Baynham Meikle Partnership

Hatfield Business Park Plot 5100

Geoenvironmental and Geotechnical Site Investigation

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RSK

RSK GENERAL NOTES

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CONTENTS

1 INTRODUCTION 4
1.1 Commissioning 4
1.2 Proposed development 4
1.3 Objectives 4
1.4 Scope of works 4
1.5 Existing reports 5
1.6 Limitations 5
2 SITE DETAILS 7
2.1 Site location 7
2.2 Site description 7
2.3 Surrounding land uses 7
3 DESK-BASED ASSESSMENT 8
3.1 Site history 8
3.1.1 Historical development record 8
3.1.2 Unexploded ordnance 9
3.2 Information from environmental database report 9
3.2.1 Site services 11
3.3 Site geology 11
3.3.1 Anticipated geological sequence 11
3.3.2 Radon 12
3.4 Mining and quarrying 12
3.5 Hydrogeology 12
3.6 Hydrology 13
3.7 Sensitive land uses 13
4 SITE RECONNAISSANCE FINDINGS 14
5 INITIAL CONCEPTUAL SITE MODEL 16
5.1 Potential soil, soil vapour and groundwater linkages 16
5.1.1 Potential sources of contamination 16
5.1.2 Sensitive receptors and linking pathways 16
5.2 Potential ground gas linkages 17
5.2.1 Ground gas generation potential 17
5.2.2 Preferential pathways for ground gas migration 17
5.2.3 Sensitive receptors and linking pathways 18
5.3 Preliminary risk assessment 18
5.4 Data gaps and uncertainties 22
6 PRELIMINARY GEOTECHNICAL HAZARDS 23
6.1 Design class 23
6.2 Preliminary geotechnical hazards assessment 23
6.2.1 Chalk 25
7 SITE INVESTIGATION STRATEGY & METHODOLOGY 26
7.1 Introduction 26

7.2 Objectives ... 26
7.3 Selection of investigation methods ... 26
7.4 Investigation strategy ... 26
7.5 Implementation of investigation works ... 28
7.6 Monitoring programme ... 28
7.6.1 Ground gas monitoring ... 28
7.7 Laboratory testing ... 29
7.7.1 Chemical analysis of soil samples ... 29
7.7.2 Geotechnical analysis of soils ... 30
7.7.3 Infiltration testing ... 31
8 SITE INVESTIGATION FACTUAL FINDINGS ... 32
8.1 Ground conditions encountered ... 32
8.1.1 Made ground ... 32
8.1.2 Topsoil ... 33
8.1.3 Lowestoft Formation ... 33
8.1.4 Lewes Nodular and Seaford Chalk Formation ... 34
8.1.5 Visual/olfactory evidence of soil contamination ... 35
8.2 Groundwater ... 35
8.2.1 Groundwater encountered during intrusive works ... 35
8.2.2 Groundwater encountered during monitoring ... 35
8.2.3 Visual/olfactory evidence of groundwater contamination ... 36
8.3 Chemical laboratory results ... 36
8.4 Geotechnical laboratory results ... 36
8.5 Ground gas monitoring ... 36
9 GEO-ENVIRONMENTAL ASSESSMENT ... 37
9.1 Refinement of initial CSM ... 37
9.1.1 Linkages eliminated after refinement of the initial CSM ... 37
9.1.2 Linkages added after refinement of the initial CSM ... 37
9.2 Linkages for assessment ... 37
9.3 Methodology and assessment of soil results ... 38
9.3.1 Oral, dermal and inhalation exposure with impacted soil by future occupants/site users ... 38
9.3.2 Inhalation exposure of future occupants/site users to asbestos fibres ... 38
9.3.3 Impact of organic contaminants on potable water supply pipes ... 38
9.3.4 Leaching of contaminants and dissolved phase migration ... 39
9.4 Ground gas risk assessment ... 39
9.4.1 Appropriate guidance ... 39
9.4.2 Summary of the refined conceptual site model for ground gas ... 40
9.4.3 Empirical semi-quantitative approach using borehole monitoring data (Wilson and Card approach) ... 40
9.4.4 Implications ... 42
9.5 Uncertainties and implications in refined CSM and GQRA ... 42
10 PRELIMINARY WASTE ASSESSMENT ... 43
10.1 Hazardous waste assessment ... 43
10.1.1 Chemical contaminants ... 43
10.1.2 Asbestos within waste soils ... 43

10.2 WAC assessment ... 44
11 GEOTECHNICAL ASSESSMENT ... 45
11.1 Proposed development ... 45
11.2 Key geotechnical hazards / development constraints ... 45
11.3 Foundations ... 45
11.3.1 General Suitability ... 45
11.3.2 Piled Foundations ... 46
11.3.3 Deep Ground Improvement ... 48
11.3.4 Foundation works risk assessment ... 49
11.4 Floor slabs ... 49
11.5 Roads and hardstanding ... 49
11.6 Excavations for foundations and services ... 50
11.7 Chemical attack on buried concrete ... 51
11.8 Infiltration drainage ... 52
12 CONCLUSIONS AND RECOMMENDATIONS ... 53
12.1 Geo-environmental assessment ... 53
12.2 Geotechnical assessment ... 53
REFERENCES ... 55

FIGURES

Figure 1 Site location plan
Figure 2 Site layout and exploratory hole location plan

APPENDICES

Appendix A Service constraints
Appendix B Development drawings
Appendix C Summary of legislation and policy relating to contaminated land
Appendix D Environmental database report
Appendix E Supporting desk study information
Appendix F Utility service plans
Appendix G Site reconnaissance photographs
Appendix H Technical background
Appendix I Exploratory hole records
Appendix J Ground gas monitoring data
Appendix K Laboratory certificates for soil analysis
Appendix L Laboratory certificates for geotechnical analysis
Appendix M Generic assessment criteria for human health
Appendix N Generic assessment criteria for potable water supply pipes
Appendix O Generic assessment criteria for controlled waters
Appendix P GQRA data screening tables – soils
Appendix Q WM3 assessment

1 INTRODUCTION

1.1 Commissioning

RSK Environment Limited (RSK) was commissioned by Baynham Meikle Partnership (the Engineer) on behalf of Arlington Business Parks GP Ltd (the Client) to carry out a Geoenvironmental and Geotechnical Site Investigation of the land at Hatfield Business Park Plot 5100, Mosquito Way, AL10 9WN.

The project was carried out to an agreed brief as set out in RSK's proposal (Ref. 314394-T01 (01), dated 25th January 2019).

This report is subject to the RSK service constraints given in **Appendix A** and limitations that may be described through this document.

1.2 Proposed development

The Site in question is being considered for development with a warehouse and distribution centre. The planned layout of the site is shown in **Appendix B**.

1.3 Objectives

The objective of the work is to assess the contamination status of the site and characterise the ground conditions for future foundation and infrastructure design.

1.4 Scope of works

The scope of this assessment has been developed in accordance with relevant British Standards and authoritative technical guidance as referenced through the report. The assessment of the contamination status of the site is in line with the technical approach presented in CLR 11 Model Procedures for the Management of Land Contamination (Environment Agency, 2004) and in general accordance with BS 10175: 2011 + A2 2017 (BSI, 2017). It is also compliant with relevant planning policy and guidance.

The scope of the intrusive investigation has been designed in line with the recommendations of BS5930: 2015 Code of practice for ground investigations (BSi, 2016), which maintains compliance with BS EN 1997-1 and 1997-2 and their related standards. It has also been developed in general accordance with BS 10175: 2011 + A2 2017.

A brief summary of relevant legislation and policy relating to contaminated land is given in **Appendix C**.

The scope of works for the assessment has included the following:

Desk Study:

- review of the history of development on the site and surroundings, including a study of historical ordnance Survey mapping and other sources of historical information via an environmental database report
- assessment of local geology, hydrogeology and surface water setting, including the identification of potential geological hazards including mining etc
- review of relevant information held by appropriate statutory authorities, e.g. local authority obtained from the environmental database report or consultations
- completion of a site reconnaissance survey to assess the visual condition of the site
- development of an initial conceptual site model (CSM) identifying potential contaminant linkages for potential contaminants, completion of a preliminary risk assessment (PRA) and identification of key uncertainties and assumptions in the CSM
- preliminary consideration of geotechnical constraints and hazards.

Intrusive Investigation

- design and implementation of an intrusive investigation, in situ testing, soil sampling, laboratory geo-environmental and geotechnical testing, groundwater and ground gas monitoring of installed boreholes
- interpretation of data to develop a refined conceptual site model (CSM)
- generic quantitative risk assessment (GQRA) to evaluate potentially complete contaminant linkages identified in the refined CSM
- identification of the need for further action, e.g. supplementary intrusive investigations/ monitoring, remediation works or other mitigation, if any.
- interpretation of ground conditions and geotechnical data to provide preliminary recommendations with respect to foundations and infrastructure design;
- preliminary assessment of the potential waste classification (hazardous / non-hazardous) implications of soil arisings
- preparation of this factual and interpretative report with recommendations for further works (i.e. undertake a remedial options appraisal to identify appropriate mitigation measures/produce a remedial implementation and verification plan) and/or remediation as necessary.

1.5 Existing reports

RSK are unaware of any existing reports pertaining to the site.

1.6 Limitations

The comments given in this report and the opinions expressed are based on the ground conditions encountered during the site work and on the results of tests made in the field and in the laboratory. However, there may be conditions pertaining to the site that have not been disclosed by the investigation and therefore could not be taken into account. In particular, it should be noted that there may be areas of made ground not detected due to the limited nature of the investigation or the thickness and quality of made ground across the site may be variable. In addition, groundwater levels and ground gas concentrations and flows may vary from those reported due to seasonal, or other, effects and the limitations stated in the data should be recognised.

Asbestos is often present in soils in discrete areas. Whilst asbestos-containing materials may not have been locally encountered during the fieldworks or supporting laboratory analysis, the history of the site indicates that asbestos may be present in soils and could be encountered during more extensive ground works.

