Providing Ground Solutions

Daniel Watney LLP

Kenley Campus, Caterham, Surrey

Desk Study, Geotechnical and Geoenvironmental Interpretative Report

February, 2023

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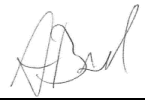
Author	Andrew Bond, Engineer *PhD MSc BSc (Hons) FGS AFHEA*		
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EXECUTIVE SUMMARY

Card Geotechnics Limited (CGL) has been commissioned by Daniel Watney LLP to complete a Desk Study, Geotechnical and Geoenvironmental Interpretative Report for Kenley Campus, Caterham, Surrey.

The site is former Ministry of Defence land which currently comprises areas of mature vegetation (east and west), a football pitch (south) and an area covered by hardstanding and occupied by a dilapidated Grade II Listed building (north). The site surrounds a school, which is not included within the site boundary, and is bound to the north by RAF Kenley, to the west by a housing estate, to the south by Salmons Lane, and to the east by a small woodland. The proposed development is understood to comprise a residential scheme with private gardens and areas of soft landscaping.

Historically, the site was occupied by a field (until c.1917) and was later developed into RAF Kenley Airfield Base (c.1917). The buildings on site were demolished from c. 1992 with the exception of the structure in the north of the site. As a result of the previous site use there is an elevated risk of unexploded ordnance across the site. From available inhouse LIDAR data, potential ground dissolution features associated with the chalk have been recorded in the vicinity of the site.

The ground conditions encountered during the ground investigation comprised Concrete (0.1m thick), Made Ground (0.1m to 1.2m thick) and/or Topsoil (0.3m to 0.4m thick) overlying the Clay-with-Flints Formation (2.70m to 4.80m thick) and the White Chalk Subgroup (minimum 11.45m thick, base not proven). No groundwater strikes, free product or putrescible material were recorded during the ground investigation, however, perched water was recorded during monitoring within positions WS1 and WS5 at depths ranging between 1.45mbgl (metre below ground level) and 4.88mbgl.

Based on testing and comparison of data against human health generic assessment criteria for a residential use with homegrown produce, there is a moderate / low risk from contamination in soils to future site occupants. It is, therefore, recommended that either i) where Made Ground remains at formation level in areas of soft landscaping, it is stripped back to the natural soils or ii) a capping layer is installed in areas of soft landscaping where Made Ground is to remain at formation level. The risk to construction workers is low assuming that potential risks are mitigated with appropriate site practices including good hygiene, dust control and personal protective equipment (PPE). The risk to off-site users is considered to be low assuming appropriate site practices as above. Elevated concentrations of contaminants were not recorded in the perched water based on the testing undertaken. Furthermore, no viable pathway to surface water receptors was identified in light of the nearest surface water body being >8km away as well as the low permeability of the Clay-with-Flints Formation. Therefore, no

groundwater remediation is proposed. The risk to vegetation and plants is considered to be very low due to low concentrations of phytotoxic elements within the soils and Made Ground on site. Signs of vegetative distress were also not observed on site. The risk to buried water supply pipes is considered to be moderate / low due to high pH levels and organics within the Made Ground and shallow superficial soils in the north of the site. Barrier water supply pipes may be required where Made Ground exists, subject to agreement with the local water company.

Based on three rounds of ground gas monitoring, an assessment of the ground gas potential of shallow soils and the conceptual site model, a precautionary gas Characteristic Situation 1 (CS1) is recommended for the site and subsequently no gas protection measures are required within new structures nor is further monitoring recommended.

In light of contamination already identified within the Made Ground a contamination watching brief and discovery strategy are recommended as part of construction works. Made Ground on site is classified as both hazardous and non-hazardous and may be disposed of at either a hazardous waste facility or inert waste facility subject to waste acceptance criteria testing and classification. A detailed remediation strategy will be required for the site in light of the recorded contamination.

Shallow soils should be designed to account for the presence of potentially desiccated and medium volume change potential soils. However, should shallow foundations prove to be inappropriate for the site, preliminary pile safe working loads have also been provided within the report based on the ground conditions encountered. Where ground bearing floor slabs are adopted, they should be constructed above a void former/compressible layer to account for heave/shrink of the cohesive Clay-with-Flints deposits. A design California Bearing Ratio (CBR) value of <2.5% is recommended for pavement design. Design classes for concrete in each stratum encountered have been provided.

In light of the potential high ground dissolution risk, it is recommended that a geophysical survey is undertaken to evaluate dissolution of the White Chalk Subgroup directly beneath the site.

1. INTRODUCTION

Card Geotechnics Limited (CGL) has been commissioned by Daniel Watney LLP to provide a combined desk study, geoenvironmental and geotechnical report for Kenley Campus, Caterham, Surrey, CR3 5FX herein referred to as "the site". The site comprises a disused Ministry of Defence (MOD) site surrounding an active school. However, the school is not part of the development boundary.

The aim of this report is to evaluate potential human health, environmental and geotechnical risks and constraints associated with the development of the site for a residential use including private gardens; this report may be used to support a planning application for the site.

This report presents the following:

- A review of published and unpublished records, to provide information on the historical, environmental, geological, hydrogeology and hydrological setting of the site and undertake a preliminary risk assessment;
- Details on the ground conditions encountered during the ground investigation and analysis and interpretation of chemical and geotechnical laboratory testing undertaken on representative soil/groundwater samples;
- A Conceptual Site Model based on the findings of the desk study, ground investigation and laboratory testing;
- A generic quantitative risk assessment to assess potential risks to human health, controlled waters, buildings, structures, plants and vegetation and preliminary recommendations with respect to waste disposal; and,
- Recommendations for geotechnical design aspects of the proposed development, including foundations, road/pavements, excavations, groundwater control, drainage and buried concrete.

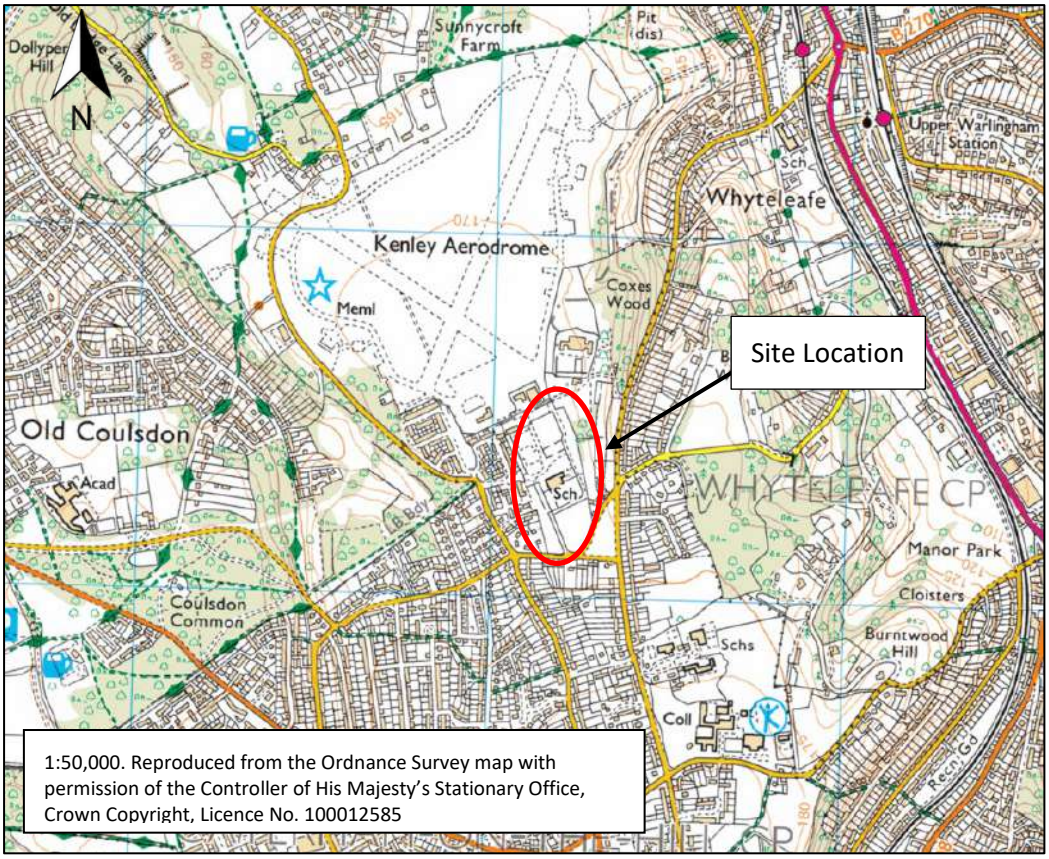
It should be noted that this report makes interpretations based on points over a wide area and that the report is subject to the inherent limitations of intrusive investigation.

2. SITE LOCATION AND DESCRIPTION

2.1 Site Location

The site is located to the north of Salmons Lane and to the east of Caterham Close and Kenley Close, Caterham, Surrey, CR3 5FX (*Plate 1*). National Grid coordinates for the approximate centre of the site are 533186E 157278N. The site is approximately 5 hectares in area.

Plate 1: Site Location Plan

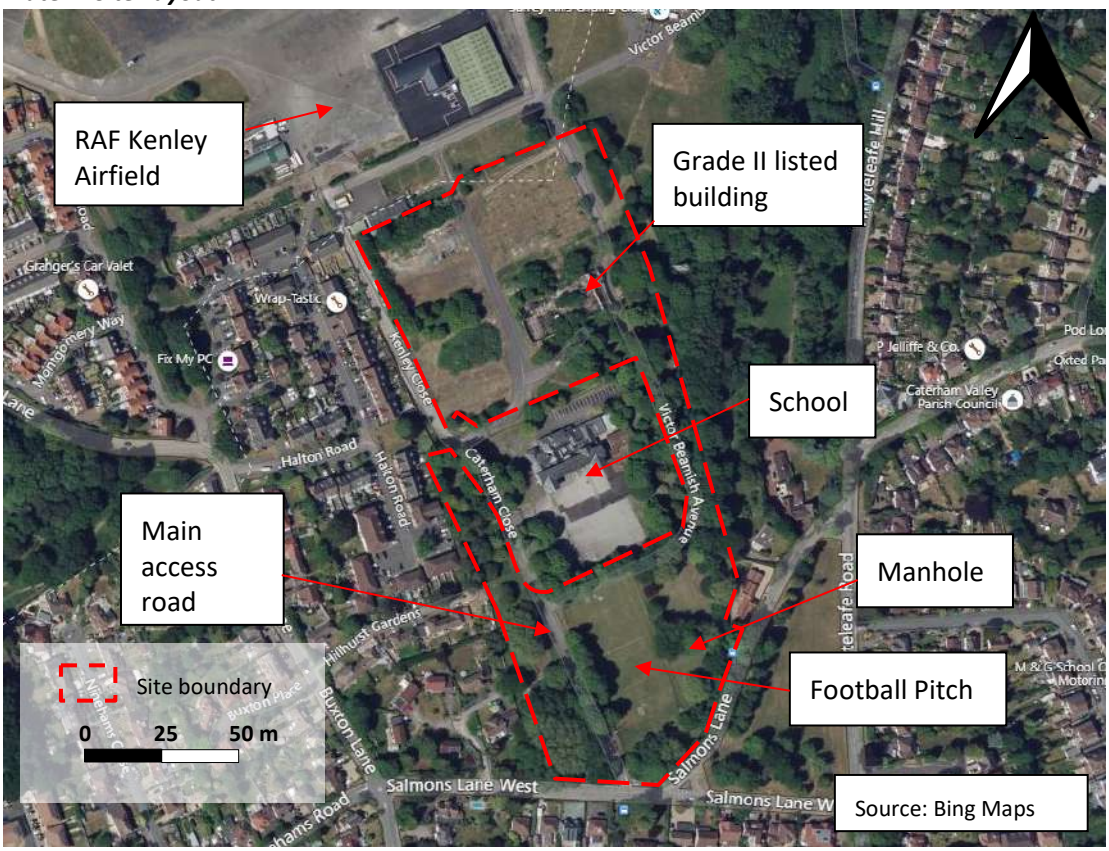


2.2 Site Description and Walkover

The site is located to the north of Caterham-On-The-Hill, directly south of RAF Kenley Airfield (*Plate 2*). The Halton Road housing estate is to the west of the site and a large wooded area is situated to the east. The site is roughly rectangular in shape and comprises a disused Ministry of Defence (MOD) site which was formerly part of RAF Kenley Airfield Base. The northern portion of the site comprises areas of hardstanding/former building floor slabs and a dilapidated, Grade II listed building (*Plate 2*). Kenley Close transects the northern area of the site in a north-south direction. A school is located in the central area of the site (*Plate 2*), with areas of mature vegetation in the east and west, although, the school is not included in the proposed development plans and is not within the site boundary. The southern portion of the site comprises a football pitch, which is associated with the off-site school, with

