme conditions, a low altitude attack resulting in a low angle UXB strike could produce even greater horizontal offset, up to 15.0m.

5.3 British Records of Bombing

5.3.1 Official Records

The Bomb Census was undertaken by the Ministry of Home Security. The Bomb Census was compiled using information primarily gathered by ARP (Air Raid Precautions) wardens. Standardised forms were used to keep a written record of each incident. In many areas, these reports were used to create bomb plot maps. The Ministry also calculated bombing density statistics for every administrative area and created Daily Intelligence Reports, recording the date and location of every single air raid.

The Bomb Census commenced in September 1940, more than three months after the German bombing campaign commenced. Initially, only information relating to London, Birmingham and Liverpool was collated. It was not until September 1941 that the Bomb Census was extended to cover the entire UK. Consequently, many pre-September 1941 records were not standardised and, in some cases, were poor quality.

The level of detail varied greatly with location. Furthermore, the Bomb Census did not cover air raids on military property. The armed forces had no formal process for recording air raids and processing associated records.

As well as bombing incident records, some local authorities produced war damage maps. Council engineers carried out street by street surveys to create a record of the varying degrees of damage sustained by buildings.

Today, many original (archived) bombing records are incomplete, some collections are missing altogether and in some cases, entire records were destroyed at the time by German bombs.

5.3.2 Unofficial Records

In some parts of the UK where official bombing records are incomplete or missing, historic eyewitness accounts, newspaper articles, aerial photographs, etc can be used to build up a picture of WW2 air raids. The credibility of any such information, however, must be addressed and assessed.

5.4 Luftwaffe Targets

5.4.1 Brief Overview

The Luftwaffe carried out reconnaissance flights over the UK. Numerous aerial photographs were taken with subsequent German annotations earmarking various facilities for attack. Luftwaffe crews were also given British OS maps with German annotations highlighting their target area. In the absence of detailed bombing records, the presence of a known target increases the likelihood that bombs fell locally.

Although official German doctrine did not specifically target civilian residential areas, the Blitz raids on individual targets were gradually replaced by what was, for all intents and purposes, unrestricted indiscriminate bombing. This was due to the effectiveness of British countermeasures. The Luftwaffe identified city centre aiming points for some attacks, as well as identifying individual targets. Typical types of target:

- **Common Primary (strategic) Targets:** RAF airfields, Royal Navy bases, commercial docks, weapons (chiefly aircraft) factories and RADAR installations.
- **Common Secondary Targets:** engineering works, steel works, factories, depots, railway marshalling yards, gasworks, power stations, army camps / barracks, AA artillery batteries, coastal gun batteries etc.

Note, the inherent inaccuracies in WW2-era aerial bombardment resulted in many wayward bomb strikes in areas surrounding targeted facilities.

5.4.2 Site-Specific

Original Luftwaffe target mapping and target reconnaissance photography of the region was accessed. One such image is displayed at **FIGURE 7**.

Target Category	Relevance and Approx. Proximity to the Site
Confirmed primary aiming point (indiscriminate bombing)	None within 10km
Closest confirmed primary individual target(s)	ROF Wrexham (on Site)
Confirmed secondary individual target(s)	None within 2km
Unconfirmed but potential target(s)	None within 2km

TABLE 6: WW2 Bombing Targets

5.5 Bombing Decoy Installations

5.5.1 Brief Overview

British decoys were intended to draw enemy bombers away from the true targets. 839No. decoys were built at 602No. sites in England, with approximately 200No. more established in Wales, Scotland and Northern Ireland. Although success rates varied greatly, the confirmed presence of a bombing decoy significantly increases the likelihood that bombs fell near or on that location. 5No. types were fielded:

- **'K' and 'Q' Sites - Dummy Aerodromes**. 230No. were established. 'K' decoys (landing field, mock-up buildings, and inflatable aircraft) were for daylight use. 'Q' decoys used lights to create a flarepath simulating a runway at night.
- **'QL' Sites - Urban Lighting**. Electric lights were used to simulate poorly implemented blackout procedures. As a bomber force approached, the lights would be extinguished erratically.
- **'SF' and 'QF' Sites - Diversionary Fires**. The largest and most sophisticated decoys. When lit, 'Starfish' sites gave the impression of an urban area set alight by incendiary bombing. They were installed near cities. Similar to, however smaller than 'SF' decoys, 'QF's were installed near and for the protection of specific vulnerable points (VPs) such as factories, military sites, oil storage tank farms, etc. Some 100No. 'QF' sites were established in England.
- **'M' and 'C' Sites - Dummy Factories and AA Batteries**. The former comprised a scale model of a specific factory, vital to the war effort. They were made from wood and canvas and had other features, such as access roads and equipment.
- **ASQL - Assault.** During August and September 1943, 18No 'QL' sites were installed along the south coast of England during a deception operation. These temporary decoys received very little attention.

Between 1942 and 1943, most 'K' sites were dismantled, however many of the other decoys were used up until late 1944 when Luftwaffe activity over the UK had all but ceased. By the end of 1941, the airfield decoys had received 359No. attacks compared with 358No. raids carried out against the real airfields. By June 1944, approximately 730No. attacks had been recorded on all decoy types. At least 5% of the total weight of German bombs dropped are estimated to have been aimed at Britain's decoy sites.

5.5.2 Site-Specific

No bombing decoys were installed locally. The closest was ~6.7km southeast of the Site.

5.6 Local Air Raids Information

5.6.1 Brief Summary

Wrexham occupied a region that was relatively insignificant, in the context of likely bombing target areas. Indeed, this is part of the reason why the area was chosen for a ROF. It was located far from the Luftwaffe bases in occupied Europe and not under any major Luftwaffe flight path to / from other frequently bombed cities.

Wrexham experienced just five small-scale air raids during WW2 and RAF Wrexham airfield was neither frequently nor heavily bombed. Even though the ROF itself was earmarked for attack by Luftwaffe planners, in the event, the factory was never the specific subject of a medium or large-scale bombing raid.

5.6.2 Bombing Density

The table below records the Ministry of Home Security's (MoHS) bombing density calculation for Wrexham Rural District, within which the Site was historically located. It gives a breakdown of the number of large Luftwaffe bombs reported within the administrative area. These figures do not include UXBs, 1kg / 2kg IBs, or 2kg HE AP bombs. The adjacent table displays IAL's bombing density parameters.

Administrative Area Size (Acres)	72,370
HE 'iron' bombs (all types)	273
HE Parachute Mines	4
'Flam' Oil IBs	1
Phosphorus IBs	0
'Fire Pot' Phosphorus IBs	0
V1 Flying Bomb	0
V2 Long Range Rocket	0
Total (excluding V Weapons)	278
Bombs Per 1,000 Acres (405ha)	**3.8**

Qualitative	Quantitative
Very Low	<5 bombs per 1,000 acres (405ha)
Low	5 to 15 bombs per 405ha
Low to Moderate	15 to 30 bombs per 405ha
Moderate	30 to 75 bombs per 405ha
Moderate to High	75 to 150 bombs per 405ha
High	150 to 300 bombs per 405ha
Very High	>300 bombs per 405ha

TABLE 7: Bombing Statistics and Parameters - National Source

5.6.3 Site-Specific

The bombing density figure for a whole administrative area is not always a good indication of the bombing density over a specific site. Within larger districts, particularly rural districts, bombing density figures may be skewered by the presence of a heavily bombed target.

This rural district covered a very large area, reducing the accuracy of the above bombing density figure when applied to the study area. However, further research confirms that **the study area did indeed experience a very low bombing density**.

5.7 Bomb Failure Rate

5.7.1 Brief Overview

There are three reasons why German 'iron' bombs dropped during WW2 failed to function as designed:

- **Human Error:** failure of the aircraft's crew to charge the electrical condenser in the fuze.
- **Very Low Altitude Release:** the fuze would not have enough time to arm itself before impact.
- **Faulty Fuze:** inadvertently during manufacture or sabotage by POWs working in German factories.

The Bomb Census recorded a daily average of 84No. German 'iron' bomb UXBs dropped on civilian targets throughout Britain, between 21st September 1940 and 5th July 1941. 8.5% of these were Delayed Action (DA) bombs (time bombs) which exploded sometime later. The remainder were unintentional 'duds' (UXBs).

By the end of WW2, the Ministry of Home Security calculated a total figure of 200,195No. HE bombs recorded as exploded in Britain. An additional 25,195No. HE UXBs were recorded, giving a HE bomb failure rate of 12.6%.

The Luftwaffe figure for the total number of bombs dropped on the UK was approximately 11% higher than the number observed and reported by UK authorities. This suggests that the total number of UXBs remaining buried in the UK today is greater. However, anecdotal evidence suggests that German sources overstated their bombing statistics for propaganda reasons.