Preliminary geotechnical recommendations are presented and these should be verified in a Geotechnical Design Report once proposed construction and structural design proposals are confirmed.

2 SITE DETAILS

2.1 Site location

Site location details are presented in **Table 1** and a site location plan is provided on **Figure 1**.

Table 1 Site location details

Site name	Hatfield Business Park Plot 5100
Full site address and postcode	Plot 5100, Mosquito Way, Hatfield, AL10 9WN
National Grid reference (centre of site)	TL 21404 09191

2.2 Site description

The site boundary and current site layout are shown on **Figure 2**. The site covers an area of approximately 2.1 hectares of undeveloped land covered in rough vegetation and is surrounded by a bund on the southern and western sides, and there is an approximately 1m rise in ground level to the north and east. There is also a pumping station in the south-eastern corner of the site and a 'utility' pump located towards the centre of the site.

2.3 Surrounding land uses

The Site is located within Hatfield Business Park, therefore has a predominantly commercial and industrial setting. Immediate surrounding land uses are described in **Table 2**.

Table 2 Surrounding land uses

North	Various commercial and industrial units including photography services, printers, air conditioning contractors and a motor parts supplier
East	Gypsy Moth Avenue, with Grange Land Rover Dealers, offices and an Arla distribution centre beyond
South	Mosquito Way, with multiple commercial and office units beyond
West	Air Business distribution depot with Howe Dell School beyond

3 DESK-BASED ASSESSMENT

3.1 Site history

3.1.1 Historical development record

The development history of the site and pertinent historical data from the surrounding area based upon assessment of historical plans and records is detailed in **Table 3.**

The historical maps reviewed are shown within the environmental database report in **Appendix D**.

Table 3 Summary of pertinent historical development

Historical Land Use (on-site)	Area of site	Date from	Date to
Agricultural land with a footpath crossing the centre of the site from east to west	Whole	Pre. 1879	1930
Aerodrome including a runway which crosses the site through the centre to the northern boundary to the south western corner	Whole	1930	2002 (closed in 1994)
Unspecified commercial/industrial unit encroaches on the southern boundary of the site (presumed to be associated with aerodrome)	South	1988	2002 (closed in 1994)
Historical Land Use (off-site)	**Distance (m) and orientation**	**Date from**	**Date to**
Large unspecified warehouse building	E 15m	1937	1960
Aircraft works	E 12m	1960	2002
Electricity substation	SE 170m	1960	2002
Tanks	SE 173m	1976	2002
Electricity substation	SE 192m	1969	2002
Former airfield and aircraft works demolished and replaced with a business park, offices and a school	Adjacent E, S and W	2005	Present
Relevant information sources: Historical OS maps ☒ Town plans ☐ Information from the Local Planning Authority ☒ Aerial photography ☒			
Note: Reference to published historical maps provides invaluable information regarding the land use history of the site, but historical evidence may be incomplete for the period pre-dating the first edition and between successive maps.			

Potential sources of contamination at the site from historical sources have been identified as historical use as an airfield, including taxi-ways, buildings and potential UXO. Potential sources of contamination in the vicinity of the site have been identified as aircraft works, tanks and other industrial land uses.

3.1.2 Unexploded ordnance

A review of publicly available unexploded ordnance (UXO) risk maps indicates that the site is located within a moderate risk area with respect to wartime bombing (Zetica, 2019).

3.2 Information from environmental database report

Relevant environmental permits and incidents detailed within the environmental database report (see **Appendix D**) are summarised below in **Table 4**.

Table 4 Summary of environmental permits, landfills and incidents

Data type	Entries on-site	Entries <250m or >250m from site of relevance	Details
Agency and Hydrological			
Environmental permits – incorporating Integrated Pollution Prevention and Control, Integrated Pollution Controls, Local Authority Integrated Pollution Prevention and Control	N	8no. entries from 348m NE	Closest to the site is 348m NE. 2no. entries at 412m and 433m S of the site have had significant impact to air quality via the respective incidents. The other 6no. entries have had either no impact or minor impact to either water, land or air.
Enforcement and prohibition notices	N	N	N/a
Pollution incidents to controlled waters	N	N	N/a
Prosecutions relating to controlled waters	N	N	N/a
Substantiated pollution incident register	N	N	N/a
Water Industry Act referrals	N	N	N/a
Discharge consents	N	2no. entries both 494m SE	Ellen Brook receives sewage discharge from Stonehouse, Hatfield. Initial temporary permit issued in November 1989 and revoked on 02/09/2010. Second permit was issued on 03/09/2010 and revoked August 2014.
Registered radioactive substances	N	1no. entry 96m SE	License is operated by EISAI Limited and has been active from 20/09/2010. Unknown wastes permitted but under HP3693ST permission number.

Data type	Entries on-site	Entries <250m or >250m from site of relevance	Details
Landfill and Waste			
Active landfills	N	1no. entry 928m SW	Hatfield Aerodrome disposing of inert waste. Landfill Reference: 403832.0
Historic / closed landfills	N	2no. entries <1000m	N/a
Other waste management licences	N	4no. entries	Closest is located 77m SE of the site and is operated by Affinity Water. (Waste) Licence Number: THR011. Other licenses are <1000m from the site.
Hazardous Substances			
Control of Major Accident Hazards (COMAH) sites	N	N	N/a
Explosives sites	N	N	N/a
Notification of Installations Handling Hazardous Substances (NIHHS)	N	N	N/a
Planning hazardous substance consents/ enforcements	N	N	N/a
Industrial Land Uses			
Contaminated land Part 2A register entries and notices	N	N	N/a
Contemporary trade directory entries	0	27no. entries	As the site is based on an industrial estate there is a range in activities including repair and servicing, industrial products, infrastructure and facilities and foodstuffs.
Fuel station entries	0	1no. entry	Harpsfield Broadway, located 444m SE of the site and is currently obsolete
Note: Entries have only been included within the table where they are located within a 250m radius of the site or, where they fall outside of this radius but are considered to comprise a significant entry.			

In summary, items that have been identified to represent an on-going potential source of contamination that could affect the site comprise Industrial land uses in the vicinity including vehicle repair and servicing, industrial production and infrastructure facilities, although none of these take place on the site directly.

These entries have been carried forward for consideration within the initial conceptual site model contained in **Section 6**.

3.2.1 Site services

Buried utility services and their backfill can provide preferential pathways for gas, vapour or groundwater to migrate along to another part of the site or to a receptor. They can also represent significant constraints to development.

Service plans obtained from utility companies either by RSK or the client are dated February 2019. Buried services are shown to be present on site in the south east corner where there is a pumping station.

A copy of the utility service plans are included within **Appendix E**.

3.3 Site geology

3.3.1 Anticipated geological sequence

Published records (British Geological Survey, 2019) for the area and available historical borehole logs indicate the geology of the site to be characterised by the succession recorded in Error! Reference source not found.**Table 5**. There are 19 publicly available BGS historical boreholes located on or within 250m of the site, a selection of which are presented in **Appendix E**.

Table 5 Site geology

Strata	Description	Estimated thickness	Aquifer designation*
Lowestoft Formation	Chalky till with variable outwash sands, gravels, silts and clays	<18m	Secondary Undifferentiated
Lewes Nodular Chalk Formation and Seaford Chalk Formation (Undifferentiated)	White chalk with flints and marl seams	>20m	Principal
Relevant information sources: BGS Geoindex ☒ BGS borehole logs ☒ Previous SI reports ☐ * Note: A full summary of the aquifer characteristics/properties is contained in the technical summary contained in **Appendix E**.			

Given the historical use of the site as a part of Hatfield Aerodrome it is anticipated that made ground may also be present at the site, however this is expected to be of limited thickness.

Historical boreholes indicate that the groundwater table is anticipated to be between 6m to 7m bgl.

3.3.2 Radon

The environmental database report indicates that the site is not located within an 'Affected Area'. An 'Affected Area' is one with 1% or more properties above the radon Action Level of 200 Bq m^{-3}, and therefore the risk of significant ingress of radon into structures on-site is considered low and protection measures are not necessary in the construction of non-domestic buildings.

Although the radon data used in production of the ukradon indicative atlas comes from measurements in homes, the maps indicate the likely extent of the local radon hazard in all buildings.

3.4 Mining and quarrying

Evidence has been sought to identify any mining, quarrying, landfilling and land reclamation operations, past and present, which have taken place in the vicinity of the site.

The site lies in an area with a known history of chalk mining. Where chalk is present at or close to the surface, it is possible that historically small-scale mining may have occurred and resulted in unrecorded mines. As the chalk is anticipated to be some 18m bgl at the site the risk associated with this is likely to be low.

3.5 Hydrogeology

A summary of the hydrogeological setting of the site, with respect to the anticipated geological sequence set out in **Section 3.5** is presented below in **Table 6**.

Table 6 Summary of hydrogeological setting

Condition	Description
Aquifer characteristics	The site is underlain by a secondary undifferentiated aquifer within the superficial Lowestoft Formation and a principal aquifer within the bedrock of Lewes Nodular Chalk Formation and Seaford Chalk Formation (Undifferentiated). The presence of low permeability clay at relatively shallow depths beneath the site, while restricting downwards migration, may increase the potential for lateral migration of shallow groundwater (and therefore mobile contamination, if present).
Depth to groundwater and flow	The anticipated depth to the groundwater table is in the order of 6.5m below ground level estimated from BGS logs. Shallow groundwater in the site area is anticipated to flow in a south westerly direction, i.e. towards and in the direction of flow of Ellen Brook. Clay layers within the Lowestoft Formation have been known to create locally confined aquifer conditions with artesian pressures in the vicinity.
Rising groundwater levels	Whilst regionally rising groundwater is not considered an issue, previous experience in the vicinity has shown that groundwater may rise in association with output from the nearby groundwater abstraction well.

