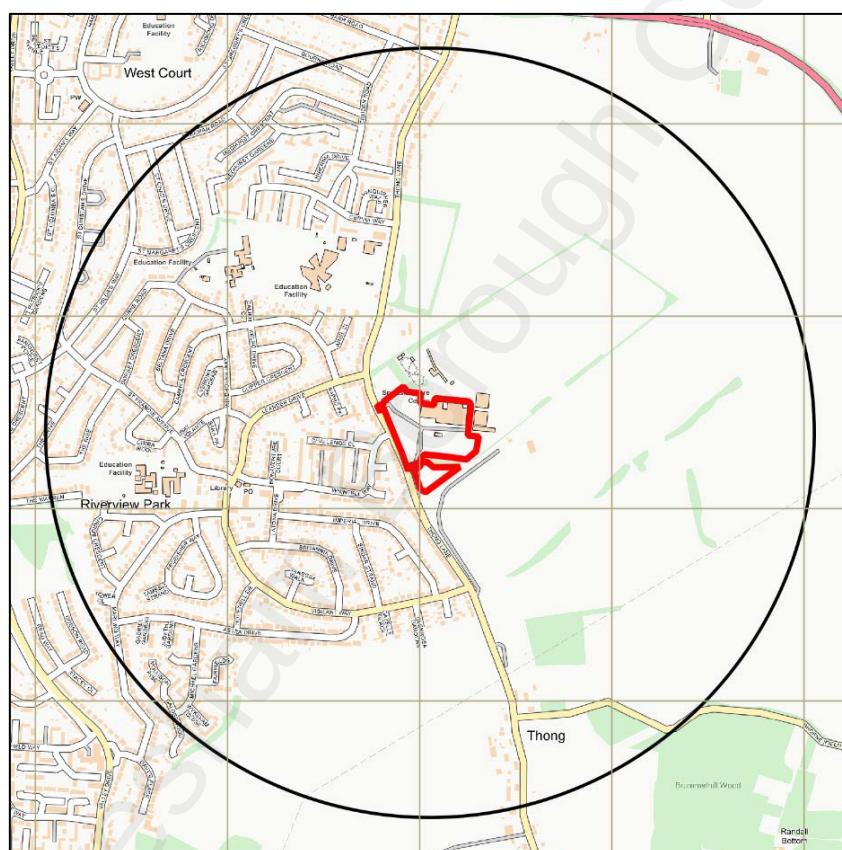


Detailed Unexploded Ordnance (UXO) Threat & Risk Assessment

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



6 ALPHA PROJECT NUMBER	10210	ORIGINATOR	R. Taylor
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CLIENT REFERENCE	15971	RELEASED BY	L. Gregory
PROJECT	Thong Lane	DATE	10 th November 2022
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 “Cascades Leisure Centre, Thong Lane, Gravesend, DA12 4LG” and it is centred on NGR 567030, 171700.

Risk Level

HIGH

Potential Threat Sources

The most probable UXO threat is posed by *British AXO/LSA/SAA* associated with *RAF Gravesend*. *German HE bombs* and *IBs* also pose a possible threat given the bombing recorded in the vicinity of the Site, whilst *British AAA projectiles* 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 *Gravesend Municipal Borough*, which recorded 17 HE bomb strikes per 100 hectares, a “low” level of bombing.

Luftwaffe aerial reconnaissance photography associated with the Study Site identified *Gravesend Airfield* located on-site as a primary bombing target. Although it was initially operated as a civilian airfield, the site was requisitioned and became *RAF Gravesend* during WWII. The airfield operated as a training site during its early military life but became an operational *RAF Fighter Command* airfield during the *Battle of Britain*. Furthermore, *Canadian* pipemines were deployed at *RAF Gravesend* in order to render the airfield inoperable in the event of a *German* invasion during WWII. An analysis of post-war documentation noted that the pipemines had been removed “*wholly or in part*”, and a survey carried out by *Royal Engineers* in 1989-90 discovered 15 pipemines at the former airfield, in addition to 75 10lb *British* practice bombs. It is therefore considered possible that not all pipemines or other ordnance related to *RAF Gravesend* were removed at the end of WWII and in the absence of clear evidence that the Study Site has been subject to any post-WWII clearance operations it is considered possible that similar munitions might be encountered in any areas of undisturbed (post-WWII) ground.

Official written records identified multiple 50kg and 500kg HE bomb strikes on the airfield on 21st/22nd January 1944. Whilst not all of the written entries provide a geospatial reference, 500kg HE bomb strikes were documented on the western perimeter of the airfield, and on grassland and “waste ground” around the airfield “dispersal points”. Official written records also identified that three *AB 1000/2* containers (which could each contain 600 IBs) were dropped on *RAF Gravesend* during WWII; approximately 110m south-west, 110m south-west and 245m south-east of the Study Site boundary.

Official bomb damage mapping associated with the Study Site was not available. Nonetheless, official written records identified bomb damage to structures on *RAF Gravesend* (located on-site and in the vicinity) due to the aforementioned bomb strikes on the airfield, including the partial demolition of a brick defence post, *Nissen* huts and blister hangar (located approximately 830m south-west). Furthermore, an analysis of post-war mapping identified multiple “*ruins*” in the south and central sectors of the Study Site, all of which are possibly indicative of potential bomb damage given the extent of bombing recorded in the area.

