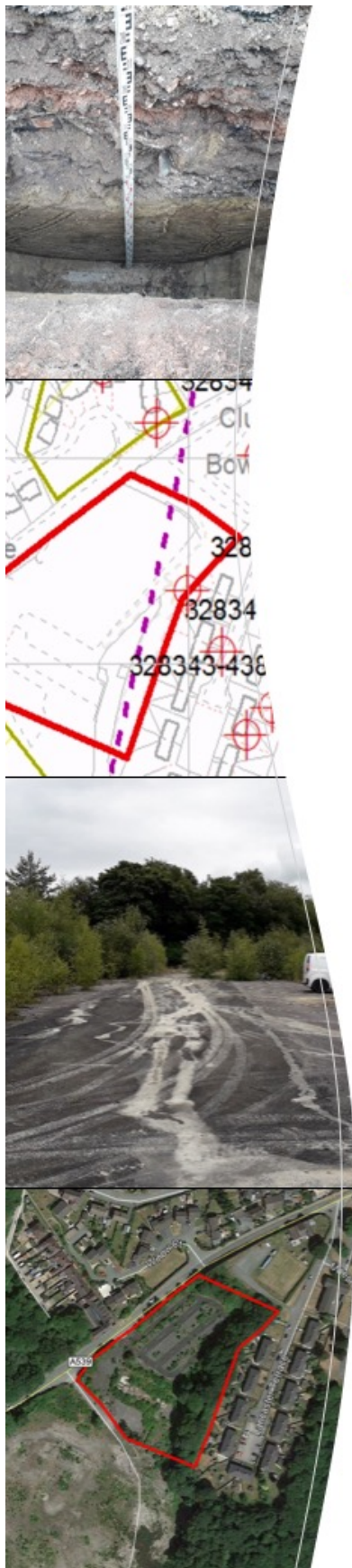




EARTH ENVIRONMENTAL
& GEOTECHNICAL

Phase II
GeoEnvironmental
Investigation

Acrefair

Wrexham

September 2020

On behalf of
GAROB Acrefair Ltd

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SITE INVESTIGATION

ACREFAIR

WREXHAM

Report Ref: A3341/20/SI/V2

SEPTEMBER 2020

Prepared on Behalf of:

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SITE INVESTIGATION

ACREFAIR, WREXHAM

Report Reference: A3341/20/SI/V2

Version B.0

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1.0 EXECUTIVE SUMMARY

Appointment	A Site Investigation has been commissioned by GAROB Acrefair Ltd to examine ground conditions for a proposed residential development at a site located off Llangollen Road, Acrefair, Wrexham.
The Investigation	The investigation comprised rotary boreholes and trial pits with associated sampling and in situ testing, laboratory geotechnical and contamination testing.
The Site	The site is located approximately 11km south west of Wrexham town centre and 16km north of Oswestry. The approximate National Grid Reference for the centre of the site is SJ 28138 43231. The site is underlain by Made Ground followed by clay (completely weathered mudstone), mudstone, sandstone, siltstone and coal of the Pennine Lower Coal Measures Formation.
Site History	The site has been occupied by an ironworks, followed by offices and car parking for an engineering works. The site has remained largely unchanged since. At the time of reporting, the site was vacant and covered in hardstanding.
Ground Conditions Encountered	The exploratory holes encountered Made Ground (up to 2.75m thick) overlying generally stiff to very stiff sandy gravelly clay (completely weathered mudstone). Mudstone bedrock was encountered below the clay as part of a sequence of mudstone, sandstone, siltstone and coal of the Pennine Lower Coal Measures. During the fieldwork, groundwater was only encountered as perched water within the Made Ground.
Geotechnical Assessment	Foundation options are conventional shallow depth (strip/pad) foundations or concrete piles in areas of deeper Made Ground. Pavement Design – preliminary design value = 4% in Clay, 1% in Made Ground Design Sulphate Class = DS-2 ACEC Site Classification = AC-1s
Contamination Assessment	Risk from contamination to groundworkers during development – Moderate Risk from soil contamination to future site users – Moderate. Risk from water contamination to controlled waters – Low. Soil Waste Assessment: All samples tested have been classified as Non-Hazardous.
Ground Gas Assessment	Basic radon protection measures will be necessary in new structures as the site is within a Radon Affected Area, unless a site-specific assessment is conducted. Based on the gas monitoring results the site can be classified as Gas Regime A and protection measures are therefore not needed for these gases.
Coal Mining Assessment	Six rotary open hole boreholes have been drilled across the site, to a depth of 30m, and despite the identification of coal under the site, they have revealed a lack of evidence for the presence of shallow abandoned mine workings. As a result, ground remedial measures such as strengthening of foundations or mine grouting will not be required.
<i>This sheet is intended to provide a summary only of the report. It does not provide a definitive engineering analysis for the purposes of costing or construction and is subject to the limitation of the agreed brief.</i>	

2.0 INTRODUCTION

2.1 Background

A Site Investigation has been commissioned by GAROB Acrefair Ltd to examine ground conditions for a proposed residential development at a site in Acrefair, Wrexham.

2.2 Previous Investigations

2.2.1 Earth Environmental & Geotechnical Ltd, Coal Mining Risk Assessment (A3341/G/1), dated December 2019

The report finds that the site lies within a Coal Authority Development High Risk Area due to the outcropping of three coal seams (Main Coal, Bind Coal and Quaker Coal) as well as an ironstone seam.

It was thought to be prudent to drill boreholes across the site to 30m below ground level in order to assess the potential for shallow mineworkings beneath the site.

2.2.2 Earth Environmental & Geotechnical Ltd, Phase I GeoEnvironmental Desk Study (A3341/19), dated December 2019

The desk study highlighted that, historically, the site has been occupied by an ironworks, followed by offices and car parking for an engineering works. At the time of reporting, the site was vacant and covered in hardstanding.

The risk from soil contamination to commercial end users was considered to be **MODERATE to LOW**. The risk to controlled waters was concluded to be **MODERATE to LOW**. The risk from ground gas to end users was considered to be **MODERATE to LOW**.

An intrusive investigation was recommended in order to carry out geotechnical and contamination testing.

2.3 Terms of Reference

Earth Environmental and Geotechnical Ltd (EEG) have been commissioned by the Client, to undertake a Site Investigation of the site in accordance with proposal A3341/20 dated 22nd May 2020. The objectives of this investigation are as follows:

- *Provide factual information on the work undertaken including sampling location plan, trial pit/borehole logs, monitoring, geotechnical and chemical testing.*
- *Tier 1 (semi-quantitative) risk assessment will be undertaken. This will compare the concentrations of soil, groundwater and ground gas contaminants identified against current and appropriate published guidelines, in relation to identified receptors, e.g. existing/ future end users and site neighbours.*
- *Classification of soil for offsite disposal.*
- *Assessment of ground conditions for foundation design.*
- *Assessment of shallow coal mining regime.*

2.4 Report Scope

This report presents full factual records of the site work carried out, the ground conditions encountered in the exploratory holes, the in situ and laboratory test results. All information collected has been used to provide an interpretation of the ground conditions, with recommendations on geotechnical design and potential ground contamination risks for the proposed development.

2.5 Limitations of the Study

The report is written in the context of an agreed scope of work and budget and should not be used in a different context. New information, improved practices or changes in legislation may require a reinterpretation of the report in whole or in part. EEG reserve the right to amend either conclusions or recommendations in light of any further information that may become available. The report is provided for the sole use by the client and is confidential to them.

Recommendations within this report are also based on exploratory records and examination of samples and, where applicable, laboratory tests. No liability can be accepted for conditions not revealed by the boreholes and trial pits particularly at intervening locations. Whilst every effort is made to ensure accuracy of data supplied, all opinions expressed as to the spatial distribution of strata between sampling locations is for guidance only and no responsibility is accepted as to its accuracy.

3.0 SITE LOCATION & DESCRIPTION

The site is located approximately 11km south west of Wrexham town centre and 16km north of Oswestry. The approximate National Grid Reference for the centre of the site is SJ 28138 43231 (X: 328138, Y: 343231) with the closest postcode being LL14 3HW.

The site is irregular in shape with maximum dimensions of approximately 150m north-south and 155m east-west. The area of the site is 1.12 ha. The site is flat with a gentle slope to the south west.

At the time of this investigation, the site was a disused parcel of land with the majority covered in asphalt hardstanding. Patches of trees and shrubs can be seen spread across the site, especially surrounding a concrete slab in the south of the site. A steep slope covered in mature trees is present along the eastern site boundary.

To the northwest of the site is Llangollen Road (A539) with residential properties and vacant land beyond, to the north east is a bowling green, to the east is a steep slope with residential properties beyond and to the south is a vacant plot of land.

The site location is shown in the aerial photograph presented as Figure 1 below.

Figure 1: Site Location Plan



Access to the site is via a gate opening onto Llangollen Road to the north west of the site.

