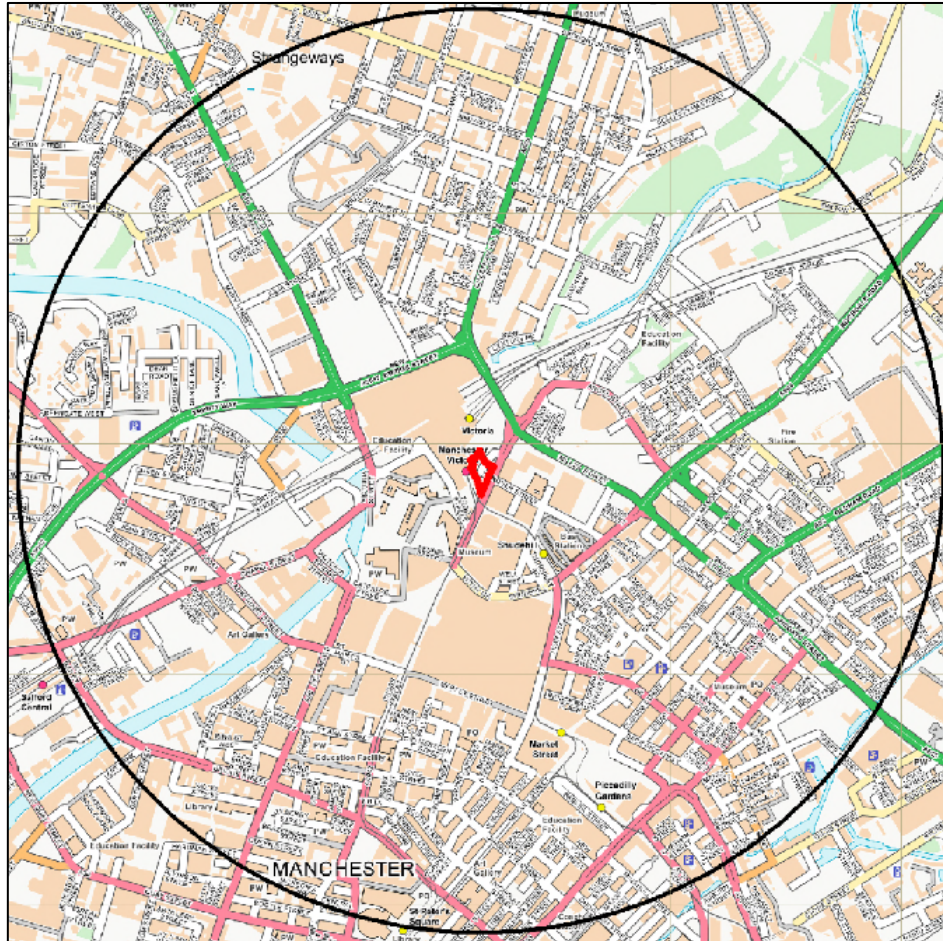


Detailed Unexploded Ordnance (UXO) Threat & Risk Assessment

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



PROJECT NUMBER	9720	ORIGINATOR	D. Barrett
PROJECT	New Victoria	REVIEWED BY	B. Wilkinson
CLIENT	Toriview Ltd	RELEASED BY	L. Gregory
VERSION	1.0	DATE	12 th May 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 “New Victoria, Next to Victoria Station, Manchester” and it is centred on NGR 384090, 398941.

Risk Level

HIGH

Potential Threat Sources

The most probable UXO threat is posed by WWII-era *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 *Manchester County Borough*, which recorded six HE bomb strikes per 100 hectares, a “very low” level of bombing.

Luftwaffe aerial reconnaissance photography associated with the Study Site identified *Victoria Station and Marshalling Yard* (on-site) as a primary bombing target.

ARP records associated with the Study Site identified one HE bomb strike and two Incendiary Bomb (IB) strikes within it. In addition, a further five HE bomb strikes were recorded in the vicinity of the Site; 230m to the north-west, 300m to the west-south-west, 335m to the south-west, 355m to the west-north-west, and 375m to the south-west. Further IB strikes were also documented 5m to the south-west, 25m to the south-west, 30m to the south-west and 35m to the south-west of the Site.

