5 PRELIMINARY GEOTECHNICAL CONSTRAINTS

5.1 Design class

BS EN 1997-1 defines three different Geotechnical Categories that structures may fall into, which are summarised as follows:

- Category 1: Small and relatively simple structures for which it is possible to ensure that the fundamental requirements will be satisfied on the basis of experience and qualitative geotechnical investigations; with negligible risk;
- Category 2: Conventional types of structure and foundation with no exceptional risk or difficult ground or loading conditions; or
- Category 3: Structures or part of structures, which fall outside limits of Geotechnical Categories 1 and 2. Examples include very large or unusual structures; structures involving abnormal risks, or unusual or exceptionally difficult ground or loading conditions; structures in highly seismic areas; structures in areas of probable site instability or persistent ground movements that require separate investigation or special measures.

Based on the information provided above on the proposed development and in view of the anticipated ground conditions, a Geotechnical Category of Category 2 has been assumed for the purposes of designing the geotechnical investigation. This should be reviewed at all stages of the investigation and revised where necessary.

5.2 Preliminary geotechnical hazards assessment

A summary of commonly occurring geotechnical hazards associated with the anticipated geology outlined in **Section 3.4** above is given in **Table 11** together with an assessment of whether the site may be affected by each of the stated hazards.

Table 11 Summary of preliminary geotechnical risks that may affect site

Hazard category	Hazard status based on desk study findings and proposed development		Engineering considerations if hazard affects site
	Could be present and/or affect site	Unlikely to be present and/or affect site	
Sudden lateral changes in ground conditions	☒	☐	Variation in depth of made ground – potentially associated with infilled basement(s) to the south. Likely to affect ground engineering and foundation design and construction

Hazard category	Hazard status based on desk study findings and proposed development		Engineering considerations if hazard affects site
	Could be present and/or affect site	Unlikely to be present and/or affect site	
Shrinkable clay soils	☒	☐	Design to NHBC Standards Chapter 4 or similar
Highly compressible and low bearing capacity soils, (including peat and soft clay)	☒	☐	Likely to affect ground engineering and foundation design and construction
Silt-rich soils susceptible to rapid loss of strength in wet conditions	☐	☐	Likely to affect ground engineering and foundation design and construction
Running sand at and below water table	☐	☒	Likely to affect ground engineering and foundation design and construction
Karstic dissolution features (including 'swallow holes' in Chalk terrain)	☒	☐	May affect ground engineering and foundation design and construction – refer to Section 4.1.2
Evaporite dissolution features and/or subsidence	☐	☒	May affect ground engineering and foundation design and construction
Ground subject to or at risk from landslides	☐	☒	Likely to require special stabilisation measures
Ground subject to peri-glacial valley cambering with gulls possibly present	☐	☒	Likely to affect ground engineering and foundation design and construction
Ground subject to or at risk from coastal or river erosion	☐	☒	Likely to require special protection/stabilisation measures
High groundwater table (including waterlogged ground)	☐	☒	May affect temporary and permanent works
Rising groundwater table due to diminishing abstraction in urban area	☐	☒	May affect deep foundations, basements and tunnels
Geological faults, fissures and break lines	☐	☒	May affect ground engineering and foundation design and construction
Underground mining including shafts and adits (e.g. coal, mineral)	☐	☒	Likely to require further assessment including potentially special stabilisation measures

Hazard category	Hazard status based on desk study findings and proposed development		Engineering considerations if hazard affects site
	Could be present and/or affect site	Unlikely to be present and/or affect site	
Effects of extreme temperature (e.g. cold stores or brick kilns/furnaces)	☒	☐	Likely to affect ground engineering and foundation design and construction
Existing sub-structures (e.g. tunnels, foundations, basements, and adjacent sub-structures)	☒	☐	Likely to affect ground engineering and foundation design and construction
Filled and made ground (including embankments, infilled ponds and quarries)	☒	☐	Likely to affect ground engineering and foundation design and construction
Adverse ground chemistry (including expansive slags and weathering of sulphides to sulphates)	☐	☒	May affect ground engineering and foundation design and construction
Site topography	☐	☒	May affect ground engineering and foundation design and construction
Note: Seismicity is not included in the above table as this is not normally a design consideration in the UK.			

5.2.1 Chalk

In view of the prevailing ground conditions, with Chalk at shallow depth beneath the site, it is normal practice to consider the potential risk of ground subsidence related to the presence of swallow holes and other natural chalk solution features or man-made cavities.

Based on the Edmund's risk assessment model for natural dissolution features referred to in CIRIA Report C574 (Lord et al. 2002), the site falls into the 'very low anticipated subsidence risk' category. With reference to Edmund's database of known natural and man-made chalk solution features there are no such features in the immediate vicinity of the site. With reference to Edmund's database of known natural and man-made chalk solution features there is a single natural solution feature within 500 m of the study site, associated with a subsidence doline, some 239 m to the west / northwest of the site.

6 INITIAL CONCEPTUAL SITE MODEL

In the UK land contamination is assessed using a risk-based approach taking account of the magnitude (severity of the hazard) and likelihood (probability) of occurrence. A ‘receptor’ is something that could be adversely affected by contamination (e.g. people, an ecological system, property or a water body). A ‘pathway’ is a route or means by which a receptor is or could be exposed to or affected by a contaminant. A ‘contaminant source’ is a hazard but it can only pose a risk to a receptor where a pathway is present. The relationship between sources, pathways and receptors are referred to as a conceptual site model. A risk can only be released where a contaminant source, pathway and receptor are all in place, referred to as a ‘pollutant linkage’.

6.1 Potential soil, soil vapour and groundwater linkages

6.1.1 Potential sources of contamination

Potential sources of soil and groundwater contamination identified from current activities and the history of the site and surrounding area are presented in **Table 12**. Ground gas sources are addressed in the next section.

Table 12 Potential sources of soil and groundwater contamination

Potential sources	Contaminants of concern
On-site Historical	
Hatfield Brewery (c. 1800 to 1920).	Potentially petroleum hydrocarbons / fuel oils, Polycyclic aromatic hydrocarbons (PAHs), asbestos
Warehouse-type building in north of site (c. late 1800’s to 1930’s).	Petroleum hydrocarbons, PAH, asbestos
Works – (c. 1940’s to c. 1970’s).	Petroleum hydrocarbons, PAH, asbestos, hydrocarbons
Off-site Current	
Launderette	No current potential sources have been identified associated with this small unit, however, potentially organic solvents if dry cleaning practices also operate.
Car Parking in the northern portion of the site	Petroleum hydrocarbons
Existing retail, office and fast-food units	No current potential sources have been identified.
Made Ground (i.e. fill material).	Unknown fill material (but potentially including heavy metals, ash, clinker, sulphates, PAHs, asbestos etc.).
Off-site	
Electricity Substation	Polychlorinated Biphenyls (PCBs)
Garage (assumed automotive), immediately east of site	Fuel oils, lubricating oils, PAHs.

Potential sources	Contaminants of concern
Various industrial land uses including: Smithy, 100 m SW and 120 m SW (c. late 1800's to 1920s), Gas Works, 180 m SW (c. late 1800's to 1920's), unspecified 'works', 40 m NW, 120 m S, 90 m SW (1960's to 1990's), Woodworks Factory, 150 m NW, Printing Works, 120 m W, Tool Factory 170 m SW (c. late 1960's to late 1990's), Heating and Ventilation Works (c1980's to 2000's).	Fuel oils, lubricating oils, heavy metals, PCBs, PAHs, solvents and other common industrial contaminants.
Railway, 60 m west of site (c. 1800s-present)	Fuel oils, lubricating oils, heavy metals, PAHs, PCBs, ash, sulphate, herbicides and asbestos.

The principal source of contamination associated with the historic activities across the site relate to the former use as Hatfield Brewery and 'Works', particularly in the southern portion of the site. These former land-uses also had the potential to impact upon the made ground that is likely to be present across the site. Furthermore, there is the potential for any former basements to be infilled with potentially contaminated material. The potential for the existing site operations to have a contaminative threat to the site is considered to be low owing to the widespread cover of hardstanding and generally low risk land-use.

In terms of off-site sources, the industrial activities to the west of the site (both former and current), including the railway line, have the most potential to be a contaminative threat to the site. However, the distance from the site and general topography of the surrounding area suggest that the potentially most contaminative surrounding land-uses are unlikely to impact the subject site directly.