General site photographs are presented in Figure 2 below.

Figure 2: General Site Photographs

View across the northern portion of the site, looking north east



View of a relict concrete slab in southern portion of the site, looking south east



View of the southern site boundary, looking south east



Representative trial pit (TP8)



3.1 Proposed Development

At the time of reporting, a proposed development plan was not available for this site.

4.0 SITE INVESTIGATION

4.1 Exploratory Fieldwork

The fieldwork was carried out by EEG between 29th June to 1st July 2020 and comprised:

- Six boreholes (designated RH1 to RH6) were drilled to 30.0m below existing ground level, using a track-mounted rotary open hole drilling rig. The boreholes were initially drilled through overburden using a rock roller down the hole hammer, producing a 112mm nominal diameter hole. Water was used as the flushing medium. The boreholes were backfilled on completion with bentonite grout. Exploratory hole logs are included in Appendix 1.
- Four of the rotary boreholes were installed with 50mm diameter monitoring standpipes to enable subsequent gas and groundwater monitoring.
- Twelve trial pits (designated TP1-TP12) were excavated to a maximum depth of 3.15m, using a tracked excavator. Representative disturbed samples were recovered from the excavated material as pitting proceeded. Trial pits were backfilled immediately on completion of sampling.

Exploratory hole locations were determined by EEG prior to visiting the site. Each exploratory location was scanned using a Cable Avoidance Tool (CAT) in order to locate unrecorded underground services, and the exploratory locations were repositioned if necessary.

On completion, samples recovered from the site were taken to specialist laboratories for chemical and geotechnical testing.

All site investigation work was supervised full time by a representative of EEG. The logging of soils and rocks has been carried out in accordance with BS5930⁽²⁰¹⁵⁾ except where superseded by the soil and rock description methodology in BS EN14688-1⁽²⁰⁰²⁾, BS EN 14688-2⁽²⁰⁰⁴⁾ and BS EN 14689-1⁽²⁰⁰³⁾.

An Exploratory Hole Location Plan is presented as Figure 3 overleaf.

Figure 3: Exploratory Hole Location Plan



A summary of exploratory holes undertaken during the investigation are presented in Table 1 below.

Table 1: Summary of Exploratory Holes Undertaken

Hole	Type*	Depth (m)	Date Started	Date Finished	Easting (m)	Northing (m)	Backfill Details**
RH1	RO	30.00	01/07/2020	01/07/2020	328101.78	343236.28	BG, SP
RH2	RO	30.00	30/06/2020	30/06/2020	328150.29	343260.21	BG, SP
RH3	RO	30.00	01/07/2020	01/07/2020	328110.74	343216.08	BG
RH4	RO	30.00	30/06/2020	30/06/2020	328148.69	343242.95	BG, SP
RH5	RO	30.00	01/07/2020	01/07/2020	328188.51	343271.19	BG, SP
RH6	RO	30.00	30/06/2020	30/06/2020	328176.43	343285.55	BG
TP1	TP	2.85	29/06/2020	29/06/2020	328160.59	343283.11	A
TP2	TP	2.20	29/06/2020	29/06/2020	328136.30	343263.29	A
TP3	TP	2.25	29/06/2020	29/06/2020	328115.21	343246.74	A
TP4	TP	2.50	29/06/2020	29/06/2020	328099.40	343230.63	A
TP5	TP	2.30	29/06/2020	29/06/2020	328114.48	343190.43	A
TP6	TP	2.00	29/06/2020	29/06/2020	328147.54	343222.34	A
TP7	TP	2.10	29/06/2020	29/06/2020	328166.76	343242.95	A
TP8	TP	2.80	29/06/2020	29/06/2020	328168.63	343267.43	A
TP9	TP	2.35	29/06/2020	29/06/2020	328142.14	343242.81	A
TP10	TP	1.90	29/06/2020	29/06/2020	328126.21	343214.42	A

Hole	Type*	Depth (m)	Date Started	Date Finished	Easting (m)	Northing (m)	Backfill Details**
TP11	TP	2.10	29/06/2020	29/06/2020	328147.38	343201.63	A
TP12	TP	3.15	29/06/2020	29/06/2020	328138.51	343183.23	A
*RO = Rotary Open Borehole, TP=Triaxial Pit **BG=Bentonite Grout, A=Arising, SP=Standpipe							

4.2 Laboratory Testing

4.2.1 Geotechnical Testing

A programme of laboratory testing was carried out on samples taken from the various strata to assist in classification and determine the engineering properties of the materials underlying the site. The tests were scheduled by EEG and carried out by Murray Rix. The test procedures used were generally in accordance with the methods described in BS1377:1990. Details of the specific tests used in each case are given in Table 2 below.

Table 2: Summary of Laboratory Geotechnical Tests Undertaken

TEST	STANDARD	No.
Moisture Content	BS1377:1990 Part 2, Clause 3.2	10
Liquid Limit, Plastic Limit, Plasticity Index	BS1377:1990 Part 2, Clause 4/5	10
Particle size distribution (wet)	BS1377:1990 Part 2, Clause 9.2	5
Sulphate content of 2:1 soil:water extract	BS1377:1990 Part 3, Clause 5	10
pH value	BS1377:1990 Part 3, Clause 9	10

The results of the laboratory geotechnical tests are discussed in Section 6 and included in Appendix 2.

4.2.2 Environmental Testing

The environmental chemistry of the ground was investigated by specialist chemical analysis of selected samples, scheduled by EEG and carried out by DETS.

Chemical analyses were carried out on fifteen soil samples and were submitted for the following suite of determinants:

Asbestos Screen, Arsenic, Barium, Beryllium, Boron, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Selenium, Vanadium, Zinc, Cyanide, Phenol, Sulphate (SO₄), Sulphide, pH, Soil Organic Matter, Extractable Petroleum Hydrocarbons (EPH), Speciated Petroleum Hydrocarbon (TPH) and Speciated Polyaromatic Hydrocarbons (PAH).

The results of the laboratory contamination tests are discussed in Section 8 and included in Appendix 3.

5.0 GROUND CONDITIONS ENCOUNTERED

5.1 Soil Profile Encountered

The sequence of strata encountered beneath the site was as follows:

- **Made Ground** – Variable Made Ground was encountered in all the exploratory holes, comprising:
 - Asphalt hardstanding.
 - Gravels with varying sand and cobble content (containing brick, slag, glass, timber, clinker, concrete, metal, pottery fragments, carbonaceous fragments, sandstone and mudstone).
- **Clay** was encountered in all the exploratory holes. The clay is thought to be a completely weathered mudstone that becomes less weathered with depth. This lithology was recovered as:
 - Sandy gravelly clay (containing gravel of mudstone and carbonaceous fragments).
 - Clayey mudstone was encountered in the rotary boreholes.
- **Mudstone** was encountered in all of the rotary boreholes as:
 - Mudstone with occasional siltstone and sandstone bands.
- **Sandstone** was also encountered in all of the rotary boreholes as:
 - Sandstone with mudstone bands and strong sandstone bands.
- **Coal** was encountered in RH1 and RH3 and was found to be intact and separated by a thin layer of black shale.

The depths of the various materials encountered in the exploratory holes are summarised in Table 3 overleaf.

5.2 Observable Indications of Contamination

With the exception of Made Ground gravel, no visual/olfactory evidence of contamination was encountered in any of the exploratory holes during the fieldwork.

5.3 Obstructions

No man-made obstructions were encountered in any of the excavations carried out during the fieldwork.

5.4 Groundwater

Groundwater was encountered in TP1 (1.30m) and TP3 (1.05m). However, this was just localised perched water within the Made Ground.

Due to the use of a water-based drilling flush, groundwater levels in the rotary boreholes were not recorded.

