

GROUND INVESTIGATION REPORT- INTERPRETATIVE

St Gabriel's, Manchester

PREPARED FOR: McLaren Living

ISSUE 02

Concept: 23/3814-GIR-GIR

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1.0 INTRODUCTION

Concept Engineering Consultants (Concept) have been instructed by Meinhardt on behalf of McLaren Living to provide a Geo-environmental and Geotechnical Interpretative Report for a new development at a site known as St Gabriels in Manchester.

This report provides an appraisal of the ground conditions with interpretation and assessment of geo-environmental and geotechnical elements of the ground investigation.

Between the 17th of April and the 31st May 2023, Concept undertook a ground investigation at specific locations at the proposed development site. These are summarised in the Concept Factual Report:

- Concept Site Investigations (2023). Ground Investigation Report- Factual, St Gabriels Manchester (23/3814-GIR-F01 Issue 01 31-08-2023)

Samples from the ground investigation works, have been screened positive for the presence of asbestos. Please note that during all subsequent works on site, particularly where the ground will be disturbed, all appropriate steps should be taken having regard to the presence of asbestos.

Concept have no liability in terms of their commission in relation to the management or treatment of asbestos and therefore recommend that the Client appoint a suitably qualified asbestos specialist to deal with these issues. In addition, Concept cannot be held responsible for any issues arising from the movement of the asbestos during sampling or subsequent excavations.

This report has been prepared for Meinhardt on behalf of McLaren Living based on their specific requirements and instructions. Any other party using the information in this report for any other purpose whatsoever does so at their own risk and any duty of care to that party is excluded. Reasonable skill and care has been exercised in the preparation of this report in accordance with the technical requirements of the brief. Notwithstanding the efforts made by the professional team, it is possible that ground conditions other than those indicated in this report may exist at the site. The designers of the scheme should satisfy themselves that the opinions and parameters presented in this report are appropriate for their proposed design.

2.0 THE SITE

2.1 Site Description

The site is at St Gabriel's, Manchester, centred approximately on National Grid Reference E385214, N395751. The approximate site location is shown in Figure 2.1

The site is generally an area of residential and commercial properties. It's bounded by Hathersage Road to the north, commercial and residential buildings and Oxford Road to the west, Oxford Place Road and student accommodation to the south, and residential properties and vacant land to the east.

Whitworth Park is located approximately 250m west of the site. The Royal Manchester Children's Hospital is located approximately 100m to the north. A petrol station is located approximately 230m to the southwest.

The site itself was student accommodation and consists of three vacant buildings plots; St Gabriel's Hall, Woodthorpe Hall and St David's Chapel, on the western, central and eastern plots respectively. Some small ancillary structures were on the site, including an electrical substation to the southwest of the site. An underground culvert exists north of the site, orientated east to west. The site comprises landscaping and hardstanding to the south, with a general topographical level of +39.50m OD (Ordnance Datum).



Figure 2.1: Approximate Site Location and Setting (Google, 2023)

2.2 Ground Conditions

The British Geological Survey (BGS) Geological Viewer of Great Britain shows the site to be underlain by superficial deposits comprising Glacial Till. The Bedrock geology is comprised of the Chester Formation (sandstone) to the west and Manchester Marls Formation (mudstone) to the east.

The BGS nomenclature database generic description of the Glacial Till is a diamicton, a sedimentary superficial deposit of unsorted and unstratified drift of clay, sand, gravel and boulders. The Chester Formation is a sandstone interbedded with conglomerates and subordinate mudstones. The Manchester Marl Formation comprises a red marl (calcareous mudstone and siltstone) with thin beds of fossiliferous limestone and dolomite. The formation is sandy in places, especially in the top part with localised breccias and pebbly beds.

The RSK Phase 1 Desk Study Report (ref 11671 R01 (00)) (provided by the Client) summarised the geology from the BGS historical boreholes located within 250m of the site. The desk study identified Made Ground (clay gravel of brick, ash and cinders) to depths of 0.75m to 2.20m. Till deposits comprising stiff/very stiff, brown silty sandy clay to an approximate depth of 10.4m. Manchester Marls Formation were identified in the eastern area of the site to depths between 45m to 60m and was identified to be a generally fine grained mudstone, red marl thinly bedded with limestone and dolomite and locally sandy and local breccias and pebbly beds. The Chester Formation was identified in the southwest of the site and is anticipated to depths of 220m. It is identified as a fine to coarse grained sandstone.

2.3 Coal Mining Risk

The RSK Phase 1 Desk Study Report (ref 11671 R01 (00)) obtained a Coal Mining Risk Assessment (CMRA) report as the site is located over Coal Measures Bedrock and may have been affected by coal mining activities. The report identified the site was not a Development High Risk area.

2.4 Hydrogeology and Hydrology

The Magic Maps website shows that the Till is classified as a Secondary Undifferentiated Aquifer. Secondary Undifferentiated Aquifers are layers that were neither categorised as Secondary A Aquifer or Secondary B Aquifer. In most cases, this means that the specific stratum was defined both as minor and non-aquifer at different locations due to the variability in the rock/ soil type characteristics. The presence of low permeability clay at relatively shallow depths beneath the site may increase the potential for lateral migration of shallow groundwater.

The underlying Bedrock is designated as a Principal Aquifer in the west and a Secondary B Aquifer in the eastern area of the site. A Principle Aquifer is strategically important rock that has high permeability and water storage capacity. The Environment Agency considers the Principal Aquifer to be critical to existing of future water supplies.

The nearest surface water feature is Gore Brook which is 1.1km southeast of the site. A surface water within the potential culvert was located to the north of the site, with the water running in a westerly direction.

Previous investigations within the site area suggest the groundwater encountered was perched within Made Ground deposits and within granular horizons of Till. The groundwater within the Principal aquifer was identified within the upper 5m of sandstone (approximately +21m AOD and +26m AOD).

2.5 The Proposed Development

The proposed development comprises two existing buildings and two new builds for student accommodation and will range between 2 and 5 stories. The foundations are anticipated to comprise piles founded within the Bedrock. Shallow foundations on the clay layer within the Till deposits is to be considered. The St David's Chapel will be demolished as part of the redevelopment.

2.6 Desk Study Review

As mentioned above the following desk study was provided by the Client:

- RSK Phase 1 Desk Study Report ref 11671 R01 (00) dated February 2022

Below is a summary of the desk study report.

2.7 Summary of Site History

The following information has been taken from RSK Phase 1 Desk Study Report issued in February 2022, provided in the tender:

- From earliest available map data, 1848, the site was originally agricultural fields, part of the Blackstake Farm, with a channel running through the northern area of the site, orientated east to west;
- From 1893 to 1938, several buildings were located on the site, including 'The Lodge' and 'Woodthorpe'. With residential semi-detached properties with gardens adjacent to the site. The channel is no longer shown;
- From 1908, all trees have been removed;
- From 1933, an extension to The Lodge has been done and part of the Woodthorpe building has been removed.
- The 1951 map indicates the site comprises of St Gabriel's Hall, Woodthorpe and St David's Church. 'The Stone Lodge' is shown in the southwestern corner of the site and unknown buildings are along the north of the site;
- From 1970 to 1993, the map indicates an extension to St Gabriel's Hall. The Stone Lodge is no longer shown and St David's Church is renamed St David's Hall;
- The map from 1999 to the present day shows the site in its current configuration.

2.8 UXO

The desk study referenced above identified that:

- A basic UXB risk map indicates that the site is in a moderate risk area with respect to UXB;
- A pre-desk study assessment indicates neither military activity or WW1 bombing was identified on site. The assessment identifies several WWI and WWII strategic targets within 5km of the site and reports that WWII bombs are recorded to have fallen in close proximity to the site.

2.9 Geotechnical Risks

The desk study referenced, identified the following in the initial geotechnical assessment:

- Basements identified on site;
- Retaining earth structure identified to the western extension of St Gabriel's building;
- Potential rising groundwater table due to diminishing abstraction in urban area;
- Shallow perched water likely within granular deposits of Till and Made Ground.

2.10 Environmental Risks

No environmental features were identified within 250m of the site.

2.11 Preliminary Conceptual Model

The Desk Study identified the following sources, pathways and receptors in the Preliminary Concept Model.

Made ground material from demolition and construction of various phases within the site are potential sources of unknown materials and may contain significant depths of made ground. Storage of oils/chemicals was identified on-site, with a gas room with tanks identified in the basement of St Gabriel's building. There is historical evidence of coal mining. Approximately 10m west of the site a former motor works / garage was identified, 10m to 30m west a formal industrial works and 70m north the Central Manchester University Hospital.

There is potential for the presence of contamination associated with the following:

- Made Ground from various phases of on-site development;
- Waste materials buried;
- Asbestos containing materials (ACM);
- Ground gas associated with Made Ground
- Leaked fuels from nearby electrical sub-stations and tanks (lube oil, diesel, kerosene, chlorinated solvents);
- Groundwaters and potential culverted watercourse containing leaked fuels from electrical sub-stations or tanks from gas rooms;

- Contaminants may therefore include brick, ash, clinker, toxic and phytotoxic metals, inorganics, petroleum hydrocarbons, fuel additives, polycyclic aromatic hydrocarbons (PAH), chlorinated solvents and asbestos.

Potential Receptors

The following receptors have been considered for the construction and operational stages of the proposed redevelopment.

- Future site users;
- Current adjacent site users;
- Current and future buildings and services;
- Groundwater in the principal aquifer within the Chester Formation bedrock (west), and secondary B aquifer within the Manchester Marl Formation (east);
- Potential culverted watercourse on site.

The construction workers and future maintenance workers were not identified in the conceptual model as receptors because these risks are considered to be managed through health and safety procedures.

A site walkover by RSK discerned no obvious existing vegetation discolouration or die back and thus it was deemed to be low risk and not assessed as a receptor.

The following receptors were considered for the potential ground gas linkages:

- Future site users;
- Adjacent land users, both residential and commercial;
- Current and future buildings and services

The RSK Phase 1 Desk Study Report ref 11671 R01 (00) did not identify construction workers as receptors for the assessment, however, there may still be risks present to construction workers where works include entry to excavations within the ground.

Potential Pathways

The following pathways have been considered for the construction and operational stages of the proposed redevelopment.

- Dermal contact, ingestion, inhalation pathways of potentially contaminated soils/groundwater, dust/fibres, soil/groundwater vapours, home-grown produce;
- Downward vertical migration of leachate to shallow groundwater;
- Vertical or lateral migration of surface water/drainage, ground gas; and
- Ground gas migration and ingress to buildings / confined spaces.

Summary of Risks from Contamination

The desk study concluded that:

- Moderate risk was determined on site made ground including ACM for future residential users through oral, dermal and inhalation exposure with impacted soil and dust/fibres, ingestion of home-grown produce;
- Moderate to low risk of storage of oil/chemicals on site to future residential users through oral, dermal and inhalation exposure with impacted soil and soil vapours, ingestion of home-grown produce, inhalation of vapours from groundwater and/or NAPL if present;
- Moderate to low risk of on-site made ground including ACM to adjacent residential and commercial users through oral, dermal and inhalation exposure with impacted soil and dust/fibres;
- Moderate to low risk on site from the made ground to current/future buildings/services via direct contact with contaminated soils or groundwater and chemical attack;
- Moderate to low risk of on-site made ground and potential storage of oils/chemicals to the second undifferentiated superficial aquifer via leaching from soils/percolation to the aquifer or lateral migration of the dissolved phase etc;
- Moderate to low risk on site from made ground and potential storage of oils/chemicals to the potential culvert on site via leaching from soils or lateral migration of the dissolved phase etc;
- Moderate risk from the made ground on site to future residential users, current and future site buildings and current adjacent site users via the migration and ingress of ground gases into buildings, build-up within confined spaces and explosion/asphyxiation.

The desk study identified that the site investigation had to target the identified sources of potential contamination and re-assess the pathways.

3.0 CONCEPT 2023 GROUND INVESTIGATIONS

Concept Site Investigations carried out a ground investigation between the 17th of April and the 5th of May 2023 with subsequent laboratory testing and monitoring. The extent and scope of the site investigation was specified by Meinhardt in their document :

- St Gabriel's, Manchester" Ground Investigation Specification document, with reference 2998-SG-S-SP-002 dated 10 February 2022

The laboratory testing was specified by Concept to identify the geo-environmental and geotechnical characteristics of the soils on site.

The scope of the works comprised the following:

- 3 No. Cable Percussion Boreholes to a maximum depth of 13.50m;
- 14 No. Dynamic Sampling Boreholes to a maximum depth of 3.95m;
- 3 No. Machine Excavated Trial Pits to a maximum depth of 1.30m;
- 5 No. Hand Excavated Trial Pits to a maximum depth of 1.50m;
- 1 No. Hand Excavated and 1 No. Machine Excavated Trial Pits to facilitate soakaway testing a maximum depth of 1.50m;
- 4 No. Dynamic Probing Testing (DP) to 7.90m depth;
- Soakaway Testing;
- Logging and Photographing;
- Instrumentation Monitoring and Sampling;
- Chemical Testing comprising asbestos screen and quantification, heavy metals, phenols, pH, Total Petroleum Hydrocarbons (TPH) and Polynuclear aromatic hydrocarbons (PAH's);
- Geotechnical Testing on recovered soil samples including moisture content, liquid and plastic limits, particle size distribution (PSD), sulphate testing, Undrained Shear strength, oedometer, dry density moisture content relationships and California Bearing Ratio (CBR)

Full details of the ground investigations are provided in the Concept GIR – Factual Report:

- Concept Site Investigations (2023). Ground Investigation Report- Factual, St Gabriels Manchester (23/3814-GIR-F01 Issue 01 31-08-2023)

3.1 Stratigraphy

The ground conditions identified on site comprised Made Ground, over Glacial Till and the Chester Formation. The stratigraphy revealed during the ground investigation confirmed the anticipated geology based on geological maps from the BGS website and a review of the historical development of the site. However, Manchester Marls were not identified in the boreholes.

