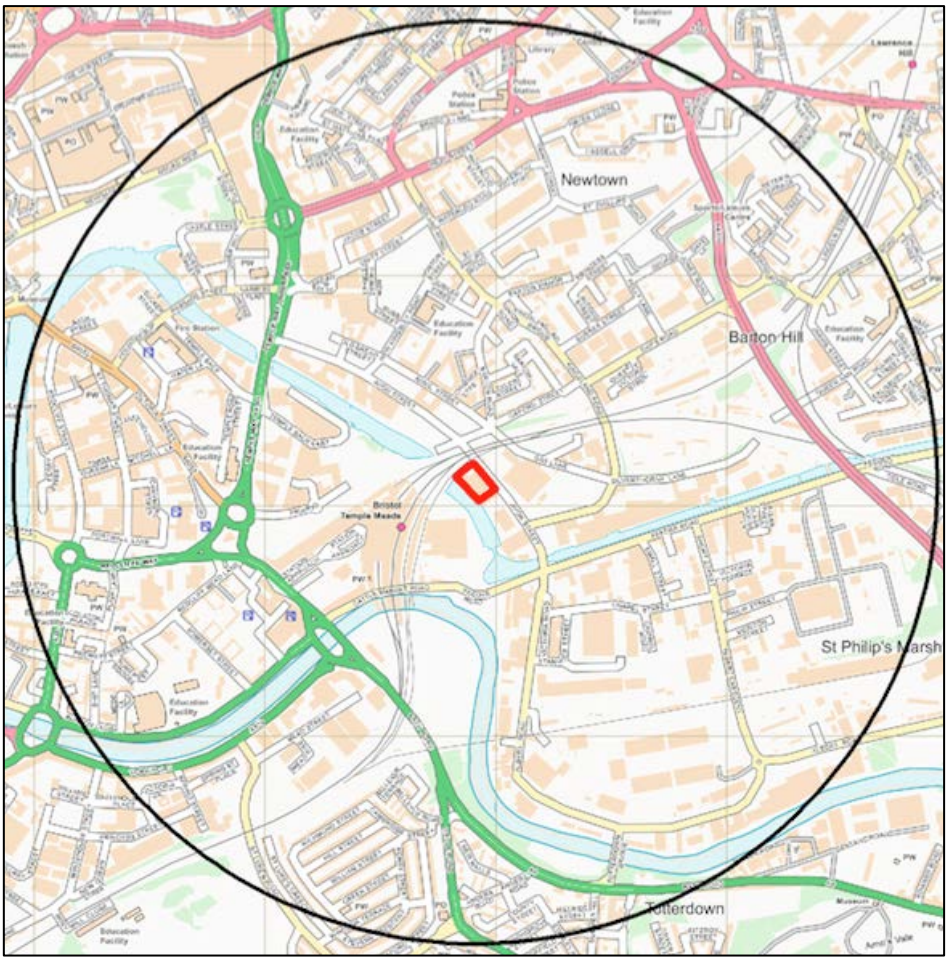
Detailed Unexploded Ordnance (UXO) Threat & Risk Assessment

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



PROJECT NUMBER	P6864	**ORIGINATOR**	L. Gregory
VERSION NUMBER	1.0	**REVIEWED BY**	B. Wilkinson (4th September 2018)
CLIENT	Delta Simons	**RELEASED BY**	R. Griffiths (7th September 2018)
SITE	Avon Street, Bristol, BS2		
RATING	**HIGH** - This Site requires further action to reduce risk to ALARP during intrusive activities.		

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Acronyms and Abbreviations

AA	Anti-Aircraft
AAA	Anti-Aircraft Ammunition
ALARP	As Low As Reasonably Practicable
AOD	Above Ordnance Datum
ARP	Air Raid Precaution
AXO	Abandoned Explosive Ordnance
BD	Bomb Disposal
BDO	Bomb Disposal Officer
bgl	Below Ground Level
BGS	British Geological Survey
BH	Borehole
BPD	Bomb Penetration Depth
CDP	Cast Driven Piles
CFA	Continuous Flight Auger
CIRIA	Construction Industry Research and Information Association
CPT	Cone Penetration Testing
CS	County Series
EO	Explosive Ordnance
EOC	Explosive Ordnance Clearance
EOD	Explosive Ordnance Disposal
GI	Ground Investigation
GIS	Geographic Information Systems
GL	Ground Level
GP	General Purpose
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
NEQ	Net Explosive Quantity
NFF	National Filling Factory
NGR	National Grid Reference
OD	Ordnance Datum
OS	Ordnance Survey
PM	Parachute Mine
PoW	Prisoner of War
RADAR	Radio Detection And Ranging
RAF	Royal Air Force
RN	Royal Navy
RNAS	Royal Naval Air Service
ROF	Royal Ordnance Factory
SAA	Small Arms Ammunition
TA	Territorial Army
TNT	Trinitrotoluene
UK	United Kingdom
UN	United Nations
USAAF	United States Army Air Force
UXB	Unexploded Bomb
UXO	Unexploded Ordnance
V Weapons	*Vergeltungswaffe* – Vengeance Weapons
WD	War Department
WWI	World War One
WWII	World War Two

EXECUTIVE SUMMARY

Study Site

The Client has defined the Study Site as "Avon Street, Bristol, BS2". The Site is located at NGR 359956, 172551.

Risk Level

HIGH

Potential Threat Sources

The most probable UXO threat is posed by WWII *German* HE bombs, 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 *Bristol County Borough,* which recorded 63 HE bomb strikes per 100 hectares, a very high level of bombing. However, given that the Site was situated adjacent to a number of primary bombing targets during WWII, the localised bombing density may in fact have been much greater.

Luftwaffe aerial reconnaissance photography associated with the Site identified a railway bridge (located 10m to the north-west), gas works (located 25m to the east), warehouses (located 30m to the south-west) and port installations (located 80m to the south) as primary bombing targets. In addition, railway lines and a railway station located in the vicinity may have been considered secondary bombing targets.

ARP records associated with the Site did not note any HE bomb strikes within it however, five were recorded; 20m to the north-east, 180m to the south-east, 185m to the south-west, 190m to the south-west and 200m to the north-east.