Manchester Corporation bomb damage mapping recorded “*Damaged Buildings*” on-site, 20m to the south-east, and 45m south-east of the Site. In addition, “*Demolished Buildings*” were also documented 85m to the south-west and 145m to the north-west. An analysis of post-war mapping also noted “*Ruins*” 75m to the south-west and 90m to the south-west, which further research indicates is indicative of significant bomb damage at *Manchester Grammar School*.

Pre-WWII mapping (1933) associated with the Study Site shows that it was located within a densely developed urban area during WWII, with the Study Site itself consisting of multiple structures and *Long Millgate*. Therefore, it is likely that footfall within the Site would have been relatively high and as a result, it is considered possible that a local civilian would have observed and reported any obvious UXB entry holes during WWII. However, given that significant bomb damage was documented on-site and nearby, it is plausible bomb damage debris may have masked a UXB entry hole within the Site—causing it to go unnoticed.

By 1986, the WWII-era structures had been demolished and cleared from the Site, with hardstanding car parks installed on-site by 2000. 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.

Given the Study Site was subjected to bombing, 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
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)
Piling	✓	✓	✗	✗	✗	✓	ALARP

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

For further information, please contact 6 Alpha Associates:

Website: <http://www.6alpha.com>

Telephone: +44 (0)2033 713 900

Email: enquiry@6alpha.com

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 “New Victoria, Next to Victoria Station, Manchester”. The Study Site is centred at NGR 384090, 398941 as presented at *Figures 1 and 2*, respectively.

Location Description

The Study Site is situated within the *City of Manchester* and totals an area of 0.21 hectares (ha).

Furthermore, the Study Site is bounded by:

- North: *Manchester Victoria Station* and temporary buildings;
- East: *Long Millgate* and *Corporation Street*;
- South: *Corporation Street* and hardstanding;
- West: *Manchester Victoria Station* and railway lines.

Aerial Photography (Current) (*Figure 3*)

Current aerial photography corroborates the information above and shows that the Study Site is situated within a densely developed urban area. The Study Site itself consists of hardstanding and temporary buildings.

Proposed Works

The Client has described the following:

“Extensive piling and substructure to the underneath of both buildings... piling depths of 15-20m...archaeological trenching.”

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.

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.

Borehole Log

BGS borehole log “SJ89NW59 – Manchester Corp.B.Sewer 59” (located 50m to the south-east), recorded the following strata:

Depth bgl (m)	Strata	Description
0.00m to 4.60m	Made Ground	Gravel + marl
4.60m to 12.20m	Sandstone	

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 “*Chester Formation - Sandstone*”.

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. *Official Bomb Damage maps*;
6. *Information gathered from the National Archives at Kew*;
7. *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 *Greater Manchester*

Manchester's importance to the *British* war economy as an inland port, industrial centre, and aircraft manufacturer, meant the city and surrounding area represented a significant bombing target for the *Luftwaffe*. The first air raids occurred during August 1940 and continued until 1942.

The *Luftwaffe* bombing campaign of *Manchester* peaked between the 22nd and the 24th December 1940 (the *Manchester*, or *Christmas, Blitz* as it was known) and involved over 400 aircraft delivering more than 460 tons of HE bombs and 37,000 IBs. Following this raid, approximately 65 warehouses, 200 business premises and 150 offices were destroyed or damaged with the *Manchester Cathedral*, the *Royal Exchange*, and the *Free Trade Hall* among the significant buildings damaged. An estimated 684 people were killed, and a further 2,364 people were injured.

WWII HE Bomb Density (*Figure 4*)

The Study Site was located within *Manchester County Borough*, which recorded six 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 *Victoria Station and Marshalling Yard* (on-site) as a primary bombing target. Additional bombing targets were identified in the vicinity of the Site with the *Henry Wallwork Iron Foundry and Machine Works* (335m to the north-east), *Victoria Station Gasworks* (525m to the north-east), *Oldham Road Station* (550m to the east-north-east), *Salford Station* (780m to the west-south-west), *Western Manchester Gasworks* (855m to the west-south-west) and *Central Station* (955m to the south-west) all documented as primary bombing targets.

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 one HE bomb strike and two incendiary bomb strikes within it. In addition, a further five HE bomb strikes were recorded in the vicinity of the Site; 230m to the north-west, 300m to the west-south-west, 335m to the south-west, 355m to the west-north-west, and 375m to the south-west. Further IB strikes were also documented 5m to the south-west, 25m to the south-west, 30m to the south-west and 35m to the south-west of the Site.

