

Marco Living 2 Ltd & Axis-Re Ltd

1NQ Tariff Street, Manchester

Ground Investigation Report

143404/R2 – Rev 3

July 2023



FAIRHURST

CONTROL SHEET

CLIENT: Marco Living 2 Ltd & Axis-Re Ltd
PROJECT TITLE: 1NQ Tariff Street, Manchester
REPORT TITLE: Phase 2 Ground Investigation Report
PROJECT REFERENCE: 143404
DOCUMENT NUMBER: 143404/R2 – Rev 3
STATUS: FINAL

Issue & Approval Schedule		Name	Signature	Date
	Prepared by	A. Petts		09/06/2023
	Checked by	B. Jones		09/06/2023
	Approved by	B. Jones		09/06/2023

Revision Record	Rev.	Date	Status	Description	Signature	
	1	14/06/2023	DRAFT	Interim interpretive ground investigation report	By	A. Petts
					Checked	B. Jones
					Approved	A. Simmons
	2	27/07/2023	FINAL	Updated to include outstanding lab results	By	A. Petts
					Checked	B. Jones
					Approved	A. Simmons
	3	31/07/2023	FINAL	Addition of conclusion summary and Groundtech Factual Report	By	A. Petts
					Checked	B. Jones
					Approved	A. Simmons

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Executive Summary

Site Details & Proposed Development

The site is located within a larger area characterized by similar development plots, as well as commercial and industrial establishments in Manchester City Centre.

The site is approximately 0.3ha and currently comprises of hard standing resulting from the clearance of a former building.

The site is situated between Port Street to the north and Tariff Street to the south, with access available from both roads.

The proposed development involves the construction of two residential blocks. One of the buildings will have nine floors, with an additional setback amenity level, while the other will be a standalone twelve storey structure. Additionally, there will be ground floor commercial space, amenities for residents, bicycle parking, landscaping, access points, street loading facilities, and other associated works, including a basement structure.

Background & Objectives

This report has been prepared to present and interpret the site investigation data and provide design parameters. The purpose of the ground investigation works was to assess the geotechnical and environmental conditions present at the site and identify any associated constraints that may hinder the proposed development.

This report should be read in conjunction with the development's Phase I desk study which provides full details on the site setting and history which includes a number of historical buildings with end uses including:

- Infilled canal
- Canal Wharfe
- Warehouses
- Vehicle repair
- Localised potential for tanks

Ground Conditions

The site includes Made Ground beneath asphalt or concrete hardstanding. Most exploratory holes encountered Granular Made Ground at depths of around 1.8mbgl, with Cohesive Made Ground observed typically to depths of 2.8mbgl. The Made Ground, associated with the infilled canal, is typically about 1m deeper than the surrounding area ranging from 3.5mbgl to 4.0mbgl. The infilled canal similar to the wider site, consists of a layer of Granular Made Ground over laying Cohesive Made Ground.

The upper layer of Cohesive Glacial Till was encountered across the entire site, ranging in depth from 4.5m to 18.0mbgl. This layer is described as firm to stiff slightly gravelly Clay. It contains fine to medium gravels, including flint, sandstone, siltstone, and limestone. This is underlain by an upper layer of Granular Glacial Till which ranges in depth from 8.0mbgl to 18.1mbgl, with a thickness between 0.5m and 3.1m and comprises a slightly silty clayey gravelly fine Sand. It directly overlays a second lower layer of Cohesive Glacial Till present to depths between 16.5m and 24.0mbgl and comprises a firm to stiff brown sandy gravelly Clay with occasional cobble content. The Lower Granular Glacial Till ranges in depth from 19.0m to 27.2mbgl. It is often found above the sandstone bedrock and consists of dense to very dense sandy gravel with low cobble content.

Deposits from the Chester Formation Sandstone are present beneath the site at elevations of between 20.72m and 21.76m AOD (27.2m and 26.8mbgl), indicating the

	bedrock level beneath the site is relatively uniform. The sandstone is recorded as comprising an upper weathered zone (<0.7m thick), grading with depth into intact rock.
Geo-Environmental Assessment	There was limited visual and olfactory evidence of widespread contamination encountered during the investigation works. Hydrocarbon odours were noted in two boreholes encountered in the Made Ground strata. As such, some elevated concentrations of organic and inorganic contamination was encountered within the Made Ground Deposits. Namely arsenic, lead and B(a)P. Based on the monitoring to date, the production of gas is low and the site can be classified as CS1. Asbestos was encountered within the matrix of one sample of Granular Made Ground. The extent, and concentration of these contaminants was not identified by the investigation to be widespread but will require basic mitigation measures in the development and allowances for the removal of localised hotspots if encountered. The following general remedial works are expected: • Provision of clean covers to landscape/garden areas as 150mm of topsoil over 300mm of subsoil; • Soil gas protection measures as a solid floor slab with basic gas membrane with sealed joints and penetrations; • Standard protection to buried water service pipes and sewer joints; • Concrete design in accordance with BRE digest; Although not encountered during the works the following risks items may be present: • In view of the nature of the historical development the presence of unidentified areas of asbestos buried on site or in the soil matrix cannot be discounted; • Localised buried tanks; • Localised "hotspots" of soil contaminants as hydrocarbons; • If encountered these contaminants should be delineated, subject to review by risk assessment, and, if elevated risks are identified, may require removal.
Geotechnical Assessment	Pad or raft foundations are not feasible for the structures based on the form of development, likely structural loads, and underlying ground conditions. Therefore, piled foundations are considered appropriate for the project. The piled foundations may comprise either continuous flight auger (CFA) or rotary bored piles. It should be noted that an obstruction within the Glacial Till was observed at depth, which may require the use of rotary bored techniques for pile formation. The presence of relict foundations across the site including the infilled canal basin and structure may give rise to difficulties for piling techniques and should be considered by the specialist contractors piling design and risk assessment. The stability of any Made Ground or granular soils should not be relied upon in unsupported excavations

A detailed strategy and temporary works design for managing obstructions and groundwater ingress within the Made Ground should be developed by the ground works and piling contractor; this is particularly important for the basement structure.

Temporary works design will be required for pile platform design.

Perched groundwater may be encountered and could result in standing water to excavations and should be accommodated for in the temporary works design to the basement construction.

The following groundwater risk items cannot be discounted:

- Presence or requirement of cut of barrier within the canal infill;
- Presence of Historical drainage within the infilled canal structure.

Excavations will encounter buried structures, foundations and general obstructions associated with the former development on site.

External area sub-formations will comprise of Made Ground with a predominantly granular nature. A California Bearing Ratio (CBR) of approximately 2% should be achievable with proper preparation with the following:

- Proof roll to identify and allow removal of any soft spots;
- A typical design thickness of 495mm and should include for a basal geotextile separator layer.

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Appendices

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Appendix 3	Groundtech Consulting Factual Ground Investigation Report

1 Introduction

Fairhurst have been appointed by Marco Living 2 Ltd & Axis-Re Ltd to design, supervise, and report on a geo-environmental and geotechnical site investigation for the development of two residential blocks at its site in Manchester. The site is located between Tariff Street and Port Street, c.1km east of Manchester City centre, at grid reference 384790, 398380 (postcode: M1 2FJ). The location of the site is shown on the map appended in Appendix 1 of this report. At present the existing site is utilised as a car park which is owned by the client and managed by The Parking Space.

Fairhurst have previously produced a desk based Geo-environmental and Geotechnical Phase 1 Desk Study for the site (Ref: 143404/01, dated: November 2022), as referenced in full in Section 1.4 of this report.

1.1 Aims

The purpose of the ground investigation works was to assess the geotechnical and environmental conditions present at the site and identify any associated constraints that may hinder the proposed development. The specific objectives include:

- Refine and update the Conceptual Site Model that was presented as part of the Desk Study;
- Identification, assessment, and evaluation of potential contaminants including any sources, pathways, and receptors;
- Carry out and report on an intrusive ground investigation designed to determine ground conditions and hydrogeology underlying the site and to identify any potentially significant environmental or geotechnical development constraints;
- Use the chemical and geotechnical testing results to inform and develop a conceptual site model;
- Make recommendations for further actions, if applicable, relating to any remaining pollutant linkages identified by the ground investigation;
- Make recommendations relating to any potential geo-environmental and geotechnical site risks and constraints to the proposed development which have been identified by the ground investigation works to render the site suitable for its intended final development proposal; and
- Provide a geotechnical assessment to identify any potential constraints with respect to the geotechnical design.

1.2 Development Proposal

It is understood that the site is intended to be developed for residential and commercial end use and this report has been prepared to accompany a full planning application for the demolition of an existing building on site and the erection of two residential apartment buildings (Use Class C3) including a part 9, part 10 (with setback amenity level) and a separate stand-alone 12 storey building (comprising of 267 dwellings in total), with ground floor commercial use (Use Class E), associated resident's amenity space, cycle parking, landscaping, access, street loading and other associated works. The development will include a basement/semi basement structure.

The proposed development plan is shown in Appendix 1.

1.3 Sources of Information

Further details are presented below, however, in summary, the following information has been reviewed during the preparation of this report:

- Available existing site plans and external layout plans;
- British Geological (BGS) 1:50,000 map (Sheet 85 – Manchester: solid and drift geology);
- British Geological (BGS) recorded borehole record (BGS BH Ref: SJ89NW357 and SJ89NW362);
- 1NQ Tariff Street, Manchester Phase 1 Desk Study, Ref: 143404/01, dated: November 2022
- Zetica UXO risk maps;
- UKHSA Public Radon map;
- Groundtech Consulting factual ground investigation report (dated July 2023) appended as Appendix 3;
- Soil, gas and groundwater monitoring data, and laboratory analysis of soil and groundwater samples; and
- Review of publicly available site investigation data to development land bordering the site.

1.4 Previous Reports

The following report pertaining to the subject site has been previously prepared by the Fairhurst Group and should be read in conjunction with this Ground Investigation Report (GIR):

- 1NQ Tariff Street, Manchester Phase 1 Desk Study, Ref: 143404/01, dated: November 2022.

2 Site Description

This section provides a brief summary of the background information provided within the Phase 1 Desk Study (Ref: 143404/01, dated November 2022).

2.1 Location and Topography

The site is located between Tariff Street and Port Street, in Manchester, at grid reference 384790, 398380 (postcode: M1 2FJ). The site is approximately 0.3ha (0.74 acres) in size and the location of the site is shown on the drawing which is attached to this report in Appendix 1.

The site currently comprises of hard standing associated with the clearance of former warehouse development. At present the site is utilised as a car park owned by the client and managed by The Parking Space.

2.1.1 Topography

Available Ordnance Survey plans and open-source LIDAR data from the Environment Agency indicates that ground level is relatively flat and situated at an elevation between 54mAOD and 56mAOD. However, a topographical survey of the site shows a number of retaining walls are present.

2.2 Summary of Site History

A review of the historical plans dating back to 1893, which are presented in Appendix B of the desk study report, indicate that the site is located in an area that has been predominantly industrial in nature and comprises of historical factory units, chimneys, a canal wharf, warehouses and garages.

The site initially consisted of various warehouse buildings and a canal as part of a wharf in 1893. The canal in the north of the site linked to the nearby Rochdale Canal. In the following years from 1922 to 1932, the canal was infilled with an unknown material and replaced with a garage, paint works, and furniture warehouse. By 1951, the furniture warehouse was removed and between 1963 and 1981, Hills Service Garage was divided into two units. From 1983 to 1990, the site had two main buildings with a shared wall and hardstanding. These buildings were demolished between 1990 and 1992. Since then, there have been no significant changes to the site.

In 1893, the land surrounding the site consisted of residential and industrial units connected to the wharf, with a rail line to the south, with additional buildings developed around the wharf by 1908. Between 1922 and 1932, new outbuildings were constructed to the east, with additional units and chimneys to the north and south. A machine tool warehouse was recorded in 1948 to the east of the site, with some of the outbuildings having been demolished. Between 1990 and 1992, remaining structures to the east of the site were combined into one. Since 1992, no significant changes have taken place, and the structures on the eastern side remain combined.

2.3 Geology

A brief summary of the geological and hydrogeological situation of the site, based on the Desk Study, is provided below.

2.3.1 Made Ground

The historical plans show extensive development from the 1890's including multiple iterations of buildings and a now infilled canal basin, which linked to the adjacent Rochdale canal. As such, the presence of Made Ground associated with the historical development and the infilled canal is to be expected. BGS borehole records from the neighbouring sites suggest that the canal infill may comprise of ash, cinder and stone and, it is anticipated that in the vicinity of the backfilled canal deeper Made Ground will be present.

2.3.2 Superficial Geology

The BGS drift geology map (sheet 85 - Manchester) and BGS online viewer (GeoIndex Onshore) suggest that Glacial Till is present across the site and is anticipated to comprise sandy and or gravelly Clay. Local BGS borehole records suggests that stiff brownish grey clay is present to c.26m depth.

2.3.3 Solid Geology

The BGS drift geology map (sheet 85 - Manchester) and BGS online viewer (GeoIndex Onshore) also indicates that the entire site is underlain by deposits from the Chester Formation which typically comprises a red sandstone. Examining the nearby BGS borehole records, it is anticipated that the Chester Formation should be encountered at a depth of around 26m.

2.4 Hydrogeology, Hydrology & Flooding

The Environment Agency classifies the superficial deposits as a Secondary undifferentiated aquifer. It is also possible that localised pockets of perched water may exist within the Made Ground deposits anticipated at the site. Furthermore perched water may be present within the infilled former canal basin.

The Chester Formation is defined as a Principal aquifer by the Environment Agency.

Groundwater vulnerability beneath the site is classified as low risk due to the protection afforded by the overlying Glacial Till, as such the site is not within a groundwater source protection zone or Nitrate Vulnerable Zone. There are three groundwater abstraction points within 1km of the site, however these are not for a potable use.

Whilst there are no onsite surface water features the Rochdale canal is present c40m southeast of the site. The Envirocheck report suggests that there are areas of controlled waters in the southern and eastern part of the site and that there are a number of discharge consents located around the site.

2.5 Geo-environmental Considerations

2.5.1 Land Filling & Hazardous Gas

There are several retained level changes within the site boundary. As such, the site is expected to be underlain by a variable thickness of Made Ground deposits, likely comprising of demolition rubble and canal infill.

Whilst the Made Ground is unlikely to contain significant putrescible waste, it could still be a potential source of hazardous gas. If proven as a gas source, it is likely gas productions would be at a low concentration and emission rate.

The Envirocheck report indicates that there are infilled (water) areas on site in the location of a historical canal and that there are areas of potentially infilled land (water) located within 500m of the site.

A preliminary site conceptual model has been formulated based on the data recovered as part of the desk study. The conceptual model presents the viable source, pathway, and receptor contamination linkage for the site and is set out in the following sections. The principles of environmental risk assessment are presented in Appendix 2. The significance of the viable linkages has been evaluated by carrying out a qualitative risk assessment.

Based on the initial conceptual site model (CSM) and Phase 1 Desk Study, the majority of identified potentially complete pollutant linkages were given a risk rating of moderate/low or low. The desk study identified the following potential pollution sources:

- Made Ground associated with the demolition of former buildings is anticipated and whilst these materials are unlikely to represent a significant source of contamination, localised and low-level contamination may be present as organic compounds, inorganic compounds, or hazardous gas;
- The presence of the former Hill service garage has the potential to be a source for hydrocarbon, PAH, heavy metal and solvent contamination;
- The presence of the former paint works has the potential to be a source for solvent contamination;
- The presence of former warehouses has the potential to be a site for hydrocarbon, PAH, heavy metal and solvent contamination depending on the materials stored;
- The historical use as a furniture warehouse has the potential to be a source of localised and low level contamination of organic compounds, inorganic compounds or hazardous gas;
- Potential ground gases and hydrocarbons may be present at localised low concentrations associated with the current use of the development site as a car park;
- Given the age and nature of the former buildings on site, these are expected to have contained Asbestos containing materials (ACM's) and the presence of asbestos, buried on site or within the Made Ground soil fabric, cannot be discounted; and
- Potential ground gases and hydrocarbons may be present at low concentrations and emission rates associated with general made ground, canal infill material and specific historical land uses on site.

Contaminants of concern associated with these sources are listed in Table 1 below. These contaminants have been determined using guidance and it should be noted that whilst the list is not exhaustive it only contains contaminants likely to be present within the anticipated Made Ground.

Table 1: Contaminants of Concern (CoC).

Contaminants of concern	Potential Source
	Made Ground Deposits
Metals	X
TPH	X
PAH	X
Ammonia	
Sulphate	X
pH	X
Ground Gas	X
SVOCs/ VOCs	X
PCBs	
Asbestos	X
Cyanide	

2.5.2 Summary of Preliminary Conceptual Site Model and Qualitative/Quantitative Risk Assessment

The following risk assessment has been based on information available at the time of the production of the Desk Study and does not include detail gained from the ground investigation discussed within this report. The following geo-environmental source pathway-receptor pollutant linkages that were identified have been summarised below:

Table 2: Preliminary Qualitative Risk Assessment for Identified Sources of Contamination.

Source	Potential Contaminants	Potential Pathway	Potential Receptors	Assessment	Potential Severity	Potential Probability	Risk Class
Historical land use as infilled Canal	Metals TPH PAH Sulphate pH Asbestos	Ingestion, inhalation, dermal contact, direct contact	Future site users	Made Ground is anticipated to be present on site and contamination may be present, as such, there is a potential risk of harm to end users. There is a potential risk to construction workers, however, this risk can be mitigated using appropriate PPE. Foundations and services (including water pipes) could be affected by aggressive ground conditions or contamination. It is considered a very low risk to the local water environment from contamination associated with the Made Ground if present.	Minor	Unlikely	Low
			Construction workers		Minor	Unlikely	Low
			Adjacent land users		Medium	Unlikely	Low
		Direct contact	Buried structures and services		Medium	Unlikely	Low
		Migration/leaching of mobile contaminants	Groundwater		Medium	Unlikely	Low
Made Ground	Metals TPH PAH Sulphate pH Asbestos	Ingestion, inhalation, dermal contact, direct contact	Future site users	It is considered a very low risk to the local water environment from contamination associated with the Made Ground if present.	Minor	Unlikely	Very Low
			Construction workers		Mild	Likely	Moderate
			Adjacent land users		Mild	Unlikely	Very Low
		Direct contact	Buried structures and services		Mild	Unlikely	Very Low
		Migration/leaching of mobile contaminants	Groundwater		Mild	Unlikely	Very Low
			Surface water		Mild	Unlikely	Very Low
Historical land uses as: Garage, Paint works, Furniture warehouse	Metals TPH PAH Sulphate pH VOCs & SVOCs Asbestos	Ingestion, inhalation, dermal contact, direct contact	Future site users	Historical land uses have the potential to be a source of contamination. The risk to future site users is Very Low and the risk to construction workers is Moderate/Low. In order to reduce this level of risk to low, construction workers must adopt appropriate health and safety measures and PPE during works.	Minor	Unlikely	Very Low
			Construction workers		Medium	Likely	Moderate /Low
			Adjacent land users		Minor	Unlikely	Very Low
		Direct contact	Buried structures and services		Minor	Unlikely	Very Low
		Migration/leaching of mobile contaminants	Groundwater		Mild	Unlikely	Very Low
			Surface water		Mild	Unlikely	Very Low
Current land use as a Car Park	TPH PAH	Ingestion, inhalation, dermal contact, direct contact	Future site users	Potential hydrocarbons may be present at low concentrations and emission rates associated with the current use of the development site as a car park. The risk to future site users and construction workers is considered to	Medium	Unlikely	Low
			Construction workers		Medium	Unlikely	Low
			Adjacent land users		Medium	Unlikely	Low
		Direct contact	Buried structures and services		Medium	Unlikely	Low
		Migration/leaching of mobile contaminants	Groundwater		Medium	Unlikely	Low
			Surface water		Medium	Unlikely	Low

Source	Potential Contaminants	Potential Pathway	Potential Receptors	Assessment	Potential Severity	Potential Probability	Risk Class
				be Low. In order to reduce this level of risk to low, construction workers must adopt appropriate health and safety measures and PPE during works.			
Asbestos (buried onsite or within the Made ground soil fabric)	Asbestos	Ingestion, inhalation, dermal contact, direct contact	Future site users	Historical buildings built before 2000 likely have Asbestos Containing Materials (ACMs). Asbestos may be buried on site or in the Made Ground matrix, posing a risk to future site users and construction workers. To minimize these risks, disposal of asbestos should be to landfill. Construction workers should adhere to proper health and safety measures and personal protective equipment (PPE).	Severe	Low	Moderate
			Construction workers		Severe	High	Very High
Ground Gas (Made Ground and canal infill)	Hazardous Gas (CO ₂ , CH ₄ , VOCs, SVOCs)	Inhalation	Future site users	Ground gas may be present due to the existing Made Ground. The current use of the development site as a car park may also result in low concentrations and emission rates of ground gases and hydrocarbons. There is risk to future site users and construction workers. To mitigate this risk construction workers must follow appropriate health and safety measures and use personal protective equipment (PPE).	Medium	Unlikely	Low
			Construction workers		Medium	Low	High
			Adjacent land users		Medium	Unlikely	Low
Fly Tipped Material	Metals TPH PAH Asbestos	Dermal contact	Future site users	Any fly tipped material on site can be collected and disposed of. There is a potential risk to construction workers, however, this risk can be mitigated using appropriate PPE.	Minor	Unlikely	Very Low
			Construction workers		Minor	Unlikely	Very Low
			Adjacent land users		Minor	Unlikely	Very Low

2.6 Geotechnical Considerations

The following potential geotechnical constraints have been identified by the desk study:

- Made Ground is anticipated across the site and would likely comprise of demolition rubble associated with the former development;
- Deeper deposits of Made Ground are expected and these are anticipated to be associated with the infilled canal.
- Shallow groundwater perched within the Made Ground deposits may be present on site. Perched groundwater may be in continuity with the adjacent canal via the infilled canal;
- There is potential for aggressive ground for concrete due to the potential contaminants from previous industrial use;
- There is a risk of possible variation in shear strength of the Glacial Till deposits which may arise due to the varied densities and composition of these materials; and
- The on-site derelict building, which is to be removed as part of the development, is understood to provide some structural support to the adjacent Sam's Yard building which will be retained by the adjacent land owner. Structural support works will be required to facilitate removal of the on-site derelict building; and
- Relict foundations are likely to be present and will require chasing out prior to any redevelopment. The presence of buried obstructions associated with the previous development on site. Where demolition works are to be undertaken or have already been undertaken, it should be considered that existing foundations may cause obstructions with the proposed development and such investigation should be completed to determine the extent and risk of this;
- Existing buried services may be present across the site which may interfere with the proposed development; and
- Interface with party boundary wall and neighbouring structures. Therefore, the proposed structural design shall take consideration of existing on-site and neighbouring foundations and structures to avoid undermining the integrity of such.

