LITHOS

Geoenvironmental Appraisal

Land at Barnsley West, Land Transfer One

For Strata Homes Ltd

Report no: 3104/1

Date: March 2022

SUMMARY OF GEOENVIRONMENTAL ISSUES

Job No.	3104	**Site area/ha**	21.4 hectares
Client:	Strata Homes Ltd	**NGR:**	SE 315 077
Site:	Barnsley West, Land Transfer One	**Nearest postcode:**	S75 1NU

The site is located to the south of Barugh Green Road between Higham and Barnsley town centre and currently comprises arable and grazing farmland. The topography of the site slopes down to the northeast whilst the topography of the wider area slopes down to the north and up to the south.

About 60% of the site's area has been subject to coal extraction from two areas of opencast; Craven I which underlays the majority of the site area, targeted a Thin Coal and the Swallow Wood Coal and reaches depths of between c. 5.0m and 12.6m; and Craven II which underlays the south of the site (line of a proposed spine road), targeted the Thin, Swallow Wood, Top Haigh and Low Haigh coals and reaches depths of around 30m.

Lithos were commissioned by Strata to provide a geoenvironmental appraisal of the site, which it is understood is to be redeveloped with a mixture of residential dwellings (Development Areas 1 & 2), retail units (Development Area 3) and a school (Development Area 4). In addition, a spine road is proposed which runs north to south through the site and extends to the south.

Lithos' investigation included a review of 3rd party reports, the site's history and environmental setting, and a ground investigation comprising 102 trial pits, 44 trial trenches, 20 cable percussion boreholes, 10 rotary cored boreholes, 70 rotary open probeholes and 17 groups of rotary stitch probeholes.

A summary of salient geoenvironmental issues is provided in the table below:

Issue	Remarks
Made ground	Made Ground is present across the majority of the site area, both inside & outside the footprint of former opencasts, and typically comprises the following succession: Made Ground Topsoil over Cohesive Made Ground over Cohesive & Granular Opencast Backfill which often includes oversized cobbles & boulders. The site has been divided into Areas based on the depth of made ground: Area A; <0.9m of MG; Area B; 0.9m to 2.5m of MG; Area C; >2.5m of MG & beyond opencasts; &, Area D; within opencasts & 5.0m to 12.6m MG (Craven I & c. 30m of MG (Craven II).
Natural ground	Comprises a veneer of Cohesive & Granular Residual Soil over Lower Coal Measures bedrock which lies at between c. 1.0m (outside of opencasts), up to 12.6m (Craven I opencast) & c. 30m (within Craven II opencast). The bedrock typically comprises mudstone, with interbedded sandstone and siltstone.
Contamination	To date no significant contamination has been encountered. Topsoil & Cohesive Made Ground across the site is considered chemically suitable for re-use in gardens and areas and POS.
Mining & quarrying	No evidence of shallow underground mineworkings has been encountered. About 60% of the total site area has been subject to opencast coal extraction in the Craven I (majority of the site; c. 5.0m to 12.6m deep) & Craven II (south of the site, c. 30m deep) opencast sites.
Hazardous gas	Monitoring wells have been installed in 34 boreholes/probeholes & monitoring for hazardous gasses is ongoing. A Hazardous Gas Risk Assessment shall be issued on completion of the monitoring in July 2022.
Preparatory works	Topsoil strip & stockpile. Regrade of site topography to levels determined during the geotechnical design phase. Turnover of the uppermost 3.0m of made ground across the development platform & re-engineering of soils may allow for the adoption of rafts, semi-raft or reinforced beam foundations.
Foundations	Plots where made ground is c. <2.5m thick could be founded on strip/trench footings seated in Coal Measures bedrock or Residual Soils. Plots underlain by >2.5m of made ground shall require alternative foundation solutions; likely rafts, semi-rafts, reinforced strips/ring beams or piles. The depth of made ground beneath plots will be strongly affected by the final development platform levels.

This brief summary should not be assumed to represent a complete account of all the potential geo-environmental issues that may exist at the site. As such it is strongly recommended that the report be read in its entirety.

SUMMARY OF GEOENVIRONMENTAL ISSUES

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Issue	Remarks
Settlement	Preliminary settlement assessment indicates that the potential range of total settlement (consolidation & creep) for the deepest area of backfill post development over the 60-year design life of the properties is between c. 30mm and c. 65mm. In areas of typical backfill depths, the potential range of total settlement is between c. 25mm and c. 50mm. Differential settlement will be of greatest concern in the highwall zone of influence, however, this will be mitigated via the use of a more robust foundation type. Away from the highwall zone of influence, differential settlement beneath individual plots is not expected to be more than c. 15mm (c. 25% of total maximum settlement).
Groundwater & excavations	Shallow excavations should generally remain dry in the short term, but deeper excavations, such as those for regrade or deep drainage may encounter some groundwater ingress. Localised areas perched groundwater in the Opencast Backfill should be expected, especially in the eastern parts of the site. Excavations should remain stable in the short term (where dry), but some overbreak is likely when excavating through Granular Colliery Spoil.
Flooding & drainage	The site lies in a Flood Zone 1 where the risk of flooding from rivers and sea is classified as low. Given the significant thicknesses of made ground across the site soakaways will not provide a suitable means of surface water disposal meaning alternative drainage solutions shall be required.
Highways	Made ground beneath highways should be excavated and reengineered to provide CBR values of at least 3%. Highways spanning buried highwalls should be reinforced with 2 layers of geogrid at the base of the engineered made ground.

Significant developer abnormals relating to geoenvironmental issues at the site are:

- Regrade of levels to those specified in the final geotechnical design
- Turnover of the uppermost 3.0m of made ground across the LT1 development platform and re-engineering of made ground to remove obstructions & enable the use of raft/reinforced ring beam foundations.
- Additional design & consideration to be given to any plots or structures which overlay the highwall zone of influence.

Some further work is required, most notably:

- Completion of monitoring & issue of a Hazardous Gas Risk Assessment.
- Preparation of a Remediation Statement.
- Preparation of an Earthworks Specification.
- Preparation of a Materials Management Plan (MMP) if import of materials is required.
- Further settlement assessment once proposed final ground levels are known, taking into account areas of cut (net stress reduction) and fill (net stress increase).

This brief summary should not be assumed to represent a complete account of all the potential geo-environmental issues that may exist at the site. As such it is strongly recommended that the report be read in its entirety.

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FOREWORD (geoenvironmental appraisal report)

This report has been prepared for the sole internal use and reliance of the Client named on page 1. This report shall not be relied upon or transferred to any other parties without the express written authorisation of Lithos Consulting Limited (Lithos); such authorisation not to be unreasonably withheld. If any unauthorised third party comes into possession of this report, they rely on it at their peril and the authors owe them no duty of care and skill.

This report has been reviewed by a Competent Person, as defined in the National Planning Policy Framework. We ensure that all projects are managed by individuals with necessary experience, relevant qualifications, and current membership of a relevant professional organisation. Records of engineers, project managers and reviewers involved in this project are maintained by us. Lithos QA/QC procedures for all our work forms an integral part of our ISO9001 accreditation and as such is regularly audited.

The report presents observations and factual data obtained during our site investigation and provides an assessment of geoenvironmental issues with respect to information provided by the Client regarding the proposed development. Further advice should be sought from Lithos prior to significant revision of the development proposals.

The report should be read in its entirety, including all associated drawings and appendices. Lithos cannot be held responsible for any misinterpretations arising from the use of extracts that are taken out of context. However, it should be noted that in order to keep the number of sheets of paper in the hard copy to a minimum, some information (e.g. full copy of the Landmark/Groundsure Report) is not included in the pdf, by request, it can be provided on a CD.

The findings and opinions conveyed in this report (including review of any third-party reports) are based on information obtained from a variety of sources as detailed within this report, and which Lithos believes are reliable. Reasonable care and skill has been applied in examining the information obtained. Nevertheless, Lithos cannot and does not guarantee the authenticity or reliability of the information it has relied upon.

The report represents the findings and opinions of experienced geoenvironmental consultants. Lithos does not provide legal advice and the advice of lawyers may also be required.

Intrusive investigation can only investigate shallow ground beneath a small proportion of the total site area. It is possible therefore that the intrusive investigation undertaken by Lithos, whilst fully appropriate, may not have encountered all significant subsurface conditions. Consequently, no liability can be accepted for conditions not revealed by the exploratory holes. Any opinion expressed as to the possible configuration of strata between or below exploratory holes is for guidance only and no responsibility is accepted as to its accuracy

It should be borne in mind that the timescale over which the investigation was undertaken may not allow the establishment of equilibrium groundwater levels. Particularly relevant in this context is that groundwater levels are susceptible to seasonal and other variations and may be higher during wetter periods than those encountered during this commission.