The average HE bomb failure rate of all boroughs and districts making up the London Civil Defence Region (the most heavily bombed part of the UK) was calculated as 10%, with rates ranging from 6% to 15%. Note, those areas of the capital that suffered the most damage, had the most ruins into which subsequent UXBs could fall unnoticed / go unrecorded. This limits the accuracy of the observed failure rates in those areas.

The discrepancy between the British and German records combined with the fact that HE UXBs are still consistently being discovered in the UK today (averaging five per year), confirms that the UK's 12.6% rate is inaccurate and is in fact higher. As rates of 15% were observed in some areas, this is considered to be a more accurate estimate of the true failure rate.

5.7.2 Site-Specific

No evidence has been found to suggest that the local HE bomb failure rate differs significantly from the national average.

5.8 Site-Specific Bombing Incident Records

5.8.1 Wrexham ARP - Incident Reports

The rural district council's collection of original ARP incident message forms (produced by ARP wardens at the scene of an incident) is not available in the public domain and therefore may not have survived to the present day, or may now be held in a private collection. No ARP bomb plot map(s) were held by the relevant archives either.

Note, original Ministry of Supply records relating to the ROF were available, however none reference Ministry of Supply personnel taking on ARP duties at the ROF.

5.8.2 Bomb Census - Daily Intelligence Reports

The MoHS collated data on every reported air raid throughout the UK. Daily intelligence reports were short form reports, including only basic information relating to air raids (the administrative area affected and any resulting casualties).

A search of this record for Abenbury and Isycoed (the two parishes that encompassed the Site and wider study area) did not result in any reported air raids. The closest air raid occurred in the parish of Marchwiel (precise location unknown but >500m south of the Site) on the 30th / 31st August 1940.

5.8.3 Bomb Census - Incident Reports

Three separate MoHS collections of written incident reports for the civil defence region that could potentially include reports describing local bombs strikes, were accessed. Note, one of these record types (providing minimal detail) covers the entire WW2 bombing campaign, however the other two (more detailed record types) are incomplete, only recording only a fraction of the total incidents in the region.

A search of these collections highlighted one relevant incident (an intelligence summary report):

31st August 1940 at 00:10hrs - IBs fell at the ROF, Marchwiel. No damage or casualties caused.

5.8.4 Bomb Census - Incident Plot Maps

Collections of original MoHS plot maps and plot trace maps for the civil defence region were searched. Such maps were only produced from late 1941 onwards and only record a selection of local air raids. As such, they do not represent a complete picture of local bombing. They also record HE bomb strikes only.

No such maps covering the study area were available.

5.8.5 Anecdotal and Secondary Source Evidence

A search of online resources and local history publications was carried out with the intention of locating any relevant anecdotal / eyewitness accounts or secondary source information relating to local bombing incidents.

A desk study including local eyewitness accounts was located (Townscape Chartered Town & Heritage Consultant Ltd. 2017). The following statement was included:

'In the past 50 years that I have been connected with the site [ROF Wrexham] *I have never heard that it was attacked by enemy action of any description. I have never heard of any German bombs being dropped on any part of the ROF or any surrounding land*.'

5.9 Abandoned Bombs

5.9.1 Brief Overview

When a WW2 BD team arrived at the scene of a confirmed UXO strike, they would classify the incident by its potential hazard, Categories A, B, C and D, with A the highest priority for immediate removal and disposal. Occasionally, BD engineers could not find or recover the UXO and its location was simply recorded as an 'abandoned bomb'. The reasons for abandonment could be inaccessibility, extremely soft ground (extreme burial depth) or simply a harmless location (e.g. an isolated field). Note, BD teams in heavily bombed areas were constantly overstretched due to the sheer number of UXBs reported.

The archive office of the British Army's 29 EOD&S Group holds an Abandoned Bomb Register for Britain, as does the Ministry of Housing, Communities & Local Government. The registers lack detail, particularly with regards to locations. A general address rather than a precise position (grid refence) is usually given. Some of the abandoned bombs are likely to have been subsequently recovered or discredited, however remain on the register.

5.9.2 Site-Specific

No abandoned bombs are listed locally.

5.9.3 WW2 Bombing Incident Records Conclusion

- **Number and intensity of local air raids**: One single aircraft sortie raid may have affected the wider study area (within 500m of the Site boundary).
- **Number of local bombing incidents**: Multiple 1kg / 2kg IBs dropped, unknown number.
- **Local bomb-stick orientations**: The flight path of this aircraft during its bombing run is unknown.

5.10 Aircraft Crash Sites

5.10.1 Brief Overview

Numerous German aircraft came down over the UK during WW2. In most cases, the pilot was able to jettison any remaining bombload prior to impact or the aircraft belly-landed resulting in only superficial damage to the fuselage. However, in some cases, mechanical malfunction and / or crew injury meant bombs were not released. If the aircraft struck the ground at a steep angle and at high velocity, high density objects (engines and bombs) became buried, sometimes to significant depths.

5.10.2 Site-Specific

No Luftwaffe aircraft crashed within the Site boundary.

6 WW2 Enemy Action Assessment: Other

6.1 V Weapons

6.1.1 Brief Overview

In mid-1944 Germany launched the V1 Flying Bomb campaign. The V1 was a primitive cruise missile carrying an 848kg HE warhead. Between 13th June 1944 and 29th March 1945, V1s were launched from static sites in France and Belgium. 5,823No. missiles landed in England, 2,419No. of which reached London, their intended target.

Not long after, Germany launched the V2 Rocket campaign. The V2 was a primitive ballistic missile carrying a slightly smaller HE warhead (735kg). Between 8th September 1944 and 27th March 1945, V2s were launched from static and mobile sites in Holland. 1,102No. rockets landed in England, 516No. of which hit London, the initial target area. Later on, Norwich was targeted, sustaining 43No. strikes.

Both weapons were constructed of thin sheet steel and consequently had very limited ground penetration ability, if they failed to function. Therefore, V Weapons do not themselves pose a UXO risk, however the damage they caused can hamper the accurate assessment of Luftwaffe UXB risk.

6.1.2 Site-Specific

No V Weapons struck the wider Wrexham area.

6.2 Artillery Bombardment

6.2.1 Brief Overview

Six German Navy artillery batteries (comprising 20No. guns of between 21cm and 40.6cm calibre) were established in the German occupied Pas-de-Calais area from July 1940. In addition, the German army brought railway-mounted guns to this area of France, seven of which (six 28.0cm calibre guns and one 21.0cm gun) were capable of striking inland targets in Kent.

The first shells were fired at Kent on the 12th August 1940 with frequent attacks occurring during each of the next four years until the final bombardment on the 26th September 1944. In all, at least 1,000No. attacks (each involving multiple projectiles fired) were recorded, an average of one every two days. The towns of Folkestone, Deal and Dover were targeted, however many shells landed in the surrounding countryside. UXO finds of this type are rare.

6.2.2 Site-Specific

Wales was located well beyond the range of the German cross-channel artillery batteries.

7 WW1 Enemy Action Assessment

7.1 Aerial Bombing

7.1.1 Brief Overview

Between December 1914 and August 1918, the German navy air wing and army air wing carried out 51No. Zeppelin airship raids and 52No. fixed-wing aircraft raids (involving multiple aircraft) against England and south-east Scotland. Note, many more attacks involving solitary fixed-wing aircraft occurred. An estimated total of 9,000No. HE bombs and IBs were dropped, with London and the east Kent towns experiencing the most raids. During the four years long campaign, Britain suffered 4,820No. casualties.

The German bombing campaign of WW1 was significantly smaller in scale than the WW2 campaign, in terms of the number of raids, number of aircraft per raid, and size of bombloads (for fixed-wing aircraft). As it was the first time Britain had experienced aerial bombardment, the small-scale daytime attacks often attracted spectators, which increased the chance of any UXB being observed and reported. When combined with the fact that most WW1 bombsites have been redeveloped, German WW1 UXB finds are rare.

7.1.2 Site-Specific

Wales was not bombed during WW1.

7.2 Naval Bombardment

7.2.1 Brief Overview

Several coastal towns in Yorkshire, Norfolk, Suffolk, and Kent were subjected to naval bombardment from German warships during seven raids in 1914, 1916 and 1917. These raids varied in intensity, both in terms of duration (number of shells expended) and calibre of artillery employed. The heaviest attack resulted in >1,000No. shells fired, with the lightest raid expending only several rounds.

The relatively short firing distances during these bombardments resulted in many shells failing to explode, as there was not enough time for some shells to arm themselves before striking the coast. German WW1 UX naval shell finds are extremely rare.

7.2.2 Site-Specific

The wider Wrexham area was not subjected to naval bombardment during WW1.

8 Explosive Ordnance Migration

8.1 Introduction

Any fill material deposited on a site is unlikely to be contaminated with EO, as the material will have experienced excavation, transport, and processing during which any large objects are likely to have been observed and removed. However, EO encounters within such material do occur, confirming that items can be missed.