Table 3.1: Stratigraphy

Stratum	Top mbgl (mOD)	Base mbgl (mOD)	Proven Thickness (m)	Description
<p>MADE GROUND (Hard surfacing areas)</p> <p>(BH01, BH02, BH03, WS01, WS03, WS04, WS05, WS07, WS08, WS09, WS10, WS12, WS13, WS15, TP01, TP01A, TP02, TP03, TP03A, TP04)</p>	<p>0.00</p> <p>+40.29 to +38.87</p>	<p>0.60 to 2.00</p> <p>+39.39 to +37.28</p>	<p>0.60 to 2.00</p>	<p>Asphalt (0.08m to 0.30m) Concrete (WS12 and TP05) 0.10m Reinforced Concrete TP07 0.26m Paving Slab (TP04) 0.09m</p> <p>Dark grey sandy angular to subrounded fine to coarse brick, concrete, granite, limestone or basalt GRAVEL. Sand is fine to coarse. (Subbase)</p> <p>Dark brown, grey to black fine to coarse SAND and GRAVEL with medium to high sandstone and brick cobble content. Gravel comprises angular to subrounded fine to coarse brick, slag, sandstone and granite fragments. Occasional glass and ceramic fragments.</p> <p>Brown mottled grey slightly gravelly sandy CLAY. Gravel comprises angular to subrounded fine to coarse siltstone, mudstone, quartzite, sandstone, clinker and brick fragments</p>
<p>MADE GROUND (Landscaped Areas)</p> <p>(WS02, WS03A, WS06, WS11, WS14, INFL01 & 02)</p>	<p>0.00</p> <p>+39.99 to +39.13</p>	<p>0.55 to 1.00</p> <p>+39.33 to +38.13</p>	<p>0.55 to 1.00</p>	<p>Grass over dark brown gravelly clayey fine to coarse SAND with frequent roots and rootlets and wood fragments. Gravel comprises angular to subrounded fine to coarse concrete, brick, clinker, mudstone and sandstone fragments.</p>
<p>GLACIAL TILL (Fine Grained)</p> <p>(BH01, BH02, BH03, WS01, WS02, WS03A, WS04, WS05, WS06)</p>	<p>0.55 to 2.00</p> <p>+39.39 to +37.28</p>	<p>8.90 to 9.20</p> <p>+30.57 to +30.03</p>	<p>7.10 to 7.80</p>	<p>Firm to stiff, brown mottled grey or dark brown slightly sandy gravelly CLAY with occasional pockets of brown fine to coarse sand. Gravel comprises angular to subrounded fine to coarse sandstone, coal, mudstone, siltstone and quartzite fragments.</p>
<p>GLACIAL TILL (Coarse Grained)</p> <p>(BH01, BH02, BH03)</p>	<p>8.90 to 9.20</p> <p>+30.57 to +30.03</p>	<p>9.50 to 10.90</p> <p>+29.97 to +28.13</p>	<p>0.60 to 1.90</p>	<p>Medium to very dense, brown fine to coarse SAND and GRAVEL. Gravel comprises angular to rounded fine to coarse quartzite, siltstone and sandstone fragments</p>
<p>CHESTER FORMATION</p> <p>(BH01, BH02, BH03)</p>	<p>9.50 to 10.90</p> <p>+29.97 to +28.13</p>	<p>>13.50</p> <p><+25.53</p>	<p>>3.20</p>	<p>Reddish brown SANDSTONE recovered as very dense medium to coarse sand.</p> <p>Reddish brown thinly to thickly laminated SANDSTONE and MUDSTONE recovered as: very dense gravel. Gravel comprises angular to subangular fine to coarse sandstone and mudstone fragments.</p>

3.2 Obstructions & Problems whilst Drilling and Excavating

The following is a summary of slow drilling in cable percussive boreholes.

- BH01 slow drilling 12.00 to 12.50 sandstone
- BH03 slow drilling between 8.70m and 12.50m due to hard strata.

The majority of dynamic sample boreholes refused due to the nature of the Glacial Till. The following locations were aborted at shallow depth:

- TP01A aborted due to brick culvert at 1.00m
- TP03 was aborted at 1.50m in Made Ground due to brick content and difficulty in excavating
- TP04 was aborted at 0.72m in Made Ground due to potential services
- TP07 was aborted at 1.50m in Glacial Till due to difficulty in excavating with hand tools.
- WS03 was aborted at 0.80m in Made Ground due to concrete slab
- WS07 aborted at 1.30m in Made Ground due to potential services.

TP02, TP03 and TP04 were recorded as unstable, the other pits were recorded as stable. In TP01 a clay pipe was recorded at 0.65m in Made Ground and stagnant water noted in the base of the pit

3.3 Zones of No Recovery

Area of core loss during dynamic sampling were recorded as follows due to the nature of the Made Ground and Glacial Till :

- WS02 AZCL 1.20 to 1.43 Glacial Till
- WS05 AZCL 2.00 to 2.30 Glacial Till
- WS12 AZCL 1.20m at base of Made Ground
- WS13 AZCL 2.00 to 2.50 Glacial Till

3.4 Evidence of Contamination

There was no evidence of significant contamination in the form of odours or staining identified in any of the locations.

Clinker and occasional slag were identified throughout the Made Ground. Frequent pockets of ash were encountered in Made Ground in WS04 between 0.15m and 0.40m and Made Ground in TP01 between 0.10m and 0.25m.

A photo ionisation detector (PID) was used to determine if there were volatile substances in shallow soil samples and results were between 0.1 ppm and 1.4 ppm (parts per million). It is considered that there is unlikely to be a source of volatile substances in the shallow soils based on the PID results.

3.5 Groundwater

During the fieldworks groundwater was encountered as follows:

- In TP01 stagnant water noted in the base of the pit, possibly from a clay pipe in the Made Ground.
- TP04 water at 0.68m in Made Ground

Nine monitoring wells for gas and groundwater monitoring were installed at various depths in the boreholes across the site. A summary of the installation depths and targeted strata is provided in Table 3.2.

Table 3.2: Groundwater Monitoring Installations

Hole ID	Base of Borehole (m bgl)	Diameter of Installation (mm)	Type of Installation	Base of Installation (m bgl)	Response Zone		Targeted Strata
					Top (m bgl)	Bottom (m bgl)	
BH01	12.50	50	GMP	12.50	9.50	12.50	Chester Formation
BH02	13.50	50	GMP	13.50	9.00	13.50	Base of Till and Chester Formation
BH03	13.00	50	GMP	13.00	2.00	13.00	Glacial Till and Chester Formation
WS02	3.25	50	GMP	3.00	1.00	3.00	Glacial Till
WS05	3.20	50	GMP	1.00	0.50	1.00	Made Ground
		19	SPIE	2.80	2.00	2.80	Glacial Till
WS10	2.50	50	GMP	1.00	0.50	1.00	Made Ground
		19	SPIE	2.50	2.00	2.50	Glacial Till
WS14	3.15	50	GMP	2.70	1.00	2.70	Glacial Till

Post-fieldwork the installations were developed and groundwater monitoring of the installations has been conducted on 7 occasions between the 2nd of June 2023 and the 7th of August 2023. An interface meter was used on the first monitoring visit and no evidence of free product was identified. The monitoring results are summarised in Table 3.3.

Table 3.3: Groundwater Monitoring Results

Strata	Borehole	Depth of Installation (mbgl)	Water Level	
			(mbgl)	(mOD)
Made Ground	WS05	1.00	0.15 to 0.66	+38.83 to +38.32
	WS10	1.00	Dry	-
Glacial Till	WS02	3.00	0.91 to 1.02	+39.21 to +39.10
	WS05	2.80	0.34 to 0.45	+38.64 to +38.53
	WS10	2.50	1.03 to 2.19	+38.84 to +37.68
	WS14	2.70	Dry	-
Glacial Till and Chester Formation	BH02	13.50	10.94 to 11.80	+28.09 to +27.23
	BH03	13.00	11.33 to 11.43	+28.44 to +28.34
Chester Formation	BH01	12.50	10.80 to 10.95	+28.28 to +28.13

The monitoring results show that there is a localised perched groundwater in the Made Ground and Glacial Till and it is recommended that a design groundwater level at the surface is adopted. The highest groundwater level in the Bedrock is +28.44m OD.

The shallow groundwater levels are anticipated to increase/fluctuate during times of heavy rainfall. Furthermore, the local hydrology may be influenced by flooding, damaged or leaking water mains, and leakage from foul or storm drainage systems.

3.6 Groundwater Sampling and Testing

On the final monitoring visit on the 7th of August 2023 a water sample was obtained from BH03 (Glacial Till/ Bedrock) and WS02 (Shallow Glacial Till). In the other locations samples could not be obtained as the wells were either dry or there was insufficient recharge to obtain an adequate water sample. A suite of chemical tests on the two water samples were scheduled by Concept and carried out by Eurofins Chemtest. The results of these tests are summarised in Table 3.4 below. The results are in ug/l unless indicated otherwise.

Table 3.4: Groundwater Analysis Results Summary

Determinant	Minimum (ug/l)	Maximum (ug/l)	Number of Samples Tested
pH	7.7	7.8	2
Boron (Hot Water Soluble)	86	100	2
Sulphate (mg/l)	120	170	2
Cyanide (Total) (mg/l)	<0.050	<0.050	2
Arsenic	0.74	0.75	2
Cadmium	<0.11	<0.11	2
Chromium	<0.50	<0.50	2
Copper	<0.50	1.8	2

Determinant	Minimum (ug/l)	Maximum (ug/l)	Number of Samples Tested
Mercury	<0.05	<0.05	2
Nickel	0.53	2.1	2
Lead	<0.50	<0.50	2
Selenium	0.69	0.80	2
Zinc	<2.5	3.9	2
Aliphatic TPH >C5-C6	<0.10	<0.10	2
Aliphatic TPH >C6-C8	<0.10	<0.10	2
Aliphatic TPH >C8-C10	<0.10	<0.10	2
Aliphatic TPH >C10-C12	<0.10	<0.10	2
Aliphatic TPH >C12-C16	<0.10	<0.10	2
Aliphatic TPH >C16-C21	<0.10	<0.10	2
Aliphatic TPH >C21-C35	<0.10	<0.10	2
Aliphatic TPH >C35-C44	<0.10	<0.10	2
Total Aliphatic Hydrocarbons	<5.0	<5.0	2
Aromatic TPH >C5-C7	<0.10	<0.10	2
Aromatic TPH >C7-C8	<0.10	<0.10	2
Aromatic TPH >C8-C10	<0.10	<0.10	2
Aromatic TPH >C10-C12	<0.10	<0.10	2
Aromatic TPH >C12-C16	<0.10	<0.10	2
Aromatic TPH >C16-C21	<0.10	<0.10	2
Aromatic TPH >C21-C35	<0.10	<0.10	2
Aromatic TPH >C35-C44	<0.10	<0.10	2
Total Aromatic Hydrocarbons	<5.0	<5.0	2
Total Hydrocarbons	<10	<10	2
Naphthalene	<0.10	<0.10	2
Acenaphthylene	<0.10	<0.10	2
Acenaphthene	<0.10	<0.10	2
Fluorene	<0.10	<0.10	2
Phenanthrene	<0.10	<0.10	2
Anthracene	<0.10	<0.10	2
Fluoranthene	<0.10	<0.10	2
Pyrene	<0.10	<0.10	2
Benzo[a]anthracene	<0.10	<0.10	2
Chrysene	<0.10	<0.10	2
Benzo[b]fluoranthene	<0.10	<0.10	2
Benzo[k]fluoranthene	<0.10	<0.10	2
Benzo[a]pyrene	<0.10	<0.10	2
Indeno(1,2,3-c,d)Pyrene	<0.10	<0.10	2
Dibenz(a,h)Anthracene	<0.10	<0.10	2

Determinant	Minimum (ug/l)	Maximum (ug/l)	Number of Samples Tested
Benzo[g,h,i]perylene	<0.10	<0.10	2
Total Of 16 PAH's	<2.0	<2.0	2
Total Phenols (mg/l)	<0.030	<0.030	2

3.7 Gas Monitoring

The shallow standpipes installed in the Superficial or Made Ground Deposits were monitored for ground gas. The gas monitoring was completed at the same time as groundwater monitoring on 7 occasions between the 2nd of June 2023 and the 7th of August 2023 and the results are recorded in Table 3.5 below. On all monitoring visits the carbon monoxide and hydrogen sulphide readings were zero. In some of the standpipes the water level was above the response zone and the results are not likely to be representative of the ground gas regime. These are highlighted in blue in the table below. The red results are the maximum values in deeper Bedrock and shallower Made Ground/ Glacial Till and natural soils.

Table 3.5: Ground Gas Monitoring

BH	Air (mb)	Flow Rate (l/hr)		CH4 (%)		LEL (%)		CO2 (%)		O2 (%)	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
BH01 (Bedrock)	1001 to 1023	0.0	0.0	0.0	0.0	0.0	0.0	0.2	12.7	1.5	20.3
BH02 (Bedrock)	1001 to 1023	-2.6	3.0	0.0	0.0	0.0	0.0	1.2	9.4	1.6	16.5
BH03 (Bedrock)	1001 to 1023	0.0	2.8	0.0	0.0	0.0	0.0	0.9	6.9	8.3	19.7
WS02 (Glacial Till)	1001 to 1023	0.0	0.0	0.0	0.0	0.0	0.0	0.1	5.0	5.3	20.5
WS05 (Made Ground)	1001 to 1023	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7	4.4	20.4
WS10 (Made Ground)	1001 to 1023	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.4	11.9	21.0
WS14 (Glacial Till)	1001 to 1023	0.0	0.0	0.0	0.0	0.0	0.0	0.2	10.7	3.5	20.4

3.8 Soil Sampling and Testing

As part of Concept Site Investigation, a suite of chemical tests on selected soil samples retrieved from the boreholes were scheduled by Concept and carried out by Eurofins Chemtest on 29 samples of Made Ground and 8 samples of natural soils. The results of these tests are summarised in Table 3.6 below. The results are in mg/kg unless indicated otherwise.