Where the report refers to the potential presence of invasive weeds such as Japanese Knotweed, or the presence of asbestos containing materials, it should be noted that the observations are for information only and should be verified by a suitably qualified expert.

Lithos cannot be responsible for the consequences of changing practices, revisions to waste management legislation etc that may affect the viability of proposed remediation options.

Lithos reserve the right to amend their conclusions and recommendations in the light of further information that may become available.

GEOENVIRONMENTAL APPRAISAL
of land at
BARNSLEY WEST, LAND TRANSFER ONE

1 INTRODUCTION

1.1 The commission and brief

1.1.1 Lithos Consulting Limited were commissioned by Strata Homes Ltd to carry out a geoenvironmental appraisal of land between Barnsley town and Higham.

1.1.2 The current area of interest comprises about 20% of a wider development area (c. 80 hectares) which is called Barnsley West. The current area occupies 21.4 hectares in the north of the wider development area and is called Barnsley West Land Transfer one (LT1).

1.1.3 Correspondence regarding Lithos' appointment, including the brief for this investigation, is included in Appendix C. The agreed scope of works included:

- A review of third party reports.
- A site walkover and inspection.
- An assessment of the land use history.
- Determination of the site's environmental setting.
- A mining risk assessment in accordance with Coal Authority guidance.
- An intrusive ground investigation comprising 102 trial pits, 44 trial trenches, 20 cable percussion boreholes, 10 rotary cored boreholes, 70 rotary probeholes and 17 groups of stitch probeholes.
- Assessment of the geotechnical properties of the near surface deposits to enable provision of foundation and highway recommendations.
- A qualitative assessment of contamination risks.
- Recommendations for the necessary site preparatory and remediation works.

1.1.4 Primary aims of this investigation were to identify salient geoenvironmental issues affecting the site to support the submission of a planning application, and also to enable Strata to obtain budget costs for: foundations; gas protection measures; and site preparatory and remediation works.

1.2 The proposed development

1.2.1 It is understood that the current area of interest (LT1) will be divided into four sub-areas as summarised below:

- **Development Area 1**; 93,800m^2 in the west of the site; to be developed with 229 residential dwellings by Strata Homes.
- **Development Area 2**; 42,300m^2 in the northeast; to be developed with 137 residential dwellings by Miller Homes.
- **Development Area 3**; 5,000m^2 in the centre to be developed with a retail building and associated parking.
- **Development Area 4**; 17,000m^2 in the southeast to be developed with a school building & associated outdoor play areas etc.

1.2.2 In addition, a **spine road** is proposed which runs roughly north to south through the site, divides Development Area 1 from Development Areas 2, 3 and 4 and which will extend beyond the southern boundary to provide access to the wider Barnsley West Development.

1.2.3 Portions of all 4 Development areas will be given to POS, adoptable roads, sewers, and gardens (attached to dwellings).

1.2.4 Site layouts for the Development Areas have been provided and a 'composite' development layout has been derived which is shown on Drawing 3104/2 in Appendix B.

1.2.5 It is understood that the wider Barnsley West site (c. 80 hectares to the south) will be given to a mixed residential and commercial end use in the future.

1.3 Report format and limitations

1.3.1 All standard definitions, procedures and guidance are contained within Appendix A, which includes background, generic information on:

- Assessment of the site's environmental setting
- Ground investigation fieldwork
- Geotechnical testing
- Contamination testing
- Hazardous gas

1.3.2 General notes and limitations relevant to all Lithos geoenvironmental investigations are described in the Foreword and should be read in conjunction with this report. The text of the report draws specific attention to any modification to these procedures and to any other special techniques employed.

1.3.3 In accordance with the agreed scope of works, the ground investigation reported here is not fully compliant with Eurocode 7 (EC7) and this report does not purport to be a Ground Investigation Report, nor a Geotechnical Design Report as defined by EC7. The ground appraisal, parametric assessment and preliminary design guidance presented are intended to assist others as they prepare the design of the proposed works.

2 SITE DESCRIPTION

2.1 General

2.1.1 The site's location is shown on Drawing 3104/1 presented in Appendix B to this report. Site details are summarised in the table below:

Detail	Remarks
Location	3km northwest of Barnsley town centre.
NGR	SE 315 077
Approximate area	21.4 hectares (52.9 acres).
Known services	Underground sewers & overhead electric.

2.2 Site features

2.2.1 Lithos completed a walkover survey of the site on the 5th & 11th October 2021.

2.2.2 Existing salient features, at the time of the walkovers are presented on Drawing 3104/3 in Appendix B to this report and summarised in the table below:

Feature	Remarks
Current Access	Several access points available; • Off Longley Street in the west. • Off Hermit Lane & across adjacent land to the south • Off Barugh Green Road to the north • Off Redbrook Road & through adjacent farmyard to the east.
Topography	Slopes down to the north with a typical gradient of about 1v:40h, and maximum gradients of c. 1v:12h. The wider area, notably land to the south, continues to rise up to the south.
Approximate areas	56,300m^2 arable farmland (stubble). 157,700m^2 grassland (grazing farmland).
Nature of boundaries	North – mature trees & hedgerows. South – no physical boundary. East – mature hedgerows (northeast) & no physical boundary (southeast). West – garden fences & hedgerows.
Surrounding land uses	North – Baugh Green Road, industrial & commercial buildings beyond. South – arable farmland. East – arable farmland, farm buildings & residential dwellings. West – residential dwellings.

2.2.3 A selection of site photographs is included on Drawing 3104/4.

2.2.4 The topography of the site and surrounding area falls to the south with an average gradient of about 1v:40h. The steepest gradients on site are in the southwest where slopes reach about 1v:12h. Ground is generally smooth underfoot with very broad and gentle undulations.

2.2.5 Within LT1, the grounds surface has an elevation of c. 125m AOD in the southwest corner, falling to c. 83m AOD in the far northeast part of the site. The topography of the wider site (beyond LT1) rises to the south, reaching an elevation of c. 155m AOD in the far south, and c. 140m AOD in the far east of the site.

2.2.6 LT1 is divided up into 6 fields by mature Hawthorne hedgerows with openings or gates between fields. The majority of fields comprise gazing land and are surfaced by grasses. The field in the west of the LT1 comprises arable farmland which was occupied by stubble and weed growth at the time of Lithos' walkovers.

2.2.7 The grazing land was occupied by a herd of cattle.

2.2.8 Three overhead electrical utilities run east to west across the south of the site atop wooden posts.

2.2.9 Access can be gained via a gate off Barugh Green Road in the north, via a farmyard which is located off-site to the east, via a gate off Hermit Lane and through adjacent fields to the south or via gaps between residential dwellings along Welland Court (road) and Avon Close (road) to the east.

2.2.10 Shallow drainage ditches run along the base of hedgerows in the north of LT1, which at the time of Lithos' walkover were dry, however during Lithos' ground investigation and following periods of rainfall, the ditches filled with a steady flow of surface water and drained to the northeast.

3 SITE HISTORY

3.1 Site centred extracts from Ordnance Survey (OS) plans dating back to 1855 have been examined. Some of these plans are presented in Appendix D to this report. The table below provides a summary of the salient points relating to the history of the site. It is not the intention of this report to describe in detail all the changes that have occurred on or adjacent to the site. Significant former uses/operations are highlighted in **bold** text for ease of reference.

Date	Site	Surrounding land
1855	Comprises open fields divided up by hedgerows. Areas of woodland in the south (along line of spine road). **Stream** issues in the centre-west & flows northeast through centre & northeast within a **valley**.	Higham (village) from 200m west. Gawber (village) from 400m east. Barugh Green Road runs east to west along northern boundary. Hermit Lane runs east to west beyond far-southern boundary.
1891	No significant changes.	Dwellings constructed immediately beyond northern boundary. Further residential dwellings developed in Higham (west) & Gawber (east). Bleach works shown 400m west. Residential dwellings developed from 350m north making up Barugh Green village.
1907	No significant changes.	Bleach Works renamed as Linen Works
1931	Footpath crosses south of the site.	No significant changes.
1938	No significant changes.	Railway sidings, chemical works, coke & by-product works, and associated buildings shown 250m to 350m northeast.
1948	Footpath no longer shown.	Development & expansion of Barugh Green & Higham to the west.
1960	**Opencast workings** (Craven I) in centre & south of site, with the extent of workings / highwalls not shown. Overhead electrical utility crosses the south. Drains shown across the centre-north & south. Woodland in the far-south no longer shown. Stream no longer shown.	Development of residential dwellings to the east. Extensive earthworks from c. 200m northeast associated with rail sidings, coke & chemical works & colliery buildings c. 1,000m north. **Opencast** workings directly south (Craven II), extent of workings / highwalls not shown.
1973	Opencast workings no longer shown, with current field boundaries in place.	Works buildings from 100m north. Colliery sidings, coke & chemical works to the north no longer shown. Opencast workings to the south no longer shown.
1983	No significant changes.	Further residential dwellings constructed to the east, west & immediately beyond western boundary. Linen works no longer shown. Tip shown from 250m northeast.
1993		Further residential dwellings developed to the west, southwest & east. Further works buildings & garages developed from 100m north & northeast. Tip no longer shown & partly developed with commercial buildings.
2000		No significant changes.
2013		Further industrial/commercial buildings to the north.