Table 3: Summary of Ground Conditions Encountered

Hole	Depth to Stratum (m bgl)							GROUNDWATER (m bgl)
	MADE GROUND	CLAY (COMPLETELY WEATHERED MUDSTONE)	MUDSTONE	SANDSTONE	COAL	BLACK SHALE	SILTSTONE	
RH1	GL-1.00	1.00-5.10	5.10-13.20 15.50-16.60 20.40-30.00	13.20-15.50 16.60-18.40	18.40-19.90 (1.50m) 20.10-20.40 (0.30m)	19.90-20.10	-	-
RH2	GL-1.00	1.00-2.40	2.40-12.40 17.10-22.20 25.10-30.00	12.40-17.10 22.20-25.10	-	-	-	-
RH3	GL-1.40	1.40-5.60	5.60-13.20 15.50-17.00 23.30-30.00	13.20-15.50 17.00-20.60	20.60-22.00 (1.40m) 22.30-23.30 (1.00m)	22.00-22.30	-	-
RH4	GL-1.20	1.20-2.60	2.60-6.60 7.50-12.40 17.10-23.20 24.20-30.00	6.60-7.50 12.40-17.10 23.20-24.20	-	-	-	-
RH5	GL-1.10	1.10-2.30	2.30-13.60 18.30-24.00 24.20-30.00	13.60-18.30 24.00-24.20	-	-	-	-
RH6	GL-1.70	1.70-6.90	9.70-14.10 17.10-23.20 25.30-30.00	6.90-9.70 23.20-25.30	-	-	14.10-17.10	-
TP1	GL-1.30	1.30-2.85	-	-	-	-	-	Perched water at 1.30m
TP2	GL-1.95	1.95-2.20	-	-	-	-	-	-
TP3	GL-1.05	1.05-2.25	-	-	-	-	-	Perched water at 1.05m

Hole	Depth to Stratum (m bgl)							GROUNDWATER (m bgl)
	MADE GROUND	CLAY (COMPLETELY WEATHERED MUDSTONE)	MUDSTONE	SANDSTONE	COAL	BLACK SHALE	SILTSTONE	
TP4	GL-1.30	1.30-2.50	-	-	-	-	-	-
TP5	GL-1.10	1.10-2.30	-	-	-	-	-	-
TP6	GL-1.00	1.00-2.00	-	-	-	-	-	-
TP7	GL-0.20	0.20-2.10	-	-	-	-	-	-
TP8	GL-1.10	1.10-2.80	-	-	-	-	-	-
TP9	GL-0.90	0.90-2.35	-	-	-	-	-	-
TP10	GL-0.85	0.85-1.90	-	-	-	-	-	-
TP11	GL-1.50	1.50-2.10	-	-	-	-	-	-
TP12	GL-2.75	2.75-3.15	-	-	-	-	-	-

6.0 ENGINEERING PROPERTIES OF SOILS ENCOUNTERED

6.1 General

The following sections discuss the engineering properties of the strata encountered, based on results of in situ testing and laboratory testing obtained during this investigation.

The results of laboratory geotechnical testing are summarised in the following table.

Table 4: Summary of Laboratory Geotechnical Test Results

Location	Depth (m)	Strata*	CLASSIFICATION											STRENGTH	CHEMICAL	
			Moisture Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	PSD Cobbles (%)	PSD Gravel (%)	PSD Sand (%)	PSD Silt (%)	PSD Clay (%)	Bulk Density Mg/m³	Dry Density (Mg/m³)	Shear Strength (kN/m²)	pH Value	Water Soluble Sulphate SO ₄ (mg/l)
TP1	2.70	Clay	14	34	12	22	-	3	14	56	27	-	-	-	7.0	140
TP3	1.20	Clay	17	38	13	25	-	-	-	-	-	-	-	-	7.0	130
TP4	2.00	Clay	16	37	13	24	-	3	4	64	29	-	-	-	7.1	190
TP5	1.50	Clay	20	39	15	24	-	3	4	66	27	-	-	-	7.0	90
TP6	1.10	Clay	18	39	15	24	-	5	1	72	22	-	-	-	7.1	110
TP7	0.60	Clay	14	35	14	21	-	9	7	51	33	-	-	-	7.1	110
TP8	1.40	Clay	13	32	12	20	-	-	-	-	-	-	-	-	7.0	200
TP9	2.00	Clay	18	34	13	21	-	-	-	-	-	-	-	-	7.2	170
TP11	1.50	Clay	15	36	13	23	-	-	-	-	-	-	-	-	7.0	180
TP12	2.95	Clay	16	38	16	22	-	-	-	-	-	-	-	-	7.0	80

6.2 Clay

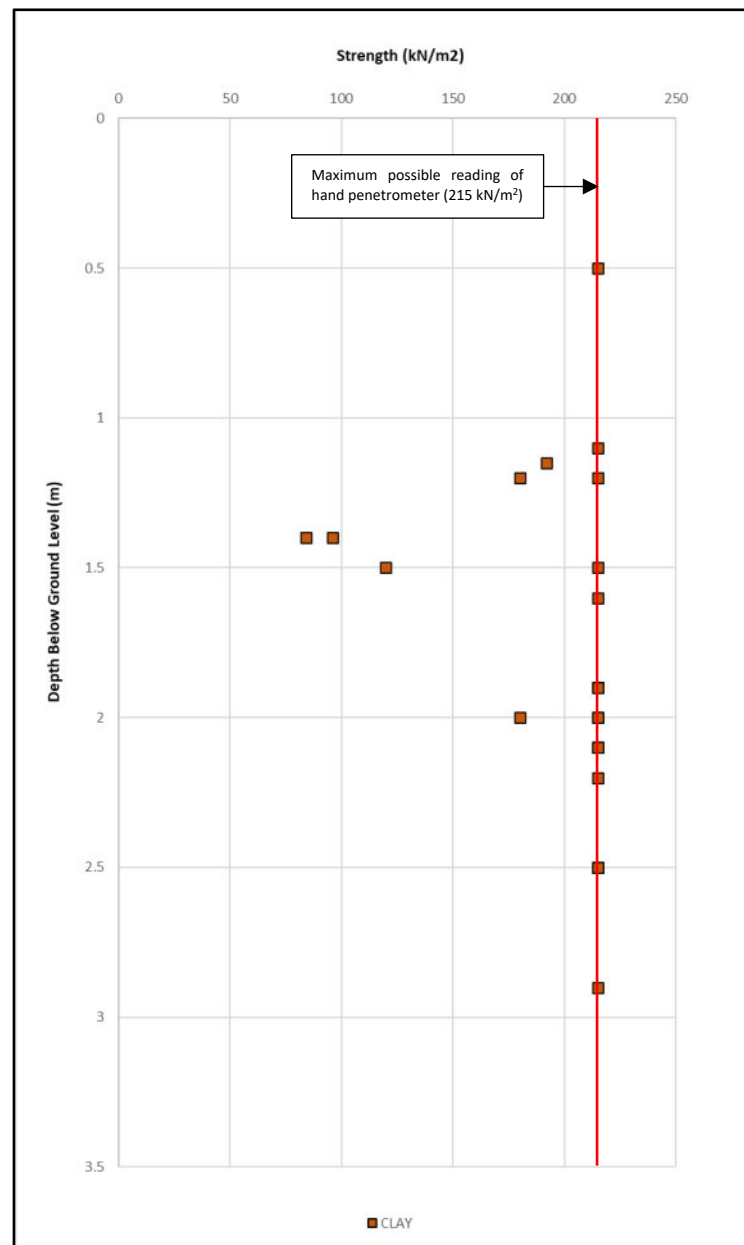
Atterberg Limit tests have given values of **liquid limit** in the range 32% to 39% and **plastic limit** values in the range 12% to 16%, resulting in values of **plasticity index** in the range 20% to 25%. These results suggest the samples tested are clay of low to intermediate plasticity as shown on the Plasticity Charts included in Appendix 2. For design purposes, a value of plasticity index = 23% is recommended.

Hand penetrometer tests carried out in the clay resulted in shear strength values in the range of 84 kN/m² to greater than 215 kN/m² (the maximum value of the hand penetrometer), as shown on the Strength v Depth Plot (Figure 4) overleaf. The results suggest the clay is stiff to very stiff.

A plot of shear strength against depth is presented in Figure 4 overleaf.

Laboratory testing has given a value of **water-soluble sulphate** in the range 80mg/l to 200mg/l, together with **pH Values** in the range 7.0 to 7.2.

Figure 4: Strength v Depth Plot (Clay)



Based on all the above, the following values are recommended for design purposes:

Table 5: Summary of Design Strength Values (Clay)

Depth	Range of Strength Values	Design Value*
1.0-2.0m	84 to >215kN/m ²	165kN/m ²
2.0-3.0m	180 to >215kN/m ²	215kN/m ²

*based on lower quartile value of all results and correlations by Stroud & Butler⁽¹⁹⁷⁵⁾

7.0 GEOTECHNICAL ASSESSMENT

7.1 Proposed Development

At the time of writing this report, a development plan is not available for the site and therefore the anticipated structural loadings were not known.

7.2 Ground Conditions Encountered

The exploratory holes encountered Made Ground (up to 2.75m thick) overlying generally stiff to very stiff gravelly clay. The clay is the remains of a completely weathered mudstone that becomes less weathered with depth and it noted to become clayey mudstone in the rotary boreholes. Asphalt hardstanding was encountered in all the exploratory holes (with the exception of TP10 to TP12 and RH3) at depths of between existing ground surface to 0.10m below existing ground level. The rotary boreholes encountered mudstone, siltstone, sandstone and intact coal of the Pennine Lower Coal Measures.

Groundwater was encountered in TP1 (1.30m) and TP3 (1.05m). However, this was just localised perched water in the Made Ground. Due to the use of a water-based drilling flush, groundwater levels in the rotary boreholes were not recorded.

7.3 Foundation Considerations

Based on the ground conditions encountered conventional shallow depth foundations (strip/pad), placed in the natural clay and sand should be suitable below 1.5m below ground level, depending on allowable bearing pressures and tolerance of structures to settlement.