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 Study 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 7)

Manchester Corporation bomb damage mapping recorded “*Damaged Buildings*” on-site, 20m to the south-east, and 45m south-east of the Site. In addition, “*Demolished Buildings*” were also documented 85m to the south-west and 145m to the north-west.

An analysis of post-war mapping also noted “*Ruins*” 75m to the south-west and 90m to the south-west, which further research indicates is indicative of significant bomb damage at *Manchester Grammar School*.

Abandoned Bombs

An examination of the official abandoned bomb records has not identified 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 *Manchester County Borough* from 1940-45 within 1,000m. However, it is known that these records are incomplete, some having been destroyed by *Luftwaffe* action during WWII.

Military Activity

There is no evidence to suggest that the Study Site has previously been occupied by military personnel. Therefore, it is considered unlikely that munitions were previously stored, located and/or fired from this Study Site during WWII.

WWII Site Use

The CS mapping prior to WWII (1933) shows that the Study Site was located within a densely developed urban area during WWII, with the Study Site itself consisting of multiple structures and *Long Millgate*. Therefore, it is likely that footfall within the Site would have been relatively high and as a result, it is considered possible that a local civilian would have observed and reported any obvious UXB entry holes during WWII. However, given that significant bomb damage was documented on-site and nearby, it is plausible bomb damage debris may have masked a UXB entry hole within the Site—causing it to go unnoticed.

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, however the following tasks were undertaken in the area:

- The removal of one unexploded tank cartridge, found during construction activities at *New Quay Street* (located 1,230m to the south-west) on the 24th October 2018.

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). 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
1895 CS Map	The Study Site was located in a densely developed docklands area. The Study Site consisted of several structures and <i>Long Millgate</i> .
1923 CS Map	<i>Manchester Victoria Station</i> was built over the northern sector of the Study Site.
1933 CS Map	Changes were not recorded at the Study Site.
1951 OS Map	Changes were not recorded at the Study Site.
1963 OS Map	Changes were not recorded at the Study Site.
1972 OS Map	Changes were not recorded at the Study Site.
1986 OS Map	All structures on-site had been demolished.
1994 OS Map	Changes were not recorded at the Study Site.
2000 Aerial Photography	Hardstanding car parks were visible across the Study Site.
2009 Aerial Photography	Changes were not recorded at the Study Site.
2016 OS Map	Changes were not recorded at the Study Site.
2021 OS Map	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?	✓	Seven primary bombing targets were identified within 955m, the closest being <i>Victoria Station and Marshalling Yard</i> (on-site).
Was the Study Site or the immediate area bombed during WWII?	✓	ARP records identified one HE bomb strike and two IBs within the Site.
Did the Study Site or the immediate area experience bomb damage?	✓	Official bomb damage mapping recorded “ <i>Damaged Buildings</i> ” on-site.
Would munitions have been manufactured, stored and/or fired from the Study Site previously?	✗	There is no evidence to suggest munitions were located or fired from this Study Site.
Was the ground undeveloped during WWII?	✗	The Study Site consisted of numerous structures during WWII.
Would the footfall have been high in the area?	✓	Given the level of development on-site and in the immediate vicinity, it is likely that footfall would have been high.
Would a UXB entry hole have been observed during WWII?	✗	Given that bomb damage was recorded on-site, it is possible that bomb damage debris may have concealed a UXB entry hole and therefore it may have gone unnoticed.
Has UXO been encountered previously at the Study Site?	✗	There have been no documented UXO encounters within 1,000m.
Have previous intrusive works removed the potential for UXO to be present?	✗	The Study Site has been subjected to varying levels of redevelopment; therefore, 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 the Study Site was subject to bomb strikes, 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, whilst IBs and *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 within sandstone is assessed to be approximately 5m bgl, with the maximum BPD considered to be approximately 10m 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 (Px C=R)
Excavations	HE Bombs	2+2=4	3+3=6	4x6=24
	AAA Projectiles	1+2=3	3+1=4	3x4=12
	IBs	2+2=4	3+1=4	4x4=16
Trenching	HE Bombs	2+2=4	3+3=6	4x6=24
	AAA Projectiles	1+2=3	3+1=4	3x4=12
	IBs	2+2=4	3+1=4	4x4=16
Piling (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	2+3=5	3+1=4	5x4=20

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 Study Site.