Date	Site	Surrounding land
2021		No significant changes.

3.2 The surrounding villages of Higham, Barugh Green and Gawber predominantly housed colliery workers throughout the 19th and early 20th centuries. Collieries were located in the immediate area including Higham Colliery (c. 1km south, operated from 1854 to 1898) and Beevers Colliery (c. 700m east, operated from 1888 to 1925).

3.3 Examination of contours shown on historical mapping prior to open-casting operations suggest that levels across the west of the site were around 1.0m lower than current day levels and that there was a broad valley in the centre of LT1, the base of which was about 3.5m lower than current day ground levels. It is apparent that during backfilling, following open-casting some regrading of site ground levels took place, most notably raising of ground levels in the west and infilling of the valley in the centre.

4 ENVIRONMENTAL SETTING

4.1 General

4.1.1 Notes describing how the site's environmental setting has been assessed are included in Appendix A to this report. Reference has been made to publicly available Government held digital data via QGIS (an Open Source Geographic Information System). Extracts from the response received from Landmark, and responses from the Coal Authority are presented in Appendix E. These responses are summarised below, together with the findings of our own "desk study" investigation.

Issue	Data reviewed	Summary
Geology	1:10,000 BGS map (Sheet SE30NW) BGS Memoir/Technical Report Geology of the county around Barnsley	Drift soils – none mapped; likely veneer of Residual Soils (gravelly clays). Solid (bedrock) – Lower Coal Measures (interbedded mudstone, siltstone & sandstone with coals, marine bands etc). Shallowest coal seam – Several seams outcrop across the site; Swallow Wood, Thin Coal & Gawber; further coal seams below. Strata dip - 5° to the east. Faults – several faults cross the immediate surrounding area, the southern & north western peripheries.
Mining	Coal Authority	The majority of the site is located within a Coal Mining Development High Risk Area. Opencast workings present across about 60% of the total site area. Potential for shallow workings; although if present, many of the workings are likely to have been removed during opencast. No known mine entries in, or within 20m of, LT1s boundary. Further details in Section 5 below.
Quarrying	Historical OS plans	c. 60% of the site's area has been subject to opencast coal extraction.
Radon	Public Health England Environment Agency electronic open data via QGIS Envirocheck Report	The site lies in an area where between 1% & 3% of homes are estimated to be above the action level. See Section 14.
Hydrogeology		Groundwater Source Protection Zone? None of significance. Aquifer None mapped (Drift); Secondary A (Solid). Groundwater abstractions? None of significance. Soil leaching potential - Medium. Pollution incidents? None of significance.
Hydrology		Nearest watercourse(s) – Un-named drainage ditches flow east across the northern boundary. Flow into Red Brook (c. 250m west) which in turn flows to the River Dearne; water quality moderate ecological & failing chemical. Pollution incidents? None of significance. Abstractions? None of significance. Discharge consents? None of significance.
Flood risk		The site lies in Flood Zone 1, where the risk of flooding from rivers or the sea is classified as low. In accordance with Chapter 10 of the National Planning Policy Framework, a site-specific flood risk assessment is required for proposals of 1 hectare or greater in Flood Zone 1, or in an area within Flood Zone 1 which has critical drainage problems (as notified to the local planning authority by the Environment Agency).

4.2 Landfills

4.2.1 Known or suspected areas of landfill in the vicinity of the proposed development site are summarised below:

Location	Proximity to site	Remarks	Source of data
Barugh Green Road, Barugh Green	70m north	Waste included inert waste. Provider ref. EAHLD04340. Operated by F Booker Builders/Contractors ltd.	Environment Agency & Landmark Report
South Yorkshire Industrial Estate (Redbrook, Barnsley)	120m northeast	Input from 30th September 1983 to 29th January 1990. Waste included commercial & inert waste. Provider ref. EAHLD04335. Operated by Northern Properties Ltd.	

4.2.2 The above areas of landfill have been developed with commercial/industrial units with associated estate roads, parking and ancillary buildings. Given the area has been developed it is unlikely that the deposited waste is overly degradable and capable of generating excessive volumes of hazardous ground gasses (although this cannot be discounted at this stage).

4.2.3 Furthermore, in relation to hazardous ground gasses, given the areas of backfilled opencast beneath this site and land to the south (see Section 5 below) the risk posed by the areas of off-site landfill, which have since been developed is somewhat reduced in comparison to the risks posed by the deep made ground located within LT1s boundary and across land to the south.

4.3 Mineral safeguarded areas

4.3.1 The site is underlain by coal and might therefore be considered by the Local Authority to lie within a Mineral Safeguarding Area (MSA).

4.3.2 MSAs are areas of known mineral resources that are of sufficient economic or conservation value to warrant protection for generations to come. The purpose of MSAs is not to preclude automatically other forms of development, but to make sure that mineral resources are adequately and effectively considered in land-use planning decisions.

4.3.3 Specialist guidance on Mineral Safeguarding "A Guide to Mineral Safeguarding in England" has been produced by The Coal Authority and the British Geological Survey.

4.3.4 Paragraph 204 of the National Planning Policy Framework (NPPF) requires Local Authorities, when preparing Local Plans to:

- Define Minerals Safeguarding Areas and adopt appropriate policies in order that known locations of specific minerals resources of local and national importance are not needlessly sterilised by non-mineral development, whilst not creating a presumption that resources defined will be worked; and define Minerals Consultation Areas based on these Minerals Safeguarding Areas.
- Set out policies to encourage the prior extraction of minerals, where practicable and environmentally feasible, if it is necessary for non-mineral development to take place.

4.3.5 NPPF Paragraph 144 notes that when determining planning applications, local planning authorities should give weight to the benefits of the mineral extraction.

4.3.6 As a consequence of the NPPF, and the presence of coal beneath the site, the Local Authority may require Strata to consider the opportunity to recover (extract) the coal. Applicants submitting planning applications may need to demonstrate to the Local Authority that they will extract the coal, unless:

- It can be shown it is not economically viable to do so, or
- It is not environmentally acceptable to do so, or
- The need for the development outweighs the need to extract the coal, or
- The coal will not be sterilised by the development

4.3.7 The majority of this site has already been subject to opencast coal extraction, consequently shallow coal of economic value has already been removed across most of the site area.

4.4 Agriculture

4.4.1 Historical plans show that the site has been occupied by arable farmland. Generally farming is not considered likely to have caused significant ground contamination. However, activities such as slurry spreading, the discharge of chemicals to ground, and unregulated burial are known to have occurred on farmland. Potential contaminants associated with farming activity could include any of the following.

Agricultural activity	Potential contaminant
Sewage farming, slurry spreading	Methane, metals, nitrates, oxygen depletion
Carcase burial	Anthrax & other biohazards
Plant & animal protection	Pesticides & herbicides
Timber processing/treatment	Metals, PAH, chlorinated organics
Soil conditioners	Metals, sulphates, PAH
Equipment maintenance	Hydrocarbons, metals
Waste burial, land levelling, backfilling ponds/quarries	Methane, metals, PAH etc
Naturally occurring contaminants	Arsenic, metals

4.4.2 Whilst it is likely that pesticides have been applied during arable use of the land, these are not likely to include the persistent organochloride pesticides such as Dieldrin, Aldrin, DDT etc. Pesticides routinely used on arable crops the UK (Phenoxy Acetic acid herbicide or PAAH) rapidly degrade in soils or leach via rainwater infiltration to groundwater. It is highly unlikely these would be detected by soil sampling and therefore it is not proposed to undertake analysis of these.

4.4.3 The generation of ground gas in quantities with the potential to impact upon the proposed development would only occur with the presence of significant quantities of organic matter. Ground gas monitoring is not considered necessary unless significant quantities of organic matter are identified during the ground investigation.

5 COAL & MINING

5.1 General

5.1.1 In July 2011 the Coal Authority (CA) formalised their requirements in relation to planning applications and introduced some new terminology relating to coal mining development areas. This Section (and Sections 11.8 and 11.9) provides the necessary mining risk assessment required by the proposed planning application.

5.1.2 About 60% of the total site area of LT1 is located in a Coal Mining Development **High Risk Area** – an area with specific mining legacy risks to the surface, including mine entries; shallow coal workings etc. The remaining c. 40% of the site area lies in a Development **Low Risk Area** - within the defined coalfield, but no known defined risks have been recorded by the Coal Authority; there may still be unrecorded issues.