2.7 Previous Ground Investigations

No previous site investigation data is available to review for this report, any available data from the BGS borehole records were considered in the Phase 1 Desk Study.

3 Ground Investigation

3.1 Scope of Investigation

Based on the information summarised in Section 2 of this report, a ground investigation was scoped by Fairhurst to provide geotechnical information to support the cost-effective design of the substructures and data to assess the contamination status of the site. Fieldwork was undertaken between the 2nd and 18th May 2023 by Groundtech Consulting and observed by Fairhurst. The site investigation comprised the following:

- 12No. cable percussive boreholes referenced CP01 to CP12;
 - 2 no. cable percussion boreholes to bedrock with rotary coring follow on to 35mbgl;
 - 4 no. cable percussion boreholes to 25mbgl;
 - 5 no. cable percussion boreholes to 5mbgl; and
 - 1 no. cable percussion borehole to 7mbgl.
- Installation of 7 no. groundwater and gas monitoring wells with three rounds of monitoring;
- In situ testing by SPTs;
- Geotechnical soil sampling and laboratory testing; and
- Geo-environmental soil sampling and laboratory testing.

The ground investigation was undertaken in accordance with techniques outlined in BS EN 1997-1:2004, BS EN 1997-2:2004, BS5930:2015 Code of Practice for Site Investigations and BS10175 2011+A2:2017 Investigation of potentially contaminated sites. The locations of the exploratory positions are provided within Groundtech Consulting's factual ground investigation report present in Appendix 3.

3.2 Methodology for the Collection of Soil Samples

Geotechnical and environmental soil samples were collected across a range of depths representative of the strata in the trial pits and boreholes, in general accordance with British Standard BS5930:2015 "Code of Practice for Ground Investigations" and 10175:2011 "Investigation of Potentially Contaminated Sites".

3.3 Environmental Testing Summary

Samples of Made Ground and natural soils were submitted for laboratory chemical analysis of the following determinants:

- Metals: Arsenic, cadmium, chromium (total, III and VI split), selenium, mercury, lead, copper, nickel, zinc, boron;
- Asbestos identification;
- Speciated Total Petroleum Hydrocarbons (TPH);
- Total Organic Carbon (TOC);
- Waste Assessment Criteria (WAC); and
- pH & Sulphate.

Groundwater was sampled from monitoring wells BH03 and BH04 during the second monitoring round in July 2023. Laboratory chemical analysis of the groundwater samples comprised the following determinants:

- Cyanide (total);
- Metals suite – arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium and zinc;
- PAHs;
- TPHCWG including benzene, toluene, ethylbenzene and xylene (BTEX);
- pH;
- Phenols (monohydric);
- Sulphide; and
- Water-soluble sulphate.

The test results are presented in Groundtech Consulting's factual ground investigation report in Appendix 3 and summarised in Section 5.

3.4 Geotechnical Testing Summary

In-situ testing was carried out in the form of Standard Penetration Tests (SPT), and ex-situ laboratory testing was also scheduled on selected samples. Geotechnical testing scheduled by Fairhurst comprised the following:

- Moisture Content;
- Atterberg Limits;
- PSD Wet & Dry Sieve Method;
- pH Value of Soil;
- BRE Full Suite;
 - Sulphates
- Unconfined Compressive Strength; and
- Consolidation Test (undrained).

Geotechnical testing results are presented in Groundtech Consulting's factual ground investigation report in Appendix 3 and summarised in Section 7.

3.5 Monitoring Installations

Combined groundwater and gas monitoring installations were placed in selected boreholes. Details of the installations are presented on the exploratory hole records and summarised in the Table 3 below.

Table 3: Monitoring well installation details.

Exploratory Hole	Standpipe (mm)	Screen Top & base (m BGL)	Strata Installed
BH01	50	6.5 – 9.0	Cohesive and Granular Glacial Till
BH04	50	0.5 – 2.0	Made Ground and Cohesive Glacial Till
BH05	50	0.5 – 4.5	Made Ground and Cohesive Glacial Till
BH07	50	1.0 – 3.5	Made Ground and Cohesive Glacial Till
BH08	50	2.8 – 5.8	Made Ground and Cohesive Glacial Till
BH10	50	14.5 – 18.0	Cohesive and Granular Glacial Till
BH12	50	1.5 – 5.0	Cohesive Made Ground

3.6 Surveying

All exploratory holes were surveyed by Groundtech Consulting, with the easting, northing, and Ordnance Datum elevation presented on the exploratory hole records.

3.7 Groundwater & ground gas monitoring visits

Three ground gas/ groundwater monitoring visits were specified over a 3-month period in accordance with guidance presented in BS 8484:2015 (BSI, 2019) and CIRIA C665 (Wilson et al, 2007) for a moderate sensitivity, low ground gas generation potential site. The monitoring results to dated are included in Section 5.4.

4 Ground Conditions

Published geological mapping (BGS, 2004) and the site history suggest a sequence of Made Ground, overlying Glacial Till, and sandstone bedrock of the Chester Formation. The ground investigation generally confirmed this sequence. However, layers of granular Glacial Till were also recorded in the cable percussion boreholes towards the base of the superficial deposits.

Based on the information obtained, the following ground summary has been derived for the site. Geological logs detailing the soil profile at each exploratory hole location are presented in Groundtech Consulting's factual ground investigation report in Appendix 3. A summary of the ground conditions is given in Table 4.

Table 4: Ground Model

Strata		Typical Description	Depth to Base (mBGL)	Elevation of Base (mAOD)	Thickness (m)	Notes
Surfacing		Macadam / Concrete	0.1 – 0.7	46.89 – 48.64	0.03 – 0.4	Recorded in every borehole except BH12
Made Ground	Granular	Slightly clayey sandy fine to coarse gravel of mudstone, sandstone, brick, and concrete	0.15 – 3.1	44.59 – 48.34	0.1 – 3.0	Granular Made Ground was recorded in every borehole except BH11 where only Cohesive Made Ground was recorded.
	Cohesive	Soft to firm slightly sandy slightly gravelly Clay. Gravel is of brick, coke, sandstone, concrete and clinker	0.8 – 4.0	43.59 – 47.15	0.3 – 2.55	Cohesive Made Ground was encountered in every hole except BH03, BH04 and BH12.
Upper Cohesive Glacial Till		Firm becoming stiff slightly sandy slightly gravelly clay with occasional lenses of sand	4.5 – 18.0	29.95 – 43.56	0.6 – 13.2	Recorded in all boreholes
Upper Granular Glacial Till		Dense becoming very dense gravelly fine to coarse sand	13.5 – 19.0	33.07 – 48.06	0.5 – 3.1	Encountered in BH01, BH02, BH10 and BH12
Lower Cohesive Glacial Till		Stiff slightly sandy gravelly sandy clay	15.0 – 24.0	23.95 – 33.40	1.5 – 6.0	Encountered in BH01, BH02, BH05 and BH12

Strata	Typical Description	Depth to Base (mBGL)	Elevation of Base (mAOD)	Thickness (m)	Notes
Lower Granular Glacial Till	Dense becoming very dense gravelly fine to coarse sand	12.9 – 27.2	20.72 – 35.5	0.6 – 9.7	Encountered in BH01, BH02, BH05, BH08, and BH12
Chester Formation Sandstone	Red firm to medium grained Sandstone	Encountered from 24.6 – 27.2	Encountered from 20.72 – 35.16	-	Encountered in BH01, BH02, BH05, BH08 and BH12. BH01 and BH12 had rotary coring to collect samples of rock core. BH02, BH05 and BH08 proved bedrock by chiseling and SPT refusals.

4.1 Made Ground Deposits

The following section discusses the ground conditions determined from the ground investigation.

4.1.1 Made Ground

Made Ground associated with the historical development across the site was recorded in all exploratory positions below a hardstanding area of asphalt or concrete surfacing, except in BH12, where no surfacing was recorded. The surfacing ranged in thickness between 0.03m and 0.4m.

Granular Made Ground was recorded in every exploratory hole, typically to depths of 1.8mbgl except in BH11 where only Cohesive Made Ground was recorded to a depth of 2.7mbgl. In five of the boreholes (BH01, BH02, BH08, BH09 and BH10), the Granular Made Ground was underlain by a layer of Cohesive Made Ground typically to a depth of 2.8mbgl.

Beyond the perimeter of the former canal basin, the depth to the base of the Made Ground was greatest in BH09 (3.5mbgl) and BH08 (3.2mbgl), with both of these positions located in the southern part of the site. Across the remainder of the site, the depth to the base of the Made Ground ranged between 0.15mbgl (BH12) and 3.0mbgl (BH02).

4.1.2 Made Ground - Former Canal Basin

Made Ground associated with the historical canal basin was encountered in BH05, BH06 and BH07 typically to depths of 3.7mbgl, and was approximately 1m deeper in thickness than the surrounding site. The depth to the base of the Made Ground deposits were thickest in BH04 (4.0mbgl) and BH05 (4.0mbgl) with both of these positions being located in the centre of the site, within the footprint of the former canal basin, whilst the base of Made Ground was slightly thinner, to a depth of 3.5mbgl in BH06. The Made Ground associated with the infilled canal comprised a layer of Granular Made Ground to a depth of 0.9mbgl, with Cohesive Made Ground to a depth of 3.7mbgl.

The Granular Made Ground encountered within the infilled canal is similar in composition to that within the wider site, typically being described as brown very gravelly sand with medium to coarse gravel of brick, concrete, sandstone, and glass. The Cohesive Made Ground below was described as soft to firm dark greyish black gravelly sandy Clay with gravels typically comprising of fine to medium glass, brick, sandstone, and occasional limestone.

4.2 Natural Superficial Deposits

Glacial Till was recorded in every borehole that penetrated the Made Ground deposits. The Glacial Till comprised an upper cohesive layer, with a band of granular material, before returning to a cohesive stratum, and typically turning to a granular composition towards the boundary of superficial drift and the Chester Formation Sandstone bedrock. The investigation confirmed the presence of Glacial Till deposits across the entire site and indicated that there was some variance in the composition and nature of this material.

4.2.1 Granular Glacial Till

BH01, BH02, BH10 and BH12 encountered a shallower layer of Granular Glacial Till (Upper Granular Glacial Till) to depths of between 8.0mbgl and 18.1mbgl. The thickness of this granular layer ranged between 0.5m and 3.1m and this granular layer was recorded to be directly overlying a lower layer of Cohesive Glacial Till. This material is typically described as greyish brown slightly silty clayey gravelly fine Sand with gravel comprising of fine to medium flint, sandstone, siltstone, and occasional coal.

In BH01, BH02, BH05, BH08 and BH12 a second, lower layer of granular Glacial Till (Lower Granular Glacial Till) was recorded to depths between 19.0m and 27.2mbgl with thicknesses of 0.6m and 9.7m. This second layer of granular material was often recorded lying directly over the sandstone bedrock and comprised of dense to very dense sandy fine to coarse Gravel with low to moderate cobble content of sandstone (likely destroyed sandstone from glacial activity during deposition).

4.2.2 Cohesive Glacial Till

Cohesive Glacial Till was recorded in every exploratory hole to depths between 4.5m and 18.0mbgl. This upper layer of Cohesive Glacial Till (Upper Cohesive Glacial Till) is typically described as firm to stiff brown mottled grey slightly gravelly Clay, with fine to medium gravels comprising of flint, sandstone, siltstone, and limestone.

In BH01, BH02, BH05 and BH12 a second lower layer of Cohesive Glacial Till (Lower Cohesive Glacial Till) was recorded to depths between 16.5m and 24.0mbgl (23.95m – 31.90m AOD) with thicknesses between 2.0m and 6.0m. This material is described as firm to stiff brown sandy gravelly Clay with occasional cobble content. Gravel is typically fine to medium of sandstone, siltstone and flint.

4.3 Chester Formation

Deposits from the Chester Formation Sandstone were recorded in 5 of the boreholes (BH01, BH02, BH05, BH08 and BH12) across the site and these deposits were recorded to underlie the Glacial Till at elevations between 20.72m and 21.76m AOD (27.2m and 26.8mbgl), indicating the bedrock level beneath the site is relatively uniform.

The sandstone is recorded as comprising an upper weathered zone, grading with depth into intact rock. Within this report, the weathered zone has been taken as the depth over which the

sandstone is recorded as having been recovered as fine to coarse sand. In the boreholes this zone is recorded to be between 0.05m and 0.75m thick.

The intact rock is generally recorded as weak to medium strong fine to medium grained sandstone.

The Chester Formation Sandstone was encountered in 5 boreholes typically from a depth of 26.2mbgl (25.05m AOD) and comprised of a weak becoming moderately strong red fine to medium grained Sandstone.

4.4 Obstructions and Services

A boulder was encountered in BH10 at a depth of 18.1mbgl, terminating the hole early. Whilst this is generally not a significant risk in the Manchester area, the risk of boulders within the Glacial Till will also need to be considered by the specialist piling contractor, given the proposed foundation solution is anticipated to comprise of piles.

4.5 Groundwater

Details of groundwater strikes during the drilling are provided in Table 5 below.

Table 5: Groundwater Strike Data

Hole ID	Water Strike/Seepage		Water Level After 20 mins		Nature of Groundwater Strike/Seepage	Strata in which Strike was Encountered
	Depth (mbgl)	Elevation (mAOD)	Depth (mbgl)	Elevation (mAOD)		
BH01	7.5	40.90	2.2	46.60	Strike	Glacial Till (Sand)
BH02	2.0	46.84	1.8	47.04	Seepage	Cohesive Made Ground
BH04	1.0	45.59	0.8	45.79	Seepage	Cohesive Made Ground
BH05	0.8	47.15	-	-	Seepage	Cohesive Made Ground
BH06	1.0	46.59	0.6	46.99	Seepage	Granular Made Ground
BH07	1.0	46.65	0.6	47.05	Seepage	Cohesive Made Ground

4.6 Evidence of Contamination

The following visual and olfactory evidence of contamination was noted during the investigation from a depth of:

- Hydrocarbon odours in BH1 from 0.35mbgl to 2.0mbgl;
- Hydrocarbon odours in BH05 at 2.0mbgl;
- There was no obvious hydrocarbon sheen to the perched groundwater encountered during the works;
- There were no obvious putrescible materials encountered in the made ground;
- There was only localised wood degradable debris encountered in the made ground; and
- There was no obvious visual evidence of significant asbestos debris encountered during the works.

5 Chemical Testing

5.1 Assessment Criteria and Approach – Risks to Human Health

For the assessment of the soil analytical results, with the exception of Lead, the human health assessment criteria applied are the 2015 LQM/CIEH 'Suitable 4 Use Levels' (S4ULs) that have been developed in accordance with developments in UK human health risk assessment. The S4ULs are based on Health Criteria that represent minimal or tolerable levels of risks to health as described in the Environment Agency's SR2 guidance, ensuring that the resulting assessment criteria are 'suitable for use' under planning.

In general, for Lead, the 'medium risk' Category 4 Screening Level (C4SL) for the 'residential without home grown produce' land-use was adopted.

For each substance, these criteria have been derived for six generic land uses (including the two Public Open Space land uses defined in C4SL guidance) and a range of Soil Organic Matter contents (organic contaminants only). All toxicological and physical-chemical data inputs used in the derivation of the S4ULs and C4SLs are presented and discussed in the respective LQM/CIEH and C4SL publications.

The assessment criteria outlined above have been used to provide a Generic Quantitative Risk Assessment (GQRA). No statistical analysis has been completed and recorded concentrations have been compared directly to the applied S4ULs / C4SL.

The most sensitive human health receptors on site are considered to be the construction phase workers and operational team, therefore, results have been assessed against assessment criteria 'residential without home grown produce' which represents the most conservative assessment criteria derived for this land-use. Should any future development plans vary from this end use, the contaminated land risk assessment should be revised.

Individual laboratory results are presented in the Groundtech Factual Investigation Report in Appendix 3 of this report.

5.2 Summary of Analytical Laboratory Testing Undertaken

Geo-environmental laboratory testing was undertaken on 21 no. samples collected during the ground investigation. Testing was undertaken from representative samples of Made Ground and the underlying Cohesive Glacial Till for contaminants of concern as determined within the preliminary risk assessment.

The results of these are summarised in the following sections:

5.2.1 Inorganic Contaminants

The total organic carbon was tested in five of the ten samples of Made Ground. The results ranged from 1.1% to 10.4% with an average of 4.2%. This has been converted into a SOM value of 7.2% using the multiplier of 1.72. Therefore, the 6% SOM SSV value has been used for comparing organic determinands.

Of the nine samples of Cohesive Made Ground and three samples of Granular Made Ground tested for inorganic determinands, three of the Cohesive and one of the Granular Made Ground samples are classified as contaminated.

Elevated arsenic was encountered in BH05 at a depth of 2.0 mbgl (142 mg/kg) and in BH06 at a depth of 2.0 mbgl (92 mg/kg) with respect to their relevant Tier 1 value of 40 mg/kg.

Elevated lead was encountered in BH05 at a depth of 2.0 mbgl (779 mg/kg), BH06 at a depth of 2.0 mbgl (908 mg/kg), BH07 at a depth of 1.5 mbgl (370 mg/kg) and BH10 at a depth of 1.0 mbgl (384 mg/kg). Table 6 below summarises the exceedances relative to their Tier 1 SSV.