Should the allowable bearing pressure and settlement prove unfavourable, then alternative foundations options will need to be considered, such as ground improvement and piles.

In the area surrounding TP12, Made Ground was observed to a depth 2.75m below ground level. Therefore, alternative foundation solutions may need to be adopted at this location, for example, shallow piles.

The above foundation options are discussed in the following sections.

7.3.1 Conventional Shallow Depth Strip/Pad Foundations

Strip/pad foundations should be taken down below any Made Ground and placed in the natural clay beneath. If any Made Ground, particularly loose or soft material, is encountered at foundation level this should be excavated and replaced with suitable granular fill or the foundation extended at least 150mm into suitable natural strata.

Foundations should be placed in materials of similar bearing and consolidation characteristics to avoid potential differential settlement occurring.

Table 6 overleaf summarises anticipated allowable bearing pressures for strip/pad foundations placed in the natural clay. The bearing capacities are calculated based on Hansen's ⁽¹⁹⁷⁸⁾ method and assuming a factor of safety against bearing capacity failure of 3. For the purpose of the calculation, groundwater has been assumed to be at 3.0m below existing ground level.

Table 6: Summary of Allowable Bearing Pressures

Foundation Strata	Design Value (Section 6)	Foundation Depth (m bgl)	Foundation Type	Foundation Size (m)	Allowable Bearing Pressure (kN/m ²)
CLAY	$c_u=165\text{kN/m}^2$	1.5	Strip	0.4	440
				0.9	409
			Pad	1.0 x 1.0	479
				2.0 x 2.0	434
	$c_u=215\text{kN/m}^2$	2.0	Strip	0.4	583
				0.9	550
			Pad	1.0 x 1.0	647
				2.0 x 2.0	590

Assuming materials beneath foundations are homogeneous over the depth of influence of the foundation for a loading of 75kN/m^2 , settlement of the order of around 3mm is anticipated for 0.60m wide strip foundations placed in the natural clay.

Floor slabs should be designed as suspended if Made Ground of 600mm thickness or greater is present. Made ground is not considered an appropriate bearing stratum due to its variable nature. Floor slabs may be designed as ground bearing where Made Ground is excavated and replaced with suitable granular fill.

All foundation excavations should be inspected by a suitable qualified engineer to prove that the founding strata is suitable and uniform along the length of the foundation, and capable of taking the anticipated structural loadings. If foundations cross from granular to cohesive soils, nominal reinforcement should be incorporated.

7.3.2 Piled Foundations

The proposed building may be founded on piles taken down to depth to a suitable founding stratum, such as the very stiff clay, when in areas of deep Made Ground.

A variety of pile types may be used, including bored and continuous flight auger (CFA) piles. Driven piles may be suitable, subject to environmental and noise/vibration constraints.

Because of the various advantages and limitations of each pile type, and the cost implications, advice should be sought from specialist piling contractors to determine the most suitable and cost-effective type. They should also be able to give recommended pile diameters and depths and likely pile capacities, with guaranteed performance. It is recommended a pile test be carried out to confirm pile capacities. In assessing the pile capacities, contractors should make an allowance for the effects of negative skin friction, particularly in the made ground and soft clays.

There may be differential settlement between piled structures and the surrounding ground level. Provision should, therefore, be made to make up ground levels at threshold positions, loading bays, vehicle access doorways, etc. Alternatively, these materials should be removed and replaced in a controlled manner by suitable existing materials or imported engineered fill.

It is essential the advice of a specialist piling contractor is sought and that positive assurances are provided by the piling contractor that their proprietary system is capable of providing the required working loads in the ground conditions encountered.

7.4 Pavement Design

Based on the ground conditions encountered it is recommended a design CBR of 4% is used for near surface cohesive materials. A conservative design CBR value of 1% should be adopted in areas where Made Ground is encountered at subgrade level.

Consideration should be given to the potential differing ground conditions near surface, which could cause pavements to be constructed on variable made ground. In this context a flexible pavement design may be required.

Consideration should also be given to the use of geotextiles to allow reduction of capping thickness. For examples biaxial geogrids such as Tensar SSLA20 and SSLA30 are often used to reduce capping thickness. The advice of a suitable contractor should be sought as to the most appropriate type of geotextile to use in the ground conditions encountered at this site. For guidance, the following table gives a comparison of granular layer thickness with and without the use of a geotextile, in accordance with the requirement of HA25/94 Part 2.

Table 7: Comparison of Capping Thickness with and without Geotextile

CBR	Unreinforced			Reinforced with Tensar Geogrid				
	Sub-base	Capping	Total	Sub-base	Capping	No. of grids	Total	Thickness saving
0.5%	Design not suitable			200mm	400mm	2	600mm	-
1.0%	150mm	600mm	750mm	400mm	0	1	400mm	350mm
1.5%	150mm	600mm	750mm	310mm	0	1	310mm	440mm
2.0%	150mm	600mm	750mm	260mm	0	1	260mm	490mm
3.0%	150mm	350mm	500mm	210mm	0	1	210mm	290mm
4.0%	150mm	300mm	450mm	175mm	0	1	175mm	275mm
5.0%	150mm	250mm	400mm	160mm	0	1	160mm	240mm
These figures are suitable for light access roads and car parks, based on 1000 standard axles. For heavier loaded pavements the advice of specialist contractor should be sought.								

It should be noted the type of construction will depend on proposed finished pavement levels across the site and it is recommended the pavement design is reviewed once these levels are known. In this context, it is essential further in situ CBR testing is carried out once formation levels are known to confirm design CBR values.

All formation excavations should be examined by a suitably experienced engineer or inspector to check for soft or unsuitable material, which should be removed and replaced with compacted granular fill. Also, to ensure good compaction and remove unevenness, the formation should be compacted with equipment suitable for use in the ground conditions encountered. Careful inspection of this work will also help identify any soft spots at or just below formation level.

7.5 Chemical Attack on Buried Concrete

Chemical tests (see Appendices) some slightly elevated levels of water-soluble sulphates in the Made Ground with non-acidic pH conditions. Based on these conditions, it is recommended that for concrete placed in the Made Ground the Design Sulphate Class for the site, as defined in BRE Special Digest 1⁽²⁰⁰⁵⁾, be taken as DS-2, and the Aggressive Chemical Environment for Concrete (ACEC) site classification be taken as AC-1s. The recommendations of BRE Special Digest 1 should be followed for concrete foundations and ground bearing floor slabs.

7.6 Suitability of Excavated Materials

Acceptability criteria and testing, and methods of compaction/placement will depend on the type of contract and specification used for the construction of the proposed development and it is recommended that earthworks specifications are reviewed by a suitably qualified engineer, once these have been prepared by the relevant parties.

Near surface soft natural clays are unlikely to be suitable as structural fill and should be used for landscaping purposes only, providing they are not contaminated.

Granular Made Ground and natural sand/gravel could be suitable for re-use as structural fill, providing it is not contaminated and does not contain excessive amounts of clay and providing moisture contents are controlled during placement. The control of moisture contents will be important as the cohesive content of this stratum is likely to be sensitive to moisture content changes.

7.7 Temporary Works

Formations will be susceptible to damage both by weather and trafficking, and should be protected immediately on exposure, particularly in areas where construction plant will access the site.

Excavations in Made Ground are likely to be unstable and should be battered back to an angle of 1 in 2, or a system of close sheeting and shoring adopted to ensure stability, and in particular where personnel are required to enter excavations. All excavations should be adequately supported where personnel are required to enter.

Groundwater seepages could be encountered near surface within excavations, particularly during the wetter months of the year. Pumping of excavations from a suitable located sump is likely to be required to keep excavations dry.

All-natural materials on site should be capable of being excavated using conventional excavating machinery.

7.8 Drainage

Based on the ground and groundwater conditions encountered, soakaway drainage is unlikely to be suitable at this site.