5.2 Site geology

5.2.1 Several sources have been reviewed to determine the geology, including coal seams and underground/opencast workings, beneath this site. The anticipated geological succession is discussed below, and the underlying geology and coal mining features are shown on Drawings 3104/8 and 3104/10 respectively.

BGS Data

5.2.2 The geological map ref. SE30NW and the BGS memoir ref. 87 have been reviewed. These suggest that two coal seams outcrop at this site, with a further 4 seams present at shallow to moderate depth. These are the:

- **Thin (un-named) Coal:** Outcrops in the centre-south/walls of former opencast comprising a thin band of coal.
- **Swallow Wood Coal:** Outcrops in the walls of former opencast comprising a seam of 0.3m to 1.15m thickness made up of thin leaves of coal interbedded with dirt partings.
- **Top Haigh Coal:** About 28m below the Swallow Wood Coal comprising a single seam of 0.69m to 1.19m thickness.
- **Low Haigh Coal:** About 36m below the Swallow Wood Coal (c. 8m below the Top Haigh Coal) comprising a single seam of 0.43m to 1.02m thickness.
- **Lidgett Coal:** About 68m below the Swallow Wood Coal (c. 32m below the Low Haigh Coal) comprising a single seam of 0.3m to 1.52m thickness.
- **Joan Coal:** About 100m below the Swallow Wood Coal (c. 32m below the Lidgett Coal) comprising a single seam of 0.36m to 0.61m thickness.

5.2.3 Whilst the majority of the rock between the above coals is likely to comprise mudstone with intermittent sandstone and siltstone bands/beds, the Haigh Moor Rock Sandstone unit makes up the geology between the Swallow Wood and Top Haigh Coal Seams.

5.2.4 Geological mapping shows that about 60% of the total site area is occupied by backfilled coal opencast sites.

5.2.5 The BGS report notes that the Joan Coal has been worked by underground methods in the Pilley, Denton and Birdwell localities (both located greater than 5km south). The Lidgett Coal has been worked to the east of Pilley (7km to the south).

5.2.6 The Low Haigh, Top Haigh and Swallow Wood Coals were all worked from the Barugh Colliery, which was located c. 500m north.

5.2.7 The BGS report also notes that the Top Haigh and Swallow Wood Coals are often synonymous (i.e. both names can refer to a single, or two separate seams, and mapping is often inconsistent). The seams are described as being of variable quality/thickness but are generally of a quality which justifies underground working.

5.2.8 It should be noted that there is some confusion in the local area relating to the naming of coal seams and several coals appear to 'chop and change' names in the geological literature; most notably the Top Haigh and Swallow Wood Coal Seams.

5.2.9 It should also be noted that seam outcrops plotted on geological maps have been known to be inaccurate by distances in excess of 100m.

Coal authority mining report

5.2.10 A Coal Authority Consultants Mining Report has been obtained. It should be noted that the CA report covers a larger area than the current site of interest. The mining report states that:

- No known shallow underground mineworkings are present beneath the current site (*shallow workings are recorded, however these are located to the south*).
- Probable shallow workings are expected (*i.e. the CA is aware of shallow coals beneath the site which could have been worked at some time in the past*).
- There are no known mine entries in, or within 20m of, the current site's boundary (*although 20 known entries are located to the south, beyond LT1*)
- Opencast coal extraction has taken place in two opencast sites within the site's boundary.
- There are no CA managed tips within 500m.
- There are no known mines gas emissions within 500m.
- The property is in an area where notices to withdraw support have been given in 1956, 1976, 1977 & 1987. This entitlement to withdraw support has not been cancelled.

5.2.11 Whilst the Coal Authority has an entitlement to Withdraw Support (i.e. continue mining coal from beneath the site) it is Lithos' understanding that no further underground mining is proposed in the UK, and this is unlikely to change in the foreseeable future. However, it would be prudent to discuss this with the Coal Authority prior to starting construction.

Coal Mining Abandonment Plans

5.2.12 Both the geological maps and Coal Authority (CA) Mining Report show areas of opencast coal extraction across about 60% of the total site area. Abandonment Plans relating to these opencasts have been obtained; CA Refs NE498, sheet 1 of 3 and NE498 Sheet 2 of 3. The plans are dated May 1964 which is expected to be the date of completion of opencast operations. The abandonment plan NE498, sheet 1 of 3 is reproduced on Drawings 3104/10.

5.2.13 The abandonment Plans discuss two areas of opencast, named Craven I and Craven II. Craven I underlies much of the north of the site whilst Craven II underlies the southern spur of the site.

5.2.14 **Craven I** targeted the Swallow Wood Coal, with some localised opportune extraction of the thin coal around the opencast edges. The base of Craven I ranges from about 7m to 12m below ground levels. The opencast has a roughly 'doughnut' shape with an area of ground in the centre which has not been extracted; the central 'island' broadly aligns with the location of the valley feature shown on historical mapping.

5.2.15 **Craven II** targeted the Thin, Swallow Wood, Top Haigh Moor and Low Haigh Moor Coal Seams, as well as the Gawber Coal (outside the site boundary & does not dip beneath the site). The opencast reached depths of between about 20m to 40m below ground levels.

5.2.16 The abandonment plans include a stratigraphic column which shows the thickness and spacing of coal seams beneath the LT1 and the wider site. The column broadly aligns with the data included on BGS mapping but given that the plan is based on actual coal extraction beneath this site the thicknesses and depths of coal seams are likely to be more accurate:

- **Thin Coal**: single seam coal 0.35m thick, with a fireclay of 0.6m thickness.
- **Swallow Wood Coal**: (7.4m below thin); two seams with single dirt parting; total thickness of 0.91m.
- **Top Haigh Moor Coal**: (12.3m below Swallow Wood); three seams with two dirt partings & a seat earth; total thickness of 1.42m.
- **Low Haigh Moor Coal**: (7.1m below Top Haigh); two seams with single dirt parting; total thickness 0.63m.

5.2.17 The abandonment plans indicate that underground workings were not encountered in in any coal seams during opencast excavation works.

5.3 Ironstone

5.3.1 As well as containing valuable coal seams the Coal Measures include bands of ferrous rich ironstone which have historically been extracted by both underground and surface methods as a raw material for the production of iron and steel.

5.3.2 The BGS memoir notes that iron ore extraction and smelting took place in the surrounding area since the roman period, reaching its peak between the 12th and 17th century.

5.3.3 The major ironstone horizons of the general area are associated with coals which are not present beneath this site, however the Swallow Wood Mine (an ironstone band) which lies stratigraphically above the Swallow Wood Coal has been subject to localised extraction.

5.3.4 Consequently, it cannot be discounted that ironstone may have been extracted in underground workings located just above the Swallow Wood Coal.

5.3.5 In Lithos' experience ironstone extraction usually takes place alongside coal extraction (often within the same mine) and therefore it may be the case that underground workings of the Swallow Wood Coal could have also removed ironstone. This often results in ironstone workings being mistakenly identified as coal extraction, and with the total possible thickness of workings being under-estimated.

5.4 Summary of coal & mining

5.4.1 Several coal seams underlie this site at shallow to moderate depth. Much of the coal has been extracted by opencast excavation at the Craven I and Crave II sites.

5.4.2 To date no evidence of shallow underground mineworkings has been encountered in the shallow seams beneath this site, although workings in deeper seams are known.

5.4.3 However, any workings in these seams, if present, could pose a risk to surface stability.

5.4.4 Furthermore the opencast highwalls present a geotechnical hazard and the proposed layout should consider the difficulty of founding over the highwalls (notably issues associated with differential settlement and ensuring foundations socket into competent ground).

5.4.5 The possibility of ironstone mining above the Swallow Wood Coal Seam cannot be discounted at this stage.

5.4.6 An intrusive mining investigation is required to determine the potential risk posed to the proposed development; see Sections 11.8 and 11.9 of this report.

6 POTENTIAL ISSUES ASSOCIATED WITH DEEP BACKFILL

6.1 Opencast

6.1.1 It is considered likely that the backfill within the Craven I and Craven II opencasts was placed without systematic mechanical compaction in irregular and thick layers, without any screening to remove oversized materials or degradable waste etc. Such material poses a risk to any proposed development due to the potential for differential settlement and long term 'creep' settlement.

6.1.2 It is understood that the backfill has been in place for c. 70 years at Craven I and c. 60 years at Craven II opencasts.

6.1.3 Settlement of deep made ground is initially (first 5 years or so) predominantly associated with immediate settlement and inundation (caused by changes in the water table depth and/or surface water infiltration) as groundwater levels return to equilibrium (i.e. pre opencasting).

6.1.4 Consolidation settlement is associated with a reduction in volume caused by expulsion of water from soil pores and transfer of load from excess porewater pressure to the soil particles.