Official bomb damage mapping associated with the Site noted bomb damage to the buildings located on-site. Further analysis of post-war mapping and further research of historical records identified potential bomb damage to structures both in the immediate vicinity and in the wider area.

Pre-WWII mapping (1938) associated with the Site shows that it was located within a densely developed industrial area during WWII with the Site itself comprising of a large rectangular structure. As a result, it is plausible that industrial workers or local civilians associated with the Site may have noticed and recorded UXB entry holes following any raids.

The building previously occupying the Site was demolished in the late 1940's/early 1950's and replaced by another large structure across the majority of the Site which was built between 1955 and 1973. Consequently, it is considered likely that any UXO within the structural foundations of post-war buildings would have been discovered and removed, however, the potential for deep buried UXO to be present within remaining areas is assessed to be extant. Given that the immediate vicinity of the Site was subjected to bombing and bomb damage, 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 had potentially become contaminated with UXO.

EXECUTIVE SUMMARY (…continued)

Recommended Risk Mitigation

All Groundworks 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 confirmed 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 an UXO / UXB 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 an UXO / 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 UXO / 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 *Health & Safety Plan* for the Site and helps to evidence conformity with the principles laid down in the *CDM* regulations 2015 (this briefing can be delivered directly, or in some cases remotely, by *6 Alpha*).

Boreholing into Previously Undisturbed Ground:

3. 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 *assessed average bomb penetration depth* 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*).

For further information, please contact *6 Alpha Associates*:

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ASSESSMENT METHODOLOGY

Approach

6 Alpha Associates is an independent, specialist risk management consultancy practice, which has assessed the risk of encountering UXO (as well as buried bulk high explosives) at this Site, by employing a process advocated for this purpose by *CIRIA*. The *CIRIA* guide for managing UXO risks in the construction industry (C681) not only represents best practice but has also been endorsed by the *HSE*. Any risk mitigation solution is recommended *only* because it delivers the Client a risk reduced to ALARP at best value.

UXO hazards can be identified through the investigation of local and national archives associated with the Site, *MoD* archives, local historical sources, historical mapping as well as contemporaneous aerial photography (if it is available). Hazards will have only been recorded if there is specific information that could reasonably place them within the boundaries of the Site. The amalgamation of information is then assessed to enable the researcher to provide relevant and accurate risk mitigation practices.

The assessment of UXO risk is a measure of *probability of encounter* and *consequence of encounter*; the former being a function of the identified hazard and proposed development methodology; 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, at the moment of encounter.

If UXO risks are identified, the methods of mitigation we have recommended are considered reasonably and sufficiently robust to reduce them to ALARP. We advocate the adoption of the legal ALARP 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

Key source material is referenced within this document, whilst secondary/anecdotal information may be available upon request.

Although this report is up to date and accurate at the time of writing, our databases are continually being populated 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 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 – SITE LOCATION AND DESCRIPTION

Study Site

The Client has defined the Study Site as "Avon Street, Bristol, BS2". The Site is located at NGR 359956, 172551. The Site location and Site boundary are presented at *Figures 1* and *2* respectively.

Location Description

The Study Site is situated within *Bristol* and covers an area of 0.34 hectares (ha).

Furthermore, the Site is bounded by:

- North-east: *Avon Street;*
- North-west: Railway infrastructure*;*
- South-east: *Bristol Kawasaki* commercial business*;*
- South-west: Waters of the *Floating Harbour.*

Aerial Photography (2017) (*Figure 3*)

Aerial photography (2017) corroborates the information above and shows that the Site is situated within a developed urban-industrial area. The Study Site itself consists of a large regularly shaped structure surrounded by areas of hard standing.

Proposed Works

The Client has described the following proposed works:

- *"A single cable percussion borehole (6" diameter) to circa 15m-20m depth;*
- *Five to six shallow dynamic sampler boreholes (4" diameter) to circa 4m-5m depth."*

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 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.

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

STAGE ONE – SITE LOCATION AND DESCRIPTION (…continued)

Ground Conditions

BGS borehole log "ST57SE243 – Bristol Spine Road" (located 120m to the north-west), recorded the following strata:

Depth bgl (m)	Strata	Description
0m to 1m	Fill	MADE GROUND; Very dark grey sand sized angular to rounded gravel sized angular cobble sized fragments of sandstone, clinker and slag with a little silty clay matrix and occasional plastic.
1m to 1.9m	Fill	MADE GROUND: Firm brown silty clay with some sand sized and angular gravel sized fragments of sandstone coal, ash and slag.
1.9m to 2.4m	Clay	Very soft brown silty CLAY.
2.4m to 3.1m	Clay	Firm dark grey to grey silty CLAY with some decomposed plant material.
3.1m to 6.2m	Clay	Firm grey with occasional brown mottled silty CLAY with occasional shell fragments and decomposed plant remains.
6.2m to 7.4m	Sand	Very dense brown fine to medium grained clayey very silty SAND with occasional subangular to subrounded gravel of red brown sandstone.
7.4m to 8.5m	Sandstone	Red brown fine grained discoloured locally partly decomposed silty Sandstone, weak.

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

In general, there are several activities that might contaminate 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*. The most common type of UXO discovered today is the aerially delivered high explosive (HE) bomb, which are comparatively thick-skinned and dropped from enemy 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. More rarely, additional forms of *German* UXO are occasionally discovered including *inter alia V1* and *V2* rockets, Incendiary Bombs (IBs), and Anti-personnel (AP) bomblets.

Although the *Luftwaffe* had designated primary bombing targets across the *UK*, their high-altitude night bombing was not accurate. As a result, thousands of buildings were damaged and civilian fatalities were common. Bombs were also jettisoned over opportunistic targets and residential areas were sometimes struck.

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 best practice guide for dealing with your UXO risks on land (CIRIA publication C681) suggests that approximately 10 per cent of all munitions deployed failed to function as designed. ERW are therefore, still commonly encountered, especially whist 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;
- Poor precision during targeting (due to high altitude night bombing and/or poor visibility) resulted in bombs landing off target, but within the surrounding area.
- *British* decoy sites were also constructed to deliberately cause incorrect targeting. For obvious reasons, such sites were often built in remote and uninhabited areas.