surrounding areas of soft landscaping. Caterham Close transects the southwestern area of the site in a north south direction (providing access to the school) (*Plate 2*). It is understood that Tree Preservation Orders are present on all the trees across the site.

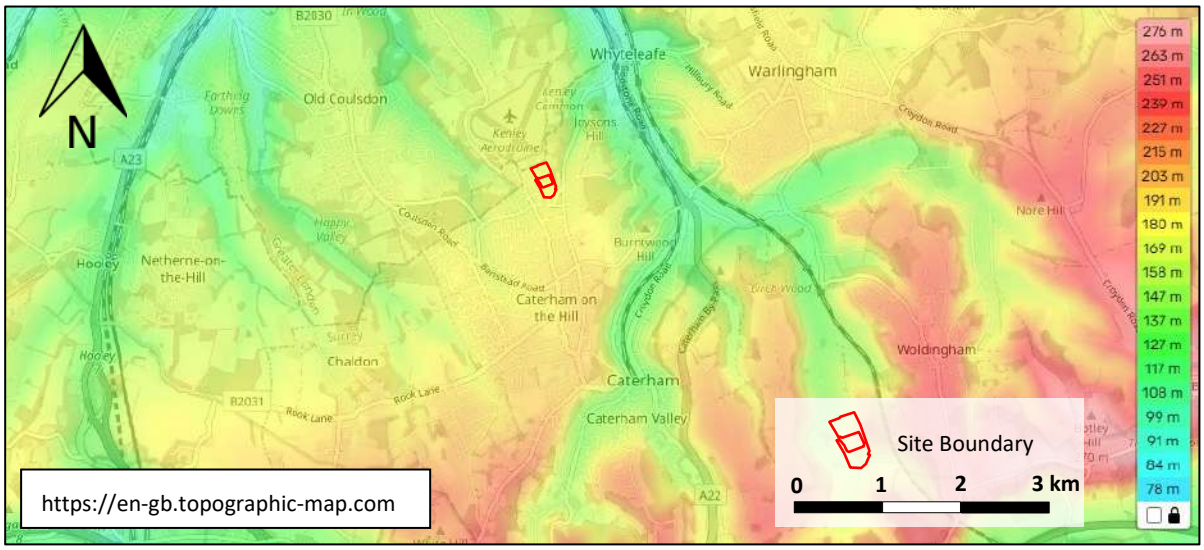
Plate 2: Site Layout



A site walkover was undertaken prior to the ground investigation on 5 December 2022. The site walkover noted the following key features:

- A large bolted manhole is located in the southeast of the site which has subsequently been revealed as being associated with a deep soakaway (*Plate 2*).
- Despite the site comprising dense areas of mature vegetation the site is broadly accessible through a single track road which runs around the outside of the site from the northeast to the southeast.
- The site is relatively level and very gently slopes towards the north of the site (~172mOD in the north to ~174mOD in the south).
- A second world war electrical substation is located in the south of the site.

Plate 3: Topography surrounding the site (topographic scale in m OD).



With reference to publicly available topographic data[1], the ground surrounding the site is relatively level and at an elevation of ~180 m OD (metres Ordnance Datum refer to *Plate 3*).

2.3 Proposed Development

The development will comprise the demolition of the Grade II listed structure in the north of the site[2]. The site will be developed for residential use, most likely in the form of a housing estate with private gardens and soft landscaping[3]. The current development plans for the site are included as Appendix A.

[1] https://en-gb.topographic-map.com, [Accessed January 2023]
[2] Email correspondence between CGL and Charlotte Yarker of Daniel Watney LLP on 5 December 2022
[3] Email correspondence between CGL and Charlotte Yarker of Daniel Watney LLP on 1 September 2022

3. DESK STUDY

3.1 Sources of Information

The historical development of the site has been traced from Ordnance Survey maps dating between 1867-1869 and 2022. These maps were produced on scales ranging from 1:2,500 to 1:10,560 and are presented in Appendix B.

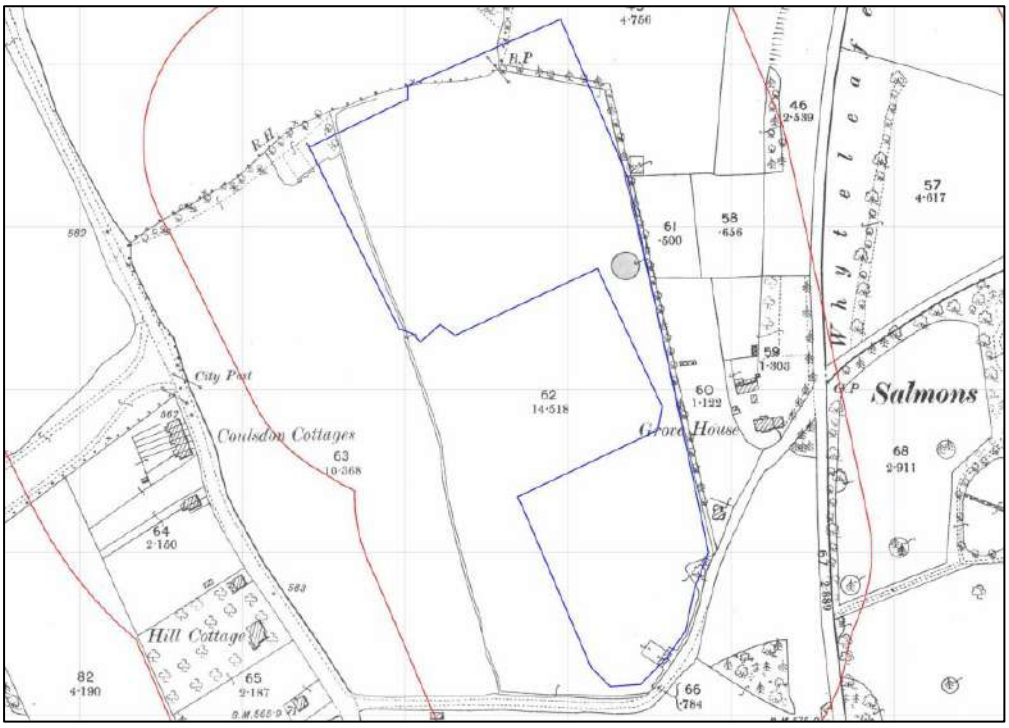
3.2 Site History

Details of the site history and surrounding area are summarised below with approximate distances taken from the nearest boundary of the site.

With reference to the earliest Ordnance Survey map dated 1867-1869, the site was occupied by a field. From c. 1870 the site remained a field, however small developments were constructed in the vicinity of the site in the form of *Grove House* (50m east) and *Hill Cottage* (150m west). *Whiteleaf Road* was also constructed between 75m and 150m east of the site.

From c. 1897 an unmarked circular structure was present in the north of the site and another unmarked structure was present in the south of the site. *Coulsdon cottages* were also constructed 140m west of the site. The site and the surrounding area as it would have appeared in 1897 is shown in an extract of an historical map in Plate 4.

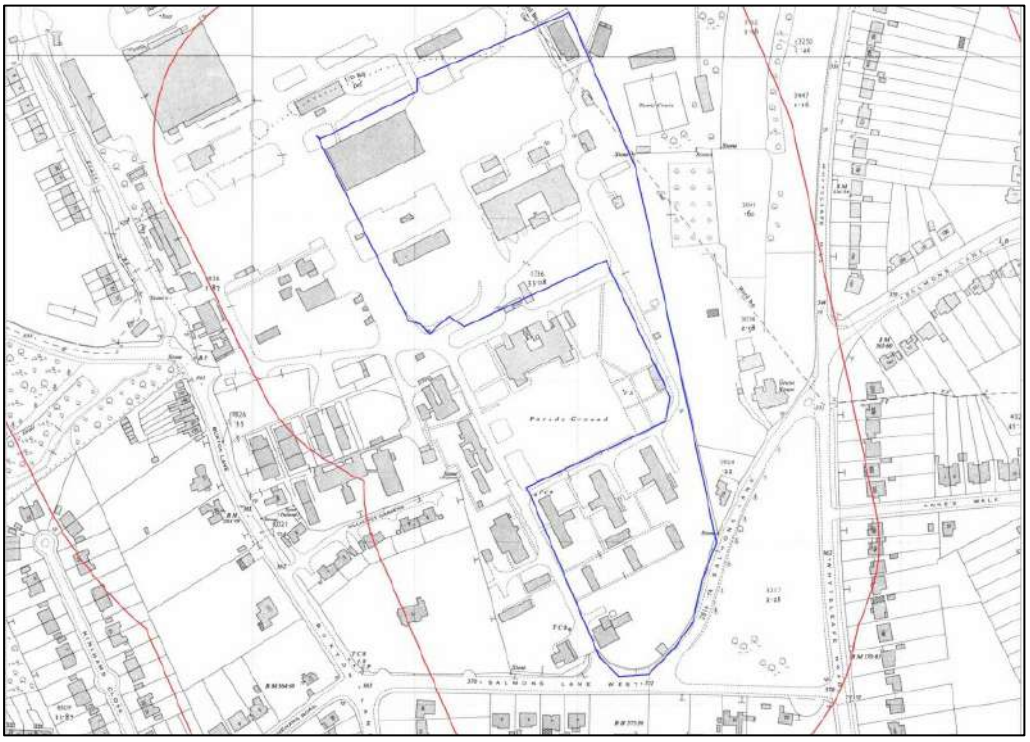
Plate 4: An excerpt from a 1:2,500 map from 1897



From 1910 the *Hillhurst* development was constructed 100m west of the site and from 1934 residential housing was constructed between 50m and 175m south and east of the site. Despite not being mapped in 1934, RAF Kenley Airfield Base is known to have been present since 1917[4].