Pre-WWII mapping (1933-1936), 1940 aerial photography and post-war mapping (1946) associated with the Study Site shows that it was located in the rural outskirts of a developed urban area; the Study Site itself consisted undeveloped land, structures, areas of hard standing all associated with *RAF Gravesend*. Therefore, it is probable that military personnel may have inspected the Study Site for UXB entry holes following any air raids as part of any damage assessment that would have likely taken place. However, this does not preclude the potential for a UXB encounter at the Site given that extensive bomb damage was evidenced in the immediate vicinity of the Site – such damage could conceivably obscure a UXB entry hole at the Site, or in close proximity.

Key Findings (...continued)

The Study Site has undergone some post-war redevelopment, specifically concerning the construction of *Cascades Leisure Centre* in the 1980s and the removal of almost all traces of *Gravesend Airfield*. Consequently, it is considered likely that any UXO within post-war disturbed and developed ground would potentially have been discovered and removed. However, the potential for deep buried UXO to be present within any remaining areas of undisturbed ground is assessed to be extant.

Conclusions

Given that the Study Site was situated in *RAF Gravesend* during WWII, which was then subject to bombing, combined with the lack of clear evidence of the complete removal of all ordnance from the airfield and the limited post-WWII redevelopment of the 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).

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)
Trial Pits	✓	✓	✗	✓	✓	✗	ALARP
Excavations	✓	✓	✗	✓	✓	✗	
Trenching	✓	✓	✗	✓	✓	✗	

“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)
Boreholes	✓	✓	✗	✗	✗	✓	ALARP
Window Sampling	✓	✓	✗	✗	✗	✓	
Piling	✓	✓	✗	✗	✗	✓	
Horizontal Directional Drilling	✓	✓	✗	✓	✓	✓	

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

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 “Cascades Leisure Centre, Thong Lane, Gravesend, DA12 4LG”. The Study Site is centred at NGR 567030, 171700 as presented at *Figures 1 and 2*, respectively.

Location Description

The Study Site is situated within the *Town of Gravesend* and totals an area of 3.7 hectares (ha).

Furthermore, the Study Site is bounded by:

- North: areas of hard standing and undeveloped land;
- East: undeveloped land and a hard standing road;
- South: undeveloped land;
- West: *Thong Lane*.

Aerial Photography (2021) (*Figure 3*)

Current aerial photography corroborates the information above and shows that the Study Site is situated on the outskirts of a densely developed urban area. The Study Site itself consists of multiple structures and areas of hard standing associated with *Cascades Leisure Centre*, alongside areas of undeveloped land.

Proposed Works

The Client has described the following:

- *“Shallow Trial Pit up to 1m below ground level;*
- *Medium Trial Pit between 1m and 5m below ground level;*
- *Window Sampling up to 1m below ground level;*
- *Shallow Trenching up to 2m below ground level;*
- *Deep Trenching greater than 2m below ground level;*
- *Shallow Bulk Excavation up to 2m below ground level;*
- *Deep Bulk Excavation greater than 2m below ground level;*
- *Horizontal Directional Drilling;*
- *Grading;*
- *Borehole: assume 30m;*
- *Piling: assume sheet piling and CFA;*
- *Excavation: assume in open cut by standard 360 excavator”*

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:

“Chalk anticipated at shallow depth - no superficial deposits mapped but some likely to be present.”

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.

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

Ground Conditions

BGS borehole log “TQ67SE455 – Lower Thames Crossing – Phase 2A – Package A TP02004” (located approximately 100m south-east of the Study Site boundary), recorded the following strata:

Depth bgl (m)	Strata	Description
0.00m to 0.30m	Made ground	Grass over firm brown slightly sandy, slightly gravelly clay
0.30m to 0.80m	Made ground	Dark brown locally clayey slightly sandy gravelly silt with brick and concrete cobble content
0.80m to 1.30m	Clay	Firm brown slightly sandy gravelly silty clay
1.30m to 1.70m	Chalk	Structureless chalk composed of slightly sandy silty gravel
1.70m to 4.50m	Chalk	Very weak low and medium density white N9 with rare black specks chalk

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 “*Lewes Nodular Chalk formation, Seaford Chalk Formations and Newhaven Chalk Formation* (undifferentiated) - Chalk”.

STAGE TWO – REVIEW OF HISTORICAL DATASETS

Sources of Information Consulted

The following primary information sources have been used in order to establish the background 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 aerially 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 Kent

During WWII, *Kent* was subjected to numerous air raids. The high concentration of airfields and industrial areas within *Kent* made it an important strategic bombing target for the *Luftwaffe*, in addition to its location under the main flight path to *London*. Even after *The Blitz* had largely ceased in 1944 and 1945, the county continued to suffer heavily. It is estimated that 2,500 V1 flying rockets, launched from continental bases, impacted upon the county in the last years of the war- causing much devastation to civilian life and property.

The threat of a potential *German* invasion during WWII also prompted considerable fortification efforts in the county of *Kent*, particularly in areas such as *Dover* and around the *River Medway*. Consequently, numerous defensive features such as pillboxes and artillery guns were established around the county to defend against any prospective naval invasions, notwithstanding anti-aircraft artillery positions to defend against, and intercept, the frequent aerial bombing raids passing overhead.