Site History

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

Year	On-site	Vicinity
1884-1885 CS Map	The Study Site consisted of the *Panther Works* building.	The Site was situated within a developed urban-industrial area.
1903-1904 CS Map	The structure on-site was demolished and *Avonside Goods Warehouse No3* was constructed.	Changes were not recorded in the vicinity.
1918 CS Map	Changes were not recorded at the Study Site.	Changes were not recorded in the vicinity.
1938 OS Map	Changes were not recorded at the Study Site.	Changes were not recorded in the vicinity.
1951 OS Map	The structure previously located on-site was demolished.	A structure to the south-east was also demolished and railway infrastructure to the north was expanded.
1973-1976 OS Map	A large unnamed structure was built across the majority of the Site	An unnamed rectangular structure was also developed to the south-east.
1991 OS Map	Changes were not recorded at the Study Site.	Changes were not recorded in the vicinity.
2018 OS Map	Changes were not recorded at the Study Site.	Changes were not recorded in the vicinity.

WWII Bombing of *Bristol*

During WWII *Bristol* sustained 77 separate bombing raids with a total of 919 tons of bombs dropped over *Bristol* between 2nd November 1940 and 15th May 1941. The first *German* bombs landed on *Bristol* on 2nd November 1940 in the area of the old city. In the following months, *German* bombs killed 1,299 of the city's inhabitants, with an additional 1,303 seriously injured. The most intense periods of bombing, between 24th November 1940 and 11th April 1941, have become known as the *Bristol Blitz*. When the final bombs to be dropped on *Bristol* landed on 15th May 1941 many buildings, both residential and commercial, had been completely or partially destroyed. Public services had also sustained intensive targeting with gas, electricity and water supplies often cut-off following damage. Major landmarks such as *St James' Presbyterian Church of England* and four of *Bristol's* ancient churches were amongst the worst hit cultural sites.

During WWII the local authority ARP wardens compiled detailed records of bomb strikes across their respective districts. However, many industries compiled their own bomb strike records independently, which were not immediately released into the public domain. It is now estimated that 81,830 houses were destroyed with a further 3,000 were later demolished as a result of WWII bombing.

WWII Luftwaffe Bombing Targets (*Figure 4A & 4B*)

Prior to WWII, the *Luftwaffe* conducted numerous aerial photographic reconnaissance missions over *Britain*, recording key military, industrial and commercial facilities 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 Site identified a railway bridge (10m to the north-west), gas works (25m to the east), warehouses (30m to the south-west) and port installations (80m to the south) as primary bombing targets. In addition, railway lines (immediately north) and a railway station (200m to the west-south-west) may have been considered secondary bombing targets.

WWII HE Bomb Strikes (*Figure 5*)

During WWII, ARP wardens compiled detailed logs of bomb strikes across their respective districts. ARP records associated with the Site did not note any HE bomb strikes within it, nonetheless five were recorded; 20m to the north-east, 180m to the south-east, 185m to the south-west, 190m to the south-west and 200m to the north-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 therefore, their prospective presence cannot be either corroborated or discounted.

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. Despite this, there is no evidence to suggest that the Site (or its immediate vicinity) was subjected to rockets strikes during WWII.

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 (*Figure 6*)

Official bomb damage mapping associated with the Site noted bomb damage to the buildings located on-site. Further analysis of post-war mapping identified areas of potential bomb damage 15m to the north-east, 125m to the south, 125m to the north-west and 140m to the north-east. Further research of historical records also identified photographic evidence of bomb damage to *Temple Meads Station* approximately 200m to the west-south-west.

WWII HE Bomb Density (*Figure 7)*

The Study Site was located within *Bristol County Borough,* which recorded 63 HE bombs per 100 hectares, a very high level of bombing. However, given that the Site was situated adjacent to a number of primary bombing targets during WWII, the localised bombing density may in fact have been much greater.

Abandoned Bombs

An examination of the official abandoned bomb records did not identify any abandoned bombs within 1,000m of the Site.

Records of WWII UXB Disposal Tasks

Civil defence records did not identify any UXB disposal tasks within *Bristol County Borough* from 1940-45. However, it is known that these records are incomplete, some having been destroyed by enemy action during WWII.

Records of Post-WWII UXB Disposal Tasks

An examination of the post-WWII BDO tasks associated with the area has not identified any BDO operations within 1,000m of the Site.

WWII Site Use

The CS mapping prior to WWII (1938), shows that the Study Site was located in a developed urban-industrial area with the Site itself consisting of a large unnamed structure. As a result, it is possible that local civilians or employees based at the site would have noticed and reported UXB entry holes following any raids, which would have been dealt with at the time.

Sources of UXO Contamination

The most likely source of UXO contamination is from *German* aerially delivered ordnance, which ranges from small IBs through to large HE bombs (the latter forms the principal threat). Additional residual contamination may be present from *British* AAA projectiles (which were used to defend the UK against *German* bombing raids).

STAGE THREE – DATA ANALYSIS

Variable	Result	Comment
Was the area considered to be a primary bombing target?	✔	A railway bridge (10m north-west), gas works (25m east), warehouses (30m south-west) and port installations (80m south) were identified as primary bombing targets.
Was the Site or the immediate area bombed during WWII?	✔	Five HE bomb strikes were identified within 200m of the Site boundary, the closest being 20m to the north-east.
Did the Site or the immediate area experience bomb damage?	✔	Official bomb damage mapping showed bomb damage to the on-site an post-war mappoing showed potential bomb damage 15m to the north-east.
Was the ground undeveloped during WWII?	✘	The Site consisted of a large unnamed structure during WWII.
Would the footfall have been high in the area?	✔	Given that a large structure was located on-site during WWII, combined with the Site's location within a developed urban-industrial area, it is likely that footfall would have been high.
Would a UXB entry hole have been observed during WWII?	✔	It is possible that a local civilian or employee associated with the on-site structure may have noticed and reported UXB entry holes following any raids.
Have military personnel ever occupied the Site?	✘	No military facilities were identified within 1,000m.
Would munitions have been manufactured, stored and/or fired from the Site?	✘	There is no evidence to suggest munitions were located or fired from this Site.
Would previous intrusive works have removed the potential for UXO to be present?	✘	The Site has been subjected to significant redevelopment, therefore it is likely that any UXO within the structural foundations of post-war buildings would have been discovered and removed. However, the probability of UXO discovery within all previously undisturbed areas of the Site is extant.
Are proposed intrusive works likely to extend into previously undisturbed ground?	✔	Areas of the Site have not been subjected to significant redevelopment since WWII and therefore 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 the Site was subjected to bomb strikes, combined with the significant but not total redevelopment of the Site, it is considered possible for an unplanned encounter with UXO to occur.
Does the probability of UXO vary across the Site?	✔	The probability of discovering UXO within the structural foundations of post-war buildings is considered to be remote, however, the probability of UXO discovery within all previously undisturbed areas of the Site is extant.