Intrusive Methods of Mitigation – Intrusive magnetometry may be effective on this Study Site, prior to 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
Excavations and Trenching into Previously Undisturbed Ground	3. EOD Engineer in the Watching Brief Role; Where “open” intrusive works into previously undisturbed ground are proposed, 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

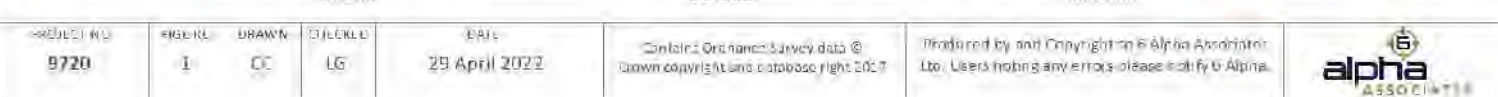


Figure Two - Study Site Boundary

Site Boundary

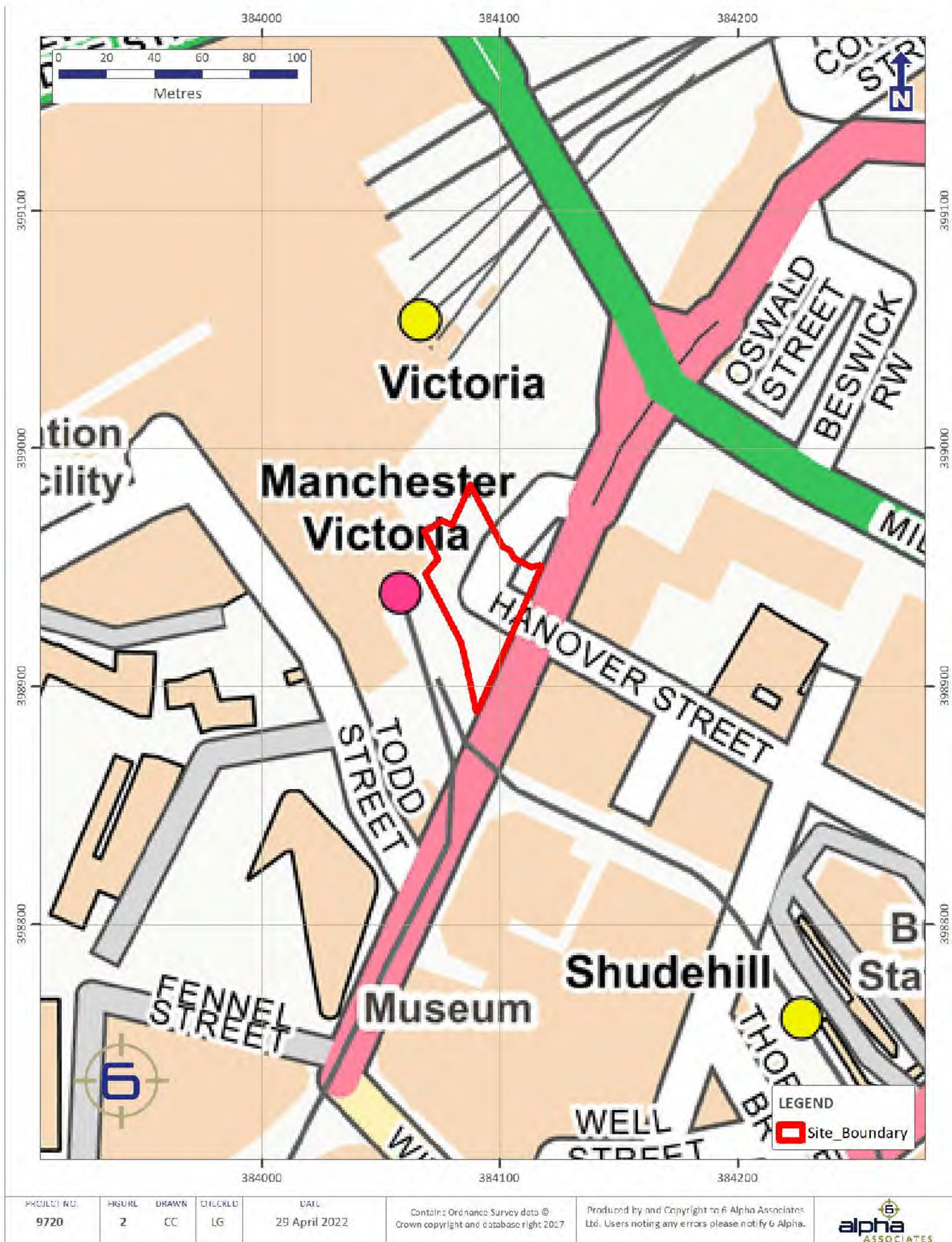
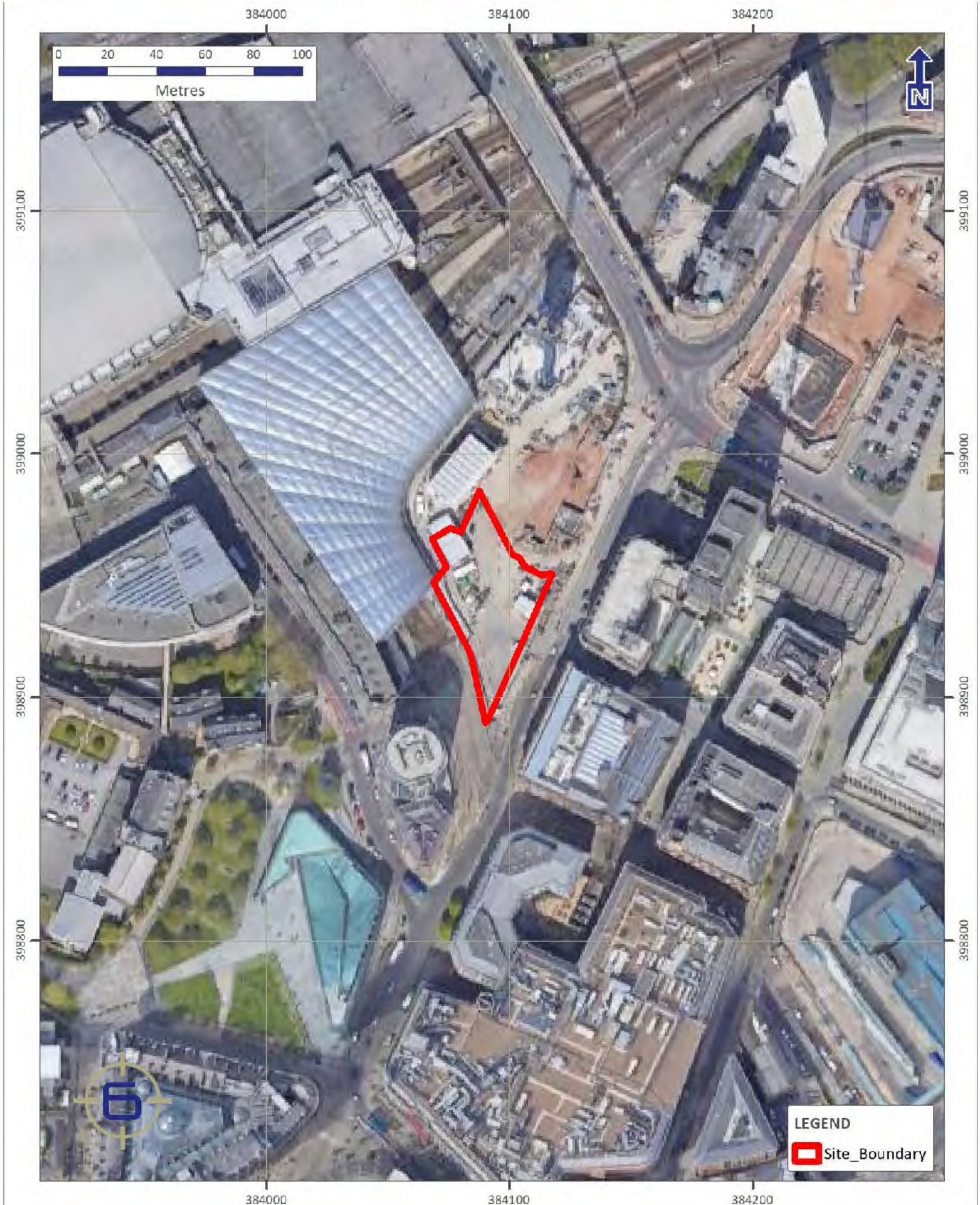