One known reason is WW2 Blitz rubble. The Blitz resulted in vast quantities of bombsite rubble. This material was put to use in a variety of ways. >750,000No. tonnes of London's rubble were used to build runways for new USAAF airfields in East Anglia and Liverpool's rubble was used to create and maintain flood defences throughout Merseyside. Blitz rubble was also commonly used for smaller scale construction works, immediately following WW2.

In 2010, two German HE UXBs were encountered in, what was later identified as, Blitz rubble at a Plymouth building site. Such incidents are rare however, and such contamination is much more likely to take the form of smaller items e.g. UX AA projectiles or UX 1kg / 2kg German IBs.

8.2 Site-Specific

No evidence has been found indicating that WW2 'Blitz rubble' or any other EO contaminated soil / material was deposited on Site historically and there is a low likelihood of such activity occurring.

9 Local Explosive Ordnance Encounters

9.1 Introduction

Even if research does not identify potential sources of EO contamination at a given site, knowledge of a recent EO encounter in the vicinity could indicate an elevated risk at that site. EO encounters on civilian land are often reported in the media and therefore a web search of media outlets was carried out.

9.2 Site-Specific

No evidence of an EO incident on or adjacent to the Site has been identified.

10 Site-Specific Risk Assessment

10.1 Introduction

Two key Site-specific considerations must be assessed, the likelihood of an EO linkage (source-pathway-receptor) becoming complete and the severity of the resulting consequences. The 'likelihood' consideration itself is a function of the likelihood of contamination, the degree of subsequent risk mitigation (if any), the likelihood of encounter and the likelihood of initiation. These factors (in relation to the Site) are assessed at **Headings 10.2 to 10.5**.

10.2 The Likelihood of Contamination

10.2.1 Hazard Items

The table below details the most common EO types encountered in the UK today. The / those EO type(s) relevant to the Site (the Site-specific hazard item / items) are:

- British LSA and SAA
- British AA projectiles
- German UXBs

EO Type	NEQ or Incendiary Hazard	Likely Contamination Depth	Hazard Class
German HE 'iron' bombs	25kg to 220kg HE (most common) 530kg to 990kg HE (least common)	Deep (3.0m to 10.0m+)	**Very High**
German 41kg and 50kg Incendiary 'iron' bombs	13kg incendiary composition or 7kg HE	Shallow / Deep (2.0m to 6.0m)	**High**
British HE HAA Shells and Rockets	1.1kg - 2.2kg HE	Shallow (0.5m to 2.0m)	
Some British HE Land Service Ammunition	1 - 2kg HE	Very Shallow (<1.0m)	
Some British HE Land Service Ammunition	<1kg HE	Very Shallow (<1.0m)	**Moderate**
German 2kg Incendiary + HE Bombs	680g thermite (incendiary) + 100g HE	Very Shallow (<1.0m)	

German 1kg Incendiary Bombs	680g thermite	Very Shallow (<1.0m)	**Low to Moderate**
British HE LAA Autocannon Shells	4g to 70g HE and / or incendiary composition	Very Shallow (<0.5m)	
British Small Arms Ammunition	Small quantity of black powder. Inert projectile or <1g incendiary composition	Very Shallow (<0.5m)	**Low**

TABLE 8: Most Common Hazard Items

10.2.2 Subsequent Detection

There are many variables that affect the likelihood that a German UXB or British UX AA projectile strike was detected and reported, either as it fell to the ground or subsequently. Accurately assessing the precise conditions that existed at a given site >75 years ago is problematic. The most pertinent variables are addressed below.

Historic Ground Cover	
Risk Elevating Ground Cover	Site-Specific Comment
Bombsite: a UXO strike to a building in ruin will likely have remained undetected. The entry hole of a UXB will have been easily obscured under the rubble / debris. However, a small UX AA projectile or UX 1kg / 2kg IB may not have achieved ground penetration, instead coming to rest within the rubble.	n/a
Water: UXO landing in a stream, canal, river, pond, lake or the sea would have been immediately lost beneath the waterline and would not have resulted in any persistent evidence of its incidence.	The reservoir was likely a concrete structure and therefore insignificant.
Soft / Waterlogged / Unconsolidated Ground: a UXO entry hole within marshland, tidal riverbank sediment, tidal coastal sediment / sand dunes, etc will have closed up / collapsed relatively soon after it occurred.	The adjacent drainage ditches may have softened the peripheral soil on Site.
Dense Vegetation: Peripheral unmaintained vegetation or woodland in an urban location. Or rural forest, heathland, etc. A UXO entry hole within inaccessible vegetation could have been overlooked. Note, WW2-era woodland obscures the view of the ground cover beneath and therefore it must be assumed that vegetation exists beneath the canopy.	None.
Arable Land: a field under dense crop growth or ploughed soil. A UXO entry hole within this dense foliage or broken soil could have been overlooked.	n/a
Risk Reducing Ground Cover	Site-Specific Comment
Undamaged Building / Structures: any UXO strike would have caused substantial damage and incontrovertible evidence of the incident.	The reservoir was likely a concrete structure.
Undamaged Hardstanding: A UXO strike on historic hard surfacing (roads, pavements, commercial yards, etc) would have created an easily recognisable entry hole.	None.
Maintained Grass Lawns: a grass lawn known to have been in use throughout WW2 and therefore subject to regular grounds maintenance, e.g playing fields, parkland, sports pitches, golf course fairways. A UXO strike would have created an easily recognisable entry hole.	The grass appears to have been maintained during WW2.

Less Easily Assessed Ground Cover Types	Site-Specific Comment
Waste / scrap / aggregate etc storage area: a UXO strike to a heap of unconsolidated material could have collapsed / become obscured. However, if the ground cover beneath was hard surfaced, a large UXB entry hole could have been subsequently observed and reported.	n/a
Wasteland: the ground cover on such land may not be easily identifiable. Weed-covered bare earth or broken up made ground could conceivably obscure a UXO entry hole. Alternatively, a UXO strike to hard unvegetated earth ground could have been recognisable.	n/a
Railway Tracks: a small UXO entry hole within material in between tracks could conceivably have collapsed. Alternatively, a large UXB strike to rail track would have caused obvious damage.	n/a
Quarry: clay pit, gravel pit, etc. The type and condition of the ground cover might not be easily identifiable. Note, disused quarries could easily become flooded.	n/a

TABLE 9: Historic Ground Cover

Historic Site Occupancy and Access	
UXO Observed as it Occurred	Site-Specific Comment
Air Raid Timing: If most local air raids occurred during the hours of darkness, there is a greater chance that any UXO fall occurred unobserved. If the study area only experienced daylight attacks, there is a greater chance that any UXO strike was witnessed as it occurred.	The one local air raid occurred during the early hours of the morning.
Population Density: If the study area was sparsely populated, there is a greater chance that any UXO strike could occur unobserved. Within a densely populated built up area, the opposite is true. Note however, most people would have been sheltering during large scale night raids.	The wider study area was sparsely populated however occupied by a vast ROF.
Civil Defence and Military Defence: Many vital facilities (factories, dockyards, etc) had their own teams of Fire Watchers tasked with extinguishing small IBs. These observers would have also reported any UXB strikes. AA batteries, searchlight batteries, barrage balloon sites, and Royal Observer Corps posts. Associated personnel would have reported any UXB strikes.	HG soldiers on night time sentry and patrol duty in and around the ROF. Confirmed evidence of fire watchers (air raid observers) at the ROF.
Civil Defence Requisition: many schools, churches and other public buildings in frequently bombed areas were requisitioned by Civil Defence for use as first aid posts, reception centres and canteens for bombed out civilians. Such buildings were therefore in use during night raids.	n/a
UXO Subsequently Observed	Site-Specific Comment
Bomb Damage: If substantial bomb damage occurred, parts or all of a site would have been abandoned for the remainder of the war. Any subsequent evidence of a UXO strike is more likely to have remained unobserved for a significant period.	n/a
Site Occupancy: If a site was occupied by buildings that survived the war intact, it likely remained inhabited or in use during the bombing campaign. Probably accessed on a daily basis, evidence of a UXO strike is highly unlikely to have gone unreported. Undeveloped sites could have been neglected for significant periods. Any UXO is more likely to have remained unobserved and gone unreported.	There was a small hut with access path immediately west of the Site. This was likely associated with the reservoir on Site. The Site was probably accessed multiple times during WW2.

UXB Searches: the Luftwaffe used delayed-action (DA) bombs, designed to detonate up to 72hrs after impact. As a result, ARP wardens, residents and workers often carried out specific searches for DA / UXB entry holes within the environs of their buildings, following local raids. Undeveloped isolated land is unlikely to have been searched.	Following any witnessed air raids, the affected areas would likely have been searched for UXB entry holes.

TABLE 10: Historic Site Occupancy and Access

10.2.3 Site-Specific Conclusion

German UXO:

The official records state that the one air raid to have affected the ROF occurred in Marchwiel Parish. The border of this parish passed ~500m south of the Site at its closest point. Therefore, the resulting bomb strikes may have all occurred beyond the wider study area. That said, as the air raid also mentions the ROF, it is possible that the bombing affected any part of this vast site.