STAGE FOUR – RISK ASSESSMENT

Threat Items

The most probable UXO threat items are *German* HE bombs, whilst IBs and *British* AAA projectiles pose a residual threat. The consequences of initiating *German* HE bombs are 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 within clay, sand and sandstone is assessed to be approximately 6m bgl, with the maximum BPD considered to be approximately 13m 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) 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 single ground investigative methodology has been described for analysis at this 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.

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. Risk Rating is determined by calculating the probability of encountering UXO and the consequences of initiating it.

UXO Risk Calculation Table – All Areas				
Activity	**Threat Item**	**Probability (SH+EM=P)**	**Consequence (D+PSR=C)**	**Risk Rating (PXC=RR)**
Cable Percussive Boreholes (15m to 20m 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
Shallow dynamic sampler Boreholes (4m to 5m 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
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 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 *Health & Safety Plan* for the Site and helps to evidence conformity with the principles laid down in the *CDM* regulations 2015 (this brief can be delivered directly, or in some cases remotely, by *6 Alpha*).	**ALARP**
Boreholing into Previously Undisturbed Ground	**3. 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 *assessed average bomb penetration depth* 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 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

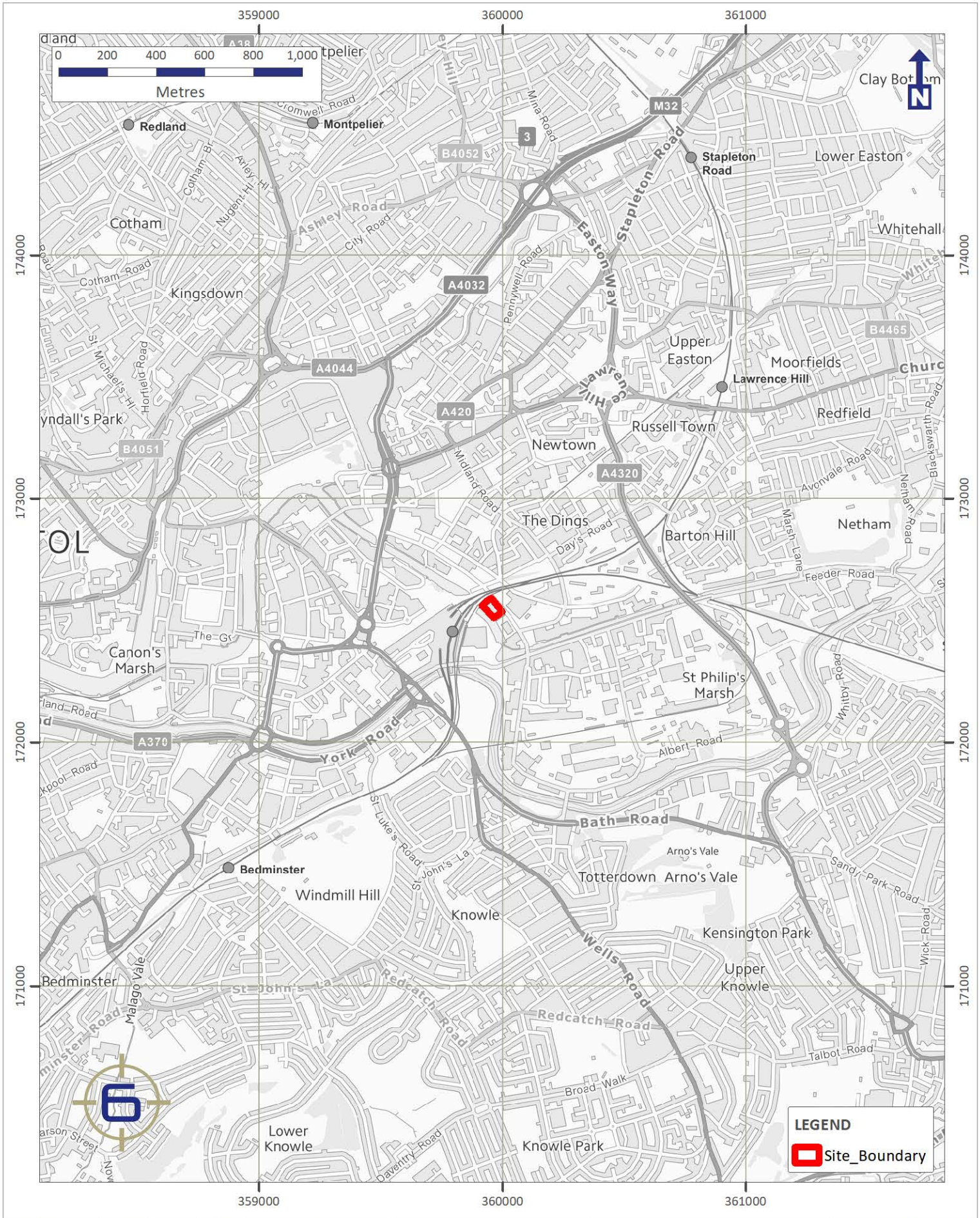
Figure One - Site Location

BRITISH NATIONAL GRID

AVON STREET, BRISTOL, BS2

Site Location

BOMB SEARCH
WWW.6ALPHA.COM



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P6864	1	LG	CC	29 August 2018	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