From c. 1943 further houses were constructed 150m east of the site as well as the *Ninehams Close* housing estate 250m west of the site. From c. 1956-1957 RAF Kenley is shown to cover much of the site, as well as the land to the north, northeast and west. The *Hillhurst* development was also further developed into a housing estate and renamed to '*Hillshurst Gardens'*. This is shown in an extract of the 1958 historical map in Plate 5. Electricity transformers, electricity substations and unspecified tanks associated with the use of the site as an airfield base are noted from 1970.

Plate 5: An excerpt from a 1:2,500 map from 1958



From c. 1974 new housing was constructed 250m northwest in the form of *Anson Close* and *Quantlet Crescent* shortly after which (from c. 1992) most of the buildings on site were demolished with the exception of the listed structure in the north of the site. From c. 2010 further housing was constructed 50m northwest of the site and between 2010 and 2022 the building to the north of the *Parade Ground* was converted into a school. Some of these developments are shown in an extract of the 2022 ordnance survey map in Plate 6.

[4] https://www.kenleyrevival.org/content/history/raf-kenley/1917-present/raf-kenley-1917-1938. Accessed 3 February 2023

Plate 6: An excerpt from a 1:10,000 map from 2022

3.3 Planning History

A search of the Tandridge District Council planning portal has been carried out for the site which returned numerous records[5]. These largely relate to amendments and alterations to the Navy, Army and Air Force Institutes (NAAFI) building, due north of the former *Parade Ground,* as well as the conversion of the structure into a day school:

- An application to convert existing store buildings, the NAAFI building and listed officer's mess into accommodation, parking and soft landscaping; April 2001;
- Conversion of former NAAFI to create B1 accommodation with associated parking and landscaping (Application for listed building consent); April 2001;
- Change of use (of former NAAFI building) to provide day school, incorporating use of parade ground as play area and upgrading of field to use as playing field; June 2004;
- Internal and external alterations (of the former NAAFI building); October 2004;

[5] https://tdcplanningsearch.tandridge.gov.uk visited 20 January 2023

- Change of use (of former NAAFI building) to provide day school, incorporating use of parade ground as play area and upgrading of field to use as playing field- application to extend time limit for implementation of permission; October 2009;
- Change of the former NAAFI building to be used as an independent secondary school. Formation of roof over voids and internal alterations (Listed Building Consent); February 2015;
- Change of use of former NAAFI building to secondary school (Class D1). Formation of roofs to voids within existing building to centre and north of building. Formation of new access drive and parking; February 2015; and,
- Pruning and tree surgery of trees with fall under the tree protection order; August 2018, January 2022, November 2022.

3.4 Unexploded Ordnance (UXO)

A Preliminary Unexploded Ordnance (UXO) Risk Assessment has been carried out for the site by 1st Line Defence and is included in Appendix C. The report notes that the site was situated within the technical area of RAF Kenley with the site being within the vicinity of various hangars and gun posts. The report also notes that a spigot mortar emplacement and a pillbox were located approximately 50m to the east of the site. RAF Kenley was heavily involved in both the Battle of Britain and defending against the 'Blitz' with fighter aircraft from the airfield being later used when escorting Bristol Blenheim bombers to their targets in cross-channel operations. The site was situated within the Caterham and Warlingham Urban District, which sustained an overall low to moderate density of bombing. However, evidence suggests that the airfield was heavily bombed during the Battle of Britain, notably on 18 August 1940[6]. 1st Line Defence conclude that further research is recommended in the form of a Detailed UXO Risk Assessment in accordance with CIRIA guidelines and that, prior to this or in lieu of this, appropriate UXO Risk Mitigation Measures are provided for intrusive works.

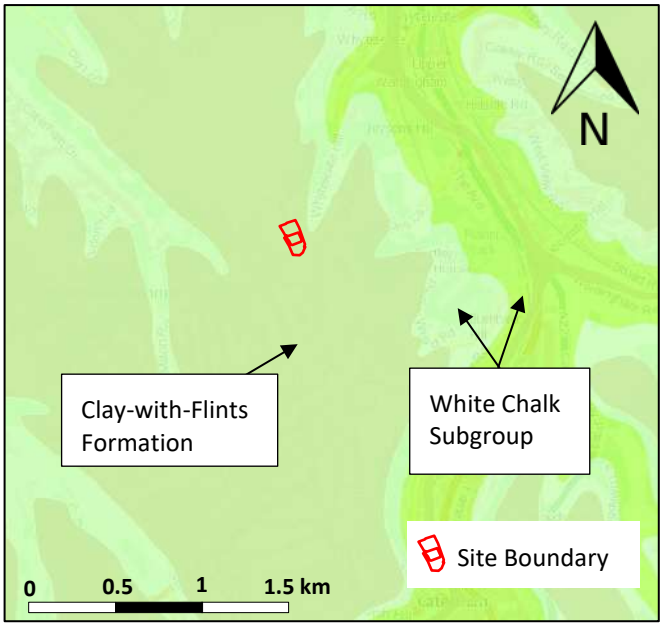
[6] First Line Defence, Preliminary UXO Risk Assessment, PA16965-00, 23 November 2022.

3.5 Geology

3.5.1 Published Geology

With reference to the British Geological Survey (BGS) GeoIndex[7] and the Groundsure Enviro+Geo Insight Report (included in Appendix D), the site is anticipated to be underlain by the Clay-with-Flints Formation with the White Chalk Subgroup at depth (*Plate 7*). Made Ground may be present beneath the site associated with previous construction on site. With reference to the BGS 1:50,000 maps which cover the site and the surrounding area[8] the Clay-with-Flints Formation is a maximum of ~10 metres thick however can be as little as ~3 metres thick in places.

Plate 7: Bedrock and superficial geology underlying the site.



The following geological descriptions for the above strata are provided based on the BGS Lexicon[9]:

- Clay-with-Flints Formation: Unbedded and heterogenous orange-brown and red-brown sandy clay with abundant nodules and rounded pebbles of flint. There is a common discontinuous basal layer up to 10cm thick, with dark brown to black matrix, stiff, waxy and fissured, with relatively fresh flint nodules stained black or dark green. The deposits locally include bodies of yellow fine- to medium- grained sand, reddish brown clayey silt, and sandy clay with beds of well-rounded flint pebbles.

[7] https://mapapps2.bgs.ac.uk/geoindex/home.html? [Accessed January 2023]
[8] British Geological Survey, 1932. Reigate (South London). England and Wales Sheet 270. Solid and Drift Geology. 1:50 000.
[9] https://www.bgs.ac.uk/technologies/the-bgs-lexicn-of-named-rock-units/ [Accessed January 2023]

- White Chalk Subgroup: Chalk with flints, With discrete marl seams, nodular chalk, sponge-rich and flint seams throughout.

3.5.2 Unpublished Geology

With reference to the BGS GeoIndex[7] seven borehole records are located within 500m of the site. Information from these boreholes is summarised in Table 1. Levels have been provided where available. Borehole records and a borehole location plan are included in Appendix E.

Table 1: Summary of BGS Borehole Records

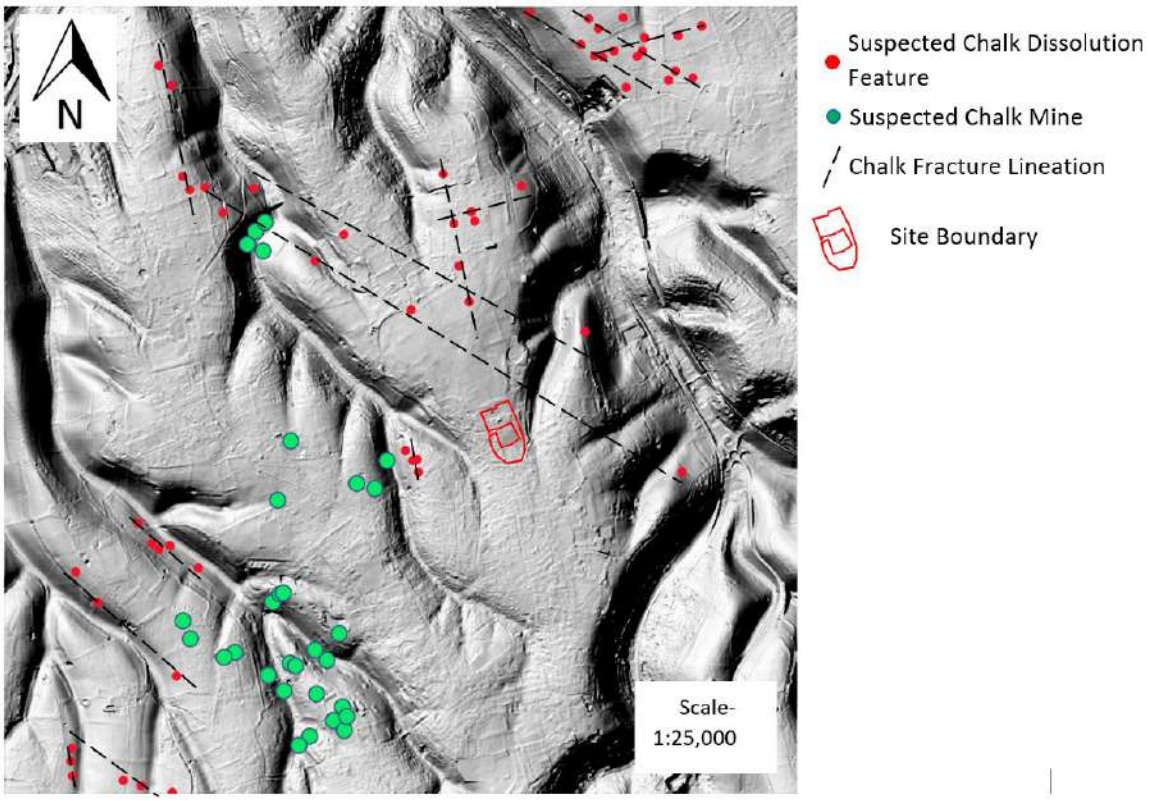
BGS reference	Grid reference	Direction	Base of borehole (mbgl) [mOD]	Date	Water level (mbgl) [mOD]	Depth to top of stratum (mbgl) [mOD]	
						Clay-with-Flints Formation	White Chalk Subgroup
TQ35NW41	533381 157125	110m SE	10.4 [NR]	May 2016	NR	Dark brown clay with large flint; (0.0) [NR]	Hard fractured chalk with flint; (9.6) [NR]
TQ35NW40	533416 157132	140m SE	19 [NR]	May 2016	NR	Dark brown clay with large flints; (0.0) [NR]	Hard fractured chalk and flint; (6.0) [NR]
TQ35NW39	533436 157125	170m SE	11 [NR]	May 2016	NR	Dark brown clay with flints; (0.0) [NR]	Hard fractured chalk with flint; (5.8) [NR]
TQ35NW37	533437 157110	170m SE	9.6 [NR]	May 2016	NR	Dark brown clay with flints; (0.0) [NR]	Putty chalk; (6.0), Hard fractured chalk and flint; (7.1) [NR]
TQ35NW38	533442 157112	180m SE	10 [NR]	May 2016	NR	Dark brown clay with flints; (0.0) [NR]	Putty chalk; (6.0), Hard fractured chalk and flint; (7.2) [NR]
TQ35NW36	533450 157112	180m SE	12.6 [NR]	May 2016	NR	Dark brown clay with flints; (0.0) [NR]	Hard fractured chalk with flint; (6.5) [NR]
TQ35NW35	533458 157112	190m SE	11.6 [NR]	May 2016	NR	Dark brown clay with flints; (0.0) [NR]	Hard fractured chalk with flint; (6.5) [NR]

NR- not recorded

3.5.3 Mining

The Groundsure report notes the potential presence of small-scale underground mining on site and approximately 346m west of the site. Nearby suspected chalk mines have also been identified through in house Light Detection and Ranging (LIDAR) data (*Plate 8*). Given the shallow depth of the chalk it is considered that the risk from chalk mining is moderate.