6.1.2 Sensitive receptors and linking exposure / migration pathways

Sensitive receptors identified at or in the vicinity of the site that could be affected by the potential sources identified above comprise:

- end users of the site who may have acute exposure to sources of contamination on a regular and predictable basis [ingestion, inhalation of soil / dust particulates or contaminant vapours, dermal contact (absorption through skin), and consumption of garden vegetables and fruit];
- current adjacent site users – residential, commercial, public open space users* [migration of contamination via dust/fibre deposition, vapour or groundwater migration combined with inhalation*];
- controlled waters, being defined as all surface water, groundwater or perched water [migration through granular Glacial Deposits]; and

- building structures and services placed in or on the ground [contact with aggressive/contaminated ground, gas migration through granular Glacial Deposits between the site and source of any potential ground gas].

Potential linking pathways are shown in brackets for each item above.

Please note that construction workers and future maintenance workers have not been identified in the conceptual model as receptors because risks are considered to be managed through health and safety procedures according to the CDM Regulations.

Ecological receptors are only considered within the conceptual model in the context of statutory protected sites.

6.2 Potential ground gas linkages

6.2.1 Ground gas generation potential

Potential ground gas sources identified for the site and surrounding are shown in **Table 13**.

Table 13 Potential ground gas sources

Potential sources	Indicative ground gas generation potential (CIEH, 2008)	Additional information
On-site		
Made ground with low degradable organic content (e.g. up to 5% organic material and no easily degradable waste).	Very low	Composition of made ground unknown, however not anticipated to be present in significant quantities nor contain putrescible material.

Given the anticipated ground conditions set out above, no significant ground gas sources on or off-site have been identified and therefore this pollutant linkage is not considered any further.

6.3 Preliminary risk assessment

The preliminary risk assessment findings and potentially complete contaminant linkages are shown in **Table 14** overleaf. The risk classification based on the combination of hazard consequence and probability using a risk matrix from CIRIA C552 (Rudland et al., 2001), a summary of which is included in **Appendix G.** This relates to Tier 1 preliminary risk assessment in LCRM (Environment Agency, 2021).

Table 14 Risk estimation for potentially complete contaminant linkages

Potential source	Potential receptor	Possible pathway	Likelihood	Severity	Potential risk	Justification
Car park in northern portion of the site **(Point source)**	Controlled waters Human health (future site users) Human health (construction workers) Building materials	Leakage into unsaturated zone and migration to shallow groundwater Migration via shallow groundwater flow Ingestion of contaminated soil, dust, liquid Inhalation of contaminated dust and vapours/gases Contact with contaminated ground/liquid	Unlikely	Medium	**Low**	Whilst low rise housing with private gardens is understood to be constructed in this part of the site, no evidence of vehicle fuel spills was observed during the site walkover and the hardstanding appeared to be in a good condition. The risks are considered to be very low where buildings and/or hardstanding are to be constructed across this particular area. The risks would be considered moderate should hydrocarbon contamination be encountered in this area during enabling works.
Made Ground across site (may include heavy metals, PAH, sulphate, asbestos, etc.) **(Diffuse contamination)**	Human health (future site users) Controlled waters Vegetation Building materials	Leakage into unsaturated zone and migration to shallow groundwater Migration via shallow groundwater flow Ingestion of contaminated soil, dust, liquid	Low likelihood	Medium	**Low / Moderate**	Private gardens and soft landscaped areas to be created as part of redevelopment works. In these areas, infiltration of rainwater would be expected to occur, which could leach potential contaminants from the soil and carry them into the underlying groundwater.

Potential source	Potential receptor	Possible pathway	Likelihood	Severity	Potential risk	Justification
Made Ground across site (may include heavy metals, PAH, sulphate, asbestos, etc.) **(Diffuse contamination)**		Inhalation of contaminated dust and vapours/gases Contact with contaminated ground/liquid Root uptake				Future site users also have the potential to come into direct contact with contaminated soils in these areas of the site. The risks are considered to be very low in areas of the site overlain by buildings and/or hardstanding.
Former light industrial use of the site – Hatfield Brewery and Unspecified Works. **(Point / Diffuse)**	Controlled waters Human health (construction workers)	Leakage into unsaturated zone and migration to shallow groundwater Migration via shallow groundwater flow Dermal contact with contaminated soil/water/liquid	Likely	Medium	**Moderate**	Given industrial history of site and anticipated groundwater within the Kesgrave Catchment Subgroup
Railway Land (off-site) **(Diffuse)**	Human health (construction workers)	Leakage into unsaturated zone and migration to shallow groundwater Migration via shallow groundwater flow Surface run-off (although unlikely due to distance)	Unlikely	Medium	**Low**	Unlikely to affect controlled waters beneath the site owing to the anticipated direction of groundwater flow.
Various off-site sources including light industrial / manufacturing	Controlled waters	Leakage into unsaturated zone and migration to shallow groundwater	Unlikely	Medium	**Low**	Unlikely to affect controlled waters beneath the site owing to the

Potential source	Potential receptor	Possible pathway	Likelihood	Severity	Potential risk	Justification
(former and current) **(Diffuse)**		Migration via shallow groundwater flow Surface run-off (although unlikely due to distance)				anticipated direction of groundwater flow.

Risk matrix		Consequences			
		Severe	Medium	Mild	Minor
Probability	Highly likely	Very high	High	Moderate	Moderate/low
	Likely	High	Moderate	Moderate/low	Low
	Low likelihood	Moderate	Moderate/low	Low	Very low
	Unlikely	Moderate/low	Low	Very low	Very low

Potentially complete contaminant linkages with a potential risk of moderate to low or higher identified in **Table 14** comprise:

- Direct contact, ingestion and dust/vapour inhalation of contaminants of potential concern (COPC) within shallow made ground in areas of private gardens and soft landscaping by future users of the site;
- Root uptake of COPC by proposed vegetation;
- Leakage of COPC from shallow made ground / past industrial use into unsaturated zone and vertical migration to shallow groundwater;
- Lateral migration of COPC within shallow aquifer to wider groundwater body; and
- Degradation of plastic utilities and building structures by COPC within made ground.

These potentially complete contaminant linkages need to be assessed further through appropriate site investigation to target the identified sources of potential contamination and assess the feasibility of identified pathways.

6.4 Data gaps and uncertainties

Key data gaps and uncertainties identified in the CSM at desk study stage include:

- Site was developed before first published OS map and prior history not known;
- There are no previous investigations available for the site, therefore no information on actual concentrations of contaminants in soil and groundwater or ground gas at this stage; and
- Groundwater depth and flow direction are conceptual at this stage.

7 SITE INVESTIGATION STRATEGY & METHODOLOGY

7.1 Introduction

RSK carried out intrusive investigation works and subsequent monitoring of boreholes between 2nd and 4th February 2011.

7.2 Objectives

The specific objectives of the investigation were as follows:

- To establish the ground conditions underlying the site including the extent and thickness of any made ground;
- To investigate specific potential sources of contamination identified in initial CSM; and
- To assess geotechnical properties of soils.

7.3 Selection of investigation methods

The techniques adopted for the investigation were chosen with consideration of the objectives and site constraints, which are described below.

Cable percussion drilling was chosen based on the targeted drill depth, requirement for in-situ geotechnical data, the opportunity to collect both disturbed and undisturbed samples and install monitoring wells. This was supplemented by mechanically excavated trial pitting and manually advanced trial pits to obtain a number of investigation locations and achieve greater visibility of the Made Ground for an accurate log of the upper strata.

Prior to conducting intrusive works, utility service plans were obtained and buried service clearance undertaken in line with RSK's health and safety procedures.

7.4 Investigation strategy

The purpose of the intrusive investigation is to aid confirmation of the ground conditions and potential pollutant linkages identified within the Preliminary CSM. The techniques adopted for the investigation have been chosen considering the anticipated ground conditions and the proposed development.

With respect to ground contamination issues, the investigation was designed to target specific potential sources identified within the Preliminary CSM, and also to provide targeted and non-targeted coverage across the site in relation to the proposed redevelopment.

7.4.1 Site work undertaken

The site work was carried out between 2nd and 4th February 2011, and comprised the activities summarised in **Table 15**, below, which includes a justification for each exploratory hole location. The investigation and the soil descriptions were carried out in general accordance with BS5930:1999 - Code of Practice for Site Investigations. The exploratory hole logs and other site work records are presented in **Appendix H**.