5.2.2 Asbestos

Asbestos screening was carried out on ten samples of Made Ground. Of the ten samples tested for asbestos, one sample of Granular Made Ground (BH10 at 1.0m depth) was found to contain chrysotile as fibres/clumps.

Asbestos was not identified in any other samples, however, in view of the historical use of the development site and variable Made Ground the presence of asbestos either buried on site or within the soil matrix cannot be discounted.

5.2.3 Organic Contaminants

Nine samples of Cohesive Made Ground, four samples of Granular Made Ground, two samples of Cohesive Glacial Till and one sample of Macadam were tested for a series of organic contaminants, namely PAH, TPH, BTEX and PCBs.

Of the nine samples of Cohesive Made Ground tested, six can be classed as uncontaminated, whilst three can be considered as contaminated with elevated B(a)P concentrations encountered in BH03 at a depth of 3.0mbgl, BH05 at a depth of 2.0 mbgl and BH07 at a depth of 1.5 mbgl. Elevated Benzene was also encountered in BH01 at a depth of 0.1 mbgl depth with elevated Aromatic C21-C35 encountered in BH05 at a depth of 2.0 mbgl.

Of the four samples of Granular Made Ground, one sample (BH10 at 1.0m) contained elevated B(a)P and Dibenzo(ah)anthracene. The other three samples can be classified as uncontaminated.

The two samples of Cohesive Glacial Till are considered uncontaminated with not determinands exceeding their relevant Tier 1 values. The single sample of Macadam from BH10 at 0.2m contains elevated concentrations of B(a)P, Coronene and Dibenzo(ah)anthracene.

Table 7 below summarises the exceedances relative to their Tier 1 SSV.

5.2.4 Phenols

No exceedances of Tier 1 values were encountered.

Table 6: Summary of inorganic results.

Hole ID	Depth (m bgl)	Ground Type	pH	Arsenic	Boron	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Zinc	Free Cyanide	Total Cyanide	Thiocyanate	Asbestos Type	
				Residential without Home Grown Produce Soil Screening Value based on 1-6% SOM														
				40	11,000	85	910	7,100	310	15	180	430	40,000	34	-	-		N.D.
BH01	1.0	Cohesive Made Ground	8.1	17	3.4	<0.1	48	104	106	0.3	36	<1.0	84	<0.5	<0.5	<0.6	-	
BH02	2.3	Cohesive Made Ground	8.1	24	-	<0.1	33	87	128	0.7	30	<1.0	91	-	<0.5	-	-	
BH03	3.0	Cohesive Made Ground	7.9	16	-	<0.1	48	51	125	0.3	25	<1.0	121	-	1.1	-	-	
BH04	1.0	Cohesive Made Ground	8.5	12	-	0.7	36	29	171	<0.1	26	<1.0	86	-	<0.5	-	N.D.	
BH05	2.0	Cohesive Made Ground	8.4	142	-	3.3	56	647	779	2.8	72	4.0	1965	-	56	-	-	
BH06	2.0	Cohesive Made Ground	7.8	92	-	4.2	58	463	908	3.0	76	2.0	2471	-	54	-	-	
BH07	1.5	Cohesive Made Ground	8.2	35	-	1.1	51	186	370	1.2	40	<1.0	807	-	44	-	N.D.	
BH08	3.0	Cohesive Made Ground	8.5	10	-	<0.1	45	57	27	<0.1	35	<1.0	75	-	<0.5	-	-	
BH11	0.5	Cohesive Made Ground	-	-	-	-	-	-	-	-	-	-	-	-	-	-	N.D.	
BH11	2.0	Cohesive Made Ground	8.2	13	-	<0.1	44	62	160	0.2	33	<1.0	83	-	<0.5	-	-	
BH01	0.5	Granular Made Ground	-	-	-	-	-	-	-	-	-	-	-	-	-	-	N.D.	
BH02	0.2	Granular Made Ground	-	-	-	-	-	-	-	-	-	-	-	-	-	-	N.D.	
BH03	1.0	Granular Made Ground	-	-	-	-	-	-	-	-	-	-	-	-	-	-	N.D.	
BH08	1.0	Granular Made Ground	-	-	-	-	-	-	-	-	-	-	-	-	-	-	N.D.	
BH09	1.0	Granular Made Ground	8.9	8.5	-	0.8	412	66	204	<0.1	28	2.0	96	-	<0.5	-	N.D.	
BH10	1.0	Granular Made Ground	8.0	28	-	7.9	48	119	384	0.3	39	<1.0	805	-	<0.5	-	Chrysotile	
BH12	0.5	Granular Made Ground	7.2	19	1.7	<0.1	49	51	120	<0.5	30	<1.0	82	<0.5	<0.5	1.8	-	
BH12	1.0	Granular Made Ground	7.9	-	-	-	-	-	-	-	-	-	-	-	-	-	N.D.	

Table 7: Summary of organic (PAH) results.

Hole ID	Depth (m bgl)	Ground Type	Acenaphthene	Acenaphthylene	Anthracene	Benzo(a)anthracene	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Benzo(a)pyrene	Benzo(ghi)perylene	Chrysene	Coronene	Dibenzo(ah)anthracene	Fluoranthene	Fluorene	Indeno(123cd)pyrene	Naphthalene	Phenanthrene	Pyrene
			Residential without Home Grown Produce Soil Screening Value based on 6% SOM																
			6,000	6,000	37,000	15	4.0	110	3.2	360	32	1.2	0.32	1,600	4,500	46	13	1,500	3,800
BH01	3.2	Cohesive Glacial Till	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
BH10	6.0	Cohesive Glacial Till	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
BH01	1.0	Cohesive Made Ground	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
BH02	2.3	Cohesive Made Ground	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	0.2	-	<0.1	0.2	<0.1	<0.1	<0.1	0.2	0.2
BH03	3.0	Cohesive Made Ground	2.1	0.9	4.9	13	20	7.9	13	12	14	-	1.5	32	2.1	14	1.9	14	27
BH04	1.0	Cohesive Made Ground	<0.1	<0.1	0.2	0.4	0.4	0.2	0.4	0.2	0.4	-	<0.1	0.8	<0.1	0.2	<0.1	0.6	0.7
BH05	2.0	Cohesive Made Ground	5.5	0.9	5.8	17	15	5.8	9.0	7.3	17	-	0.9	63	5.1	7.5	2.4	12	50
BH06	2.0	Cohesive Made Ground	1.5	0.3	1.8	4.6	4.4	1.7	3.7	2.3	5.1	0.4	0.5	19	1.4	2.0	0.7	4.4	15
BH07	1.5	Cohesive Made Ground	3.4	0.6	5.4	11	11	4.3	6.6	5.7	11	-	0.7	30	2.5	5.8	1.3	18	25
BH08	3.0	Cohesive Made Ground	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
BH11	2.0	Cohesive Made Ground	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	0.2	-	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	0.2
BH09	1.0	Granular Made Ground	1.8	0.3	3.3	5.9	6.8	2.7	4.3	4.3	6.2	-	0.4	16	1.5	4.6	0.5	12	14
BH10	1.0	Granular Made Ground	1.2	1.8	4.5	15	21	8.3	14	13	17	-	1.6	31	1.5	13	4.1	15	30
BH12	0.5	Granular Made Ground	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
BH12	1.0	Granular Made Ground	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
BH10	0.2	Macadam	1.3	1.8	5.0	15	22	8.6	15	13	18	2.4	1.6	31	1.5	14	3.7	16	29

Table 8: Summary of organic (TPH) results.

Determinand	No. Samples Tested	SSV (mg/kg)	Soil Concentration		Location and depth of maximum
			Minimum (mg/kg)	Maximum (mg/kg)	
Aliphatic TPH >C5-C6	2	160	<0.1	<0.1	-
Aliphatic TPH >C6-C8	2	530	<0.1	0.6	BH01 at 1.0m
Aliphatic TPH >C8-C10	2	150	<0.1	0.9	BH01 at 1.0m
Aliphatic TPH >C10-C12	2	770	0.2	6.4	BH01 at 1.0m
Aliphatic TPH >C12-C16	2	4,400	4.0	15	BH05 at 2.0m
Aliphatic TPH >C16-C21	2	110,000	7.0	173	BH05 at 2.0m
Aliphatic TPH >C21-C35	2	110,000	7.0	2283	BH05 at 2.0m
Aromatic TPH >C5-C7	2	1400	<0.1	<0.1	-
Aromatic TPH >C7-C8	2	3,900	<0.1	<0.1	-
Aromatic TPH >C8-C10	2	270	<0.1	<0.1	-
Aromatic TPH >C10-C12	2	1200	0.2	3.5	BH05 at 2.0m
Aromatic TPH >C12-C16	2	2,500	4.0	70	BH05 at 2.0m
Aromatic TPH >C16-C21	2	1,900	7.0	899	BH05 at 2.0m
Aromatic TPH >C21-C35	2	1,900	7.0	2077	BH05 at 2.0m
Total Petroleum Hydrocarbons	2	-	38	5333	BH05 at 2.0m

Table 9: Summary of organic results.

Determinand	No. Samples Tested	SSV (mg/kg)	Soil Concentration		Location and depth of maximum
			Minimum (mg/kg)	Maximum (mg/kg)	
MTBE	5	220	<5.0	51	BH01 at 1.0m
Benzene	5	1.4	<5.0	26	BH01 at 1.0m
Toluene	5	3,900	<5.0	<5.0	-
Ethylbenzene	5	440	<5.0	10	BH01 at 1.0m
m/p-Xylene	5	430	<5.0	14	BH01 at 1.0m
o-Xylene	5	480	<5.0	<5.0	-
PCB 28	4	-	<5.0	<5.0	-
PCB 52	4	-	<5.0	<5.0	-
PCB 101	4	-	<5.0	<5.0	-
PCB 118	4	-	<5.0	<5.0	-
PCB 138	4	-	<5.0	<5.0	-
PCB 153	4	-	<5.0	<5.0	-
PCB 180	4	-	<5.0	<5.0	-
Total Phenols	12	1,200	<0.2	<0.2	-

5.3 Groundwater testing

Groundwater testing was scheduled on five samples of groundwater taken on the second monitoring visit from BH01, BH04, BH05, BH07 and BH08. These samples showed elevated concentrations of Arsenic, Benzo(a)Pyrene, Indeno(123cd)pyrene, and Benzo(bk)fluoranthene, as well as elevated sulphate.

5.4 Gas Monitoring

The site is unlikely to be affected by sources of methane and carbon dioxide gas generation as it is:

- Not underlain by shallow mineworkings nor located in an area considered susceptible to mines gas emissions;
- Not underlain by Peat or shallow chalk deposits; and
- No significant evidence of putrescible materials was encountered during the investigation. The Made Ground has been identified with a low wood/degradable content and would only be expected to be a source of low concentration soil gas at low emission rate.

However, based on the investigation encountering the presence of Made Ground deposits, then three rounds of gas monitoring have been scheduled, a record of monitoring visits to date is provided in Appendix 3. Gas monitoring results are summarised in Table 10 below.

Monitoring of gas and groundwater levels was carried out post fieldworks using a GFM43 ground gas analyser and electronic dip meter for standard water depth monitoring. Specific data monitored included:

- Ground gas concentrations:
 - Flammable gases (CH₄ %Vol);
 - Carbon Monoxide (PPM);
 - Carbon Dioxide (%Vol);
 - Oxygen (%Vol); and
 - Hydrogen Sulphide (PPM).
- Atmospheric Pressure (mBar);
- Flow (L/hr);
- Groundwater level (mbgl); and
- Local weather (both recent and current)

Table 10: Summary of Gas Monitoring Results

Hole ID	Source(s) located in near proximity	Response Zone		Strata	Flow (l/hr)	Methane (CH4) concentration (%)		Carbon Dioxide (CO2) concentration (%)		GW Level (mbgl)
		Top (m bgl)	Bottom (m bgl)		Overall max.	Overall max.	Average	Overall max.	Average	Overall average
BH01	Made Ground	6.5	9.0	Cohesive and Granular Glacial Till	0.0	0.0	0.0	1.9	1.8	2.36
BH04		0.5	2.0	Made Ground and Cohesive Glacial Till	0.0	0.0	0.0	0.3	0.3	0.93
BH05		0.5	4.5	Made Ground and Cohesive Glacial Till	0.0	0.0	0.0	3.2	2.3	0.91
BH07		1.0	3.5	Made Ground and Cohesive Glacial Till	0.0	0.0	0.0	0.7	0.6	0.76
BH08		2.8	5.8	Made Ground and Cohesive Glacial Till	0.0	0.0	0.0	1.4	1.0	2.80
BH10		14.5	18.0	Cohesive and Granular Glacial Till	0.0	2.0	2.0	3.9	2.9	NR
BH12		1.5	5.0	Cohesive Made Ground	0.0	0.0	0.0	6.3	6.3	NR

6 Tier 1 Quantitative Risk Assessment

6.1 Summary of Analytical Laboratory Testing Undertaken

Geo-environmental laboratory testing was undertaken on samples collected during the ground investigation from the Made Ground and Glacial Till deposits.

The results of the environmental testing were assessed using the Tier 1 Risk Assessment Criteria. A copy of the chemical test results are in Groundtech Consulting's factual ground investigation report in Appendix 3.

6.2 Assessment Criteria

6.2.1 Soils

The assessment criteria utilised are derived from the following sources:

- LQM / CIEH (2015) Suitable 4 Use Levels (S4ULs);
- CL:AIRE (January 2010) The Soil Generic Assessment Criteria for Human Health Risk Assessment;
- DEFRA (2014) C4SL value (lead only);
- Atkins At Risk Site Specific Values (cyanide only); and
- ICRC 64/85 (1990) Asbestos on Contaminated Sites.

The future development is for a "residential property without home grown produce" end use scenario and thus it is these assessment criteria that are used. The application of these SSV criteria is notably more conservative because the development is predominantly situated on hardstanding and concrete oversite, effectively eliminating most potential pathways to the receptors. Furthermore, the communal landscaped area is exclusively accessible to the six ground floor apartments, and it is not intended for the cultivation of produce.

For the assessment of the Made Ground results a soil organic matter content of 6.0% has been used based on the average measured TOC of 4.2%. The highest recorded TOC was 10.4%, with the lowest recorded being 1.1% in the Made Ground deposits.

6.2.2 Groundwater & Surface water

In accordance with the Water Framework Directive (Standards and Classification) Directions (England and Wales; 2015) where there is a potentially significant risk to surface water receptors (see section 3.2) the applicable primary standard for risk assessment of leachate and groundwater chemical results are current Environmental Quality Standards (EQS) or equivalent. Where groundwater is the primary receptor, the applicable primary standard is the UK Drinking Water Standards (DWS) or analogous standards, where not available.

6.3 Soils Total Organic

CL:AIRE research bulletin RB17, A Pragmatic Approach to Ground Gas Risk Assessment, dated November 2012, outlines the methodology and use of TOC analysis in ground gas risk assessment which Fairhurst utilised for the assessment of Made Ground.

6.4 Summary of Tier 1 Exceedances

The most sensitive human health receptors on site are considered to be the construction workers and proposed end users i.e. people living on the site in the future. Should any future development plans vary from this end use, the contaminated land risk assessment should be revised.

6.4.1 Made Ground

Of the nine samples of Cohesive Made Ground and three samples of Granular Made Ground tested for inorganic determinands, three of the Cohesive and one of the Granular Made Ground samples can be classified as contaminated. Elevated lead and arsenic were encountered in BH05 at a depth of 2.0m, BH06, at a depth of 2.0m with only elevated lead encountered in BH07 at a depth of 1.5m and BH10 at a depth of 1.0m. Table 6 below summarises the exceedances relative to their Tier 1 SSV.

Of the nine samples of Cohesive Made Ground tested for organic determinands, six can be classed as uncontaminated, whilst three can be considered as contaminated with elevated B(a)P concentrations encountered in BH03 at a depth of 3.0m, BH05 at a depth of 2.0m and BH07 at a depth of 1.5m. Elevated Benzene was also encountered in BH01 at 0.1m depth with elevated Aromatic C21-C35 encountered in BH05 at a depth of 2.0m. Of the four samples of Granular Made Ground, one sample (BH10 at 1.0m) contained elevated B(a)P and Dibenzo(ah)anthracene. The other three samples can be classified as uncontaminated.

Samples of the Made Ground were also scheduled for BRE Suite D aggressive environment for concrete (ACEC) classification in accordance with BRE Special Digest 1:2005. The results indicate that throughout most of the Made Ground a classification of Design Sulphate Class DS-2, with the site allocated an ACEC Classification of AC-2.

Lead results, in the absence of a S4UL, were compared to Defra's Category Four Screening Level (C4SL) and were found to exceed the safe value for a residential end use with no home grown produce.

6.4.2 Natural Soils

Of the two natural soil samples taken from the site, none of them exceeded the safe levels of TPHs, PAHs, and Metals for residential properties with 6% SOM based on the CL:AIRE (January 2010) 'The Soil Generic Assessment Criteria for Human Health Risk Assessment' criteria.

These two samples of natural soils were also scheduled for BRE Suite D aggressive environment for concrete (ACEC) classification in accordance with BRE Special Digest 1:2005. The results indicate that throughout the entirety of natural ground a classification of Design Sulphate Class DS-2, with the site allocated an ACEC Classification of AC-2.

Lead results, in the absence of a S4UL, were compared to Defra's Category Four Screening Level (C4SL) and were found to be of a safe value for a residential end use with no home grown produce.

6.5 Risks to Human Health

6.5.1 Assessment of Inorganic Contamination

Utilising the assessment criteria discussed, the results of the geo-environmental soil laboratory analysis have been compared against the relevant assessment criteria. Whilst some exceedances for inorganic contaminants were encountered, where localised contaminants are present these will not generally be in contact with human health receptors due to the presence of building hard covers, though contact during the construction stage remains a potential risk.

As such, the risk to human health receptors can be classified as low.

6.5.2 Asbestos Containing Materials (ACM) in Soils

Based on visual observation during the investigation there was no widespread asbestos contamination identified.

Asbestos screening was carried out on ten samples of Made Ground. Of the ten samples tested for asbestos, one sample of Granular Made Ground (BH10 at 1.0m depth) was found to contain chrysotile as fibres/clumps. Due to the human risk from asbestos, it is recommended that the quantification of samples is carried out if further asbestos is encountered.

However, given the historical development nature of the site and the duration at which the site has been developed, the presence of asbestos deposits cannot be entirely ruled out. Therefore, due to the human risk from asbestos, it is recommended that if localised areas are encountered on site these should be delineated through additional testing and if appropriate removed.

Where localised contaminants are present these will not generally be in contact with human health receptors/ end users due to the presence of building hard covers. Contact during the construction stage remains a potential risk and appropriate health and safety measures should be in place during groundworks.

As such, the risk to human health receptors/ end users is low.

The risk to construction workers is increased and can be managed through appropriate health and safety measures.

6.5.3 Assessment of Organic Contamination

This site is classified as brownfield, and the receptors for human health are residential but with no ability for home grown produce, as such only acute exposure will occur on site. Therefore, for organic compounds, the screening values used in this report have been derived with reference to a CSM that assumes a residential property with no home grown produce, limited green space and very limited chance of encounter.

The CLEA model has been used to derive risk-based screening values for hydrocarbons, in accordance with the methodology detailed by the TPHCWG, and reviewed by a UK workshop of experts with respect to UK adoption of the method.

These screening values assume a Soil Organic Matter (SOM) of 6% (equivalent to a TOC of 3.5%). Many organic contaminants are more mobile when the SOM is lower, and consequently comparison of soil results with lower screening values may be required. In this scenario it is deemed suitable to utilise a SOM value of 6% for the SSV as no significant organic contamination was recorded in this soil type. All determinands well below "6%" SOM screening value; most below limit of detection.

There are numerous PAH compounds. The USEPA identified 16 PAHs that are considered to represent the most problematic in terms of toxicology, fate, and behaviour. The UK have also focused on these 16 and these are included in the laboratory report where speciated PAH analysis has been scheduled.

The majority of the site is hard cover with no pathway for contaminants to reach the receptors on site. Only six ground floor apartments have access to the communal landscaped area.