Plate 8: Suspected chalk mines, dissolution features and fracturing



3.6 Hydrogeology and Hydrology

The Environment Agency (EA)[10] has produced an aquifer designation system consistent with the requirements of the Water Framework Directive (WFD)[11]. The designations have been set for superficial and bedrock geologies and are based on the importance of aquifers for potable water supply and their role in supporting surface water bodies and wetland ecosystems.

The site is located within the outer catchment (Zone 2) of a groundwater Source Protection Zone (SPZ). The underlying Clay-with-Flints Formation is classified as unproductive strata and the White Chalk Subgroup at depth is categorised as a principal aquifer. The cohesive deposits of the Clay-with-Flints formation act as an aquiclude for the highly vulnerable underlying principal aquifer.

There are no surface water features within 250m of the site with the closest water framework directive surface water body being >8km to the north. The site is underlain by the Epsom North Downs Chalk WFD Groundwater body which was mostly recently given a “poor” chemical, quantitative and overall rating. The site is not within Flood Zone 2 or Flood Zone 3. The site is at a low risk of groundwater flooding, negligible risk of surface water flooding and very low risk of flooding from rivers or the sea.

[10] https://magic.defra.gov.uk/MagicMap.aspx [Accessed January 2023]
[11] https://environmental.ec.europe.eu/topics/water/water-framework-directive_en [Accessed January 2023]

3.7 Ground Hazards

The risks associated with potential geological hazards are recorded within the Enviro+Geo Insight report (*Appendix D*) and are summarised in Table 2.

Table 2: Geological Hazards

Hazard	*Risk*
Shrink-swell clays	Low
Landslides	Very low
Ground dissolution	Moderate
Compressible deposits	Negligible
Collapsible deposits	Very low
Running sands	Negligible

The risk of ground dissolution on site has been evaluated as 'moderate' by the Enviro+Geo Insight report. However, numerous chalk dissolution features are suspected within the immediate vicinity of the site with a chalk fracture passing directly beneath the site (*Plate 10*). Dissolution is caused by the migration of water along planes of weakness within the chalk (e.g., fractures or joints) which results in the formation of voids. In light of this information, we consider the risk of ground dissolution as being high.

3.8 Environmental Setting

The Groundsure Enviro+Geo Insight report (Appendix D) has been obtained to provide information on the environmental setting of the site and assist in identifying possible sources of ground contamination. A summary of the pertinent points is set out below:

- There are no historical or active (licensed) waste sites within 500m of the site nor historical or active landfills;
- There are 20 waste exemptions within 500m of the site, all related to the Merlewood Estates Office, 453m to the southwest, and all associated with the spreading, burning, storage and treatment of waste;
- There are six records of current industrial land use within 250m of the site including Kenley Airfield (on site), a telecommunications mast (5m northeast), two electricity substations (141m southwest and 189m west), a label and sign supply company (222m northeast) and a building supply company (244m southeast);

- There are no records of licensed pollutant release with 250m of the site and just 1 historical record of licensed discharge to controlled waters within 500m of the site relating to sewage discharge into Croydon Bourne (326m west);
- There have been no pollution incidents or pollutant release within 500m of the site;
- There is one historical and one active record of groundwater abstraction within 2000m of the site, located 1.7km away;
- The site is part of the Water Framework Directive surface water body catchment area "Wandle and Graveney";
- The site is part of a Site of Specific Scientific Interest (SSSI) Impact risk zone and there are three records of SSSIs within 2000m of the site;
- The site is partly occupied by deciduous woodland which is listed on the priority habitat inventory; and,
- It should be noted that due to the nature of the site as a former MOD base there may be unknown sources of contamination on site, the record for which are not available.

3.9 Radon

The Groundsure Enviro+Geo Insight report identifies that the vast majority of the site is in an area where <1% of properties are above the Radon Action Level with a small slither of the site being in an area where between 1% and 3% of properties are above the Radon Action Level. This indicates that no radon protective measures are required for new properties. Current development plans do not indicate the construction of basements; should this change then the radon assessment should be re-evaluated.

3.10 Regulatory Enquiries

Croydon Council was contacted for information[12] regarding potentially contaminated land across the site and in the surrounding area. To date, a response is awaited from the Council. Any pertinent information received will be forwarded as an addendum to this report.

[12] Croydon Council contacted via email on 30 January 2023

4. PRELIMINARY RISK ASSESSMENT

Historical contamination of land may present harm to human health and the environment. Current UK legislation stipulates that the risk associated with potential land contamination is assessed and remediated, if necessary. Under the Town and Country Planning Act 1990 (as amended), potential land contamination is a "material planning consideration" together with the National Planning Policy Framework[13] (revised in July 2021), which means that a planning authority must consider contamination when they prepare development plans or consider individual applications for planning permission. It is the responsibility of the developer to carry out the remediation where it is required and satisfy the Local Authority that the remediation has been carried out as agreed.

Additionally, Part 2A of the Environmental Protection Act 1990 requires that a significant source-pathway-receptor linkage exists to determine a site as contaminated land. This means that there has to be a contaminant present, a receptor that could be harmed by this contaminant, and a pathway linking the two. Part 2A deals with the contamination risk from a site in its current use, however, the planning system requires that the proposed use is considered. Where remediation is carried out under the planning system, it should be ensured that the site is in such a condition that it would still not meet the definition of contaminated land under Part 2A.

4.1 Preliminary Conceptual Site Model

A preliminary conceptual model has been compiled for the site with respect to the proposed development to identify the potential sources of contamination and the associated potential contaminant linkages. This model also informs the potential need for investigation at the site.

4.1.1 Potential Sources

Potential contamination sources can include both current and historical activities on site and in the surrounding area. The following potential sources have been identified at the site.

- On-site sources: Made Ground associated with the redevelopment of the site as well as former buildings on site associated with the MOD/RAF use of the site could be a source of total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAH), semi-volatile and volatile organic compounds (SVOCs and VOCs), heavy metals, asbestos containing material and polychlorinated biphenyls (PCBs). Made Ground can be a source of ground gas where an appreciable organic content is present. Hydrocarbon/organic chemicals can also product

[13] Ministry of Housing, Communities and Local Government (2021). National Planning Policy Framework.

organic vapours and ground gases. It should also be noted that the exact use of the site in the past is uncertain and there may be unknown sources of contamination.

- Groundwater – Perched water in the Made Ground may be a source of contamination resulting from impacts from the current and previous (including MOD/RAF use) on and off-site sources. Potential contaminants in perched water would be similar to those present in the soils, as discussed above. However, the Water Framework Directive most recently identified the overall rating of the Epsom North Downs Chalk WFD Groundwater body as being poor.

4.1.2 Potential Pathways

The potential migration pathways that may be present at the site include:

- Ingestion and inhalation – contamination within the Made Ground can result in the ingestion or inhalation of contaminated soils (and asbestos fibres if present);
- Direct/dermal contact – direct/dermal contact with contaminated soils or shallow groundwater can results in the uptake of contaminants through the skin or permeation of contamination through structures;
- Root uptake – uptake of phytotoxic contamination by plants/vegetation within areas of proposed soft landscaping;
- Lateral and vertical migration – leaching from potential contamination in the soils may impact the groundwater and nearby surface water features. However, the underlying shallow soils are expected to be cohesive of a very low permeability which will prevent migration to sensitive receptors (aquifer at depth and the closest surface water feature located over 8km from the site);
- Ground gas/vapour migration – lateral migration of ground gases and/or vapours through the soil matrix could lead to accumulation within buildings and other enclosed spaces such as service and drainage runs, posing a risk of asphyxiation;
- Drainage and services – could provide a preferential pathway for dissolved phase contamination migration and/or ground gases/vapour transport; and,
- Foundation works – potential creation of contaminant pathway to deeper aquifers via piling if used as part of foundation works.

4.1.3 Potential Receptors

Based on the proposed end use of the site for residential with plant uptake end use, the main receptors at the site are considered to be:

- Future site occupants/users – future homeowners are primarily at risk from direct contact, inhalation or ingestion if soil is exposed within soft landscaping and from ground gas/vapour accumulation within buildings, arising from contaminated soils and inhalation of asbestos fibres.
- Construction workers – primarily at risk from direct contact, inhalation or ingestion of contaminants and inhalation of asbestos fibres for the duration of the works. Workers will be subject to site-specific health and safety assessments.
- Off-site residents – potential contamination risks are likely to be low assuming appropriate practises during construction.
- Controlled waters - the White Chalk Subgroup principal aquifer is a potential receptor from the presence or migration of contaminants in Made Ground. However, the aquifer is unlikely to be impacted by contamination in shallow soils/ perched water unless foundation / deep utilities groundworks create preferential pathways for contaminant migration. Surface water receptors have been discounted based on the absence of potential receptors within 8km of the site.
- Buildings and infrastructure – buried concrete and services, such as plastic water supply pipes, can be at risk from chemically aggressive ground and permeation of organic contaminants into water supply pipes. Elevated hydrocarbon concentrations have the potential to influence the curing time of fresh concrete. Ground gases and vapour may also accumulate in buildings; structures and services/service corridors presenting an explosive risk.
- Plants and vegetation – if new vegetation within soft landscaping is proposed, it will primarily be at risk from phytotoxic contaminants such as copper, boron, nickel and zinc. It is noted that the current vegetation on site does not appear to be showing signs of distress.

4.2 Preliminary Qualitative Risk Assessment

A preliminary qualitative risk assessment has been undertaken based on the findings of the conceptual site model and the potential contaminant linkages that may exist at the site in accordance with the October 2020 Land Contamination Risk Management Guidance (LCRM)[14]. Using criteria broadly based

[14] Environment Agency (2020). *Land Contamination Risk Management (LCRM)*.

on those presented in CIRIA Report C552[15], the magnitude of the risk associated with potential contaminant linkages has then been assessed and is summarised below in Table 3, below.

The risk assessment methodology is presented in Appendix F and the findings of the risk assessment are summarised in Table 3 below.