Condition	Description
Groundwater recharge/ attenuation	Most of the site is currently unsurfaced and will therefore drain to ground.
Licensed groundwater abstractions	The environmental database report indicates that there are 8no. current licensed groundwater abstractions within a 2km radius of the site. One extraction borehole is a public water supply borehole, located 1490m southeast of the site.
Source protection zones	Information available on the Magic website indicates that the site lies within Zone 2 (outer catchment) of the groundwater Source Protection Zone (SPZ) for the public supply borehole located to the southeast.

3.6 Hydrology

A summary of the hydrology within the site area is summarised in **Table 7**.

Table 7 Summary of hydrology in site area

Condition	Description
Surface watercourses/ features	There is an unidentified surface feature located 4m SW of the site, however it does not appear on current or historical maps. This feature was not observed during the site visit.
Surface water abstractions	The environmental database report indicates that there are no currently licensed surface water abstractions within a 2km radius of the site.
Site drainage	Surface drainage from the site is likely to be through infiltration to the shallow geology due to the unsurfaced nature of the site.
Preliminary flood risk assessment	The indicative floodplain map for the area shows the site does not lie within a floodplain and is designated as Flood Zone 1 (i.e. an area with a low probability of flooding. The risk of flooding each year has been assessed by the EA as Low –i.e. less than 1 in 1,000 annual probability of river or sea flooding. A flood risk assessment (FRA) is outside the scope of this report.

3.7 Sensitive land uses

Based on the environmental database report there are no environmentally sensitive sites, such as Site of Special Scientific Interest (SSSI), National Nature Reserve (NNR) and ancient woodland, within a 1km radius of the site.

4 SITE RECONNAISSANCE FINDINGS

A site reconnaissance survey was completed on 26th February 2019 by RSK. The characteristics of the site observed during the walkover and from current ordnance Survey maps are summarised in **Table 8**.

A site plan is provided in **Figure 2** with photographic records included in **Appendix G** detailing the main features identified below.

Whilst the walkover summary includes consideration of current operations and housekeeping on the site as potential sources of contamination, it does not constitute a comprehensive environmental audit of the site, as covered under ISO 14001.

Table 8 Site reconnaissance findings

Feature	Description
Physical characteristics	
Access constraints	Access cannot be gained to the site via the western entrance due to an approximately 1.50m high bund blocking the route. The southern site entrance has a hardstanding road which is then blocked by mounded vegetation, with only a small dirt path for pedestrian access.
Site topography	The site is essentially level, however there is evidence of some cutting of approximately 1m particularly around the pumping station to the east of the site. There small embankment along the northern boundary of the site to the adjacent plots.
Surface cover	The site is covered by rough vegetation and some hardstanding via all three access routes. There is also a gravel / paved area in the centre of the southern boundary that is used as a helipad.
Site drainage	The site is mostly covered in rough vegetation; therefore, drainage is straight to the ground. In addition, there is an exposed drain on the southern boundary of the site, suggesting there has been a drainage network implemented at some point.
Surface water	There are no streams or drainage ditches on or adjacent to the site.
Trees and hedges	Vegetation present on-site comprises trees of mixed maturity and hedges which are located around the site boundary.
Invasive species	Based upon the walkover survey obvious evidence of Japanese Knotweed or other invasive species has not been identified on-site. However, it should be noted that a detailed survey of the possible presence or absence of invasive species is outside of the scope of investigation and consideration should be given to commissioning a specialist survey, as necessary.
Existing buildings on-site	No buildings are present on-site.

Feature	Description
Retaining walls and adjacent buildings on or close to site boundary	There are no such structures on or close to the site boundary.
Basements on-site	No evidence of existing or infilled basements was observed.
Made ground, earthworks and quarrying	Some made ground present within small 1 – 1.5m bunds along the southern and western site boundaries.
Potentially unstable slopes on or close to site	None observed.
Buried and overhead services present	There is a pumping station located in the south eastern corner of the site. There is also a utility 'pump' located along a footpath towards the centre of the site.
Environmental characteristics	
Underground/ above ground storage tanks and pipework	None observed.
Potentially hazardous materials storage and use	None observed.
Asbestos-containing materials	No obvious asbestos construction materials were observed but a detailed survey would be required to confirm the presence or otherwise of asbestos-containing materials.
Waste storage	None observed.
Fly-tipping	None observed.
Electricity sub-stations/ transformers	None observed on or close to site.
Evidence of possible land contamination on-site	None observed.
Potential off-site sources of ground contamination	The site is located within a business park, with various commercial and industrial units, therefore it is probable there will be sources of off-site contamination affecting the site.

No potentially significant land contamination or geotechnical issues were identified during the site reconnaissance survey.

5 INITIAL CONCEPTUAL SITE MODEL

In line with CLR11 (Environment Agency, 2004) and BS 10175: 2011 + A2 2017 (BSI, 2017), RSK has used information in the preceding sections to identify sources of contaminants, receptors that may be impacted and plausible linking pathways. Where all three are present this is termed a potentially complete contaminant linkage and a qualitative risk estimation is made.

5.1 Potential soil, soil vapour and groundwater linkages

5.1.1 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 9**. Ground gas sources are addressed in the next section.

Table 9 Potential sources of soil and groundwater contamination

Potential sources	Contaminants of concern	Current or historical?
On-site		
S1 - Aerodrome with associated commercial/ industrial unit	Lube oil, diesel, kerosene, chlorinated solvents	Historical
S2 – Potential made ground associated with historical runway (not known if removed)	Unknown fill material but potentially including brick, ash and clinker and containing toxic and phytotoxic metals, inorganics, polycyclic aromatic hydrocarbons (PAHs), asbestos	Current/ Historical
Off-site		
S3 - Various aircraft works (closest 12m from site extending to 295m)	Lube oil, diesel, kerosene, chlorinated solvents	Historical
S4 - Electricity substation (50m N)	Polychlorinated biphenyls (PCBs)	Current
S5 – Garage (M G Stickland) – vehicle repair, testing and servicing (16m NW)	Petroleum hydrocarbons, fuel additives, PAHs, chlorinated solvents, asbestos	Current

5.1.2 Sensitive receptors and linking pathways

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

- future site users – commercial/ industrial workers [oral, dermal and inhalation exposure with impacted soil, soil vapour and dust]
- current adjacent site users – commercial, [migration of contamination via dust/fibre deposition, vapour or groundwater migration combined with inhalation]

- future buildings and services [direct contact with contaminated soils or groundwater and chemical attack]
- groundwater in secondary (undifferentiated) aquifer within Lowestoft Formation superficial deposits [leaching from soils/ percolation to aquifer/ lateral migration of dissolved phase/ NAPL etc.]
- groundwater in principal aquifer within Lewes Nodular Chalk Formation and Seaford Chalk Formation bedrock deposits [percolation through permeable strata to aquifer/ lateral migration of dissolved phase/ NAPL etc.]

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.

5.2 Potential ground gas linkages

5.2.1 Ground gas generation potential

Potential ground gas sources identified for the site and surrounding are shown in **Table 10**.

Table 10 Potential ground gas sources

Potential sources	Ground gas generation potential *	Additional information
On-site		
Chalk bedrock geology	Very low	Chalk is expected to be some 18m below ground level
Made ground	Very low	Made ground may be present on site associated with the historical runway and the historical buildings along the southern portion of the site.
Off-site		
No significant sources identified		
Note: * ground gas generation potential in accordance with BS8576 Figure 6		

Given the anticipated ground conditions set out above, limited potential sources of ground gas gave been identified in the form of natural carbonate strata and potential for made ground.

5.2.2 Preferential pathways for ground gas migration

Credible preferential pathways potentially connecting the source and receptor through vertical and lateral migration are:

- Mixed granular and cohesive nature of the Lowestoft formation;

- building foundations;
- construction joints and cracks within building structure; and
- utility routes and service penetrations into buildings.

5.2.3 Sensitive receptors and linking pathways

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

- Future site users – commercial/ industrial workers [migration and ingress of ground gases into buildings, build-up in confined spaces and explosion/ asphyxiation]
- current/ future buildings and services [migration and ingress of ground gases into buildings, build-up in confined spaces and explosion].

The assessment has identified receptors to include building structures and proposed end-users.

Construction workers have not been identified as receptors for the purposes of this assessment. Risks may still be present to construction workers especially where works include the entry into excavations within the ground. Construction workers should undertake appropriate risk assessments and risks should be managed through health and safety procedures and the use of PPE.

5.3 Preliminary risk assessment

The preliminary risk assessment findings and potentially complete contaminant linkages are shown in Error! Reference source not found.**1** 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 H**.

