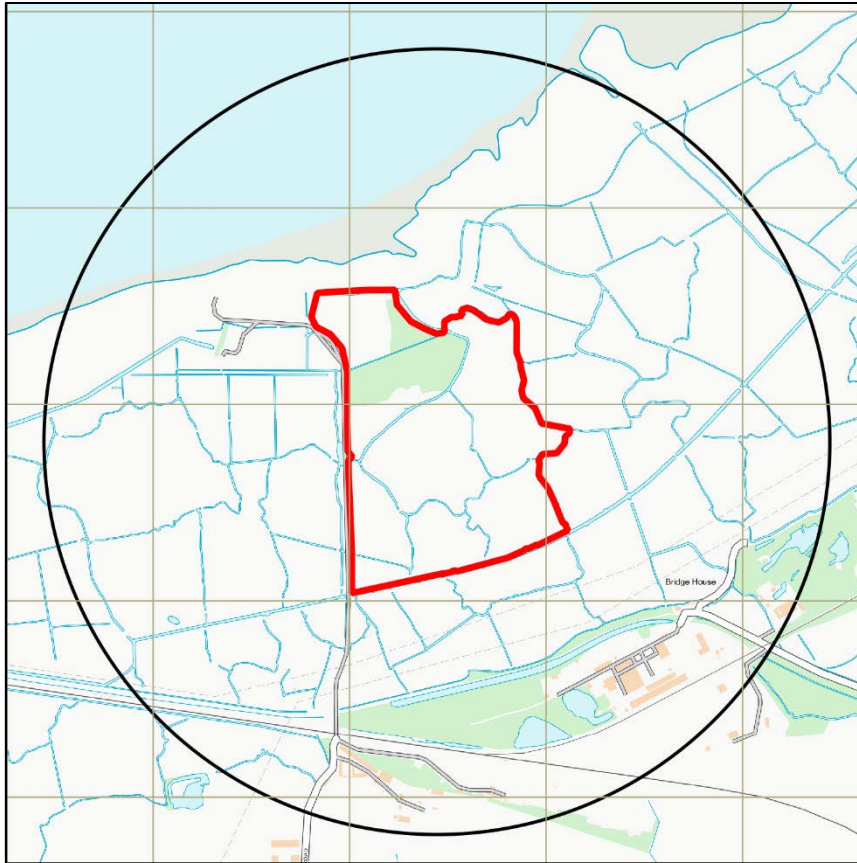


Detailed Unexploded Ordnance (UXO) Threat & Risk Assessment

Meeting the requirements of *CIRIA C681* 'Unexploded Ordnance (UXO)
A Guide for the Construction Industry' Risk Management Framework



PROJECT NUMBER	10651	ORIGINATOR	J. Hancock
PROJECT	RSPB Gravesend	REVIEWED BY	R. Griffiths
CLIENT	RSPB	RELEASED BY	L. Gregory
VERSION	1.0	DATE	26 th June 2023
UXO RISK RATING	HIGH - This Study Site requires further action to reduce risk to ALARP during intrusive activities.		

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Acronyms and Abbreviations

AA	Anti-Aircraft	NEQ	Net Explosive Quantity
AAA	Anti-Aircraft Ammunition	NFF	National Filling Factory
ALARP	As Low As Reasonably Practicable	NGR	National Grid Reference
AOD	Above Ordnance Datum	OD	Ordnance Datum
ARP	Air Raid Precaution	OS	Ordnance Survey
AXO	Abandoned Explosive Ordnance	PM	Parachute Mine
BD	Bomb Disposal	PoW	Prisoner of War
BDO	Bomb Disposal Officer	RADAR	Radio Detection And Ranging
bgl	Below Ground Level	RAF	Royal Air Force
BGS	British Geological Survey	RN	Royal Navy
BH	Borehole	RNAS	Royal Naval Air Service
BPD	Bomb Penetration Depth	ROF	Royal Ordnance Factory
CDP	Cast Driven Piles	SAA	Small Arms Ammunition
CFA	Continuous Flight Auger	TA	Territorial Army
CIRIA	Construction Industry Research and Information Association	TNT	Trinitrotoluene
CPT	Cone Penetration Testing	UK	United Kingdom
CS	County Series	UN	United Nations
EO	Explosive Ordnance	USAAF	United States Army Air Force
EOC	Explosive Ordnance Clearance	UXB	Unexploded Bomb
EOD	Explosive Ordnance Disposal	UXO	Unexploded Ordnance
GI	Ground Investigation	V Weapons	<i>Vergeltungswaffen</i> – Vengeance Weapons
GIS	Geographic Information Systems	WD	War Department
GL	Ground Level	WWI	World War One
GP	General Purpose	WWII	World War Two
GPS	Global Positioning Systems		
HAA	Heavy Anti-Aircraft		
HE	High Explosive		
HO	Home Office		
HSE	Health and Safety Executive		
IB	Incendiary Bomb		
kg	Kilograms		
km	Kilometres		
LAA	Light Anti-Aircraft		
LCC	London County Council		
LE	Low Explosive		
LSA	Land Service Ammunition		
m	Metres		
MoD	Ministry of Defence		
mm	Millimetres		

EXECUTIVE SUMMARY

Study Site

The Client has defined the Study Site as “RSPB Gravesend” and it is centred on NGR 569722, 174404.

Risk Level

HIGH

Potential Threat Sources

The most probable UXO threat is posed by WWII-era *German* HE bombs and *British* AXO/LSA/SAA, whilst IBs and *British* AAA projectiles (which were used to defend against *German* bombing raids) pose a residual threat.

Risk Pathway

Given the types of UXO that might be present on-site, all types of aggressive intrusive engineering activities may generate a significant risk pathway.

Key Findings

During WWII, the Study Site was situated within *Strood Rural District*, which recorded nine HE bomb strikes per 100 hectares, a “very low” level of bombing.

Luftwaffe aerial reconnaissance photography associated with the Study Site identified *Shorne Mead Battery* (located on-site) as a primary bombing target.

ARP records associated with the Study Site did not identify any bomb strikes directly on-site; however, six were documented within 270m of its boundary, the closest being 10m to the south.

Bomb damage maps associated with the Study Site were not available. Whilst further research of historical records and an analysis of post-war mapping failed to identify any instances of bomb damage on-site, or within the immediate vicinity of the Study Site boundary, these records may have been restricted in associated with the military facilities, or else not recorded given the undeveloped nature of much of the Site.

CS mapping prior to WWII, and *Luftwaffe* aerial photography (1939) shows that the *Shorne Mead gun battery* was located on the northern periphery of the Study Site during WWII, with marshland in the remaining areas. As a result, it is plausible that footfall within the majority of the Study Site would have been relatively low, and any UXBs impacting in the marshland could potentially have been hidden by potentially waterlogged ground conditions. However, it is presumable that footfall within the area of the gun battery would have been relatively high and as a result, UXB entry holes in close proximity to this area were more likely reported and dealt with at the time.

The majority of the Study Site has not been subject to any significant post-WWII alterations, though there are isolated areas where development has occurred. Consequently, it is considered likely that any UXO within post-war disturbed ground would potentially have been discovered and removed. However, the potential for shallow buried UXO to be present within any remaining areas of undisturbed ground is assessed to be extant.