WWII HE Bomb Density (Figure 4)

The Study Site was located within *Gravesend Municipal Borough*, which recorded 17 HE bombs per 100 hectares, a “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 *Gravesend Airfield* (located on-site) 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. However, ARP personnel are unlikely to have been collected for this Site given its location within a military airfield during WWII. Instead, official written military records associated with *RAF Gravesend* identified multiple 50kg and 500kg HE bomb strikes on the airfield on 21st/22nd January 1944. Whilst not all of the written entries provide a geospatial reference, 500kg HE bomb strikes were documented on the western perimeter of the airfield, and on grassland and “waste ground” around the airfield “dispersal points”. The exact locations of these bomb strikes were not mapped but it is likely they impacted either within, or in very close proximity to the Study Site – this is corroborated by the (undermentioned) proximity of “ruins” documented on post-WWII mapping near to the Study Site. Official written records also identified that three *AB 1000/2* containers (which could each contain 600 IBs) were dropped on *RAF Gravesend* during WWII; approximately 110m south-west, 110m south-west and 245m south-east of the Study Site boundary.

Furthermore, ARP records covering the Site’s wider area also recorded three bomb strikes in the vicinity; 400m to the north-north-east, 685m to the north-west and 820m to the south-west – which was corroborated by military records documenting bomb strikes at *RAF Gravesend*. These records documented multiple 50kg HE bomb strikes on residential areas around the airfield.

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

Official bomb damage mapping associated with the Study Site was not available. Nonetheless, official written records identified bomb damage to structures on *RAF Gravesend* (located on-site and in the vicinity) due to the aforementioned bomb strikes on the airfield, including the partial demolition of a brick defence post, *Nissen* huts and blister hangar (located approximately 830m south-west). In addition, minor damage was recorded to a *Spitfire* and 16 vehicles around the blister hangar. Furthermore, an analysis of post-war mapping identified multiple “ruins” in the south and central sectors of the Study Site, all of which are possibly indicative of potential bomb damage given the extent of bombing recorded in the area.

Abandoned Bombs

An examination of the official abandoned bomb records did not identify any abandoned bombs on-site or within 1,000m of the Study Site boundary.

Records of WWII UXB Disposal Tasks

Civil defence records did not identify any UXB disposal tasks within *Gravesend Municipal Borough* from 1940-45, within 1,000m of the Study Site. However, it is known that these records are incomplete, some having been destroyed by *Luftwaffe* action during WWII.

Military Activity

The Study Site is located within the former *Gravesend Airfield* (designated as *RAF Gravesend* during WWII). Prior to WWII, *Gravesend Airfield* was used by private civil aviation and the *Gravesend School of Flying*, however in 1937, it was requisitioned by the *RAF*. Initially, the airfield was used by *No. 20 Elementary and Reserve Flying Training School*, however at the outbreak of WWII *RAF Gravesend* became a satellite airfield for *RAF Biggin Hill* and it operated as an independent fighter airfield, which was home to multiple different squadrons. However, by 1944 the increased presence of *German V1* rocket attacks meant *Gravesend Airfield* was at risk of attack and therefore closed on 30th July. Following WWII, *RAF Gravesend* was put under Care and Maintenance and later closed. An analysis of 1940 aerial photography shows that minor structures and hardstanding were located on-site during WWII, with the Site located at the perimeter of the airfield.

Furthermore, *Canadian* pipemines were deployed at *RAF Gravesend* in order to render the airfield inoperable in the event of a *German* invasion during WWII. An analysis of post-war documentation noted that the pipemines had been removed “wholly or in part”, and a survey carried out by *Royal Engineers* in 1989-90 discovered 15 pipemines at the former airfield, in addition to 75 10lb *British* practice bombs. The area under survey comprised of the southern sector of the Study Site and Site’s immediate vicinity. It is therefore considered possible that not all pipemines or other ordnance related to *RAF Gravesend* were removed at the end of WWII and in the absence of clear evidence that the Study Site has been subject to any post-WWII clearance operations it is considered possible that similar munitions might be encountered in any areas of undisturbed (post-WWII) ground.

WWII Site Use (Figure 7)

The CS mapping prior to WWII (1933-1936), 1940 aerial photography and post-WWII OS mapping (1946) shows that the Study Site was located in the rural outskirts of a developed urban area; the Study Site itself consisted undeveloped land, structures, areas of hard standing all associated with *Gravesend Airfield* (*RAF Gravesend*). Therefore, it is probable that military personnel may have inspected the Study Site for UXB entry holes following any air raids as part of any damage assessment that would have likely taken place. However, this does not preclude the potential for a UXB encounter at the Site given that extensive bomb damage was evidenced in the immediate vicinity of the Site – such damage could conceivably obscure a UXB entry hole at the Site, or in close proximity.

Sources of UXO Contamination

Given the historic military activity documented at the Study Site, the most likely source of UXO contamination *British* AXO/LSA/SAA and practice bombs associated with *RAF Gravesend* during WWII and *German* aerially delivered ordnance (which ranges from small IBs through to large HE bombs (the latter forms the principal threat). *British* AAA projectiles (which were used to defend the UK against *German* bombing raids) pose a residual threat.