Table 15 Exploratory hole and monitoring well location rationale

Investigation type	Number	Designation	Monitoring well installation	Rationale
Boreholes - by light cable percussive methods	2	BH1 to BH2	BH2 Gas/ groundwater (see below)	To prove the geological succession beneath the site, obtain geotechnical data and to determine the contamination status of the shallow soils in relation to the proposed redevelopment, to install ground gas monitoring wells.
Boreholes – by drive-in-sampler methods	3	WS1 to WS3	WS2 Gas/ groundwater (see below)	To prove the geological succession, obtain geotechnical data, to determine the contamination status of the ground and install additional dual purpose groundwater and gas monitoring wells. These exploratory holes were located in the area proposed for the construction of residential dwellings (north of the site)
Boreholes – by drive-in-sampler methods	1	WS4	WS4 Gas/ groundwater (see below)	To prove the geological succession, obtain geotechnical data and to determine the contamination status of the ground.
Monitoring well installations	3	WS2, WS4, BH2	N/A	Ground gas and groundwater monitoring installations
Trial Pits - excavated by hand	3	TP1 to TP3	N/A	To accurately log the upper strata in areas proposed for car parking as part of the proposed redevelopment, provide in-situ CBR determinations and determine the contamination status of the shallow soils.
PID screening of samples	All*	N/A	N/A	Detection of volatile organic compounds

Investigation type	Number	Designation	Monitoring well installation	Rationale
Water level monitoring in shallow installations	3	WS2, WS4, BH2	N/A	Measurement of depth to groundwater
Ground gas monitoring in monitoring well installations	3	WS2, WS4, BH2	Gas/ groundwater	Measurement of ground gas emission rates

* All shallow samples of made ground and natural underlying soils tested.

The investigation points were located approximately by reference to physical features present on the site at the time of investigation. The ground levels at the exploratory locations have not been measured.

An exploratory hole location plan is presented as **Figure 2**.

7.4.2 Implementation of investigation works

The exploratory holes were logged by an engineer in general accordance with the recommendations of BS5930:A1:2020 (which incorporates the requirements of BS EN ISO 14688-1, 14688-2 and 14689-1).

The soil sampling and analysis strategy was designed to characterise each encountered soil strata, permit an assessment of the potential contaminant linkages identified and investigate the geotechnical characteristics. In addition, samples were taken to allow for geo-environmental and geotechnical testing to be undertaken.

Soils collected for laboratory analysis were placed in a variety of containers appropriate to the anticipated testing suite required. They were dispatched to the laboratory in cool boxes under chain of custody documentation. Samples were stored in accordance with the RSK quality procedures to maintain sample integrity and preservation and to minimise the chance of cross contamination.

Selected samples were placed in polythene bags for headspace screening with a photo-ionisation detector (PID) fitted with a 10.6 eV bulb. The PID screening results are presented on the exploratory hole records.

7.5 Monitoring programme

7.5.1 Ground gas and groundwater monitoring

The preliminary CSM indicated that the made ground on site would be classed as a low risk source and was not considered any further. Whilst made ground was anticipated to be present, associated with historic phases of demolition and construction, it was not anticipated to be present in significant quantities and an element of partial removal would occur in any case during the construction of the proposed basement car park.

The intrusive investigation encountered a maximum thickness of made ground of 4.9 m and an average thickness of around 2.3 m. On this basis, ground gas monitoring was carried out as a precautionary measure to identify whether ground gases were present associated with this increased thickness of material.

Two rounds of monitoring were undertaken on return visits of the site to establish baseline conditions. An infrared gas meter was used to measure gas flow, concentrations of carbon dioxide (CO2), methane (CH4) and oxygen (O2) in percentage by volume, while hydrogen sulphide (H2S) and carbon monoxide (CO) were recorded in parts per million.

Initial and steady state concentrations were recorded. In addition, during the first monitoring round, all wells were screened with a PID to establish if there are any interferences and cross-sensitivity of other hydrocarbons with the infrared gas meter.

The atmospheric pressure before and during monitoring, together with the weather conditions, were recorded. The monitoring included periods of falling atmospheric pressures and after/during rainfall.

All ground gas monitoring results together with the temporal conditions are contained within **Appendix I**. Equipment calibration certificates are available on request.

7.6 Laboratory testing

Laboratory testing was undertaken at a UKAS accredited laboratory with ISO17025 and MCERTS accredited test methods were specified where applicable for contamination testing and as shown in the laboratory test certificates appended.

7.6.1 Chemical analysis of soil samples

The programme of chemical tests was undertaken on samples obtained from the intrusive investigation as presented in **Table 16**. The scope of the testing undertaken is based on the findings of the Phase 1 study discussed above and includes the Contaminants of Concern listed within the Preliminary CSM. Additional tests may also have been specified as a consequence of observations made from the exploratory holes during the investigation.

The testing was carried out to assess the levels of contamination within the made ground and natural soils encountered on the site with regard to identified receptors as detailed within the Conceptual Model. Testing was undertaken by a UKAS accredited laboratory (Envirolab). MCERTS accredited test methods were specified where applicable.

The programme of chemical tests undertaken on soil samples obtained from the intrusive investigation is presented in **Table 16** with the laboratory testing results contained in **Appendix J**.

Table 16 Summary of chemical testing of soil samples

Stratum	Tests undertaken	No. of tests
Made Ground	Heavy Metals Suite – As, Cd, tCr, Pb, Hg, Se, wsB, Cu, Ni, Zn, pH Speciated PAH	14 11

Stratum	Tests undertaken	No. of tests
	TPHCWG (Speciated TPH) Total TPH Polychlorinated Biphenyls Phenols – Total monohydric Fibre Screen Total Organic Carbon (TOC)	2 4 1 6 11 4
Glacial Deposits (Granular)	Heavy Metals Suite – As, Cd, tCr, Pb, Hg, Se, wsB, Cu, Ni, Zn, pH Speciated PAH	2 2

7.6.2 Geotechnical analysis of samples

The programme of geotechnical tests undertaken on samples obtained from the intrusive investigation is presented in **Table 17**, the main purpose of which was to accurately classify the natural soils beneath the site. Where appropriate, testing was undertaken in accordance with BS 1377:1990 Method of Tests for Soils for Civil Engineering Purposes within RSK's UKAS accredited laboratory.

Tests carried out in order to classify the concrete class required on site have been undertaken following the procedures within BRE SD1:2005 by a UKAS accredited laboratory (Structural Soils). The laboratory testing results are contained in **Appendix K**.

Table 17 Summary of geotechnical testing

Strata	Tests undertaken	No of Tests
Made Ground	Moisture Content Plasticity Index pH and water soluble sulfate	1 1 5
Lowestoft Formation	Moisture Content Plasticity Index Undrained Triaxial Compression Test pH and water soluble sulfate	5 3 2 2
Kesgrave Catchment Subgroup (Granular)	Particle Size Distribution pH and water soluble sulfate	2 2

8 SITE INVESTIGATION FACTUAL FINDINGS

The results of the intrusive investigation and subsequent geo-environmental and geotechnical laboratory analysis undertaken are detailed below.

8.1 Ground conditions encountered

The descriptions of the strata encountered, notes regarding visual or olfactory evidence of contamination, list of samples taken, field observations of soil and groundwater, in-situ testing and details of monitoring well installations are included on the exploratory hole records presented in **Appendix H**.

The exploratory holes revealed that the site is underlain by a variable thickness of made ground overlying an interbedded sequence of granular and cohesive Glacial Deposits comprising Lowestoft Formation and Glacial Gravels. The White Chalk Subgroup was not encountered within the terminal depth of the investigation. This generally appears to confirm the stratigraphical succession described within the Preliminary CSM.

For the purpose of discussion, the ground conditions encountered during the fieldworks are summarised in **Table 18** with the strata discussed in subsequent subsections.

Table 18 General succession of strata encountered

Stratum	Exploratory holes encountered	Depth to top of stratum m bgl	Proven thickness (m)
Made Ground	All	0.00	1.8 to 4.9
Glacial deposits (shallow granular)	BH1, BH2, WS2, WS3, WS4	1.8 to 4.9	0.50 to 3.0
Lowestoft Formation	BH1, BH2, WS1, WS2, WS3, WS4	2.7 to 5.6	6.5 to 7.9 (thickness proven in BH1 and BH2 only)
Kesgrave Catchment Subgroup (deep granular)	BH1, BH2	11.8 to 13.5	Proven to 14.5 m bgl

8.1.1 Made ground

The exploratory holes encountered a variable thickness of made ground across the site ranging from 1.8 m in the northern portion of the site to 4.9 m in the southern portion of the site (within the Salisbury Square area).