Figure Two - Site Boundary

BRITISH NATIONAL GRID

AVON STREET, BRISTOL, BS2

Site Boundary

BOMB SEARCH
WWW.6ALPHA.COM

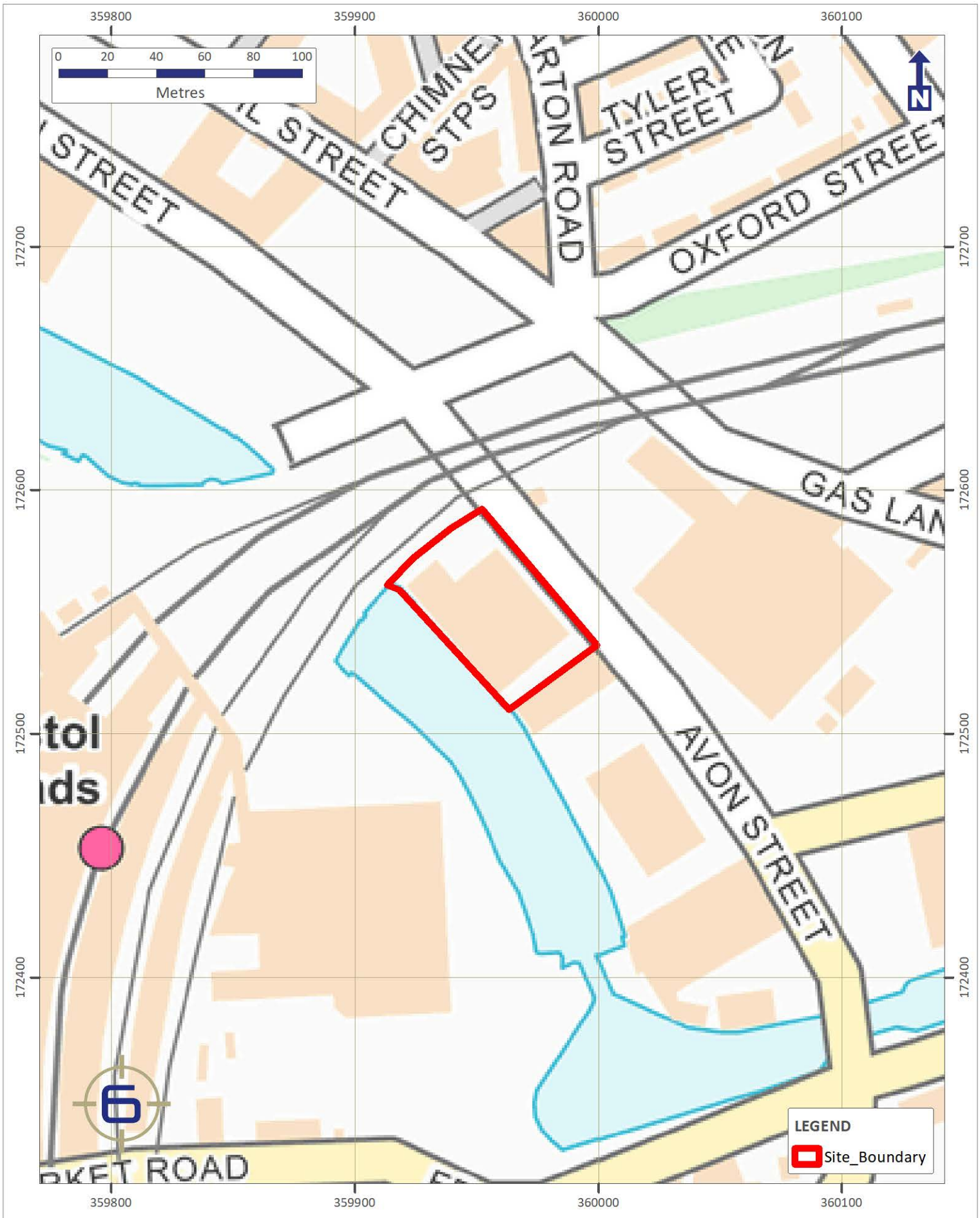

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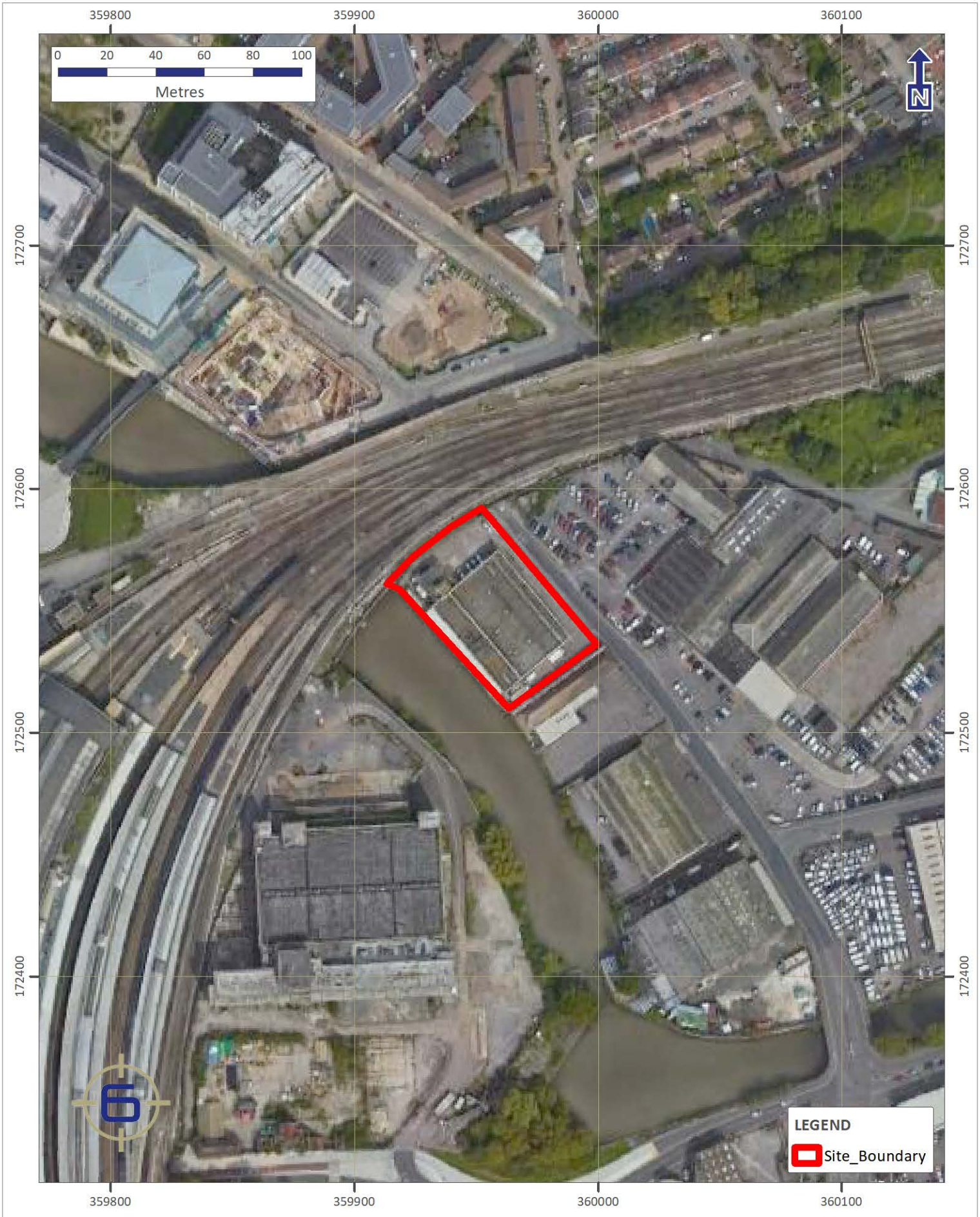
Figure Three - Aerial Photography (2017)