This one raid (a single aircraft sortie attack) occurred in the middle of the night during August 1940. At this time, the ROF was probably in the final stages of construction. The national importance of this wartime facility probably meant that it was to be built as quickly as possible, necessitating a night shift of construction workers.

As the threat of German invasion and sabotage was very high at this time, HG troops would have been active throughout the night, on the sentry and perimeter patrol duties. Once ROF Wrexham was operational, it was protected by a large team of fire-watchers stationed at multiple fire-watcher posts distributed throughout the ROF. Their job was to quickly extinguish any German 1kg / 2kg IBs before they could take hold and cause an uncontrollable fire. These observers (on night duty throughout the remainder of the conflict) would have also reported any UXB falls they observed. Therefore, it is considered highly likely that the one known air raid (or any other unknown incidents) was witnessed by multiple people as it occurred, with any UXB falls probably observed and reported.

And even if a HE UXB struck the Site, its entry hole (at least 200 / 300mm in diameter) would have been easily recognisable on the maintained grassland that accounted for most of the Site area. Any such strike to the reservoir would have created a clean / recognisable entry hole in the (assumed) concrete base, which would have been reported and investigated when the reservoir was drained during the mid to late 1940s.

British EO:

Although the ROF was fortified against an anticipated German invasion, the local HG battalion's defence scheme is unlikely to have seen defence measurers of any type built / dug / placed on Site. This is due to the Site's wartime occupancy / use and its central position within the ROF. It is conceivable that the Site was accessed infrequently by HG soldiers during training exercises or routine armed patrols, however neither activity typically would have seen hazardous forms of EO used, i.e. live LSA (e.g. grenades).

There is also a low likelihood of surplus / unwanted EO being disposed of (buried) on Site by ROF or HG personnel, again due to its occupancy and well-maintained ground cover. Note, the small man-made reservoir is not considered significant in this regard.

During WW2, a small number of HAA and LAA guns within firing range of the Site probably expended ammunition on multiple occasions, however due to the low intensity of local Luftwaffe activity, each engagement will have been short. The local UX AA shell strike density was low and the Site was small. Consequently, there is a low likelihood of such UXO contamination.

10.3 Degree of Risk Mitigation

10.3.1 Ground Works

Ground works on an EO contaminated site could have resulted in the partial or complete removal of the buried EO threat. If EO was uncovered during intrusive ground works, the incident would have been reported and dealt with by the armed forces. Note, it is usually not possible to accurately determine the volume of soil disturbance associated with historic or even recent ground works at a given site.

10.3.2 Explosive Ordnance Clearance

EOC was not as effective historically as it is today. Surveys were not always undertaken to set parameters and degrees of certainty. Recent EO finds on land known to have been previously surveyed for EO confirm that older detection equipment was ineffective. Furthermore, some EOC tasks did not result in 100% clearance of all EO, by design. Magnetometer surveys can be calibrated to ignore magnetic anomalies that model under a certain mass.

EOC tasks are not conducted on all MOD land prior to disposal / sale. An EOC task will only be carried out on land where there is a known risk of EO contamination, e.g. a former firing range. For example, when numerous WW2-era RAF airfields were closed down and sold off, they were not automatically subject to site-wide magnetometer surveying for EO. Any EOC activity was usually prioritised for airfield bomb dump, other ammunition stores and burning / demolition grounds. Due to a lack of capacity, historic RAF EOC activities were largely reactive (not proactive), the result of call outs to EO finds.

EO is occasionally discovered at sites where EOC activities are known to have occurred. The detail and level of survey and targeted investigation undertaken by the military will depend on the former use of the site and purpose of the clearance (i.e. disposal, redevelopment, return to agriculture, etc). The level of clearance will also depend on the available technology, resources and practices of the day. Note, a standard notice accompanying British Army EOC documentation states that ‘the presence of EO can never be completely discounted. Although considered unlikely, there still remains the possibility of buried or stray [EO] items.’ Therefore, it cannot be assumed that the risk of EO remaining has been completely mitigated, even if EOC tasks have been undertaken.

IAL has access to a database of historic EOC tasks carried out by the British Army’s 33 Engineer Regiment EOD (now part of 29 EOD&S Group). However, this database is only complete up until the early 2000s and only provides basic details on each task.

The RAF’s recently disbanded EOD unit (No. 5131 Bomb Disposal Squadron) kept records of EOD incidents and EOC tasks at numerous former military airfield sites. However, freedom of information requests confirm that the MOD are usually unable to provide British Army or RAF records relating to EOD / EOC activities.

10.3.3 Site-Specific Conclusion

Ground Works: Post-WW2 / Post Military Use	Site-Specific Comment
EOC Activity: evidence of EOC task(s) affecting the Site. Or, is there an increased chance that the Site has experienced partial or complete EOC?	Unlikely. Such activity was focused on the ROF’s danger areas.
Phases of Development / Redevelopment: How many phases of ground work have affected the Site?	None.
Greenfield Land: Does the Site contain any significant areas of undisturbed greenfield land?	Yes, most of the Site.
Very Shallow Buried EO: Have any parts of the Site experienced very shallow level soil / made ground disturbance? e.g. demolition, soil stripping, site enabling works, minor grading works, agricultural ploughing, etc.	Most of the Site area will not have experienced very shallow ground disturbance since WW2.

Shallow Buried EO: Have any parts of the Site experienced shallow level soil disturbance? e.g. grading works, strip / pad foundations, buried services installation (drainage), etc.	Unlikely.
Deep Buried German 'Iron' UXBs: Have any parts of the Site experienced deep level soil disturbance? e.g. bulk excavations (basement levels), dense pile layout, installation of large subsurface tanks, cut and fill, etc.	Highly unlikely.
Conclusion	
Within the Site's undisturbed areas of soft ground, the risk associated with any EO (shallow or deeper buried) remains unmitigated.	

TABLE 11: The Degree of Risk Mitigation: Site-Specific Comments

10.4 The Likelihood of Encounter

10.4.1 Introduction

The likelihood of an EO encounter at a given site will vary depending on the hazard items, the EO burial depth and the type(s) of intrusive methodology employed. The greater the volume of soil disturbed within the Zone of Potential EO Contamination (ZPC), the greater the likelihood of an EO encounter.

Most domestic AXO and UXO (LSA and SAA), British UXAA projectiles and small (1kg and 2kg) German IBs will typically be encountered at very shallow or shallow burial levels (<1.0m and <2.0m). Whereas heavy German 'iron' bombs will typically be encountered at deeper levels.

The ZPC is defined as the site-specific volume of soil which could contain EO. The size of a ZPC will depend on the history of the site. At a site where the hazard items are German UXBs only, the ZPC will exist between just below WW2 ground level and the maximum BPD. Alternatively, at an active military site where the threat items are known to be British AXO only, the ZPC will exist between just below present-day ground level and approx. 1.0m bgl.

The smaller the mass of the individual EO threat item, the shallower the likely 'as found' depth, generally speaking. There are however some noteworthy exceptions regarding German 'iron' UXBs. In extreme cases, heavy UXBs can be encountered at shallow depths.

10.4.2 Bomb Penetration Depth Calculations

To calculate BPDs for a given site, one must make assumptions based on the most likely bomb impact scenario:

- **Impact Velocity:** The majority of German HE bombs dropped on the UK resulted from large-scale carpet-bombing raids. These attacks were carried out at altitudes exceeding 5,000m which would have resulted in a 500kg HE UXB impacting the ground at approximately 260m/s.
- **Impact Angle:** Luftwaffe high altitude bombing resulted in bomb impact angles of 10 to 15 degrees from the vertical. Note, it will be assumed that the bomb was stable at the point of impact.
- **Bomb Design:** Some larger German bombs had metal 'Kopfrings' fitted around the nose of the bomb to limit ground penetration. It must be assumed that no such retarder units were fitted.

10.4.3 Site-Specific Maximum Bomb Penetration Depth

As a significantly elevated likelihood of German HE UXB contamination has not been concluded, a Site-specific calculation of the maximum BPD is unnecessary.

10.4.4 Site-Specific Conclusion

The Site's undisturbed areas of soft ground represent an area of potential concern. That said, the likelihood of EO remaining in-situ here is neither high nor moderate. As the ZPC exists just below the present-day ground level, all intrusions / excavations of the area of potential concern will be exposed to a potential EO encounter.

The GI works will disturb a very small volume of soil and geology within the ZPC, significantly limiting the likelihood of encountering anything buried (e.g. EO). There is a greater likelihood of encountering shallow buried EO during the post-GI development phase mechanical excavations. However, this is partly offset by the 'blind' intrusive nature of borehole works, during which there is a greater likelihood of forcefully striking buried EO when compared to 'open' mechanical excavations of the same material.