In general terms, the made ground in the northern portion of the site (with the exception of BH1) comprised granular made ground deposits comprising an initial granular layer (sub-base) with variable proportions of flint and concrete overlying clayey gravelly sand with flint and brick. Decomposing organic matter was noted within the sandy deposits in WS3 at 1.6 m depth.

The made ground soils in the remaining exploratory locations (generally to the south of the site, except BH1) predominantly comprised a sandy gravelly clay with variable proportions of flint, brick, concrete and occasional ash and clinker-rich soils. Locally, fragments of bitumen (TP2), chalk (TP3) and ceramics (WS1). Occasional lenses of decomposing organic matter were noted within the cohesive made ground deposits between 0.9 and 1.9 m depth within WS1.

Visual/olfactory evidence of contamination was encountered in the form of ash and clinker within the made ground soils at a number of locations. On-site PID screening of disturbed samples indicated concentrations of volatile organic compounds (VOCs) at <5ppm, indicating the absence of VOCs within the samples.

Roots were generally noted in the shallow made ground soils within the exploratory holes in the areas of soft landscaping within Salisbury Square. However, it is noted that the mature deciduous trees would extend to a greater depth. Roots were also noted within the made ground soils beneath the current car parking area to the north to 0.45 m depth in WS1, at 1.6 m depth in WS3, and to 1.25 m depth in WS4.

A summary of the in-situ and laboratory test results recorded in the stratum are presented in **Table 19**.

Table 19 Summary of in-situ and laboratory test results for made ground

Soil parameters	Range	Reference
Liquid Limit (%)	36*	**Appendix K**
Plastic Limit (%)	17*	**Appendix K**
Plastic Index (%)	17*	**Appendix K**
Modified Plasticity Index (%)	11.39*	-
Plasticity Term	Intermediate*	**Appendix K**
Volume Change Potential (NHBC)	Low*	-
Moisture Content (%)	22*	-
Modified Moisture Content (%)	33*	-
SPT 'N' Values	8 - 47	**Figure 3**
Notes: * Cohesive made ground soils		

8.1.2 Kesgrave Catchment Subgroup (Granular Glacial Deposits)

Granular Glacial Deposits were encountered both above and below the Lowestoft Formation. The shallow granular deposits were encountered in all exploratory locations with the exception of the hand-excavated trial pits and WS1. The hand-excavated trial pits did not extend into natural soils and granular soils were absent above the Lowestoft Formation in WS2.

The shallow granular deposits generally comprised a very loose to medium dense brown/orange silty sand with variable proportions of flint gravel.

The deeper granular deposits were encountered directly below the Lowestoft Formation in exploratory holes BH1 and BH2 and comprised a very dense slightly clayey (BH1 only) sandy gravel.

Visual/olfactory evidence of contamination was not encountered within the granular glacial deposits. On-site PID screening of disturbed samples indicated the absence of VOCs within the samples.

The measured and inferred soil parameters for the stratum are listed in **Table 20**.

Table 20 Summary of Soil Parameters for Granular Glacial Deposits

Soil parameters	Range	Reference
SPT 'N' Values*	4 - 17	**Figure 3**
SPT 'N' Values	90 – 105**	**Figure 3**
Density Term*	Very Loose to Medium Dense	
Density Term	Very Dense	
Notes: * Shallow granular deposits (encountered above the Lowestoft Formation) ** Extrapolated SPT N Values		

8.1.3 Lowestoft Formation

This unit was generally encountered beneath an initial granular layer of Glacial Deposits, with the exception of WS1, where the shallow granular Glacial Deposits were absent.

The Lowestoft Formation comprised a firm to very stiff grey/dark grey sandy gravelly clay with variable proportions of flint and chalk gravels. These deposits were encountered to a maximum depth of 13.5 m bgl in BH2.

Visual/olfactory evidence of contamination was not encountered in the Lowestoft Formation. On-site PID screening of disturbed samples indicated the absence of VOCs within the samples.

No roots were noted in this unit at the locations investigated.

The measured and inferred soil parameters for the stratum are listed in **Table 21**.

Table 21 Summary of Soil Parameters for Lowestoft Formation

Soil parameters	Range	Reference
Liquid Limit (%)	45 – 49	**Appendix K**
Plastic Limit (%)	20 – 22	**Appendix K**
Plastic Index (%)	24 – 27	**Appendix K**
Modified Plasticity Index (%)	21.6 – 22.68	-

Soil parameters	Range	Reference
Plasticity Term	Intermediate Plasticity	**Appendix K**
Volume Change Potential (NHBC)	Medium	-
Moisture Content (%)	16 - 22	-
Modified Moisture Content (%)	16 - 25	**-**
SPT 'N' Values	6 - 67	**Figure 3**
Undrained Shear Strength (kN/m2) measured by Triaxial Testing	236 - 273	**-**
Undrained Shear Strength (kN/m2) inferred from SPT 'N' values	26* - 288	**-**
Undrained shear strength measured by triaxial testing (kN/m^2)		**Appendix K**
Notes: * Based on in-situ SPT test at the surface of the strata		

8.2 Groundwater

8.2.1 Groundwater encountered during intrusive works

Groundwater was only encountered in the form of a perched groundwater table on top of the Lowestoft Formation and at the base of the made ground soils within BH2. Subsequent monitoring has also established the standing level at this location, as shown in **Table 22**.

Table 22 Groundwater Results

Location	Strata m bgl	Strike m bgl	Rise m bgl	Monitoring Results m bgl
BH2	Made Ground	4.9	4.7	4.16 to 4.18
WS2	Made Ground / Glacial Deposits	Dry	Dry	Dry
WS4	Made Ground / Glacial Deposits	Dry	Dry	Dry / 2.41

The findings reflect the perched groundwater table in the deeper area of made ground in the southern portion of the site.

It should be noted that groundwater levels might fluctuate for a number of reasons including seasonal variations. On-going monitoring would be required to establish both the full range of conditions and any trends in groundwater levels.

8.3 Ground Gas

8.3.1 Ground Gas Monitoring Results

Ground gases were monitored in the well installation on two return visits to the site after the main fieldwork and the results are presented in **Appendix I**. The preliminary gas monitoring programme has detected the absence of methane, up to 3.4%vol carbon dioxide and near normal oxygen concentrations, over a monitoring period with atmospheric pressure conditions varying between 999 and 1016 m bar. The results are summarised and interpreted in **Section 9.5**.

8.4 Chemical laboratory results

The soil testing results are presented in **Appendix J**.

The visual inspection at the laboratory identified no materials suspected of potentially containing asbestos and the scheduled laboratory screening for asbestos found no detectable asbestos fibres within the samples of made ground.

8.5 Geotechnical laboratory results

The results of the geotechnical testing are discussed in **Section 12** and presented in **Appendix K**.

8.6 Ground gas monitoring

The results of the ground gas monitoring and testing carried out are given in **Appendix I** and discussed in **Section 9**.

9 GEO-ENVIRONMENTAL ASSESSMENT

9.1 Refinement of initial CSM

The investigation confirmed the presence of a moderate to significant thickness of made ground overlying mixed granular and cohesive glacial superficial deposits to depths in excess of 14.5 mbgl. A persistent groundwater table was not encountered, although perched groundwater was encountered within areas of deeper made ground.

In light of the absence of a groundwater table beneath the site, the following pollutant linkages have been removed:

- Leakage of COPC from shallow made ground / past industrial use into unsaturated zone and vertical migration to shallow groundwater; and
- Lateral migration of COPC within shallow aquifer to wider groundwater body.

All other pollutant linkages identified within the conceptual site model remain unchanged.

9.2 Linkages for assessment

As described in LCRM (Environment Agency, 2021), there are two stages of quantitative risk assessment (QRA), Tier 2 generic (GQRA) and Tier 3 detailed (DQRA). The GQRA comprises the comparison of soil, groundwater, soil gas and ground gas results with generic assessment criteria (GAC) that are appropriate to the linkage being assessed. This comparison can be undertaken directly against the laboratory results or following statistical analysis depending upon the sampling procedure that was adopted. This assessment relates to LCRM Stage 1, Tier 2 generic quantitative risk assessment

Following the refinement of the CSM, the potentially complete contaminant linkages that require further assessment and the methodology of assessment are presented in **Table 23**.