Figure Three - Aerial Photography (Current)

Aerial Photography (Current)



LEGEND
 Site_Boundary

Figure Four - WWII High Explosive Bomb Density

WWII High Explosive Bomb Density



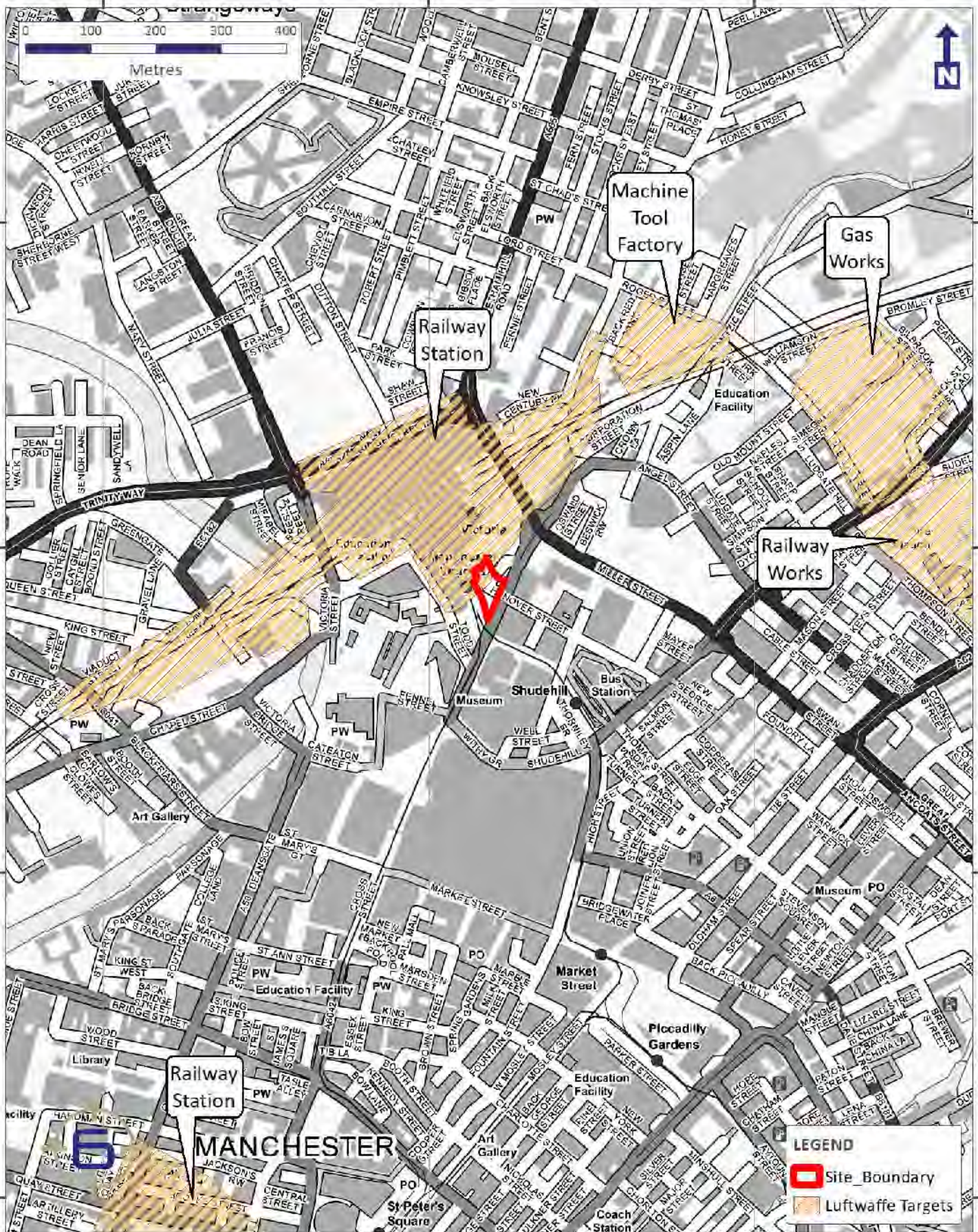
Figure Five - WWII *Luftwaffe* Bombing Targets