Table 3.6: Soil Analysis Results Summary

Determinant	Minimum (mg/kg)	Maximum (mg/kg)	Number of Samples Tested
ACM Screen	Not detected	Detected in 2 samples	37
Asbestos Identification	Chrysotile/ Amosite	Chrysotile/ Amosite	2
Asbestos by Gravimetry	<0.001	0.001	2
Total Asbestos	<0.001	0.001	2
Moisture	7.80	28.00	37
pH	7.00	11.30	37
Boron (Hot Water Soluble)	<0.40	3.10	37
Sulphate (2:1 Water Soluble) as SO ₄ (g/l)	<0.010	0.66	37
Cyanide (Total)	<0.50	3.50	37
Arsenic	4.20	45.00	37
Cadmium	<0.10	0.92	37
Chromium	10.00	41.00	37
Copper	9.70	140.00	37
Mercury	<0.05	5.20	37
Nickel	7.40	76.00	37
Lead	5.90	720.00	37
Selenium	<0.25	1.50	37
Zinc	26.00	500.00	37
Aliphatic VPH >C5-C6	<0.05	<0.05	37
Aliphatic VPH >C6-C7	<0.05	<0.05	37
Aliphatic VPH >C7-C8	<0.05	<0.05	37
Aliphatic VPH >C8-C10	<0.06	0.16	37
Total Aliphatic VPH >C5-C10	<0.25	15.00	37
Aliphatic EPH >C10-C12	<0.05	5.30	37
Aliphatic EPH >C12-C16	1.30	70.00	37
Aliphatic EPH >C16-C21	<2.00	65.00	37
Aliphatic EPH >C21-C35	3.60	65.00	37
Aliphatic EPH >C35-C40	<10	67.00	37
Total Aliphatic EPH >C10-C35	7.60	160.00	37
Total Aliphatic EPH >C10-C40	<10	160.00	37
Aromatic VPH >C5-C7	<0.05	<0.05	37
Aromatic VPH >C7-C8	<0.05	<0.05	37
Aromatic VPH >C8-C10	<0.05	<0.05	37
Total Aromatic VPH >C5-C10	<0.25	<0.25	37
Aromatic EPH >C10-C12	2.10	17.00	37
Aromatic EPH >C12-C16	<1.0	77.00	37
Aromatic EPH >C16-C21	<2.00	770.00	37

Determinant	Minimum (mg/kg)	Maximum (mg/kg)	Number of Samples Tested
Aromatic EPH >C21-C35	<2.00	1900.00	37
Aromatic EPH >C35-C40	1.10	290.00	37
Total Aromatic EPH >C10-C35	21.00	2800.00	37
Total Aromatic EPH >C10-C40	22.00	3100.00	37
Total VPH >C5-C10	< 0.50	< 0.50	37
Total EPH >C10-C35	32.00	2900.00	37
Total EPH >C10-C40	37.00	3200.00	37
Organic Matter	<0.40	33.00	37
Naphthalene	<0.10	1.30	37
Acenaphthylene	<0.10	3.10	37
Acenaphthene	<0.10	13.00	37
Fluorene	<0.10	12.00	37
Phenanthrene	<0.10	76.00	37
Anthracene	<0.10	49.00	37
Fluoranthene	<0.10	390.00	37
Pyrene	<0.10	370.00	37
Benzo[a]anthracene	<0.10	200.00	37
Chrysene	<0.10	200.00	37
Benzo[b]fluoranthene	<0.10	250.00	37
Benzo[k]fluoranthene	<0.10	85.00	37
Benzo[a]pyrene	<0.10	220.00	37
Indeno(1,2,3-c,d)Pyrene	<0.10	130.00	37
Dibenz(a,h)Anthracene	<0.10	18.00	37
Benzo[g,h,i]perylene	<0.10	110.00	37
Total Of 16 PAH's	<2.0	2100.00	37
Total Phenols	<0.10	0.71	37

3.9 Insitu Testing

3.9.1 Standard Penetration Tests

Standard penetration tests (SPTs) were conducted in all borehole locations, these are discussed in more detail in the geotechnical interpretation section of this report.

3.9.2 Dynamic Probing

Dynamic Probing was undertaken in 4 locations. The results are provided in the Factual Report.

3.9.3 Soakaway Tests

During the fieldworks soakaway tests were undertaken in four locations. The infiltration rates were as follows:

- INFL01 – water depth between the surface and 1.40m through Made Ground with the base in Glacial Till. In two tests the water did not drain to 75% of the depth of the pit and therefore infiltration characteristics could not be calculated in accordance with BRE guidance. An Infiltration rate calculated based on the water that drained from the pit was between 7.34×10^{-6} m/s and 7.38×10^{-6} m/s
- INFL02 – water depth between the surface and 1.50m through Made Ground with the base in Glacial Till. In two tests the water did not drain to 75% of the depth of the pit and therefore infiltration characteristics could not be calculated in accordance with BRE guidance. An Infiltration rate calculated based on the water that drained from the pit was between 1.75×10^{-5} m/s and 2.47×10^{-5} m/s.
- TP02 – water depth between the surface and 1.30m in Made Ground. In two tests the infiltration rate was between 1.05×10^{-4} m/s and 6.54×10^{-5} m/s.
- TP03 – water depth between the surface and 1.50m in granular Made Ground. In this location the water drained too quick for a test to be completed.

4.0 GEO-ENVIRONMENTAL RISK ASSESSMENT

4.1 Soils Human Health Risk Assessment

A review of the contamination results from the site has been undertaken by comparing the results above detection limits to published criteria for a residential without plant uptake land use.

Where chemical test data records contaminant concentrations that are on or beneath the laboratory detection limits these have been excluded from further assessment. This is based upon the conclusion that the determinant in question will be at such low concentrations that they do not represent a potential source.

In addition to those determinants which are below detection limits, the following determinants have also not been assessed further with regard to human health as justified below:

- pH, sulphate and organic matter content does not pose any identified human health-based risks under normal circumstances.
- Total PAH and TPH values have not been considered as, in accordance with current best practice, the individual species have been assessed in accordance with their differing toxicological properties.

The risk assessment utilises published and authoritative generic assessment criteria produced by Land Quality Management/Chartered Institute of Environmental Health (Suitable For Use Levels – S4UL) 2015 and DEFRA (Category For Screening Levels – C4SL) 2014 to determine the likelihood of harm being caused to human health.

Table 4.1 compares the determinants with concentrations above the limit of detection against the published generic assessment criteria.

Table 4.1: Assessment of Soil Contamination Results

Determinant	Maximum (mg/kg)	Target (mg/kg)	Elevated results	Source
ACM Type	Detected in 2 samples	No asbestos	2 of 37	-
Asbestos Identification	Chrysotile/ Amosite	No asbestos	2 of 37	-
Asbestos by Gravimetry	0.001	No asbestos	2 of 37	-
Total Asbestos	0.001	No asbestos	2 of 37	-
Boron (Hot Water Soluble)	3.1	11000	0 of 37	S4UL
Arsenic	45	40	1 of 37	C4SL-S4UL
Cadmium	0.92	85	0 of 37	C4SL-S4UL
Chromium	41	910	0 of 37	S4UL
Copper	140	7100	0 of 37	S4UL
Mercury	5.2	1.2	1 of 37	S4UL

Determinant	Maximum (mg/kg)	Target (mg/kg)	Elevated results	Source
Nickel	76	180	0 of 37	S4UL
Lead	720	300	2 of 37	C4SL
Selenium	1.5	430	0 of 37	S4UL
Zinc	500	40000	0 of 37	S4UL
Aliphatic VPH >C8-C10	0.16	27	0 of 37	S4UL
Aliphatic EPH >C10-C12	5.3	130	0 of 37	S4UL
Aliphatic EPH >C12-C16	70	1100	0 of 37	S4UL
Aliphatic EPH >C16-C21	65	-	0 of 37	S4UL
Aliphatic EPH >C21-C35	65	-	0 of 37	S4UL
Aliphatic EPH >C16-C35	85	65000	0 of 37	S4UL
Aliphatic EPH >C35-C40	67	65000	0 of 37	S4UL
Aromatic EPH >C10-C12	17	250	0 of 37	S4UL
Aromatic EPH >C12-C16	77	1800	0 of 37	S4UL
Aromatic EPH >C16-C21	770	1900	0 of 37	S4UL
Aromatic EPH >C21-C35	1900	1900	0 of 37	S4UL
Aromatic EPH >C35-C40	290	1900	0 of 37	S4UL
Naphthalene	1.3	2.3	0 of 37	S4UL
Acenaphthylene	3.1	2900	0 of 37	S4UL
Acenaphthene	13	3000	0 of 37	S4UL
Fluorene	12	2800	0 of 37	S4UL
Phenanthrene	76	1300	0 of 37	S4UL
Anthracene	49	31000	0 of 37	S4UL
Fluoranthene	390	1500	0 of 37	S4UL
Pyrene	370	3700	0 of 37	S4UL
Benzo[a]anthracene	200	11	3 of 37	S4UL
Chrysene	200	30	1 of 37	S4UL
Benzo[b]fluoranthene	250	3.9	11 of 37	S4UL
Benzo[k]fluoranthene	85	110	0 of 37	S4UL
Benzo[a]pyrene	220	3.2	12 of 37	S4UL
Indeno(1,2,3-c,d)Pyrene	130	45	1 of 37	S4UL
Dibenz(a,h)Anthracene	18	0.31	12 of 37	S4UL
Benzo[g,h,i]perylene	110	360	0 of 37	S4UL
Total Phenols	0.71	750	0 of 37	S4UL

From a review of the data summarised in Table 4.1, when compared to a residential without plant uptake land use there were samples with elevated metals and PAH's. Samples with elevated metals are described further below:

- BH02 @ 0.30m, elevated Arsenic of 45 mg/kg (compared to 40 mg/kg) material described as dark brown mottle dark brown fine to coarse SAND and GRAVEL. Gravel comprises angular to subrounded fine to coarse brick, concrete and slag fragments.
- TP5 @ 0.40m, elevated Mercury of 5.2 mg/kg (compared to 1.2 mg/kg) material described as red and light grey sandy GRAVEL with high brick and concrete cobble content. Gravel comprises angular to subangular fine to coarse brick and concrete fragments. Sand is fine to medium.
- WS01 @ 0.25m, elevated Lead of 720 mg/kg (compared to 300 mg/kg) material described as dark grey very sandy GRAVEL with low brick cobble content and occasional glass and ceramic fragments. Gravel comprises angular to subangular fine to coarse brick and asphalt fragments. Sand is fine to coarse.
- WS01 @ 1.10m, elevated Lead of 310 mg/kg (compared to 300 mg/kg) material described as greyish brown slightly gravelly slightly sandy silty CLAY with occasional clinker and ceramic fragments. Gravel comprises angular to subangular fine to coarse brick and clinker fragments.

The table below provides further details of the locations where elevated PAH's were encountered.

Table 4.2: Review of Elevated PAH Results

	Benzo (a) Anthracene	Chrysene	Benzo [b] fluoranthene	Benzo [a] pyrene	Indeno (1,2,3- c,d)Pyrene	Dibenz (a,h) Anthracene
Target (mg/kg)	11	30	3.9	3.1	45	0.31
BH01 @ 1.00m Brown mottled grey slightly gravelly sandy CLAY. Gravel comprises angular to subrounded fine to coarse sandstone and brick fragments.	-	-	-	3.4	-	0.35
WS01 @ 0.25m Dark grey very sandy GRAVEL with low brick cobble content and occasional glass and ceramic fragments. Gravel comprises angular to subangular fine to coarse brick and asphalt fragments. Sand is fine to coarse.	-	-	-	-	-	0.35
WS02 @ 0.50m Grass over dark brown gravelly clayey fine to coarse SAND with frequent roots and rootlets. Gravel comprises angular to subrounded fine to coarse concrete, brick and sandstone fragments.	-	-	5.8	5.8	-	0.60
WS03 @ 0.20m Dark grey fine to coarse SAND and GRAVEL. Gravel comprises angular to subrounded fine to coarse granite, brick and concrete fragments.	-	-	9.5	8.7	-	1.2
WS04 @ 0.30m Dark brown fine to coarse SAND and GRAVEL with high brick cobble content and frequent pockets of ash. Gravel	200	200	250	220	130	18

	Benzo (a) Anthracene	Chrysene	Benzo [b] fluoranthene	Benzo [a] pyrene	Indeno (1,2,3- c,d)Pyrene	Dibenz (a,h) Anthracene
Target (mg/kg)	11	30	3.9	3.1	45	0.31
comprises angular to subangular fine to coarse granite, brick, concrete and slag fragments.						
WS05 @ 0.50m Brown mottled grey slightly gravelly sandy CLAY. Gravel comprises angular to subrounded fine to coarse sandstone, mudstone, siltstone, coal and brick fragments.	-	-	6.6	6.2	-	0.53
WS07 @ 0.50m Greyish brown mottled very gravelly fine to coarse SAND with high brick cobble content. Gravel comprises angular to subangular fine to coarse brick, clinker, quartz and slate fragments.	-	-	8.6	7.8	-	-
WS08 @0.25m Grey and brown slightly gravelly slightly sandy silty CLAY with low brick cobble content. Gravel comprises angular to subrounded fine to coarse brick, clinker and chalk fragments. Sand is fine to coarse	19	-	37	34	-	3.9
WS08 @0.60m – As above	-	-	19	18	-	1.9
WS09 @ 1.00m Greyish brown very sandy clayey GRAVEL with high brick cobble content and occasional roots and rootlets. Gravel comprises angular to subangular fine to coarse brick and clinker fragments. Sand is fine to coarse.	-	-	15	13	-	1.5
WS10 @ 0.20m Brown slightly gravelly slightly sandy silty CLAY with low sandstone and brick cobble content and occasional roots and rootlets. Gravel comprises angular to subangular fine to coarse sandstone, brick, slate and asphalt fragments. Sand is fine to coarse.	-	-	10	9.7	-	0.93
TP1 @ 0.15m Dark brown fine to coarse SAND and GRAVEL with frequent pockets of ash. Gravel comprises angular to subangular fine to coarse granite and brick fragments.	22	-	34	31	-	3.1
TP2 @ 0.30m Dark grey gravelly very clayey fine to coarse SAND with low brick and asphalt cobble content, occasional glass fragments and occasional roots and rootlets. Gravel comprises angular to subrounded fine to coarse quartzite, brick, charcoal and clinker fragments.	-	-	15	14	-	1.8

From a review of the locations in the table above they are distributed across the site. The PAH concentrations and soil descriptions, show that ash is the likely source of the highest PAH results in WS04. In the other locations the elevated PAH's are likely from materials in the Made Ground such as ash, clinker, charcoal and slag and possibly also from cross contamination from overlying asphalt.

In relation to the above elevated PAH and heavy metal results, a further assessment of the results was undertaken using guideline values related to residential buildings in a public open space. In this land use scenario, heavy metals were no longer elevated but there was still widespread exceedance related to PAH results.

Asbestos was detected in 2 of 37 samples which are summarised as follows:

- WS01 @ 0.25m Fibres/ clumps of Amosite – quantified as 0.001% – soils described as above.
- WS03 @ 0.20m Fibres/ clumps of Chrysotile – quantified as <0.001% – soils described as above.

Generally asbestos was identified in coarse grained Made Ground. The two locations where it was detected were in the west of the development area.

Further actions relations to heavy metals, PAH and asbestos results are:

- It is recommended that the Client appoint a suitably qualified asbestos specialist to deal with issues related to the control of asbestos during subsequent works.
- No further action is required in areas beneath buildings or pavements as hardstanding would remove pathways to end site users.
- In soft landscaped areas it is recommended that a cover system is constructed to limit contamination pathways to end users. The cover system should comprise 500mm of imported clean soils comprising topsoil and subsoil overlying a separation membrane.

4.2 Groundwater Analysis

The results from the groundwater sampling and testing (Table 3.4) have, for an initial assessment, been compared against the very conservative UK Drinking Water Standards (UKDWS) . Where the results in Table 3.4 are below detection limits these have not been assessed further. Results and comparison values are in µg/l unless indicated otherwise.