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
1898 CS Map	The Study Site was located in a sparsely developed rural area. The Study Site consisted of undeveloped land
1909 CS Map	Significant changes were not recorded at the Study Site.
1933-1936 CS Map	Significant changes were not recorded at the Study Site.
1940 Aerial Photography	Structures and areas of hard standing associated with an <i>Airfield</i> had been developed throughout the Site.
1946 OS Map	Significant changes were not recorded at the Study Site.
1961 OS Map	A small structure had been developed in the north-eastern sector of the Site.
1968 OS Map	All structures associated with the <i>Airfield</i> had been removed.
1982 OS Map	Structures associated with a <i>Sports Centre</i> (including <i>Tennis Courts</i> and a <i>Playground</i>) had been developed in the northern and central sectors of the Site.
1990 OS Map	Further structures and areas of hard standing associated with <i>Cascades Leisure Centre</i> had been developed throughout the Site.
2003 Aerial Photography	Significant changes were not recorded at the Study Site.
2016 OS Map	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>Gravesend Airfield</i> (located on-site) was identified as a primary bombing target
Was the Study Site or the immediate area bombed during WWII?	✓	Official written records identified numerous HE bomb strikes and IBs on <i>Gravesend Airfield</i> during WWII.
Did the Study Site or the immediate area experience bomb damage?	✓	Official written records identified bomb damage to structures on <i>RAF Gravesend</i> (located on-site and in the vicinity) due to the aforementioned bomb strikes on the airfield.
Would munitions have been manufactured, stored and/or fired from the Study Site previously?	✓	<i>Canadian</i> pipemines and <i>British</i> practice bombs were encountered at <i>RAF Gravesend</i> in 1989-1990. And it is generally likely that munitions might have been located at the Site due to its location within <i>RAF Gravesend</i> .
Was the ground undeveloped during WWII?	✓	The Study Site was located within <i>RAF Gravesend</i> during WWII and consisted of small structures, hardstanding and areas of undeveloped ground.
Would the footfall have been high in the area?	✓	Given that <i>Gravesend Airfield</i> was located on-site and in the immediate vicinity, it is likely that footfall would have been relatively frequent.
Would a UXB entry hole have been observed during WWII?	✗	Given that extensive bomb damage was documented in the vicinity, it is plausible that bomb damage debris could have obscured a UXB entry hole at, or near, the Study Site.
Has UXO been encountered previously at the Study Site?	✓	75 <i>British</i> practice bombs and <i>Canadian</i> pipemines were identified and removed from <i>RAF Gravesend</i> , of which some may have been located on-site or in the immediate vicinity.
Have previous intrusive works removed the potential for UXO to be present?	✗	It is likely that any UXO within post-war disturbed and developed ground 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 <i>RAF Gravesend</i> was located on-site combined with bomb strikes recorded in close proximity and the extent of previous UXO encounters at the airfield, 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 – UXO RISK ASSESSMENT

Threat Items

The most probable UXO threat items are *British* AXO/LSA/SAA associated with *RAF Gravesend* which, if present, are likely to be encountered in previously undisturbed ground to depths of circa 2.0m. *German* HE bombs and IBs also pose a possible threat given the bombing recorded in the vicinity of the Site, whilst *British* AAA projectiles pose a residual threat. The consequences of initiating *German* HE bombs are generally more severe than initiating IBs or AAA projectiles, and thus they pose the greatest prospective risk to intrusive works.

Bomb Penetration Depth

Considering the ground conditions (highlighted in Stage 1), the average BPD for a 250kg *German* HE bomb is assessed to be approximately 6m bgl, with the maximum BPD considered to be approximately 14m 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 an inadvertent UXO initiation may include:

1. Fatalities or serious injuries to 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 an inadvertent UXO discovery may 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	Threat Item	Probability (SH+EM=P)	Consequence (D+PSR=C)	UXO Risk (Px C=R)
Trial Pits (to 5m 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
Window Sampling (to 1m 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
Boreholes (~30m 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
Excavations (>2m 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
Trenching (>2m 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	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

UXO Risk Calculation Table – All Areas (...continued)

Activity	Threat Item	Probability (SH+EM=P)	Consequence (D+PSR=C)	UXO Risk (PxC=R)
Horizontal Directional Drilling	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 and made ground within the Site.

Intrusive Methods of Mitigation – Intrusive magnetometry may be effective on this Site, prior to boreholing and piling especially. 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, beyond the contaminated strata such a survey should prove effective.

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
Trial Pits, Excavations, Trenching and HDD 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).	
Window Sampling, Piling, Boreholing and Horizontal Directional Drilling 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