Table 23 Linkages for GQRA

Potentially relevant contaminant linkage	Assessment method
Soil data	
1. Oral, dermal and inhalation exposure with impacted soil, soil vapour and dust by future residents	Human health GAC in **Appendix L** for a proposed “residential with home-grown produce” and “residential without home grown produce” since the proposed end use includes residential gardens, areas of public open space and commercial units.
2. Inhalation exposure of future residents to asbestos fibres	Qualitative assessment based on the asbestos minerals present, their form, concentration, location and the nature of the proposed development.
3. Uptake of contaminants by vegetation potentially impacting plant growth (phytotoxicity)	Comparison of soil data to GAC in **Appendix M** for phytotoxicity.

Potentially relevant contaminant linkage	Assessment method
4. Contaminants permeating potable water supply pipes	Comparison of soil data to GAC in **Appendix N** for plastic water supply pipes using UKWIR (2010) guidance.
Ground Gas	
5. Concentrations of methane and carbon dioxide in ground gas entering and accumulating in enclosed spaces or small rooms in new buildings, which could affect future site users. For methane this could create a potentially explosive atmosphere, while death by asphyxiation could result from carbon dioxide.	Precautionary assessment only and to establish baseline conditions. Gas screening values (GSV) have been calculated using maximum methane and carbon dioxide concentrations with maximum flow rates recorded at the site.

9.3 Methodology and assessment of soil results

The analysis of laboratory results relating to soil samples submitted for testing, including leachate analysis, is included in the following sections.

9.3.1 Oral, dermal and inhalation exposure with impacted soil by future occupants/site users

In order to assess the soil results against the appropriate GAC, the soil results have been split into appropriate data sets by portion of the site, relevant to the oral, dermal and inhalation linkage.

The datasets being considered in the assessment are:

- Data set 1 Made ground in northern part of site; and
- Data set 2 Made ground in southern part of site.

As an initial assessment of each dataset, all soil results in each dataset have been directly compared against the GAC for residential with home-grown produce / residential without home-grown produce end use.

For non-volatile contaminants the human health risk assessment has been conducted to a depth of 1 m. At depths greater than 1 m it is considered that no relevant pathway for human exposure to occur will be present. For volatile contaminants, the human health risk assessment may be conducted on samples collected at depths in excess of 1 m as it is assumed that an inhalation pathway (i.e. from vapours) could potentially be present regardless of the depth of the contamination.

Non-volatile contaminants are considered to be those that have a Henry's Law Constant of less than 0.001 whilst volatile contaminants are considered to be those that have Henry's Law Constants greater than 0.001.

9.3.1.1 *Data set 1 – Made ground in northern part of site*

All concentrations of potential contaminants with samples collected from the northern portion of the site have been directly compared against their respective "residential with home grown produce GAC" as the development proposals in this part of the site include low rise housing with private gardens. A soil organic matter (SOM) of 1 % has been selected. Exceedances are shown in **Table 24** below:

Table 24 Data summary table – Data set 1 (made ground in northern part of site)

Data Set/Material	Determinant	No. of samples tested	GAC (mg/kg)	No of exceedances	Maximum concentration (mg/kg)	
					Value	Location / depth (m bgl)
Made Ground **Northern Portion of Site**	Lead	7	200	1	278	BH1, 0.7

One lead exceedance within BH1 at 0.7 m was identified within the shallow made ground in the northern portion of the site. Due to the proposed terrace house development in the northern end of the site which may include soft landscaping, further assessment surrounding BH1 may be required.

9.3.1.2 *Data set 2 – Southern Portion*

All concentrations of potential contaminants with samples collected from the southern part of the site have been directly compared against their respective "residential without home grown produce GAC" as the development proposals in this part of the site include an area of soft communal landscaping. A soil organic matter (SOM) of 1 % has been selected. Exceedances are shown in **Table 25** below:

Table 25 Data summary table – Data set 2 (made ground in southern part of site)

Data Set/Material	Determinant	No. of samples tested	GAC (mg/kg)	No of exceedances	Maximum concentration (mg/kg)	
					Value	Location / depth (m bgl)
Made Ground **Southern Portion of Site**	Lead	7	310	1	345	TP3, 0.1

A single exceedance was encountered in the southern portion of the site when compared directly against the residential without home grown produce GACs with respect to lead (TP3). As such, remediation and / or further assessment would be required to facilitate the proposed redevelopment plans depending on the final proposed covering.

9.3.1.3 *Summary*

Concentrations of potential contaminants within all samples tested were found to be below their respective GAC, with the exception of lead concentrations within TP3 at 0.1 m and BH1 at 0.7 m.

For the wider site area, the shallow soils encountered are considered suitable for retention; however remediation and / or further assessment may be required in the areas of identified hotspots, depending on the location of the exceedance in relation to hardstand covering or soft surface covering.

9.3.2 Inhalation exposure of future occupants/site users to asbestos fibres

The visual inspection at the laboratory identified no materials suspected of potentially containing asbestos and the scheduled laboratory screening for asbestos found no detectable asbestos fibres within the samples of made ground.

9.3.3 Uptake of contaminants by vegetation potentially inhibiting plant growth (phytotoxicity)

Table 26 Summary of soil results with respect to plant phytotoxicity effects

Substance	Assessment value adopted (mg/kg) from The Soil Code (1998)				Maximum concentration where in excess of assessment value (mg/kg)
	pH <5.5	pH 5.5-6	pH 6-7	pH >7	
Boron	3	4	5	6	None
Copper	250	250	250	250	None
Nickel	50	60	75	110	None
Zinc	200	200	300	300	306mg/kg TP3

In view of the single marginally elevated concentration of zinc encountered within the shallow made ground (0.10 m bgl) in TP3 and concentrations elsewhere of generally <100mg/kg, there are not considered to be any significant risks associated with the phytotoxicity effects from the contaminants within the soils. This assumes that an appropriate depth of topsoil is placed to provide a suitable growing medium in any tree pits and areas of soft landscaping.

9.3.4 Impact of organic contaminants on potable water supply pipes

For initial assessment purposes, the results of the investigation have been compared with the GAC presented in **Appendix N** for this linkage, which are reproduced from *UKWIR Report 10/WM/03/21. Guidance for the Selection of Water Supply Pipes to be used in Brownfield Sites* (UKWIR, 2010).

Mild concentrations of petroleum hydrocarbons in the made ground soils in the vicinity of BH2 may have the potential to permeate plastic water supply pipes. It is therefore recommended that barrier pipe be adopted in this area of the site to protect potable water supplies from this potential threat.

It should be noted that at the time of this investigation the future routes of water supply pipes had not been established, hence the investigation and sampling strategy may not be fully compliant with UKWIR recommendations. Consequently, a targeted investigation and specific sampling/analytical strategy may be required at a later date once the route(s) of the supply pipe(s) are known. In addition, it is recommended that the relevant water supply company be contacted at an early stage to confirm its requirements for assessment, which may not necessarily be the same as those recommended by UKWIR.

9.4 Ground gas risk assessment – bulk gases

9.4.1 Appropriate guidance

The results have been assessed in accordance with the guidance provided in CIRIA C665, *"Assessing risks posed by hazardous ground gases to buildings"* (CIRIA, 2007). In the assessment of risks posed by hazardous ground gases and selection of appropriate mitigation measures, CIRIA C665 identifies two types of development, termed Situation A (modified Wilson & Card method), appropriate to all development excluding traditional low-rise construction, and Situation B (NHBC) only appropriate to traditional low-rise construction with ventilated sub-floor voids.

Both methods are based on calculations of the limiting borehole gas volume flow for methane and carbon dioxide, renamed as the Gas Screening Value (GSV). The Gas Screening Value (litres of gas per hour) is calculated by multiplying borehole flow rate (litres per hour) and gas concentration (percent by volume). The GSV is calculated for both methane and carbon dioxide and the worst case value adopted.

Situation A relates to all development types except low rise housing and, by combining the qualitative assessment of risk (see preliminary CSM in Section 5) with the gas monitoring results, provides a semi-quantitative estimate of risk for a site. The method is based on that proposed by Wilson & Card (1999), which was a development of a method proposed in CIRIA publication R149 (CIRIA, 1995). The method uses both gas concentrations and borehole flow rates to define a characteristic situation for a site based on the limiting borehole gas volume flow for methane and carbon dioxide. Having calculated the worst case GSVs for methane and carbon dioxide, the Characteristic Situation is then determined from Table 8.5 of CIRIA C665.