8.0 SOIL CONTAMINATION RISK ASSESSMENT

8.1 Tier I Human Health Soil Risk Assessment – Groundworkers During Development

To assess the risk of soil contamination to construction and ground workers during development, guidelines from the HSE Document 'Protection of workers and the general public during development of contaminated land'⁽¹⁹⁹¹⁾ are used. The document assesses soil contamination test results and classifies the site as being uncontaminated or contaminated with varying degrees of contamination from 'slight' to 'unusually heavy'. The guideline values and laboratory test results are summarised in the following table:

Table 8: Summary of Guideline Values for Protection of Workers and the General Public During Development of Contaminated Land

Contaminant	Typical Values* for:					Test Results	Class
	Uncontaminated Soils	Slight Contamination	Contaminated	Heavy Contamination	Unusually Heavy Contamination		
	Class A	Class B	Class C	Class D	Class E		
pH (alkaline)	7 - 8	8 - 9	9 - 10	10 - 12	12	7.4 - 8.3	A - B
Arsenic	0 - 30	30 - 50	50 - 100	100 - 500	500	7 - 29	A
Cadmium	0 - 1	1 - 3	3 - 10	10 - 50	50	< 0.2 - 0.8	A
Chromium	0 - 100	100 - 200	200 - 500	500 - 2500	2500	10 - 48	A
Copper	0 - 100	100 - 200	200 - 500	500 - 2500	2500	22 - 115	A - B
Lead	0 - 500	500 - 1000	1000 - 2000	2000 - 1%	1.0%	19 - 307	A
Mercury	0 - 1	1 - 3	3 - 10	10 - 50	50	< 1 - 1.5	A - B
Nickel	0 - 20	20 - 50	50 - 200	200 - 1000	1000	11 - 59	A - C
Zinc	0 - 250	250 - 500	500 - 1000	1000 - 5000	5000	54 - 1050	A - D
Boron	0 - 2	2 - 5	5 - 50	50 - 250	250	< 1 - 1.4	A
Selenium	0 - 1	1 - 3	3 - 10	10 - 50	50	< 3	A
Barium	0-500	500-1000	1000-2000	2000-1.0%	1.0%	147 - 503	A - B
Beryllium	0 - 5	5 - 10	10 - 20	20 - 50	50	0.7 - 2.8	A
Vanadium	0 - 100	100 - 200	200 - 500	500 - 2500	2500	16 - 99	A
Sulphate	0 - 2000	2000 - 5000	5000 - 1%	1% - 5%	5.05%	948-19210	A - D
Sulphide	0 - 10	10 - 20	20 - 100	100 - 500	500	< 5	A
Cyanide (free)	0 - 1	1 - 5	5 - 50	50 - 100	100	< 2	A
Phenol	0 - 2	2 - 5	5 - 50	50 - 250	250	< 2	A

Based on the above results it is considered there is a moderate potential risk from soil contamination to construction workers, ground workers and members of the public during construction. Appropriate measures, such as PPE, site health plans, and appropriate disposal of material arising will be required to mitigate any risk.

8.2 Tier I Human Health Soil Risk Assessment – Future Site Users

The following section provides a Human Health Soil Assessment for future site users. The following section compares the results of contamination analyses to residential types of end development as specified by Defra/LQM/CIEH. As part of the contamination assessment, the chemical results obtained by EEG have been screened against accepted compliance criteria, namely:

- Defra C4SL Health Criteria Values (March 2014), where available; and
- Tier 1 assessment values - based on LQM/CIEH Suitable 4 Use Levels⁽²⁰¹⁵⁾ (S4ULs).

The soil chemical testing results are summarised in Table 9 overleaf.

Table 9: Soil Results Comparison with C4SL/S4UL Values

Determinand	C4SL/S4UL Levels Residential (mg/kg)	TP1 0.75m MG	TP1 1.20m MG	TP2 0.80m MG	TP3 0.30m MG	TP3 1.00m MG	TP4 0.50m MG	TP5 0.40m MG	TP6 0.30m MG	TP6 0.90m MG	TP7 0.20m MG	TP8 0.70m MG	TP9 0.50m MG	TP10 0.40m MG	TP11 0.60m MG	TP12 1.00m MG	No of Exceedances
Metals																	
Arsenic	37	11	18	29	21	25	14	13	14	16	13	7	14	8	7	27	0
Boron	290	< 1	1.4	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	0
Cadmium	22	0.2	0.7	0.8	0.4	< 0.2	0.3	0.3	< 0.2	0.2	0.3	0.2	0.3	0.3	< 0.2	< 0.2	0
Chromium	910	22	20	28	25	48	27	29	30	27	36	10	20	20	16	38	0
Chromium VI	21	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	0
Copper	2400	33	71	115	90	90	67	32	57	84	86	22	33	26	22	107	0
Lead	200	24	307	196	128	80	110	39	88	96	54	108	68	113	19	162	1
Inorganic Mercury	1.2	< 1	< 1	1.5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	1
Nickel	180	19	23	28	26	33	26	15	20	27	59	11	24	16	18	24	0
Selenium	250	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	0
Vanadium	410	28	42	53	59	99	50	61	54	51	56	16	31	25	23	82	0
Zinc	3700	54	1050	375	127	127	111	89	75	127	99	144	115	708	111	128	0
Petroleum Hydrocarbons																	
Benzene	0.087	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0
Toluene	130	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0
Ethylbenzene	47	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0
o-xylenes	60	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.004	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0
m-xylenes	59	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.005	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0
p-xylenes	56	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.005	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0
Aliphatic EC >5-6	42	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0
Aliphatic EC >6-8	100	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0
Aliphatic EC >8-10	27	< 2	< 2	< 2	< 2	< 2	< 2	8	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	0
Aliphatic EC >10-12	130 (v)	< 2	< 2	< 2	< 2	< 2	< 2	6	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	0
Aliphatic EC >12-16	1100 (s)	< 3	< 3	< 3	< 3	< 3	< 3	12	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	0
Aliphatic EC >16-21	65000 (s)	< 3	< 3	< 3	15	< 3	< 3	7	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	0
Aliphatic EC >21-35	65000 (s)	< 10	< 10	< 10	141	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	0
Aromatic EC >5-7	70	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0
Aromatic EC >7-8	130	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0
Aromatic EC >8-10	34	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	0
Aromatic EC >10-12	74	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	0
Aromatic EC >12-16	140	< 2	7	3	3	< 2	< 2	20	67	8	< 2	< 2	< 2	< 2	11	9	0
Aromatic EC >16-21	260	< 3	18	15	23	< 3	< 3	26	327	21	16	< 3	< 3	13	44	22	1
Aromatic EC >21-35	1100	< 10	14	49	163	< 10	< 10	< 10	353	26	94	< 10	< 10	< 10	44	36	0

Determinand	C4SL/S4UL Levels Residential (mg/kg)	TP1 0.75m MG	TP1 1.20m MG	TP2 0.80m MG	TP3 0.30m MG	TP3 1.00m MG	TP4 0.50m MG	TP5 0.40m MG	TP6 0.30m MG	TP6 0.90m MG	TP7 0.20m MG	TP8 0.70m MG	TP9 0.50m MG	TP10 0.40m MG	TP11 0.60m MG	TP12 1.00m MG	No of Exceedances
Polycyclic Aromatic Hydrocarbons																	
Naphthalene	2.3	< 0.1	0.51	0.11	0.19	< 0.1	0.13	0.17	0.86	0.22	< 0.1	< 0.1	< 0.1	< 0.1	0.2	0.42	0
Acenaphthylene	210	< 0.1	0.14	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	1.58	0.26	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0
Acenaphthene	170	< 0.1	0.14	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	1.06	0.23	< 0.1	< 0.1	< 0.1	< 0.1	2.75	0.29	0
Fluorene	170	< 0.1	0.22	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	5.58	0.26	< 0.1	< 0.1	< 0.1	< 0.1	1.53	0.17	0
Phenanthrene	95	< 0.1	2.4	0.5	0.55	0.23	0.67	0.69	44.6	2.72	0.37	0.32	0.2	0.75	14.7	2.8	0
Anthracene	2400	< 0.1	0.52	0.16	0.18	< 0.1	< 0.1	< 0.1	23	0.69	0.15	< 0.1	< 0.1	< 0.1	4.07	0.5	0
Fluoranthene	280	< 0.1	3.52	2.71	1.81	0.5	0.47	0.17	55.1	2.75	2.61	0.19	< 0.1	1.07	16.9	3.53	0
Pyrene	620	< 0.1	3.25	3.46	2.06	0.49	0.46	0.22	42.9	2.31	2.82	0.18	< 0.1	0.78	13.6	3	0
Benzo(a)anthracene	7.2	< 0.1	1.85	1.82	1.1	0.32	0.23	0.16	24.3	1.67	2.98	< 0.1	< 0.1	0.32	5.04	1.24	1
Chrysene	15	< 0.1	1.87	1.76	1.17	0.38	0.3	0.16	21.7	1.48	2.6	0.13	< 0.1	0.57	4.14	1.27	1
Benzo(a)pyrene	5	0.12	1.15	2.81	1.64	0.27	0.36	< 0.1	13.3	1.28	5.46	< 0.1	< 0.1	0.33	3.72	0.85	2
Benzo(b)fluoranthene	2.6	0.16	1.99	3.21	1.97	0.43	0.53	< 0.1	16.4	1.51	5.37	0.13	< 0.1	0.52	4.04	1.27	4
Benzo(k)fluoranthene	77	< 0.1	0.71	1.25	0.9	0.18	0.2	< 0.1	6.65	0.67	2.44	< 0.1	< 0.1	0.24	1.84	0.37	0
Indeno(1,2,3-cd)pyrene	27	0.12	0.52	1.63	1.02	0.16	0.27	< 0.1	4.43	0.56	2.75	< 0.1	< 0.1	0.2	1.93	0.42	0
Dibenz(a,h)anthracene	0.24	< 0.1	0.16	0.3	0.19	< 0.1	< 0.1	< 0.1	1.14	0.19	0.48	< 0.1	< 0.1	< 0.1	0.3	0.15	4
Benzo(ghi)perylene	320	0.12	0.47	1.49	0.89	0.16	0.27	< 0.1	3	0.5	2.32	< 0.1	< 0.1	0.18	1.83	0.4	0
Phenols																	
Phenol	280	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	0
Concentrations in red above assessment criteria MG = Made Ground																	

Elevated concentrations of contaminants of concern, with respect to the long-term protection of human health, have been identified at four locations across the site when compared to residential end use (with plant uptake) assessment criteria. The contaminants identified are presented as Table 10 below.