Table 3: Preliminary Risk Assessment

Potential Source/Medium	*Potential Exposure Route*	*Potential Receptor*	*Severity*	*Probability*	*Risk Rating*	*Comments*
Explosive/ asphyxiating gases/vapours from underlying soils (Made Ground if present) and potential on and off-site sources	Migration of gases and vapours through the surface via permeable soils and drainage & services	Internal building spaces & future occupiers	Severe	Low likelihood	Moderate	Made Ground may be present on site associated with the previous development of the site.
Organic/ inorganic contaminants such as hydrocarbons, PAH, PCBs, metals and asbestos within underlying soils (based on historical (including MOD/RAF use) on-site and off-site sources)	Direct/indirect ingestion of soil and dust, inhalation of particle vapours and asbestos fibres and dermal contact	Construction workers	Medium	Likely	Moderate	There is potential for shallow soils to be impacted by asbestos and/or contaminants. Chemical analysis and assessment of shallow soils required to assess risk.
		Future site users	Medium	Likely	Moderate	The site is anticipated to be partly covered with buildings and hardstanding. However, a significant part of the site is to be covered with soft landscaping, including private gardens.
	Direct contact with underground structures and services	Buildings and structures	Mild	Likely	Moderate/ Low	Sulfate concentrations in the natural soils beneath the site may present a risk to buried concrete. There is potential for contamination within Made Ground if new buried water supply pipes will be laid. Chemical assessment of soils required to assess risk.
	Root uptake	Plants and vegetation	Minor	Likely	Low	Soft landscaping and private gardens are to cover much of the site.
Organic/inorganic contaminants within groundwater (perched groundwater within the Made	Direct contact and ingestion of contaminated groundwater	Future site users	Medium	Unlikely	Low	Construction workers may come into contact with perched groundwater during excavation works. Hardstanding will limit contact for future site users. Assessment of groundwater
		Construction workers	Medium	Likely	Moderate	
		Off-site residents	Medium	Unlikely	Low	

[15] CIRIA (2001) *Contaminated Land Risk Assessment*. A guide to good practice. C552.

Potential Source/Medium	*Potential Exposure Route*	*Potential Receptor*	*Severity*	*Probability*	*Risk Rating*	*Comments*
Ground, if present)	Inhalation of vapours	Future site users	Medium	Low likelihood	Moderate/ Low	contamination is required to assess risks.
	Vertical migration	Principal Aquifer (White Chalk)	Medium	Low likelihood	Moderate / Low	If excavation and/or piling is proposed which extends down into the White Chalk Subgroup, then there is a possible pathway for contaminant migration into the principal aquifer. A Piling Works Risk Assessment may be required to assess risk based on piling method.
	Direct contact with underground structures and services	Buildings and structures	Mild	Likely	Moderate/ Low	Buried concrete to be designed as appropriate for ground conditions. Chemical assessment of groundwater required to assess risk.

5. FIELDWORK

The CGL Investigation was undertaken between 6 and 12 December 2022 and comprised twelve machine excavated trial pits (TP1 to TP12), one cable percussion borehole (BH1) and eleven windowless sampler boreholes (WS1 to WS11). Hand dug inspection pits were excavated to a maximum depth of 1.2metres below ground level (m bgl) prior to commencement of drilling, trial pits were excavated to a maximum depth of 4.0mbgl, windowless sampler boreholes were drilled to a maximum depth of 5.45mbgl, the cable percussion borehole was drilled to a maximum depth of 15.45mbgl. The cable percussion borehole and four windowless sampler boreholes (WS1, WS4, WS5 and WS9) were installed with ground gas and groundwater monitoring wells. A summary of the exploratory holes is provided in Table 4.

Table 4. Excavation(s) Summary

Location ID	*Easting (m)*	*Northing (m)*	*Level*	*Hole Type*	*Final Depth (m)*	*Termination Reason*
TP1	533157.830	157175.336	176.146	TP	4.0	Achieved Target Depth
TP2	533247.010	157150.678	173.736	TP	4.0	Achieved Target Depth
TP3	533250.858	157192.933	172.877	TP	3.2	Maximum reach of JCB arm
TP4	533185.536	157227.395	172.760	TP	3.5	Achieved Target Depth
TP5	533227.214	157397.076	172.116	TP	3.5	Achieved Target Depth
TP6	533243.146	157238.832	172.166	TP	3.5	Achieved Target Depth
TP7	533134.647	157469.396	171.784	TP	3.1	Refusal on flint bed
TP8	533158.664	157449.890	171.816	TP	3.5	Achieved Target Depth
TP9	533091.101	157429.864	172.298	TP	3.5	Achieved Target Depth
TP10	533082.400	157410.539	172.313	TP	3.7	Achieved Target Depth
TP11	533134.980	157361.703	172.736	TP	4.0	Achieved Target Depth
TP12	533139.417	157245.869	173.024	TP	3.7	Maximum reach of JCB arm
WS1	533160.622	157215.136	172.709	WS	5.45	Achieved Target Depth
WS2	533203.714	157208.383	173.039	WS	5.45	Achieved Target Depth
WS3	533229.679	157172.933	173.511	WS	5.45	Achieved Target Depth
WS4	533218.673	157140.644	173.756	WS	5.45	Achieved Target Depth
WS5	533197.366	157467.833	171.758	WS	5.45	Achieved Target Depth
WS6	533123.832	157440.798	171.484	WS	5.45	Achieved Target Depth
WS7	Unable to Survey due to loss of signal.			WS	5.45	Achieved Target Depth
WS8	533166.632	157361.854	172.656	WS	5.45	Achieved Target Depth
WS9	533111.730	157351.576	172.655	WS	5.45	Achieved Target Depth
WS10	533106.744	157307.799	173.235	WS	3.5	Refusal on Flint bed
WS11	Unable to Survey due to addition of position towards end of ground investigation.			WS	5.45	Achieved Target Depth
BH1	533157.036	157497.723	171.815	CP	15.45	Achieved Target Depth

- *CP denotes Cable Percussion boreholes, WS denoted Windowless Sample holes, TP denotes trial pits*

The borehole and trial pits were positioned to provide coverage across the site to inform the ground and groundwater model, windowless samplers were positioned to provide coverage and inform the ground gas model.

Prior to commencing ground penetrating works, a buried services survey was undertaken by a subcontracted specialist surveyor (Midland Survey). The investigation was undertaken in general accordance with the requirements of BS 5930:2015+A1:2020[16] and BS 10175:2011+A2:2017[17]. The exploratory holes were logged by an Engineer from CGL, and representative soil samples were retrieved and sent for laboratory analysis.

All intrusive investigation locations were carried out under supervision of a UXO specialist which provided down hole clearance of the boreholes and windowless sample locations and a watching brief during the trial pitting works.

An exploratory hole plan for the CGL ground investigation is included as Figure 1 and the exploratory hole records are included as Appendix G.

5.1 Monitoring

A total of five monitoring wells were installed within the exploratory holes including single installations within the cable percussive borehole (BH1) and four of the windowless sampler borehole locations (WS1, WS4, WS5 and WS9). Given the limited thickness of the Made Ground in the boreholes (max 1.2m thick), no monitoring installations were installed in this material. Three rounds of ground gas and ground water monitoring were undertaken at the site between 22 December 2022 and 23 January 2023. The monitoring data is included as Appendix H and a summary of the monitoring well installation details is included in Table 5.

Table 5. Monitoring Well Installation Details

Location ID	*Instrument*	*Installed*	*Response Top (mbgl)*	*Response Base (mbgl)*	*Response Zone Strata*
BH1	Standpipe	12/12/2022	4	15	White Chalk
WS1	Standpipe	9/12/2022	0.5	5.0	Clay-with-Flints
WS4	Standpipe	9/12/2022	0.5	5.0	Clay-with-Flints
WS5	Standpipe	8/12/2022	0.5	5.0	Clay-with-Flints
WS9	Standpipe	8/12/2022	0.5	5.0	Clay-with-Flints and White Chalk

[16] British Standards Institution. (2015). *Code of practice for site investigations*. BS 5930:2015+A1:2020
[17] British Standards Institution. (2017*). Investigation of potentially contaminated sites – Code of practice*. BS 10175:2011+A2:2017

5.2 Laboratory Testing

7.2.1 Chemical

Representative soil samples were submitted to i2 Analytical Limited (UKAS and MCERTS accredited laboratories) for chemical testing. The contaminant testing included the following determinants:

- Heavy metals / metalloids including antimony, arsenic, barium, beryllium, boron, cadmium, chromium, copper, lead, mercury, nickel, selenium, vanadium and zinc;
- PAH and total petroleum hydrocarbons (TPH by Criteria Working Group banding);
- Total monohydric phenols;
- BTEX compounds (benzene, toluene, ethylbenzene, xylenes);
- Total cyanide;
- Soil Organic Matter (SOM);
- pH and sulfate;
- Asbestos screen and identification where found in Made Ground samples;
- 7 PCB congener testing in the vicinity of the sub-station.

In addition, two groundwater samples, and six Made Ground samples processed via leachate analysis, were analysed for a similar testing suite to the soil suites, which included additional testing for calcium and hardness, but did not include the asbestos testing. The results of the chemical laboratory testing are included in Appendix I.

5.2.1 Geotechnical

Representative soil samples were taken for geotechnical testing and were sent to i2 Analytical Limited (a UKAS accredited laboratory).

The following tests were scheduled at the geotechnical laboratory:

- Natural moisture content;
- Particle Size Distribution;
- Atterberg Limits;

- pH, sulfate and water soluble sulfate;
- Saturated Moisture Content; and
- Dry Density.

The results of the geotechnical laboratory testing are included in Appendix J.

6. GROUND AND GROUNDWATER CONDITIONS

6.1 Summary

The ground conditions encountered within the CGL ground investigation are summarised in Table 6 and were generally consistent with the anticipated geology.

Table 6. Summary of Ground Conditions

Stratum	*Top of Stratum (mbgl) [mOD]*	*Thickness (m)*
Grass over soft, dark brown sandy clay / silty gravelly clay / silt with occasional to frequent, angular to subangular, fine to coarse flint gravel. *(Only present in positions TP1, WS1, WS8)* **[TOPSOIL]**	0.00 [+172.66 to +176.15]	0.30 to 0.40
Occasional turf and asphalt over concrete. *(Only present in positions BH1, TP7, TP8, TP9, TP10)* **[CONCRETE]**	0.00 [+171.78 to +172.31]	0.10
Variable, comprising both granular and cohesive deposits. Cohesive deposits generally comprising: Soft to stiff, dark to light brown sandy gravelly clay to sandy clayey silt with abundant to rare gravel. Sand fine to coarse. Gravel comprises angular to subangular, fine to coarse of brick, flint, concrete, chalk, clinker, plastic and terracotta roof tiling. Rare cobble sized concrete and brick. Granular deposits generally comprising: light to dark brown and black, clayey gravelly sand to sandy gravel. Sand is fine to coarse. Gravel is angular to subangular, fine to coarse of brick, flint and clinker. Rare brick cobbles. **AND** Medium dense, white / light grey, angular to subrounded, fine to coarse chalk gravel with occasional chalk and flint cobbles. *(Present in positions BH1, TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP9, TP10, TP11, TP12, WS2, WS3, WS4, WS5, WS6, WS7, WS9, WS10, WS11)* **[MADE GROUND]**	0.00 to 0.10 [+171.48 to +173.76]	0.10 to 1.20
Generally comprising soft to very stiff light to dark brown , mottled orange, grey and red sandy CLAY to slightly clayey slightly sandy SILT with rare to abundant flint nodules recovered as angular to rounded fine to coarse flint gravel, occasional flint cobbles, occasional partially decomposed organic matter, occasional yellow streaking, rare red veining and rare chalk cobbles. Sand is fine to coarse. *(Present in all positions)* **[CLAY-WITH-FLINTS FORMATION]**	0.20 to 1.20 [+170.98 to +175.80]	2.70 to 4.80
Variable comprising both structureless, structured, and unassigned deposits*. Structureless CHALK generally composed of white slightly gravelly SILT to silty GRAVEL. Gravel is low to high density, very weak to moderately weak, angular to subangular and fine to coarse of white chalk. Localised dissolution of chalk occasionally reflected through red-brown patches. (Grade Dm). Structured CHALK generally recovered as white slightly gravelly slightly sandy SILT. Gravel is low to very high density, very weak to moderately strong, angular to subangular, fine to coarse of white chalk. Localised dissolution of chalk occasionally reflected through red-brown patches. Rare chalk cobbles. *(Present at BH1, TP5, TP12, WS4, WS9, WS11)** **[WHITE CHALK SUBGROUP]**	4.00 [+167.82] 4.40 to 6.50 [+165.32 to +168.26]	2.50 Base not proven**

**Chalk recovered from TP5, TP12, WS4 and WS11 was not assigned a grade due to the destructive recovery method (TP) and insufficient sample size (WS).*

***Structured chalk at least 8.50m in thickness.*

Plots of the Standard Penetration Test (SPT) N60 values and undrained shear strength (c_u) plotted against depth are included as Figure 2 and Figure 3 respectively.