Table 4.3: Assessment of Groundwater Results

Determinant	Maximum (ug/l)	UK Drinking Water Standard (ug/l)	Number of Elevated Results
pH	7.8	-	-
Boron (Hot Water Soluble)	100	1000	0 of 2
Sulphate (mg/l)	170	250	0 of 2
Arsenic	0.75	10	0 of 2
Copper	1.8	2000	0 of 2
Nickel	2.1	50	0 of 2
Selenium	0.80	10	0 of 2
Zinc	3.9	5000	0 of 2

From Table 4.3 it can be seen that there were no elevated concentrations in the two water samples when the results were compared UK Drinking Water Standards.

4.3 Building Materials and Services

Contaminants in the ground can pose a risk to potable water supply by permeating plastic water supply pipes. UK water supply companies require robust evidence from developers to demonstrate either that the ground in which new plastic supply pipes will be laid is free from specific contaminants, or that the proposed remedial strategy will mitigate any existing risk. If these requirements cannot be demonstrated to the satisfaction of the relevant water company, it becomes necessary to specify an alternative pipe material on the whole development or specific zones.

The potential risks to water supply pipes have therefore been assessed against the threshold concentrations for PE and PVC pipe specified in Table 3.1 of Report 10/WM/03/21, UK Water Industry Research (UKWIR) published Guidance for the “Selection of Water Supply Pipes to be used in Brownfield Sites” which have been adopted as the GAC’s for this project. Table 4.4 summaries the results.

Table 4.4: Assessment of Results against WRAS Criteria

Determinant	WRAS criteria (mg/kg)		Recorded Concentrations (mg/kg)	
	PE pipe	PVC pipe	Minimum	Maximum
SVOCs (including PAH’s)	2	1.4	<detection	2100
Phenols	2	0.4	<detection	0.71
Mineral Oils C11-C20	10	Pass	17	929
Mineral Oils C21-C40	500	Pass	22	3028

The results presented within Table 4.3 indicate that, based on the available chemical test results, the presence of PAH’s could be detrimental to PE and PVC pipes, and hydrocarbons might limit the use of PE pipe. It is recommended that the local Water Authority are forwarded the available information to determine their assessment of the ground conditions and confirmation of their required specification pipework.

4.4 Ground Gas Risk Assessment

In the Conceptual Ground Model, Bedrock is underlying around 8.50m of Glacial Till. The Glacial Till was proven to be a 7.50m thick layer of low permeability clay with circa 1.00m of coarse grained material at the base. This clay will provide a barrier between upper Made Ground/ shallow Glacial Till and the underlying bedrock.

A review of the gas monitoring results in Table 3.5 demonstrates that

- Methane was not detected in any of the installations
- There are elevated levels of carbon dioxide in the Bedrock (BH01, BH02 & BH03). The highest flow rates were also detected in these boreholes. These boreholes were intended for groundwater monitoring, although gas monitoring has been undertaken and carbon dioxide has been recorded, there is no viable pathway for this to impact on the site. These results have therefore been discounted in relation to assessing the risk from ground gas.

- In WS02 and WS05 the monitoring installations targeted the Made Ground and Glacial Till respectively. In these two installations the water level was above the response zone and therefore this data is not representative of the ground gas regime at the site.
- In WS10 and WS14 the monitoring installations targeted the Made Ground and Glacial Till respectively.
 - The highest recorded flow rate was 0 litres per hour
 - The maximum CO₂ result was 5.4% in the Made Ground and 10.7% in shallow Glacial Soils.

Using the recorded values in accordance with the CIRIA publication C665 “Assessing risks posed by hazardous ground gases to buildings” the maximum gas screening values (GSV) can be calculated as follows:

$$\text{Methane GSV} = (0 / 100) \times 0 = 0.00 \text{ l/hr}$$

$$\text{Carbon Dioxide GSV} = (10.7 / 100) \times 0 = 0.00 \text{ l/hr}$$

As detailed in Table 8.5 of CIRIA publication C665 – the site would be a very low risk (CS1) based on GSV values but as the CO₂ levels are above 5% the site would be a CS2 low risk site where some gas protection measures would be required.

It is anticipated that the gas protection measures will be designed in accordance with BS8485: 2015 utilising

- Cast in situ monolithic reinforced ground bearing raft or reinforced cast in situ suspended floor slab with minimal penetrations and well reinforced to control cracking
- Membrane

A single membrane providing damp proofing and gas resistance might be appropriate provided that it is sufficiently strong to resist damage during construction and meets the following requirements:

- Constructed from Virgin polymer;
- sufficiently impervious to the gases with a methane gas transmission rate <40.0 ml/day/m²/atm (average) for sheet and joints (tested in accordance with BS ISO 15105-1 manometric method);
- sufficiently durable to remain serviceable for the anticipated life of the building and duration of gas emissions;
- sufficiently strong to withstand in-service stresses (e.g. settlement if placed below a floor slab);
- sufficiently strong to withstand the installation process and following trades until covered (e.g. penetration from steel fibres in fibre reinforced concrete, penetration of reinforcement ties, tearing due to working above it, dropping tools, etc);
- capable, after installation, of providing a complete barrier to the entry of the relevant gas; and
- Independently verified in accordance with CIRIA C735 [N1]

A Verification Plan demonstrating how the gas protection is to be installed and the results of testing and verification is to be provided by the Contractor responsible for the design and installation of the gas protection.

4.5 Waste Soils

As part of the construction works, it is likely that waste materials will be generated and it is anticipated that off-site disposal of the waste soils will be the most likely solution. As it is probable that Made Ground will require removal from site an assessment of the waste categorisation has been undertaken.

The waste assessment is necessary to comply with the various legislation and guidance related to waste. All material removed from site must be adequately described by reference to the appropriate codes in the List of Waste regulations and the developer or the consultant on their behalf is required to identify the following:

- the European Waste Catalogue (EWC) code for the waste;
- the relevant hazard code (HP1 to HP14)
- the landfill class where the waste may be accepted.

Prior to disposal of any material at a licensed landfill it is necessary to classify soils within one of the following categories:

- Inert Waste
- Non-hazardous Waste
- Hazardous Waste

For the determination of whether the soils revealed on the site are hazardous the chemical analysis results obtained have been assessed using the HazWaste Online computer program.

The following samples would be classed as hazardous waste EWC 17 05 03 as described further below:

- WS02 0.50m (Coarse Made Ground) based on hydrocarbon content of 1800 mg/kg. (HP7: Carcinogenic, HP11: Mutagenic);
- WS04 0.30m (Coarse Made Ground) based on hydrocarbon content of 3200 mg/kg. (HP7: Carcinogenic, HP11: Mutagenic);
- WS08 0.25m (Fine grained Made Ground) based on hydrocarbon content of 1000 mg/kg. (HP7: Carcinogenic, HP11: Mutagenic).

All the remaining 34 samples screened would be classified as EWC 17 05 04 – non-hazardous waste.

During the recent ground investigation Waste Acceptance Criteria Tests were undertaken on three samples of shallow soils as follows:

- BH01 1.90m is natural soil that might require processing prior to disposal at inert landfill to reduce total organic carbon;
- WS12 1.00m (coarse Made Ground) would not be suitable for disposal at inert landfill due to slightly elevated Fluoride;
- WS14 1.20m (natural soil) would be suitable for disposal at inert landfill.

An alternative to disposal at a landfill could be to dispose of the soils, if accepted, at a licensed treatment facility, which would remove the requirement to classify the soils, undertake further WAC testing and the inclusion of landfill tax. Regardless of the destination of the surplus soils appropriate documentation should be retained, and be available for inspection, that demonstrates the nature of the material disposed of including chemical analysis, when it was removed and its destination.

Asbestos has been identified in Made Ground and although the levels are below the limit for hazardous waste, the presence of asbestos may determine where the material can be disposed. Prior to disposal of any material the receiving landfill/facility should be forwarded the available chemical test results so they can confirm their classification and acceptance of the material.

5.0 FINAL CONCEPTUAL MODEL

The preliminary Conceptual Model provided by RSK in their desk study report is updated below based on the findings of the ground investigation.

5.1 Sources

The potential on and off-site sources of contamination proven by the ground investigations are summarised in Table 5.1.

Table 5.1: Summary of Potential Sources of Contamination

Potential Source from RSK Desk Study	Potential contaminants of Concern	Evidence From Site Investigation
Made Ground from various phases of on site development including buried waste materials and asbestos containing materials	Heavy metals, asbestos, hydrocarbons and PAH's, phenols, solvents, oils, lubricants, methane and carbon dioxide	<p>Asbestos was identified in 2 locations and quantified as between <0.001% and 0.001%.</p> <p>When compared to a residential without plant uptake land use there was elevated heavy metals in 2 samples and PAHs in 12 samples.</p> <p>A cover system is recommended in soft landscaped areas.</p> <p>No evidence for a significant source of methane</p> <p>Monitoring standpipes identified carbon dioxide in shallow deposits in excess of 5%. The site was characterised as CS2.</p> <p>There was no evidence of elevated contamination in groundwater</p>
Leaking from nearby tanks and sub stations	Heavy metals, PAH's, hydrocarbons, phenols, solvents, oils, lubricants, Vapours	There was no evidence in soil, groundwater or gas monitoring to indicate that these offsite sources were impacting the site.

5.1 Receptors

The following receptors from the Preliminary Conceptual Site Model remain unchanged on completion of the investigation.

- Future site users (sources related to soil, water or ground gas);
- Current adjacent site users (sources related to water or ground gas);
- Current and future buildings and services (sources related to soil, water or ground gas);
- Groundwater in the principal aquifer within the Chester Formation bedrock (soil or water sources);
- Potential culverted watercourse on site (water sources).

The construction workers and future maintenance workers were not included as receptors in the Preliminary Conceptual Model because risks to these receptors are considered likely to be managed through health and safety procedures for the Contractors conducting the works.

5.2 Pathways

The following pathways were identified by RSK in their Preliminary Conceptual Site Model for the construction and operational stages of the proposed redevelopment. These have been reviewed on completion of the ground investigation.

- Dermal contact, ingestion, inhalation pathways of potentially contaminated soils/groundwater, dust/fibres, soil/groundwater vapours;
- Downward vertical migration of leachate to shallow groundwater;
- Vertical or lateral migration of surface water/drainage, ground gas; and
- Ground gas migration and ingress to buildings / confined spaces.

5.3 Quantitative Risk Assessment

This quantitative risk assessment has been undertaken in accordance with CIRIA C552: Contaminated Land Risk Assessment, A Guide to Good Practice (Rudland et al., 2001). The CIRIA C552 risk categories and the assessment methodology are detailed in Table 5.2.

Table 5.2: Definition of Magnitude of Consequence

Category	Definition
Severe	Acute risks to human health, catastrophic damage to buildings/property, major pollution of controlled waters
Medium	Chronic risk to human health, pollution of sensitive controlled waters, significant effects on sensitive ecosystems or species, significant damage to buildings or structures
Mild	Pollution of non-sensitive waters, minor damage to buildings or structures
Minor	Requirement for protective equipment during site works to mitigate health effects, damage to non-sensitive ecosystems or species

The likelihood of an event (probability) considers both the presence of the hazard and target and the integrity of the pathway and has been assessed based on the categories given in Table 5.3.

Table 5.3: Definition of Probability of Exposure

Category	Definition
High Likelihood	Pollutant linkage may be present, and risk is almost certain to occur in long term, or there is evidence of harm to the receptor
Likely	Pollutant linkage may be present and it is probable that the risk will occur over the long term
Low Likelihood	Pollutant linkage may be present and there is a possibility of the risk occurring although there is no certainty that it will do so
Unlikely	Pollutant linkage may be present, but the circumstances under which harm would occur are improbable

The potential severity of the risk and the probability of the risk occurring have been combined in accordance with the matrix presented in Table 5.4 below.

Table 5.4: Risk Assessment Matrix

		Potential Severity			
		Severe	Medium	Mild	Minor
Probability Risk	High Likelihood	Very High	High	Moderate	Low/Moderate
	Likely	High	Moderate	Low/Moderate	Low
	Low Likelihood	Moderate	Low/Moderate	Low	Very Low
	Unlikely	Low/Moderate	Low	Very Low	Very Low

5.4 Summary of Potential Pollutant Linkages

Table 5.5 presents a summary of the Final Conceptual Site Model (CSM) in the form of a Quantitative Risk Assessment. This summarises the primary pollutant linkages based on the findings of the ground investigation.

Table 5.5: Quantitative Risk Assessment

Hazard/ Pollutant	Pathways	Receptors	Probability	Severity	Risk	Comments and mitigation measures
On-Site Sources (Asbestos Heavy metals and PAH's for a residential land use without plant uptake)	Direct ingestion of soil or dust	Construction workers employed on site during the development works	Likely	Medium	Moderate	Excavation works associated with the redevelopment could introduce pollutant linkages during the handling of excavated soil and other earthworks. Construction workers could therefore be exposed to potentially contaminated soil.
	Dermal contact with soil or dust					The assigned risk can be reduced to Low with the appropriate level of health, safety and welfare precautions typically required under CDM regulations and as advised by an asbestos specialist as well as effective management, training and instruction. These risks are to be managed by the Contractor on site completing the works.
	Inhalation of fibres and particulates					
	Direct ingestion or dermal contact with groundwater.					
		Neighbours during construction.	Low likelihood	Medium	Moderate to Low	The assigned risk can be reduced to Low with appropriate site working methods being employed to reduce the risk of windborne dust and fibres leaving the site. These risks will be managed by the Contractor on site.
		Site users after development	Unlikely	Medium	Low	In soft landscaped areas it is recommended that a cover system is utilised to sever a potential contamination pathway between Made Ground and site users.
		Future site workers including maintenance and utility workers	Unlikely	Medium	Low	If the removal of any potentially contaminated soils is not undertaken during the redevelopment, the potential for exposure needs to be recorded in the Health & Safety file in accordance with the CDM regulations and future site workers informed.
	Inhalation of vapours and gases	Construction workers employed on site during the development works	Low likelihood	Severe	Moderate to low	The ground investigation did not identify vapours or methane. Carbon dioxide was identified in shallow soils. These risks are to be managed by the Contractor on site.
	Build-up of methane to explosive limits and CO ₂ to asphyxiation levels	Site users after development, and neighbouring residents	Unlikely	Severe	Low	Gas protection measures for a CS2 site will be included in the final construction.
On-Site Sources (as above)	Vertical and lateral infiltration and dispersion of contaminants to the groundwater (soil leaching to groundwater)	Near Surface Groundwater: Principal aquifer	Unlikely	Medium	Low	There was no evidence that contaminants from the soil are leaching to shallow groundwater.