BRITISH NATIONAL GRID

AVON STREET, BRISTOL, BS2

Aerial Photography (2017)

BOMB SEARCH
WWW.6ALPHA.COM



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P6864	3	LG	CC	29 August 2018	Map data: Google	Produced by and Copyright to 6 Alpha Associates Ltd. Users noting any errors please notify 6 Alpha.

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Figure Four A - WWII Luftwaffe Bombing Targets

BRITISH NATIONAL GRID

AVON STREET, BRISTOL, BS2

WWII Luftwaffe Bombing Targets

BOMB SEARCH
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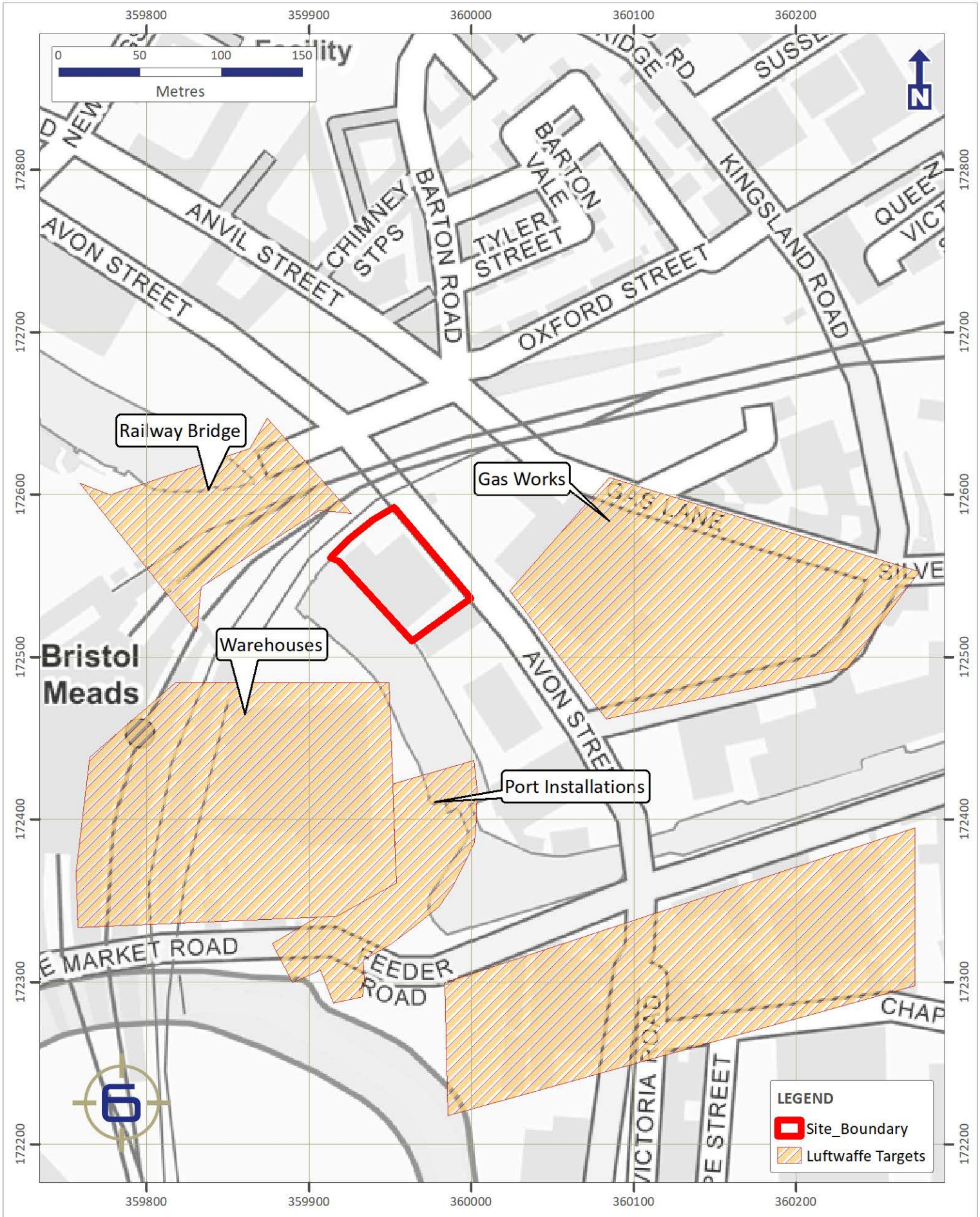

PROJECT NO.	FIGURE	DRAWN	CHECKED	DATE
P6864	4A	LG	CC	30 August 2018

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Figure Four B – WWII Luftwaffe Aerial Photography

BRITISH NATIONAL GRID

AVON STREET, BRISTOL, BS2

WWII Luftwaffe Aerial Photography

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P6864	4B	LG	CC	30 August 2018	Map data: NARA	Produced by and Copyright to 6 Alpha Associates Ltd. Users noting any errors please notify 6 Alpha.