A summary of the in-situ and geotechnical laboratory data is provided in Table 7.

Table 7. Summary of CGL Geotechnical Test Data

SPT 'N' Data							
Strata		***Range of SPT N values***		***Range of SPT N60 values***			
Clay-with-Flints Formation		6 to 50		6.6 to 55			
White Chalk Subgroup		5 to 50		5.3 to 53.3			
Atterberg Limits							
Strata	***Moisture Content (%)***	***Liquid Limit (%)***	***Plastic Limit (%)***	***Plasticity Index (%)***	***% material <425µm***	***Modified Plasticity Index [I'_p] (%)***	***Volume Potential Change[19]***
Clay-with-Flints Formation	19 to 44	36 to 111	17 to 49	18 to 62	64 to 100	14.25 to 60	Low to High
Particle Size Distribution							
Strata	***Very Coarse %***	***Gravel %***	***Sand %***	***Silt %***	***Clay %***	***Fines %***	
Clay-with-Flints Formation	0	0 to 13	9 to 28	14 to 60	16 to 66	58 to 84	
Moisture Content							
Strata		***Moisture Content***		***Saturated Moisture Content***			
Clay-with-Flints Formation		19 to 44		-			
White Chalk Subgroup		22 to 32		23 to 32*			

**Chalk supplied failed to meet volume requirements of BS 1337:2 Clause 3.3.5.1*

6.2 Topsoil

Topsoil was encountered in three of the exploratory hole positions in the west and north of the site (TP1, WS1, WS8) and was 0.30 to 0.40m thick at those locations. The stratum comprised grass over soft, dark brown sandy clay / silty gravelly clay / silt with occasional to frequent, angular to subangular, fine to coarse flint gravel.

6.3 Concrete

Concrete was encountered in five of the exploratory hole positions (BH1, TP7, TP8, TP9, TP10) in the north of the site, was 0.1m thick, and was occasionally overlain by turf or asphalt.

6.4 Made Ground

Made Ground was encountered in all but three of the exploratory hole positions (TP1, WS1, WS8) ranging in thickness between 0.1 and 1.20m. The maximum thickness of Made Ground was

encountered in the middle of the football pitch, in the south of the site. The composition of the Made Ground was found to comprise both cohesive and granular layers.

The cohesive deposits comprised of soft to stiff, dark brown / light brown, clay / sandy clay / sandy gravelly clay / silt / sandy silt / sandy clayey silt with abundant to rare gravel. Sand was fine to coarse. Gravel was angular to subangular, fine to coarse of brick, flint, concrete, chalk, clinker, plastic and terracotta roof tiling. Rare cobble-sized concrete and brick were noted. It is noted that no one location included all of the man-made materials presented in the summary above.

The granular deposits comprised loose, dark brown / light brown / black, clayey sand / clayey gravelly sand / sandy gravel. Sand was fine to coarse. Gravel was angular to subangular, fine to coarse of brick, flint and clinker. Rare brick cobbles were noted. The granular deposits also comprised a chalk fill of medium dense, white / light grey, angular to subrounded, fine to coarse chalk gravel with occasional chalk and flint cobbles.

No in-situ testing was undertaken within the Made Ground due to it being relatively thin and predominantly encountered within the hand dug pits.

6.5 Clay-with-Flints Formation

The Clay-with-Flints Formation was encountered in each exploratory hole location. Within the cable percussive borehole (BH1), two of the trial pits (TP5, TP12) and three of the windowless sampler locations (WS4, WS9, WS11) the thickness of the Clay-with-Flints Formation was noted to range between 2.70 and 4.80m. The strata comprised of predominantly cohesive lithologies.

The strata comprised of soft to very stiff dark brown / light brown / yellowy brown / brown mottled orange / light brown mottled orange and grey / brown mottled red and orange / orangey brown / orangey brown mottled red / orange mottled red / orangey yellow / red mottled brown / red brown / red clay / slightly sandy clay / sandy clay / slightly sandy slightly silty clay / slightly gravelly slightly sandy clay / slightly clayey slightly sandy silt with rare to abundant flint nodules recovered as angular to rounded fine to coarse flint gravel, occasional flint cobbles, occasional partially decomposed organic matter, occasional yellow streaking, rare red veining and rare chalk cobbles. Sand was fine to coarse.

A total of 43 in situ SPTs were undertaken in the Clay-with-Flints Formation. N values within the formation ranged from 6 to 50 blows. The N values were used to calculate N60 values with values ranging between 6.6 and 55. N60 values for the Clay-with-Flints Formation were subsequently used to calculate for undrained shear strength (Cu), when multiplied by a f1 value of 4.5[18]. The correlated N60

[18] Stroud, M A & Butler, F G. 1975 – The standard penetration test and the engineering properties of glacial materials. In: Proceedings of the Symposium of glacial materials, University of Birmingham, April 1975.

derived undrained shear strength tests ranged between 29.7kPa and 247.5kPa. In situ hand shear vane tests were carried out during the windowless sampling boreholes and trial pits which recorded undrained shear strengths ranging between approximately 21kPa and 150kPa.Classification testing was undertaken within the stratum. The results of the testing are presented below:

- Moisture Content of 19% to 44%;
- Liquid Limit of 36% to 111%;
- Plastic Limit of 17% to 49%; and,
- Modified plasticity index of 14.25% to 60%.

The modified plasticity index (I'p) indicates that the Clay-with-Flints Formation has a low to high potential for volume change[19] with an average I'p of 30.5%, 'medium volume change potential'. A total of 14 samples of the Clay-with-Flints Formation plot above the 'A Line' as a clay soil, two samples plot below the 'A Line' as a silt soil and two samples plot on the A-line as a silt/clay soil.

Seven particle size distribution (PSD) tests were undertaken in the Clay-with-Flints Formations which recorded the following particle distribution:

- Cobbles and Boulders 0%, average 0%;
- Gravel 0 to 13%, average 7.6%;
- Sand 9 to 28%, average 16.3%;
- Silt 14 to 60%, average 30.6%;
- Clay 16 to 66%, average 47.4%; and,
- Fines (sum of silt and clay) 58 to 84%, average 71%.

The results of the testing indicate that the Clay-with-Flints Formation typically comprises a slightly sandy slightly silty clay with occasional gravel.

6.6 White Chalk Subgroup

The White Chalk Subgroup was encountered in six of the exploratory hole locations (BH1, TP5, TP12, WS4, WS9, WS11) comprising of at least 11.45m of stratum (base not proven). The stratum consisted of

[19] https://nhbc-standards.co.uk/4-foundations/4-2-buildings-near-trees [Accessed January 2023]

structureless and structured chalk which have been distinguished on the basis of SPT N values and chalk density tests. A chalk grade was not assigned for the samples retrieved from positions TP5, TP12, WS4 and WS11 due to either the destructive recovery method (TP5, TP12) or the insufficient sample size (WS4, WS11).

The structureless White Chalk Subgroup consisted of structureless chalk composed of white slightly gravelly silt / gravelly silt / slightly gravelly slightly sandy silt / silty gravel. Gravel was low to high density, very weak to moderately weak, angular to subangular and fine to coarse of white chalk. Localised dissolution of the chalk was occasionally reflected through red-brown patches. The grade of the structureless chalk was identified as Grade Dm (BH1).

The structured White Chalk Subgroup consisted of structured chalk recovered as white slightly gravelly silt/ gravelly silt / silt with occasional gravel / silt with rare gravel / sandy silt / sandy silt with rare gravel / slightly sandy gravelly silt / slightly gravelly slightly sandy silt. Gravel was low to very high density, very weak to moderately strong, angular to subangular, fine to coarse of white chalk. Localised dissolution of chalk was occasionally reflected through red-brown patches. Rare chalk cobbles were noted. Structured chalk was encountered at positions BH1 and WS9.

A total of three in situ SPTs were undertaken in the structureless White Chalk Subgroup with N values between 5 and 10 blows. Also, a total of eight in situ SPTS were undertaken in the structured White Chalk Subgroup with N values between 19 and 50 blows.

Three samples of the structureless White Chalk Subgroup were analysed for dry density and saturated moisture content (SMC) with a dry density between 1.44 Mg/m^3 and 1.62 Mg/m^3 and an SMC between 25% and 32%. Despite the chalk samples failing to comply with the volume requirements of BS 1377:2 Clause 3.3.5.1[20], principally due to the disturbance of the samples during drilling, the broad similarity of the results can be used to provide an indication of chalk density and strength (in general accordance with BS 1337:2 Clause 3.3.5.1). An average dry density of 1.54 Mg/m^3 for the structureless chalk coincides with a uniaxial compressive strength of approximately 2 MN/m^2 which indicates a weak overall strength and low density [21]. An average SMC of 27.3 % would indicate a low density [22].

Two samples of the structured White Chalk Subgroup were analysed for dry density and SMC with a dry density between 1.62 Mg/m^3 and 1.67 Mg/m^3 and an SMC between 23% and 25%. An average dry density of 1.65 Mg/m^3 for the structured chalk coincides with a uniaxial compressive strength of

[20] BS 1377-2:2022. Methods of test for soils for civil engineering purposes.
[21] Bowden, A. J., Spink, T. W. and Mortimore, R. N. The engineering description of chalk: its strength, hardness and density. 2002.
[22] Lord, J. A., Clayton, C. R. I. and Mortmore, R. N. Engineering in chalk. CIRIA C574. 2002.

approximately 4 MN/m^2 which indicates a weak to moderately weak overall strength and a medium density[21]. An average SMC of 24% would indicate a low density[22].

6.7 Ground Gas

Three rounds of ground gas monitoring were completed between 22 December 2022 and 23 January 2023. The visits were undertaken during atmospheric pressures ranging between 964mb and 987mb in rising, stable and falling pressure systems. The results of the ground gas monitoring are summarised in Table 8. BH1 was only monitored twice on account of the borehole having frozen over during the third monitoring visit.