The analytical data for this site has been compared against Commercial screening values for the most problematic (16 USEPA) PAHs. All concentrations are below the Commercial screening values, therefore whilst a range of PAHs may be present, these are not considered to pose a risk to health.

Speciated PAH analysis has been undertaken in order to determine concentrations of the key “marker” compounds: benzo(a)pyrene (considered the most toxic of the PAHs); and naphthalene (the most mobile and volatile of the PAHs).

Speciated analysis has confirmed the presence of significant concentrations of benzo(a)pyrene, however no exceedances of naphthalene in the soils beneath this site were encountered. As such the contaminated Made Ground will require chasing out and burial beneath concrete oversite or hard standing or disposal off site, likely to landfill.

6.6 Risks to Drinking Water Supply Pipes

The site is underlain by made ground with localised observations of hydrocarbon contaminants. Elevated concentrations of organic and inorganic contamination have been encountered, as such, it is expected that protective measures to water supply pipework and sewer connections will be required.

6.7 Risk to Controlled Waters

A Generic Controlled Waters Assessment has been conducted by directly comparing chemical concentrations measured in groundwater samples with established Water Quality Standards (WQS). These standards are designed to safeguard both surface water and groundwater resources. This provides an initial conservative assessment of potential risks from contamination to groundwater and surface waters and assumes there is a viable migration pathway.

The site overlies a bedrock Principal Aquifer (Chester Formation Sandstone) and is within proximity to Rochdale Canal, both considered to be viable controlled waters receptors in this assessment. Therefore, WQS relevant to both drinking water and surface water receptors have been used in this assessment to provide an initial assessment of risks to controlled waters from chemical concentrations in groundwater.

The following determinants were recorded in exceedance of their respective surface water criterion:

- Arsenic in BH01 at a concentration of 12.7µg/l, exceeding the GAC of 10µg/l;
- B(a)P in BH04 at a concentration of 0.093µg/l, BH05 at 0.056µg/l and BH07 at 0.304µg/l, exceeding the GAC of 0.01µg/l;
- Indeno(123cd)pyrene in BH07 at 0.167µg/l, exceeding the GAC of 0.1µg/l;
- Benzo(ghi)perylene in BH07 at 0.168µg/l, exceeding the GAC of 0.1µg/l;
- Benzo(b)fluoranthene in BH04 at 0.138µg/l and in BH07 at 0.380µg/l exceeding the GAC of 0.1µg/l;
- Benzo(k)fluoranthene in BH07 at 0.148µg/l exceeding the GAC of 0.1µg/l; and
- Sulphate in BH01 and BH05 at 296µg/l and 507µg/l respectively.

The site investigation has not identified any significant pathways or visual evidence of significant ground water contaminants. Slightly higher concentrations of heavy metals, hydrocarbons, and PAH have been detected in the groundwater from the five monitoring wells on the site. However, considering that the nearest sensitive surface water course, the Rochdale Canal, is likely lined with a relatively impermeable barrier such as clay, and there are low-permeability superficial strata beneath the site, it is probable that the migration of concerning contaminants toward the controlled water receptors, including the underlying Principal aquifer, is limited.

Considering the historical industrial land uses in the surrounding area, it is unlikely that the contaminants present in the soil and groundwater on the site will significantly impact the water quality of the receptors. Moreover, the proposed development is expected to further reduce the infiltration of surface water into the site's soils and limit percolation by increasing non-permeable groundcover.

As a result of these factors, the risks to the controlled waters are considered to be low.

6.8 Waste Classification

Fairhurst scheduled four Made Ground soils samples for WAC testing. A summary of results is shown in Table 11 below.

Table 11: Summary of WAC testing.

Solid Waste Analysis	BH12 At 1.0m		BH01 at 1.0m		BH08 at 3.0m		BH06 at 2.0m	
Total Organic Carbon (%)	3.58		5.83		1.49		10.35	
Loss on Ignition (%)	6.6		7		2.5		12.1	
Sum of BTEX (mg/kg)	<0.025		0.050		<0.025		<0.025	
Sum of 7 PCBs (mg/kg)	<0.035		<0.035		<0.035		<0.035	
Mineral Oil (mg/kg)	<30		<30		<30		1910	
PAH Sum of 17(mg/kg)	<0.64		<0.64		<0.64		68.54	
pH (pH Units)	7.85		8.13		8.48		7.76	
ANC to pH 7 (mol/kg)	0.11		0.11		0.14		<0.03	
ANC to pH 4 (mol/kg)	0.39		0.42		0.11		1.17	
Eluate Analysis	C ₁₀	A ₁₀	C ₁₀	A ₁₀	C ₁₀	A ₁₀	C ₁₀	A ₁₀
	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Arsenic	0.0027	0.027	0.0065	0.065	0.0038	0.038	0.0232	0.232
Barium	0.087	0.87	0.101	1.01	0.044	0.44	0.155	1.55
Cadmium	<0.0005	<0.005	<0.0005	<0.005	<0.0005	<0.005	<0.0005	<0.005
Chromium	<0.0015	<0.015	<0.0015	<0.015	<0.0015	<0.015	<0.0015	<0.015
Copper	<0.007	<0.07	<0.007	<0.07	0.010	0.10	<0.007	<0.07
Mercury	<0.001	<0.01	<0.001	<0.01	<0.001	<0.01	<0.001	<0.01
Molybdenum	0.023	0.23	0.041	0.41	0.018	0.18	0.028	0.28
Nickel	<0.002	<0.02	0.002	0.02	<0.002	<0.02	0.002	<0.02
Lead	<0.005	<0.05	<0.005	<0.05	<0.005	<0.05	<0.005	<0.05
Antimony	0.003	0.03	0.005	0.05	0.004	0.04	0.002	<0.02
Selenium	<0.003	<0.03	<0.003	<0.03	<0.003	<0.03	<0.003	<0.03
Zinc	<0.003	<0.03	<0.003	<0.03	<0.003	<0.03	<0.003	<0.03
Chloride	0.4	4	2.6	26	1.6	16	7.2	72
Fluoride	0.6	6	0.6	6	0.8	8	<0.3	<3
Sulphate as SO4	41	410	220.3	2204	28.3	283	20.7	207
Total Dissolved Solids	190	1900	496	4963	132	1319	182	1820
Phenol	<0.01	<0.1	<0.01	<0.1	<0.01	<0.1	<0.01	<0.1
Dissolved Organic Carbon	6	60	7	70	3	30	9	90

Any waste containing asbestos cannot be classified as inert waste. The recorded asbestos contents within the single asbestos positive Made Ground sample will require quantification testing to determine if it is below the hazardous waste limit of 0.1%. Waste with an asbestos content below the hazardous waste limit may be classified as non- hazardous.

6.9 Ground Gas Risk Assessment

There is no universally agreed (or authoritative) approach to determination of ground gas risk, although the approach given in CIRIA (2007) "Assessing Risks from Hazardous Ground Gases to Buildings - C665" is widely used and is also referred to in British Standard BS 8485:2015. This approach involves the calculation of Gas Screening Values (GSVs), but is also cognoscente of total ground gas concentrations.

The GSV for a borehole is provided by multiplying the maximum gas concentration (methane or CO₂) by the maximum flow rate. BS 8485:2015 indicates that it is reasonable to do this on an individual borehole basis where there is comprehensive data (which is the case here). As such, a site can be 'zoned' if appropriate. The following classification system, from CIRIA (2007), applies:

- Characteristic Situation 1 (Very Low Risk) = GSV values <0.07; methane <1%; CO₂ <5%
- Characteristic Situation 2 (Low Risk) = GSV values <0.7
- Characteristic Situation 3 (Moderate Risk) = GSV values <3.5

A gas risk assessment to determine the risk to the development is presented below, based on the three rounds of monitoring data available at the time of writing.

Table 12 below shows the GSV calculation for the site based on data available to date after one round of monitoring. The results to date show that the gassing situation on site is indicated to be Characteristic Situation CS1, Very Low risk due to the low flow rate of Methane and Carbon Dioxide.

Table 12: Characteristic Gas Situation

Gas	Maximum Concentration (%)	Max Flow (l/hr)	GSV (l/hr)	Characteristic Gas Situation
Methane	2.0	0.0	0.00	CS1 – Very Low Risk
Carbon Dioxide	3.2		0.00	CS1 – Very Low Risk

When each monitoring well is assessed individually the GSVs calculated using the gas monitoring results indicate the site is predominantly Characteristic Gas Situations of 1 – Very Low Risk. Table 13 below shows the GSV calculations for each monitoring well.

Table 13: Individual Borehole Characteristic Gas Situations

Hole ID	Peak Methane (%)	Peak Carbon Dioxide (%)	Peak Flow rate (l/hr)	Methane GSV (l/hr)	Carbon Dioxide GSV (l/hr)	Characteristic Gas Situation (Note 1)
BH01	0.0	1.9	0.0	0.0	0.0	CS1
BH04	0.0	0.3	0.0	0.0	0.0	CS1
BH05	0.0	3.2	0.0	0.0	0.0	CS1
BH07	0.0	0.7	0.0	0.0	0.0	CS1
BH08	0.0	1.4	0.0	0.0	0.0	CS1
BH10	2.0	3.9	0.0	0.0	0.0	CS1
BH12	0.0	6.3	0.0	0.0	0.0	CS1

Note 1: Characteristic Gas Situation determined from maximum calculated GSV

In the absence of any widespread degradable materials noted by the investigation soil gas is only expected to be present at low concentration and emission rate. Based on the data collected to date and the proposed site use, whilst in some there is generation of methane and carbon dioxide there is Very Low Risk from Hazardous Gas due to the flow rate. Although the monitoring data shows very low gas concentrations and emission rates there is deep Made Ground on site and the development will have basement structures.

Therefore, the following soil gas protection measures are recommended:

- Soil floor slabs and substructures;
- Sealed penetrations; and
- Basic soil gas barrier as minimum 2000g vapour/moisture barrier with sealed and lapped joints.

6.10 Discussion of Tier 1 Linkages

The revised site conceptual model has been formulated based on the data recovered from the ground investigation. The conceptual model presents the viable source, pathway, and receptor contamination linkage for the site base on the Tier 1 assessment above. Table 14 shows the Revised Quotative Risk Assessment for the site. Risk class definitions are presented below:

- High - The available information indicates a significant possibility of harm to a receptor requiring further investigation, assessment, or treatment;
- Moderate - The available information indicates a potential for significant harm to a receptor requiring further investigation and assessment; or
- Low - The available information does not indicate a significant potential for harm to a receptor requiring further investigation. However, this does not indicate zero risk.

Further information regarding the principles of environmental risk assessment are presented in Appendix B. The significance of the viable linkages elements has been evaluated by carrying out a qualitative risk assessment.

Based on the revised conceptual site model (CSM) and data received from the ground investigation, the majority of identified potentially complete pollutant linkages have been lowered to risk ratings of moderate/low or low. The ground investigation identified the following potential pollution linkages:

- Made Ground associated with previous developments and historical is present on-site but does not contain gross organic or inorganic contamination;
- The contamination present means there is a potential risk to end users, workers and foundations/below-ground services;
- Asbestos fibres have been encountered in one sample of Granular Made Ground, as such it is anticipated that further asbestos debris may be present in the soil and Made Ground deposits. If encountered during the works, this material will require chasing out and either burial or export to landfill, depending on quantity and severity of asbestos contamination;
- The proposed development comprise an increased sensitivity with respect to land use;
- Based on the revised CSM and Qualitative Risk Assessment, most pollutant linkages are of moderate/low and low risk, with linkages associated with ground gas allocated a very low risk rating; and
- The risks to groundwater as a resource potential is considered Low due to the lack of free product and gross contamination encountered within the Made Ground and natural strata.

Table 14: Revised Qualitative Risk Assessment for Identified Sources of Contamination.

Source	Potential Contaminants	Potential Pathway	Potential Receptors	Assessment	Potential Severity	Potential Probability	Risk Class
Historical land use as infilled Canal	Metals TPH PAH Sulphate pH Asbestos	Ingestion, inhalation, dermal contact, direct contact	Future site users	Made Ground onsite containing elevated concentrations of lead and arsenic as well as elevated B(a)P to be present on site and this contamination may present a potential risk of harm to end users.	Minor	Unlikely	Low
			Construction workers		Minor	Unlikely	Low
			Adjacent land users		Medium	Unlikely	Low
		Direct contact	Buried structures and services		Medium	Unlikely	Low
		Migration/leaching of mobile contaminants	Groundwater		Medium	Unlikely	Low
Made Ground	Metals TPH PAH Sulphate pH Asbestos	Ingestion, inhalation, dermal contact, direct contact	Future site users	There is a potential risk to construction workers, however, this risk can be mitigated using appropriate PPE. Foundations and services (including water pipes) could be affected by aggressive ground conditions or contamination. It is considered a very low risk to the local water environment from contamination associated with the Made Ground if present.	Minor	Unlikely	Very Low
			Construction workers		Mild	Likely	Moderate
			Adjacent land users		Mild	Unlikely	Very Low
		Direct contact	Buried structures and services		Mild	Unlikely	Very Low
		Groundwater	Mild		Unlikely	Very Low	
		Migration/leaching of mobile contaminants	Surface water		Mild	Unlikely	Very Low
Historical land uses as: Garage, Paint works, Furniture warehouse	Metals TPH PAH Sulphate pH VOCs & SVOCs Asbestos	Ingestion, inhalation, dermal contact, direct contact	Future site users	Historical land uses have the potential to be a source of contamination. The risk to future site users is Very Low and the risk to construction workers is Moderate/Low. In order to reduce this level of risk to low, construction workers must adopt appropriate health and safety measures and PPE during works.	Minor	Unlikely	Very Low
			Construction workers		Medium	Likely	Moderate /Low
			Adjacent land users		Minor	Unlikely	Very Low
		Direct contact	Buried structures and services		Minor	Unlikely	Very Low
		Migration/leaching of mobile contaminants	Groundwater		Mild	Unlikely	Very Low
			Surface water		Mild	Unlikely	Very Low
Current land use as a Car Park	TPH PAH	Ingestion, inhalation, dermal contact, direct contact	Future site users	Hydrocarbons present at low concentrations and emission rates associated with the current use of the	Medium	Unlikely	Low
			Construction workers		Medium	Unlikely	Low
			Adjacent land users		Medium	Unlikely	Low

FAIRHURST

Source	Potential Contaminants	Potential Pathway	Potential Receptors	Assessment	Potential Severity	Potential Probability	Risk Class
		Direct contact	Buried structures and services	development site as a car park. The risk to future site users and construction workers is considered to be Low. In order to reduce this level of risk to low, construction workers must adopt appropriate health and safety measures and PPE during works.	Medium	Unlikely	Low
		Migration/leaching of mobile contaminants	Groundwater		Medium	Unlikely	Low
			Surface water		Medium	Unlikely	Low
Asbestos (buried onsite or within the Made ground soil fabric)	Asbestos	Ingestion, inhalation, dermal contact, direct contact	Future site users	Chrysotile asbestos was encountered in one sample of granular made ground. Further asbestos may be present in burial pits or Made Ground, posing a risk to future site users and construction workers. Construction workers should adhere to proper health and safety measures and personal protective equipment (PPE).	Severe	Low	Moderate
			Construction workers		Severe	High	Very High
Ground Gas (Made Ground and canal infill)	Hazardous Gas (CO ₂ , CH ₄ , VOCs, SVOCs)	Inhalation	Future site users	Based on monitoring to date the potential for ground gas is very low. The current use of the development site as a car park may also result in low concentrations and emission rates of ground gases and hydrocarbons. There is risk to future site users and construction workers. To mitigate this risk construction workers must follow appropriate health and safety measures and use personal protective equipment (PPE).	Medium	Unlikely	Low
			Construction workers		Medium	Low	High
			Adjacent land users		Medium	Unlikely	Low

Source	Potential Contaminants	Potential Pathway	Potential Receptors	Assessment	Potential Severity	Potential Probability	Risk Class
Fly Tipped Material	Metals TPH PAH Asbestos	Dermal contact	Future site users	Any fly tipped material on site can be collected and disposed of. There is a potential risk to construction workers, however, this risk can be mitigated using appropriate PPE.	Minor	Unlikely	Very Low
			Construction workers		Minor	Unlikely	Very Low
			Adjacent land users		Minor	Unlikely	Very Low

6.11 Remediation Recommendations

Given the presence of Made Ground deposits across the site, the historical nature and development, and localised asbestos containing material and elevated heavy metals (arsenic and lead) localised contaminant hotspots may be encountered during the development works.

Further, the elevated hydrocarbons, TPH and PAH's (due to the former car workshop/garage and within the former canal channel/wharf) indicates contaminant hotspots may be present associated with these sources.

The following general remedial works are expected:

- Provision of clean covers to landscape/garden areas as 150mm of topsoil over 300mm of subsoil;
- Soil gas protection measures as a solid floor slab with basic gas membrane with sealed joints and penetrations;
- Standard protection to buried water service pipes and sewer joints; and
- Concrete design in accordance with BRE digest.

Although not encountered during the works the following risks items may be present:

- Localised buried asbestos;
- Localised buried tanks;
- Localised "hotspots" of soil contaminants as hydrocarbons;
- If encountered these contaminants will require delineation, assessment through an updated risk assessment and if increased risks are identified the material may require removal.

7 Geotechnical Testing

The following section discusses the ground conditions and material properties determined from the ground investigation.

Where necessary, determination of geotechnical parameters has been based on cautious estimates of laboratory derived results, published correlations, and field tests, complemented with engineering judgement. Where material parameters are assumed, derived by calculation, or taken from published sources, further details are provided as to their derivation.

Geotechnical testing (including BRE Suite) was undertaken by PSL, with appropriate MCERTS and ACAS accreditations for the relevant testing. All laboratory results are provided within Appendix 3. Table 15 below summarises the geotechnical testing scheduled for the works.

Table 15: Summary of Geotechnical Testing Undertaken

Geotechnical Test		Made Ground	Granular Glacial Till	Cohesive Glacial Till	Chester Formation
Laboratory	Moisture Content Determination	7	6	13	3
	Atterberg Limit Determination	3	-	13	-
	Particle Size Distribution (PSD) Analysis	-	9	-	-
	Aggressive Ground Conditions (Concrete) BRE SD1 Suite D	5	6	8	2
In-Situ	Standard Penetration Testing (SPT)	20	29	67	22 (all refused)

7.1 Classification Tests

7.1.1 Particle Size Distributions (PSDs)

The grading of eight samples of Granular Glacial Till were determined by wet sieving. The results of which are summarised in Table 16.

Table 16: Summary of PSD results.

Sample & Depth	Field Description	% Passing 37.5mm sieve	% Passing 20mm sieve	% Passing 2mm sieve	% Fines	Material description (based on grading)
BH01 @ 7.5m	Slightly silty clayey gravelly fine SAND	100	100	89	26	Clayey silty SAND with gravel
BH01 @ 21.8m	Slightly clayey slightly gravelly silty SAND	93	69	60	40	Clayey silty sandy GRAVEL
BH05 @ 24m	Sandy GRAVEL	100	81	24	1	Slightly silty sandy GRAVEL
BH08 @ 21m	Slightly gravelly SAND and firm sandy CLAY	83	54	44	12	Slightly clayey silty sandy GRAVEL
BH08 @ 24m	Slightly gravelly SAND and firm sandy CLAY	68	39	9	1	Slightly silty sandy GRAVEL
BH10 @ 17.5m	Silty clayey gravelly SAND	100	100	94	36	Gravelly clayey silty SAND
BH12 @	Slightly gravelly	100	100	99	28	Slightly gravelly clayey

Sample & Depth	Field Description	% Passing 37.5mm sieve	% Passing 20mm sieve	% Passing 2mm sieve	% Fines	Material description (based on grading)
12m	silty clayey SAND					silty SAND
BH12 @ 20m	Gravelly SAND	100	100	98	74	Slightly gravelly sandy clayey SILT

NHBC Chapter 4.2 considers shrinkable soils to be those containing more than 35% fines and having a Modified Plasticity Index greater than 10%.

Fines (silt and clay) were found to comprise between 1% and 40% (average 20%) of the Granular Glacial Till sampled. Therefore, both the Granular Alluvium and Granular Made Ground encountered on this site should also be regarded as being of low shrinkability.