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Figure Five - WWII High Explosive Bomb Strikes

BRITISH NATIONAL GRID

AVON STREET, BRISTOL, BS2

WWII High Explosive Bomb Strikes

BOMB SEARCH
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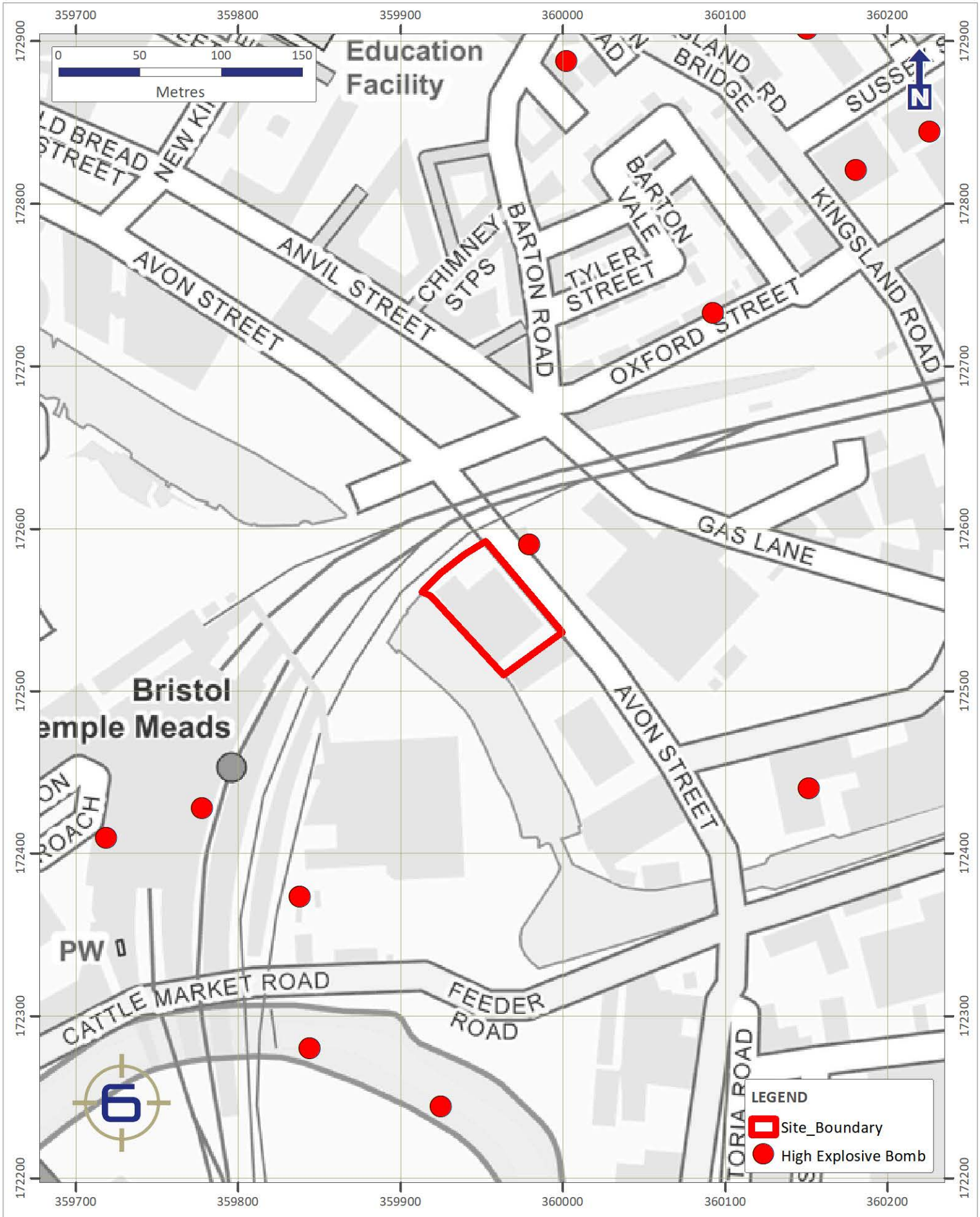

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Figure Six – Areas of Potential WWII Bomb Damage