10.5 The Likelihood of Initiation

10.5.1 Introduction

The likelihood of initiating EO depends on the type of EO and how aggressively it is encountered. Various types of EO buried in the UK require an impact, vibration or heat to initiate. Most EO contains a fuze and most fuzes contain a small quantity of shock-sensitive primary explosive. An impact to a fuze can therefore cause it to initiate, in turn detonating the main explosive charge.

German UXBs buried in the UK do not spontaneously self-detonate. The vast majority of German WW2 'iron' bombs contained an electrical fuze. Decades of burial (exposure to environmental conditions) will have caused these fuzes to corrode and lose their electrical charge. Consequently, during any such UXO encounter, it would be almost impossible for the fuze to initiate via its original (electrical) explosive train.

In theory, German UXBs could still initiate if the bomb were impacted with enough force. Percussive piling and bore-holing are engineering works that could impart enough force to detonate the main explosive charge of an EO, without requiring the fuze to function. Furthermore, the 'blind' nature of these intrusions elevates the likelihood of an EO impact.

Excavators and loaders impart less energy via their buckets and site workers might be able to notice a partially unearthed EO and halt works prior to an impact. For these reasons, IAL conducts separate risk rating calculations for different intrusive methodologies.

During WW2, the Allied air forces used mechanical (not electrical) fuzes, which pose a greater long-term UXB hazard on the continent. Furthermore, in Germany, 1No. buried Allied WW2 HE bomb per year (on average) self-detonates due to degradation of the chemical detonator in its time-delay fuze.

Sensitive types of EO include German 2kg (mechanically fuzed) 'Butterfly' bombs, types of British (mechanically fuzed) unexploded LSA ('blind' / 'dud' items), and bombs with chemical time-delay fuzes.

10.5.2 Site-Specific Conclusion

There is no reason to believe that the Site-specific hazard items are more sensitive to an initiation when compared to similar EO contamination elsewhere in the UK.

As borehole works ('blind' and percussive intrusive methodology) are planned, the likelihood of an EO initiation / detonation is elevated.

11 The Historical Record: Extent and Accuracy

11.1 Introduction

The availability of key documents and data will affect the completeness and accuracy of the Site-specific risk assessment. Furthermore, historical records can sometimes be proven inaccurate, when compared with other records. Some inaccuracies could significantly affect the outcome of a risk assessment and therefore a Site-specific review must be conducted.

11.2 Site-Specific

No inconsistencies between the available records have been highlighted and the quality of the historical record relating to WW2 German bombing is sufficient. As the official HG defence scheme for ROF Wrexham is missing, assessment of EO contamination relating to invasion defence activities is limited, however the indirect records that are available combined with IAL's previous experience at similar sites, is deemed sufficient.

12 Site-Specific Risk Calculation

12.1 Introduction

The first stage of the semi-quantitative risk model considers potential sources of buried EO on Site. The next stage evaluates the possible linkages, identifying whether significant harm could occur (as a result of the proposed Site works) and the impact of such harm. To provide a numerical evaluation of risk, the two key considerations must be assigned a score and then multiplied together to provide a final risk rating / risk level:

- The likelihood of an EO linkage becoming complete: **FACTOR 3** (= Factors 1 x 2)
- The severity of the consequence(s) resulting from this linkage completion: **FACTOR 6** (= Factors 4 x 5)

12.2 Factor 1 (F1): Explosive Ordnance Presence

The Likelihood of EO contamination of the Site combined with the degree of subsequent risk mitigation. This factor is described and scored in the table below.

Classification	Example Descriptions	F1 Rating
Impossible	No EO contamination due to complete subsequent excavation / removal of the ZPC.	**0**
Highly Unlikely	EO contamination is highly unlikely to have occurred. Most of the ZPC subsequently excavated or EOC task(s) have been conducted.	**1**
Unlikely	EO contamination is unlikely to have occurred. Part of the ZPC subsequently excavated or EOC task(s) have been conducted.	**2**
Possible	EO contamination could have occurred. Part or none of the ZPC subsequently excavated.	**3**
Likely	EO contamination is likely to have occurred. Only a fraction or none of the ZPC subsequently excavated.	**4**
Almost Certain	EO contamination is almost certain or confirmed evidence of local EO contamination. Greenfield land / ZPC remains undisturbed.	**5**

TABLE 12: Factor 1 Scoring

12.3 Factor 2 (F2): Explosive Ordnance Initiation

The likelihood of encountering EO during the proposed works combined with the likelihood of initiating EO during the proposed works. This factor is described and scored in the table below.

Classification	Example Descriptions	F2 Rating
Impossible	The ZPC will not be disturbed during the proposed ground works.	**0**
Highly Unlikely	Fraction of the ZPC will be intruded / excavated. Hand-dug trial pits. Vegetation clearance / soil stripping. Hazard items include relatively insensitive EO.	**1**
Unlikely	Part of the ZPC will be intruded / excavated. Mechanically excavated trial pits. Shallow excavations for traditional foundations. Piling or boreholes. Hazard items include relatively insensitive EO.	**2**
Possible	Moderate to high intrusion / excavation of the ZPC. Large-scale shallow excavations for traditional foundations. Single basement level construction. Piling or boreholes. Hazard items include relatively insensitive and possibly sensitive EO.	**3**
Likely	Almost the entire ZPC will be excavated. Multi-level basement construction. Large scale piling works (including percussive piling). Hazard items include sensitive EO.	**4**
Almost Certain	The entire ZPC will be excavated. Multi-level basement construction. Large scale piling works (including percussive piling). Hazard items include highly sensitive EO.	**5**

TABLE 13: Factor 2 Scoring

12.4 Factor 3 (F3): Calculating the Likelihood of an Explosive Ordnance Initiation Event

The table below includes the calculations of 'Likelihood' and descriptions of the resulting scores.

F1 x F2 = F3	Classification	Example Descriptions	F3 Rating
F3 = 0	**Impossible**	Confirmed evidence that no EO is present or no pathway to sensitive receptors present.	**0**
F3 = 1 to 4	**Highly Unlikely**	EO is highly unlikely to be present. No pathway to sensitive receptors present. Initiation of EO is highly unlikely.	**1**
F3 = 5 to 8	**Unlikely**	EO is unlikely to be present. There is an established pathway to sensitive receptors. Initiation of EO unlikely.	**2**
F3 = 9 to 13	**Possible**	EO could be present. There is an established pathway to sensitive receptors. Initiation of EO is unlikely but possible.	**3**
F3 = 14 to 20	**Likely**	EO is likely to be present. There is an established pathway to sensitive receptors. Initiation of EO could occur.	**4**
F3 = 21 to 25	**Almost Certain**	Confirmed evidence of EO contamination or almost certainty. There is an established pathway to sensitive receptors. Initiation of EO is likely.	**5**

TABLE 14: Factor 3 Scoring

12.5 Factor 4 (F4): Explosive Ordnance Event Magnitude

The potential hazard associated with each hazard item combined with the likely depth of EO initiation. This factor is described and scored in the table below.

Classification	Example Descriptions	F4 Rating
None	British military training device (inert).	**0**
Very Small	British SAA at depth. 1kg German bomb at depth.	**1**
Small	British LSA or HAA projectile at depth. British LAA projectile near the surface. 2kg German bomb at depth. 1kg German bomb near the surface. British SAA near the surface.	**2**
Medium	British LSA or HAA projectile near the surface. 2kg German bomb near the surface. Medium German 'iron' bombs at depth.	**3**
Large	Large German 'iron' bombs at depth. Medium German 'iron' bombs near the surface.	**4**
Very Large	Large German 'iron' bombs near the surface.	**5**

TABLE 15: Factor 4 Scoring

12.6 Factor 5 (F5): Sensitive Receptors

The presence and sensitivity of receptors in the vicinity at the time of the proposed works. This factor is described and scored in the table below.

Classification	Example Descriptions	F5 Rating
Single	Plant / equipment.	**1**
Few	Human, plant / equipment.	**2**
Medium	Human, plant / equipment, buried services.	**3**

Most	Human, plant / equipment, buried services, buildings.	**4**
All	Human, plant / equipment, buried services, buildings, listed buildings, scheduled ancient monuments, protected environment (e.g. TPO).	**5**

TABLE 16: Factor 5 Scoring

12.7 Factor 6 (F6): Calculating the Consequence of an Explosive Ordnance Initiation Event

The table below includes the calculations of 'Consequence' and descriptions of the resulting scores.