Given that bomb strikes and military activity were recorded on-site and/or in the immediate vicinity, combined with the limited post-war redevelopment of the Study Site, the following risk mitigation measures are recommended as a minimum in order to reduce risks ALARP during intrusive works in all previously undisturbed ground (i.e., that which has not previously been excavated, probed, drilled or otherwise intrusively disturbed since it was potentially contaminated with UXO).

EXECUTIVE SUMMARY (...continued)

Recommended Risk Mitigation Measures Overview

“Open” Intrusive Works

Engineering Methodology	UXO Emergency Response Plan	UXO Safety and Awareness Briefing	On-Call EOD Engineer	Non-Intrusive Magnetometer Survey	EODE Watching Brief	Intrusive Magnetometer Survey	UXO Risk Rating (Post-Mitigation)
Excavations	✓	✓	✓	✓	✓	✗	ALARP
Installation of Fencing	✓	✓	✓	✓	✓	✗	

“Blind” Intrusive Works

Engineering Methodology	UXO Emergency Response Plan	UXO Safety and Awareness Briefing	On-Call EOD Engineer	Non-Intrusive Magnetometer Survey	EODE Watching Brief	Intrusive Magnetometer Survey	UXO Risk Rating (Post-Mitigation)
Piling	✓	✓	✗	✗	✗	✓	ALARP

A full and detailed guide to the recommended risk mitigation measures is presented at Section 5 of this report.

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ASSESSMENT METHODOLOGY

Approach

6 Alpha Associates is an independent, specialist risk management consultancy practice, which has assessed the prospective UXO risk at this Study Site by employing a process advocated by CIRIA. The CIRIA guide for managing UXO risks in the construction industry (C681) not only represents industry best practice but has also been endorsed by the UK's HSE. 6 Alpha were the lead technical author of the CIRIA C681 guide.

UXO hazards can be identified through the investigation of local and national archives associated with the Study Site, MoD archives, local historical sources, historical mapping as well as contemporary aerial photography (where it is available). Prospective hazards will have only been recorded if there is specific information that could reasonably place them within the boundaries of the Study Site. The amalgamation of information is then assessed within a Semi-Quantitative Risk Assessment (as per industry best practice outlined in CIRIA C681) in order to form the basis of a proportional UXO risk mitigation strategy in circumstances where the SQRA evidences that further action is necessary in order to reduce the UXO risk at the Study Site.

The assessment of UXO risk is a measure of the probability of UXO encounter and initiation and the consequence of an inadvertent UXO initiation; the former being a function of the identified hazard and proposed development methodology and the latter being a function of the type of hazard and the proximity of personnel (and/or other 'sensitive receptors', such as equipment) to the hazard. UXO risk is thus calculated using the following formula:

$$\text{Risk (R)} = \text{Probability (P)} \times \text{Consequence (C)}$$

If intolerable UXO risks are identified, the methods of mitigation we have recommended are considered reasonable and sufficiently robust to reduce them to ALARP. We advocate the adoption of the ALARP legal principle because it is a key factor in efficiently and effectively ameliorating UXO risks. It also provides a ready means for assessing the Client's tolerability of UXO risk. In essence, the principle states that if the cost of reducing a risk significantly outweighs the benefit, then the risk may be considered tolerable. This does not mean that there is never a requirement for UXO risk mitigation, but that any mitigation must demonstrate that it is beneficial. Any additional mitigation that delivers diminishing benefits and that consume disproportionate time, money and effort are considered *de minimis* and thus unnecessary. Because of this principle, UXB and UXO risks will rarely be reduced to zero (nor need they be).

Important Notes

Although this report is up to date and accurate at the time of writing, 6 Alpha's UXO threat databases are continually being populated and updated as and when additional information becomes available. Nonetheless, 6 Alpha have exercised all reasonable care, skill and due diligence in providing this service and producing this report.

The assessment levels are also based upon our professional opinion and have been supported by our interpretation of historical records and third-party data sources. Wherever possible, 6 Alpha has sought to corroborate and to verify the accuracy of all data we have employed, but we are not accountable for any inherent errors that may be contained in third party data sets (e.g., *National Archive* or other library sources), and over which 6 Alpha cannot exercise control.

STAGE ONE – STUDY SITE LOCATION AND DESCRIPTION

Study Site

The Client has defined the Study Site as “RSPB Gravesend”. The Study Site is centred at NGR 569722, 174404 as presented at *Figures 1 and 2*, respectively.

Location Description

The Study Site is situated within the *Civil Parish of Shorne* and totals an area of 33.14 hectares (ha).

Furthermore, the Study Site is bounded by:

- North: *The Saxon Shoreway footpath*;
- East: *Shorne Marshes*;
- South: *Shorne Marshes*;
- West: *A road associated with Shorne Mead Fort*.

Aerial Photography (2022) (*Figure 3*)

Aerial photography from 2022 corroborates the information above and shows that the Study Site is situated within a sparsely developed rural area, to the east of *Gravesend*. The Study Site itself consists of marshland with no structures present.

Proposed Works

The Client has provided a cross section of the proposed anti-predator exclusion fence, showing the emplacement of fence posts to a depth of 1.3m bgl, with the fencing partially buried to a depth of 0.40m bgl for added security.

As a result, *6 Alpha* will assume that a number of construction methodologies might be undertaken.

Ground Conditions

It is important to establish the specific ground conditions in order to determine the maximum *German UXB* penetration depth as well as the potential for other types of munitions to be buried.

If the site investigations and/or construction methodologies change, and/or if a specific methodology is to be employed, and/or if the scope of work is focused upon a specific part of the Study Site, then *6 Alpha* are to be informed so that the prospective UXO risks and the associated risk mitigation methodology might be re-assessed. Certain ground conditions may also constrain certain types of UXO risk mitigative works e.g., magnetometer survey is adversely affected in mineralised and made ground.

The Client has described the ground conditions as follows:

- “*Soils are loamy and clayey, typical of coastal flats around the Thames Estuary and with naturally high groundwater where drainage is not a limiting factor*;
- *The bedrock geology comprises either Chalk (including Red Chalk) or a combination of Oldhaven, Blackheath, Woolwich and Reading and Thanet beds*”.

It is important to establish the provenance of made ground, where this is recorded as being part of the ground make-up, in order to accurately determine the ground levels at the time when UXO contamination may have occurred so as to accurately determine the average/maximum bomb penetration depths and subsequently to make appropriate recommendations aimed at reducing the risk to ALARP.

It is also important to note that the potential depth of UXO bgl may have considerably altered since WWII due to natural coastal processes of deposition and erosion acting on the alluvium in the marsh environment (relatively unstable).