Table 10: Summary of Soil Contamination

Contaminant	Location
Lead	TP1 (1.20m)
Inorganic Mercury	TP2 (0.80m)
TPH	TP6 (0.30m)
PAH	TP2 (0.80m), TP6 (0.30m), TP7 (0.20m) & TP11 (0.60m)

Asbestos fibres or fragments were not identified in any of the samples tested during this investigation.

8.3 Controlled Water Assessment

In the absence of specific UK guidelines regarding groundwater quality in the UK, chemical results obtained by EEG have been compared with the following statutory and non-statutory standards:

- Environmental Quality Standards (EQS); and
- UK Drinking Water standards⁽²⁰⁰⁰⁾.

EQS values have been derived to protect surface water, however there are no surface water features identified within 250m of the site boundary.

In the absence of EQS values, Drinking Water Standards have been used for comparison of results. Again, these standards are highly conservative, especially in this site context. A direct comparison was made between the groundwater analyses results and the EQS and Drinking Water Standards, and the results are summarised in Table 11, overleaf.

The laboratory analyses encountered levels of contamination below the EQS and Drinking Water Standards.

Table 11: Groundwater Results Comparisons with EQS/Drinking Water Quality Values

Determinand	EQS Value (1)	Drinking Water Quality (DWQ) Value (2)	RH1	RH4	RH5	No. of Exceedances
Arsenic	50	10	<5	<5	< 5	0
Cadmium	0.9	5	< 0.4	< 0.4	< 0.4	0
Chromium	50	-	< 5	< 5	< 5	0
Copper	10	2000	< 5	< 5	<5	0
Lead	1.2 - 14	10	< 5	< 5	< 5	0
Mercury	0.1	1.0	< 0.05	0.07	0.1	0
Selenium	-	10	< 5	< 5	< 5	0
Nickel	50 - 200	20	<5	<5	< 5	0
Zinc	75	-	< 2	< 2	<2	0
Total Cyanide	-	50	< 5	< 5	< 5	0
Phenol	7.7 - 46	-	< 10	< 10	< 10	0
Sulphate	250000	250000	74	87	168	0
pH	6 - 9	-	7.9	7.8	7.8	0
Naphthalene	10	-	<0.01	<0.01	< 0.01	0
Anthracene	0.1		< 0.01	< 0.01	< 0.01	0
Benzo(a)pyrene	0.27	0.01	<0.01	< 0.01	< 0.01	0
Benzo(b)fluoranthene	0.017	0.10	< 0.01	< 0.01	< 0.01	0
Benzo(k)fluoranthene	0.017		< 0.01	< 0.01	< 0.01	0
Indeno(123cd)pyrene	-	0.10	< 0.01	< 0.01	< 0.01	0
Fluoranthene	0.12		0.08	< 0.01	< 0.01	0
EPH		10 (withdrawn)	< 10	< 10	< 10	0
Benzene	10 - 50		< 1	< 1	< 1	0
Toluene	50 - 380		< 5	< 5	< 5	0
Ethylbenzene	20 - 200	-	< 5	< 5	< 5	0
Xylenes	30	0.10	< 10	< 10	< 10	0

8.4 Soil Waste Assessment

An assessment of the disposal characteristics of the soil in accordance with Environment Agency guidance WM3.1, edition of June 2018, "Guidance on the classification and assessment of waste" has been carried out on soils recovered from the site, using HazWasteOnline.

The results are summarised in Table 12 below and presented in full in Appendix 4.

Table 12: Waste Classification of Soils

Location	Depth (m bgl)	WM3.1 Classification	Comments
TP1	0.75	Non-Hazardous	-
TP1	1.20	Non-Hazardous	-
TP2	0.80	Non-Hazardous	-
TP3	0.30	Non-Hazardous	-
TP3	1.00	Non-Hazardous	-
TP4	0.50	Non-Hazardous	-
TP5	0.40	Non-Hazardous	-
TP6	0.30	Non-Hazardous	-
TP6	0.90	Non-Hazardous	-
TP7	0.20	Non-Hazardous	-
TP8	0.70	Non-Hazardous	-
TP9	0.50	Non-Hazardous	-
TP10	0.40	Non-Hazardous	-
TP11	0.60	Non-Hazardous	-
TP12	1.00	Non-Hazardous	-

9.0 GROUND GAS AND RADON GAS CONTAMINATION RISK ASSESSMENT

9.1 Radon Gas

The site is located within a Radon Affected Area as defined by the Health Protection Agency, as between 3% and 5% of properties are above the Action Level of exposure and therefore basic radon protection measures will be necessary for any new properties.

9.2 Analyses of Monitoring Results

The potential risk associated with gases being generated in the ground (whether from natural or man-made sources) depends on the concentrations of gas and its flow rate to the surface. These factors are assessed by monitoring of the gas installations in the boreholes. The variable nature of gas generation and the effect of barometric pressure on gas flow, means that the volume of gas potentially reaching the ground surface is normally inconsistent over time.

Four gas monitoring visits have been completed by Earth Environmental & Geotechnical Ltd so far. The monitoring visits were conducted on 21st and 5th August 2020. The results recorded methane (CH₄) levels of 0.0% to 0.2% v/v with carbon dioxide (CO₂) levels of 0.1% to 7.4% v/v.

A peak flow rate of 0.1l/hr was detected across the site visits. Atmospheric pressure was recorded to be between 983mb and 1012mb.

Full results of the monitoring to date are presented in Appendix 5.

Table 13 overleaf, adapted from Table 1 of the technical paper Risk and Reliability in Gas Protection Design by Card et al. 2019, shows a summary of the current UK practice with respect to appropriate gas protection measures based upon a Gas Screening Value (GSV). A GSV for the site has been obtained by multiplying the maximum concentration of gas by the maximum flow rate, which represents worst-case scenario conditions.

- Carbon dioxide: maximum flow rate = 0.1 l/hr, max concentration = 7.5%
- Methane: maximum flow rate = 0.1l/hr, max concentration = 0.2%.

Based on the above figures, the GSV is calculated as:

- **Carbon dioxide:** $GSV = 0.1 \times 7 / 100 = 0.0074 \text{ litres/hr}$
- **Methane:** $GSV = 0.1 \times 0.2 / 100 = 0.0002 \text{ litres/hr}$

The above results suggest the site can be given a Gas Regime A classification, i.e. 'negligible to very low risk', in accordance with Table 12 overleaf.

Table 13: Modified Ground Gas Classification Table (Risk and Reliability in Gas Protection Design, 2019)