Situation B is a characterisation system developed by the NHBC (Boyle and Witherington, 2006), which relates only to low rise housing development constructed with a clear ventilated underfloor void. The system provides a risk-based approach that is designed to allow an identification of gas protection for low-rise housing by comparing the measured gas emission rates to generic "Traffic Lights". The Traffic Lights include "Typical Maximum Concentrations" and are provided for initial screening purposes and risk-based GSVs for consideration for situations where the Typical Maximum Concentrations are exceeded. Based on the typical maximum gas concentrations and the GSVs, the appropriate Traffic Light, ranging from Green through Amber 1 and Amber 2 to Red, is determined from Table 30 of CIRIA C665.

In both Situations, it is important to note that the GSV is a guideline value and not an absolute threshold. The GSV may be exceeded in certain circumstances, if the site conceptual model indicates it is safe to do so. Similarly, consideration of additional factors such as very high concentrations of methane, should lead to consideration of the need to increase the Characteristic Situation or Traffic Light.

The site is to be redeveloped with a mixed commercial and residential development and therefore falls under Situation A and B. The gas monitoring data has identified the absence of methane and a maximum concentration of carbon dioxide of 3.4%. A maximum gas flow rate of 0.5l/hr has been recorded. The calculated GSV for carbon dioxide is 0.017l/hr. Based on the GSVs and maximum methane and carbon dioxide concentrations, the site is characterised as Characteristic Situation 1 for the commercial units and Green according to the NHBC traffic light assessment.

For both types of development, CIRIA C665 provides details of the typical scope of protective measures to be adopted for the relevant site characterisation.

For the proposed mixed development, Characteristic Situation 1 and Green classifications require no specific precautions to be taken in relation to ground gas owing to the negligible gas regime identified.

9.4.2 Summary of results

The presence of ground gases has been investigated by monitoring the well installations on two return visits to the site. The results of the monitoring of gas concentrations are summarised in **Appendix I**.

Table 27 Summary of ground gas monitoring results

Bore-hole	Resp-onse Zone / Strata	Probable Source(s) of Ground Gas	No Monitoring Visits	Methane (%)	Carbon Dioxide (%)	Oxygen (%)	Flow Rate (l/hr)	Water Level (m bgl)	Atmospheric Pressure
BH2	MG/ GD	Made Ground	2	<0.1	0.1	20.1-20.2	0.4-0.5	4.16-4.18	999-1016
WS2	MG/ GD	Made Ground	2	<0.1	2.7-3.4	17.1-18.3	0.1	Dry	999-1015
WS4	MG/ GD	Made Ground	2	<0.1	1.2-1.4	18.5-18.8	0.5	Dry – 2.41	999-1015
Key: MG – Made Ground, GD – Glacial Deposits									

The monitoring has recorded maximum concentrations of carbon dioxide ranging between 0.1% and 3.4%, with corresponding slightly depleted oxygen concentrations. The low concentrations recorded are considered indicative of the low gassing potential of the on-site made ground.

BS8485 suggests that the GSV should be derived by multiplying the worse credible (worst case) recorded flow value in any standpipe in that strata or zone with the maximum gas concentration in any other standpipe in that strata or zone. Further guidance is given in BS8485 section 6.3.

Considering the assessment of the gas monitoring results the following maximum GSVs have been derived for the site.

- Carbon Dioxide GSV (0.017 l/hr) = carbon dioxide concentration (3.4 % v/v)/100 x flow rate (0.5 l/hr); and
- Methane GSV (0.0 l/hr) = methane concentration (0.0 % v/v)/100 x flow rate (0.5 l/hr).

Based on the current understanding of the conceptual site model and the assessment undertaken, the site has been classified as CS1 and 'Green', for which ground gas protection measures are not considered to be necessary.

Although limited data has been collected, it is considered that the gas monitoring programme carried out to-date is likely to have established the "worst case" scenario and has characterised the ground gas regime sufficient to enable the confident assessment of risk and subsequent design of an appropriate gas protection scheme(s) for the proposed development.

The risk assessment has been undertaken based on the current understanding of the CSM.

9.5 Uncertainties and implications in refined CSM and GQRA

In accordance with good practice, data gaps and uncertainties in the refined CSM have been identified at this stage. These are summarised in **Table 28** along with the likely implications.

Table 28 Data gaps and uncertainties

Data gap/ uncertainty	Details	Implications
Asbestos not found in made ground samples tested	Although not encountered to date, asbestos containing material (ACM) could still be present in discrete locations	Vigilance should be maintained for any potential ACM or fibrous material during below ground works
No assessment of groundwater was undertaken	There may be contamination in groundwater that has not been addressed.	As only perched groundwater was encountered, contamination through groundwater is considered unlikely.

10 PRELIMINARY WASTE ASSESSMENT

In accordance with the definition provided in the Waste Framework Directive (WFD), materials are only considered waste if 'they are discarded, intended to be discarded or required to be discarded, by the holder'. Naturally occurring soils are not considered waste if reused on the site of origin for the purposes of development. Soils such as made ground that are not of clean and natural origin (irrespective of whether they are contaminated or not) and other materials such as recycled aggregate, do not become waste until the criteria above are met. Further background information is provided in **Appendix H**.

Excavation arisings from the development may therefore be classified as waste if surplus to requirements or unsuitable for reuse. The following assessments assume the material tested is classified subsequently as waste.

RSK recommends that a Sampling Plan be prepared to support any waste classifications and hazardous waste assessments, prior to any material being excavated. Given the level of data obtained, scale of the development and heterogeneity of the site soils, the following assessment should be considered indicative and further assessment should be undertaken following the preparation of a waste sampling plan.

10.1 Hazardous waste assessment

Appendix D of Technical Guidance WM3 (EA, 2018) sets out requirements for waste sampling. It is a legal requirement to correctly assess and classify waste. The level of sampling should be proportionate to the volume of waste and its heterogeneity. The preliminary assessment provided below is based only upon the available sample results and may not be sufficient to adequately classify the waste.

10.1.1 Chemical contaminants

Envirolab, an RSK company, has developed a waste soils characterisation assessment tool (HASWASTE), which follows the guidance within Technical Guidance WM3. The analytical results have been assessed using this tool to assess the hazardous properties to support potential off-site disposal of materials in the future. Note that it is ultimately for landfills to confirm what wastes they are able to accept within the constraints of their permit.

None of the samples tested were found to contain hazardous properties.

The made ground on site is therefore likely to be classed as either a non-hazardous or inert waste, dependent on the results of WAC testing. WAC testing has not been carried out as part of any previous investigations.

10.1.2 Asbestos within waste soils

Technical Guidance WM3 requires that within a mixed waste the separately identifiable wastes be assessed separately.

For instance, where waste soil contains identifiable pieces of asbestos (visible to the naked eye) the asbestos should, where feasible, be separated from the soil and classified separately. This should be disposed of within a hazardous, stable non-reactive hazardous waste landfill or a special cell in a non-hazardous waste landfill.

Samples of made ground were collected from site and analysed for the presence of asbestos, the results of which are presented in **Appendix J**. Analysis confirmed that asbestos is not present within any of the samples tested.

11 CONTAMINATION APPRAISAL

Based upon the findings of the generic quantitative risk assessment (GQRA), the following pollutant linkages have been identified, which will warrant further consideration:

- Direct contact, ingestion and dust/vapour inhalation of lead within shallow made ground at locations BH1 and TP3 where these areas intersect with private gardens and soft landscaping;
- Root uptake of zinc within shallow made ground at location TP3 where this area intersects with soft landscaping; and
- Degradation of plastic utilities by organic contamination within made ground at location BH2, should proposed utilities be laid through this area of the site.

Remedial works and/or further assessment will therefore be required to break the identified pollutant linkages and ensure the site is suitable for its intended use.

11.1 Potential mitigation measures

11.1.1 Adoption of clean cover system in soft covered areas

The investigation has recorded elevated concentrations of lead within two samples of shallow made ground – BH2 at 0.7 m and TP3 at 0.1 m.

Based on current development proposals, TP3 is located within an area of proposed car parking. This surface hardstanding would be considered to sever the potential pollutant linkages and therefore no further works are considered necessary in this area unless development proposals change.

In the northern part of the site, the identified lead contamination within the made ground at BH1 currently intersects rear private gardens of the proposed low-rise housing. Mitigation measures, comprising a clean cover system, would be required within the western 3No rear gardens.