Hazard/ Pollutant	Pathways	Receptors	Probability	Severity	Risk	Comments and mitigation measures
	Contact with contaminated soil and groundwater during and after development	Building materials and underground services (utilities)	Unlikely	Medium	Low	Mobile ground water could lead to the oxidation of sulphide minerals within the Glacial Till and Bedrock which can also lead to an acidic corrosive environment for sub structures. Concrete will be specified to resist aggressive ground conditions as per recommendations in the geotechnical sections of this interpretative report. If water pipes are proposed in Made Ground then protective pipe materials are likely to be required.
Off-Site Sources (heavy metals, hydrocarbons, phenols, solvents, oils, lubricants, methane and carbon dioxide)	Migration of groundwater and dermal contact or ingestion. Migration of groundwater and inhalation of vapours. Vertical or lateral migration of ground gas or vapours and inhalation or build up in confined spaces.	Construction workers employed on site during the development works.	Unlikely	Medium	Low	There is no evidence that potential offsite sources of contamination are impacting the site. The assigned risk is Low with the appropriate level of health, safety and welfare precautions typically required under CDM regulations as well as effective management, training and instruction.
		Site users after development including maintenance and utility workers.	Unlikely	Medium	Low	There is no evidence that potential offsite sources of contamination are impacting the site.
		On site migration of landfill gases	Unlikely	Medium	Low	There is no evidence that potential offsite sources of contamination are impacting the site.

5.5 Conclusions from Contaminated Land Risk Assessment

The preliminary qualitative risk assessment provided by RSK at desk study stage has been updated based on the findings of recent ground investigations.

The site is being developed with residential buildings and therefore the soil results were compared to residential without plant uptake land values. Elevated heavy metals and PAH's were identified in the Made Ground on the site. Asbestos fibres were also identified in Made Ground materials.

During the development it is recommended that an asbestos qualified specialist is appointed to advise on remediation and the control measures that might be required.

In relation to the heavy metal and PAHs in the Made Ground it is recommended that a cover system is constructed in soft landscaped areas to limit contamination pathways.

During groundworks, given the relatively short exposure times to sources of contamination on site then the risk to construction workers is considered low provided standard health and safety precautions and good practice site management procedures are adopted.

In relation to the risk from ground gas, the site has been characterised as a low gas risk site (CS2) that would require gas protection.

In some locations the soils on site would be classified as hazardous waste.

Based on the available information the risk estimations to the following receptors have been made:

- Construction workers – **MODERATE TO LOW** mitigated as **LOW** with the appropriate use of PPE and implementation of CDM regulations
- Future site users – **LOW** (assuming a capping layer is adopted in soft landscaping and gas protection measures for a CS2 site are implemented)
- Groundwater – **LOW**
- Onsite property/buildings and services –**LOW** (assuming barrier pipe is used in Made Ground)
- Offsite residents – **MODERATE TO LOW** mitigated to **LOW** with the appropriate management of risks by the Contractor during construction
- Adjacent land/property– **LOW**

5.6 Recommended Further Actions

It is recommended that further advice is sought from an asbestos specialist contractor regarding remediation of Made Ground containing asbestos.

Depending on the final development proposals and site layout it is likely that a capping system will be required in areas of soft landscaping.

Due to the potential for as yet unidentified contamination to be present on site we would recommend a watching brief for unforeseen contamination during construction.

Gas protection is required for a CS2 site. This is likely to comprise a membrane that will comply with BS8485 and on completion of installation membranes are to be independently verified.

Prior to disposal of any material the receiving landfill/facility should be forwarded the available chemical test results so they can confirm their classification and acceptance of the material.

6.0 GEOTECHNICAL ASSESSMENT

6.1 Surfacing and Made Ground

The investigated areas were either hard or soft landscaped. In the hard surfaced areas the surfacing generally comprised Asphalt up to 0.30m thick. Concrete was encountered in WS12 and TP05, reinforced concrete in TP07 and paving slabs in TP04. Directly beneath the surfacing was generally a thin layer of gravel comprised of various materials which was assumed to be a base layer.

Beneath the base layer the Made Ground in the hard surfaced areas generally comprised of a sand and gravel layer, described as

- Dark brown, grey to black fine to coarse SAND and GRAVEL with medium to high sandstone and brick cobble content. Gravel comprises angular to subrounded fine to coarse brick, slag, sandstone and granite fragments. Occasional glass and ceramic fragments.

Beneath this material was further Made Ground in a fine grained matrix described as:

- Brown mottled grey slightly gravelly sandy CLAY. Gravel comprises angular to subrounded fine to coarse siltstone, mudstone, quartzite, sandstone, clinker and brick fragments

In the hard surfaced areas the Made Ground was up to 2.00m thick (WS08) with the base elevation between +39.39m OD to +37.28m OD.

In the soft landscaped areas the Made Ground was generally shallower up to 1.00m thick with the base elevation between +39.33m OD to +38.13m OD.

In comparison to the hard surfaced areas there were no fine grained soils in the landscaped areas where the Made Ground was described as :

- Grass over dark brown gravelly clayey fine to coarse SAND with frequent roots and rootlets and wood fragments. Gravel comprises angular to subrounded fine to coarse concrete, brick, clinker, mudstone and sandstone fragments.

6.1.1 Classification Testing

The Moisture content was measured on 1 No. Sample of Made Ground as 21%. (See Figure 6.1).

Although no specific density tests have been carried out, a bulk unit weight of 18kN/m³ can be assumed in the design based on previous experience.

6.1.2 Compaction Testing

One sample of Made Ground (Clay) from TP01 at 0.70m was subject to compaction testing using a 2.5kg rammer. The Maximum Dry Density was 1.75 Mg/m³ and the Optimum Moisture Content 18%. The natural moisture content of the sample was above the optimum moisture content at 21%.

The same sample was compacted into a mould using a 2.5kg rammer at the natural moisture content. The California Bearing Ratio (CBR) was measured as 4.2%.

6.1.3 Strength and Stiffness

Five Standard Penetration tests (SPTs) were undertaken in the Made Ground with SPT N-values between 1 and 11 blows per 300mm.

Figure 6.4 shows a plot of SPT results v elevation where it can be seen that the Made Ground is variable but generally likely to be a soft/ weak material based on the SPT results.

6.1.4 Geo Chemical Tests

The Made Ground was tested for aggressivity to concrete using sulphate and pH testing. The results for coarse grained Made Ground with BRE Special Digest characteristic values are:

- The water-soluble sulphate ranged between <10 mg/l and 310 mg/l (14 results)
- Characteristic sulphate content is 200 mg/l
- The pH ranged between 7.0 and 11.3 (14 results)
- Characteristic pH is 7.5

Similarly for fine grained Made Ground the results are as follows

- The water-soluble sulphate ranged between <10 and 1500 mg/l (15 results)
- Characteristic sulphate content is 750 mg/l
- The pH ranged between 7.4 and 8.7 (15 results)
- Characteristic pH is 7.6

Using the characteristic values above the Made Ground would be classified as DS2.

6.2 Glacial Till

Glacial Till was proven beneath the Made Ground at depths between 0.55m to 2.00m (elevations +39.39m OD to +37.28m OD). The Glacial Till was encountered in two distinct layers. The upper layer 7.10m to 7.80m thick and was fine grained in nature, described as :

- Firm to stiff, dark brown slightly sandy gravelly CLAY with occasional pockets of brown fine to coarse sand. Gravel comprises angular to subrounded fine to coarse sandstone, coal, mudstone, siltstone and quartzite fragments.

The lower boundary for this material was only identified in the three boreholes where it ranged between 8.90m to 9.20m deep (elevations +30.57m OD to +30.03m OD)

Underlying the fine grained Glacial Till was a layer of coarse grained soil between 0.60m and 1.90m thick and described as:

- Medium to very dense, brown fine to coarse SAND and GRAVEL. Gravel comprises angular to rounded fine to coarse quartzite, siltstone and sandstone fragments

6.2.1 Classification Testing

The natural moisture content test was measured on 35 No. samples of fine grained Glacial Till and ranged between 9.5% and 24%. Figure 6.1 shows a slight decrease in the moisture content with depth.

A sample of coarse grained Glacial Till was tested from each borehole and the three results ranged between 5.7% and 14%.

12 No. Particle Size Distribution tests was carried out on the fine grained Glacial Till. It comprised 2% to 13% Gravel, 11% to 48% Sand, 25% to 48% Silt and 18% to 41% Clay (See Figure 6.3a). The combined silt and clay content ranged between 36% and 87%.

3 further PSD tests were conducted on the coarse grained Glacial Till which demonstrated between 26% to 73% Gravel, 22% to 51% Sand, and 4% to 22% silt and Clay (See Figure 6.3b).

Atterberg limit tests show the strata to be clay of low to high plasticity with the plasticity index ranging between 7% and 33%, a liquid limit ranging between 23% and 54% and a plastic limit between 14% and 24% (based on 20 results) (Figure 6.2).

In accordance with NHBC Guidance 4.2.3 Building Near Trees (<https://nhbc-standards.co.uk/4-foundations/4-2-building-near-trees/4-2-3-building-near-trees/> accessed July 2023) the modified plasticity index for these soils would be between 5.9% and 31%. From the 20 samples tested only 2 were below 10%, 12 were low risk and 6 were medium risk.

As the modified plasticity index was above 10% on the majority of samples, and the particle size distributions demonstrated that on all 12 samples the combined silt and clay content was above 35%, then the Glacial Till would be classified as shrinkable soil with a low to medium volume change potential.

Based on measurements of bulk density from the oedometer and undrained triaxial tests the unit weight of Glacial Till was between 19.5 kN/m³ and 23.4 kN/m³.

6.2.2 Compaction Testing

Two samples of Glacial Till from TP05 at 0.9m (Clay) and TP07 at 1.10m (Sandy clay) were subject to compaction testing using a 2.5kg rammer and CBR testing at their natural moisture content. The results are summarised as follows:

Table 6.1: Glacial Till Compaction Tests

Sample	Maximum Dry Density (Mg/m ³)	Optimum Moisture Content (%)	Natural Moisture Content (%)	CBR (%)
TP05 (0.5m) Clay	1.66	21	21	8.5
TP07 (1.10m) Sandy Clay	1.80	16	22	2.0

6.2.3 Strength and Stiffness

49 No. Standard Penetration tests (SPTs) were undertaken in the fine grained Glacial Till with N-values ranging between 4 and 50 blows per 300mm. (Figure 6.4).

A further 3 No. SPT were conducted in the underlying coarse grained Glacial Till where all three tests recorded refusal at 50 blows per 300mm. To estimate the relative strength of these deposits the SPT results were linearly extrapolated and ranged between 79 and 120 blows per 300mm.

Undrained triaxial testing was undertaken on seven samples of Glacial Till. Apart from a single result of 74 kN/m², the results were between 135 kN/m² and 345 kN/m², which indicates a stiff to very stiff soil.

The SPT results are compared to the undrained triaxial tests using the following relationship (Stroud, 1989): $C_{u \text{ char}} = 4.5 \times N_{\text{char}}$.

The shear strength results derived from SPT's ranged between 18 kN/m² and 234 kN/m². These results are plotted on Figure 6.5 against the laboratory C_u tests. When compared, both data sets show a reasonable correlation with the undrained shear strength increasing with depth. Using both data sets a design line using the relationship below is plotted on the graph.

From -2.00 m to -9.50 m

$$C_{u \text{ char}} = 27z + 60 \text{ kN/m}^2$$

z is the depth from the top of the Glacial Till which is 2m below ground level as designated by the design profile in Section 7.

For the fine grained Glacial Till for preliminary design it is recommended to adopt an effective angle of friction of 25 degrees as a characteristic value with effective cohesion of 0 kN/m². This is based on the plasticity index using the approach recommended in BS8004, 2015.

For the coarse grained Glacial Till for preliminary design it is recommended to adopt an effective angle of friction of 37 degrees as a characteristic value with effective cohesion of 0 kN/m². This is based on the approach recommended in BS8004, 2015.

One-dimensional oedometer consolidation tests were carried out on 3 No. undisturbed samples of London Clay. The results of the tests gave coefficients of compressibility (m_v) and coefficients of consolidation (C_v) for the various applied stresses (loading, unloading and reloading). These are plotted in Figures 6.6 and 6.7.

6.2.4 Geo Chemical Tests

The Glacial Till was tested for aggressivity to concrete using sulphate and pH testing. The results were as follows:

- The water-soluble sulphate ranged between <10 mg/l to 87 mg/l (16 results)
- The pH ranged between 7.9 and 8.6 (16 results)
- The total sulphur content was between 0.022% and 0.150% (9 results)
- The acid soluble sulphate was between 0.040% and 0.073% (9 results)
- The potential sulphate result was calculated as between 0.066% and 0.450% (9 results)

In accordance with the BRE Special Digest the characteristic values are:

- Characteristic sulphate content is 87 mg/l
- Characteristic pH is 7.9
- Characteristic total potential sulphate is 0.344%.

Oxidisable sulphates were calculated as above 0.3% on two of the samples indicating the presence of pyrites in some soils in this formation.

Using the characteristic values above the Glacial Till would be classified as DS1 in an undisturbed condition and DS2 if conditions permit oxidation of potential sulphates.

6.3 Chester Formation

The Chester Formation was encountered in all three boreholes, beneath the Glacial Till. The top of this stratum was between 9.50m to 10.90m (elevations +29.97m OD to +28.13m OD).

The rock was described as:

- Reddish brown SANDSTONE recovered as very dense medium to coarse sand.
- Reddish brown thinly to thickly laminated SANDSTONE and MUDSTONE recovered as: very dense gravel. Gravel comprises angular to subangular fine to coarse sandstone and mudstone fragments.

6.3.1 Classification Testing

The moisture content was measured on 7 No. samples from the Chester Formation and ranged between 12% and 25%. Figure 6.1 shows that the results are variable.

6.3.2 Strength and Stiffness

8 No. SPT's were conducted in the Chester Formation and apart from a result of 21 blows per 300mm in BH02 at +39.03m OD, the results recorded refusal at 50 blows per 300mm. To estimate the relative strength of these deposits the SPT results were linearly extrapolated and ranged between 61 and 300 blows per 300mm with an average of 108 blows per 300mm. These are plotted in Figure 6.4.

An estimate of the unconfined compressive strength of weak rock is 1.5 MN/m^2 , based on a SPT result of 100 blows per 300mm (Stroud, 1989).

6.3.3 Geo Chemical Tests

The Chester Formation was tested for aggressivity to concrete using sulphate and pH testing. The results were as follows:

- The water-soluble sulphate was <10 mg/l (2 results)
- The pH ranged between 8.8 and 9.3 (2 results)
- The total sulphur content was between 0.01% and 0.02% (2 results)
- The acid soluble sulphate was between 0.04% and 0.05% (2 results)
- The total potential sulphate result was calculated as between 0.04% and 0.06% (2 results)

Using the values above the Chester Formation would be classified as DS1.