7.1.2 Moisture content

Moisture content analysis was carried out on 28 samples, of which four were Cohesive Made Ground (12-35%), three were Granular Made Ground (1.8 to 22%), 12 were Upper Cohesive Glacial Till (10 to 30%), three were Upper Granular Glacial Till (12 to 14%), three were Lower Cohesive Glacial Till (2.1 to 11%), and two were Lower Granular Glacial Till (6.5 to 15%).

7.1.3 Atterberg Limits

Deposits of cohesive soils were encountered at the site, three samples of the Cohesive Made Ground, twelve from the Upper Glacial Till and a sample of the Lower Glacial Till was retrieved and tested.

The samples of cohesive Made Ground had a modified PI range between 16% and 29%, whilst the Upper Glacial Till had a PI of 9.8 to 34%, and the Lower Glacial Till, that only had one test had a modified PI of 16%.

Therefore, for the purpose of foundation design, it is recommended that all cohesive soils be regarded as having low to medium volume change potential, and of being low shrinkability.

7.1.4 BRE Suite

In accordance with BRE Special Digest 1:2005, this site has been classified as brownfield with a mobile groundwater regime.

It is envisaged pile foundations will typically extend through any Made Ground and end bear within natural strata. However, the piles will be present through the upper more aggressive soils of the Made Ground deposits, therefore, samples have been taken from this depth range and submitted for pH and water- soluble sulphate (2:1 soil/water extract).

The concentrations of sulphate in the aqueous natural soil extracts of 14 samples were determined along with 2 samples of the Chester Formation Sandstone. In addition, 17 samples of Made Ground were tested as part of the contamination suite. The pH value of each sample has also been determined.

The highest water-soluble sulphate concentration and the lowest pH value for each soil type analysed are shown in the Table 17 below.

Table 17: Summary of pH and Sulphate concentration

Soil Type	Lowest pH Value	Highest soluble sulphate concentration (mg/l)	ACEC Class
Granular Made Ground	7.2	350	DS-1, AC-1s
Cohesive Made Ground	7.7	771	DS-2, AC-2
Cohesive Glacial Till	8.0	174	DS-2, AC-2
Granular Glacial Till	8.3	140	DS-1, AC-1s
Chester Formation Sandstone	8.0	34	DS-1, AC-1

pH values were all above 5.5, therefore concentrations of magnesium, chloride and nitrate are considered insignificant. Exceedances of the 2:1 water soluble sulphate tests were encountered in samples of cohesive Made Ground and Cohesive Glacial Till, in BH02 at a depth of 2.0mbgl and in BH03 at a depth of 3.0mbgl respectively.

Therefore, in accordance with Table C2 of SD1, sub-surface concrete should be Design Sulphate Class DS-2, with the site allocated an ACEC Classification of AC-2.

7.1.5 Undrained shear strength in triaxial compression

The triaxial compression test data for Cohesive Glacial Till was collected from five boreholes (BH02, BH04, BH05, BH08, and BH12) at various core depths. The shear strength (C_u) values for each borehole are presented in Table 18 below.

Table 18: Summary of triaxial compression results.

Hole ID	Core Depth (mbgl)	Moisture Content (%)	Bulk Density (Mg/m^3)	Shear Strength C_u (kN/m^2)	Failure strain (%)	Mode of Failure
BH02	6.00	30	1.85	22	11.4	Plastic
BH04	3.00	19	2.05	121	13.6	Plastic
BH05	5.00	28	1.96	52	11.4	Plastic
BH08	7.50	17	1.79	92	12.4	Plastic
BH12	17.50	11	2.22	397	13.9	Brittle

The results of the above relationship and the laboratory triaxial testing are presented on Figure 3. For the Upper Cohesive Glacial Till recorded in all the boreholes the following profile of undrained shear strength is considered appropriate:

$C_u = 50kN/m^2$ at a depth of 3.0mbgl increasing linearly to $150kN/m^2$ at a depth of 15mbgl.

For the Lower Cohesive Glacial Till recorded in BH01 and BH02 at depths greater than 15mbgl, an undrained shear strength of $225kN/m^2$ is considered appropriate. Further consideration of this should be undertaken during detailed design of the proposed piled solution for the structure.

7.1.6 Consolidation test

The consolidation test data for Cohesive Glacial Till was collected from four boreholes (BH02, BH03, BH07, and BH10) at various core depths. The coefficient of consolidation (C_v) values for each borehole are presented in Table 19 below.

Table 19: Summary of Consolidation results

Hole ID	Core Depth (m bgl)	C_v (m^2/yr)
BH02	10.50	2.386
BH03	4.00	3.786
BH07	6.50	1.705
BH10	10.50	2.495

The coefficient of consolidation (C_v) represents the rate at which the cohesive Glacial Till deposits consolidates under an applied load. A higher C_v value indicates faster consolidation, while a lower value suggests slower consolidation. BH03 has the highest C_v value ($3.786 \text{ m}^2/\text{yr}$), indicating that the soil at this location consolidates relatively quickly under the applied load. On the other hand, BH07 has the lowest C_v value ($1.705 \text{ m}^2/\text{yr}$), suggesting slower consolidation compared to the other boreholes.

The differences in consolidation rates imply that settlements over time may vary in different locations leading to differential settlement. Boreholes with higher C_v values may experience relatively faster settlements, while those with lower C_v values may have slower settlements. Further consideration to the impact of variable settlement to ground bearing structures should be completed as part of the detailed design process.

8 Determination of Geotechnical Parameters

Where necessary, determination of geotechnical parameters has been based on cautious estimates of laboratory derived results, published correlations, and field tests, complemented with engineering judgement. Where material parameters are assumed, derived by calculation, or taken from published sources, further details are provided as to their derivation.

8.1 Made Ground

8.1.1 In-situ Testing, Strength and Stiffness

Twenty SPT tests were performed within the Cohesive and Granular Made Ground deposits at depths ranging from between 1.2mbgl and 3.0mbgl. The results of testing in the Granular Made Ground deposits ranged between 0 and 13 (with an average 'N' value of 7), whilst for the Cohesive Made Ground the 'N' value ranged between 0 and 15 (with an average 'N' value of 6). Given the nature and variability of the material any Made Ground present across the site, it is not considered suitable to be a founding stratum.

Due to its inherent variability, values of shear strength and stiffness have not been derived for the Made Ground.

8.1.2 Unit Weight

Based on the mean SPT N_{60} results and field descriptions for the Granular and Cohesive Made Ground the soils have been classified as loose gravel and low strength clay respectively in accordance with BS 5930:2015 (BSI, 2015) and corresponding to a unit weight between 12 and 15kN/m³ for a loose gravel and/or a low strength clay above the water table in accordance with BS 8002:2015 (BSI, 2015).

8.2 Granular Glacial Till

8.2.1 In-situ Testing, Strength and Stiffness

Twenty nine SPT tests were performed within the Granular Glacial Till at depths ranging from between 7.5mbgl and 25.5mbgl. Of the 29 tests, 19 refused (giving an 'N' value of 50). The results of the testing gave a range of 'N' values of between 17 and 50 (with an average 'N' value of 43). Based on these results, a classification for strength of dense to very dense is considered appropriate for the granular glacial till deposits.

A correlation between peak effective angle of internal friction, ϕ'_{pk} and SPT N_{60} (uncorrected) has been shown by Stroud (1989). Figure 1 presents a plot of SPT N_{60} versus depth for the Granular Glacial Till. Based on the above a representative SPT N_{60} of 20 is considered appropriate for the Granular Glacial Till above depths that are shallower than 15mbgl, with this increasing to a N_{60} 45 for material at depths deeper than 15mbgl. These therefore, correspond to peak effective angles of internal friction of 33° and 40° respectively.

The test results are presented on the exploratory hole records and a plot of SPT N_{60} versus depth is presented in Figure 1.

The drained Young's Modulus, E' has been determined from the following relationship:

$$E'(\text{MN/m}^2) = 2N_{60} \text{ (Clayton, 1995)}$$

Values determined using this method are presented in Figure 2, based on this, the following profile of drained Young's Modulus is considered appropriate:

$$E' = 40\text{MN/m}^2 \text{ above } 15\text{mbgl}$$

$$E' = 80\text{MN/m}^2 \text{ below } 15\text{mbgl}$$

8.2.2 Unit Weight

The SPT N_{60} results indicate that the Granular Glacial Till is a dense to very dense sandy gravel or gravelly sand (BS 5930, (BSI, 2015)) corresponding to a unit weight of 20kN/m^3 for a dense to very dense gravel above the water table in accordance with BS 8002:2015 (BSI, 2015).

8.3 Cohesive Glacial Till

8.3.1 In-situ Testing, Strength and Stiffness

Sixty seven SPT tests were performed within the Cohesive Glacial Till at depths ranging from between 1.5mbgl and 25.5mbgl. The results of the testing ranged between 'N' 0 and 50 (with an average 'N' value of 26). The undrained shear strength, c_u has been estimated from the following relationship with SPT N_{60} :

$$c_u(\text{kN/m}^2) = f_1 N_{60} \text{ (Clayton, 1995)}$$

Where f_1 is a factor related to the plasticity index, taken as 4.5. This value adopted will need to be confirmed with the mean plasticity index upon receipt of the geotechnical laboratory testing.

For the Upper Cohesive Glacial Till an undrained shear strength of 50kN/m^2 at a depth of 3mbgl increasing linearly to 150kN/m^2 at a depth of 15mbgl is considered appropriate.

For the Cohesive Glacial Till encountered below 15mbgl, an undrained shear strength of 250kN/m^2 is considered appropriate. The test results are presented on the exploratory hole records and a plot of undrained shear strength derived from SPT N_{60} versus depth is presented in Figure 3.

8.3.2 Unit Weight

Based on the mean SPT N_{60} results and field descriptions for the Cohesive Glacial Till the soils have been classified as medium to high strength clay respectively in accordance with BS 5930:2015 (BSI, 2015) and corresponding to a unit weight of 18kN/m^3 for clay above the water table in accordance with BS 8002:2015 (BSI, 2015).

8.4 Chester Formation

8.4.1 In-situ Testing, Strength and Stiffness

Twenty two SPT tests were performed within the Chester Formation Sandstone at depths ranging from 22.4mbgl to 32mbgl. All twenty two tests refused giving an 'N' value of 50.

The sandstone has been taken as stratum that is recovered as sand and, as such, could be considered as a granular soil. In-situ testing indicates a very dense sand and, based on the SPT N_{60} results, a characteristic ϕ'_{pk} of 40° is considered appropriate (Stroud, 1989).

Based on Fairhurst's experience and engineering judgement, a drained Young's Modulus of 250MN/m^2 is considered appropriate for the Chester Formation Sandstone.

8.4.2 Unit Weight

Based on the mean SPT N_{60} results and field descriptions for the Chester Formation Sandstone the rock has been recovered as and classified as very dense sands in accordance with BS 5930:2015 (BSI, 2015) and corresponding to a unit weight of 21kN/m^3 for very dense well graded sand above the water table in accordance with BS 8002:2015 (BSI, 2015).

8.5 Summary of Characteristic Parameters

Interpretation of the draft borehole logs for the scheme has been undertaken to provide characteristic soil parameters for the soils present beneath the site. Table 20 below, summarises the parameters that are to be used in the design process. These soil parameters have been derived in accordance with BS5930:2015, BS8002:2015 and Clayton.

Table 20: Summary of Characteristic Geotechnical Soil Parameters

Material	Unit Weight, γ_b (kN/m ³)	Undrained Shear Strength, c_u (kN/m ²)	Peak angle of shearing resistance, ϕ'_{peak} (°)	Stiffness, E' (MN/m ²)
Granular Made Ground	15	-	28	4
Cohesive Made Ground	15	20 to 40	21	4
Cohesive Glacial Till	18	50 at 3mbgl 150 at 15mbgl	27	20
Granular Glacial Till	20	-	35° above 31m AOD 41° below 31m AOD	$E' = 40$ above 15mbgl $E' = 80$ below 15mbgl
Chester Formation Sandstone	22	-	40	250

9 Geotechnical Assessment

This geotechnical assessment is carried out on the basis of current proposed levels and site layout. However, should there be any change to either of these it is recommended that this assessment is revisited as a part of a design review.

9.1 Proposed Development

The proposed development is to include the construction of two residential apartment blocks. Part of the site preparation works will include grubbing up of all hardstanding, chasing out any Made Ground encountered and the demolition of an existing building on site. The erection of two residential apartment buildings with ground floor commercial space, associated resident's amenity space, cycle parking, landscaping, access, street loading and other associated works. The development will include a basement/semi basement structure.

The proposed site and development layout plans are included in Appendix 1.

9.2 Foundations

Given the form of the development, the likely structural loads, and the underlying ground conditions, it is not considered feasible to support the structures on pad or raft foundations. As a result, the use of piled foundations is considered appropriate. The use of either continuous flight auger (CFA) or rotary bored piles are considered to be the most suitable piling techniques.

The following general comments relating to piling are provided for guidance, and further advice should be sought from a specialist-piling contractor:

- Should any impenetrable shallow obstructions be encountered, i.e. boulders, relict foundations etc, they should either be grubbed-up, or alternatively the piling layout could be re-designed (although this might also require design of foundations able to span and/or cantilever as necessary).
- The safe working load that may be supported on a pile is dependent on the pile diameter, Design Action applied to the pile, its founding depth, and the method of installation;
- It is anticipated that piles will be installed to act as end bearing piles in the underlying sandstone bedrock and by skin friction in the lower glacial soils.

9.3 Pile Design

An outline pile design has been undertaken to provide indicative pile loads for the ground conditions presented in Section 4 and 5.6 above.

Based on the characteristic values adopted in Section 5.6, an outline assessment of the shaft and base resistance for piles installed through the Glacial Till has been considered.

This assessment is indicative and may be subject to variation in the presented total pile loads, both positive and negative, dependent on a more detailed assessment being undertaken. A range of pile diameter and lengths has been considered and is presented in Table 21 below.

Table 21: Summary of Indicative Bored Pile Loads.

Pile Diameter (mm)	Length (m)	Base Resistance (kN)	Shaft Resistance (kN)	Total Capacity (kN)
450	15	150	600	750
	20	150	850	1,000
	25	150	1,050	1,200
600	15	250	900	1,150
	20	250	1,100	1,350
	25	250	1,350	1,600

The ground investigation works indicated the presence of possible boulders or large debris associated with the Glacial Till deposits at depth. While CFA techniques may be applicable for such end uses, the presence of possible obstructions at depth, within the Glacial Till deposits should be considered and rotary bored techniques may be appropriate.

The final pile technique, lengths and diameters will be determined at detailed design stage and in line with the Design Actions imposed from the relevant structural design completed for the development.

Based on the preliminary design it is understood that 450mm diameter piles are proposed for the building foundations and slab, while 600mm diameter piles are required to facilitate the anticipated shear and axial loads being applied within the retaining wall.

A Piling Risk Assessment (PRA) should be completed by the specialist pile contractor prior to the finalisation of any detailed pile design.

9.4 Design Responsibility

Any pile resistances presented in this report are provided for guidance only and further detailed design needs to be completed, once final design actions have been finalised.

Pile design should be undertaken by, and remain the sole responsibility of, a specialist piling contractor who will determine the most appropriate and cost-effective pile type for the site based on their own interpretation of the site investigation data, their own installation techniques, and experience of piling in similar ground conditions.

9.5 Working Platform

For all piling operations on the site, the temporary works design, construction, and maintenance of a working platform in accordance with guidance presented in BRE 470 "Working platforms for tracked plant" (2004) will be required.

9.6 Pile Testing

It is considered appropriate that pile testing is undertaken for all structures. It is considered that as a minimum this should comprise one sacrificial test pile per structure and serviceability testing on more than 1% of constructed piles to loads not less than 1.5 times the representative load for which they are designed. Integrity testing should be undertaken on all piles.

A piling specification should be completed prior to piling works commencing.

9.7 Earthworks & Material Management

At this stage it is not anticipated that the site will require large scale, bulk earthworks, though excavation for the main structure foundations and basement will be required.

However, the excavation and off-site disposal of any Made Ground Materials will need to be assessed and is expected to attract enhanced disposal costs associated with contaminated Non Hazardous waste with localised hazardous waste.

9.8 Presence of Existing Services

There are no services reported to be known within the site. However, in view of the historical development the presence of redundant or unknown services cannot be discounted. It is recommended that searches and/or surveys are commissioned to identify and verify the locations of any utilities. It should be noted that no services were encountered during the recent intrusive ground investigation.

The presence of existing services may require capping and or diversion associated with the development, which should be managed through the appropriate utility suppliers during the construction phase. The Principal Contractor should ensure that appropriate mitigation measures are put in place during the construction phase (i.e. during foundation excavation).

9.9 Excavations

9.9.1 Groundwater

Groundwater strikes were observed in one of the exploratory borehole positions, BH02 within the Glacial Till deposits at a depth of 7.5mbgl. A number of other minor water strikes were observed in BH2, BH4, BH5, BH6 and BH7, within the near surface Made Ground deposits, at depths of 1.0mbgl. These were recorded as seepages rather than water strikes but indicate the presence of groundwater within these deposits.

The groundwater monitoring data indicated both perched water in the made ground and superficial soils which may be encountered during excavation.

Therefore, groundwater ingress during the proposed foundation/basement excavation should be anticipated especially within the footprint of the infilled canal.

Allowances should be made for the dewatering of groundwater from excavations and temporary stabilisation/shoring of excavations when groundwater is encountered or during potential heavy periods of rainfall.

The presence of perched or trapped water within the former and infilled canal through the centre of the site cannot be discounted and the integrity of the infilled canal needs to be considered during the site works. The following risk items cannot be discounted:

- Presence or requirement of cut of barrier within the canal infill; and
- Presence of Historical drainage within the infilled canal structure.

The main contractor should undertake their own assessment to confirm the stability of their excavations to suit their working method and to further investigate the presence of any groundwater inflows.

9.9.2 Stability

Whilst trial pitting has not been undertaken, generally the stability of excavations within the Cohesive Glacial Till was good and these should remain stable during the short term.

However, the stability of Made Ground or granular soils should not be relied upon in unsupported excavations. Safe working conditions should be ensured at all times where persons are required to work in any excavations. This can be achieved by the use of ground support or battering back to a safe angle.

Based on groundwater observations recorded during the ground investigation, excavations are unlikely to encounter the main groundwater table which was located at depth. However, excavations are likely to encounter inflows of perched groundwater from within the Made Ground and historical features such as the former canal basin. Such inflows may be heavy and persistent and lead to a standing water table, particularly during periods of inclement weather.

These water flows and ground conditions will need to be managed through appropriate temporary works design by the main contractor.

Further reference should be made to CIRIA Report 97 "Trenching practice" (Irvine & Smith, 2001) and Report C515 "Groundwater control – design and practice" (Preene et al, 2000).

9.9.3 Obstructions

Whilst not encountered during the ground investigation, the risk of obstructions associated with the historical infilled canal and structures within the Made Ground deposits across the remainder of the site cannot be discounted. If present obstructions may hinder the installation of bearing piles and groundworks in general.

A strategy will be required by the groundworks and piling contractors for managing obstructions within the Made Ground to minimise potential delays on site and associated abnormal costs. Such a strategy may comprise proof digging or probing in advance of pile installation. This should limit the risk of piles encountering obstructions.

A boulder within the Glacial Till was encountered in BH10 at a depth of 18.1mbgl. This obstruction terminated the exploratory hole early. Whilst the presence of boulders of significant size is generally not considered a significant risk in Manchester, the risk of boulders within the Glacial Till will need to be considered by the specialist piling contractor during detailed design of the piled foundations.

9.10 Buried Concrete

Samples of Granular Made Ground, Cohesive Made Ground, Cohesive Glacial Till, and Granular Glacial Till have been scheduled for testing for water soluble sulphate concentration and pH. The assessment of Design Sulphate Class and Aggressive Chemical Environment for Concrete (ACEC) has been undertaken in accordance with guidance presented in BRE SD1 "Concrete in aggressive ground" (BRE, 2005).