Gravesham Borough Council

Figure One - Study Site Location

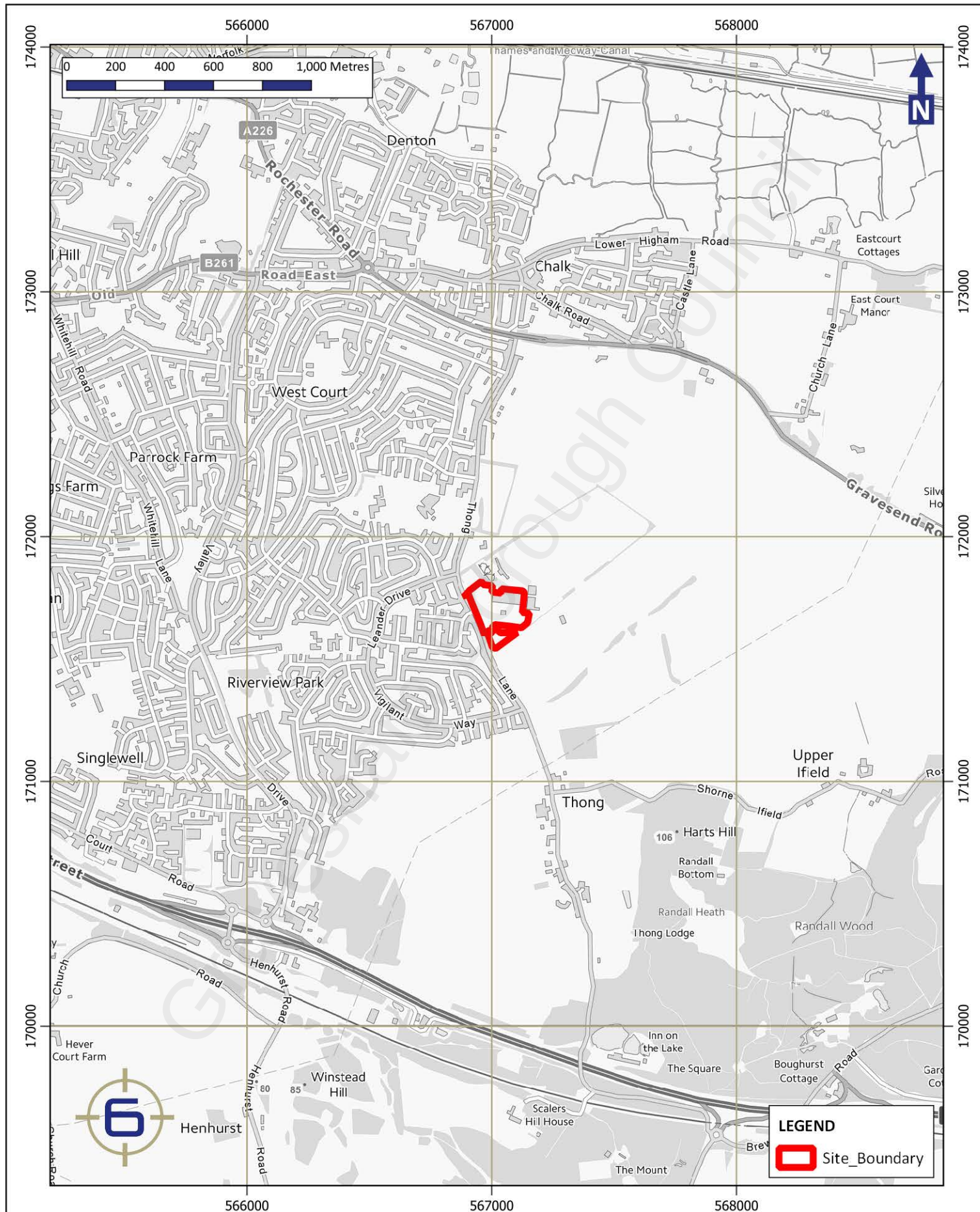
Gravesham Borough Council



British National Grid

CASCADES LEISURE CENTRE, THONG LANE, GRAVESEND, DA12 4LG

Site Location



PROJECT NO.	FIGURE	DRAWN	CHECKED	DATE
10210	1	CC	LG	02/11/2022

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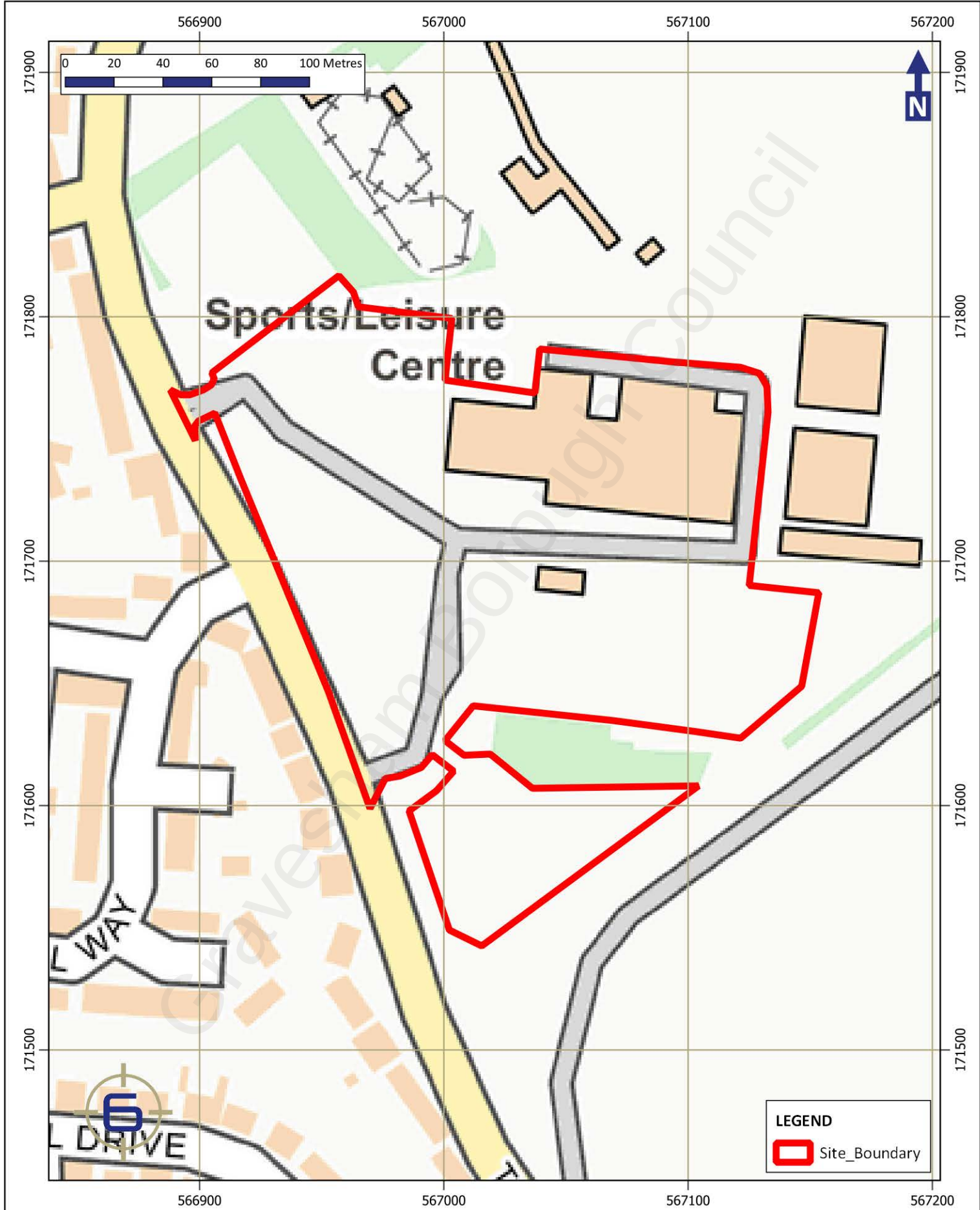
Figure Two - Study Site Boundary

Gravesham Borough Council



British National Grid

CASCADES LEISURE CENTRE, THONG LANE,
GRAVESEND, DA12 4LG
Site Boundary