6.1.5 Creep compression occurs as the particles of fill become more closely packed, under conditions of constant effective stress (arising from self-weight of the fill). Although the movements caused by creep are relatively small, often it is these long-term movements that are of most interest to foundation performance. Many coarse fills show a linear relationship between settlement and the logarithm of the time that has elapsed since the fill was placed (i.e. settlement that occurs during the first 10 years (log cycle 1) is similar to that from years 10 to 100 (log cycle 2).

6.1.6 Where development on deep fill takes place, in addition to any ongoing creep associated with self-weight, settlement is caused by the imposed foundation loads and load as a result of any ground level increases. This leads to some immediate compression and consolidation within stressed zones.

6.1.7 The strength/density of the backfill materials is likely to vary over relatively short distances, especially across the line of buried highwalls.

6.1.8 At this stage, it is considered that the presence of deep backfill will have implications for:

- Foundations – likely piled or heavily reinforced; see further details in Section 16.4.
- Drainage – likely need to be placement at maximum possible gradients using flexible connections to prevent any backfalls should differential settlement of the fill occur. There is potentially the need to pile manholes.
- New utilities – should be constructed of flexible materials. Electricity and communications cabling should also be laid with sufficient 'slack' to accommodate a degree of movement. The use of flexible joints is recommended where possible, particularly where service connections extend across a rigid/flexible structure interface (e.g. from a piled foundation into a garden area).
- Highways - a specification will need to be agreed with the adopting authority, but reinforcement of the road construction is likely to be required.

6.1.9 The foundation solution should allow for the consequences of recovery of internal groundwater levels within the opencast backfill, if equilibrium has not been reached. Precautions may also be required to avoid detrimental effects from surface water infiltration.

6.1.10 The location and detailing of drains and other trenches, and the provision of hardstanding aprons, requires attention to prevent extraneous waters deteriorating the fill.

6.1.11 However, in the context of land that has been subject to opencast coal extraction, this site can be considered relatively low risk given the limited depths of fill (c. 11m) anticipated. Fill thicknesses mean that consideration can be given to a piled foundation solution and/or a heavily reinforced strip footing.

6.1.12 If piled foundations are adopted for plots underlain by opencast backfill there should be a reduced need for further significant geotechnical analysis / modelling, although specialist piling contractors will require more data (i.e. cable percussion boreholes, possibly with rotary core follow-on).

6.1.13 Conversely, if reinforced strips (or rafts) are preferred, significant further investigation and assessment will be required. This should commence with a review of the data obtained during Lithos' investigation, and case studies data relating to other deep backfill sites, to enable preliminary estimates of anticipated settlement.

7 PREVIOUS INVESTIGATION FINDINGS

7.1 General

7.1.1 Strata have provided Lithos with a copies of the following reports:

- **1).** Geotechnical and Geo-environmental Site Appraisal Commentary, Barnsley West, report ref. 36284-001 issued by Eastwoods & Partners to Strata in October 2013.
- **2).** Geoenvironmental Desk Study Report, Barnsley West, report ref. JBW/DS/4848.v2 issued by JPG Group to Strata in July 2019.
- **3).** Preliminary Geoenvironmental Ground Investigation, Barnsley West, report ref. 4848-JPG-SW-XX-RP-G-0603-S2-P01, issued by JPG Group to Strata in July 2019.
- **4).** Coal Mining Risk Assessment and Coal Recovery Report, Residential Development (remainder of site), Barnsley West, report ref. 4848-JPG-Z1-XX-RP-G-1101-S2-P01, issued by JPG to Strata in August 2019.

7.1.2 It should be noted that all 4 of the above reports consider a larger area; the current area of interest (LT1) and the wider Barnsley West site to the south.

7.1.3 Third party exploratory hole locations are shown on Drawing 3104/9.

7.1.4 A summary of the ground conditions encountered in Reports 1 and 3 across the current area of interest is presented in the table on Page 15.

7.2 Report 1

Scope of works

7.2.1 Eastwood & Partners' Report comprises a 'high level' summary appraisal of an area of c. 80 hectares which includes LT1 as well as land to the northeast and south. The document comprises a review of historical mapping, geological mapping, and abandonment plans supplied by the Coal Authority. In addition, a ground investigation comprising 6 cable percussion boreholes was undertaken, although none fall within the current site's boundary.

Summary of Eastwood's findings

7.2.2 The findings of Eastwood's desk study are consistent with those presented in Sections 2 to 5 of this report, although, given the scope of the report, generally with less detail. As the Report covers a larger area than the current site much of the information is not relevant to this document however it does provide a good overview of the geology, features and mining issues affecting the wider area.

7.2.3 Only one of the 6 cable percussion boreholes is relevant to this site, although it is located beyond the north eastern boundary the borehole is located within the Craven I opencast which underlies much of LT1. The borehole found made ground comprising clay and mudstone and siltstone gravel to a depth of 2.6m.

7.2.4 SPT testing suggests that the made ground is generally medium dense to dense.

7.2.5 The Borehole logs provided comprise hand-written drillers logs which suggests that Eastwood's ground investigation was undertaken without the supervision of a geoenvironmental engineer.

7.3 Report 2

Scope of works

7.3.1 JPG's Report comprises a desk-based review of historical mapping, Coal Authority information, geological mapping and a site walkover. The report covers an area of c. 120 hectares including LT1 and land to the northeast and south.

7.3.2 JPG also reviewed the findings of Report 1 (above).

Summary of JPGs findings

7.3.3 JPG's desk study findings are consistent with those presented in Sections 2 to 5 of this report, and includes good detail, most notably in terms of coal mining information, although given JPGs report covers a much larger area much of the information is not relevant to LT1.

7.3.4 JPG highlight that localised ironstone mining could have taken place, most notably (for LT1) from iron rich bedrock around the Swallow Wood Coal

7.4 Report 3

Scope of works

7.4.1 JPG's report comprises a brief site overview, including reference to Report 2 and the findings of a ground investigation across an area of 116 hectares (including LT1 and land to the south, but excluding land to the northeast covered in Reports 1 & 2). In total the ground investigation comprised 14 trial pits and 28 rotary open probeholes. Of these 4 trial pits and 5 probeholes were located within LT1.

7.4.2 In-situ SPT testing was undertaken during drilling of the probeholes and samples were retrieved for chemical (12 samples) and geotechnical testing (20 samples). Monitoring wells and extensometers were installed in the probeholes and, on completion of the drilling, wells were monitored on 6 occasions for groundwater and hazardous gasses.

Summary of JPGs findings

7.4.3 Made Ground beneath LT1 varies between 0.7m and 13.0m in thickness and comprises a veneer of Topsoil and clay over clayey gravel of mudstone which JPG identified as Colliery Spoil. SPT testing suggests that the Colliery Spoil is generally medium dense to dense with N values broadly increasing with depth.

7.4.4 No evidence of grossly degradable materials, historical landfilling, tipping etc was recorded and, based on JPGs description of made ground at this site, it could be interpreted that the opencasts were backfilled with site-won arisings (re-worked coal measures bedrock).

7.4.5 No evidence of shallow underground workings was encountered beneath the LT1.

7.4.6 Settlement recorded by the extensometers by the time of reporting (July 2019) was negligible.

7.4.7 Laboratory CBR vales for shallow soils are typically greater than 5%.

7.4.8 No samples tested for contaminants (metals, organics, pesticides & asbestos) exceeded JPG's screening values and the site was considered to be essentially 'clean' and suitable for the proposed end use (residential & commercial development).

7.4.9 Characteristic Situation 2 (CS2) gas protective measures were recommended for all new properties across the site.

7.5 Report 4

Scope of works

7.5.1 JPG's report relates to an area of c. 70 hectares including LT1 and land to the south. Land to the northeast covered in Reports 1 and 2 is omitted and land to the far south covered in Reports 1, 2 and 3 is also omitted.

7.5.2 The report comprises a site description and review of CA information and abandonment plans, geological mapping and the information contained in Reports 1, 2 and 3.

Summary of JPG's findings

7.5.3 The findings of JPG's report are consistent with the information presented in Section 5 of this document, but with greater detail relating to the potential for settlement of backfilled areas of opencast, and the depth to shallow coal (no evidence of mineworkings recorded to date) as JPG had the benefit of reviewing the ground investigation date presented in Report 3.

7.5.4 Several mine entries were identified, however none are located within LT1.

7.5.5 Given the extensive opencast coal extraction which has already taken place, recovery of coal was considered unlikely to be viable, except where proposed earthworks and regrade of levels exposes coal for incidental extraction.