F4 x F5 = F6	Classification	Example Descriptions	F6 Rating
F6 = 0	**None**	Contact with inert military device. No initiation event. No risk to human health or damage sustained.	**0**
F6 = 1 to 4	**Insignificant**	Very small magnitude inadvertent initiation at depth. Possible cosmetic damage to plant. No risk to human health or buildings damaged.	**1**
F6 = 5 to 8	**Mild**	Small magnitude inadvertent initiation. Possible damage to plant. Possible risk to human health (minor first aid injury).	**2**
F6 = 9 to 13	**Moderate**	Medium magnitude inadvertent initiation. Damage to plant. Possible damage to buried services. Possible cosmetic damage to buildings. Possible risk to human health (minor injury).	**3**
F6 = 14 to 20	**Severe**	Large magnitude inadvertent initiation. Severe damage to plant, buried services and buildings. Fatality and / or severe injuries.	**4**
F6 = 21 to 25	**Catastrophic**	Large magnitude inadvertent initiation. Catastrophic damage to plant, buried services and buildings (including listed buildings, scheduled ancient monuments, etc). Multiple fatalities and severe injuries.	**5**

TABLE 17: Factor 6 Scoring

12.8 Calculating the Final Risk Level(s)

The 'Likelihood' and 'Consequence' factors are combined in the risk matrix below to produce a final risk score.

		Consequence (F6)						
		0	**1**	**2**	**3**	**4**	**5**	
Likelihood (F3)	**5**	**0**	**5**	**10**	**15**	**20**	**25**	Final Risk Score
	4	**0**	**4**	**8**	**12**	**16**	**20**	
	3	**0**	**3**	**6**	**9**	**12**	**15**	
	2	**0**	**2**	**4**	**6**	**8**	**10**	
	1	**0**	**1**	**2**	**3**	**4**	**5**	
	0	**0**	**0**	**0**	**0**	**0**	**0**	

Final Risk Rating (score)						
0 - 1	**2 - 5**	**6 - 9**	**10 - 12**	**15 - 16**	**20**	**25**
Very Low	**Low**	**Low-to-Moderate**	**Moderate**	**Moderate-to-High**	**High**	**Very High**
Risk Levels						

TABLE 18: Risk Matrix

12.9 Conceptual Site Model

Risk assessment calculations have identified one risk zone. The conceptual model is displayed in the tables below.

	Low-to-Moderate Risk Table						
	Hazard Item	Pathway	Receptor	Likelihood (F3)	Consequence (F6)	Final Risk Rating	Risk Level
German	**HE and Incendiary 'Iron' Bombs**	GI works. Blast + heat + frag.	Human, Plant, Structures.	**1** (F1:1 x F2:3)	**4** (F4:4 x F5:4)	**4** (1 x 4)	**Low**
		Post-GI mech excavations. Blast + heat + frag.	Human, Plant, Structures.	**1** (F1:1 x F2:2)	**4** (F4:4 x F5:4)	**4** (1 x 4)	**Low**
		Post-GI piling. Blast + heat + frag.	Human, Plant, Structures.	**1** (F1:1 x F2:3)	**4** (F4:4 x F5:4)	**4** (1 x 4)	**Low**
	1kg Incendiary and 2kg Incendiary (+ HE) Bombs	GI works. Blast + heat.	Human, Plant, Structures.	**1** (F1:1 x F2:1)	**2** (F4:3 x F5:2)	**2** (1 x 2)	**Low**
		Post-GI mech excavations. Blast + heat.	Human, Plant, Structures.	**1** (F1:1 x F2:2)	**2** (F4:3 x F5:2)	**2** (1 x 2)	**Low**
		Post-GI piling. Blast + heat.	Human, Plant, Structures.	**1** (F1:1 x F2:2)	**2** (F4:3 x F5:2)	**2** (1 x 2)	**Low**
British / Allied	**Anti-Aircraft Projectiles**	GI works. Blast + frag.	Human, Plant, Structures.	**1** (F1:1 x F2:3)	**3** (F4:3 x F5:3)	**3** (1 x 3)	**Low**
		Post-GI mech excavations. Blast + frag.	Human, Plant, Structures.	**1** (F1:1 x F2:2)	**3** (F4:3 x F5:3)	**3** (1 x 3)	**Low**
		Post-GI piling. Blast + frag.	Human, Plant, Structures.	**1** (F1:1 x F2:3)	**3** (F4:3 x F5:3)	**3** (1 x 3)	**Low**
	Land Service Ammunition	GI works. Blast + heat + frag.	Human, Plant, Structures.	**2** (F1:2 x F2:3)	**3** (F4:3 x F5:3)	**6** (2 x 3)	**Low-to-Moderate**
		Post-GI mech excavations. Blast + heat + frag.	Human, Plant, Structures.	**2** (F1:2 x F2:3)	**3** (F4:3 x F5:3)	**6** (2 x 3)	**Low-to-Moderate**
		Post-GI piling. Blast + heat + frag.	Human, Plant, Structures.	**2** (F1:2 x F2:3)	**3** (F4:3 x F5:3)	**6** (2 x 3)	**Low-to-Moderate**
	Small Arms Ammunition	GI works.	Human.	**1** (F1:2 x F2:1)	**1** (F4:1 x F5:1)	**1** (1 x 1)	**Very Low**
		Post-GI mech excavations.	Human.	**1** (F1:2 x F2:1)	**1** (F4:1 x F5:1)	**1** (1 x 1)	**Very Low**
		Post-GI piling.	Human.	**1** (F1:2 x F2:1)	**1** (F4:1 x F5:1)	**1** (1 x 1)	**Very Low**

TABLE 19: Low-to-Moderate Risk Table

13 Risk Mitigation

13.1 ALARP Principle

ALARP is a risk principle associated with the Health and Safety at Work Act 1974. It is used in the regulation and management of construction industry risks and states that risk must be averted unless there is a gross disproportion between the costs and benefits of doing so.

The ALARP principle arises from the fact that infinite time, effort and money could be spent attempting to eliminate a risk entirely. It should not be understood as simply a quantitative measure of benefit against detriment. Instead, a best common practice of judgement, balancing risk and societal benefit.

13.2 Risk Levels and Risk Tolerance

The table below outlines the relationship between final risk scores / levels (the output of the IAL semi-quantitative risk model), risk tolerance and the available industry standard risk mitigation measures. An elevated UXO risk should always be reduced to ALARP level.

Risk Level	IAL Recommendation	Risk Tolerance	Mitigation Measures
Very High	**Proactive** mitigation measures considered essential	Intolerable risk level in all but extreme circumstances.	► EOD Engineer supervision of ground works ► Magnetometer surveying prior to ground works ► Explosive Ordnance Safety & Awareness Briefing(s) ► Explosive Ordnance Site Safety Instructions
High			
Moderate-to-High	**Proactive** mitigation measures recommended	Intolerable level of risk where risk mitigation to ALARP is cost effective. A client may consider the risk tolerable due to impracticability of the available risk mitigation measures or disproportionately high cost of mitigation.	
Moderate		Tolerable risk level providing the recommended mitigation measures have been adopted.	
Low-to-Moderate	**Reactive** mitigation measures recommended	Possibly tolerable risk level, however **reactive** risk mitigation measures would be the prudent course of action. For sensitive, high value sites, a zero-tolerance policy may exist, mandating **proactive** risk mitigation measures.	► Explosive Ordnance Safety & Awareness Briefing(s) ► Explosive Ordnance Site Safety Instructions
Low	**Reactive** mitigation measures considered prudent (not recommended)	Likely to be a tolerable risk level for most clients. However, adoption of the basic precautionary mitigation measure would be the prudent (and very cost effective) course of action, especially for greenfield sites.	► Explosive Ordnance Safety & Awareness Briefing(s) considered prudent ► Explosive Ordnance Site Safety Instructions considered prudent
Very Low	No mitigation measures	N/A	N/A

TABLE 20: Risk Levels and Risk Tolerance

13.3 Site-Specific Recommendation(s)

The following table describes the available industry standard risk mitigation measures and identifies those (if any) that are recommended to reduce an elevated risk to ALARP level.