BRITISH NATIONAL GRID

AVON STREET, BRISTOL, BS2

Areas of Potential WWII Bomb Damage

BOMB SEARCH
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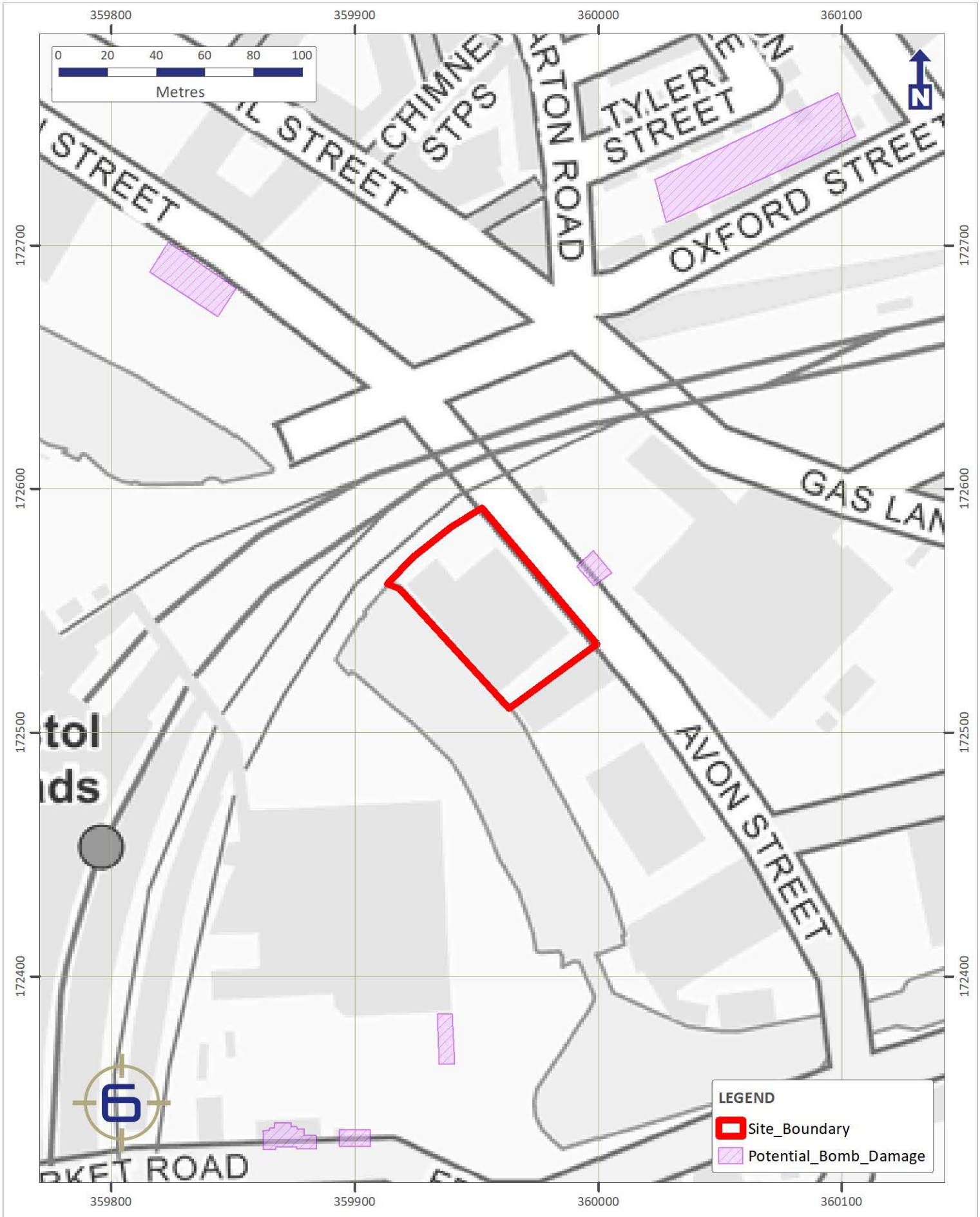

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Figure Seven - WWII High Explosive Bomb Density

BRITISH NATIONAL GRID

AVON STREET, BRISTOL, BS2

WWII High Explosive Bomb Density

BOMB SEARCH
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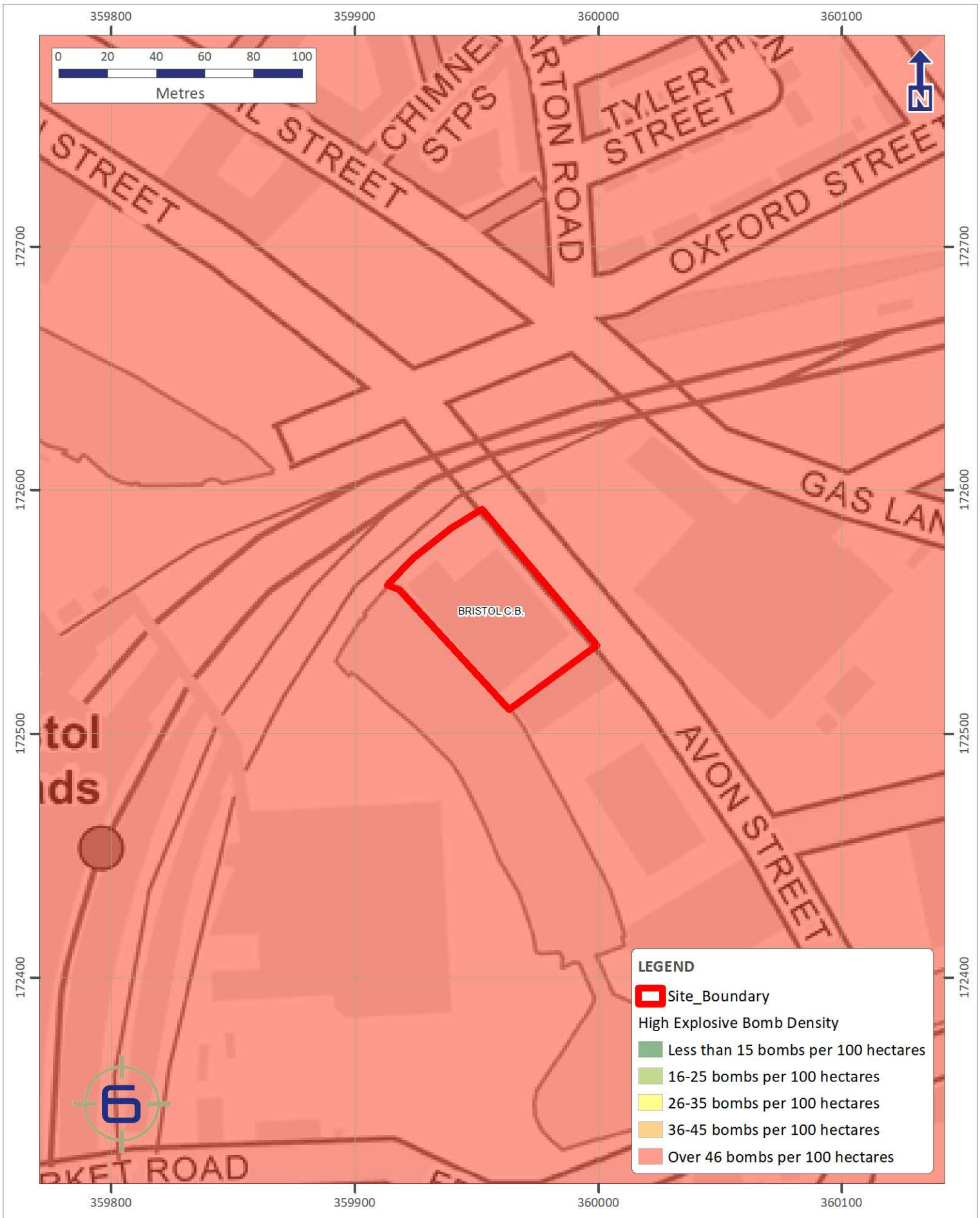

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