6.4 Groundwater

Groundwater samples were taken from two monitoring standpipes installed in the Bedrock and/ or Glacial Till. The groundwater had the following pH and Sulphate values:

- Sulphate Content between 120 and 170 mg/l (2 results)
- pH between 7.7 and 7.8 (2 results)

In accordance with the BRE Special Digest the characteristic sulphate value for groundwater would be 170 mg/l and the characteristic pH 7.7. Using these characteristic values the groundwater would be classified as DS1.

7.0 DESIGN PROFILE AND GEOTECHNICAL PARAMETERS

7.1 Geotechnical Design Profile

Based on the ground conditions described in Sections 3 and 6, it is recommended that the following design profile and characteristic geotechnical parameters are used for the design of foundations.

Table 7.1: Design Geotechnical Profile

Formation	Top of the Stratum (m bgl)	Thickness (m)
Made Ground	0	2.00
Glacial Till – Fine Grained	-2.00	7.50
Glacial Till – Coarse Grained	-9.50	1.00
Chester Formation	-10.50	>3.20*

Notes:

* True thickness not proven due to base of formation not encountered during investigation.

7.2 Geotechnical Parameters

Where characteristic parameters could not be derived, due to a lack of laboratory tests or appropriate empirical correlations, such parameters have been conservatively assumed for the purposes of preliminary foundation design and are denoted with **.

Table 7.1: Made Ground Characteristic Design Parameters

Design Parameter	Unit	Value
Bulk Unit weight (γ)	kN/m ³	18**
Angle of friction (ϕ')	Degrees (°)	27**
Drained Modulus of Elasticity (E')	kN/m ²	5,000**

Table 7.2: Glacial Till – Fine Grained Characteristic Design Parameters

Design Parameter	Unit	Value
Bulk Unit weight (γ)	kN/m ³	20**
Undrained Shear Strength (C_u)	kN/m ²	27z + 60 Z= 0 at top of Glacial Till (2mbgl)
Drained Angle of friction (ϕ')	Degrees (°)	25
Drained Cohesion (c')	kN/m ²	0
Undrained Modulus of Elasticity (E)	kN/m ²	400 x C_u **
Drained Modulus of Elasticity (E')	kN/m ²	0.75 x E **

Table 7.3: Glacial Till Coarse Grained Characteristic Design Parameters

Design Parameter	Unit	Value
Bulk Unit weight (γ)	kN/m ³	20**
Drained Cohesion (c')	kN/m ²	0
Angle of friction (ϕ')	Degrees (°)	37**
Drained Modulus of Elasticity (E')	kN/m ²	50,000**

Table 7.4: Chester Formation Characteristic Design Parameters

Design Parameter	Unit	Value
Bulk Unit weight (γ)	kN/m ³	22
Drained Angle of friction (ϕ')	Degrees (°)	27
Drained Cohesion (c')	kN/m ²	0
Estimated Unconfined Compressive Strength	MN/ m ²	1.5

8.0 DESIGN RECOMMENDATIONS

8.1 Introduction

The proposed development comprises two existing buildings and two new builds for student accommodation and will range between 2 and 5 stories. The foundations are anticipated to comprise piles founded within the Chester Formation. Shallow foundations on the clay layer within the Till deposits is to be considered. The St David's Chapel will be demolished as part of the redevelopment.

8.2 Shallow Foundations

Made Ground/ Topsoil should not be used as a founding stratum. The Glacial Till is a suitable material on which to base shallow foundations.

A safe allowable preliminary bearing pressure based on a 1m by 1m pad foundation has been calculated as 100 kN/m². This bearing capacity is provided as an aid for initial sizing of foundations and is based on a factor of safety of 3.

Provided the relevant precautions are undertaken in relation to areas that might be influenced by trees then the safe allowable bearing pressure will limit settlement to 20mm.

The Glacial Till is characterised as soil with low to medium volume change potential. It is therefore recommended that trees are surveyed and identified in the vicinity of any foundations including rafts to determine if additional measures are required in relation to the depth and type of foundation.

As advised by NHBC, raft foundations constructed in accordance with their guidance should provide adequate protection from heave in areas influenced by trees.

A soil of low to medium volume change potential could move between 50 to 100mm and this should be considered for utilities and structures. For preliminary design of raft foundations, an estimate of uplift pressure from soils of low to medium volume change potential is 5 kPa (provided that the raft is constructed as per NHBC guidance).

When the final foundation layout, tree proximity, and structural loads and soil structure interaction effects are known then it is recommended that each foundation is individually checked in accordance with EC7 for both ultimate and serviceability limit states.

The Glacial Till will deteriorate rapidly on exposure to the elements, particularly the fine-grained soils during periods of heavy rainfall and over winter due to cold weather and frost action. All formations should be excavated immediately before placing concrete or a concrete blinding layer placed immediately after excavation to limit the possibility of formation softening from the ingress of water.

All formations should be inspected and any soft spots should be removed and replaced with granular material. The formations should be proof rolled prior to construction and should be inspected by a suitably competent engineer to confirm bearing capacities of the formation soil.

8.3 Preliminary Pile Design

Preliminary pile design charts for bored piles are presented in Figure 8.1. This chart assumes piles will derive their capacity from the Glacial Till and Chester Formation. The Made Ground (2m thick) has been ignored in the pile design.

The design is based on an “ α ” factor of 0.5 in the Glacial Till. It is assumed that the piles will sit on the Bedrock and there is no provision for rock socket skin friction in the preliminary design. The base capacity for the pile has been calculated using the estimated unconfined compressive strength.

No allowance for long term heave or flotation has been made as it is assumed that the building load will exceed these forces. Should this not be the case then the forces will need to be considered in the final pile design. Piles may be subjected to negative skin friction from the Made Ground which will need to be taken into account in the final design.

The outline design has been carried out in accordance with BS EN1997-1, UK National Annex. The charts assume that a preliminary pile test will be conducted and present design lines for the following conditions associated with pile load testing.

- A. No pile testing proposed.
- B. (a) Pile testing to at least 1% of preliminary/working piles loaded to at least 1.5 the representative load for which they are designed
Or
(b) Settlement is explicitly predicted by a means no less reliable than in (a)
Or
(c) Settlement at the serviceability state is of no concern.

The design lines shown in the charts represent the design resistance. This is dictated in all the results by the Geotechnical limit state and in this respect the factors stated in table NA.A1 of the National Annex to BS EN 1990 should be applied when comparing the design resistance to the applied actions ($\gamma = 1$ for permanent and $\gamma = 1.35/0$ for variable unfavourable/favourable respectively).

Adopting higher factors of safety will limit the anticipated pile settlements and will not require confirmation of the design assumptions with pile tests. It may however lead to an uneconomical design. Adopting lower factors of safety will be subject to the type and frequency of pile testing proposed. It is prudent to seek agreement for the pile testing proposals with the local building control office in advance of piling commencing.

In accordance with BS8004:2015 circular end bearing piles should have a centre to centre spacing of at least 2 x the pile diameter.

The provided pile design is preliminary and the final design of the piles should be carried out by a piling contractor.

8.4 Excavations

Groundwater ingress is likely to be encountered during excavation from the perched groundwater above the Glacial Till. It is anticipated that pumping from sumps should maintain adequately dry working conditions.

All temporary excavations should have appropriate side support or be battered back to maintain stability, particularly where access is required.

Any open and unprotected excavations can be expected to deteriorate more readily on exposure to the elements particularly during periods of heavy rainfall and during winter due to frost action. The face may also be subject to instability from groundwater seepage depending on the height and location of the excavation.

Any excavation that is intended to remain open for any period of time should be battered to a safe angle or supported and inspected frequently for any sign of instability and should be monitored and remediated if necessary. The frequency of inspections during periods of inclement weather should be increased.

Based on the strength tests and borehole records it should be possible for deeper/larger excavations to be accomplished with convention excavation plant.

Care should be exercised to prevent any excavations from influencing the foundations of adjacent structures within a slope of 1 (horizontal) to 2 (vertical) from the base of the excavation.

In areas of deep excavation, Glacial Till can be expected to heave due to stress relief. The magnitude of this heave will depend on the depth and duration of the excavation and the magnitude of loads on completion of the construction.

8.5 Re-use of Materials

Compaction testing on Made Ground and Glacial Till has indicated that soils may require drying to obtain the optimum moisture content for compaction.

In areas where earthwork material will be used to make up ground levels or create bunds, close control on the earthworks will be required to limit any settlement especially if they have been placed above their optimum moisture content or conversely swelling may take place if they have been placed dry of their optimum moisture content. Close control of the earthworks moisture content and compaction in these areas is recommended.

8.6 Sub-surface Concrete

Concrete to be placed in contact with the soil or groundwater should be designed in accordance with the recommendations of Building Research Establishment Special Digest 1 “Concrete in Aggressive Ground” (2005) considering the pH of the soils and mobility of the water table.

Assuming mobile groundwater and based on the characteristic sulphate levels in soil and groundwater from Section 6 of this report the design sulphate classes (DS) and aggressive chemical environment for concrete (ACEC) for the deposits on site are provided in Table 8.1. Also in Table 8.1 below are DC classes based on an assumed 100-year design life.

Table 8-1: Interpretation of Sulphate Results

Stratum	DS	ACEC	DC	APM's	Comments
Made Ground (Exposed)	2	2	2	0	
Glacial Till (Unexposed)	1	1	1	0	Based on water soluble sulphate results.
Glacial Till (Exposed)	2	2	2	0	Based on TPS
Chester Formation (unexposed)	1	1	1	0	Based on water soluble sulphate results.
Groundwater	1	1	1	0	

In relation to Table 8.1 exposed means exposed to the atmosphere i.e. large excavations.

If piled foundations are to be adopted then in accordance with BRE Special Digest1:2005 (Figure C5 and Box C8) piling is unlikely to cause sufficient ground disturbance that could result in oxidation of the exposed soil. In such cases the Digest recommends that the concrete is designed in accordance with the results obtained from assessing the worst case of water-soluble sulphates or sulphates in groundwater. Therefore, for concrete in piles a Design Sulphate Class of DS-1 can currently be adopted with an ACEC classification of AC-1 and a design chemical class of DC-1.

8.7 Risk Assessment

On completion of the ground investigation key geotechnical risks that need to be considered during detailed design stage and during the construction of the development are summarised below:

Table 8-2: Geotechnical Risk Assessment

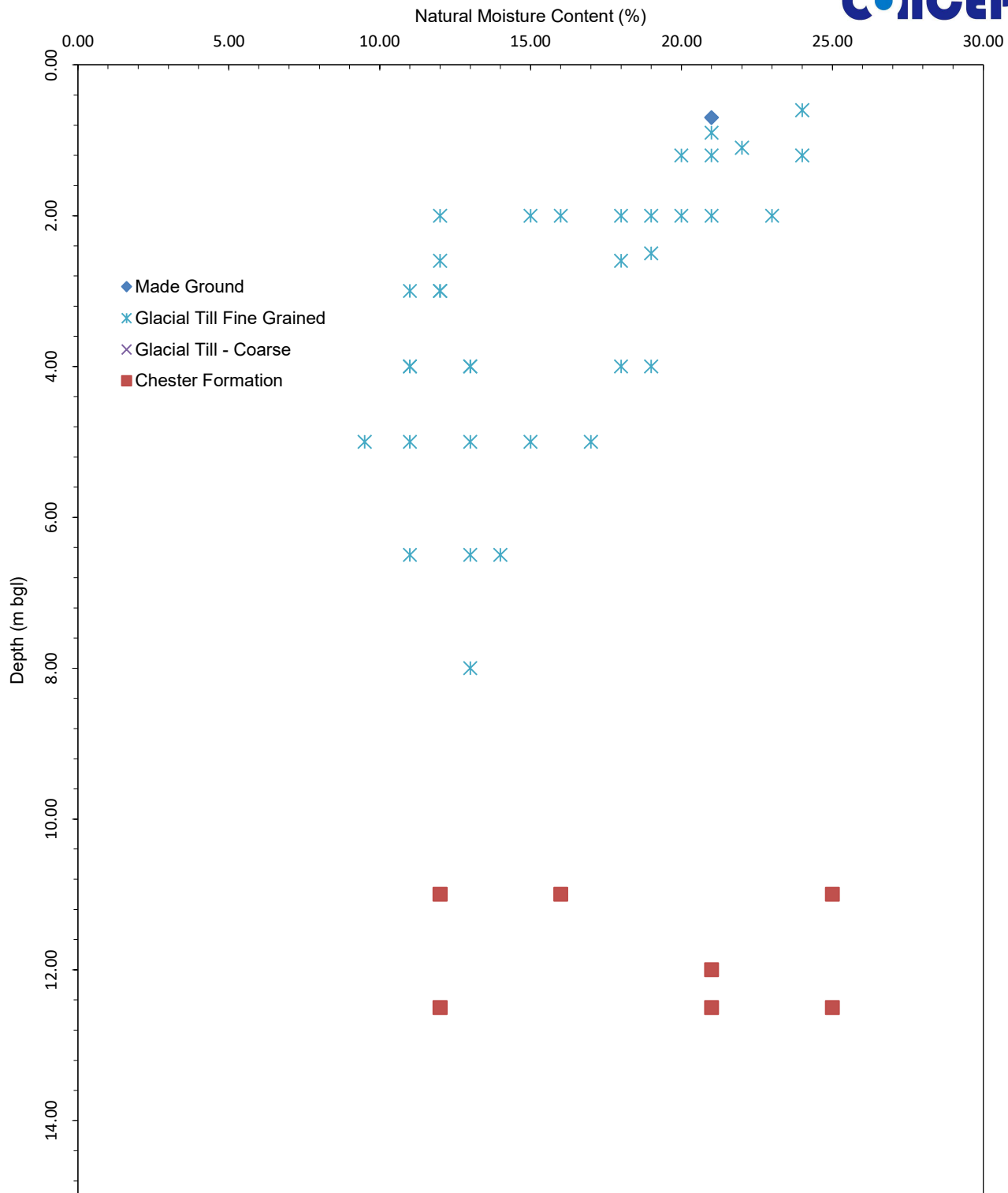
Key Geotechnical Hazards	Consequences	Risk	Proposed Mitigation	Residual Risk
Unstable excavations within Made Ground, and shallow Glacial Till	Collapse of excavation if unsupported.	High	Support excavation sides.	Low
High groundwater levels/ risk of flooding from groundwater at the surface	Uplift on structures, unstable excavations. Difficult working conditions	High	Design structures accordingly. Support excavation sides. Dewater if necessary for safe/ efficient working conditions.	Low
Variable and compressible nature of Made Ground	Excessive Settlements	High	Avoid founding on these layers.	Low
Glacial Till has low to medium volume change potential	Excessive heave or shrinkage	High	Tree survey to identify proximity and tree type in relation to foundations Construct foundations as advised in NHBC guidance	Low
Strength of Weak Sandstone	Excessive pile settlement	High	A preliminary pile test to be conducted to confirm values used in pile design	Low
Existing piles and other foundation obstructions	Obstructing the boring of new piles Increase in demolition and piling costs	High	Carry out a desk based study of available substructure information and verify on site by carrying out intrusive surveys. Where possible re-use existing foundations by carrying out structural investigations to establish condition of existing piles and adopt a risk based design approach.	Low