Rpt by	Hole ID	Final Depth (mbgl)	Depth to base (mbgl)					Rock-head (mbgl)	Penetration into bedrock (m)	Coal (top & base – mbgl)	Location	Comments
			Total Made Ground	Made Ground Topsoil	Cohesive Made Ground	Opencast Backfill	Residual Soil					
JPG	TP101	3.0	>3.0	0.2	0.5	>3.0	-	-	-	-	Craven I	-
	TP102	3.0	>3.0	0.2	0.8	>3.0	-	-	-	-	Craven I	-
	TP102A	3.75	2.75	0.25	0.7	2.75	>3.75	-	-	-	Craven I	-
	TP103	2.5	0.25	0.25	-	-	2.0	2.0	0.5	-	Craven I	-
	TP106	2.0	>2.0	0.4	0.8	2.0	-	-	-	-	Craven II	Located beyond, but close to current area of interest's boundary.
JPG	BH101	15.0	10.5	0.2	-	10.5	-	10.5	5.0	-	Craven I	-
	BH102	15.0	13	2	-	13.0	-	13.0	2.0	-	Craven I	-
	BH103	12.0	8.2	0.2	-	8.2	-	8.2	3.8	-	Craven I	-
	BH117	32.0	0.2	0.2	-	-	-	0.2	31.8	17.5 to 18.8 & 25.8 to 26.3	Craven I	-
	BH118	40.0	0.2	0.2	-	-	-	0.2	39.8	7.2 to 7.8 21.8 to 22.8 & 30.3 to 30.9	Craven I	Located beyond, but close to current area of interest's boundary.
East-wood	BH02	10.5	9.9	0.25	1.8	9.9	-	9.9	0.6		Craven II	Located beyond, but close to current area of interest's boundary.
	BH03	3.7	2.5	0.2	1.0	2.6	-	3.6	1.1		Craven I	Located beyond, but close to current area of interest's boundary.

7.6 Lithos comments

7.6.1 All 4 of the above reports cover a larger area than LT1 and consequently include ground related data and interpretations which are not of significance to LT1. However, data relating to land outside of LT1 does provide a useful overview of the geology and ground conditions across the general wider area.

7.6.2 The scope of works for Reports 2 and 3 (which included intrusive ground investigations) was limited and consequently only a limited number of exploratory holes and ground related data cover was captured within LT1.

7.6.3 Report 3 includes detailed consideration and recommendations relating to potential future settlement. However, further data and ground investigation is required to reduce uncertainty with regards to future settlement, most notably following any change of site ground levels.

7.6.4 JPG's settlement model suggests that anticipated settlement will be minimal, however given that some regrade is anticipated, allowance should be made for the effect of raising ground levels by placing fill across areas of made ground; this surcharging may increase settlement beyond the parameters of JPGs models.

7.6.5 Further intrusive ground investigation with a much closer spacing of exploratory holes is required to remove uncertainty in relation to ground conditions, most notably the line and nature of buried highwalls, the presence of any shallow underground workings, the nature and depth of made ground, the extent of below ground obstructions (boulders), the engineering properties of made ground and shallow soils, the nature of contamination and suitability of soils for re-use and the risk posed to future development by hazardous ground gasses.

7.6.6 Boreholes advanced into the Craven II opencast refused at around 10.0m, however CA abandonment plans suggest that this opencast should be much deeper (c. 40m). It is likely that boreholes have refused on oversized obstructions (i.e. mudstone/siltstone/sandstone boulders) within the opencast backfill.

8 PRELIMINARY CONCEPTUAL SITE MODEL

8.1.1 The site (LT1) comprises arable farmland and is essentially greenfield, however about 60% of the total site area has been subject to opencast coal extraction with subsequent backfilling of the opencast excavations. Based on the findings of 3rd party investigations it appears likely that excavations were backfilled with site-won arisings (re-worked coal measures bedrock) rather than landfill, refuse tipping, etc however in the absence of a comprehensive ground investigation this cannot be guaranteed.

8.1.2 A preliminary conceptual site model, presented as Drawing 3104/5 in Appendix B, has been prepared after consideration of all the data presented in Sections 2 to 7 inclusive of this report.

8.1.3 Clearly, the conceptual model will be subject to modification in light of data arising from the proposed intrusive ground investigation. Potential contaminant linkages are shown on the preliminary conceptual site model.

9 GROUND INVESTIGATION DESIGN

9.1 Anticipated ground conditions & potential issues

9.1.1 Based on the data reviewed in Sections 4 to 7 anticipated ground conditions are expected to comprise:

Anticipated conditions	Remarks
Made ground	Reworked residual soils and bedrock within the footprint of former opencasts up to c. 13.0m (Craven I) & 40m (Craven II) depth.
Natural soils	Veneer of Topsoil & Residual Soils (likely medium to high strength gravelly clays) where outside footprint of opencast.
Bedrock	Lower Coal Measures (interbedded mudstone, siltstone & sandstone) below veneer of Residual Soils (outside open cast) & immediately below made ground (inside opencast).
Mineworkings	4 coal seams anticipated at shallow to moderate depth, 3 of which could include underground workings, although to date Lithos' desk study & 3rd party SI has not found any evidence of underground workings beneath LT1.
Groundwater	Likely perched in made ground within opencast & anticipated at depth within bedrock.

9.1.2 Based on the data above and that in Sections 2 (Site Description) and 3 (History), potential ground-related issues associated with this site are likely to include:

Type of issue	Specific issue	Remarks
Potential on-site contamination sources	1. Made Ground. 2. Farming operations. 3. Underground mineworkings.	1. Potential organic/inorganic contaminants & asbestos & Generation of hazardous gasses 2. See Section 4.4 3. Generation of hazardous gasses
Potential off-site contamination sources	1. Landfill. 2. Deep made ground.	1. Land to the north; migration of hazardous gasses. 2. Areas of opencast to the northeast & south; generation of hazardous gasses.
Potential geotechnical hazards	1. Deep made ground. 2. Buried highwalls. 3. Shallow mine entries/workings. 4. Sloping topography. 5. Below ground obstructions (boulders)	1. Foundation abnormals & potential for excessive settlement. 2. Potential for differential settlement. 3. Risk to surface stability & requirement for consolidation 4. Some levels regrade & earthworks likely to be required. 5. Foundation abnormals & pile refusal ("hanging piles").
Other potential constraints	1. Overhead utilities.	1. Cross the south of LT1 & may require easements or diversion.

9.2 Ground investigation design & strategy

9.2.1 The preliminary conceptual site model was used as a basis for design of an appropriate ground investigation, the scope of which is summarised below:

Exploratory holes	Purpose
About 90 trial pits	To determine the general nature of soils underlying the site, including the: • Nature, distribution and thickness of made ground. • Nature, distribution and size of obstructions. • Nature, degree and extent of contamination. • Proportion of undesirable elements e.g. biodegradable matter, foundations etc. • Suitability of the ground for founding structures and highways.
About 45 trial trenches	To locate & describe the line & nature of buried highwalls around the opencast boundaries.
20 cable percussion boreholes	To determine the engineering properties of made ground within the former opencast, including the extents of obstructions & to install monitoring wells to: • Monitor for hazardous gasses. • Determine groundwater levels & flow direction.
10 rotary cored boreholes	To determine the engineering properties of bedrock in the base of the former opencast to inform piled foundation design.
About 50 rotary open probeholes	To determine whether shallow coal seams have been worked by underground methods and whether underground workings pose a potential risk to surface stability.
Including 15 probeholes	To install monitoring wells to: • Monitor for hazardous gasses. • Determine groundwater levels & flow direction.
About 25 groups of stitch probeholes	To locate & describe the line and geometry of the buried highwalls around the opencast boundaries.

9.2.2 Proposed exploratory hole locations were selected to provide a representative view of the strata beneath the site and to target potential areas of interest identified in Section 7.6 above. Additional exploratory locations might be scheduled by the site engineer in light of the ground conditions actually encountered.

9.2.3 The number of representative samples taken will be reflective of the geological complexity actually encountered. However, in general about 3 samples will be taken from most trial pits.

10 FIELDWORK

10.1 Objectives

10.1.1 The original investigation strategy is outlined in Section 9 above.

10.2 Exploratory hole location constraints

10.2.1 No access was available below the line of overhead utilities which cross the southern edge of the site, or above the line of an underground sewer which runs along the site's western periphery.

10.3 Scope of works

10.3.1 Fieldwork was supervised by Lithos between the 15th November and the 15th December 2021 and comprised the exploratory holes listed below.

Technique	Exploratory holes	Final depth(s)	Remarks
Trial pitting (machine excavated)	TPs 001 to 071, 101 to 107 & 201 to 224.	1.2m to 4.4m (ave. 3.2m)	Hand vane tests undertaken in 'clean' cohesive soils.
Trial Trenching (machine excavated)	TTs 001 to 022, 101 to 106 & 201 to 216.	1.m to 4.6m (ave. 3.0m)	Excavated across the line of known highwalls.
Cable Percussion Boreholes	BHs 001 to 015 & 201 to 205.	5.4m to 13.4m (ave. 8.7m)	Boreholes advanced to refusal in bedrock/obstructions. Monitoring wells installed.
Rotary Cored Boreholes	RC BHs 001 to 006 & 201 to 204.	13.5m to 16.5m (ave. 15.1m)	-
Rotary Open Probeholes	PHs 001 to 042, 101 to 109 & 201 to 219	3.0m to 39.0m (ave. 26.2m)	Monitoring wells installed in 14 PHs.
Groups of Stitch Probeholes	ST PHs 001 to 009, 101 & 201 to 207	3.0m to 12.0m (ave. 8.2m)	Drilled along the line of known highwalls.