PROJECT NO.	FIGURE	DRAWN	CHECKED	DATE	Contains Ordnance Survey data © Crown copyright and database right 2017	Produced by and Copyright to 6 Alpha Associates Ltd. Users noting any errors please notify 6 Alpha.	alpha ASSOCIATES
10210	2	CC	LG	02/11/2022			

Figure Three - Aerial Photography (2021)

Gravesham Borough Council



British National Grid

CASCADES LEISURE CENTRE, THONG LANE, GRAVESEND, DA12 4LG Aerial Photography (2021)



PROJECT NO.	FIGURE	DRAWN	CHECKED	DATE	Map data: Google	Produced by and Copyright to 6 Alpha Associates Ltd. Users noting any errors please notify 6 Alpha.	alpha ASSOCIATES
10210	3	CC	LG	02/11/2022			

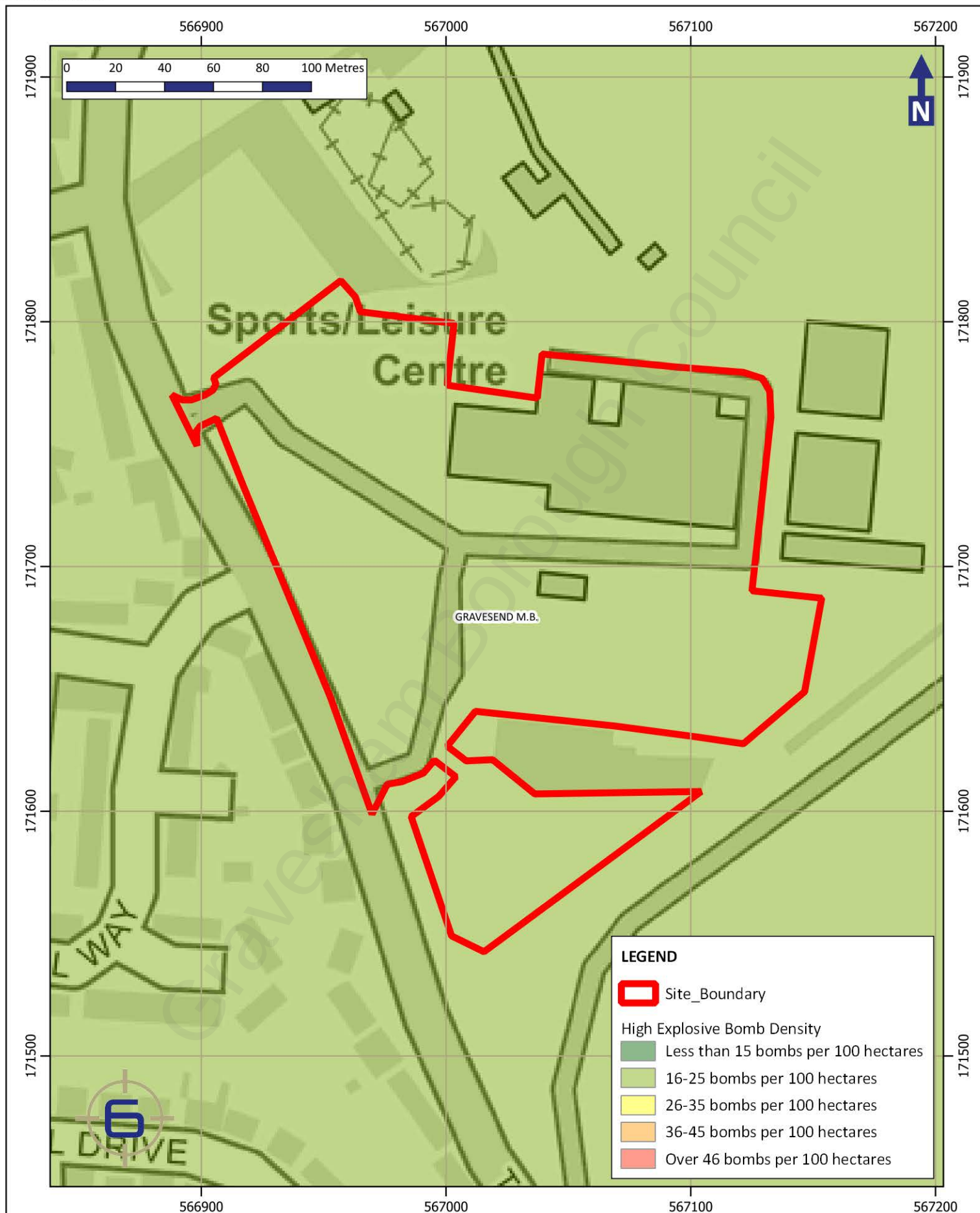
Figure Four - WWII High Explosive Bomb Density