Groundwater at this site is assumed to be mobile due to the underlying principal bedrock aquifer and superficial secondary undifferentiated aquifer.

Exceedances of the 2:1 water soluble sulphate tests were encountered in samples of cohesive Made Ground and Cohesive Glacial Till, in BH02 at 2.0m bgl and BH03 at 3.0m bgl respectively, therefore the feasibility of chemical attack on concrete is high due to the depth of contamination relative to the depth of potential foundations.

Therefore, in accordance with Table C2 of SD1, sub-surface concrete should be Design Sulphate Class DS-2, with the site allocated an ACEC Classification of AC-2.

9.11 Road & Pavement Design

Made Ground will likely form the subgrade to the external pavements and, based on the predominantly granular nature of these soils, a California Bearing Ratio (CBR) in the region of 2% should be considered achievable with appropriate preparation.

Given the inherent variability of these soils, higher CBR values are not considered achievable and values of less than 2% may be recorded.

The following design measures should be adopted;

- Any sub structure remains should be “grubbed out” to a minimum depth of 500mm below the underside of the formation to prevent hard spots from forming again, appropriately benched.
- Any resulting voids or low areas from these works should be backfilled with well compacted granular fill.
- The completed subgrade should be proof rolled with a heavy roller, inspected by an engineer and any additional soft spots or unsuitable soils identified removed and replaced with well compacted granular fill.
- Prior to the placement of the founding materials and the construction of the pavement, the subgrade and formation will need to be inspected and tested in accordance with the earthworks specification to ensure the minimum design parameters for the subgrade and pavement construction have been met.
- A typical pavement construction of 495mm is expected to be suitable (subject to confirmation)
- A Geotextile separator layer should be placed at sub-foundation level to mitigate loss of stone to softer subgrades.

9.12 Drainage

The site is underlain by made ground over generally cohesive subsoils. The development also includes a number of basement structures. As such, there is limited potential for infiltration of surface water runoff to ground.

It is recommended that flexible service connections are used on this site, in order to avoid any possible damage due to self-settlement of the weak strata once the site is developed.

9.13 Basements

The built development includes a basement/semi basement level. The structural design of this structure will follow the same form as the main structure and be piled. The following comments are noted:

- The basement is locally positioned in the area of infilled canal basin and may encounter associated deeper made ground, former structure, and ground water during construction;
- The permanent design should accommodate for appropriate uplift groundwater pressures and waterproofing in accordance with current design guidance; and

- The water seepage flows and ground conditions will need to be managed through appropriate temporary works design by the main contractor.

10 Conclusions and Recommendations

10.1 Ground Conditions

The site initially consisted of a canal with warehouses as part of a wharf in 1893. The canal in the north of the site linked to the nearby Rochdale Canal. Between 1922 and 1932, the canal was infilled with an unknown material and replaced with a garage, paint works, and furniture warehouse. By 1951, the furniture warehouse was removed and between 1963 and 1981, Hills Service Garage was divided into two units. From 1983 to 1990, the site had two main buildings with a shared wall and hardstanding. These buildings were demolished between 1990 and 1992. Since then, there have been no significant changes to the site.

The site includes Made Ground deposits present beneath asphalt or concrete hardstanding. The thickness of the hardstanding surface ranges from 0.03m to 0.4m, except in BH12 area where no surfacing was found. Most exploratory holes encountered Granular Made Ground at depths of around 1.8mbgl, with Cohesive Made Ground observed typically to 2.8mbgl. The Made Ground, associated with the infilled canal, is typically about 1m deeper than the surrounding area ranging from 3.5mbgl to 4.0mbgl. The infilled canal similar to the wider site, consists of a layer of Granular Made Ground over laying Cohesive Made Ground.

In every borehole that penetrated the Made Ground, Glacial Till was encountered. Two layers of Granular Glacial Till were identified: the Upper Granular Glacial Till and the Lower Granular Glacial Till. The Upper Granular Glacial Till ranges in depth from 8.0mbgl to 18.1mbgl, with a thickness between 0.5m and 3.1m. It directly overlays the Lower Cohesive Glacial Till and comprises a slightly silty clayey gravelly fine Sand.

The Lower Granular Glacial Till ranges in depth from 19.0m to 27.2mbgl. It is often found above the sandstone bedrock and consists of dense to very dense sandy gravel with low cobble content.

Cohesive Glacial Till was encountered across the entire site, ranging in depth from 4.5m to 18.0mbgl. The upper layer, is described as firm to stiff slightly gravelly Clay. It contains fine to medium gravels, including flint, sandstone, siltstone, and limestone. A second Cohesive Glacial Till layer is present to depths between 16.5m and 24.0mbgl and comprises a firm to stiff brown sandy gravelly Clay with occasional cobble content.

Chester Formation Sandstone is present beneath the site at elevations between 20.72m and 21.76m AOD (27.2m and 26.8mbgl), indicating the bedrock level beneath the site is relatively uniform. The sandstone is recorded as comprising an upper weathered zone (<0.7m thick), grading with depth into intact rock.

10.2 Geotechnical Conclusions

The following statements are outlined from the laboratory testing data:

- Pad or raft foundations are not feasible for the structures based on the form of development, likely structural loads, and underlying ground conditions; therefore, piled foundations are considered appropriate for the project;
- Continuous flight auger (CFA) or rotary bored piles are the recommended piling techniques and specialist advice from a piling contractor should be sought for detailed guidance;

- The safe working load of a pile depends on its diameter, design action, founding depth, and installation method and shallow obstructions like boulders or relict foundations should be removed or piling layout should be adjusted accordingly;
- The following outline pile loads are considered to be achievable subject to detailed design:
 1. A 450mm diameter, 25m long bored pile would give up to 1,200kN capacity per pile (inclusive of base and shaft friction), anticipated for the main development foundations; and
 2. A 600mm diameter, 25m long bored pile would give up to 1,600kN capacity per pile (inclusive of base and shaft friction). These piles are anticipated for the retaining wall.
- Temporary works design will be required for pile platform design;
- The stability of any Made Ground or granular soils should not be relied upon in unsupported excavations;
- A detailed strategy for managing obstructions within the Made Ground should be developed to minimise potential delays on site and associated abnormal costs;
- Pavement and road design will likely use Made Ground to form the subgrade, with a predominantly granular nature. A California Bearing Ratio (CBR) of approximately 2% should be achievable with proper preparation however given the highly variable nature of the Made Ground soft spots cannot be entirely discounted. A typical design thickness of 495mm is anticipated and should include for a basal geotextile separator layer; and
- Perched groundwater may be encountered and should be accommodated for in the temporary works design to the basement construction.

10.3 Geo-Environmental Conclusions

Two boreholes encountered Made Ground strata with a strong presence of hydrocarbon odours, as such it is expected that at least some of the Made Ground will contain elevated concentrations of organic contamination.

Olfactory evidence of contamination was noted within BH01 at depths less than 2mBGL. This location coincides with the former location of a service station/workshop and may be connected to the former site usage in this part of the site.

Discoloration and damp soils were also noted within all boreholes and Made Ground deposits and given the nature and extent of the Made Ground across the site, then the presence of hydrocarbon or other heavy metal contaminants cannot be ruled out. These contaminants may be concentrated or localised within the area of former fuelling station and infilled canal basin.

The presence of asbestos fibres or asbestos containing materials cannot be ruled out at this stage and given the historical nature of the site.

The following general remedial works are expected:

- Provision of clean covers to landscape/garden areas as 150mm of topsoil over 300mm of subsoil;
- Soil gas protection measures as a solid floor slab with basic gas membrane with sealed joints and penetrations;
- Standard protection to buried water service pipes and sewer joints; and

- Concrete design in accordance with BRE digest as DS-2 and ACEC AC-2.

Although not encountered during the works the following risks items may be present:

- Localised buried asbestos;
- Localised buried tanks;
- Localised “hotspots” of soil contaminants as hydrocarbons; and
- If encountered these contaminants will require delineation, assessment through an updated risk assessment and if increased risks are identified the material may require removal.

10.4 Overall Conclusion

The site was first developed in the 1880’s with a range of land uses including a canal wharfe, warehouses, and car repair garage. Since clearance of the site in 2014 the site has been in use as surface car parking.

Site investigations have been completed to identify ground conditions and a conceptual site model has been developed. Although localised areas of soil, water and soil gas contamination were identified these are contaminants are commensurate with the known site history and a qualitative risk assessment confirms these contaminants represent a low/moderate risk to receptors.

As such, the site’s known geotechnical and environmental conditions would not preclude development. A series of standard mitigation measures have been proposed to ensure that risks remain low within the built development and are commensurate for the known ground conditions to a city centre brownfield development.

11 References

1. British Geological Survey (BGS), Geology of Britain – www.bgs.ac.uk
2. UK Governmental Radon Map of Britain – www.ukradon.org/information/ukmaps
3. Zetica UXO Risk Maps – www.zeticauxo.com
4. CIRIA C552, Contaminated land risk assessment: A guide to good practice.
5. Environment Agency, Land contamination risk management (2020).

Figures

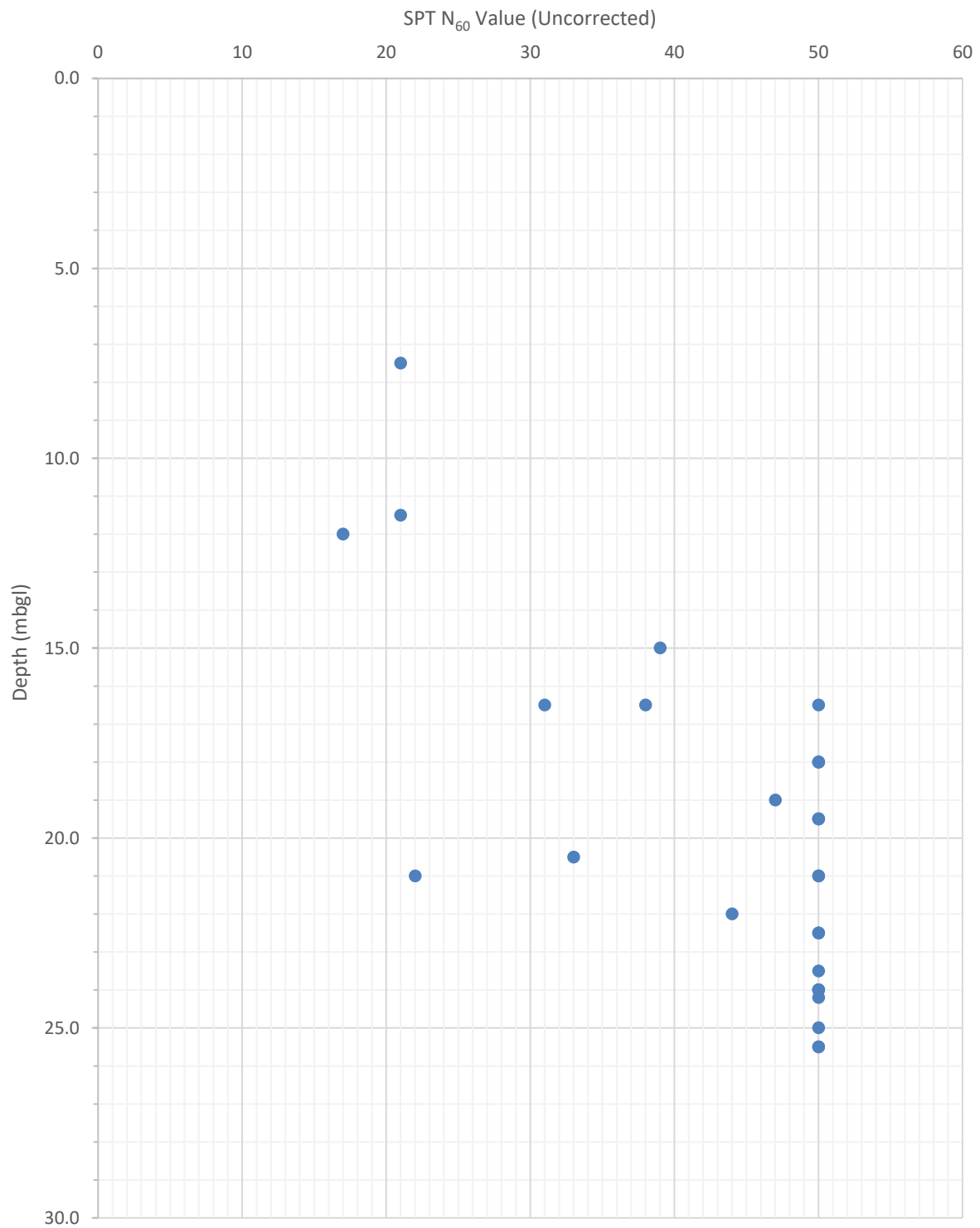


Figure 1: SPT N_{60} vs Depth - Granular Glacial Till

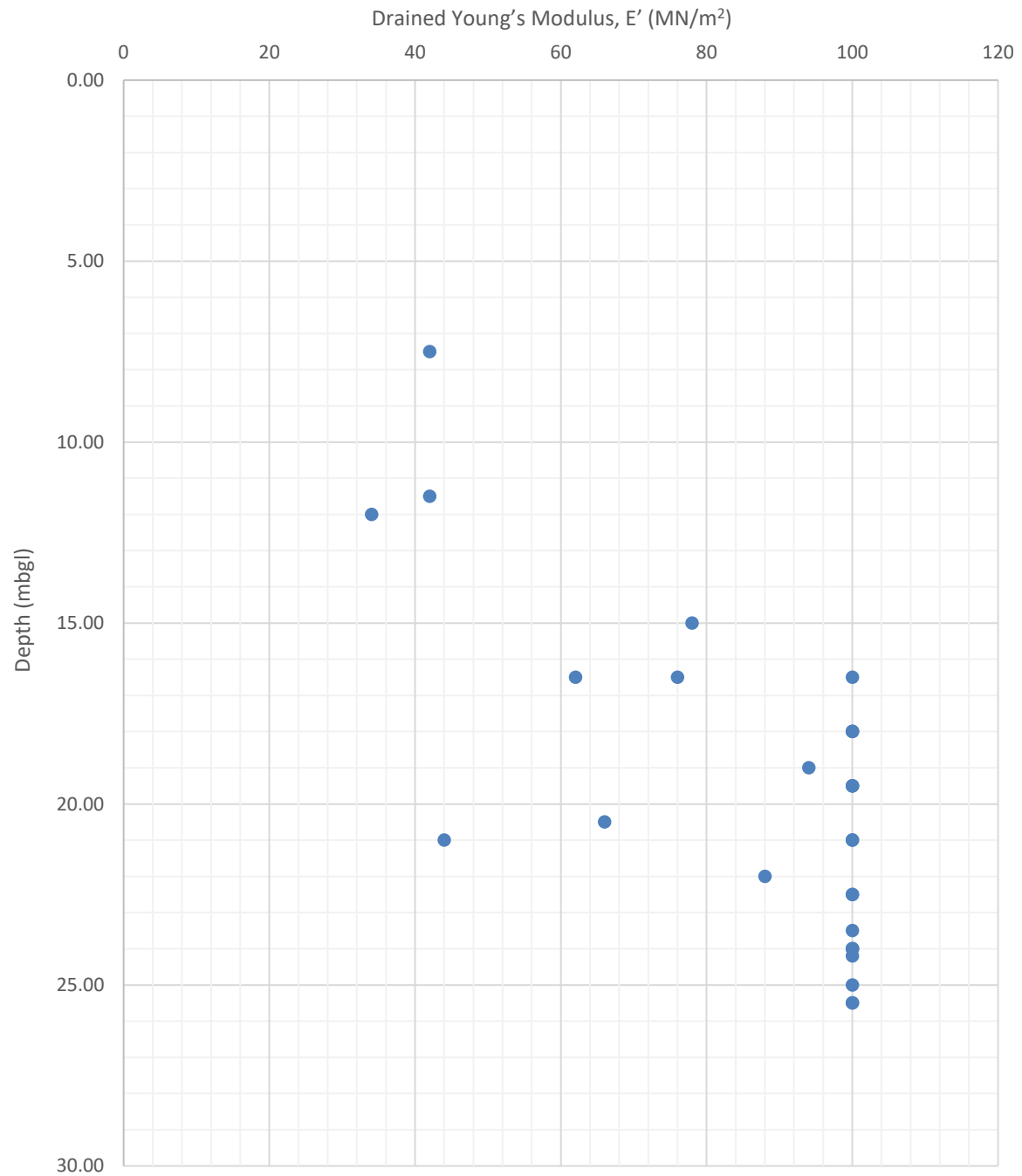
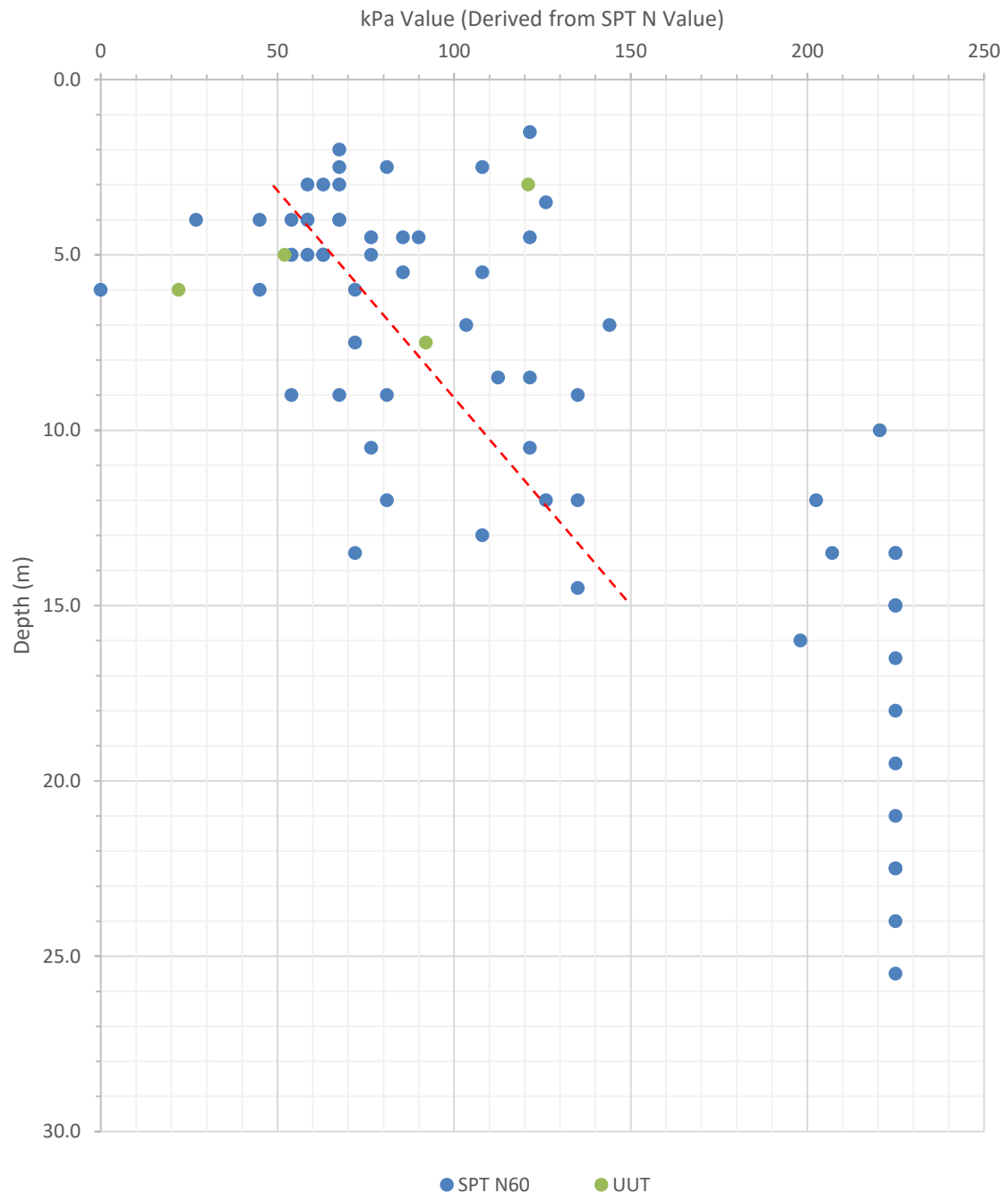


Figure 2: Drained Young's Modulus vs Depth - Granular Glacial Till



Appendix 1

Drawings

FAIRHURST

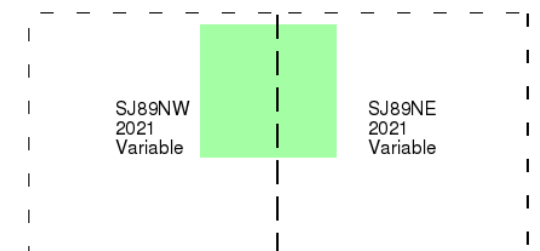
VectorMap Local

Published 2021

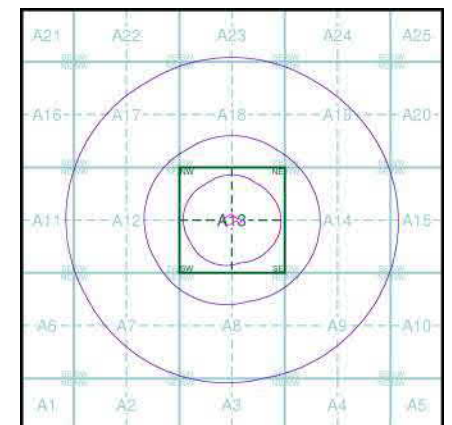
Source map scale - 1:10,000

VectorMap Local (Raster) is Ordnance Survey's highest detailed 'backdrop' mapping product. These maps are produced from OS's VectorMap Local, a simple vector dataset at a nominal scale of 1:10,000, covering the whole of Great Britain, that has been designed for creating graphical mapping. OS VectorMap Local is derived from large-scale information surveyed at 1:1250 scale (covering major towns and cities), 1:2500 scale (smaller towns, villages and developed rural areas), and 1:10 000 scale (mountain, moorland and river estuary areas).