10.3.2 Notes describing ground investigation techniques, in-situ testing and sampling are included in Appendix A to this report.

10.3.3 Exploratory hole logs are presented in Appendices F to I to this Report. These logs include details of the:

- Samples taken
- Descriptions of the solid strata, and any groundwater encountered.
- Results of the in-situ testing
- The monitoring wells installed

10.3.4 Exploratory hole locations are shown on Drawing 3104/6 presented in Appendix B; exploratory holes have been picked-up by a surveyor and co-ordinates/ground levels are included on the logs.

11 GROUND CONDITIONS

11.1 General

11.1.1 A complete record of strata encountered beneath the proposed development site is given on the various exploratory hole records, presented in Appendices F to I.

11.1.2 The site can be divided into 4 areas based on ground conditions; land inside of the former opencast sites; land outside of the former opencast sites but with some made ground; land outside the former opencast sites with significant (>2.0m) made ground); and, land outside the former opencast sites with minimal/no made ground. These areas are shown on Drawing 3104/13 and are summarised in the table below:

Site area	General location	Area (m²)
A	Outside footprint of former opencasts; northern, southern & western peripheries of the site. MG <0.9m.	38,500m²
B	Outside former opencasts; centre-east & west. MG 0.9m to 2.5m.	35,500m²
C	Outside former opencasts; centre-east. MG > 2.5m.	10,800m²
D	Inside former opencast; centre, south & east.	129,200m²

11.1.3 Typical ground conditions encountered at the site are described below in Sections 11.2 (made ground) and 11.4 (natural ground), with a summary provided in the table on pages 26 to 29.

11.2 Made ground

General

11.2.1 The made ground at this site is a heterogeneous mixture of materials and it is unlikely, even with a huge amount of sampling, that it could be accurately characterised. Nonetheless the made ground here can be categorised at one of 4 broad 'types' which are present in varying quantities across all 4 of the site areas summarised above:

- **Made Ground Topsoil:** Encountered in 17 of 20 cable percussive (CP) boreholes and 93 of 102 trial pits to between 0.2m (TP062) & 0.5m (TP063) depth (ave. 0.3m) comprising silty clay with some gravel of mudstone, siltstone and occasional sandstone, coal and pottery.
- **Cohesive Made Ground:** Encountered in all 20 CP boreholes and 84 trial pits, typically from the base of Made Ground Topsoil to between 0.4m and greater than 2.6m (TP207) depth (ave. 0.7m) comprising light brown mottled grey clay with occasional gravel of mudstone and some siltstone.
- **Opencast Backfill:** which can in turn be divided into two further made ground types:
    - **Cohesive Opencast Backfill:** Encountered in 20 CP boreholes and 73 trial pits, typically from the base of Cohesive Made Ground to between 0.8m (TP026) and 12.6m (BH002) depth (ave. 4.1m) comprising clay with gravel of mudstone, siltstone and occasional coal, pottery, brick and sandstone, a low to high cobble content (mudstone and siltstone) and a low to medium small boulder content (mudstone and siltstone).
    - **Granular Opencast Backfill:** Encountered in 52 trial pits, typically from the base of Cohesive Made Ground or Cohesive Opencast Deposits to between 0.9m (TP212) and greater than 4.1m (TP101) depth, comprising clayey/silty gravel of mudstone and occasional siltstone, mudstone, coal, brick and pottery with a medium to high cobble content (mudstone and siltstone) and a low to high small boulder content (mudstone and siltstone).

11.2.2 In 6 trial pits, and one trial trench (TPs 017, 019, 032, 044, 069, 221 & TT106) the Granular Opencast Backfill comprised a coarse soil of mudstone and siltstone cobbles and boulders with much finer material of clayey/silty gravel. It remains the possibility that much of the Opencast Backfill may include a larger proportion of oversized material (i.e. cobbles & boulders) at a depth beyond the reach of a 'typical' trial pit.

11.2.3 Cable percussion boreholes located in the Craven II opencast (BHs 006, 008, 010 & 011, located along the proposed spur road) reached depths of between 7.9m and 11.9m before refusing on mudstone obstructions. The 3rd party exploratory hole logs located in the Craven II opencast also refused at depths of around 11.0m (see Section 7). However, CA abandonment plans suggest that the Craven II opencast reached depths of around 30m to 40m. Consequently, it is unlikely that these exploratory holes refused in bedrock in the base of the opencast; it is more likely that from around 10.0m the Opencast Backfill in the Craven II opencast includes a larger portion oversized material (boulders).

11.2.4 Localized gravel of Burnt Shale was encountered in TT213, although given the location of the trench (targeting the line of a buried highwall) the Burnt Shale lies outside of the current site boundary.

11.2.5 All 4 of the above made ground types are interpreted as being made up of site-won materials (although it cannot be discounted that some soils could have been imported during the site's history).

11.2.6 The Made Ground Topsoil was likely site won and stockpiled prior to open-casting and replaced on completion of backfilling the opencast to render the site suitable for agriculture.

11.2.7 The Cohesive Made Ground is interpreted as comprising Residual Soils which have been stripped prior to open-casting and laid down over the Opencast Backfill to create a 'capping layer' to segregate the Topsoil layer (and any grown crops, ploughing, agriculture etc) from the deeper made ground which may have been considered undesirable as a near surface material.

11.2.8 The Cohesive and Granular Opencast Backfill comprised materials which were generated during excavation of the former opencast and then used to backfill excavations on completion of the open-casting.

11.2.9 Illustrative drawings showing the total thickness of made ground in m bgl across the site are given on Drawings 3104/14a and 3104/14b (inside & outside the opencast). Illustrative drawings showing the base of made ground in m AOD are shown on Drawings 3104/15a and 3104/15b (inside & outside the opencast).

Area A

11.2.10 Made Ground across Area A comprises an intermittent veneer of Made Ground Topsoil (5 of 11 TPs) and an intermittent veneer of Cohesive Made Ground (4 of 11 TPs) to a maximum depth of 0.9m.

Area B

11.2.11 Made Ground across Area B comprises a veneer of Made Ground Topsoil and Cohesive Made Ground over Cohesive and Granular Opencast Backfill to between 1.1m (TP017 &211) and 2.5m (TP106).

11.2.12 Made Ground across Area B is interpreted as being the result of some 'overspill' of arisings generated by the former opencasts and a general regrading of site levels during opencast reinstatement works; see Section 11.3 below.

Area C

11.2.13 Made Ground in Area C comprises a veneer of Made Ground Topsoil over Cohesive Made Ground over Cohesive and Granular Opencast Backfill to depths of greater than 2.5m (typically greater than 3.3m).

11.2.14 The depth of Made Ground in Area C is thought to be the result of infilling of a former valley feature which was located in the 'island' in the centre of the Craven I opencast during/following opencast backfilling works; see Section 11.3 below.

Area D

11.2.15 Made Ground in Area D comprises a veneer of Made Ground Topsoil over Cohesive Made Ground over Cohesive and Granular Opencast Backfill to depths of between 5.0m and 12.6m. The depth of made ground in Area D is the result of backfilling the former opencasts and is 'defined' by the profile of the boundary and base of the former opencasts which are described further in Section 11.9.

Obstructions

11.2.16 Obstructions (boulders) were typically not encountered while advancing the CP boreholes within the former Craven I Opencast.

11.2.17 However, boulders were encountered within 54 of the c. 150 (c. 35%) machine excavated trial pits / trenches at depths between 0.5m and 3.5m. Boulders may be present beneath 3.5m depth, however, this represents the typical maximum depth of the pits.

11.2.18 The prevalence of encountered boulders appears to be higher in the southwest, southern central and southeast, and lower in the north and northeast parts of the Craven I opencast. The size of the encountered boulders ranged between c. 0.4m to >1.2m across.

11.3 Distribution of made ground outside of former opencast in relation to historical site regrade

11.3.1 Examination of historical mapping shows that a stream/watercourse flowed through a broad valley in the centre of LT1 prior to open-casting (see Section 3).

11.3.2 However, the valley is not shown on mapping following extraction and backfilling of the opencasts. Contours shown on the 1955 historical map have been compared to contours on the current topographical survey to determine ground levels prior to, and after, open-casting.

11.3.3 Comparison of the contours shows that ground levels in the west of LT1 have been raised by up to c. 1.5m from pre-opencast topography.