Table 11 **Risk estimation for potentially complete contaminant linkages**

Potential source	Potential receptor	Possible pathway	Likelihood	Severity	Potential risk	Justification
S1 – Historic aerodrome and associated commercial/ industrial works	R1 – future site users	Direct contact	Low Likelihood	Medium	Moderate / Low	As outlined within the conceptual model above there is potential for contamination to be present within the shallow soils associated with the historical use as an aerodrome and associated buildings. Within the proposed development area hardstanding across the site will likely mitigate much of the risk of direct contact with any contamination if present.
	R2 – adjacent site users					
	R3 – future buildings and services		Low Likelihood	Medium	Moderate / Low	Direct contact of potable water supply pipes with contamination in shallow soils may result in permeation and therefore risk to human health.
	R4 – groundwater in secondary and principal aquifers	Leaching and vertical percolation through permeable strata	Low likelihood	Medium	Moderate / Low	Contamination within the shallow soils, if present, may migrate through the granular Lowestoft Formation to the principal aquifer within the chalk bedrock, however this will be partially mitigated by the presence of hardstanding in the proposed development.
S2 – Possible made ground	R1 – future site users	Direct contact	Low Likelihood	Medium	Moderate / Low	Made ground may be present on site as outlined in the above conceptual model associated with the historical runway/taxi-way and associated buildings. Due to the absence of multiple phases of development it is unlikely that significant volumes of impacted materials would be present. Hardstanding across the proposed development would also act to break the direct contact pathway.
	R1 – future site users		Unlikely	Severe	Moderate/Low	Due to the low gas generation potential of ground gas sources identified at the site there is

Potential source	Potential receptor	Possible pathway	Likelihood	Severity	Potential risk	Justification
	R2 – adjacent site users	Migration and accumulation of ground gas				unlikely to be significant ground gas ingress to future and adjacent structures.
	R3 – buildings and services	Direct contact	Low Likelihood	Mild	Low	It is possible that buried concrete and underground services could come into contact with contaminants within the shallow made ground, if present.
		Migration and accumulation of ground gas	Unlikely	Severe	Moderate/Low	Given the limited site development history, it is unlikely that significant volumes of putrescible made ground would be present.
	R4 – groundwater in secondary and principal aquifers	Leaching and/or lateral migration	Unlikely	Medium	Low	Given the limited development history of the site, it is considered unlikely that significant deposits of grossly impacted made ground would be present.
S3 – Historic off-site aircraft works	R1 – future site users	Migration and potential accumulation of ground gases, creating explosive or asphyxiating atmospheres	Unlikely	Severe	Moderate / Low	Given that the absence of multiple phases of previous development it is considered relatively unlikely that significant depths of made ground would be present that would represent a gas risk to the site.
S4 – Off-site Electricity substation	R1 – future site users	Direct contact	Unlikely	Medium	Low	Given the relatively recent age of the substation installation and the low mobility PCB compounds it is unlikely that the existing substations will have detrimentally impacted the underlying soils or groundwater.
	R4 – groundwater in principal and secondary aquifers	Leaching and vertical percolation through permeable strata				

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 11** comprise:

- Direct contact with contamination present within made ground by future site users;
- Permeation of potable water supply pipes by contamination within the made ground or associated with historical site use as an aerodrome with associated commercial / industrial works;
- Migration of contamination associated with the historical site use as an aerodrome and associated commercial / industrial works to the underlying secondary and principal aquifers; and
- Migration and accumulation of ground gases in future and adjacent site buildings from onsite and adjacent made ground and commercial / industrial land use.

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.

5.4 Data gaps and uncertainties

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

- there are no previous investigations available for the site, therefore no information on the presence of made ground or actual concentrations of contaminants in soil and groundwater or ground gas at this stage;
- groundwater depth and flow direction are conceptual at this stage; and
- it is not known whether the runway historically located on the site was removed.

6 PRELIMINARY GEOTECHNICAL HAZARDS

6.1 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
- 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 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.

6.2 Preliminary geotechnical hazards assessment

A summary of commonly occurring geotechnical hazards associated with the anticipated geology outlined in **Section 3** above is given in Error! Reference source not found. together with an assessment of whether the site may be affected by each of the stated hazards.

Table 12 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	☒	The Lowestoft Formation is of glacial origin and therefore likely to be laterally variable	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	☒	Potentially shrinkable clay strata likely present within the Lowestoft Formation	Design to NHBC Standards Chapter 4 or similar
Highly compressible and low bearing capacity soils, (including peat and soft clay)	☒	Potential for peaty and soft organic clay soils to be present locally in the eastern and eastern part of the site	Likely to affect ground engineering and foundation design and construction
Silt-rich soils susceptible to rapid loss of strength in wet conditions	☒	identified within the Glacial deposits	Likely to affect ground engineering and foundation design and construction
Running sand at and below water table	☒	Potential for running sand to be present within saturated element of the Glacial Deposits	Likely to affect ground engineering and foundation design and construction
Karstic dissolution features (including 'swallow holes' in Chalk terrain)	☒	Chalk bedrock present at intermediate depth beneath the site	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

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	
Rising groundwater table due to diminishing abstraction in urban area	☐	☒	May affect deep foundations, basements and tunnels
Underground mining	☐	☒	Likely to require special stabilisation measures
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)	☒	Buried concrete may be present associated with the former runway and ancillary buildings	Likely to affect ground engineering and foundation design and construction
Filled and made ground (including embankments, infilled ponds and quarries)	☒	Made ground may be present associated with historical use as a runway with ancillary buildings	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
Note: Seismicity is not included in the above table as this is not normally a design consideration in the UK.			

6.2.1 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 '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.

7 SITE INVESTIGATION STRATEGY & METHODOLOGY

7.1 Introduction

RSK carried out intrusive investigation works between 4th and 11th March 2019 to further investigate the potential pollutant linkages outlined within the preceding PRA, with subsequent monitoring of boreholes between March 2019 and April 2019.

The works were also designed to investigate geotechnical constraints and provide geotechnical information for future foundation and infrastructure design.

Prior to conducting intrusive works, utility service plans were obtained and buried service clearance undertaken in line with RSK's health and safety procedures. Copies of statutory service records obtained by RSK as part of the agreed scope of works are contained in **Appendix F**.

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;
- to determine groundwater depth;
- to determine the ground gas regime underlying the site;
- undertake preliminary soakage testing to assess soakaway infiltration potential;
- to investigate identified geotechnical constraints; 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 to obtain a number of investigation locations and achieve greater visibility of the Made Ground and shallow soils and to undertake soakaway testing, and drive-in sampling to retrieve environmental samples and install shallow ground gas monitoring wells.

7.4 Investigation strategy

The ground investigation was carried out using intrusive ground investigation techniques in general accordance with the recommendations of BS5930: 2015 Code of practice for ground investigations, which maintains compliance with BS EN 1997-1 and 1997-2 and their related standards.

Whilst every attempt was made to record full details of the strata encountered in the boreholes, techniques of hole formation and sampling will inevitably lead to disturbance, mixing or loss of material in some soils and rocks.

The investigation strategy involved non-targeted boreholes and trial pits. The investigation comprised an exploratory investigation.

The constraints to the investigation were as follows:

- Mapped underground services associated with the pumping station in the southeast of the site
- Underground services not shown on service plans but detected during buried service clearing, this included a deep drain >5m bgl that appeared to cross the southern area of the site east to west
- Area of shallow buried concrete in the south eastern corner of the site.

Prior to the commencement of intrusive works access was gained to the site by the removal of a bund in the southwest corner of the site. Gate posts were installed, and fencing secured between them for the duration of the works. On completion of the site works the bund was reinstated.

Details of the investigation locations, installations and rationale are presented in **Table 13**.

15 No. machine trial pits were excavated by a JCB-3CX to a maximum depth of 3.6m bgl and subsequently being backfilled with arisings. 8 No. cable percussive boreholes were advanced to a maximum depth of 25m bgl, with four boreholes installed with combined gas and groundwater monitoring wells. 7 No. window sample boreholes were advanced to a maximum depth of 5.0m bgl, all of which were installed with shallow gas monitoring wells.

Table 13 Exploratory hole and monitoring well location rationale

Investigation Type	Number	Designation	Monitoring well installation	Rationale Examples below
Boreholes by cable percussive methods	8	BH02, BH04, BH06, BH07	No installation	To prove the geological succession beneath the site and obtain geotechnical data.
		BH01, BH03, BH05, BH08	Gas/ groundwater	To prove the geological succession beneath the site and obtain geotechnical data. To monitor ground gas and groundwater.
Boreholes by dynamic sampling methods	6	WS1 to WS7	Gas/ groundwater	Non-targeted assessment to characterise shallow ground conditions across the site footprint, take environmental and geotechnical samples for

Investigation Type	Number	Designation	Monitoring well installation	Rationale Examples below
				laboratory analysis and to install additional dual purpose groundwater and gas monitoring wells.
Trial-pits excavated by mechanical excavator	15	TP1 to TP15	n/a	To accurately log the upper strata in non-targeted locations beneath the site. Collect samples for geotechnical and environmental laboratory testing.
Dynamic cone penetration tests (DCPs)	15	CBR1 to CBR15	n/a	DCP tests to obtain CBR values to inform road, pavement and parking design.

7.5 Implementation of investigation works

The exploratory holes were logged by an engineer in general accordance with the recommendations of BS 5930:2015 (which incorporates the requirements of BS EN ISO 14688-1, 14688-2 and 14689-1) and CIRIA *C574.*

The monitoring well construction and associated response zones are detailed on the exploratory hole records in **Appendix I**. The response zones were installed to target identified shallow made ground and groundwater.

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.

7.6 Monitoring programme

7.6.1 Ground gas monitoring

In line with the initial CSM, response zones were installed to target the sources or pathways as detailed in **Table 15**. Dual gas taps were installed in line with BS8576.

Three monitoring rounds have been undertaken to provide data to support refining of the CSM. The number of monitoring rounds undertaken is in general accordance with the decision matrix presented as Figure 6 of BS8576.

An infrared gas meter was used to measure gas flow, concentrations of carbon dioxide (CO_2), methane (CH_4) and oxygen (O_2) in percentage by volume, while hydrogen sulphide (H_2S) and carbon monoxide (CO) were recorded in parts per million.

Initial and steady state concentrations were recorded.

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 J**. Equipment calibration certificates are available on request.

7.7 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.

7.7.1 Chemical analysis of soil samples

The soil sampling strategy was designed to characterise made ground and/or natural strata typically within the upper 1.0m of the ground profile whilst also characterising deeper strata and the potential for contaminant migration from relevant sources of identified within the preliminary CSM.

The programme of chemical tests undertaken on soil samples obtained from the intrusive investigation is presented in **Table 14** with the laboratory testing results contained in **Appendix L**.