Gravesham Borough Council



British National Grid

CASCADES LEISURE CENTRE, THONG LANE, GRAVESEND, DA12 4LG WWII High Explosive Bomb Density



PROJECT NO.	FIGURE	DRAWN	CHECKED	DATE
10210	4	CC	LG	02/11/2022

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Figure Five - WWII Luftwaffe Bombing Targets

Gravesham Borough Council



British National Grid

CASCADES LEISURE CENTRE, THONG LANE, GRAVESEND, DA12 4LG

WWII Luftwaffe Bombing Targets

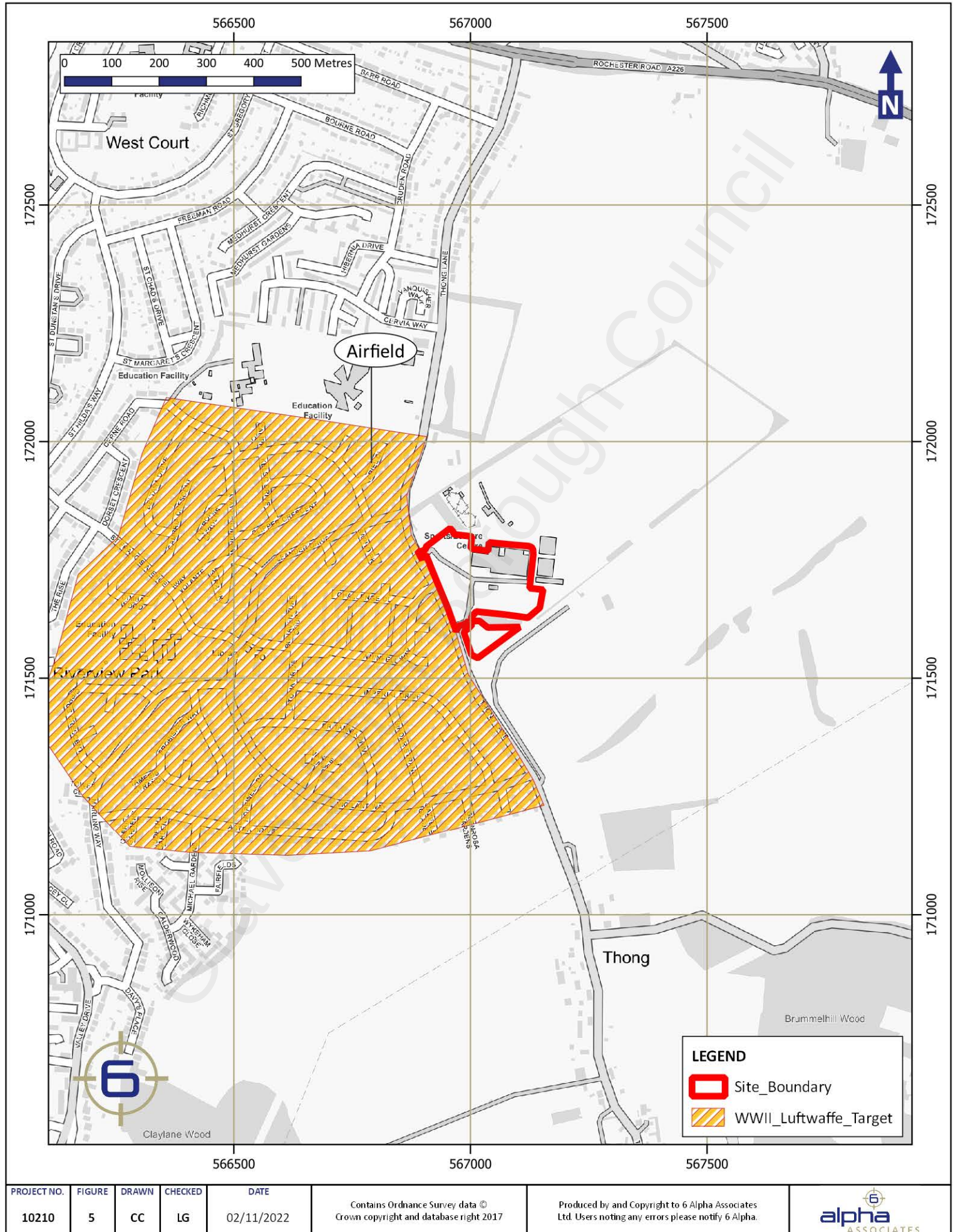


Figure Six - WWII High Explosive Bomb Strikes

Gravesham Borough Council



British National Grid

CASCADES LEISURE CENTRE, THONG LANE, GRAVESEND, DA12 4LG WWII Consolidated Bomb Strikes

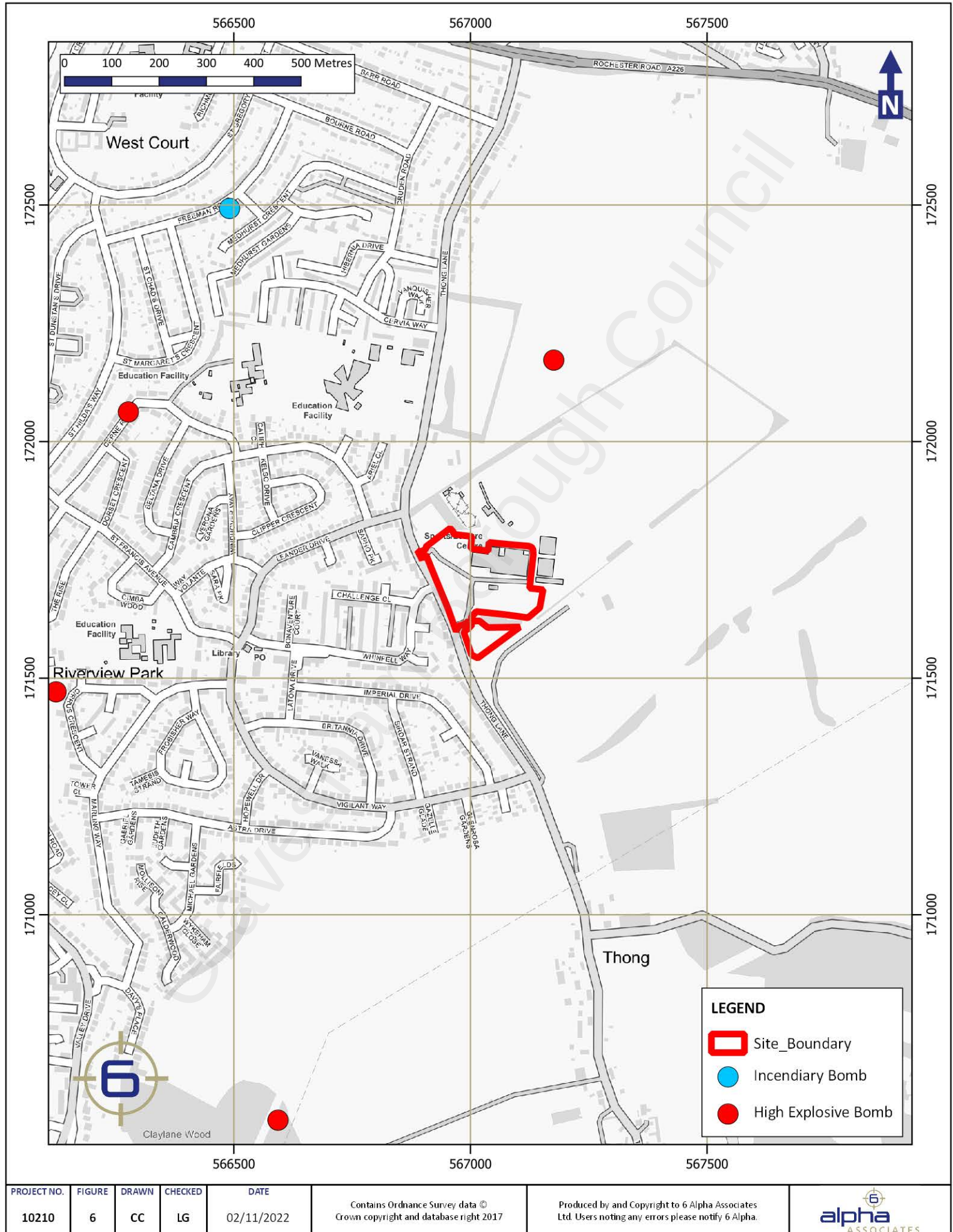


Figure Seven – Aerial Photography (1940)

Gravesham Borough Council



British National Grid

CASCADES LEISURE CENTRE, THONG LANE, GRAVESEND, DA12 4LG Aerial Photography (1945)