Table 8. Summary of Ground Gas Monitoring

Borehole	*Response Zone Strata*	*Response Zone (mbgl) [mOD]*	*Date*	*Steady Flow Rate (l/hr)*	*Minimum O_2 (% vol in air)*	*Steady CO_2 (% vol in air)*	*Maximum CH_4 (% vol in air)*	*Maximum PID (ppm)*	*Groundwater depth (mbgl) [mOD]*
BH1	White Chalk	4.0 to 15.45 [+167.82 to +156.37]	22/12/2022	<0.1	18.2	1.3	0.0	0.0	DRY
			09/01/2023	-0.3	18.4	1.0	0.0	0.4	DRY
			23/01/2023	POSITION FROZEN OVER- UNABLE TO MONITOR					
WS1	Clay with Flints Formation	0.5 to 5.0 [+172.21 to +167.71]	22/12/2022	<0.1	19.5	0.8	0.0	0.2	4.70 [+168.01]
			09/01/2023	-0.1	19	0.9	0.0	0.0	1.45 [+171.26]
			23/01/2023	<0.1	18.3	0.9	0.0	0.0	1.87 [+170.84]
WS4	Clay-with-Flints Formation	0.5 to 5.0 [+173.26 to +168.76]	22/12/2022	<0.1	17.7	2.1	0.0	0.1	DRY
			09/01/2023	-3.0	19.4	0.0	0.0	0.0	DRY
			23/01/2023	2.8	19.3	0.3	0.0	0.0	DRY
WS5	Clay-with-Flints Formation	0.5 to 5.0 [+171.26 to 166.76]	22/12/2022	<0.1	17.9	1.0	0.0	0.1	2.85 [+168.91]
			09/01/2023	-0.2	9.6	7.2	0.0	0.5	3.90 [+167.86]
			23/01/2023	<0.1	8.7	7.5	0.0	0.0	4.88 [+166.88]
WS9	Clay-with-Flints Formation & White Chalk Subgroup	0.5 to 5.0 [+172.16 to +167.66]	22/12/2022	<0.1	17.6	0.8	0.0	0.2	DRY
			09/01/2023	-0.5	13	2.1	0.0	0.0	DRY
			23/01/2023	<0.1	10.2	2.4	0.0	0.0	DRY

Notes: PID – Photoionisation Detector, PPM – parts per million.

6.8 Groundwater

No groundwater strikes were recorded during the drilling or excavation of any of the positions.

A total of three rounds of groundwater monitoring were completed between 22 December 2022 and 23 January 2023. A summary of the results is outlined in Table 9.

Table 9. Summary of Groundwater Monitoring

Borehole	*Response Zone Strata*	*Response Zone (mbgl) [mOD]*	*Date*	*Depth (mbgl) [mOD]*
BH1	White Chalk Subgroup	4.0 to 15.45 [+167.82 to +156.37]	22/12/22 to 23/09/23	DRY
WS1	Clay-with-Flints Formation	0.5 to 5.0 [+172.21 to +167.71]	22/12/22	4.70 [+168.01]
			09/01/23	1.45 [+171.26]
			23/01/23	1.87 [+170.84]
WS4	Clay-with-Flints Formation	0.5 to 5.0 [+173.26 to +168.76]	22/12/22 to 23/09/23	DRY
WS5	Clay-with-Flints Formation	0.5 to 5.0 [+171.26 to 166.76	22/12/22	2.85 [+168.91]
			09/01/23	3.90 [+167.86]
			23/01/23	4.88 [+166.88]
WS9	Clay-with-Flints Formation and White Chalk Subgroup	0.5 to 5.0 [+172.16 to +167.66]	22/12/22 to 23/09/23	DRY

Perched groundwater was recorded at depths between 1.45 and 4.88mbgl in windowless sampler locations WS1 and WS5. The water is unlikely be in hydraulic continuity based on the variable water levels across both boreholes as well as the Clay-with-Flints Formation's cohesive soil composition. The water within these boreholes is considered to be perched.

6.9 Sulphate and pH Conditions

A total of 9 soil samples from across the site have been tested in accordance with BRE SD1 for pH and sulfate conditions. The results of the testing are summarised in Table 10.

Table 10. Sulfate and pH Conditions

Stratum	*No of samples*	*pH*	*Water Soluble SO4 16hr extraction (2:1 Leachate Equivalent) (mg/l)*
Made Ground	5	8.2 to 10.2	3.1 to 400
Clay-with-Flints Formation	3	7.8 to 8.5	5 to 66
White Chalk Subgroup	1	8.8	5.1

6.10 Preliminary Desiccation Assessment

A preliminary desiccation assessment has been undertaken as shown in Table 1 of Appendix L. The desiccation assessment is based on eight locations with WS2, TP4 and TP9 acting as controls (away from mature vegetation) and WS11, WS5, TP5, WS4, WS7 being positioned closed to mature vegetation. The results of the desiccation assessment indicate that potentially desiccated soils were located at 2.4mbgl in WS4, 3mbgl in WS4 and 3.5mbgl in WS11, associated with areas closest to trees and all associated with samples of the Clay-with-Flints Formation.

7. CONTAMINATION ASSESSMENT

7.1 Introduction

This section of the report evaluates risks to potential receptors at the site from identified chemical contamination. Potential receptors have been identified with reference to the Part 2A regime and associated Defra guidance[23]. As part of the Part 2A regime, under the planning regime all receptors (humans, controlled waters, vegetation and buildings) have been considered if there is the potential for them to be adversely affected by exposure to contamination. CGL's approach and rationale to assessment criteria adoption for this site is presented in Table 1 of Appendix K.

7.2 Risks to Human Health

Soil samples were submitted for chemical analysis as part of the ground investigation, comprising 11 samples from the Made Ground, six samples of the Clay-with-Flints Formation and one sample of topsoil. The risks to human health have been assessed on a *residential with plant uptake* end use given the proposed development plans (assuming 6% SOM for Made Ground and 1% SOM for Clay-with-Flints Formation and Topsoil) and the assessment results are summarised in Tables 2 and 3 of Appendix K.

7.2.1 Risks from Soil Contaminants

7.2.1.1 Made Ground

Of the 11 samples of Made Ground assessed, three samples in the north of the site (WS5, WS6 and TP10) were noted to contain elevated concentrations of speciated PAHs including benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene and dibenzo(a,h)anthracene. Positions WS5 and WS6 also noted elevated concentrations of beryllium, chrysene, indeno(1,2,3-cd)pyrene and aromatic petroleum hydrocarbons (TPHs) (aromatic EC16-EC21 and aromatic EC21-EC25). WS5 also noted elevated concentrations of the speciated PAHs benzo(k)fluoranthene, fluoranthene and phenathrene. Following further statistical assessment (US_{95} approach), the results recorded US_{95} values which exceeded the Generic Assessment Criteria (GAC) for all of the listed contaminants, with the exception of Fluoranthene. However, despite the US_{95} values for these contaminants exceeding the GAC it cannot be confirmed whether this is statistically significant in light of the dataset size and, therefore, it is should be treated that a risk from PAHs, aromatic TPHs and beryllium is present across the site's Made Ground until proven otherwise.

[23] DEFRA. (2012). *Environmental Protection Act 1990: Part 2A Contaminated Land Statutory Guidance*. Department for Environment, Food and Rural Affairs.

Asbestos was detected at position TP3 in the form of chrysotile as a hard/cement type material and was quantified as 0.272%. Despite the fact that asbestos was not detected in anu pf the samples analysed, its presence cannot be discounted given the former uses of the site.

7.2.1.2 Natural Soils

Of the seven samples which were tested from natural soils, one sample was noted to exhibit marginally elevated concentrations of arsenic (WS4). Another sample (WS8) was also noted to exhibit elevated concentrations of the speciated PAHs benzo(a)pyrene, benzo(b)fluoranthene and di-benzo(a,h)anthracene. Both of these samples were taken from the Clay-with-Flints Formation. Following further statistical assessment (US_{95} approach), the results for benzo(a)pyrene, benzo(b)fluoranthene and di-benzo(a,h)anthracene recorded US_{95} values which exceed the GAC. No visual contamination was observed in the overlying Made Ground which can be attributed to the exceedances and therefore it is unlikely that contaminants were transferred during excavation. However, in light of these exceedances only being observed at one of the locations within the natural soils it is not considered that a risk from the listed speciated PAHs is present across the site's natural soils and is more likely associated with contaminant mobilisation from the nearby Made Ground.

7.2.2 Risks from Vapours

With reference to Table 4 of Appendix K there is an overall low risk to human health from groundwater and leachate derived vapours on account of volatile organic concentration measurements falling within the threshold for "Residential land use"[24].

7.3 Risks to Controlled Waters

As identified within the preliminary risk assessment, no surface water receptors have been identified and the potential risks to the deep aquifer from contamination in the perched water will be largely mitigated by the low permeability Clay-with-Flints Formation, although piling may result in preferential pathways (if piling is adopted and depending on piling methodologies). No free product / gross contamination was identified during the investigation in the shallow soils and perched water and on this basis, the risks to controlled waters are considered to be low.

Notwithstanding this, a total of two perched groundwater samples were scheduled for laboratory analysis with both samples originating from perched groundwater within the Clay-with-Flints Formation. The results have been screened against Drinking Water Values (DWV) to assess the general quality of the samples and the results are presented in Table 5 of Appendix K– this is a conservative

[24] Society of Brownfield Risk Assessment, Development of Generic Assessment Criteria for Assessing Vapour Risks to Human Health from Volatile Contaminants in Groundwater, Version 1.0, February 2017.

assessment in the absence of receptors / viable pathways. The results of the groundwater testing indicate that the concentrations are all within the DWV concentration values.

Six samples were also scheduled for leachate analysis with all samples originating from the Made Ground. The results have been screened against DWVs to assess the potential for drinking contamination as a result of the leaching of contaminants within the Made Ground. The results of this analysis are presented in Table 6 of Appendix K. The results of the leachate analysis indicate that the concentrations of leached metals from the Made Ground all fall within the DWV concentrations. Meanwhile, the leached benzo(a)pyrene concentrations exceed the DWV concentrations for position WS5 at 0.20mbgl; the leached TPH and PAH concentrations exceed the DWV concentrations for positions WS5 at 0.20mbgl and TP10 at 0.40mbgl; and the total monohydric phenol concentrations exceed the DWV concentrations for positions TP5 at 0.20mbgl, TP12 at 0.30mbgl, WS2 at 0.9mbgl, WS4 at 0.10mbgl, and WS5 at 0.20mbgl.

Considering that much of the Made Ground on site will be removed prior to construction, as well as the current absence of piling within the provisional development plans, the development of the site poses a moderate/low risk to controlled waters. However, this risk should be reassessed through a piling works risk assessment (PWRA) should the development plans change.

7.4 Ground Gas Risk

The ground investigation identified a relatively thin cover of Made Ground across the site, typically no more than 1m. Whilst the organic content is on average >2.5%, no putrescible material was encountered. Based on these observations and the limited thickness of Made Ground, generation of ground gases from the Made Ground is likely to be very slow and not at a volume that would generate significant flow. On this basis, the Made Ground is not considered to be a viable source of significant ground gases. Furthermore, the cohesive nature and low organic content of the Clay-with-Flints Formation is also not conducive to the generation or migration of gas flow. The underlying White Chalk Subgroup may generate CO_2 through dissolution (*Table 10*). However, the overlying, low permeability, cohesive strata of the Clay-with-Flints Formation would act as a barrier to limit vertical gas migration.