STAGE ONE – STUDY SITE LOCATION AND DESCRIPTION (...continued)

Ground Conditions

BGS borehole log “TQ67SE28 – Shorne Meade Fort Shorne” (located approximately 200m to the south-west of the Study Site), recorded the following strata:

Depth bgl (m)	Strata	Description
0.00m to 3.73m	Alluvium	Mud.
3.73m to 4.03m	Alluvium	Peat.
4.03m to 7.61m	Alluvium	Mud.
7.61m to 8.52m	Alluvium	Peat.
8.52m to 10.04m	Alluvium	Mud.
10.04m to 10.34m	Alluvium	Peat.
10.34m to 12.32m	Sand	Sand and pebbles.
12.32m to 13.99m	Clay	Clay and pebbles.
13.99m to 14.59m	Sand	Sand and pebbles.
14.59m to 15.65m	Clay	Clay.

In addition, an analysis of BGS mapping associated with the Study Site suggests that the Site is likely to be underlain by a bedrock of “White Chalk Subgroup - Chalk”.

STAGE TWO – REVIEW OF HISTORICAL DATASETS

Sources of Information Consulted

The following information sources have been employed in order to establish the nature and scope of the UXO threat:

1. *6 Alpha's Azimuth Database*;
2. *Home Office WWII Bomb Census Maps*;
3. *WWII and post-WWII aerial photography*;
4. *Official Abandoned Bomb Register*;
5. *Information gathered from the National Archives at Kew*;
6. *Historic UXO information provided by 33 Engineer Regiment (Explosive Ordnance Disposal) at Carver Barracks, Wimbish.*

Potential Sources of UXO Contamination - Overview

In general, there are several activities that might have contaminated a site with UXO, but the three most common ways are: legacy munitions from military training/exercises; deliberate or accidental dumping (AXO) and ordnance resulting from war fighting activities (also known as the Explosive Remnants of War (ERW)).

During WWII, the *Luftwaffe* undertook bombing campaigns all over the *UK* and although the *Luftwaffe* had designated primary bombing targets across the *UK*, their high-altitude night bombing was not accurate. There was also a period of indiscriminate bombing of civilian and industrial areas alike in *British* cities in an attempt to cripple the morale of the *British* people. As a result, thousands of buildings were damaged across industrial and residential areas and civilian fatalities were common. Bombs were also jettisoned over opportunistic targets and more rural locations were also attacked in this manner.

As the threat of invasion lingered over *Britain* during WWII, defensive actions were undertaken. The *British* and *Allied Forces* requisitioned large areas of land for military training and bomb storage (including HE bombs, naval shells, artillery and tank projectiles, explosives, LSA and SAA). Thousands of tonnes of these munitions were used for the *Allied Forces* weapon testing and military training alone. It has been estimated that at least 20 per cent of the *UK's* land has been used for military training at some point.

The most common type of UXO discovered today in the *UK* is the aurally delivered high explosive (HE) bomb, which are comparatively thick-skinned and were dropped from *Luftwaffe* aircraft. If the bomb did not detonate when it was dropped, the force of impact enabled the UXO to penetrate the ground, often leaving behind it a UXB entry hole. These entry holes were not always apparent, and some went unreported, leaving the bomb buried and unrecorded. *British* AXO/LSA/SAA is also commonly encountered in areas that were formerly occupied by military forces (such as RAF airfields, military camps and/or military training areas). More rarely, additional forms of *German* UXO are occasionally discovered including *inter alia* Incendiary Bombs (IBs), and Anti-personnel (AP) bomblets and fragments of V1 and V2 rockets.

"The best practice guide for dealing with your UXO risks on land" (CIRIA publication C681) suggests that approximately 10 per cent of all munitions deployed during WWII failed to function as designed. ERW are therefore, still commonly encountered, especially whilst undertaking construction and civil engineering groundwork.

Furthermore, in exceptional circumstances, UXO is discovered unexpectedly and without apparent rational explanation. There are several ways this might occur:

- When *Luftwaffe* aircraft wished to swiftly escape e.g., from an aerial attack, they would jettison some or all of their bombs and flee. This is commonly referred to as *tip and run* and it has resulted in bombs being found in unexpected locations;
- Transportation of aggregate containing munitions to an area that was previously free of UXO, usually related to construction activities employing material dredged from a contaminated offshore borrow site;
- *British* decoy sites were also constructed to deliberately cause incorrect targeting. For obvious reasons, such sites were often built in remote and uninhabited areas – few historical records concerning these sites are available.

WWII Bombing of the *Hoo Peninsula*

Located in *Kent*, the *Hoo Peninsula*'s position at the *Thames Estuary* made it an important strategic and military area and target, during both WWI and WWII. During WWII, the *Luftwaffe* identified a number of important targets in the area, including oil refineries, military installations and munitions depots. Due to this, it endured several aerial attacks during the war, and would often be hit by *Luftwaffe* bombers ditching bombs whilst returning from raids further inland, known as *tip and run* raids – the towns of *Gravesend* and *Rochester* were also subject to multiple air raids throughout WWII.

WWII HE Bomb Density (Figure 4)

The Study Site was located within *Strood Rural District* which recorded nine HE bombs per 100 hectares, a “very low” level of bombing.

WWII Luftwaffe Bombing Targets (Figure 5)

Prior to WWII, the *Luftwaffe* conducted numerous aerial photographic reconnaissance missions over *Britain*, recording key military, industrial and commercial targets for attack, in the event of war. In addition, logistics infrastructure and public services, such as railways, canals, power stations, reservoirs, water and gas works were also considered viable bombing targets.

Luftwaffe aerial reconnaissance photography associated with the Study Site identified the *Shorne Mead Battery* (located in the Study Site's north-western sector) as a primary bombing target.

WWII HE Bomb Strikes (Figure 6)

During WWII, ARP wardens compiled detailed logs of bomb strikes across their respective districts. ARP records associated with the Study Site identified bomb strikes 10m to the south, 25m to the east, 150m to the south, 195m and 270m to the west, and 270m to south-south-east. Furthermore, whilst IBs may have fallen within the Study Site, they fell in such large numbers that accurate record keeping was either non-existent or perfunctory.

In addition to IBs and HE bomb strikes, during the latter part of the war when aerial bombing had significantly declined, the main threat came from V type weapons. V1 and V2 rockets were thin-skinned, unmanned and inaccurate weapons. Specifically, within 1,000m of the Study Site, a V2 strike was recorded in the *Thames River* in proximity to the *Shorne Marshes*, potential as close as 100m north of the Study Site boundary.

The potential penetration depth of an UXB was dependent on a number of factors including but not restricted to those prior to striking the ground e.g. velocity and orientation of the UXB which in turn will be influenced on factors such as the release altitude from the aircraft and encounters with infrastructure during its fall; those encountered at the point of impact i.e. was the impact on concrete, grass, water etc. and finally, the below ground level conditions which were encountered such as infrastructure e.g. services, basements, foundations, and geology e.g. made ground, clay, sand, etc. Further, as the UXB penetrated the ground, it's velocity naturally slowed where, it either came to an abrupt stop e.g., against foundations or would continue for 10's of feet along a route of least resistance which often resulted in a curving of the trajectory back towards the surface. This is known as the “J Curve” effect and often resulted in a considerable horizontal off-set from the point of entry. This is often the reason why UXBs have been discovered against or under the foundations of buildings, which were present during WWII, or many meters from the point of impact.