Mitigation Measure	Appropriate For	Site-Specific
Explosive Ordnance Site Safety Instructions: EO Safety Instructions (compiled by an EO specialist) provide a written record of the key points that make up an EO Safety & Awareness Briefing. Including instructions on making a preliminary suspicious object threat assessment, a visual catalogue of commonly found EO types, and the steps to take in the event of a potential EO find. The instructions should be included within the site-specific Health & Safety Manual.	► Provided to Site personnel prior to commencement of excavations. ► Not appropriate for 'blind' intrusions (e.g. boreholes)	**Recommended** To be held on Site for the duration of the post-GI development phase works.
Explosive Ordnance Safety & Awareness Briefings: All personnel conducting ground works on Site should receive this briefing. It should feature as a key element of the CDM Regulations 2015 Health & Safety training package for the site. The briefing should be conducted by a trained EO specialist. Such briefings instruct recipients in the identification of EO hazards and actions to be taken in the event of an EO incident.		**Recommended** For all Site personnel conducting ground works (GI and post-GI development phases).
Explosive Ordnance Disposal (EOD) Engineer Supervision: An EOD engineer (banksman) providing a 'watching brief' of mechanical excavations. Any suspicious objects will be quickly identified, allowing works to continue if the object is not EO. This reduces the risk of delays to the project. EOD engineers can use portable / handheld magnetometer instruments to scan ground ahead of boreholes.	► SI (including some boreholes) ► Small volume earthworks on greenfield land ► Excavations within made ground	**Not Recommended**
Intrusive Magnetometer Probe Survey: A range of intrusive magnetometer methodologies can be deployed. Which equipment is most appropriate will depend upon the ground conditions and site access. This survey will scan the ground down to the maximum bomb penetration depth and therefore is the most appropriate option for clearing pile locations ahead of 'blind' piling works. Multiple overlapping surveys can be conducted, providing matrix clearance of made ground, e.g basement dig.	► Pile locations ► Boreholes ► Large volume earthworks on brownfield land	**Not Recommended**
Non-Intrusive Magnetometer Survey: A range of non-intrusive magnetometer survey methodologies can be deployed to survey ground to a limited depth. Such surveys can typically detect a 50kg 'iron' bombs at a depth of 4.5m bgl, providing the ground is 'magnetically clean'. Such surveys are not appropriate for brownfield land where 'magnetic noise' will result in unusable data.	► Large volume earthworks on magnetically clean (greenfield) land	**Not Recommended**

TABLE 21: Recommendations for Risk Mitigation

Figures: 1 - 7





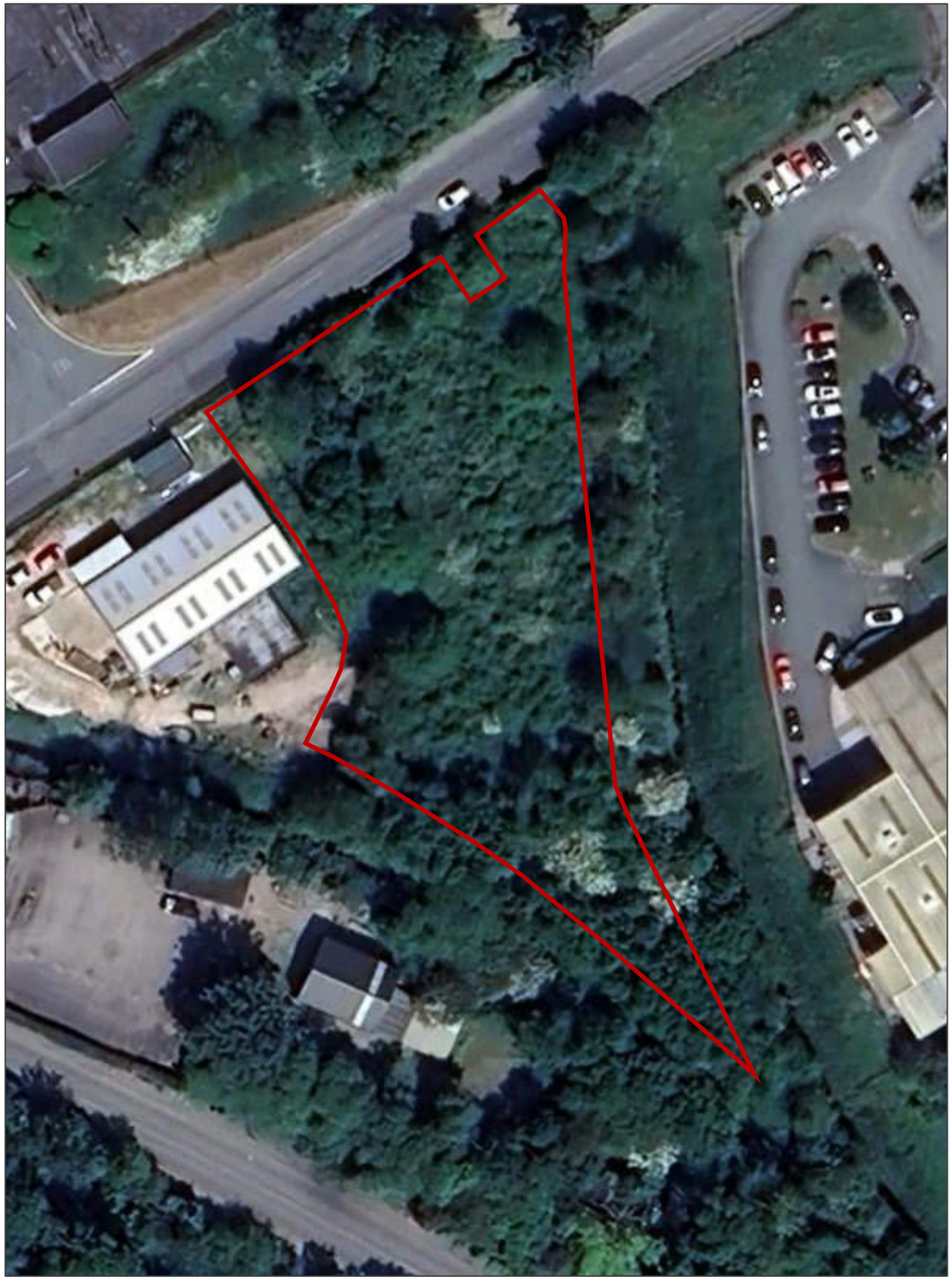


Figure: 01.0

Figure Title:
Site Location Maps and Recent Aerial Photograph

Legend:

Approx. Site boundary

General Site location

Notes:

Source: Google
OpenStreetMap

N

Project: Land South of Bridge Road North, Wrexham

Client: Geo2

Doc Ref: DRA.10173.24 **Version: 1**

IMPARTIAL ASSESSMENTS

Explosive Ordnance Risk Assessments

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Figure: 02.0

Figure Title:
Proposed Development Plan

Legend:

Site boundary

Notes:

Source: Geo2

N

Project:	Land South of Bridge Road North, Wrexham
Client:	Geo2
Doc Ref:	DRA.10173.24
Version:	1