Table 14 Summary of chemical testing of soil samples

Stratum	Tests undertaken	No. of tests
Made ground	Metals (As, Cd, tCr, CrVI Pb, Hg, Se, wsB, Cu, Ni, Zn)	3
	PAH 16MS (USEPA 16 speciated)	3
	TPHCWG (C5-36) Aliphatic/Aromatic Split (with CWG banding), BTEX & MTBE	3
	pH	3
	Asbestos	3
	Total Organic Carbon	3
	WAC E Inert, SNRHW & Hazardous (Single stage 10:1)	3
	Leachate prep (2:1) and leachable metals (As, Cd, tCr, CrVI, Cu, Ni, Pb, Zn, Hg, B, Se)	2
Topsoil	Metals (As, Cd, tCr, CrVI Pb, Hg, Se, wsB, Cu, Ni, Zn)	3
	PAH 16MS (USEPA 16 speciated)	3

	TPHCWG (C5-36) Aliphatic/Aromatic Split (with CWG banding), BTEX & MTBE	3
	pH	3
	Asbestos	3
	Total Organic Carbon	3
	WAC E Inert, SNRHW & Hazardous (Single stage 10:1)	1
	Leachate prep (2:1) and leachable metals (As, Cd, tCr, CrVI, Cu, Ni, Pb, Zn, Hg, B, Se)	1
Lowestoft Formation	Metals (As, Cd, tCr, CrVI Pb, Hg, Se, wsB, Cu, Ni, Zn)	2
	PAH 16MS (USEPA 16 speciated)	2
	TPHCWG (C5-36) Aliphatic/Aromatic Split (with CWG banding), BTEX & MTBE	2
	pH	2
	Asbestos	2
	Total Organic Carbon	2
	WAC E Inert, SNRHW & Hazardous (Single stage 10:1)	1
	Leachate prep (2:1) and leachable metals (As, Cd, tCr, CrVI, Cu, Ni, Pb, Zn, Hg, B, Se)	2

7.7.2 Geotechnical analysis of soils

Where appropriate disturbed, bulk and undisturbed soil samples were taken for geotechnical classification testing with the depth and nature of samples detailed within the exploratory hole records.

Where appropriate, testing was undertaken in accordance with BS 1377:1990 Method of Tests for Soils for Civil Engineering Purposes or, where superseded, by the relevant part of BS EN ISO 17892:2014 Geotechnical investigation and testing - Laboratory Testing of Soil. Tests carried out in order to classify the concrete class required on-site have been undertaken following the procedures within BRE SD1:2005.

The programme of geotechnical tests undertaken on samples obtained from the intrusive investigation is presented in **Table 15**. The results and UKAS accreditation of tests methods are shown in **Appendix M**.

Table 15 Summary of geotechnical testing undertaken

Strata	Tests undertaken	No. of tests
Topsoil	BRE	2
Made Ground	BRE	2
Lowestoft Formation	Moisture content %	15

Strata	Tests undertaken	No. of tests
	Liquid/ plastic limits	15
	Partical Size Distribution	4
	Single stage quick undrained triaxial	10
	Consolidation test	5
	BRE	14

7.7.3 Infiltration testing

Infiltration tests were carried out in trial pits, TP5, TP6, TP10 and TP15 to establish the infiltration rate of the near surface Lowestoft Formation.

The tests were carried out generally in accordance with the method described in BRE Digest 365 (BRE, 2016), however only one pit had the three required tests, with the other pits only undergoing one or two tests due to time constraints. This involved filling the pits with water from a tanker and recording the drop-in water level with time as the water soaked into the ground.

Copies of the testing records are included in **Appendix M**.

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 I**.

The exploratory holes revealed that the site is underlain by a variable thickness of made ground in places, overlying the Lowestoft Formation with the Lewes Nodular and Seaford Chalk encountered at depth. This 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 16** with the strata discussed in subsequent subsections.

Table 16 General succession of strata encountered

Stratum	Exploratory holes encountered	Depth to top of stratum m bgl	Proven thickness (m)
Made ground	TP01 – TP04, TP09, TP13 – TP15, TP15 WS01, WS03, WS05 BH01, BH03A, BH08	Ground level	0.20m to 1.65m (Base not found TP03, TP04, TP13, TP15)
Topsoil	TP05 – TP8, TP10 – TP12, TP15B WS02, WS04, WS06 BH02, BH04 – BH07	Ground level	0.10m to 0.50m
Lowestoft Formation	TP01, TP02, TP05 - TP12, TP14, TP15A, TP15B WS01- WS08 BH01 – BH08	0.10 to 1.65m	16.30m to 16.90m (Base not found BH01 – BH05, BH07, all TP and all WS)
Lewes Nodular and Seaford Chalk Formation	BH06, BH08	17.00 to 17.30	Proven to 25.0m bgl

8.1.1 Made ground

The made ground was encountered across much of the east of the site, as well as in the south west corner and sporadically across the rest of the site. The made ground generally comprised a cohesive soil with a significant proportion of granular matrix and ranged in thickness from 0.20m to 1.65m. The made ground was encountered across the eastern side of the site, south western corner of the site and sporadically across northern and central areas.

This stratum can generally be described as a gravelly silty sand containing variable anthropogenic materials including concrete, brick, asphalt, metal, wood and textile.

A number of exploratory holes terminated within this strata due to obstructions. TP03 was terminated at 1.0m bgl after encountering demolition rubble including concrete boulders. TP04 was terminated at 0.05m bgl on concrete hardstanding and TP13 was terminated at 0.2m bgl on concrete hardstanding. TP15 was excavated to 0.2m bgl where pea shingle was encountered, the hole was then relocated 2m to the north (and renamed TP15A) and excavated to 1.0m bgl where a potential buried service was encountered. The pit was then relocated to the centre of the southern boundary of the site.

8.1.2 Topsoil

Topsoil was encountered at the ground surface where the made ground was absent, extending to depths ranging between 0.10m and 0.50m bgl.

This stratum typically comprises a dark brown gravelly slightly sandy silt containing gravel of chert with abundant rootlets.

8.1.3 Lowestoft Formation

The Lowestoft formation was encountered directly underlying the topsoil or made ground deposits at depths ranging between 0.10m and 1.65m bgl. This stratum extended to the base of all but two exploratory holes (BH06 and BH08), with the exception of the holes terminated within the made ground. Where the base of this formation was found the thickness was proven as between 16.30m and 16.90m.

This unit was variable, containing both cohesive and granular strata. The general succession encountered at the site comprised variable silty sands and gravels to between 3.45m and 3.60m bgl, followed by a band of cohesive material to between 5.0m and 8.50m bgl. This band of cohesive soil can generally be described as a dark grey soft to firm silty clay or clayey silt with organic rich partings. The cohesive band was not encountered within BH07 and WS05.

Beneath the cohesive band sands and gravels were again encountered to between approximately 11.0 and 14.6m bgl, with the exception of BH05.

A second band of cohesive strata comprising dark grey slightly gravelly slightly sandy clay with gravel of chalk and chert was proven to between 14.0 and 15.0m bgl in BH06 and BH08.

The strata again became granular until the base of the Lowestoft Formation between 17.00m and 17.30m bgl.

A summary of the in-situ and laboratory test results recorded in the stratum are presented in **Table 17**.

Table 17 Summary of in-situ and laboratory test results for the Lowestoft Formation

Soil parameters	Range		Reference
	Cohesive	Granular	
Moisture content (%)	11.9% to 31.8%	22.8 to 28.9	**Appendix L**
Modified moisture content (%)	18% to 39%	35% to 47%	**Appendix L**
Liquid limit (%)	25% to 54%	N/a	**Appendix L**
Plasticity limit (%)	16% to 23%	N/a	**Appendix L**
Plasticity index (%)	7% to 31%	N/a	**Appendix L**
Modified plasticity index (%)	2 to 30	N/a	**-**
Plasticity term	Low to High	N/a	**Appendix L**
Volume change potential	Low to Medium	N/a	**-**
SPT 'N' values	7 to 50	1 to 89	**Appendix I**
Undrained shear strength inferred from SPT'N' values (kN/m^2)*	31.5 to 225	N/a	-
Undrained shear strength measured by shear vane testing (kN/m^2)	2.3 to 66	N/a	**Appendix I**
Undrained shear strength measured by triaxial testing (kN/m^2)	50 to 236	N/a	**Appendix L**
Consistency term from field description	Soft to Very Stiff	N/a	**Appendix I**
Strength term (inferred from Triaxial testing)	Medium to Very High	N/a	**Appendix L**
Density term	N/a	Very Loose to Very Dense	-
Notes: *derived using a Stroud Factor of 4.5.			

8.1.4 Lewes Nodular and Seaford Chalk Formation

This stratum was encountered at a depth of between 17.0m and 17.3m below ground level and was proven to 25.0m bgl. Based on the site descriptions this stratum can be described as a moderately weak high-density grade Dc chalk.

A summary of the in-situ test results recorded in the stratum are presented in **Table 18**.

Table 18 Summary of in-situ and laboratory test results for the Lewes Nodular and Seaford Chalk Formation

Soil parameters	Min. Value	Max. Value	Reference
SPT 'N' values	8	110	**Appendix I**

8.1.5 Visual/olfactory evidence of soil contamination

No significant visual or olfactory evidence of contamination was noted within any of the intrusive locations.

No visual evidence of asbestos containing materials were observed.

8.2 Groundwater

8.2.1 Groundwater encountered during intrusive works

Groundwater was encountered during the intrusive investigation works as detailed on the logs in **Appendix I**.

Across the site two groundwater strikes were generally encountered. A shallow strike at between 3.0m and 4.5m bgl was encountered in BH01, BH02, BH04 and BH08, rising to between 2.75 and 4.0m bgl after 20 minutes. A second deeper strike was recorded between 6.5m and 8.5m bgl in all boreholes excluding BH06, rising to between 6.0m and 8.0m bgl. The two water strikes were separated by low permeability clay strata.

8.2.2 Groundwater encountered during monitoring

Rest groundwater levels recorded during the monitoring programme are summarised in **Table 19** based on the data provided in B. Field data measurements are also shown in **Appendix L**.