WWII Bomb Damage

Bomb damage maps associated with the Study Site were not available. Whilst further research of historical records and an analysis of post-war mapping failed to identify any instances of bomb damage on-site, or within the immediate vicinity of the Study Site boundary, these records may have been restricted in associated with the military facilities, or else not recorded given the undeveloped nature of much of the Site.

A ruin was recorded as part of *Shorne Mead Fort* according to post-war mapping, which is potentially indicative of bomb damage. However, supplementary research noted that this structure was documented as having been ruined during the deliberate dismantling of the *Fort* following WWII.

Abandoned Bombs

An examination of the official abandoned bomb records has identified one abandoned 50kg phosphorus (incendiary) bomb which was recorded in the vicinity of *Shorne Mead Fort*, approximately 440m to the south-west. Nonetheless, this record is not considered to be wholly accurate and therefore, the abandoned bomb may have in fact been in closer proximity of the Study Site (and of *Shorne Mead Fort*).

Records of WWII UXB Disposal Tasks

Civil defence records did not identify any UXB disposal tasks within *Strood Rural District* from 1940-45, within 1,000m of the Study Site. However, these records are incomplete, some having been destroyed during WWII.

Military Activity

During WWII, the Study Site was situated within the confines of *Shorne Mead Fort*. The *Fort* was originally built in the 1790s as a gun battery to guard the entrance to the *Thames* from seaborne attack. However, it was rebuilt to new specifications with updated barracks, defences, storage rooms, and guns in the 1840s and 1860s; later being disarmed in the early 20th century due to land subsidence, and then being used as a training facility.

Moreover, during WWI and WWII, the *site* was repurposed as an emergency *gun battery*. The *Luftwaffe* aerial photography showed that the battery was installed as an extension from the original *Fort* (partially within the Study Site boundary), somewhat unsurprisingly given the instability of the original ground. In addition, a *pillbox* was also recorded 55m to the north of the Study Site. Furthermore, during the build up to D-Day during WWII (Operation Overlord), an *embarkation platform* was installed 240m to the west-north-west of the Study Site boundary.

After WWII, the area was repurposed as *barracks* for *Milton firing range*, before the *Fort complexes'* demolition by the *Army Demolition School of the Royal Engineers* in 1960 and the 1970s. The *firing range* still exists to the west of the *Fort* (approximately 930m west of the Study Site), although more recently it has been repurposed for *police* training.

There is also an alleged *minefield* on the Study Site, although it is thought that the series of small craters visible on-site were instead formed by a training exercise before the demolition works had begun. Part of the *Fort complex* was for a *submarine mining facility*, however, this was mapped in 1907 approximately 500m west of the Study Site. Thus, mines were unlikely to have been stored on-site or in close proximity. Subsequently, if mines were laid in the area, it was most likely within the *Thames River* as a defence from naval attacks.

Given the multi phases of military occupation on-site and in the vicinity, it is considered likely that munitions were stored, located and/or fired from, or in close proximity to, this Study Site during WWII. It was also common for munitions to be buried at former military facilities– the remnants of which are known as Abandoned Explosive Ordnance (AXO).

WWII Site Use

CS mapping prior to WWII, and *Luftwaffe* aerial photography (1938) shows that the Study Site was located on the periphery of *Shorne Mead gun battery* during WWII, with the Study Site itself consisting of structures in the north-west and predominantly marshland in the remaining areas.

As a result, it is probable that footfall within the majority of the Study Site would have been relatively low, and any UXB entry holes in the marshland may not have been reported at the time. However, it is presumable that footfall within the area of the gun battery would have been relatively high and as a result, UXB entry holes in close proximity to this area were more likely reported and dealt with at the time.

Post-WWII UXO Encounters

An examination of the post-WWII BDO tasks associated with the Study Site has not identified any BDO operations within the Study Site itself, or within 1,000m of its boundary.

Sources of UXO Contamination

Given the historic military activity documented at the Study Site, the most likely source of UXO contamination is *German* aerially delivered ordnance, which ranges from small IBs through to large HE bombs (the latter forms the principal threat). *British* AXO/LSA/SAA may also pose a threat. Additional residual contamination may be present from *British* AAA projectiles (which were used to defend the UK against German bombing raids).

Post-WWII Study Site Development

Generally, the probability of encountering UXO in ground that has been disturbed since it may have been contaminated with UXO is considered to be remote (up to the depth below ground level previously disturbed by any intrusive works). Therefore, an understanding of the Study Site's previous development history is crucial when assessing the likelihood that UXO might be encountered at the Study Site.

Study Site Development History

From an analysis of the CS and OS historical mapping associated with the Study Site, the following history can be deduced:

Year	Analysis
1862 CS Map	The Study Site was located in an undeveloped marshy area and did not consist of any structures.
1895 CS Map	Drainage channels were recorded through the marshes, saltings were also recorded on the northern boundary.
1907 CS Map	Earthworks/structures were recorded in the north-western corner. A trackway was also recorded along the western border.
1923 CS Map	A sentry box was recorded on the western border of the Study Site.
1939 Luftwaffe Aerial Photography	Changes were not recorded at the Study Site.
1947 Aerial Photography	No discernible changes were recorded at the Study Site.
1950 CS Map	Changes were not recorded at the Study Site.
1960 Aerial Photography	The parts of the earthworks/structures that were within the north-west boundary had been removed. There were craters/holes throughout the north-west quarter of the Site.
1966 OS Map	Woodland was recorded in the central sector of the Study Site.
1990 Aerial Photography	Significant changes were not recorded at the Study Site.
2003 Aerial Photography	Significant changes were not recorded at the Study Site.
2022 OS Map	Significant changes were not recorded at the Study Site.

The Study Site history assessment is our best interpretation of the data available at the time of writing. Given that yearly revisions of neither CS and OS mapping, nor aerial photography, are available for analysis, there are gaps between the mapping revisions.

Consequently, it should not be assumed that any new structures and/or features that are labelled on a map revision were constructed, developed, installed or demolished in the exact year that the mapping illustrates the change. It is possible – and indeed likely – that the exact date of development occurred somewhere between the two closest mapping revisions. Specifically, this may be particularly relevant where there is a gap between pre- and post-WWII mapping, as it may not be clear whether structures were present during WWII or if they were constructed in the post-WWII period.