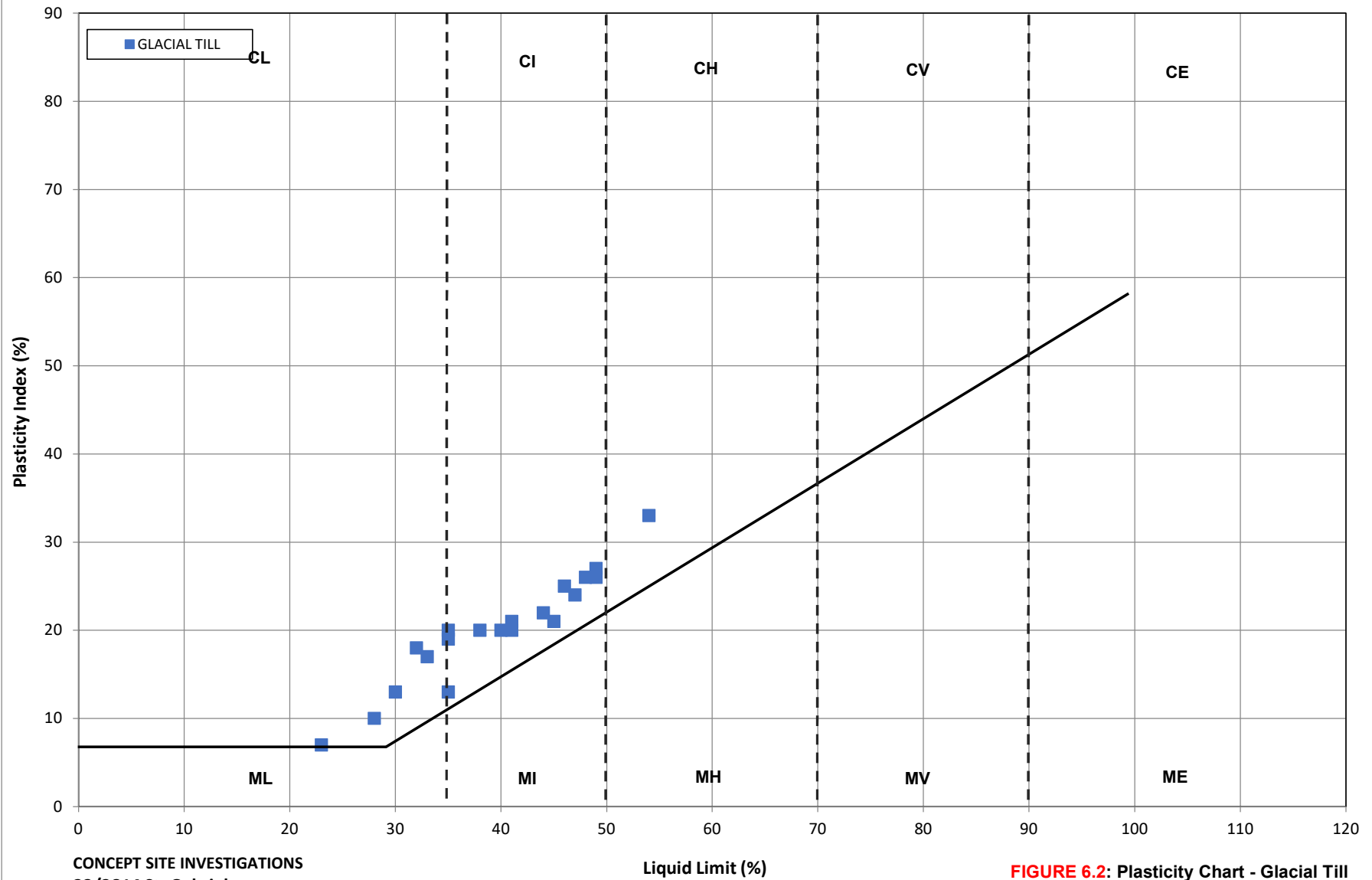
Key Geotechnical Hazards	Consequences	Risk	Proposed Mitigation	Residual Risk
Presence of UXO	Accidental Detonation of Bombs during excavations	High	Carry out detailed UXO risk assessment in accordance with CIRIA (2009). 'Unexploded Ordnance (UXO) A guide for the construction industry'. C681 to identify whether UXO in-situ survey is required during excavations	Low
Accidental Strike of Underground Services	Death/Injury/Damage to third party assets	High	Detailed mapping and surveying of services running under the site. Isolate all services before commencement of works.	Medium to Low
Dewatering	Settlements of existing structure/ infrastructure caused by water table drawdown	High	Design scheme to minimize external drawdown Monitor implementation	Low
Aggressive ground conditions	Damage to concrete	High	Design concrete in accordance with the characteristic values in this report.	Low
Ground gas	Explosions/ Asphyxiation	High	Site is classified as a low risk (CS2).	Gas protection measures required to reduce risk

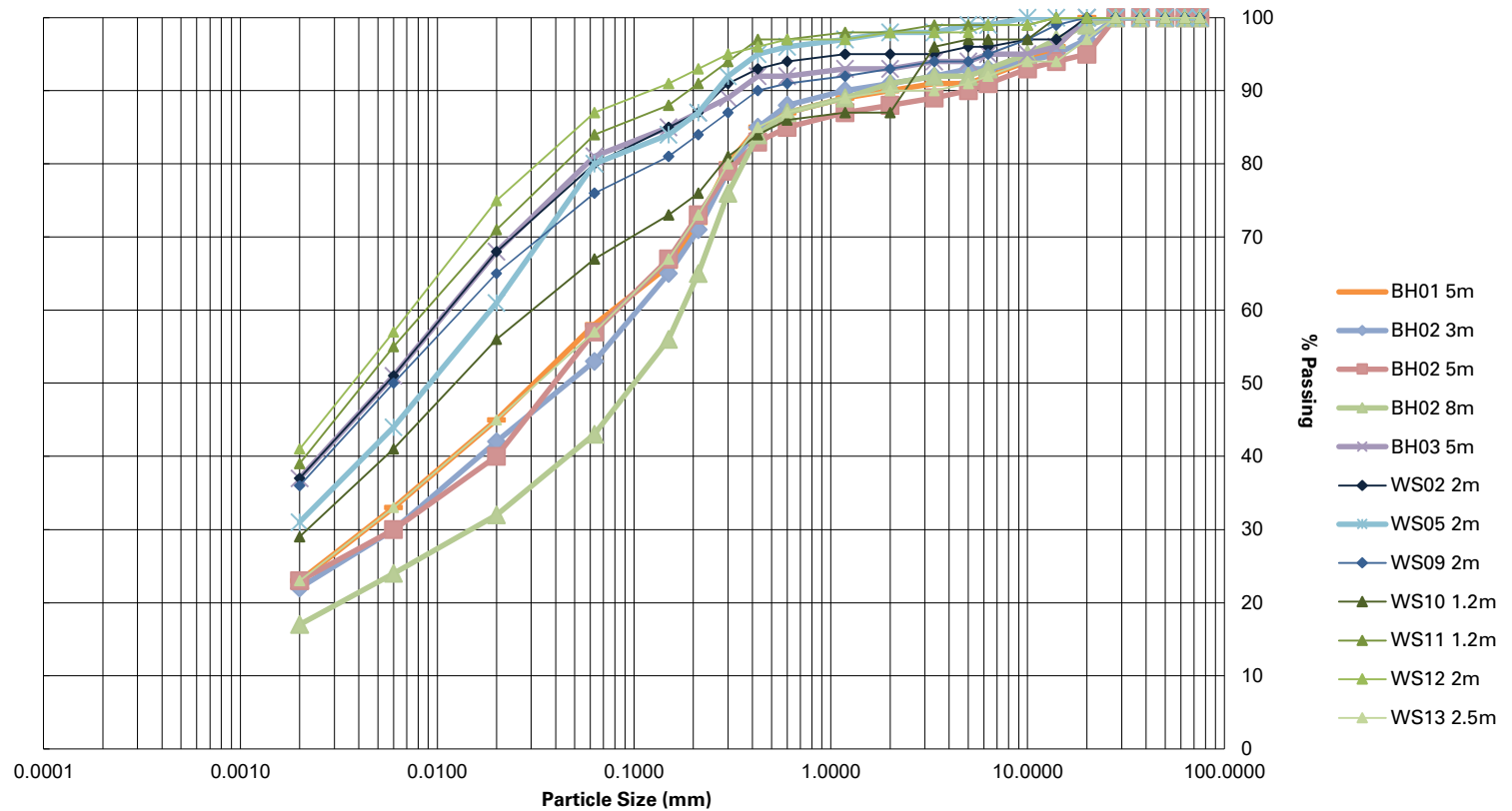
Key Geotechnical Hazards	Consequences	Risk	Proposed Mitigation	Residual Risk
Soil Contamination	Human Health Risk	High	<p>Asbestos has been identified in Made Ground. Advice from an asbestos specialist recommended regarding further actions.</p> <p>Soil is elevated in some heavy metals and PAH's in relation to a residential without plant uptake land use. Remediation = cover system in areas of soft landscaping.</p> <p>Some Made Ground would be classed as hazardous waste</p>	Moderate/ reduced to low following specialist advice during siteworks
Groundwater contamination	Human health risk	High	No elevated concentrations when compared to UK Drinking Water Standards	Low

9.0 REFERENCES

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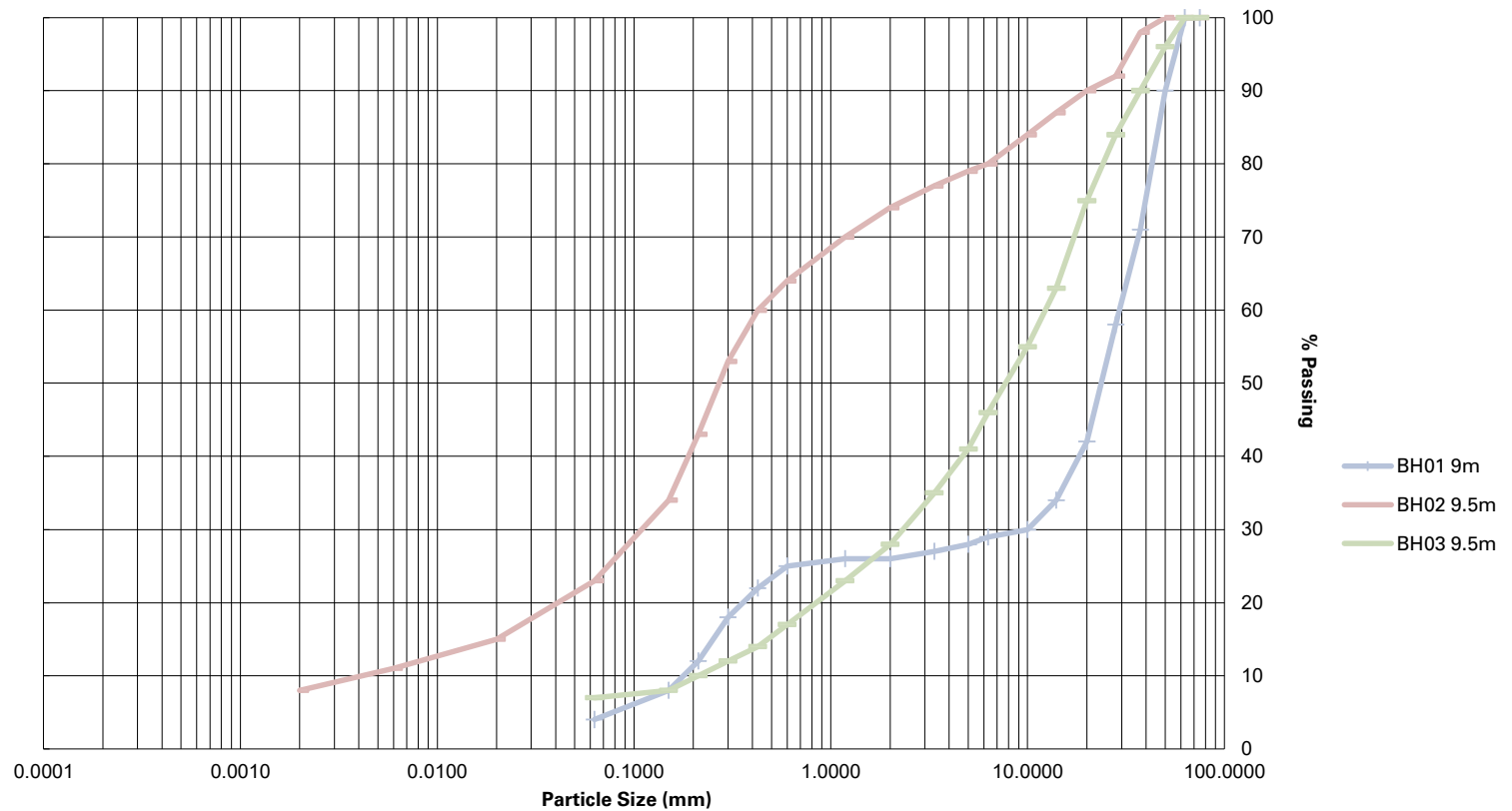
	F	M	C	F	M	C	F	M	C	
CLAY	SILT			SAND			GRAVEL			COBBLES

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FIGURE 6.3a- Glacial Till Fine Grained PSD Results