Table 19 Summary of groundwater monitoring results

Monitoring well	Response zone stratum	TOC elevation (m AOD)	Depth to water (mb TOC)		Groundwater elevation (m AOD) – min.	Groundwater elevation (m AOD) – max.
			Max (mb TOC)	Min (mb TOC)		
BH01	LOFT	74.48	5.90	5.85	68.58	68.63
BH03	LOFT	74.44	5.89	5.85	68.55	68.59
BH05	LOFT	74.79	6.25	6.19	68.54	68.60
BH08	LOFT	74.58	6.21	6.17	68.37	68.41
WS01	LOFT	74.47	Dry			
WS02	LOFT	74.17	Dry			
WS03	LOFT	74.58	Dry			
WS04	LOFT	74.20	1.89	1.85	72.31	72.35
WS05	LOFT	74.70	Dry			
WS06	LOFT	74.57	1.07	1.02	73.50	73.55

The findings reflect the groundwater table in the Lowestoft Formation, which is at an elevation of 68.37m to 73.55 m AOD. Groundwater was not encountered within the Chalk.

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.

8.2.3 Visual/olfactory evidence of groundwater contamination

Visual or olfactory evidence of groundwater contamination was not observed during monitoring.

8.3 Chemical laboratory results

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

Asbestos was not detected in any of the 8 No. samples tested.

8.4 Geotechnical laboratory results

The results of the geotechnical testing are discussed in **Section 11** and presented in **Appendix M.**

8.5 Ground gas monitoring

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

9 GEO-ENVIRONMENTAL ASSESSMENT

9.1 Refinement of initial CSM

The ground conditions encountered during the intrusive investigation generally reflect those anticipated within the initial conceptual site model and therefore the pollutant linkages identified previously still require assessment.

9.1.1 Linkages eliminated after refinement of the initial CSM

At this stage all linkages identified within the CSM are considered to potentially be complete.

9.1.2 Linkages added after refinement of the initial CSM

No additional linkages were identified during intrusive works.

9.2 Linkages for assessment

In line with CLR11 (Environment Agency, 2004), there are two stages of quantitative risk assessment, generic (GQRA) and 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.

Following the refinement of the initial CSM, the potentially complete contaminant linkages that require further assessment and the methodology of assessment are presented in **Table 20**.

Table 20 Linkages for GQRA

Potentially relevant contaminant linkage	Assessment method
Soil	
1. Oral, dermal and inhalation exposure with impacted soil, soil vapour and dust by future residents	Human health GAC in **Appendix O** for a proposed commercial end use. Consideration given to the applicability of the use of Statistical Assessment. Methodology for statistical assessment presented in **Appendix H**.
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. Contaminants permeating potable water supply pipes	Comparison of soil data to GAC in **Appendix Q** for plastic water supply pipes using UKWIR (2010) guidance.
4. Leaching of soil contaminants and dissolved phase migration	Comparison of leachate data to the relevant GAC in **Table 1** of **Appendix R**.

Potentially relevant contaminant linkage	Assessment method
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.	Gas screening values (GSV) have been calculated using maximum methane and carbon dioxide concentrations with maximum flow rates recorded at the site. The GSV have been compared with the revised Wilson and Card classification presented in BS8485.

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

Laboratory testing results have been compared directly against the RSK GAC for a commercial end use scenario.

The results of the comparison indicate that there are no exceedances of the adopted threshold criteria. As such, a pollution linkage relating to direct contact by future site residents with contaminated soils is not considered to exist on site.

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, topsoil and shallow natural deposits.

9.3.3 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).

The results indicate that a relevant linkage is unlikely to exist associated with organic contaminants and therefore pollutant polyethylene (PE) and polyvinyl chloride (PVC) water supply pipes are expected to be suitable for use on the development.

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.

9.3.4 Leaching of contaminants and dissolved phase migration

The soil leachate results found to exceed the GAC presented in **Appendix O** are summarised in **Table 21**. The UK Drinking Water Standards have been selected as the GAC as no surface water receptors have been identified in the vicinity of the site.

Table 21 Summary of soil leachate GQRA exceedances with respect to controlled waters

Determinant	Samples tested	GAC (ug/l)	No. of exceedances	Maximum recorded concentration (ug/l)	
				Value	Location (depth)
Lead	5	10	1	12	WS01 (0.5m bgl)

Only one exceedance of the GAC was identified, relating to lead in a sample of made ground. The exceedance was marginal, with 12ug/l of lead compared to the GAC of 10ug/l. Soil analysis of the same sample did not identify elevated concentrations of lead within the sample (16mg/kg) and lead concentrations across the site have generally been low.

Due to the marginal exceedance, general low concentrations of lead across the site and proposed end-use of the site with hardstanding preventing significant water infiltration it is not considered that there is a significant risk to controlled waters through leaching of contaminants.

9.4 Ground gas risk assessment

9.4.1 Appropriate guidance

The risks to development from ground gases have been assessed in accordance with BS8485:2015, which provides guidance on ground gas (methane and carbon dioxide) characterisation and hazard assessment, as well as a framework for the prescription of protection measures within new buildings.

The process involves characterising the gas hazard from combining the qualitative assessment of risk (using the conceptual site model) with ground investigation data so that a 'characteristic situation' (CS) can be derived for the site. Characteristic situations range from CS1 to CS6, the higher the CS the higher the hazard potential. Protection measures within new buildings can be prescribed using a point scoring system, taking in to consideration the CS and the proposed building type.

BS8485 indicates that the gas hazard can be characterised using the following methods:

- an empirical semi-quantitative approach using gas monitoring data to determine the 'characteristic situation' of the site (or zones of the site) and subsequent protective measures (Wilson and Card approach).

- an empirical semi-quantitative approach using TOC data to determine the 'characteristic situation' of the site (or zones of the site) and subsequent protective measures (CL:AIRE RB17 approach), or
- detailed quantitative assessment methodologies.

For the purpose of this assessment, the first approach listed above has been used to characterise the gas hazard and provide advice on the protective measures likely to be required within new buildings at the site.

9.4.2 Summary of the refined conceptual site model for ground gas

In the assessment of risks and selection of appropriate mitigation measures, BS8485 highlights the importance of the conceptual model. In summary, potential sources of ground gas within influencing distance of the site identified in section 6.2 comprise:

- Made ground deposits with a low biodegradable content, where present; and
- Chalk bedrock

The intrusive investigation found the made ground to be limited in extent, up to a maximum thickness of 1.65m. Generally, the made ground strata was not organic rich, as such there is unlikely to be significant gas generation potential from the made ground.

The intrusive investigation found the Chalk bedrock to between 17.0m and 17.3m and therefore it is not considered that there is a risk to the site from ground gas related to the Chalk bedrock geology.

This assessment has been undertaken to assess risks to building structures and proposed end users. The assessment has not taken into consideration the health and safety of construction workers. Risks may still be present to construction workers especially where works include the entry into excavations within the ground. Construction workers should undertake appropriate risk assessments and risks should be managed through health and safety procedures and safe systems of work.

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

9.4.3 Empirical semi-quantitative approach using borehole monitoring data (Wilson and Card approach)

9.4.3.1 Permanent gases – methane and carbon dioxide

The empirical semi quantitative approach using gas monitoring data is based on calculations of the gas screening value (GSV). BS8485 defines the GSV as the *'flow rate (l/hr) of a specific hazardous gas representative of a site or zone, derived from assessment of borehole concentration and flow rate measurements and taking account of all other influencing factors, in accordance with a conceptual site model'.*

Once derived for both methane and carbon dioxide the GSVs are compared to the thresholds presented in Table 2 of BS8485, so that a CS can be determined for the site, or a zone. It is important to note that the GSV thresholds are guideline values and not absolute. The GSV thresholds 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 adopt a higher risk classification than the GSV threshold indicates.

The results of the ground gas monitoring and testing undertaken at the site are given in **Appendix J**.

The minimum and maximum results are presented in **Table 22**.

The range of atmospheric pressure over the four monitoring rounds completed was 992 to 1031 mbar.

Table 22 Summary of ground gas monitoring results

Borehole	Response zone/ stratum	Probable source(s) of ground gas	Number of monitoring visits	Methane (%)	Carbon dioxide (%)	Oxygen (%)	Flow rate (l/hr)	Water level (m b TOC)	Atmospheric pressure (mbar)
BH01	LOFT	LOFT	4	<0.1	1.7 to 2.2	15.8 to 17.5	0.0 to 0.2	5.85 to 5.90	992 to 1031
BH03	LOFT	LOFT	4	<0.1	0.1 to 0.7	20.3 to 20.7	0.0 to 0.1	5.85 to 5.89	992 to 1031
BH05	LOFT	LOFT	4	<0.1	0.4 to 1.7	15.0 to 19.5	0.0 to 0.1	6.19 to 6.25	992 to 1031
BH08	LOFT	LOFT	4	<0.1	0.1 to 0.2	20.4 to 20.7	0.0 to 0.1	6.17 to 6.21	992 to 1031
WS01	LOFT	LOFT	4	<0.1	1.1 to 3.5	14.0 to 17.9	0.0 to 0.1	Dry	992 to 1031
WS02	LOFT	LOFT	4	<0.1	0.5 to 0.9	18.9 to 20.5	0.0 to 0.1	Dry	992 to 1031
WS03	LOFT	LOFT	4	<0.1	0.4 to 0.6	19.7 to 20.7	0.0 to 0.2	Dry	992 to 1031
WS04	LOFT	LOFT	4	<0.1	0.3 to 1.1	17.7 to 20.5	0.0 to 0.1	1.85 to 1.89	992 to 1031
WS05	LOFT	LOFT	4	<0.1	3.3 to 5.0	12.8 to 13.9	0.0 to 0.1	Dry	992 to 1031
WS06	LOFT	LOFT	4	<0.1	<0.1 to 3.5	15.4 to 15.9	0.1 to 0.2	1.02 to 1.07	992 to 1031
Note: *LOFT – Lowestoft Formation* *Steady state gas concentrations and flows are presented in this table.*									

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.

- Methane GSV (0.0004 l/hr) = methane concentration (0.1 % v/v) x flow rate (0.2 l/hr)
- Carbon Dioxide GSV (0.01 l/hr) = carbon dioxide concentration (5 % v/v) x flow rate (0.2 l/hr).