STAGE THREE – DATA ANALYSIS

Variable	Result	Comment
Was the area considered to be a primary bombing target during WWII?	✓	<i>Shorne Mead Battery</i> was identified as a primary bombing target on-site.
Was the Study Site or the immediate area bombed during WWII?	✓	ARP records identified the closest bomb strike being just 10m to the south.
Did the Study Site or the immediate area experience bomb damage?	✗	There is no evidence of bomb damage on-site.
Would munitions have been manufactured, stored and/or fired from the Study Site previously?	✓	Munitions were likely stored and fired on-site, whilst munitions may have been abandoned when the structures on-site were destroyed.
Was the ground undeveloped during WWII?	✓	The Study Site consisted of a track on the western boundary and structures in the north-west, however, the majority of the Study Site was relatively undeveloped marshland.
Would the footfall have been high in the area?	✗	Apart from in the north-west corner and the western border, footfall would have been relatively low.
Would a UXB entry hole have been observed during WWII?	✗	Given the undeveloped nature of most of the Site, it remains plausible that a UXB could have impacted the Site without leaving behind a clearly visible entry hole
Has UXO been encountered previously at the Study Site?	✗	There have been no documented UXO encounters within 1,000m, although an abandoned incendiary bomb was recorded in the vicinity during WWII.
Have previous intrusive works removed the potential for UXO to be present?	✗	The Study Site has been subjected to some alterations; therefore, it is likely that any UXO within ground that has been disturbed since WWII would potentially have been discovered and removed. The potential for a UXO encounter in areas of undisturbed ground remains extant.
Are proposed intrusive works likely to extend into previously undisturbed ground?	✓	Areas of the Study Site have remained undeveloped since WWII and therefore, the proposed works may extend into previously undisturbed ground.
Is there potential for an unplanned encounter with UXO to occur during proposed intrusive works?	✓	Given that bomb strikes and military activity were recorded in the immediate vicinity, combined with the limited post-war redevelopment of the Study Site, it is considered possible for an unplanned encounter with UXO to occur.
Does the probability of a UXO encounter vary across the Study Site?	✓	The probability of encountering UXO within post-war disturbed and developed ground is considered to be remote. However, the probability of a UXO encounter within all previously undisturbed areas of the Study Site is extant.

N.B. The ✓ / ✗ symbology is intended to act only as a succinct visual indicator as to whether the data analysis has returned a positive (i.e., ✓) or negative (✗) answer to each question concerning the potential for UXO contamination at the Study Site.

STAGE FOUR – RISK ASSESSMENT

Threat Items

The most probable UXO threat items are *German* HE bombs and *British* AXO/LSA/SAA – the latter, if present, are likely to be encountered in previously undisturbed ground to depths of circa 2.0m – whilst IBs and *British* AAA projectiles pose a residual threat. The consequences of initiating *German* HE bombs are generally the most severe.

Bomb Penetration Depth

Considering the ground conditions (highlighted in Stage 1), the average BPD for a 250kg *German* HE bomb within clays is assessed to be approximately 7m bgl, with the maximum BPD considered to be approximately 16m bgl. Although it is possible that the *Luftwaffe* deployed larger bombs in the area, their deployment was infrequent, and to use such larger (or the largest) bombs for BPD calculations are not justifiable on either technical or risk management grounds. WWII *German* bombs have a greater penetration depth when compared to IBs and AAA projectiles, which are unlikely to be encountered at depths greater than 1m bgl. However, due to the “J Curve” and the potential for structures to impede the penetration into the ground, HE bombs have been discovered at much shallower depths than the average.

Risk Pathway

Given the types of UXO that might be present on-site, all types of aggressive intrusive engineering activities (i.e., investigative groundworks and construction methodologies) may generate a significant risk pathway. Whilst not all UXO encountered aggressively will initiate upon contact, such a discovery could lead to serious impact on the project especially in terms of critical injury to personnel, damage to equipment and project delay.

Prospective Consequences

Consequences of UXO initiation include:

1. Fatally injure personnel;
2. Severe damage to plant and equipment;
3. Deliver blast and fragmentation damage to nearby buildings;
4. Rupture and damage underground utilities/services.

Consequences of UXO discovery include:

1. Delay to the project and blight;
2. Disruption to local community/infrastructure;
3. The expenditure of additional risk mitigation resources and EOD clearance;
4. Incurring additional time and cost.

UXO RISK CALCULATION

Site Activities

Although there is some variation in the probability of encountering and initiating items of UXO when conducting different types of intrusive activities, a number of ground intrusive methodologies have been described for analysis at this Study Site. The consequences of initiating UXO vary greatly, depending upon, *inter alia* the mass of HE in the UXO and how aggressively it might be encountered. For this reason, *6 Alpha* has conducted separate risk rating calculations for each intrusive methodology that might be employed.

Risk Rating Calculation

6 Alpha's Semi-Quantitative Risk Assessment assesses and rates the risks posed by the most probable threat items when conducting a number of different activities on the site. UXO risk is determined by calculating the probability of encountering and initiating UXO and the consequences of an inadvertent UXO detonation.

UXO Risk Calculation Table – All Areas

Activity	UXO Threat Items	Probability (SH+EM=P)	Consequence (D+PSR=C)	UXO Risk (PxC=R)
Excavations (to 0.4m bgl)	HE Bombs	2+2=4	3+3=6	4x6=24
	AAA Projectiles	1+2=3	3+1=4	3x4=12
	IBs	1+2=3	3+1=4	3x4=12
	AXO/LSA/SAA	2+2=4	3+2=5	4x5=20
Installation of Fencing (to 0.4m bgl)	HE Bombs	2+2=4	3+3=6	4x6=24
	AAA Projectiles	1+2=3	3+1=4	3x4=12
	IBs	1+2=3	3+1=4	3x4=12
	AXO/LSA/SAA	2+2=4	3+2=5	4x5=20
Piling (to 1.3m bgl)	HE Bombs	2+3=5	3+2=5	5x5=25
	AAA Projectiles	1+3=4	3+1=4	4x4=16
	IBs	1+3=4	3+1=4	4x4=16
	AXO/LSA/SAA	2+3=5	3+2=5	5x5=25

Abbreviations – Site History (SH), Engineering Methodology (EM), Probability (P), Depth (D), Consequence (C), Proximity to Sensitive Receptors (PSR) and Risk Rating (RR).

STAGE FIVE – RECOMMENDED RISK MITIGATION MEASURES

Do the ground conditions support a geophysical UXO survey?

Non-Intrusive Methods of Mitigation – Magnetometer results may be affected by ferro-magnetic contamination due to previous construction activities within the Study Site (from *Shorne Mead Fort* construction/destruction).

Intrusive Methods of Mitigation – Intrusive magnetometry may be effective on this Study Site, prior to piling. However, any ferrous metal/red brick contamination in made ground/old foundations may affect the detection capability of the UXB survey equipment, as it passes through the contaminated layer especially. Nonetheless, such a survey should prove effective in noncontaminated ground.