Map Name(s) and Date(s)



Historical Map - Slice A



Order Details

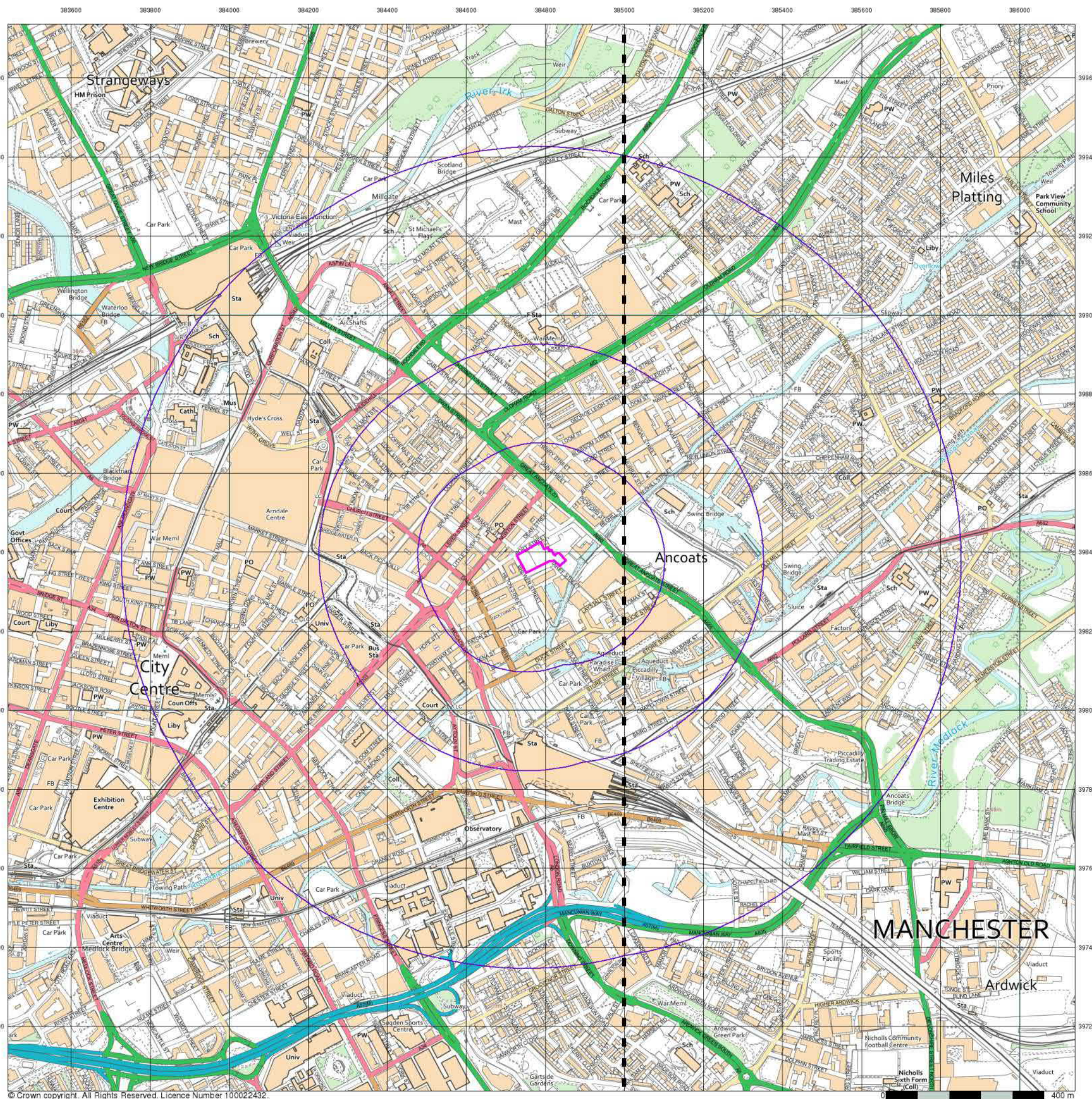
Order Number: 302490219_1_1
Customer Ref: 143404
National Grid Reference: 384790, 398380
Slice: A
Site Area (Ha): 0.47
Search Buffer (m): 1000

Site Details

Flat 1, Burlington House, 22, Tariff Street, MANCHESTER, M1 2DN

Landmark
INFORMATION GROUP

Tel: 0844 844 9952
Fax: 0844 844 9951
Web: www.envirocheck.co.uk





LEGEND

SOFTWORKS

Proposed Tree in Soft Landscape
Clear Stem specimen parkland tree
Height: 6m

Proposed Small Tree/Large Shrub in Planter
Multi-stem Tree
Height: 2m

Proposed Instant Hedge

Proposed Ornamental Planting
Mixed shrub and herbaceous planting, 5-7L pots
with 10L specimens.
Planting beds to receive 75mm depth ornamental
bark mulch.

Proposed Green Wall

HARDWORKS

Proposed Block Paving - Type 1
To match adjacent schemes

Proposed Block Paving - Type 2
With feature trim

Proposed Flag Paving
To private terraces

Proposed Block Paving - Type 3

Proposed Ornamental Gravel

Proposed Feature Paving

FURNITURE AND FEATURES

Proposed Stone Seat

Proposed Timber Table and Bench

Proposed Timber Bench

Proposed String Lights

Proposed Building Overhang
To architects detail

REVISION NOTES

Rev	By	Description	Date
A	MC	Updated in line with new architects layout	25.11.22

Client
Axis-Re / Marco Living

Project
Tariff Street, Manchester

Description
Landscape Layout

Status
For Approval

Scale @ A1
1:200
Job number
4267

Drawn
MC
Drawing number
101

Checked
CT

Date
08.11.2022
Revision
A

tpm landscape
chartered landscape architects
address: 4th Floor Studio 10 Little Lever St Manchester M1 1HR
tel: 0161 235 0600 fax 0601 email info@tpmlandscape.co.uk

GENERAL NOTES

- This drawing is the copyright of TPM Landscape Ltd and cannot be reproduced in any form without the consent of the company.
- This drawing is to be read in conjunction with detail landscape drawings, details and specification.
- This drawing is to be read in conjunction with all relevant Architects, Engineer's, Specialists, Bills of Quantities and Specifications.
- The insertion of any firm or proprietary brand on this drawing is an indication of the class or quality required and does not exclude the use of alternative materials that are equal in performance, quality and appearance, provided that they have been approved in writing by the Landscape Architect.
- The Contractor is responsible for accurately ascertaining the position of underground services and responding to all relevant service easement requirements.
- All dimensions are in millimetres unless stated otherwise, for the purposes of construction this drawing must not be scaled and only written dimensions used. Written and scaled dimensions to be checked on site, any discrepancies reported prior to work commencing. IF IN DOUBT PLEASE ASK.
- All work and materials are to be in accordance with the relevant British Standards and Code of Practice.
- All Proprietary products are to be used strictly in accordance with the manufacturer's instructions and details.

Appendix 2

Environmental Risk Assessment Principals

Principles of Environmental Risk Assessment

The Environmental Protection Act (1990), Part II A Contaminated Land (Section 57 of the Environment Act 1995), revised by Scottish Statutory Instrument No.658 (2005), and the Contaminated Land Regulations (1999) provide a basis on which to determine the risks and liabilities presented by a contaminated site. Contaminated Land is defined within Annex 3, Chapter A Part 1- Scope of Chapter and in all those Sections mentioned as:

“Any land which appears to the local authority in whose area it is situated to be in such a condition, by reason of substances in, on or under the land that:

- (a) Significant harm is being caused or there is significant possibility of such harm being caused; or*
- (b) Significant pollution of the water environment is being caused or there is a significant possibility of such pollution being caused.”*

Section 57 of the Environment Act 1995 requires that any site identified as being “contaminated” by the Local Authority will be registered by them and remediation will be required to render the site fit for use.

The presence of contamination is not the sole factor for deciding whether a site is contaminated. Relevant parties should identify site-specific risks and provide objective, cost-effective methods to manage the contamination in a manner that satisfies the proposed end-use.

A risk-based approach, which considers both technical and non-technical aspects when making decisions on contamination resulting from past, present, or future human activities, is advocated. The assessment of environmental risks generally relies on the identification of three principal elements forming a ‘pollutant linkage’:

- SOURCE:** the contaminant
- PATHWAY:** the route through which the contaminant can migrate, and
- RECEPTOR:** any human, animal, plant, water environment or property that may be adversely affected (harmed) by the contaminant

In the absence of any one of these elements, on any given site, there is no risk. Where all three elements are present, risk assessment is required to determine the significance of the harm that is being or may be caused. As outlined above, the terms of the Contaminated Land regime specify that remediation needs only be implemented where a site is causing, or there is a significant possibility that it will cause significant harm or significant pollution to the water environment.

The development of contaminated land is usually addressed through the application of planning and development legislation and guidance (i.e., Planning Advice Note 33). The suitable for use approach is seen as the most appropriate to deal with contaminated land, taking account of environmental, social, and economic objectives. The assessment is made in the context of the proposed land use (i.e., residential, retail, open space, and tourist developments).

Classification Matrix

		Consequence			
		Severe (Sv)	Medium (Md)	Mild (Mi)	Minor (Mr)
Probability	High (Hi)	Very high risk	High Risk	Moderate Risk	Moderate/low risk
	Likely (Li)	High risk	Moderate risk	Moderate/low risk	Low risk
	Low likelihood (Lw)	Moderate risk	Moderate/low risk	Low risk	Very low risk
	Unlikely (Ul)	Moderate/low risk	Low risk	Very low risk	Very low risk

After CIRIA Report C552, Contaminated Land Risk Assessment A Guide to Good Practice, 2001

Classification of Probability

Probability Classification	Definition
High likelihood	There is a pollution linkage and an event that either appears very likely in the short term and almost inevitable over the long term, or there is evidence at the receptor of harm or pollution.
Likely	There is a pollution linkage and all the elements are present and in the right place, which means that it is probable that an event will occur. Circumstances are such that an event is not inevitable, but possible in the short term and likely over the long term
Low Likelihood	There is a pollution linkage and circumstances are possible under which an event could occur. However, it is by no means certain that such an event would take place even over a longer period and is less likely in the shorter term.
Unlikely	There is a pollution linkage but circumstances are such that it is improbable that an event would occur even in the very long term.

After CIRIA Report C552, Contaminated Land Risk Assessment A Guide to Good Practice, 2001

Classification of Consequence

Classification	Definition	Examples
Severe	Short-term (acute) risk to human health likely to result in "significant harm" as defined by the Environment Protection Act 1990, Part IIA. Short-term risk of pollution (note: Water Resources Act contains no scope for considering the significance of pollution) of sensitive water resources. Catastrophic damage to buildings/property. A short-term risk to a particular ecosystem or organisation forming part of the such ecosystem (note: the definitions of ecological systems within the Draft Circular on Contaminated Land, DETR, 2000).	High concentrations of cyanide on the surface of an informal recreation area. Major spillage of contaminants from the site into controlled water. Explosion, causing building collapse (can also equate to a short-term human health risk if buildings are occupied).
Medium	Chronic damage to Human Health ("significant harm" as defined in DETR, 2000). Pollution of sensitive water resources (note: Water Resources Act contains no scope for considering the significance of pollution). A significant change in a particular ecosystem or organism forming part of the such ecosystem, (note: the definitions of ecological systems within Draft Circular on Contaminated Land, DETR, 2000).	The concentration of a contaminant from the site exceeds the generic or site-specific assessment criteria. Leaching of contaminants from a site to a major or minor aquifer. Death of a species within a designated nature reserve. Lesser toxic and asphyxiate effects of carbon dioxide
Mild	Pollution of non-sensitive water resources. Significant damage to crops, buildings, structures, and services ("significant harm" as defined in the Draft Circular on Contaminated Land, DETR, 2000). Damage to sensitive buildings/structures/services or the environment.	Pollution of non-classified groundwater. Damage to the building rendering it unsafe to occupy (e.g., foundation damage resulting in instability).
Minor	Harm, although not necessarily significant harm, may result in a financial loss or expenditure to resolve. Non-permanent health effects on human health (easily prevented by means such as personal protective clothing, etc.). Easily repairable effects of damage to buildings, structures, and services.	The presence of contaminants at such concentrations that protective equipment is required during site works. The loss of plants in a landscaping scheme. Discolouration of concrete.

After CIRIA Report C552, Contaminated Land Risk Assessment A Guide to Good Practice, 2001

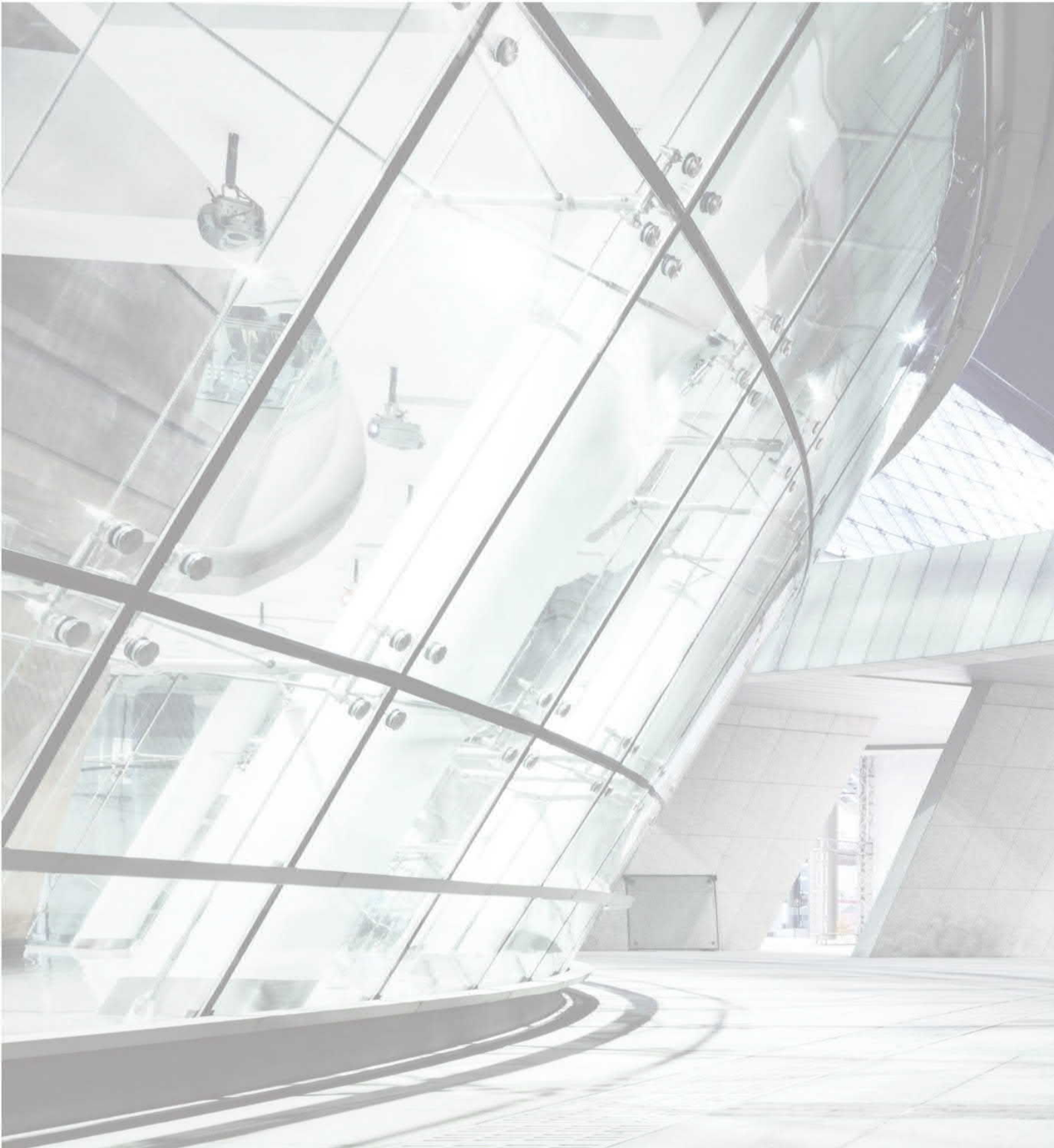
Classification of Risk and Likely Action Required

Very high risk (Vh)	There is a high probability that severe harm could arise to a designated receptor from an identified hazard, OR, there is evidence that severe harm to a designated receptor is currently happening. This risk, if realised, is likely to result in substantial liability. Urgent investigation (if not undertaken already) and remediation is likely to be required.
High risk (Hi)	Harm is likely to arise to a designated receptor from an identified hazard. The realisation of the risk is likely to present a substantial liability. Urgent investigation (if not undertaken already) is required and remedial works may be necessary for the short-term and are likely over the longer term.
Moderate risk (Md)	It is possible that harm could arise to a designated receptor from an identified hazard. However, it is either relatively unlikely that any such harm would be severe, or if any harm were to occur it is more likely that the harm would be relatively mild. Investigation (if not already undertaken) is normally required to clarify the risk and to determine the potential liability. Some remedial works may be required in the longer term.
Low risk (Lw)	It is possible that harm could arise to a designated receptor from an identified hazard, but it is likely that this harm if realised, would at worst normally be mild.
Very low risk (Vl)	There is a low possibility that harm could arise to a receptor. In the event of such harm being realised, it is not likely to be severe.

After CIRIA Report C552, Contaminated Land Risk Assessment A Guide to Good Practice, 2001

Appendix 3

Groundtech Consulting Factual Ground Investigation Report



GROUNDTECH
CONSULTING

Job title: Tariff Street

Report type: Factual Geo-Environmental
Report

Prepared for: Fairhurst

Date: July 2023

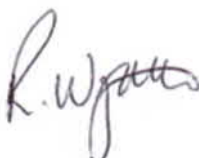
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PROJECT	TARIFF STREET, MANCHESTER
REPORT NAME	FACTUAL GEO-ENVIRONMENTAL REPORT
REPORT REFERENCE	GRO-22079-4613
STATUS	FINAL
ISSUE DATE	25 JULY 2023
REVISION	
CLIENT	FAIRHURST
CLIENT CONTACT	ANTHONY SIMMONS
For and Behalf of Groundtech Consulting	
SIGNATURE	
AUTHOR	Jamie Parr BSc (Hons)
SIGNATURE	
CHECKED	Richard Wyatt MEng (Hons) FGS
SIGNATURE	
REVIEWED	James Doyle BSc (Hons) CGeol FGS

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Plans

<i>Plan Reference</i>	<i>Revision</i>	<i>Title</i>
GRO-22079-P01	-	Project Location Plan
GRO-22079-P02	-	Exploratory Hole Location Plan

1.0 INTRODUCTION

1.1 Project Objectives

Groundtech Consulting Limited have been instructed by Fairhurst to undertake a Ground Investigation for a site at Tariff Street in Manchester.