Based on the GSVs derived and the method for determining the CS presented within Table 2 of BS8485, the site has been characterised as CS1 trace gases

9.4.4 Implications

Based on the current understanding of the conceptual site model and the assessment undertaken, the site has been classified as CS1. Considering the foregoing and in accordance with BS8485, ground gas protective measures are not considered necessary within proposed buildings.

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 23** along with the likely implications.

Table 23 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

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

Technical Guidance WM3 (EA, 2018) sets out in Appendix D 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.

No samples were found to have hazardous properties based on this assessment. This suggests that if applicable the waste would require disposal at a suitably permitted inert or non-hazardous waste landfill.

10.1.2 Asbestos within waste soils

No potentially asbestos containing materials were encountered during intrusive site works, however its presence cannot be ruled out. 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.

10.2 WAC assessment

Five soil samples were submitted for waste acceptance criteria (WAC) testing for the WAC-E (Inert, SNRHW and Hazardous) suite, the results of which are presented in **Appendix L**.

The results of the WAC testing indicate that the leaching limit values and total content of organic parameters for inert waste have not been exceeded and therefore the waste may be suitable for disposal at an inert landfill or a site that has a valid exemption from the Environmental Permitting (England and Wales) Regulations 2010 registered with the EA.

11 GEOTECHNICAL ASSESSMENT

11.1 Proposed development

It is understood that the proposed development is to involve the construction of a large warehouse and distribution centre with associated infrastructure. At this stage no specific information relating to building loads has been provided and therefore column loads of up to 1000 kN have been considered along with a ground floor loading of 30 kN/m^2.

The proposed development layout for the site is included within **Appendix B**.

11.2 Key geotechnical hazards / development constraints

The key risks identified from the available ground investigation data are discussed below:

- Laterally and vertically variable ground conditions associated with variable thickness and extent of made ground, concrete obstructions and variable granular and cohesive and organic Lowestoft Formation Deposits;
- Shrinkable soils associated with the cohesive strata within the Lowestoft Formation of Low to Medium volume change potential;
- Possibility of running sands being present where granular elements of the Lowestoft Formation are saturated;
- Low bearing capacity soft clays and very loose/loose sands within the Lowestoft Formation;
- The presence of localised made ground deposits; and
- The presence of buried utilities and concrete obstructions.

11.3 Foundations

11.3.1 General Suitability

The founding stratum of the Lowestoft Formation has been found to be highly variable, and in some locations soft clays, organic clays & silts and peaty clays and very loose/loose sands have been encountered generally between depths of 3.0m bgl and 6.0m bgl particularly identified in the east and north east. Specifically, the following low (<10) SPT N values and 'soft' clays were noted:

- BH01, loose sand and soft organic rich clay between 3.0m and 4.5m bgl, SPT N values of 9 at 3.0m and 4.0m bgl;
- BH03A, soft organic rich clay between 3.5m and 4.5m bgl, SPT N value of 7 at 3.5m bgl;
- BH05, loose sand 3.5m to 4.5m bgl and soft sandy gravelly silty clay 5.0m bgl to 6.0m bgl, SPT N values of 9 at 3.5m and 7 at 5.5m bgl;
- WS04, soft/soft to firm clay 3.6m to +5.0m bgl;

- WS05, loose gravelly sand 3.0m to 4.5m bgl, SPT N value of 1 at 3.0m bgl and 6 at 4.0m bgl; and
- WS06, loose sandy gravel and soft silt and clay between 3.0m and 3.9m bgl, SPT N value of 3 at 3.0m bgl.
- TP07, TP12 & TP14, soft/soft to firm clay at 2.9m to +3.2m, 1.2m to 2.0m and 3.0m to +3.3m bgl.

The presence of low strength/loose soils appear to be relatively sporadic across the site. The perched groundwater strikes may in some instances have resulted in localised lower SPT N values and lower plasticity clays with higher sand/gravel contents may be particularly sensitive to sampling. However, a band of low strength/soft and organic cohesive strata does appear more prevalent across the eastern part of the site.

Given the local presence of low strength organic and peaty clay and very loose/loose sands across the site, deep ground improvement or piled solution may need to be adopted for the proposed new buildings to transfer loads beyond this softer layer onto a suitable strength bearing strata and to minimise settlement risks.

Notwithstanding the above, the ground conditions may be suitable in some areas for the design and construction of conventional spread foundations, subject to the proposed loadings and further investigation to confirm the absence of any weaker soil horizons within the critical zone of influence below the foundations.

Consideration may be given to further targeted investigation beneath the proposed building footprints to confirm the extent, thickness and strength of the weaker soil horizons in order to refine foundation solutions.

11.3.2 Piled Foundations

Recommendations for the design and construction of pile foundations in relation to the ground conditions are set out in Table 24.

Table 24 Design and construction of piled foundations

Design/construction considerations	Design/construction recommendations
Pile type	The construction of bored and CFA piles is considered technically feasible at this site.
Possible constraints on choice of pile type	The locally 'dense' sand & gravel deposits encountered near surface are likely to lead to premature set of driven piles and/or significant vibration/noise associated with 'hard' driving.
Temporary casing	Given the presence of groundwater within the Lowestoft Formation during the investigation bored piles will require temporary casing throughout their depth. Alternatively, the use of continuous-flight-auger (CFA) injected bored piles or driven piles usually overcomes this issue.

Design/construction considerations	Design/construction recommendations	
Made ground /soft superficial deposits	Up to 6.0m of the made ground and soft clays have been ignored in the calculation of preliminary pile capacities in the eastern part of the site.	
Man-made obstructions	The presence of buried sub-structures or other obstructions within made ground may lead to some difficulty during piling. 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 flint bands within the White Chalk Sub-group.	
Pile design parameters for granular Lowestoft Formation deposits to 11.0m bgl.	Pile design parameter	CFA
	Shaft friction factor (k_s.tan δ)	0.52
Pile design parameters for cohesive Lowestoft Formation deposits to 17.0m bgl.	Undrained shear strength c_u (kN/m^2)	150
	Adhesion factor α	0.5
	Limiting shaft friction (kN/m^2)	110
Pile design parameters for White Chalk to 25.0m bgl.	Shaft Friction (kN/m^2)	0.8.σ_v'
	Allowable End Bearing q_{all} (kN/m^2)	800
	Limiting shaft friction (kN/m^2)	110
General parameters	Limiting concrete stress (kN/m^2)	8.75 N/mm^2
	Factor on ultimate shaft friction	1.1
	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 25 gives likely working pile loads for CFA, cast-in-situ concrete piles of various diameters and lengths, based on the design parameters given in Table 24. For this purpose, the generalised soil profile encountered in BH01 to BH08 have been considered and the depth to chalk based on BH06 and BH08. It should be noted that the depth to chalk has not been proven in the eastern half of the site and additional deep boreholes would be required in this area to inform final pile design.

Table 25 Typical pile working loads for CFA cast-in-situ piles

Typical pile working loads (kN)			
Depth of pile below existing ground level (m)	Pile diameter		
	350 mm	400 mm	450 mm
12.00	236	278	322
13.00	269	316	365
14.00	302	353	407
15.00	335	391	450
16.00	368	429	492
17.00	401	467	534
18.00	474	555	638
19.00	523	610	700
20.00	571	665	762
21.00	619	720	825
22.00	668	776	887

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.

11.3.3 Deep Ground Improvement

Given the local presence of the weaker soil zones generally between depths of circa 3.0m to 6.0m bgl, conventional spread footings and deep bases are unlikely to be suitable. Consideration can therefore be given to improving the near surface soil using some form of ground improvement such as vibro replacement stone columns, vibro concrete columns or constrained modulus columns (CMC's). These techniques would have the added benefit of facilitating ground bearing floor slabs when combined with a load transfer mat (geogrid reinforced granular mattress). Pre-drilling of 'dense' near surface strata may be required for the ground improvement technique to penetrate to the required design depth.

The advice of a specialist contractor should be sought with respect to the most suitable treatment, pattern of treatment points and design loads available after treatment. The layout of treatment points should be tailored to the structural layout and floor loading capacity requirements.

11.3.4 Foundation works risk assessment

It is anticipated that a foundation works risk assessment report will not be required for the development because the made ground present at the site was of limited thickness and chemical testing has shown the site to be generally free of significant contamination.

11.4 Floor slabs

Due to the variable composition and strength / density of the Lowestoft Formation some degree of lateral and horizontal variability in terms of composition is likely to be present within the subgrade.

The assumed design loading for the proposed ground floor slabs is 30 kN/m^2 as described in Section 11.1. The sub-grade soil conditions beneath the footprint of the proposed buildings comprise topsoil and/ or made ground soils over the variable cohesive and granular Lowestoft Formation. The groundwater conditions are likely to comprise relatively shallow (i.e. <5.00m bgl); based on the findings of the intrusive investigation and subsequent monitoring rounds.

Due to the size of the proposed buildings it is assumed that ground bearing floor slabs will be used. Therefore, a ground bearing floor slab will need to be designed in combination with a suitable depth of compacted capping and sub base and ground improvement/piling.

As the near surface soils have been found to be variable and locally weaker soil zones identified during intrusive works particularly in the east there remains a significant risk of differential settlement occurring across the floor slabs and the designer should take this into account during the design of the floor slabs and any ground improvement and piling.

Careful examination and rolling of the formation and replacement of exceptionally soft or and hard material with well compacted suitable granular fill will be necessary.

However, if high loadings are envisaged with a low tolerance for total and differential settlement then it may be necessary to adopt a ground-bearing floor slab supported by ground improvement or piling. Ground improvement techniques are likely to be restricted to vibro-replacement, excavate, select, stabilise, replace or piling options.

11.5 Roads and hardstanding

In the 1 m to 1.5 m below the proposed finished ground level the exploratory holes have revealed a soil profile comprising topsoil or made ground over sands and gravels of the Lowestoft formation. The potentially poorest sub-grade material within this profile is the 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, California bearing ratio (CBR) value for the soils and groundwater conditions described above under a completed pavement is 3%, based upon Table C1 in TRRL (1984) Report LR1132, for a for a silty/sandy clay.