The clean cover system should comprise a 600 mm thickness of verified soils, which should consist of:

- Minimum 150 mm imported topsoil; and
- remainder clean imported (or site-derived subsoil).

Depending on the changes to site levels during redevelopment, the clean cover system should either be placed directly on the existing soils or made ground should be removed to accommodate the clean capping layer. Should made ground soils be removed, then the depth of the excavation could be reduced should natural soils be encountered before the full 600 mm depth is reached.

The areas considered to require a clean cover system are shown on **Figure 4**.

Alternatively, additional sampling and analysis of shallow soils expected to form the private garden formation level could be carried out to ascertain size of the contamination hotspot and reduce the number of plots requiring mitigation measures.

11.1.2 Contaminant resistant pipes

Elevated concentrations of organic contaminants with respect to water supply pipes were encountered at location BH2. Location BH2 is currently located within the area of POS at the centre of the proposed development and it is unclear whether new utilities will be laid through this area. Should plastic water utilities be installed in this area, consideration will need to be given to the use of contaminant-resistant pipe. Clean granular fill should be used as a bedding material for all services and as backfill material for service trenches.

The specification of upgraded materials or multi-layer barrier pipes for potable water supply on site will be subject to confirmation by the water supply provider.

11.2 Summary

A summary of potential mitigation measures and recommended further works are included within **Table 29** below.

Table 29 Summary of mitigation measures

Viable pollutant linkage	Mitigation measures	Comments
Direct contact (dermal contact, ingestion and inhalation of dust) of lead within shallow made ground by future site users in areas of proposed soft landscaping at location TP3	None	Based on current development proposals i.e. area to be overlain by hardstanding car parking
Root uptake of zinc by proposed vegetation within shallow made ground at location TP3		
Direct contact (dermal contact, ingestion and inhalation of dust) of lead within shallow made ground by future site users in areas of proposed soft landscaping at location BH1	Clean capping layer in three western-most private gardens as shown on **Figure 4**	600 mm thick comprising minimum 150 mm topsoil with the remainder imported (or site derived) subsoil Additional assessment of the formation level of each garden could be carried out to refine the area of contamination and reduce number of plots requiring capping
Degradation of plastic utilities by organic contaminants within the shallow made ground at location BH2	Contaminant resistant pipe laid within clean granular trenches	Dependent on route of future water supply pipes. May need to consult water authority to gain approvals

12 GEOTECHNICAL ASSESSMENT

12.1 Proposed development

It is understood that the proposed development is to involve the construction of residential properties and a commercial area. At this stage no specific information relating to building loads has been provided and therefore a wall loading of 100 kN/m has been considered. It has been assumed the ground-bearing floor slabs will not be required and that beam and block flooring will be utilised.

The redevelopment involves the improvement of the Salisbury Square area of Old Hatfield with a mixed commercial and residential development. The proposed development specifically comprises 7 new flats, 5 terraced houses and 7 commercial units including a basement and retail area. Ground level parking spaces are proposed across the site associated with the residential developments, commercial developments and public access totalling 77 car spaces.

12.2 Key geotechnical hazards / development constraints

The key risks identified from the available ground investigation data are outlined in **Table 11** and discussed below:

- Sudden lateral changes in ground conditions;
- Shrinkable clay soils;
- Highly compressible and low bearing capacity soils;
- Existing sub-structures;
- Filled and made ground;
- London Clay soils of high volume change potential; and
- adverse ground chemistry.

12.3 Foundations

12.3.1 Foundation options

12.3.1.1 Terraced Housing

The ground conditions encountered in the northern area of the site do not appear suitable for the design and construction of conventional shallow spread foundations for the proposed terraced houses. However, relatively deep trench fill foundations appear technically feasible, although the depth to which such foundations will need to extend and potentially poor stability of open excavations through the extensive made ground may mean that piles will provide a more economic foundation solution. Alternatively, the near-surface ground conditions appear suitable for the use of selected ground improvement techniques that would facilitate the use of shallow spread footings supported on the improved ground.

12.3.1.2 *Mixed Commercial / Residential Block with Basement Car Park*

The suitability of spread foundations to support the proposed mixed commercial and residential building in the central and southern portion of the site will depend upon the structural loads and the extent of made ground remaining below the proposed basement formation level. The depth to which spread foundations will need to extend and the anticipated structural loads may mean that piles will provide the most suitable foundation solution for this aspect of the proposed development.

In view of the "very low subsidence risk" category determined by the Edmund's risk assessment model for natural dissolution features and the absence of evidence for such features in the site investigation, the need for any special foundation design measures does not appear justified. However, there will still be a potential for chalk dissolution-related features on site and hence excavations should be carefully inspected to confirm the absence of such features beneath structures.

12.3.2 Spread foundations

The recommendations for the design and construction of spread foundations in relation to the ground conditions are set out in **Table 30**.

Table 30 Design and construction of spread foundations

Design/construction considerations	Design/construction recommendations
Founding stratum	Glacial Deposits – Stiff to Very Stiff Lowestoft Formation or Medium Dense Granular Glacial Deposits
Depth	Foundations should be taken to a minimum depth of 1.0 m below finished ground level and at least 0.1 m into the founding stratum below any overlying made ground or to any greater depth required in respect of the special design considerations given below.
Special design considerations	
Shrinkable soils	Due to the presence of shrinkable soils foundations should be designed taking into account all the normal precautions, including minimum depths, to minimise the risk of future foundation movements in accordance with NHBC Standards, or similar. The findings of the ground investigation indicate that foundations should be designed for shrinkable soils of medium volume change potential.
Bearing capacity (for terraced residential houses in northern portion of the site)	Strip foundations with a width of up to 0.6 m and constructed on the Glacial Deposits at a minimum depth of 1.0 m may be designed using a net allowable bearing pressure of 125 kN/m^2. However, it should be noted that a significant depth of made ground was encountered in this area of the site and the footings should be taken at least 0.1 m into natural strata. The allowable bearing capacity includes an overall factor of safety of 3 against bearing capacity failure and with total settlements associated with the bearing pressure estimated to be less than 25 mm.

Design/construction considerations	Design/construction recommendations
Bearing capacity (for mixed residential/commercial block with basement)	Strip foundations with a width of up to 1.5 m and constructed on the medium dense granular Glacial Deposits / stiff clay of the Lowestoft Formation at a minimum depth of 1.0 m or at least 0.1 m into founding strata may be designed using a net allowable bearing pressure of 165 kN/m^2. This value may be increased to 185 kN/m^2 for pad foundations up to 2.5 m square. These allowable bearing capacities include an overall factor of safety of 3 against bearing capacity failure and with total settlements associated with the bearing pressure estimated to be less than 25 mm.
Stability of excavations	The combination of perched groundwater was encountered in two of the exploratory holes and shallow granular deposits suggest it is possible that the foundation excavations may become unstable during construction. As such, an allowance should be made for suitable support systems.
Dewatering	Localised perched groundwater was encountered in some of the exploratory holes. Dewatering may therefore be required to facilitate foundation excavation. Heavy pumping from open sumps in non-cohesive soils should be avoided as this can result in instability and general loosening of the soils at the base of the excavation. It is likely that dewatering in non-cohesive soils will require the use of well-pointing systems.
Variable founding soils	Owing to the significant lateral and vertical variability of the founding strata, consideration should be given to incorporating appropriate reinforcement into the strip foundations to minimise the risk of future differential foundation movements.
Chalk	Owing to the residual risk of possible future ground movements associated with chalk dissolution-related features, it is recommended that the foundations are designed to act as beams and are extended in a cruciform arrangement out beyond the building footprint to bridge over any future ground settlement depressions.
Construction considerations	All foundation excavations should be inspected, and any made ground and soft, organic or otherwise unsuitable materials removed and replaced with mass concrete.

12.3.3 Piled foundations

Recommendations for the design and construction of pile foundations in relation to the ground conditions are set out in **Table 31**.

Table 31 Design and construction of piled foundations

Design/construction considerations	Design/construction recommendations
Pile type	The construction of both bored and driven piles is considered technically feasible at this site.
Possible constraints on choice of pile type	Given the close proximity of the site to other properties the use of driven piles may not be acceptable due to ground vibration and noise related problems.