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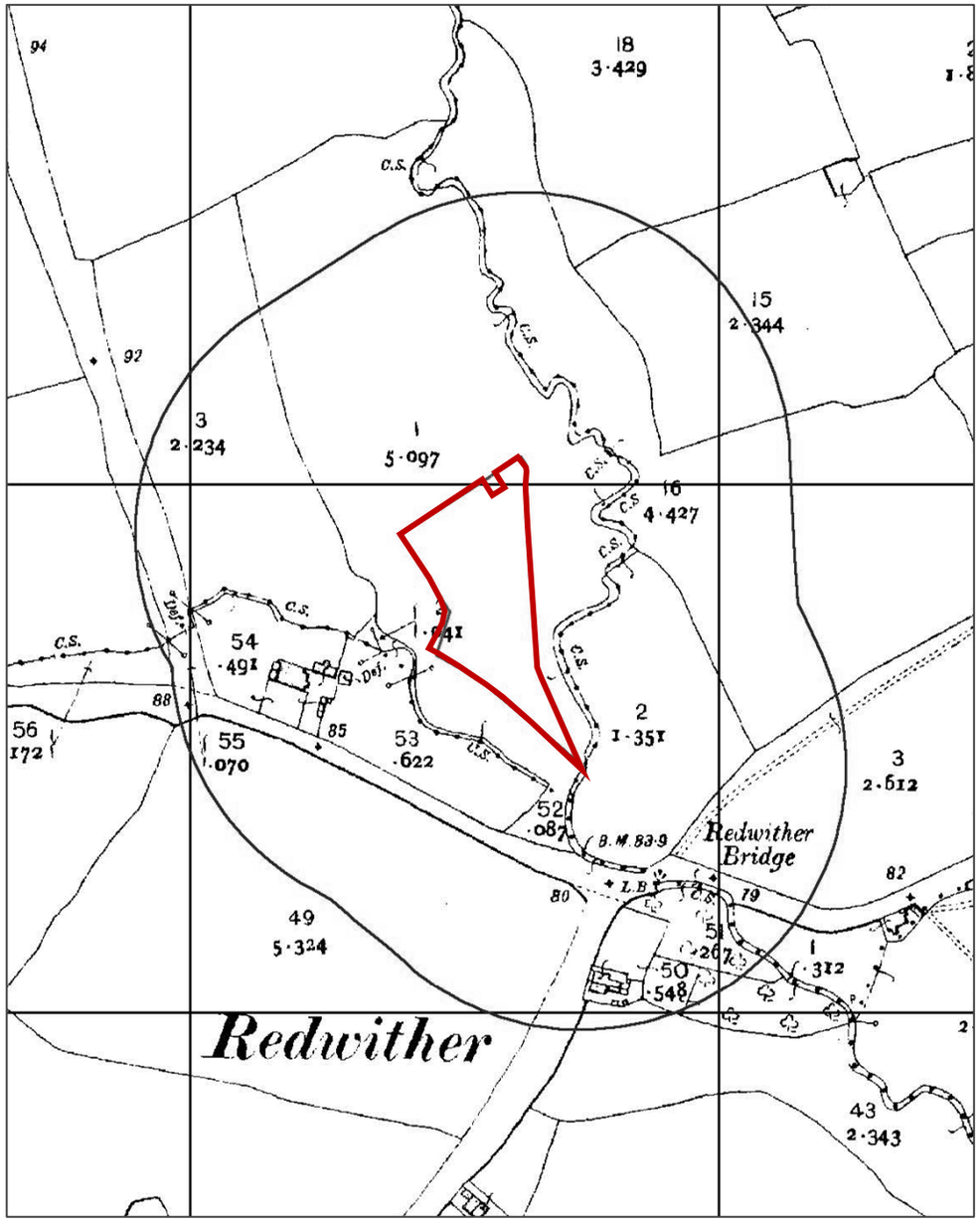
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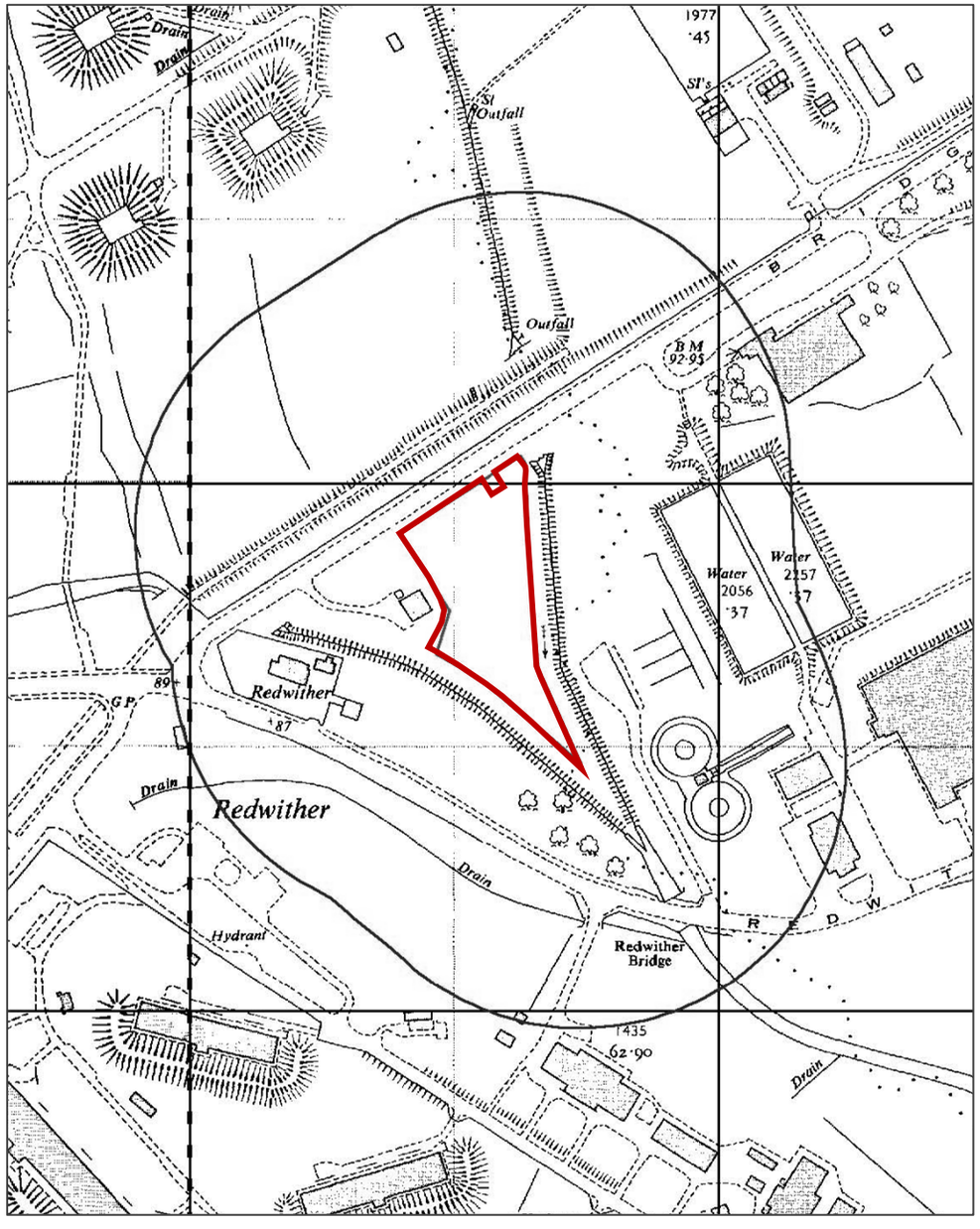
Figure: 03.0

Figure Title:
Historic OS Mapping

1911



1961



Legend:

Approx. Site boundary

Notes:

Latest available pre-WW2 and earliest available post-WW2 large-scale OS maps comparison

Source: Groundsure

N

Project:	Land South of Bridge Road North, Wrexham
Client:	Geo2
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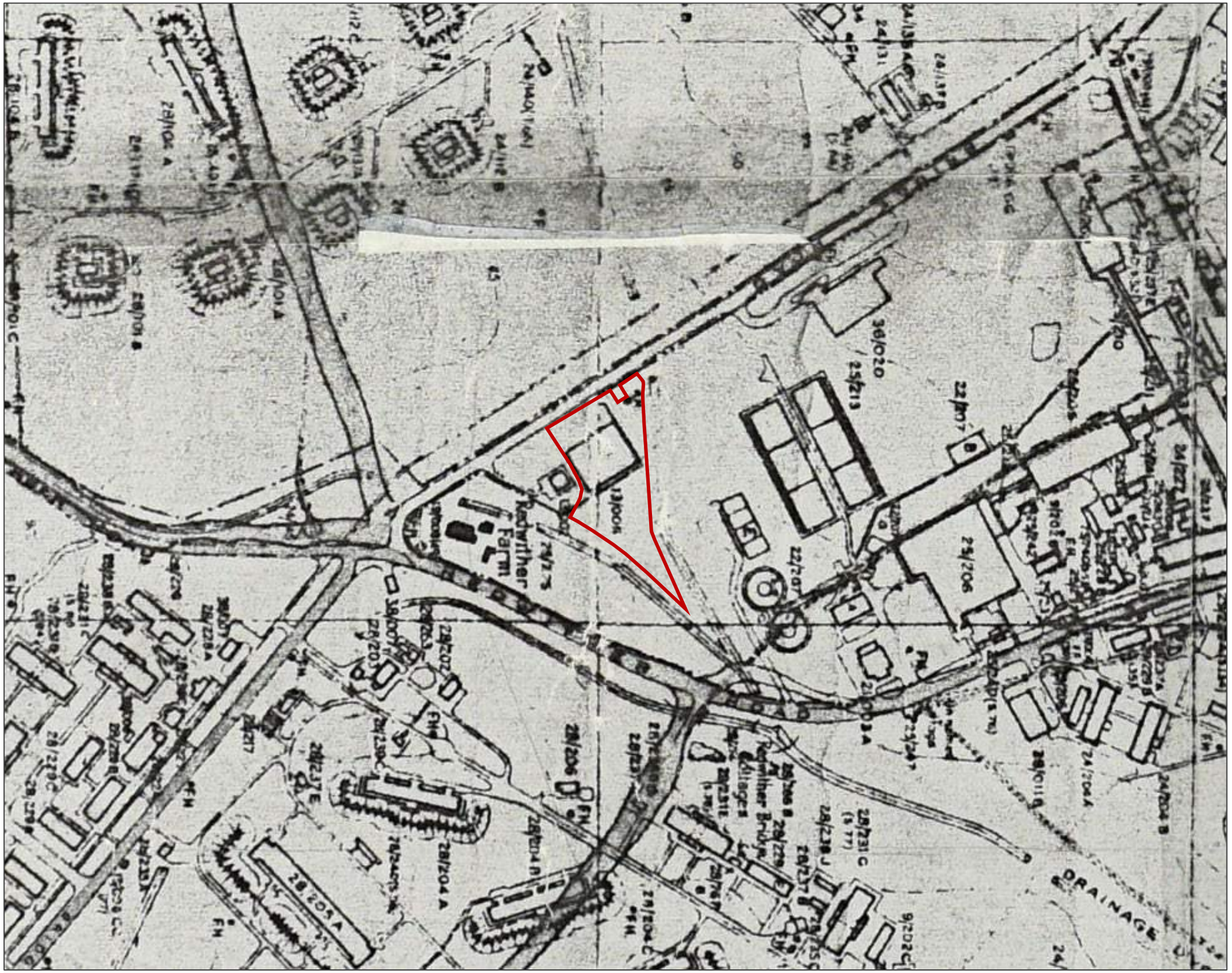


Figure: 04.1

Figure Title:
Royal Ordnance Plans - 1944

Legend:

Approx. Site boundary

Notes:

Source: North East Wales Archives

N

Project: Land South of Bridge Road North, Wrexham

Client: Geo2

Doc Ref: DRA.10173.24 **Version: 1**

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