Mitigation Measures to Reduce Risk to 'ALARP'

Activity	Risk Mitigation Measures	Final Risk Rating
All Activities in All Areas	1. Operational UXO Emergency Response Plan; appropriate site management documentation should be held on-site to guide and plan for the actions which should be undertaken in the event of a suspected or real UXO discovery (this plan can be supplied by 6 Alpha); 2. UXO Safety & Awareness Briefings; the briefings are essential when there is a possibility of explosive ordnance encounter and are a vital part of the general safety requirement. All personnel working on the site should receive a briefing on the identification of a UXB, what actions they should take to keep people and equipment away from such a hazard and to alert site management. Information concerning the nature of the UXB threat should be held in the site office and displayed for general information on notice boards, both for reference and as a reminder for ground workers. The safety awareness briefing is an essential part of the <i>Health & Safety Plan</i> for the site and helps to evidence conformity with the principles laid down in the <i>CDM regulations 2015</i> (this brief can be delivered directly, or in some cases remotely, by 6 Alpha).	ALARP
Excavations and Fence Installation into Previously Undisturbed Ground	3. Non-intrusive UXO Survey and/or EOD Engineer in the Watching Brief Role; Where “open” intrusive works into previously undisturbed ground are proposed and where the extent is considered to be within the capabilities of non-intrusive UXO survey equipment and implementation of this is assessed as likely to prove effective, a non-intrusive geophysical UXO survey should be trialled and, if it proves successful, should be employed to survey site-wide, or in specific areas where “open” intrusive works are to be implemented to identify for signs of sub-surface anomalies which may model as the target UXO in advance of said works. If the survey proves partially or wholly ineffective, an EOD Engineer should be present in the UXO Watching Brief role to monitor ongoing “open” intrusive works to identify any suspicious items that may be UXB or UXO related (this service can be provided by 6 Alpha).	
Piling into Previously Undisturbed Ground	4. Intrusive UXO Survey; Where ‘blind’ intrusive works into previously undisturbed ground are proposed, an intrusive UXO survey (employing down-hole magnetometer or MagCone techniques) is strongly recommended. Such a survey should extend to the <i>assessed average bomb penetration depth</i> or to the maximum depth of the works, whichever is encountered first, or until geology is encountered through which it is assessed a UXB would not penetrate, to identify for signs of sub-surface anomalies which may model as the target UXO in advance of said works. (This service can be provided by 6 Alpha).	

This assessment has been conducted partially based on the information provided by the Client, should the proposed works change then 6 Alpha should be re-engaged to refine this risk assessment