The results of in-situ testing are summarised in **Table 26**.

Table 26 Summary of CBR values derived from in-situ DCP tests

Test location	Material type	Minimum CBR value determined at or just below anticipated formation level
BH03A	Made Ground; gravelly sandy SILT	4%
TP01	Made Ground; gravelly very silty SAND	19%
TP02	Gravelly clayey SAND	8%
TP03	Made Ground; gravelly sandy SILT	21%
TP05	Gravelly clayey SAND	4%
TP06	Gravelly clayey SAND	4%
TP07	Sandy gravelly CLAY	9%
TP08	Clayey gravelly SAND	4%
TP09	Made Ground; gravelly clayey SAND	42%
TP10	Gravelly SAND	30%
TP11	Clayey sandy GRAVEL	10%
TP12	Gravelly sandy CLAY	14%
TP13	Refusal at 150mm on concrete obstruction	
TP14	Made Ground; gravelly clayey SAND	6%
TP15	Made Ground; clayey gravely SAND	30%

The sub-grade soils in the vicinity of test locations may be susceptible to improvement by rolling with conventional compaction plant.

The recommended sub-grade soil CBR value for road pavement design is therefore 4%. 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 condition at the time of construction should be confirmed by testing at the final formation level by in situ CBR testing.

The sub-grade soils can generally be regarded as non-frost-susceptible, based upon the criteria given in Appendix 1 of TRRL (1970) Report Road Note 29. 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 450 mm.

11.6 Excavations for foundations and services

Some of the trial pits became unstable during excavation. It is therefore recommended that excavation support systems are made available during the groundwork stage of the development.

Man entry into any excavations should not be undertaken without provision of suitable shoring and support and dewatering or suitable regrading and battering of side slopes to safe angles. Confined spaces protocols for the Health and Safety of personnel should always be used where man entry into excavations is to be undertaken as low oxygen conditions may be present.

Groundwater was encountered in some of the trial pits. Dewatering may therefore be required to facilitate foundation excavation.

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.

Excavation should be possible using conventional site plant. Breakers may be necessary to remove any concrete obstructions within the made ground.

11.7 Chemical attack on buried concrete

This assessment of the potential for chemical attack on buried concrete at the site is based on BRE Special Digest 1: Concrete in aggressive ground, which represents the most up-to-date guidance on this topic currently available in the UK.

The desk study and site reconnaissance indicate that, for the purposes of assessing the aggressive chemical environment of the site, the site should be considered as comprising natural ground unlikely to contain pyrite.

Based on testing results, **Table 27** gives the characteristic pH, water-soluble and total sulphate content values for soils from each of the geological units encountered on-site.

Table 27 Characteristic pH, water soluble sulphate and total sulphate values

Stratum	pH	Water Soluble Sulphate (mg/l)	Total Potential Sulphate (mg/l)
Topsoil	7.48	<10	30
Made Ground	7.58	174	522
Lowestoft Formation	7.45	400	1200

Based on the results above and following the steps outlined in the BRE guidance, the Design Sulphate Classes and Aggressive Chemical Environment for Concrete classifications are summarised in **Table 28**, on the basis of water soluble sulphate and total potential sulphate, respectively.

Table 28 Concrete design class

Stratum	Ground water	Water Soluble Sulphate		Total Potential Sulphate	
		DS Class	AC Class	DS Class	AC Class
Topsoil	Mobile	DS1	AC-1	DS-1	AC-1
Made Ground	Mobile	DS1	AC-1	DS-2	AC-1
Lowestoft Formation	Mobile	DS1	AC-1	DS-2	AC-2

11.8 Infiltration drainage

The results of soakaway testing are summarised in **Table 29**.

Table 29 Infiltration test results

Trial pit	Geological unit	No. tests	Test result (m/s)
TP05	Lowestoft Formation	2	Test 1: 1.45×10^{-5} Test 2: 5.2×10^{-6}
TP06	Lowestoft Formation	3	Test 1: 1.1×10^{-4} Test 2: 9.58×10^{-5} Test 3: 9.69×10^{-5}
TP10	Lowestoft Formation	1	Test 1: 1.13×10^{-5}
TP15A	Lowestoft Formation	2	Test 1: 3.22×10^{-5} Test 2: 2.28×10^{-5}
Notes: Tests carried out in general accordance with BRE 365 however three tests were not completed in every pit.			

Based upon the results of the soakaway tests presented in Section 5.1.8 above, the ground conditions appear suitable from a geotechnical viewpoint, for the use of pit soakaways to discharge surface run-off water into the Lowestoft Formation. This should be confirmed with additional soakage testing in the positions of proposed soakaways when the final design is known.

The EA should be contacted at the design stage in order to obtain a 'consent to discharge'. This may not be forthcoming where soakage will be into or just above the water table, particularly within groundwater protection zones. In addition, planning approval will have to be sought for their use.

12 CONCLUSIONS AND RECOMMENDATIONS

12.1 Geo-environmental assessment

The results of the site investigation and GQRA indicate that relevant contaminant linkages are absent based on the data available and therefore the site is suitable for the proposed end use. Although not encountered to date, localised sources of contamination could still be present, although they are unlikely to be widespread. Data gaps and uncertainties have been considered and no further assessment is considered to be required.

Gas monitoring results have indicated that the site would be classified as CS1 and therefore gas protection measure would not be required. Four monitoring visits have been completed to date. Due to the consistently low nature of monitoring results and consideration of the conceptual site model, with the absence of any significant sources of potential ground gas generation, the assessment is considered suitable to characterise the site without need for further monitoring.

Should unforeseen contamination be encountered during the development then specialist advice should be sought to determine the appropriate course of action. Imported material (e.g. topsoil, subsoil) should be validated before use on-site to confirm its suitability.

Initial findings of the waste soil characterisation tool (HASWASTE), which follow the guidance within Technical Guidance WM3 suggested that waste from the site would be considered as not hazardous. WAC testing has confirmed this assessment and suggests that waste soils from the site should be suitable for off-site disposal under an inert classification.

12.2 Geotechnical assessment

Given the local presence of low strength organic and peaty clay and very loose/loose sands across the site, deep ground improvement or piled solution may need to be adopted for the proposed new buildings to transfer loads beyond this softer layer onto a suitable strength bearing strata and to minimise settlement risks.

Notwithstanding the above, the ground conditions may be suitable in some areas for the design and construction of conventional spread foundations, subject to the proposed loadings and further investigation to confirm the absence of any weaker soil horizons within the critical zone of influence below the foundations.

Consideration may be given to further targeted investigation beneath the proposed building footprints to confirm the extent, thickness and strength of the weaker soil horizons in order to refine foundation solutions.

The recommended sub-grade soil CBR value for road pavement design is 4%.

Some of the trial pits became unstable during excavation. It is therefore recommended that excavation support systems are made available during the groundwork stage of the development.

It is recommended that buried concrete be designed assuming DS-1 and AC-1 conditions.

Based on the preliminary soakage testing results, the shallow ground conditions may be suitable for the use of pit soakaways, additional targeted soakage tests may be required once the final proposed soakaway locations have been decided.

REFERENCES

AGS Interim Guidance (2013), 'Site investigation and asbestos risk assessment for the protection of site investigation and geotechnical laboratory personnel', February.

Baker, K., Hayward, H., Potter, L., Bradley, D. and McLeod, C. (2009), CIRIA Report C682. The VOCs Handbook. Investigating, assessing and managing risks from inhalation of VOCs at land affected by contamination (London: CIRIA).

British Standards Institution (BSI) (1990), 'BS 1377:1990. Methods of test for soils for civil engineering purposes'.

British Standards Institution (2015), 'BS 5930:2015. Code of practice for ground investigations'.

British Standard Institution (BSI) (2015), 'BS 8485:2015. Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings'.

British Standards Institution (2011), 'BS 10175:2011 + A2:2017. Investigation of potentially contaminated sites: Code of practice'.

British Standards Institution (2013), BS8576:2013. Guidance on investigations for ground gas – permanent gases and volatile organic compounds (VOCs).

Building Research Establishment (2005), BRE Special Digest 1: Concrete in aggressive ground.

Card G, Wilson S, Mortimer S. 2012. A Pragmatic Approach to Ground Gas Risk Assessment. CL:AIRE Research Bulletin RB17. CL:AIRE, London, UK. ISSN 2047- 6450 (Online).

Chartered Institute of Environmental Health (CIEH) and CL:AIRE (2008), Guidance on Comparing Soil Contamination Data with a Critical Concentration (London: CIEH).

Environment Agency (2018), 'Technical Guidance WM3. Guidance on the classification of and assessment of waste, 1st Edition, v.1.1, May 2018.

Environment Agency (2004), Model Procedures for the Management of Contaminated Land. Contaminated Land Report Number 11 (CLR11), September (Bristol: Environment Agency).

Norbury, D. (2010), Soil and Rock Description in Engineering Practice (Caithness: Whittles).

Part IIA of the Environmental Protection Act (Contaminated Land Regulations (England) 2002 (London: HMSO).

Rudland, D. J., Lancefield, R. M. and Mayell, P. N. (2001), CIRIA C552. Contaminated Land Risk Assessment: A Guide to Good Practice (London: CIRIA).

Stone, K., Murray, A., Cooke, S., Foran, J., Gooderham, L., (2009) CIRIA C681, Unexploded Ordnance (UXO). A guide or the construction industry.

Transport and Road Research Laboratory (1970), 'TRRL Road Note 29 (Appendix 1). Road pavement design'.

Transport and Road Research Laboratory (1984), 'TRRL Report LR1132 (Table C1)'.

UK Water Industry Research (2010) UKWIR Report 10/WM/03/21. Guidance for the Selection of Water Supply Pipes to be used in Brownfield Sites (London: UKWIR).

FIGURES