WWII Luftwaffe Bombing Targets

383500

384000

384500



LEGEND

- Site Boundary
- Luftwaffe Targets

Figure Six - Consolidated Bomb Strikes

WWII Consolidated Bomb Strikes

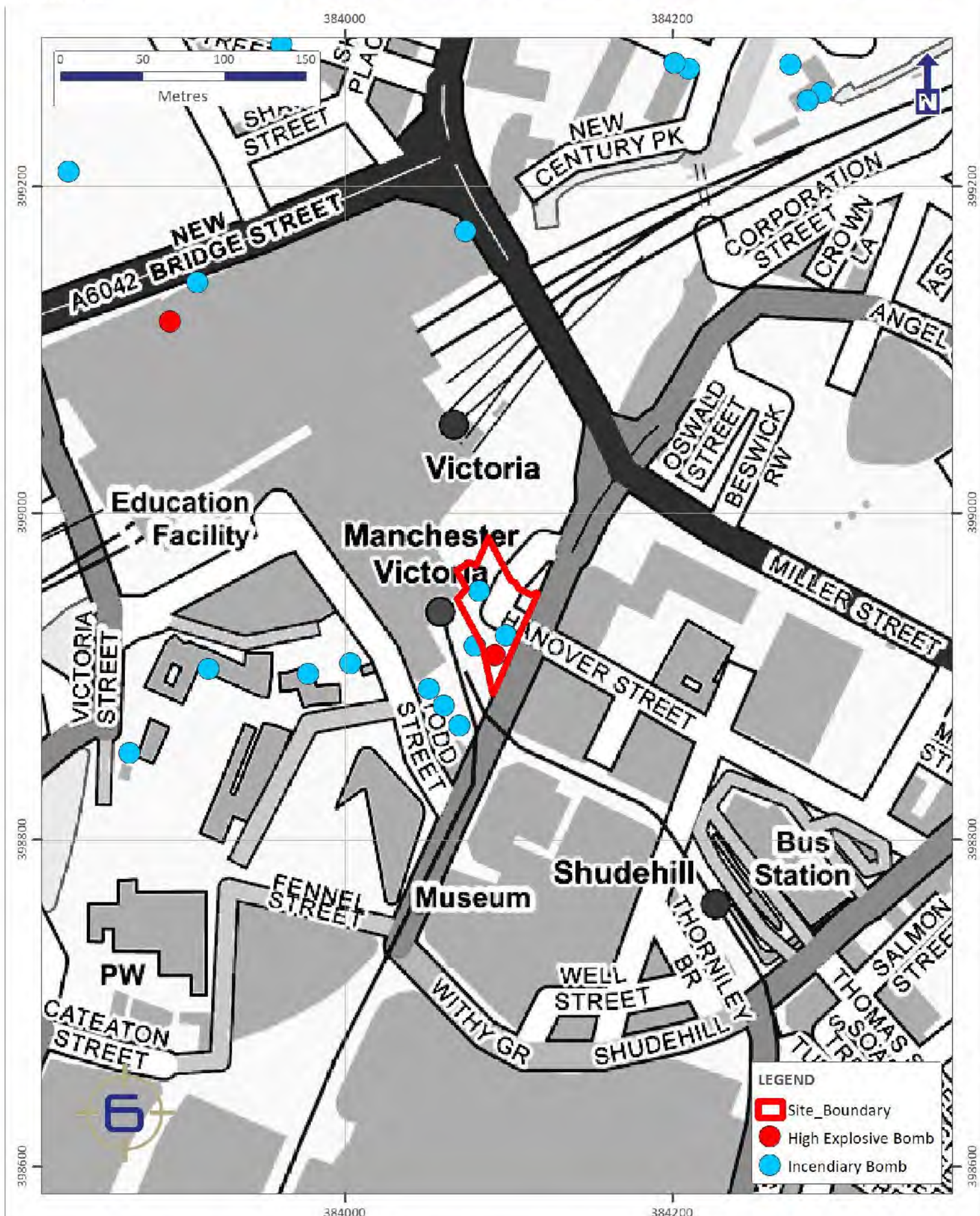


Figure Seven – Potential WWII Bomb Damage

Potential WWII Bomb Damage