A main investigation was undertaken in accordance with BS 5930:2015, BS 10175:2013, BS 8576 and BS 22475.

1.2 Proposed Development

The exact details of the proposed development are not known at this stage.

1.3 Limitations

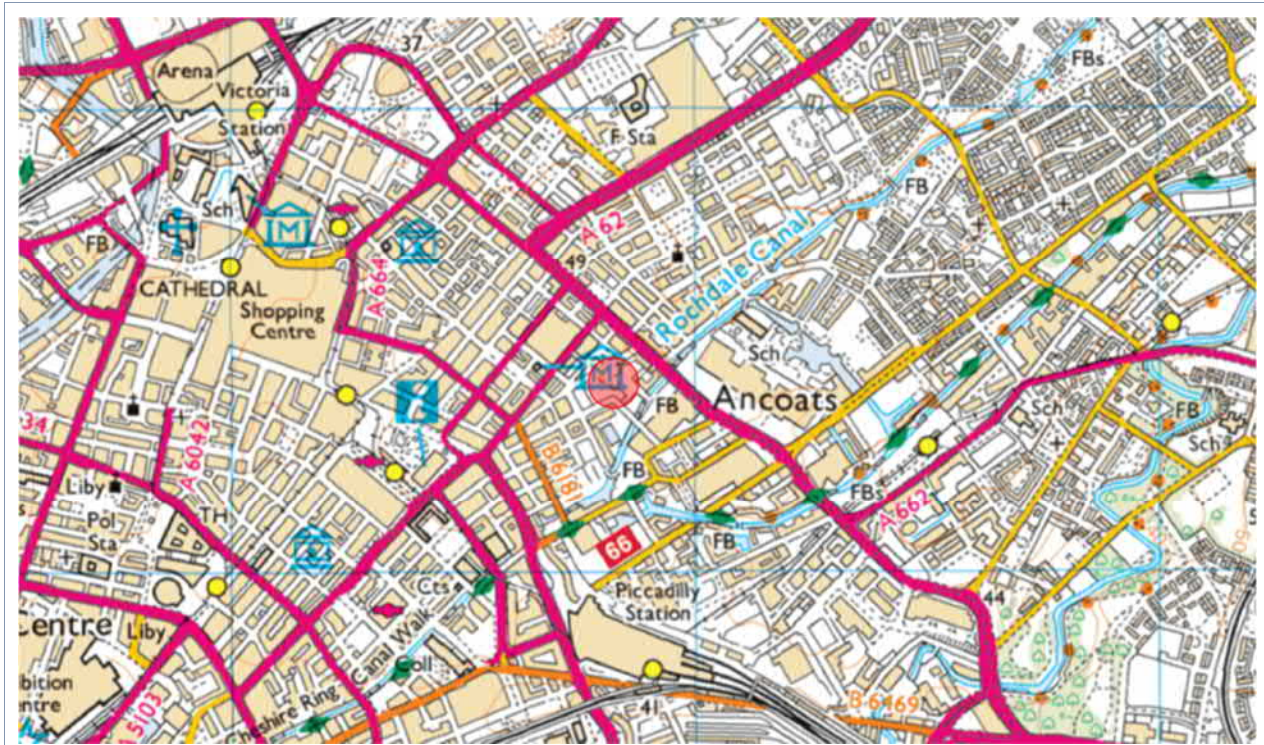
Other conditions may exist on the site that have not been taken into account in this assessment as they are outside the scope of works. Groundtech Consulting are not responsible for these circumstances that are not outlined in the report.

The assessment has been prepared for the exclusive use of the client. No third parties may rely on or reproduce the contents of the report without the written permission of Groundtech Consulting Limited. If any unauthorised third party comes into possession of the report, they rely on it at their own risk and Groundtech Consulting Limited will not be obliged to provide a duty of care.

2.0 SITE SETTING

2.1 Location

The site is located within Manchester City Centre, as shown on the Project Location Plan GRO-22079-P01 and is approximately centred on National Grid Reference 384791, 398393.



Project Location

Access to the site is gained off Tariff Street to the south and Port Street to the north.

2.2 Site Description

The site is irregular in shape and is circa 0.32ha in area. The topography of the site is generally flat, the northernmost area is slightly elevated by circa 1.0m to 1.5m from the remainder of the site and a slope is present leading up to this area.

Onsite Features

The site is currently utilised as a pay and display car park and is predominantly surfaced with concrete. Two localised areas in the south eastern corner and the north eastern corner are gravel surfaced.

There are numerous remnants of the previous development visible on the surface of the site, such as brick work which has been stripped down to the surface.

A disused building is present adjacent to the north west corner of the site.

No vegetation is present onsite.

Boundaries and Surrounding Area

This site is bound to the north by Port Street and to the south by Tariff Street. The western boundary is defined by a low brick retaining wall and at the time of the Ground Investigation the eastern site boundary was defined by hoarding associated with the neighbouring development of Brownfield Mill.

The site is surrounded by the following features/land uses:

- North - Port Street with parking beyond.
- East - Car parking and Brownsfield Mill
- South - Tariff Street with apartments beyond
- West - Car parking

Site photographs are presented in *Appendix 2*.

3.0 SCOPE OF INVESTIGATION AND RATIONALE

3.1 Project Objectives

The aim of the fieldwork was to:

Determine the stratification beneath the site.
Maintain a watching brief for visual and olfactory evidence of contamination.
Obtain samples using methodology in current guidance for contamination analysis.
Obtain samples using methodology in current guidance for geotechnical analysis.
Determine the presence of obstructions and buried structures.
Record details of buried services encountered.
Install standpipes for gas and groundwater monitoring.

3.2 Scope of Works

The following scope of works was completed between the dates of 2nd and 20th May 2023:

- All exploratory hole locations were cleared by a specialist service clearance team prior to breaking ground including GPR and CAT scanning.
- Coring of the concrete hardsurfacing was undertaken at 7 No. locations (BH01 and BH03 to BH08).
- 6 No. Cable Percussive Boreholes (BH01, BH02, BH05, BH08, BH10 and BH12) were advanced to rockhead at depths of between 24.6m and 27.2m bgl using a Dando 2000 Cable Percussive Rig.
- 5 No. Cable Percussive Boreholes (BH03, BH04, BH06, BH09 and BH11) were drilled to a depth of 5.0m bgl using a Dando 150 Cable Percussive Rig.
- 1 No. Cable Percussive Borehole (BH07) was drilled to a depth of 7.0m bgl using a Dando 150 Cable Percussive Rig.
- Rotary open hole drilling with SPTs was carried out from 30.0m to 32.0m bgl at BH01 and BH12 using a Dando rotary rig.
- Surveying of all exploratory hole locations to National Grid and meters Above Ordnance Datum (mAOD).
- Reinstatement of all locations.
- Low flow groundwater sampling.

The exploratory hole locations are presented on Groundtech Plan GRO-22079-P02 and the exploratory hole logs are in Appendix 3.

The exploratory hole locations were positioned by Fairhurst to establish the stratification beneath the site and target areas of concern as set out in the specification. The exploratory holes were logged by a suitably experienced geo-environmental engineer in general accordance with the following current guidance:

- BS 5930 'Code of Practice for Site Investigations' 2015.
- BS EN 14688-1:2002 'Geotechnical Investigation and Testing – Identification and classification of soil'.
- BS EN ISO 14689:2002 'Geotechnical investigation and testing – Identification and classification of rock'.

3.3 Soil Sampling

During the intrusive investigation, representative samples were taken at regular intervals, changes of strata and where evidence of contamination existed. Laboratory analysis was scheduled on the samples obtained.

The samples obtained are summarised in the table below:

Soil Sample	Number
<i>Environmental Sample</i>	<i>77</i>
<i>Disturbed Sample</i>	<i>152</i>
<i>Bulk Sample</i>	<i>79</i>
<i>Undisturbed U100 Sample</i>	<i>20</i>

The samples have been obtained in accordance with current environmental and geotechnical guidance. The sampling plan has been designed to obtain samples from all required strata using the correct methodology.

Disturbed samples of soil for geo-environmental testing were placed in the correct sampling containers as required by the laboratory in accordance with their MCERTS and UKAS Accreditation. Transportation was arranged in a timely manner and the samples were at the correct temperature.

The sample locations and depths are recorded on the exploratory logs.

3.4 Geo-Environmental Testing

All testing was scheduled by Fairhurst. A summary of the testing scheduled is below and the results of the geo-environmental testing is presented in *Appendix 4* for soils and *Appendix 5* for groundwater.

Contaminant of Concern (CoC)	Matrix	Number
<i>Arsenic, Cadmium, Chromium (total and hex), Copper, Nickel, Mercury, Lead, Zinc, Selenium, speciated polycyclic hydrocarbons, phenols, cyanide, organic matter, sulphate and pH.</i>	<i>Soil</i>	<i>12</i>
<i>TPH</i>	<i>Soil</i>	<i>10</i>
<i>Speciated TPH CWG</i>	<i>Soil</i>	<i>2</i>
<i>Banded TPH</i>	<i>Soil</i>	<i>1</i>
<i>Speciated PAH 16</i>	<i>Soil</i>	<i>1</i>
<i>Speciated PAH 17 (Coronene)</i>	<i>Soil</i>	<i>1</i>
<i>Total Organic Carbon</i>	<i>Soil</i>	<i>1</i>
<i>Waste Acceptance Criteria (WAC)</i>	<i>Soil</i>	<i>4</i>
<i>Asbestos Screening</i>	<i>Soil</i>	<i>10</i>
<i>Arsenic, Cadmium, Chromium (total and hex), Copper, Nickel, Mercury, Lead, Zinc, Selenium, speciated polycyclic hydrocarbons, organic matter, sulphate and pH.</i>	<i>Groundwater</i>	<i>5</i>
<i>Total Petroleum Hydrocarbons CWG including BTEX and interpretation.</i>	<i>Groundwater</i>	<i>3</i>
<i>Phenols (monohydric)</i>	<i>Groundwater</i>	<i>3</i>
<i>Sulphide</i>	<i>Groundwater</i>	<i>3</i>
<i>Total Cyanide</i>	<i>Groundwater</i>	<i>3</i>

3.6 Geotechnical Analysis

Representative disturbed samples were obtained for all soil types encountered. Selected samples were scheduled for testing at an approved laboratory in accordance with BS 1377 'Method of Test for Soils for Civil Engineering Purposes' 1990. The following tests were scheduled:

British Standard	Test Method	Number
Part 2	Water Content	28
Part 2	Plasticity Index Analysis	19
Part 3	pH Value	25
Part 3	Water Soluble Sulphate Content	25
Part 7	Undrained Shear Strength in Triaxial Compression	5
Part 2	Particle Size Distribution	8
Part 2	Particle Size Distribution Test Pipette Analysis	8
Part 5	One Dimensional Consolidation Test	4
Part 4	Dry Density / Moisture Content Relationship	6

The result of the Quick Undrained Triaxial test undertaken on the sample from BH12 at 17.0m has been confirmed with the geotechnical laboratory as an extremely high shear strength of 397kPa was recorded. The laboratory has validated this result as being correct, one theory for the high results may be localised over-consolidation in this strata.

The Geotechnical Laboratory Testing Results are presented in *Appendix 6*.

3.6 Gas and Groundwater Monitoring

Gas and groundwater monitoring installations were constructed in the boreholes. The standpipes consisted of high-density polyethylene (HDPE) pipe - a bentonite seal was placed around the plain pipe and a clean gravel pack was placed around the slotted pipe. A summary of the installation construction is presented in the table below:

Location	Depth (m bgl)	Response Zone (m bgl)	Targeted Strata	Reason
BH01	9.00	6.50 – 9.00	Glacial Till	Ground Gas & Groundwater
BH04	2.00	0.50 – 2.00	Made Ground	Ground Gas & Groundwater
BH05	4.50	0.50 – 4.50	Made Ground	Ground Gas & Groundwater
BH07	3.50	1.00 – 3.50	Made Ground	Ground Gas & Groundwater
BH08	5.80	2.80 – 5.80	Glacial Till	Ground Gas & Groundwater
BH10	18.00	14.50 – 18.00	Silty Sand	Ground Gas & Groundwater
BH12	5.00	1.50 – 5.00	Glacial Till	Ground Gas & Groundwater

Permanent gas and flow rate monitoring was carried out using a GFM 436 infrared gas monitor with integral electronic flow analyser. The measurements taken are listed below:

- *Oxygen (O₂), carbon dioxide (CO₂) and methane (CH₄) as the percentage volume in air (%v/v).*
- *Hydrogen sulphide (H₂S) and carbon monoxide (CO) as the percentage volume in air (%v/v).*
- *Lower Explosive Limit (%LEL) of methane.*
- *Atmospheric and borehole pressure, including pressure trend.*
- *Flow measurements (l/hr).*
- *Weather and ground surface conditions.*

Both peak and steady state conditions were monitored to understand the behaviour of the permanent ground gas, the steady state conditions were recorded by allowing the gas monitor to run for a minimum of 3 minutes.

Interim permanent gas and groundwater monitoring results are presented in *Appendix 7*.

3.7 Groundwater Sampling

Well development was carried out to ensure no cross contamination from the drilling activities remained in the water column in the well. During the return visit, the installations were purged to a minimum three times the volume of the water column in the borehole prior to sampling.

The method of sampling selected was using disposable low flow pump as selected by Fairhurst.

Where possible, a water meter was used to test the pH, temperature and conductivity before sampling until equilibrium conditions were met in accordance with BS 10175 guidelines.

No groundwater was encountered in BH10 and BH12 during the monitoring period.

Samples were sent to the UKAS Accredited laboratory the same day sampling was carried out in general accordance with BS 5930 and BS 5667.

All groundwater contamination testing was scheduled by Fairhurst, and the results are presented in *Appendix 5*.

4.0 GROUND MODEL

4.1 Made Ground

Made Ground was encountered in all locations across the site to a maximum depth of 4.0m bgl within BH05 and BH06.

Made Ground

Nine main Made Ground populations were encountered during the investigation and are described below:

- *Dark grey brown clayey sandy gravel of mixed lithologies including brick, flint, clinker, concrete and slate was encountered in BH01, BH02, BH08, BH09, BH10, BH12 between the depths of 0.1m and 3.1m bgl.*
- *Soft to firm dark grey slightly gravelly slightly sandy clay with minor constituents of mixed lithologies including flint and brick was encountered in BH01, BH04, BH05, BH08 to BH11 between the depths of 0.15m and 4.0m bgl.*
- *Firm dark grey slightly sandy gravelly silty clay with minor constituents of brick, concrete, clinker and flint was encountered in BH01 between the depths of 2.0m and 3.0m bgl.*
- *Brown gravelly sand with minor constituents of mixed lithologies was encountered in BH02 to BH07 between the depths of 0.20m and 1.5m bgl.*
- *Very soft black sandy gravelly silty clay with minor constituents of mixed lithologies including brick was encountered in BH02 between the depths of 2.3m and 3.0m bgl.*
- *Dark brown gravelly sandy silty clay with minor constituents of mixed lithologies including brick and glass was encountered in BH05 and BH07 between the depths of 0.8m and 3.0m bgl.*
- *Soft dark grey black slightly gravelly slightly sandy very silty clay with minor constituents of mixed lithologies including glass and brick was encountered in BH05 and BH06 between the depths of 1.5m and 3.5m bgl.*
- *Brown red gravelly Clay with minor constituents of mixed lithologies including sandstone and brick was encountered in BH06 and BH07 between the depths of 0.7m and 4.0m bgl.*
- *Dark grey orange very gravelly sand with minor constituents of mixed lithologies including clinker, glass and occasional flint was encountered in BH12 from ground level to 0.15m bgl.*



4.2 Natural Ground

The natural strata encountered generally confirmed the published geological records. Five main natural stratification were encountered during the investigation and are described below:

- Firm to stiff brown mottled grey gravelly sandy Clay with minor constituents of mixed lithologies including flint was observed in all exploratory locations between the depths of 1.2m and 18.9m bgl.
- Medium dense grey brown slightly silty clayey gravelly Sand with minor constituents of flint with occasional coal fragments was identified in BH01 and BH12 between the depths of 7.5m and 12.9m bgl.
- Dense brown slightly clayey gravelly silty Sand with minor constituents of mixed lithologies including chert was present in BH01, BH02, BH08, BH10 and BH12 between the depths of 15.0m and 26.2m bgl.
- Soft brown sandy gravelly Clay with minor constituents of mixed lithologies including sandstone was encountered in BH05 between the depths of 4.0m and 8.1m bgl.
- Dense brown sandy Gravel of mixed lithologies including sandstone was in BH05, BH08 and BH12 between the depths of 18.0m bgl and 27.2m bgl.

Stiff brown sandy cobbly gravelly Clay was encountered locally in BH05 between the depths of 22.0m and 24.0m bgl.

4.3 Bedrock

Weak red fine to medium grained Sandstone recovered as sandy gravel was observed in BH01, BH02, BH05, BH08 and BH12 between the depths of 24.6m and 27.9m bgl.

Competent, moderately strong red fine to medium grained Sandstone bedrock was present in BH01 and BH12 from depths of 26.25m and 26.8m bgl respectively to the base of the boreholes at 32.0m bgl.

4.4 Groundwater

Groundwater was encountered in the majority of the boreholes during the investigation at depths between 1.5m and 4.5m bgl. Groundwater strikes are summarised in the table below:

Location	Depth (m bgl)	Depth rising to after 20 minutes (m bgl)	Strata	Type
BH01	7.50	2.20	Sand	Strike
BH02	2.00	1.80	Made Ground	Strike
BH04	1.00	0.80	Made Ground	Strike
BH05	0.80	-	Made Ground	Strike
BH06	1.00	0.60	Made Ground	Strike
BH07	1.00	0.60	Made Ground	Strike

4.5 Watching Brief

A watching brief was maintained during the Ground Investigation for visual and olfactory evidence of contamination. A summary of the evidence of contamination encountered is presented below.

Visual Evidence of Contamination

- *Clinker was encountered within the Made Ground soils at locations BH01, BH08, BH09, BH10 and BH12 from ground level to a maximum depth of 3.2m bgl.*
- *Potash was present in the Made Ground in BH12 between the depths of 0.15m and 1.2m bgl.*
- *A slight sheen was identified at 2.0m bgl within the Made Ground of BH05.*

Olfactory Evidence of Contamination

- *A moderate hydrocarbon odour was noted in the Made Ground of BH01 between the depths of 0.35m and 2.0m bgl.*
- *A moderate hydrocarbon odour was noted at 2.0m bgl in the Made Ground of BH05.*

4.6 Borehole Stability

No evidence of spalling or collapse was noted during drilling.

4.7 Borehole Progress

Slow progress was encountered throughout the drilling works.

Cobbles and boulders were frequently encountered throughout the natural strata and chiselling was undertaken in order to advance the positions to the scheduled depth.

An obstruction in the form of a large sandstone boulder was noted at 18.1m bgl in BH10 and chiselling was undertaken to attempt to advance the position however, minimal penetration was gained in 2.5 hours. Discussions were undertaken with Fairhurst, and the location was terminated at 18.1m bgl.

5.0 RELEVANT INDUSTRY REFERENCES

British Standards Institution '*Investigation of Potentially Contaminated sites - code of practice*' BS 10175:2017.

British Standards Institution '*Code of Practice for Site Investigations*' BS 5930:2015

British Standards Institution '*Geotechnical investigation and testing – Identification and classification of soil*' BS EN ISO 14688:2002.

BS EN ISO 14689:2002 '*Geotechnical investigation and testing – Identification and classification of rock*'.