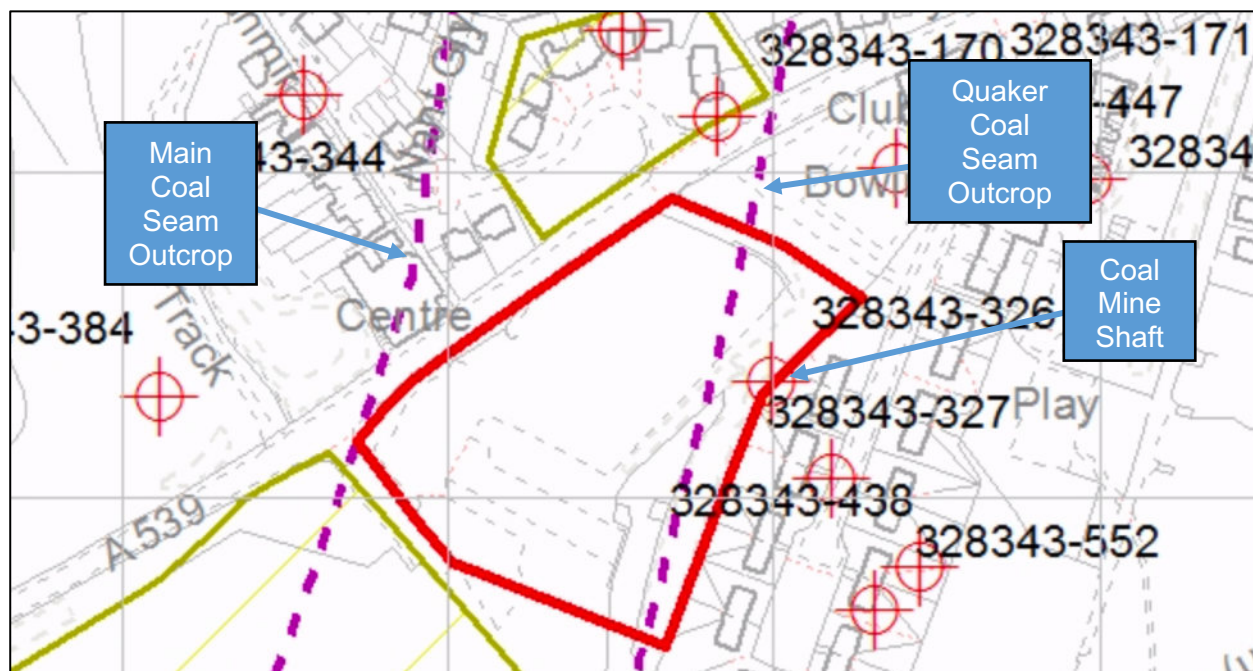
<i>Characteristic Situation</i>	<i>Pathway vertical permeability (m/s)</i>	<i>GSV CH₄ (l/hr)</i>	<i>GSV CO₂ (l/h)</i>	<i>GSV oxygen deficient gas (Nitrogen) (l/h)</i>	<i>Maximum borehole gauge pressure (Pa)</i>	<i>Limiting sustained gas concentrations in unsaturated zone within 10m of surface</i>	<i>Limitations</i>	<i>Risk level</i>
Gas Regime A	$\leq 1 \times 10^{-7}$ $1 \times 10^{-7} < k < 1 \times 10^{-5}$ $\geq 1 \times 10^{-5}$	< 2 < 1.5 < 1.3	< 12 < 9 < 7	< 217 for all permeability (care when using this value. Usually oxygen deficient gas emissions are sporadic, and monitoring should cover suitable situations)	500 (50mm water) – ASTM (2016)	$< 30\%$ methane $< 21\%$ carbon dioxide No limit on oxygen depletion because it is widespread in natural	No limit on oxygen depletion because it is widespread in natural soils and fill materials due chemical and biological processes	Negligible to very low
Gas Regime B	$\leq 1 \times 10^{-7}$ $1 \times 10^{-7} < k < 1 \times 10^{-5}$ $\geq 1 \times 10^{-5}$	≤ 10 ≤ 7.5 ≤ 6	< 140 < 100 < 85	No Limit	No limit			Low to moderate
Gas Regime C	$\leq 1 \times 10^{-7}$ $1 \times 10^{-7} < k < 1 \times 10^{-5}$ $\geq 1 \times 10^{-5}$	≤ 100 ≤ 75 ≤ 60	No limiting values	No Limit	No limit	No limit	Where oxygen deficient ground gas or carbon dioxide is likely to be emitted from shafts, fractured rock or ground where $k > 1 \times 10^{-4}$ m/s undertake DQRA	Moderate to high
Gas Regime D		N/A	N/A	N/A			DQRA required	Very high

10.0 COAL MINING RISK ASSESSMENT

Six rotary open hole boreholes were drilled due to the site area lying within a Coal Authority Development High Risk Area due to three locally outcropping coal seams.

Figure 5 (below) presents an extract from the Coal Authority Mining Report that shows the locations of the nearby coal seams. The Main Coal Seam is shown to be outcropping adjacent to the western corner of the site while the Quaker Coal Seam outcrops in the east of the site. A coal mine shaft is present on the eastern site boundary where a steep slope is located.

Figure 5: Extract from Coal Authority Mining Report



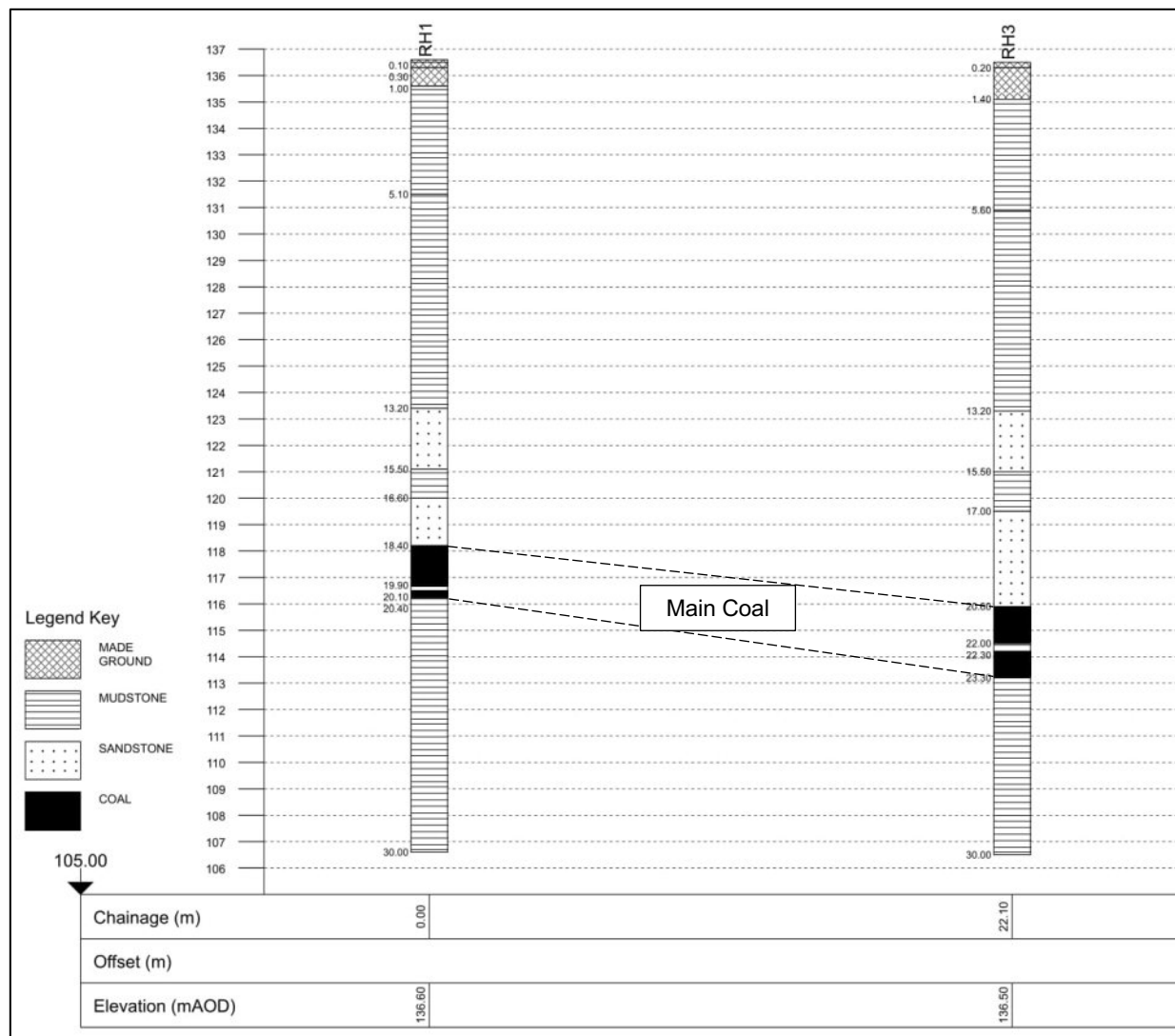
In general, a sequence of alternating mudstone and sandstone was found below the site. Intact coal (Main coal seam) was encountered in RH1 at 18.40m to 19.90m (1.50m thickness) and 20.10m to 20.40m (0.30m thickness). In RH3 the Main coal seam was encountered at 20.60m to 22.00m (1.40m thickness) and 22.30m to 23.30m (1.00m thickness). A cross-section of these boreholes is shown overleaf as Figure 6. The coal found in these boreholes is thought to be the Main Coal Seam with a thin layer of black shale separating the seam into two layers. The total thickness at RH1 is 2m and 2.7m at RH3 which accords with local records with a full sequence of 2.9m.

The dip of strata between RH1 and RH3 is six degrees which accords with local mining records of eight degrees.

All the boreholes proved an absence of any shallow mineworkings which would have been detected by drillers observations, including weight on bit, torque, loss of flush, drilling rate, drilling returns and rapid vertical displacement of the drilling rods.

During drilling an infra-red gas analyser (GA2000) was used to measure the borehole annulus for the concentration of methane, carbon-dioxide, carbon monoxide and hydrogen sulphide. No elevated concentrations of any ground gas were detected during the drilling works.

Figure 6: Cross Section of Encountered Coal Seam



11.0 CONCLUSIONS & RECOMMENDATIONS

11.1 Soil Contamination

There is a medium potential risk from soil contamination to construction workers and ground workers during development, and appropriate measures such as PPE, site health plans, appropriate disposal of material arisings will be required to mitigate this risk. The groundworks contractor must provide a soil management plan including methods of dealing with unanticipated soil contamination encountered during groundworks.