Report Figures

Figure One - Study Site Location



British National Grid

RSPB GRAVESEND

Site Location

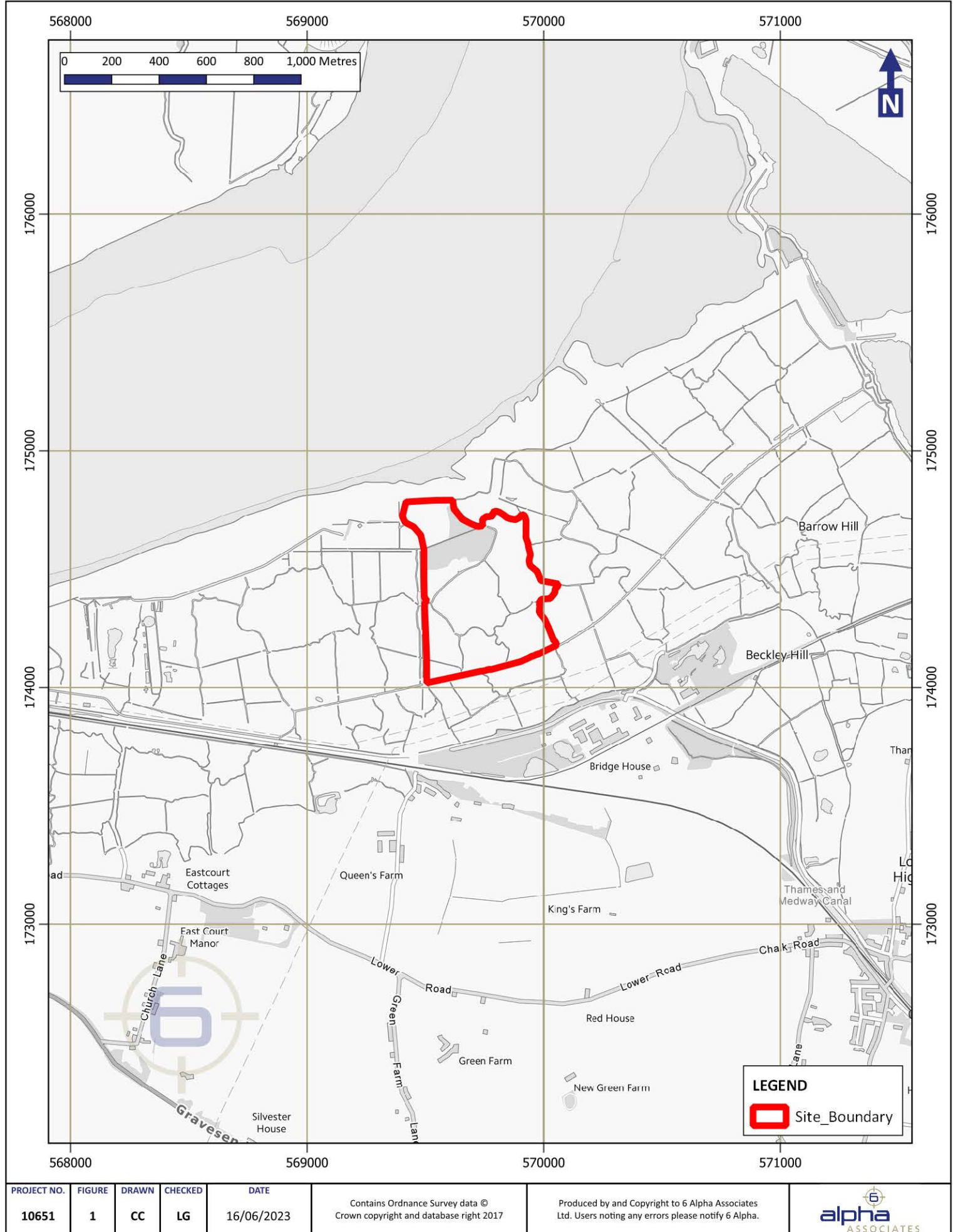


Figure Two - Study Site Boundary



British National Grid

RSPB GRAVESEND

Site Boundary

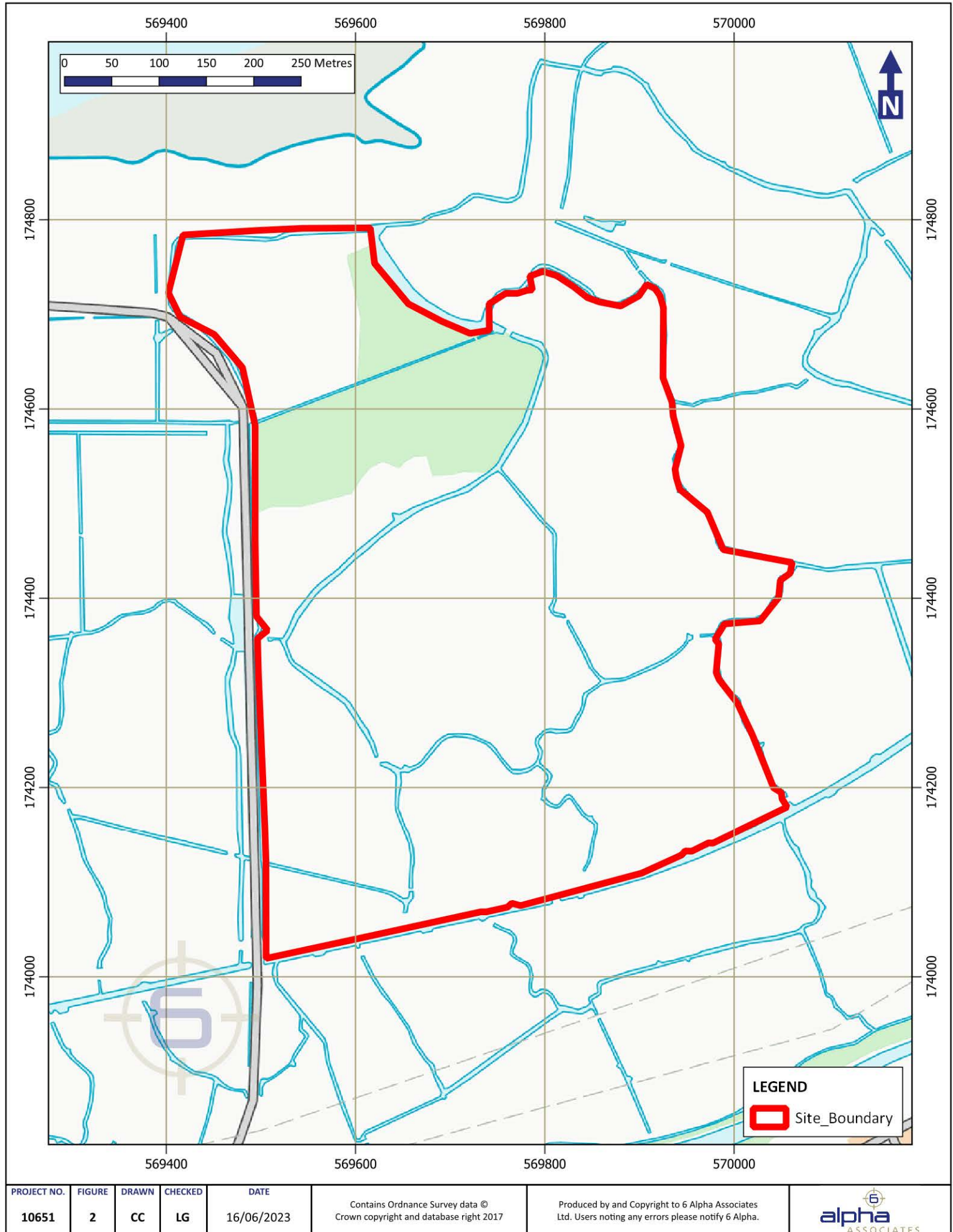


Figure Three - Aerial Photography (2022)



British National Grid

RSPB GRAVESEND

Aerial Photography (2022)