Ground Gas Screening Values (GSVs) have been calculated based on the CGL monitoring data for each borehole in general accordance with CIRIA C665[25] and BS 8485[26] using the maximum steady state sustained flow rate, the maximum recorded methane concentrations and the maximum steady state carbon dioxide readings recorded during the CGL monitoring rounds. This resulted GSVs between

[25] CIRIA, (2007). *Assessing Risks Posed by Hazardous Ground Gases to Buildings*. CIRIA Report C665.
[26] BSI Standards Publication, *BS 8485:2015+A1:2019. Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings.*

0.0001 l/hr and 0.058 l/hr for carbon dioxide (Appendix H). However, the steady state flow of 2.8 l/hr, which generated the highest GSV value, is thought to have been related to instrumental error. This is due to the flow rate remaining below 0.1l/hr until 120 seconds after which the flow rate progressively increased.

Table 11. Ground Gas Risk Assessment

Borehole	*Response Zone Strata*	*Response Zone Depth*	*Steady State Flow (l/hr)*	*CO_2 concentration (%)*	*CH_4 concentration (%)*	*GSV for CO_2 (l/hr)*	*Characteristic Gas Situation*
BH1	White Chalk	5.0-15.0	<0.1	1.3	<0.1	0.0013	CS1
WS1	Clay-with-Flints	0.5-5.0	<.0.1	0.9	<0.1	0.0009	CS1
WS4	Clay-with-Flints	0.5-5.0	2.8	2.1	<0.1	0.058	CS1
WS5	Clay-with-Flints	0.5-5.0	<0.1	7.5	<0.1	0.0075	CS1
WS9	Clay-with-Flints	0.5-5.0	<0.1	2.4	<0.1	0.0024	CS1

Based on all five boreholes falling under Characteristic Gas Situation 1 it is considered that the overall risk of ground gas at the site is low, and that Characteristic Situation 1/National House Building Council Green[27] can be adopted for the site. No specific gas protection measures are required for the site as a result.

7.5 Risks to Vegetation and Plants

Plant growth can be affected by phytotoxic contaminants, such as copper, boron, nickel and zinc. As indicated within Table 7 within Appendix K, only the US_{95} concentration of zinc (206.00) exceeds the general assessment criteria (200) with an elevated zinc US_{95} being principally driven by elevated readings in the south of the site (TP4 and WS4). However, the exceedance is only marginal and, therefore, the risk to vegetation and plants is considered to be low for the proposed development. It is also noted that visual signs of vegetative distress were not recorded whilst on site.

7.6 Risks to Buried Water Supply Pipes

With reference to Table 8 within Appendix K, elevated concentrations of hydrocarbons have been recorded in the shallow soils in the north of the site, presenting a moderate risk where Made Ground remains. Elevated concentrations of organics have not been recorded across the remainder of the site representing a low risk. Barrier pipes may be required in the north of the site where Made Ground remains. It is recommended that the water supply company is contacted to confirm their requirements for water supply pipes.

[27] NHBC (2007). *Guidance on Evaluation of Development Proposals on Sites Where Methane and Carbon Dioxide are Present.* Revision 4.

7.7 Semi-Quantitative Risk Assessment

The qualitative risk assessment has been updated based on the findings of the ground investigation and the potential pollutant linkages in accordance with LCRM and is presented within Table 12 below. A pictorial conceptual site model is included as Figure 4.

Table 12. Quantitative Risk Assessment

Potential Source/Medium	*Potential Exposure Route*	*Potential Receptor*	*Severity*	*Probability*	*Risk Rating*	*Comments*
Explosive/ asphyxiating gases/vapours from underlying soils (Made Ground if present) and potential on and off-site sources	Migration of gases and vapours through the surface via permeable soils and drainage & services	Internal building spaces & future occupiers	Severe	Unlikely	Low	Made Ground represents a limited source of ground gases which would not be generated at a rate to produce volumes sufficient to result in flow into proposed buildings. The cohesive and low total organic carbon (TOC) % nature of the Clay-with-Flints Formation would also result in a low ground gas risk with the deep chalk being the only main probably gas source. However, the overlying cohesive strata of the Clay-with-Flints Formation may act as a barrier to limit vertical gas migration. The results of the gas monitoring indicate CS 1 where no gas protection measures required.
Organic/ inorganic contaminants such as hydrocarbons, PAH and asbestos within underlying soils (based on historical on-site and off-site sources)	Direct/indirect ingestion of soil and dust, inhalation of particle vapours and asbestos fibres and dermal contact	Construction workers	Minor	Likely	Low – assuming use of PPE and good site practices	Construction workers may come into contact with contamination within shallow soils impacted by asbestos, PAHs and TPH. However, the exposure will be short term and risk mitigated by adoption of good/ safe working practise, appropriate health and safety mitigation measures and PPE.
		Future site users	Medium	Low likelihood	Moderate / Low	Where the Made Ground is exposed at finished level in gardens and areas of soft landscaping there is a potential risk to future site occupiers and mitigation will be necessary (removal of Made Ground or placement of soil capping layers).
	Direct contact with underground structures and services	Buildings and structures	Mild	Likely	Moderate/Low	Sulfate content in soils will require consideration in the design of buried concrete. The risks to new water supply pipes are considered to be Moderate to low. Barrier water supply pipes may be required where Made Ground exists, subject to agreement with the local water company.

Potential Source/Medium	*Potential Exposure Route*	*Potential Receptor*	*Severity*	*Probability*	*Risk Rating*	*Comments*
	Root uptake	Plants and vegetation	Minor	Low likelihood	Very Low	Existing topsoil / Made Ground represents a low risk to plants and vegetation due to generally low concentrations of phytotoxic elements. US_{95} for zinc marginally exceeds the GAC due to elevated values in the south of the site posing a minor risk. Therefore, capping will be required where Made Ground present at formation level. No signs of vegetative stress have been recorded on site.
Organic/inorganic contaminants within groundwater (perched water within the Made Ground)	Direct contact and ingestion of contaminated groundwater	Future site users	Medium	Unlikely	Low	Construction workers are very likely to come into contact with perched groundwater during excavation works which could include contaminants such as TPHs, PAHs and phenols. However, the risk can be mitigated through safe practices as well as the use of suitable PPE. Hardstanding will limit contact for future site users.
		Construction workers	Minor	High likelihood	Moderate/ Low	
		Off-site residents	Medium	Unlikely	Low	
	Inhalation of vapours	Future site users	Medium	Unlikely	Low	No significant source identified during ground investigation.
	Vertical migration	Principal Aquifer (White Chalk Subgroup)	Medium	Low Likelihood	Moderate/Low	The predominantly cohesive nature of the Clay-with-Flints will limit vertical migration to groundwater aquifers at depth. No free product or gross contamination has been identified in the shallow soils. However, leached concentrations of PAHs, TPHs and phenols which exceed drinking water values have been identified from the Made Ground. Piling may create a preferential pathway (if adopted and depending on methodology) between the Made Ground and deep aquifer of the Chalk, and therefore, if used, a PWRA should be drafted to reassess the risk to the deep aquifer.
	Direct contact with underground structures and services	Buildings and structures	Mild	Likely	Moderate/Low	Buried concrete to be designed as appropriate for ground conditions.

8. GEOENVIRONMENTAL RECOMMENDATIONS

The site investigation has identified generally moderate to low risks to identified receptors associated with contaminant concentrations in the shallow soils and perched water. Notwithstanding this, elevated concentrations of TPHs, PAHs and asbestos have been identified in the Made Ground which present a potential risk to future site occupiers where this material is exposed at finished level.

No unacceptable risks have been identified to controlled water receptors in the absence of viable pathways.

The risks associated with ground gases are considered to be low and no further monitoring / assessment or specific mitigation measures are considered to be required in this regard.

Whilst the existing Grade II listed structure, as well as the vegetated and spatially extensive nature of the site, has limited coverage for ground investigation, it is considered that the potential for unencountered contamination may be suitably addressed with a watching brief and discovery strategy during ground works.

8.1 Recommendations

- A remediation strategy will need to be completed for the site in light of the recorded contamination.
- A contamination watching brief and discovery strategy will need to be maintained during demolition and ground works, including site inspections by a suitably qualified geoenvironmental engineer.
- Removal of the Made Ground and installation of a growth medium or capping layer in areas of soft landscaping and private gardens.
- Standard polyethylene (PE) pipes and metal pipes (but not copper due to elevated pH concentrations) are considered appropriate for use for drinking water supplies. It is recommended that the water supply company is contacted to confirm their requirements for water supply pipes.
- A preliminary waste characterisation assessment (WM3) has been carried out on the Made Ground chemical soil data obtained during the CGL ground investigation. The results of the assessment indicate that the majority of soil samples analysed would likely be characterised as “not hazardous” with respect to waste disposal. However, the sample containing Made Ground

material encountered at WS5 and WS6, was classified as “hazardous” due to elevated TPH and PAHs within the samples. Made Ground sampled at TP3 was classified as “not hazardous” with respect to the WM3 assessment however is considered to be hazardous on account of containing >0.1% free asbestos fibres. The Made Ground from the vicinity of WS5, WS6 and TP3 should be disposed of at a hazardous waste facility. All other waste should be subject to a full waste assessment supported by Waste Acceptance Criteria testing to confirm disposal routes.

9. GEOTECHNICAL RECOMMENDATIONS

9.1 General

The following sections of this report provide preliminary recommendations regarding the geotechnical aspects of the development based on the information obtained during the ground investigations and the laboratory results.

9.2 Geotechnical Design Parameters

Geotechnical design parameters are based on the in situ SPT data, soil descriptions, results of the laboratory testing and published data. Based on the findings of the ground investigation, design parameters are provided within Table 13. These values are considered to be characteristic and are unfactored (Serviceability Limit State) parameters. Perched groundwater was identified on site however, no deeper aquifer within the chalk was encountered during the works. Therefore, a moderately conservative groundwater level of 125mOD has been adopted.

Table 13. Summary of Geotechnical Parameters

Stratum	*Approx. Level to Top of Stratum (mOD)*	*Bulk Unit Weight γ_b (kN/m³)*	*Undrained Cohesion c_u (kPa) [c']*	*Friction Angle f' (°)*	*Young's Modulus E_u (MPa) [E']*	*Base Stress (kPa)*
Made Ground (cohesive)[a]	172	18	20 [0]	21	8[b] [6.4][c]	-
Clay-with-Flints Formation	171.5	19	50 [0]	24[d]	20[b] [16][c]	-
Structureless White Chalk	169	20	-	31[e]	8[f] [6][f]	1000[e]
Structured White Chalk	165	20	[20]	39[e]	[500][e]	6000[e]

a. Material is heterogeneous however assumed to be cohesive for assigning design parameters
b. Eu = 0.4*c_u from Padfield C J and Sharrock M J, 1983. Settlement of structures on clay soils.
c. *Based on 0.8E_u – Based on CIRIA R143 p.87.*
d. BSI Standards Publication, BS 8002: 2015, Code of practice for earth retaining structures.
e. CIRIA C574 Engineering in Chalk
f. CIRIA C574 Engineering in Chalk 7.5

9.3 Preliminary Desiccation Assessment

There is indication of potential desiccation near trees within the Clay-with-Flints Formation and further assessment may be required. The Clay-with-Flints Formation has an average medium volume change potential based on an average modified plasticity index of 30.5%. Foundations should be designed as appropriate.