Design/construction considerations	Design/construction recommendations	
Temporary casing where groundwater is present	Bored piles will require temporary casing throughout the non-self supporting made ground and granular Glacial Deposits and due to the possible presence of perched groundwater. Alternatively, the use of continuous-flight-auger (CFA) injected bored piles usually overcomes this issue.	
Man-made obstructions	The presence of buried sub-structures or other obstructions within made ground may lead to some difficulty during piling. It is recommended that once the proposed pile layout has been determined, pre-pile probing be carried out at each of the pile positions. Where buried obstructions are encountered, it will be necessary to either relocate the pile(s) or make allowance for removing the obstruction.	
Hard strata	An allowance should be made for chiselling thin 'rock' bands within the White Chalk Subgroup.	
Soil and pile design parameters for Lowestoft Formation (cohesive soils)	Adhesion Factor (α)	0.5
	Bearing Capacity Factor (N_c)	9
	Undrained Shear Strength (c_u)	135 + 17z kN/m^2 where z = depth into clay to ~15m
General parameters	Limiting Concrete Stress	7.5N/mm^2
	Limiting Shaft Friction	140 kN/m^2
	Global margin of safety	2.5
Special precautions relating to bored pile shafts and bases	Bored pile concrete should be cast as soon after completion of boring as possible and in any event the same day as boring. Prior to casting the base of the pile bore should be clean, otherwise a reduced safe working load will be required. Similarly, if the pile bore is left open the shaft walls may relax/soften, leading to a reduced safe working load.	

The design procedure for piles varies considerably, depending on the proposed type of pile. However, for illustrative purposes **Table 32** gives likely working pile loads for traditional bored, cast-in-situ concrete piles of various diameters and lengths, based on the design parameters given in **Table 30**.

Table 32 Illustration of typical pile working loads for bored cast-in-situ piles

Typical pile working loads (kN)				
Depth of pile below existing ground level (m)*	Pile diameter			
	300 mm	350 mm	450 mm	600 mm
10	226	274	381	564
12.5	351	423	577	837
15	497	595	803	1149
Notes: Pile lengths to be adjusted to take account of basement formation level as required.				

It should be stressed that the above capacities do not take into consideration pile group effects which is more pronounced for a large number of closely spaced piles.

Notwithstanding the above, it is recommended that the detailed advice of a specialist-piling contractor be sought as to the most suitable type of pile for the prevailing ground conditions and as to their lengths and diameters to support the required design loads.

12.3.4 Retaining Wall

It is understood that the development in the central and southern portion of the site is to involve the construction of a single storey basement structure with associated retaining structures.

The following soil parameters in **Table 33** are recommended for preliminary design purposes.

Table 33 Retaining wall parameters

Soil Type	Undrained Shear Strength cu (kN/m2)	Unit Weight (kN/m3)	Short Term Characteristics		Long Term Strength Characteristics	
			Cu (kN/m^2)	Ø' (^{0})	c' (kN/m^2)	Ø' (^{0})
Made Ground [sandy gravelly clay]	25	17	25	0	0	25
Glacial Deposits [Granular]	-	18	0	32	0	32
Lowestoft Formation	Generally >70	19	70	0	0	28

12.3.5 Floor slabs

The Site is generally underlain by more than 600 mm of existing made ground. National House-Building Council (NHBC) standards require that ground floor slabs should be suspended in areas where made ground is greater than 600 mm in thickness.

12.4 Roads and hardstanding

In-situ CBR determination were obtained from the proposed car parking areas in the southern portion of the site only. In the 0.5 m to 1.0 m below the proposed finished ground level the exploratory holes have revealed a soil profile comprising made ground only (cohesive and granular) The potentially poorest sub-grade material within this profile is the cohesive made ground.

In pavement design terms, the groundwater conditions are anticipated to comprise a low water table, i.e. at least 1 m below the pavement formation level.

The estimated minimum, equilibrium soil-suction, CBR value for the soils and groundwater conditions described above under a completed pavement is 2 to 3%, after Table C1 in TRRL Report LR1132 (1984).

The results of in situ Clegg Hammer testing indicates that the near surface soils have a CBR value that ranges from between 2 and 28%, the results are summarised in **Table 34**.

Table 34 Summary of CBR values derived from in-situ Clegg Hammer tests

Test location	Material type	Minimum CBR value determined at or just below anticipated formation level
TP1 0.3 m	Made Ground	3%
TP1 0.5 m	Made Ground	14% (coincided with fragments of concrete below)
TP1 0.7 m	Made Ground	28% (coincided with fragments of concrete below)
TP2 0.2 m	Made Ground	2%
TP2 0.5 m	Made Ground	3%
TP2 0.8 m	Made Ground	12%
TP3 0.2 m	Made Ground	3%
TP3 0.6 m	Made Ground	7%

The sub-grade soils in the vicinity of test locations is unlikely to be susceptible to improvement by rolling with conventional compaction plant owing to the predominantly cohesive nature of the made ground soils.

The recommended sub-grade soil CBR value for road pavement design is therefore 2%. This value assumes that during construction the formation level will be carefully compacted and any soft spots removed and replaced with well-compacted granular fill.

The sub-grade soils can be regarded as frost-susceptible, after the criteria given in Appendix 1 of TRRL Report Road Note 29 (1970). When the sub-grade is frost-susceptible the thickness of sub-base must be sufficient to give a total thickness of non-frost-susceptible pavement construction over the soil of not less than 450mm.of non-frost-susceptible pavement construction over the soil of not less than 450 mm.

12.5 Chemical attack on buried concrete

The results of chemical tests carried out on soil samples indicate 2:1 water soil extract sulfate contents of up to 0.28g/l with generally near neutral to alkaline pH values.

These results indicate that, in accordance with BRE Special Digest 1: 2005 Concrete in aggressive ground, the Aggressive Chemical Environment for Concrete (ACEC) Classification is AC-1 with a Design Sulphate Class for the site of DS-1. This assumes nominally static/mobile groundwater conditions and that no significantly disturbed clay comes into contact with concrete foundations or structures.

If significantly disturbed clay is likely to come into contact with concrete foundations or structures it will be necessary to carry out additional tests on the soil to investigate its total potential sulphate content. This will facilitate a re-evaluation of the ACEC Classification and Design Sulphate Class for the material, to take into consideration potential oxidation of available sulphides (e.g. pyrite), as defined in Table C2 (brownfield sites) BRE Special Digest 1: 2005.

12.6 Soakaways

The ground conditions do not appear suitable for the use of pit soakaways to discharge surface run-off water into the underlying Glacial Deposits. This is due to the significant thickness of made ground across the areas investigated, coupled with the inherent variability of the underlying Glacial Deposits.

13 CONCLUSIONS AND RECOMMENDATIONS

13.1 Site Conditions

Details obtained from historical mapping, Groundsure report and the Local Authority indicate that the site and surrounding area has historically been subject to a number of light industrial, commercial and residential land-uses, some of which could have contributed to the contamination of the site. Furthermore, the information provided by Welwyn Hatfield Borough Council confirm that the historic site use as a brewery is a potential source of contamination.

The current site investigation confirmed the geological succession predicted in the preliminary conceptual model in that beneath a variable thickness of made ground, a sequence of granular Glacial Deposits and cohesive Lowestoft Formation was encountered. The greatest thickness of made ground was encountered in BH2 in the southern portion of the site. This is assumed to be related to the infilling of a former basement associated with historic land-use of the site.

13.2 Geo-environmental assessment

13.2.1 Direct contact pathways with future site users

Lead was identified to exceed the residential with home grown produce GACs (200 mg/kg) in BH1 0.7 at 278 mg/kg. BH1 is located within the northern portion of the site where residential dwellings are proposed. No alleviation measures are considered necessary if this location is to be covered by building(s) or hardstand. However, as private gardens are understood to be proposed in this area, additional investigation of the shallow soils in the vicinity should be undertaken to fully assess the potential risk to human health, or an appropriate capping layer designed to reduce potential contact with future receptors, or uptake by shallow rooted vegetable plantings.

Lead was identified to exceed the adopted GAC (310 mg/kg) in TP3 0.1 at 345 mg/kg. However, TP3 is currently located within an area of proposed hardstanding and this would sever any potential pollutant linkages (including phytotoxic effects associated with elevated concentrations of zinc).

13.2.2 Permeation of potable water supply pipes by organic contaminants

Whilst no significant organic contamination has been recorded on-site, mild concentrations of petroleum hydrocarbons in the made ground soils in the vicinity of BH2 may have the potential to permeate plastic water supply pipes. It is therefore recommended that barrier pipe be adopted in this area of the site if it is proposed to install potable water supply pipes through this area.

13.2.3 Ground gas risks

No specific precautions with respect to gas protection measures are considered necessary.