	F	M	C	F	M	C	F	M	C	
CLAY	SILT			SAND			GRAVEL			COBBLES

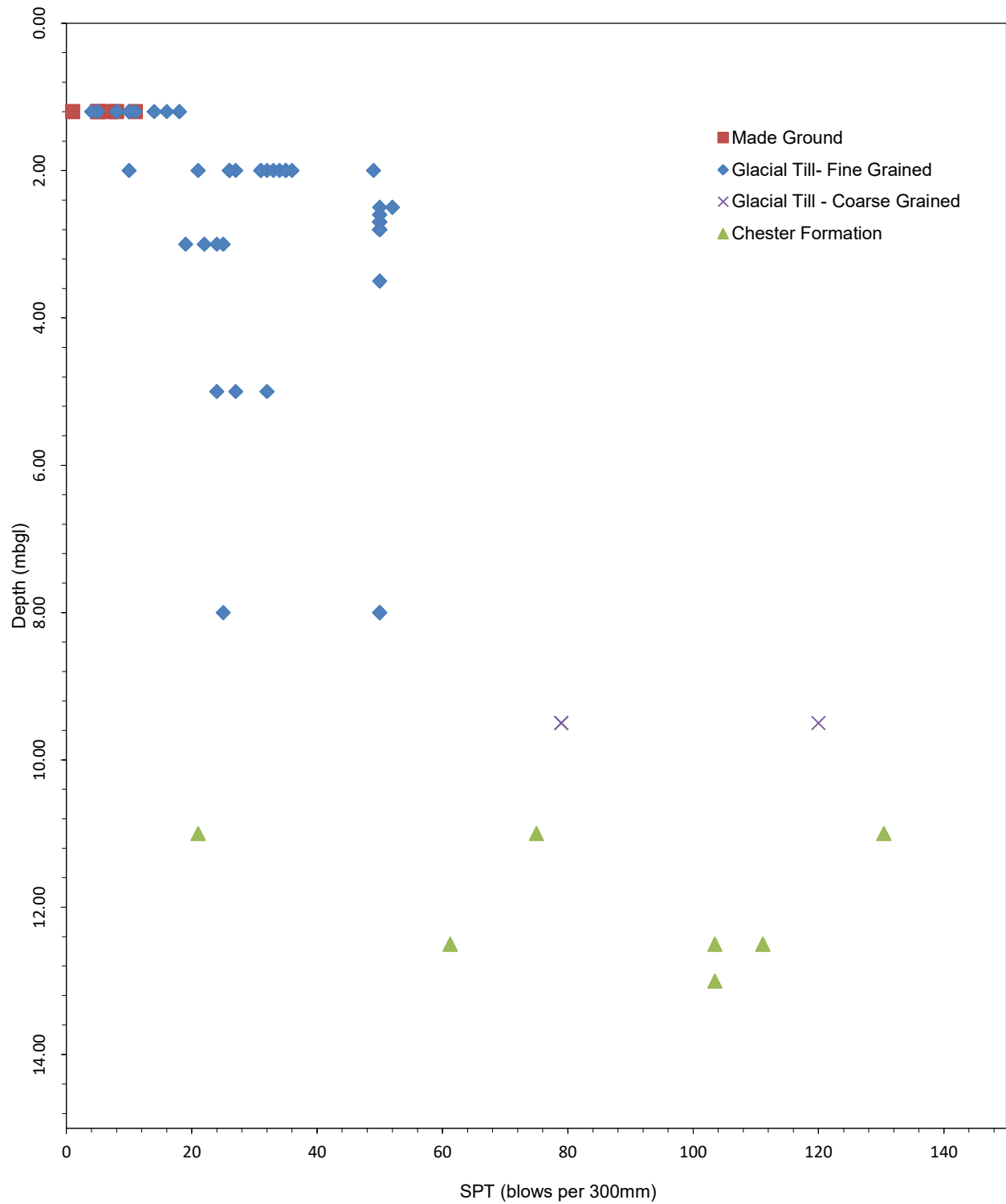




FIGURE 6.5 - Undrained Shear Strength

Figure 6.6: Coefficient of Consolidation v Applied Pressure

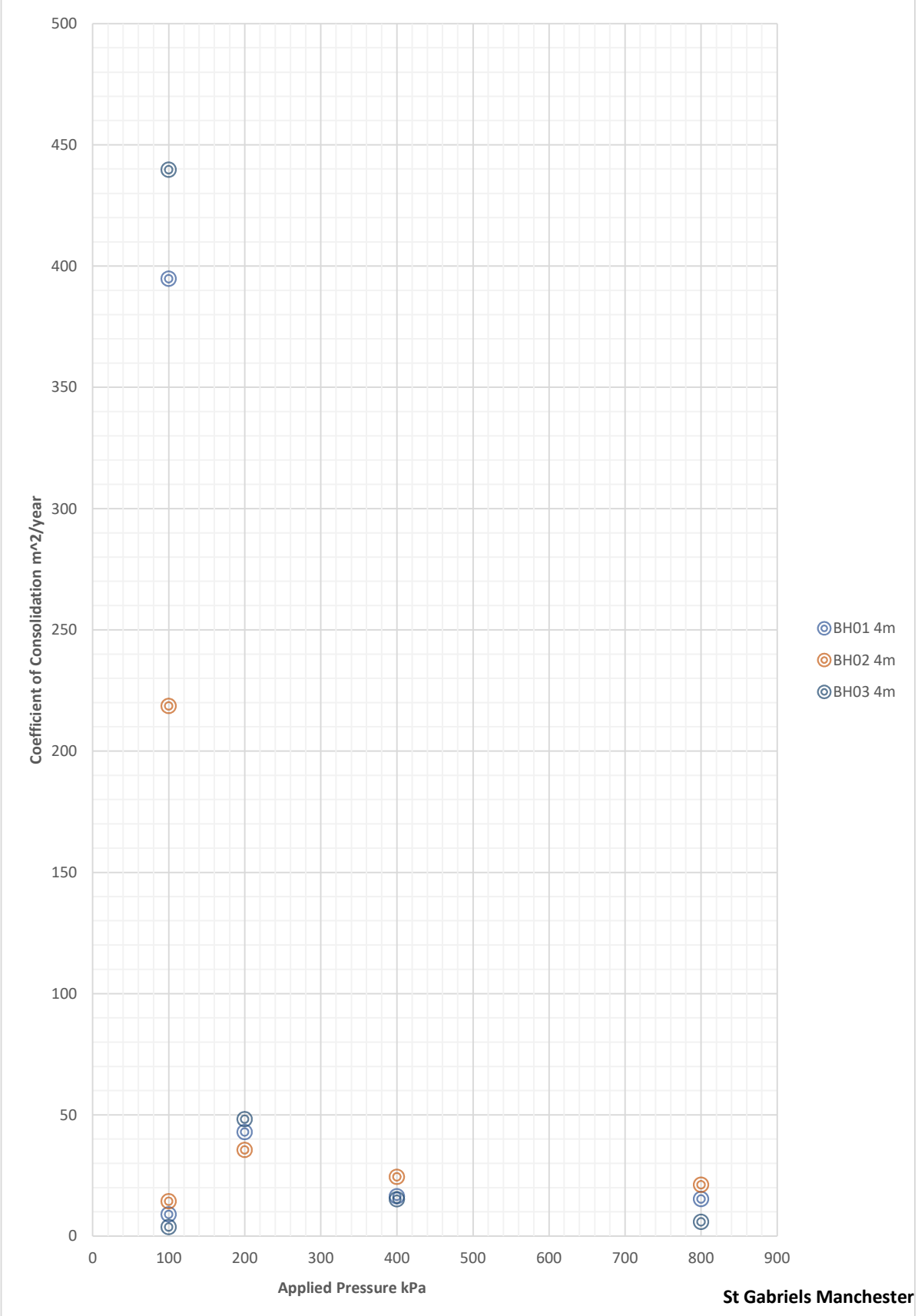
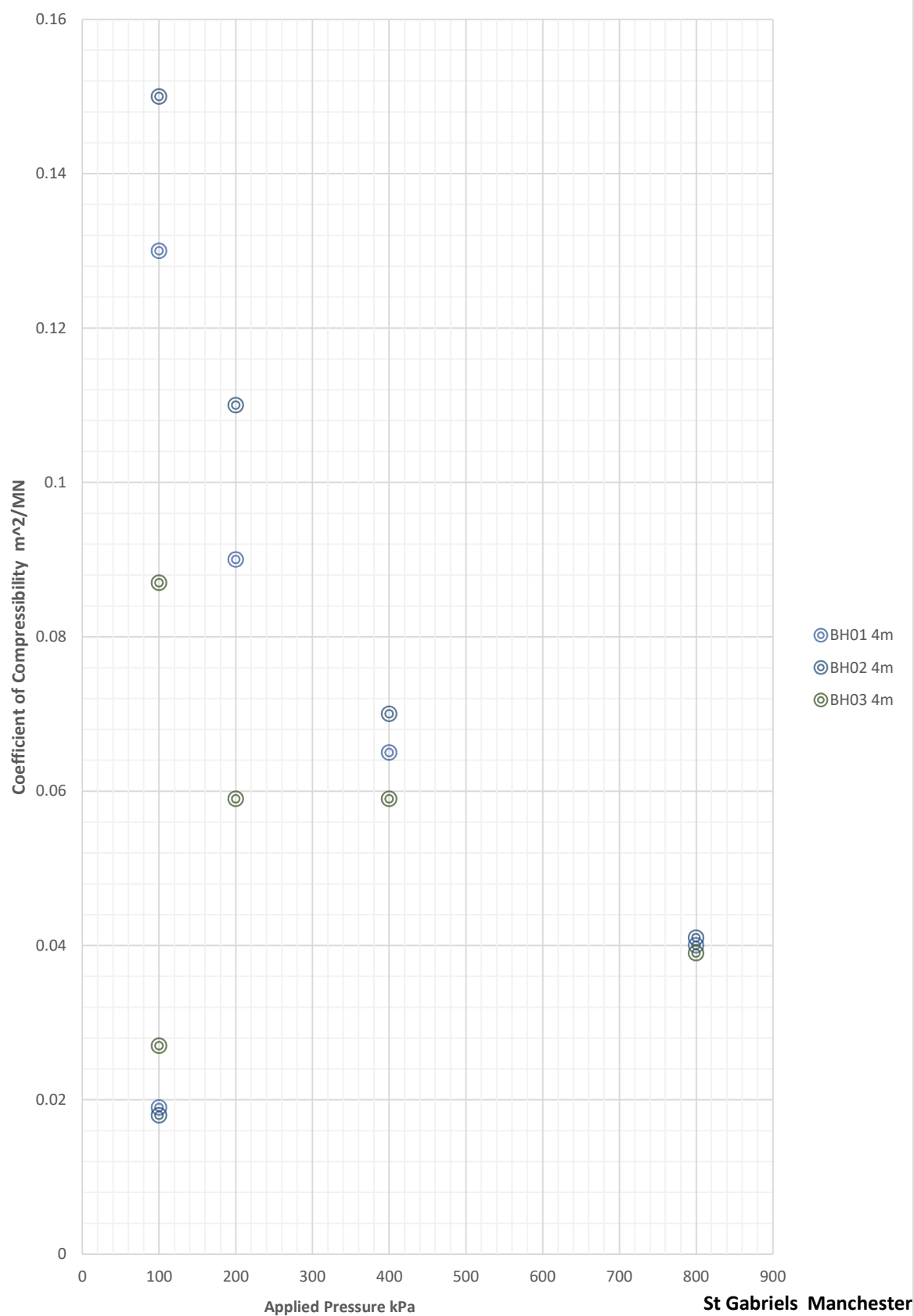


Figure 6.7: Coefficient of Compressibility v Applied Pressure



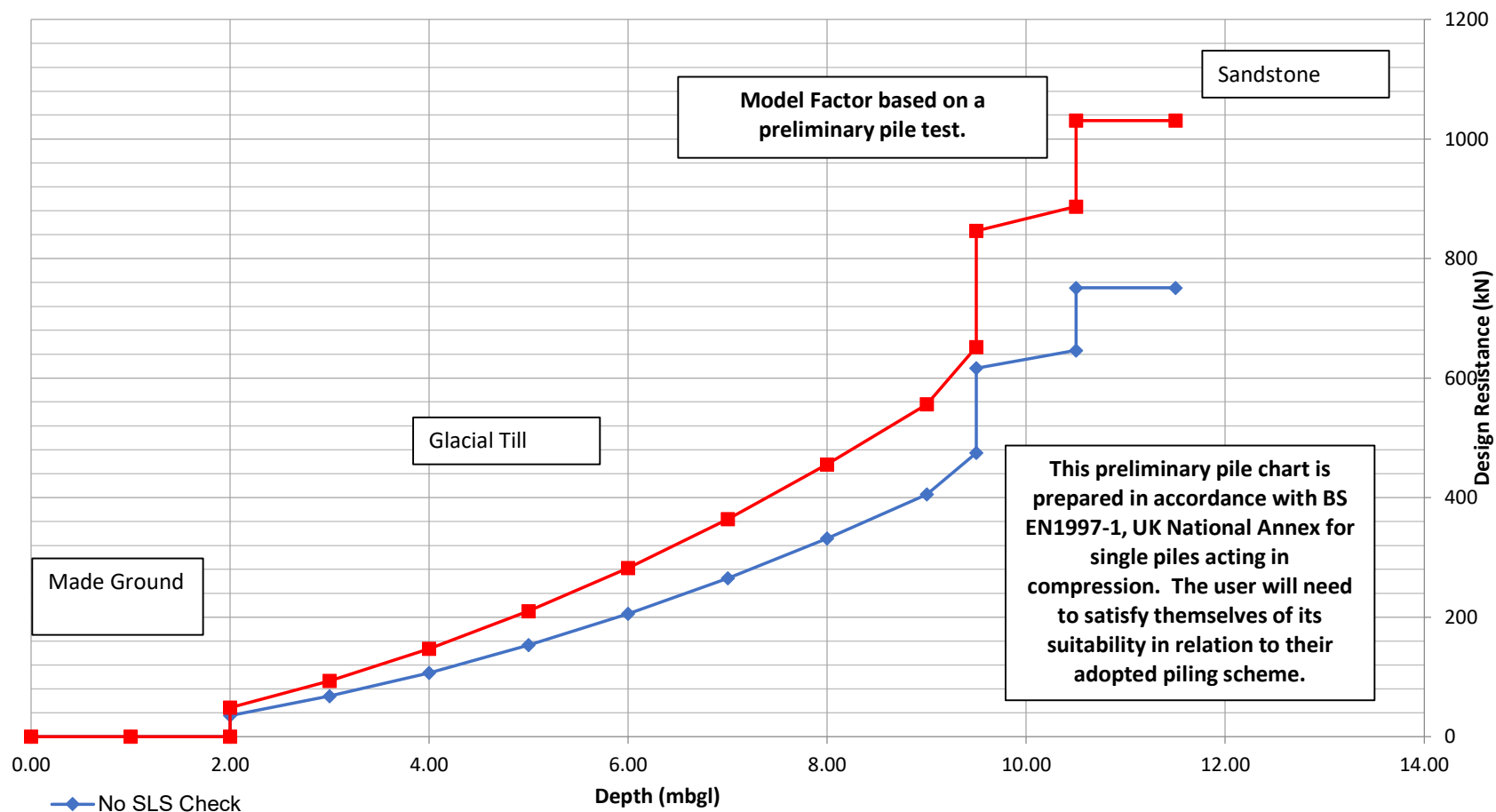


FIGURE 8.1 - PRELIMINARY PILE DESIGN CHART

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450mm Bored Piles