Based on the results of the chemical testing, exceedances in contaminants were observed in four sampling locations. The contaminants included beryllium, lead, mercury, one species of total petroleum hydrocarbons (TPH) five species of polycyclic aromatic hydrocarbons (PAHs) which pose a moderate risk to future residential end users.

In order to break potential pollutant linkages to future residential end users, it is recommended that landscaped areas in close proximity to the contaminated areas should be capped with clean cover soils.

A Remediation Strategy is recommended to specify the design of the capping system and any following validation work.

Alternatively, further contamination testing may allow for delineation of the “hot-spots”.

The presence of higher levels of contamination on areas of the site not covered by the current exploratory holes should not be discounted and additional spot checks would be prudent, particularly during groundworks. This testing can be carried out as part of the Soil Management Plan for the site.

11.2 Controlled Water Risk

11.3 Foundations

Foundations should be placed within the natural stiff clay beneath the Made Ground.

Due to the thickness of the Made Ground suspended ground floor slabs should be utilised.

For concrete placed in the Made Ground the Design Sulphate Class for the site, should be taken as DS-2, and the Aggressive Chemical Environment for Concrete (ACEC) site classification be taken as AC-1s.

11.4 Asbestos

No asbestos fibres or fragments were detected in any of the soil samples analysed during this investigation.

11.5 Soil Disposal

Soils should be disposed of at a suitable site, registered to take the levels of contamination encountered. The soils collected from all borehole locations have been classified as Non-

Hazardous (See Table 11) for the purpose of off-site disposal in accordance with Environment Agency guidance WM3.1.

Further Waste Acceptance Criteria testing may allow for the surplus material to be classified as acceptable as Inert.

11.6 Risk to Buried (Water) Services

It is considered that, due to the presence of contamination, non-standard materials may be required for new water pipes. Further advice should be sought from the local water company.

Previous guidance on buried water pipes was contained in Water Regulations Advisory Scheme (WRAS) Guidance Note No. 9-04-03⁽²⁰⁰²⁾, however this has been superseded by the UK Water Industry Research Report 'Guidance for the Selection of Water Supply Pipes to be used in Brownfield Sites' Ref 10/WM/03/21 (January 2011).

11.7 Ground Gas/Radon

The site is in a Radon Affected Area as defined by the Health Protection Agency and basic radon protection measures are therefore necessary.

It should be appreciated that the risk rating is based on a sparse dataset and a site-specific assessment may preclude the need for radon protection measures.

Appropriate construction techniques are detailed in the BRE document Radon: guidance on protective measures for new dwellings⁽¹⁹⁹⁹⁾.

Based on results of gas monitoring, protection against the ingress of ground gas (methane, carbon-dioxide) will not be required.

11.8 Coal Mining

Six rotary open hole boreholes have been drilled across the site, to a depth of 30m, and despite the identification of coal under the site, they have revealed a lack of evidence for the presence of shallow mine workings.

As a result, ground remedial measures such as strengthening of foundations or mine grouting will not be required.

11.9 Site Personnel

As with all construction sites, personnel working on the site during the construction period should be encouraged to maintain a high standard of personal hygiene and on-site washing facilities should be available.

11.10 Other Matters

Due diligence is required during the construction period, and should any further evidence of contamination be found, appropriate investigation and / or action should be taken. The significance of any contamination not discovered by this investigation is outside the scope of this report.

APPENDIX 1

EXPLORATORY HOLE LOGS

APPENDIX 2

GEOTECHNICAL TESTING RESULTS

APPENDIX 3

CHEMICAL TESTING RESULTS

APPENDIX 4

SOIL WASTE ASSESSMENT

APPENDIX 5

MONITORING RESULTS

APPENDIX 6

REPORT LIMITATIONS

REPORT LIMITATIONS

This contract was completed by Earth Environmental & Geotechnical Ltd on the basis of a defined programme and scope of works and terms and conditions agreed with the client. This report was compiled with all reasonable skill, and care, bearing in mind the project objectives, the agreed scope of works, the prevailing site conditions, the budget and staff resources allocated to the project.

Other than that, expressly contained in the above paragraph, Earth Environmental & Geotechnical Ltd provides no other representation or warranty whether express or implied, is made in relation to the services. Unless otherwise agreed this report has been prepared exclusively for the use and reliance of the client in accordance with generally accepted consulting practices and for the intended purposes as stated in the agreement under which this work was completed. This report may not be relied upon, or transferred to, by any other party without the written agreement of a Director of Earth Environmental & Geotechnical Ltd.

If a third party relies on this report, it does so wholly at its own and sole risk and Earth Environmental & Geotechnical Ltd disclaims any liability to such parties.

It is Earth Environmental & Geotechnical Ltd understanding that this report is to be used for the purpose described in the introduction to the report. That purpose was an important factor in determining the scope and level of the services. Should the purpose for which the report is used, or the proposed use of the site change, this report will no longer be valid and any further use of, or reliance upon the report in those circumstances by the client without Earth Environmental & Geotechnical Ltd review and advice shall be at the client's sole and own risk.

The report was written in 2020 and should be read in light of any subsequent changes in legislation, statutory requirements and industry best practices. Ground conditions can also change over time and further investigations or assessment should be made if there is any significant delay in acting on the findings of this report. The passage of time may result in changes in site conditions, regulatory or other legal provisions, technology or economic conditions which could render the report inaccurate or unreliable. The information and conclusions contained in this report should not be relied upon in the future without the written advice of Earth Environmental & Geotechnical Ltd. In the absence of such written advice of Earth Environmental & Geotechnical Ltd, reliance on the report in the future shall be at the client's own and sole risk. Should Earth Environmental & Geotechnical Ltd be requested to review the report in the future, Earth Environmental & Geotechnical Ltd shall be entitled to additional payment at the then existing rate or such other terms as may be agreed between Earth Environmental & Geotechnical Ltd and the client.

The observations and conclusions described in this report are based solely upon the services that were provided pursuant to the agreement between the client and Earth Environmental & Geotechnical Ltd. Earth Environmental & Geotechnical Ltd has not performed any observations, investigations, studies or testing not specifically set out or mentioned within this report.

Earth Environmental & Geotechnical Ltd is not liable for the existence of any condition, the discovery of which would require performance of services not otherwise contained in the services. For the avoidance of doubt, unless otherwise expressly referred to in the introduction to this report, Earth Environmental & Geotechnical Ltd did not seek to evaluate the presence on or off the site of electromagnetic fields, lead paint, radon gas or other radioactive materials.

The services are based upon Earth Environmental & Geotechnical Ltd observations of existing physical conditions at the site gained from a walkover survey of the site together with Earth Environmental & Geotechnical Ltd interpretation of information including documentation, obtained from third parties and from the client on the history and usage of the site. The findings and recommendations contained in this report are based in part upon information provided by third parties, and whilst Earth Environmental & Geotechnical Ltd have no reason to doubt the accuracy and that it has been provided in full from those it was requested from, the items relied on have not been verified.

No responsibility can be accepted for errors within third party items presented in this report. Further Earth Environmental & Geotechnical Ltd was not authorised and did not attempt to independently verify the accuracy or completeness of information, documentation or materials received from the client or third parties, including laboratories and information services, during the performance of the services. Earth Environmental & Geotechnical Ltd is not liable for any inaccurate information, misrepresentation of data or conclusions, the discovery of which inaccuracies required the doing of any act including the gathering of any information which was not reasonably available to Earth Environmental & Geotechnical Ltd and including the doing of any independent investigation of the information provided to Earth Environmental & Geotechnical Ltd save as otherwise provided in the terms of the contract between the client and Earth Environmental & Geotechnical Ltd.

Where field investigations have been carried out these have been restricted to a level of detail required to achieve the stated objectives of the work. Ground conditions can also be variable and as investigation excavations only allow examination of the ground at discrete locations. The potential exists for ground conditions to be encountered which are different to those considered in this report. The extent of the limited area depends on the soil and groundwater conditions, together with the position of any current structures and underground facilities and natural and other activities on site. In addition, chemical analysis was carried out for a limited number of parameters [as stipulated in the contract between the client and Earth Environmental & Geotechnical Ltd] based on an understanding of the available operational and historical information, and it should not be inferred that other chemical species are not present.

The groundwater conditions entered on the exploratory hole records are those observed at the time of investigation. The normal speed of investigation usually does not permit the recording of an equilibrium water level for any one water strike. Moreover, groundwater levels are subject to seasonal variation or changes in local drainage conditions and higher groundwater levels may occur at other times of the year than were recorded during this investigation.

Any site drawing(s) provided in this report is (are) not meant to be an accurate base plan but is (are) used to present the general relative locations of features on, and surrounding, the site.