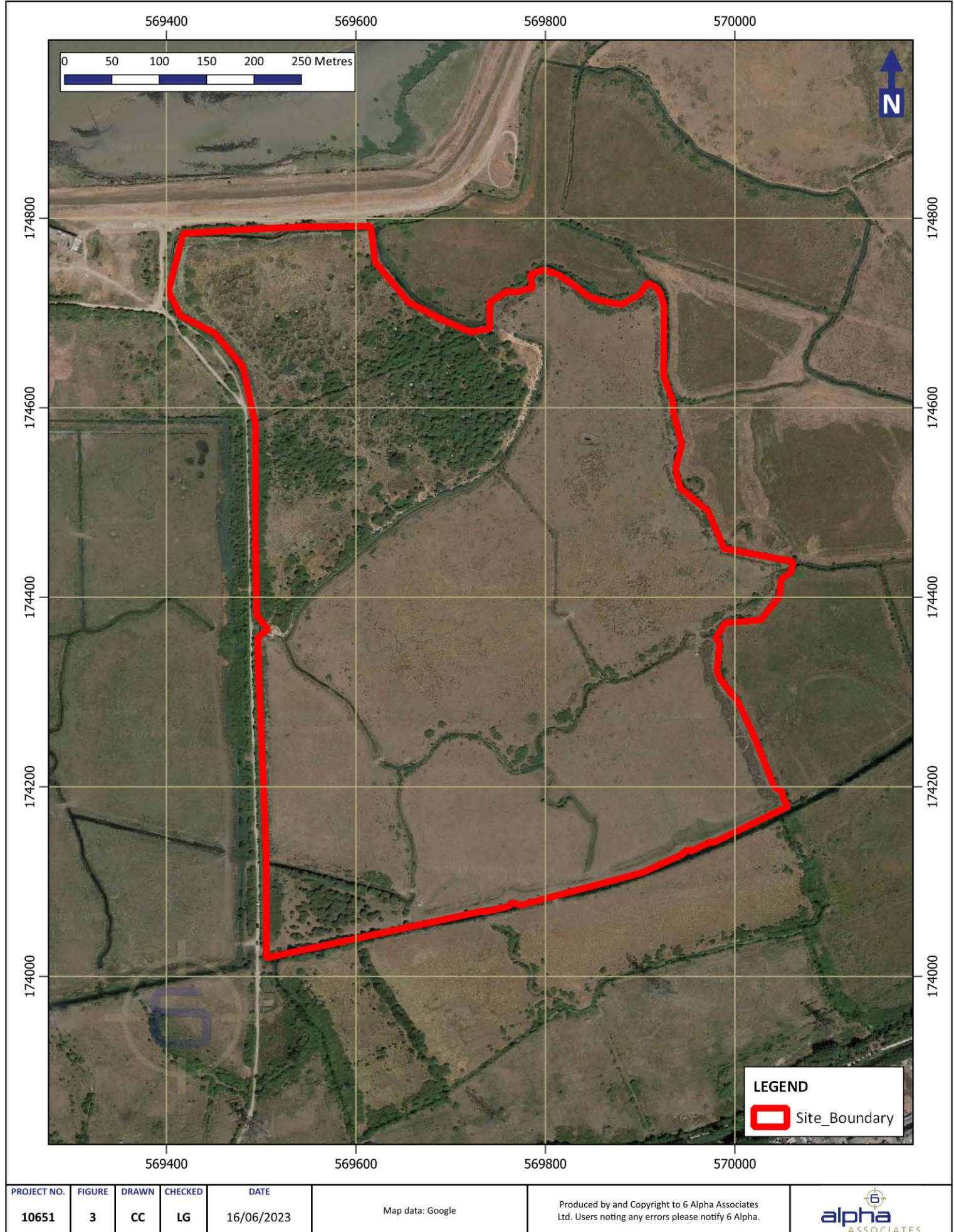


Figure Four - WWII High Explosive Bomb Density



British National Grid

RSPB GRAVESEND

WWII High Explosive Bomb Density

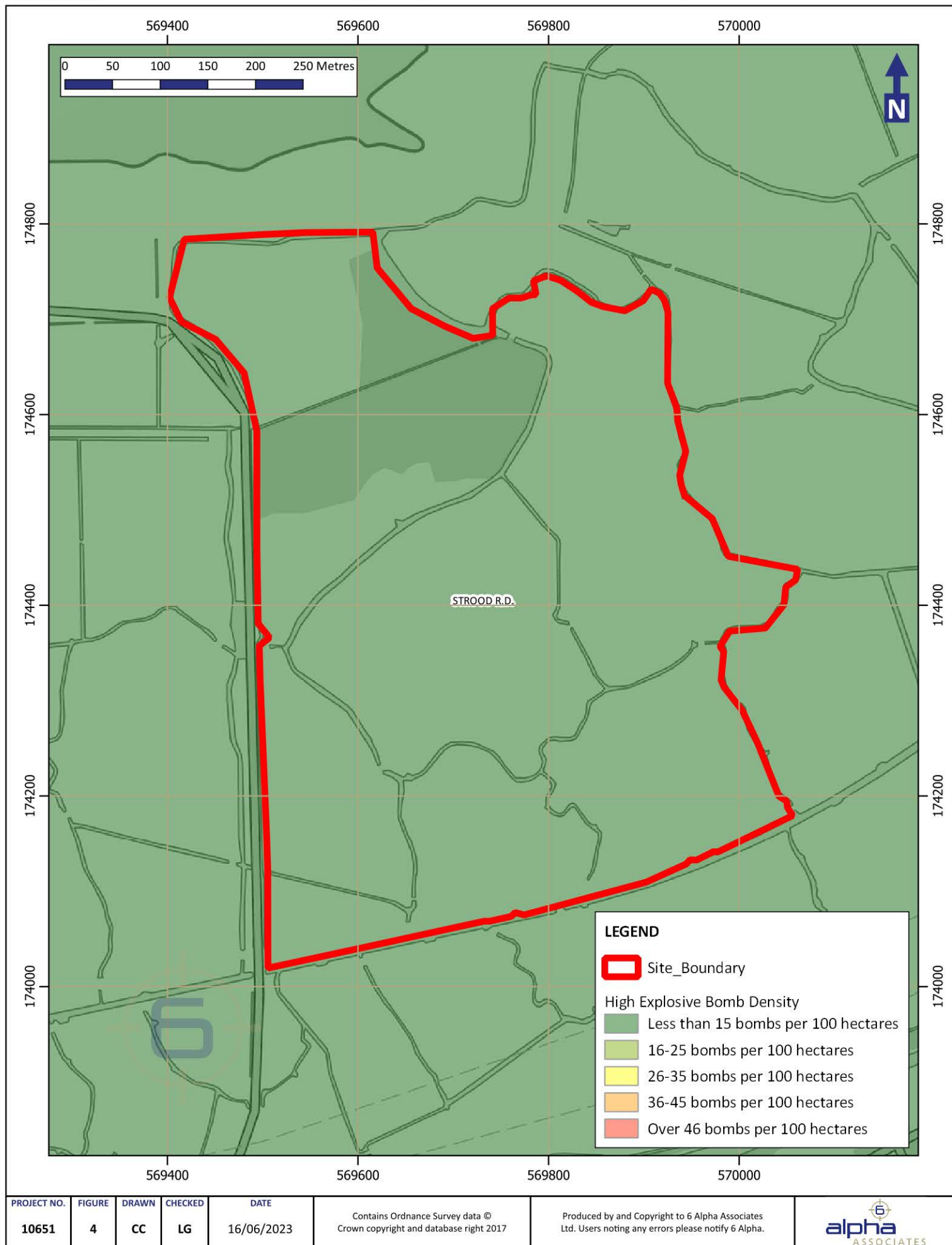


Figure Five - WWII Luftwaffe Bombing Targets



British National Grid

RSPB GRAVESEND

WWII Luftwaffe Bombing Targets

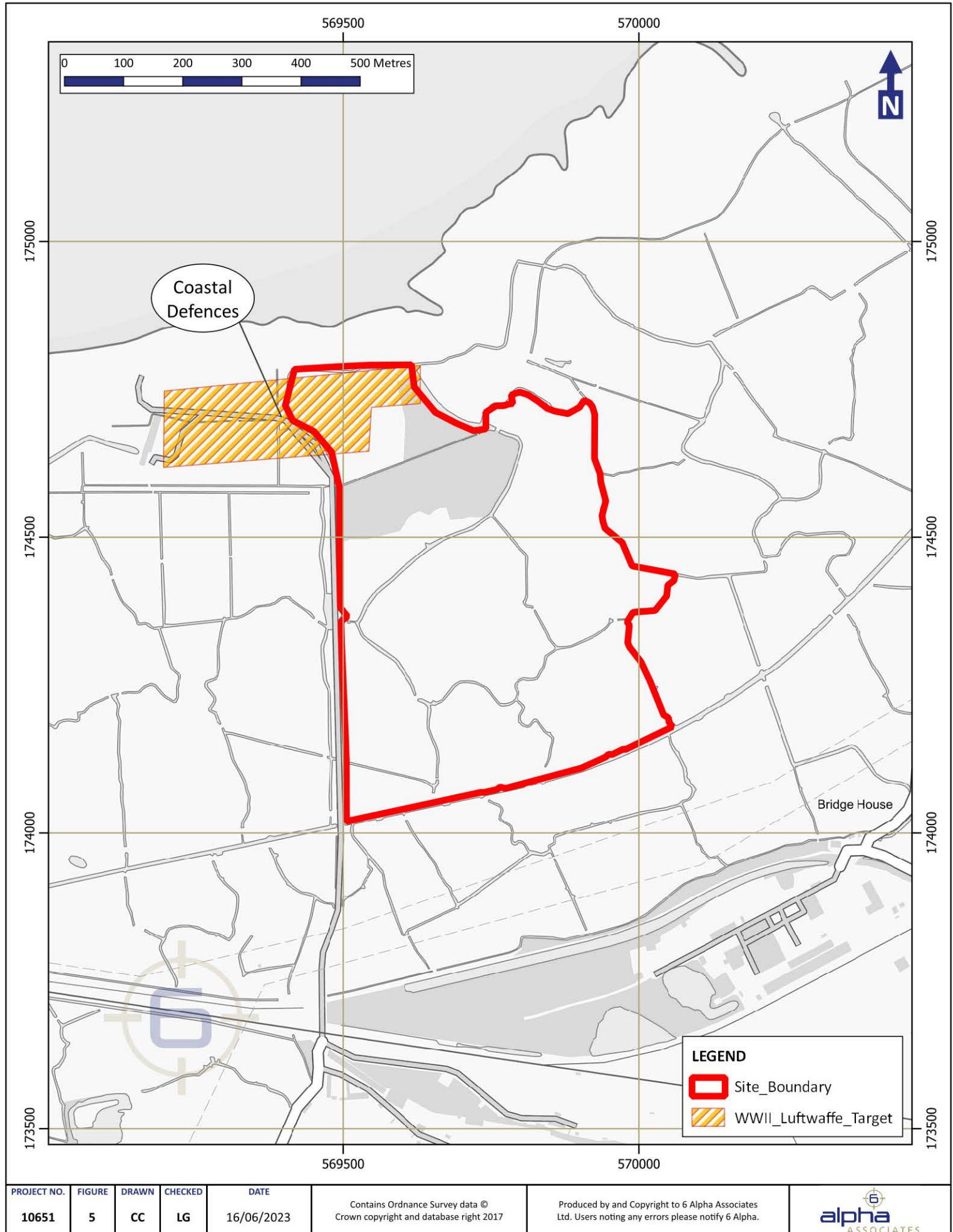


Figure Six - WWII High Explosive Bomb Strikes



British National Grid

RSPB GRAVESEND

WWII Consolidated Bomb Strikes