11.3.4 Ground levels in the centre of LT1 have been raised by up to c. 3.5m from pre-opencast topography, and it is suggested that the reason for raising levels here was to infill the valley feature in this area. The location of deep fill overlays the 'island' which was left in the centre of the Craven I opencast (see Section 5), which broadly corresponds to the extents of Area C (outside of areas of open-casting, but with made ground of greater than 2.5m depth).

11.4 Natural ground

Soils

11.4.1 Natural Soils were only encountered in significant thicknesses in Areas A, B and C beyond the areas of former the opencast. And comprised the following succession:

- **Topsoil:** Only encountered in Area A from surface to between 0.25m and 0.3m depth (typically 0.3m) comprising slightly sandy silty clay with occasional gravel of mudstone and siltstone.
- **Cohesive Residual Soil:** Encountered in Areas A (from the base of Topsoil) and Areas B and C from the base of made ground, comprising firm to stiff clay with gravel of mudstone and occasionally siltstone and sandstone.
- **Granular Residual Soil:** Encountered in Areas A and B, typically from the base of Cohesive Residual Soil, comprising clayey gravel of mudstone or siltstone.

Rock

11.4.2 All bedrock encountered belongs to the Lower Coal Measures Group; a succession of interbedded mudstones, siltstones and sandstones with intermittent seams of coal, fossiliferous marine bands and ferrous rich ironstones.

11.4.3 Bedrock was encountered in 20 trial pits typically in Areas A and B (outside of areas of former opencast) and in 16 CP boreholes within the Craven I opencast in Area D (but not in the Craven II where obstructions precluded reaching rockhead). Bedrock in Areas A and B was typically overlain by a veneer of Residual Soils whilst bedrock in Area D was overlain by made ground only.

11.4.4 Bedrock was also encountered in the rotary open probeholes and the 10 rotary cored boreholes which allowed a detailed description, including strength, fracture spacing and fracture characteristics. It should be noted that all rotary cored boreholes were advanced across Area D (within former opencasts) and the rock descriptions refer to the ground immediately below the base of the opencasts.

11.4.5 Bedrock described in the rotary cored boreholes (Area D) comprises one of three types:

- **Mudstone:** The predominant bedrock type, encountered in all 10 cored boreholes comprising moderately weak to medium strong dark grey mudstone with closely spaced thin laminations and siltstone laminations. Fractures are typically very closely spaced, horizontal and subvertical, planar, smooth, closed and clean.
- **Siltstone:** Encountered in 6 cored borehole comprising medium strong grey thinly to thickly laminated siltstone. Fractures are very closely spaced to medium spaced, horizontal and vertical, planar, smooth and occasionally rough, generally closed but occasionally with up to 10mm of grey clay fill.
- **Sandstone:** Encountered in 9 cored boreholes comprising strong to very strong thinly cross laminated fine grained sandstone. Fractures are closely spaced to medium spaced, sub horizontal and subvertical, planar, rough, closed and often with orangish brown or dark grey staining on surfaces and penetrating through the rock mass.

11.4.6 In addition to the above ‘main’ rock types RC’s 201 and 201 encountered a thin (0.2m to 0.3m thick) seam of dull ashy clay which included very closely spaced laminations of mudstone and extremely closely spaced fractures.

11.4.7 Bedrock described in the trial pits (Areas A and B) predominantly comprised a weak to moderately weak grey fossiliferous mudstone which was recovered as angular tabular fine to medium gravel.

11.4.8 The in-situ relative density of granular deposits on site was established by carrying out Standard Penetration Tests (SPTs) during the drilling of the boreholes; see Section 15.7.

Summary of Ground Conditions

Site Area	Hole ID	Final Depth (mbgl)	Total Made Ground (mblg)	Depth to base (mbgl) Made Ground Topsoil	Cohesive Made Ground	Cohesive Opencast Backfill	Granular Opencast Backfill	Topsoil	Cohesive Residual Soil	Granular Residual Soil	Coal	Seat Earth	Rock-head (mbgl)	Penetration (m)	Remarks
D	BH001	5.4	5.0	0.3	0.8	5.0	-	-	-	-	-	-	5.0	0.4	Monitoring Well Installed SPT tests undertaken throughout BH
D	BH002	13.4	12.6	0.3	0.9	12.6	-	-	-	-	-	-	12.6	0.8	
D	BH003	8.6	7.8	-	0.7	7.8	-	-	-	-	-	-	7.8	0.8	
D	BH004	8.7	7.5	0.3	1.2	7.5	-	-	-	-	-	-	7.5	1.2	
D	BH005	6.7	6.0	0.35	0.8	6.0	-	-	-	-	-	-	6.0	0.7	
D	BH006	10.1	9.8	0.3	0.9	9.8	-	-	-	-	-	-	9.8	0.3	
D	BH007	6.2	5.0	0.3	1.0	5.0	-	-	-	-	-	-	5.0	1.2	
D	BH008	12.1	11.2	0.4	1.0	11.2	-	-	-	-	-	-	11.2	0.2	
D	BH009	7.5	6.7	0.3	1.0	6.7	-	-	-	-	-	-	6.7	0.8	
D	BH010	12.0	11.9	0.4	1.2	11.2	-	-	-	-	-	-	11.9	0.3	
D	BH011	11.9	11.8	0.3	0.9	11.8	-	-	-	-	-	-	11.8	0.1	
D	BH012	8.5	8.0	-	1.4	8.0	-	-	-	-	-	-	8.0	0.5	
D	BH013	9.1	8.5	0.35	1.4	8.5	-	-	-	-	-	-	8.5	0.6	
D	BH014	7.5	6.9	0.35	0.9	6.9	-	-	-	-	-	-	6.9	0.6	
D	BH015	8.5	7.6	-	0.7	7.6	-	-	-	-	-	-	7.6	0.9	
D	BH201	9.7	9.5	0.3	0.8	9.5	-	-	-	-	-	-	9.5	0.2	
D	BH202	8.4	8.1	0.3	0.8	8.1	-	-	-	-	-	-	8.1	0.3	
D	BH203	5.4	5.0	0.3	1.0	5.0	-	-	-	-	-	-	5.0	0.4	
D	BH204	8.2	7.0	0.3	0.9	7.0	-	-	-	-	-	-	7.0	1.2	
D	BH205	6.3	6.0	0.3	0.7	6.0	-	-	-	-	-	-	6.0	0.3	
A	TP001	3.6	-	-	-	-	-	0.3	2.7	3.0	-	-	3.0	0.6	-
A	TP002	2.9	0.3	0.3	-	-	-	-	2.6	1.8	-	-	2.6	0.3	-
B	TP003	3.8	1.8	0.3	0.5	1.0	1.8	-	-	3.6	-	-	3.6	0.2	-
B	TP004	3.0	1.8	0.3	-	1.8	-	-	2.7	-	-	-	2.7	0.3	-
B	TP005	2.8	1.6	0.3	0.5	-	1.6	-	2.8	-	-	-	-	-	Overbreak & spalling - 0.4m to 1.5m
B	TP006	3.9	1.9	0.3	1.9	-	-	-	3.6	3.8	-	-	3.8	0.1	Overbreak - 1.0m - 1.9m
D	TP007	3.2	2.8	0.3	0.5	2.8	2.2	-	3.1	-	-	-	3.1	0.1	-
B	TP008	3.0	1.8	0.3	0.7	1.8	1.3		2.7	-	-	-	2.7	0.3	-
A	TP009	3.0	-	-	-	-	-	0.3	1.9	3.0	2.4	2.9	-	-	-
A	TP010	2.6	-	-	-	-	-	0.3	1.5	2.5	-	-	2.5	0.1	-
D	TP011	4.1	4.1	0.3	1.5	-	4.1	-	-	-	-	-	-	-	Spalling - 1.5m - 4.1m

Site Area	Hole ID	Final Depth (mbgl)	Total Made Ground (mblg)	Depth to base (mbgl)									Rock-head (mbgl)	Penetration (m)	Remarks
				Made Ground Topsoil	Cohesive Made Ground	Cohesive Opencast Backfill	Granular Opencast Backfill	Topsoil	Cohesive Residual Soil	Granular Residual Soil	Coal	Seat Earth			
D	TP012	3.2	3.2	0.3	0.6	3.2	-	-	-	-	-	-	-	-	-
D	TP013	3.5	3.5	0.3	0.7	3.5	1.8	-	-	-	-	-	-	-	-
D	TP014	3.9	3.9	0.3	0.6	3.8	3.9	-	-	-	-	-	-	-	Overbreak & spalling - 0.6m - 2.0m
D	TP015	3.5	3.5	0.3	0.5	3.5	3.3	-	-	-	-	-	-	-	-
D	TP016	2.8	2.8	0.3	0.6	-	2.8	-	-	-	-	-	-	-	-
B	TP017	2.5	2.5	0.4	-	1.4	2.5	-	0.6	-	-	-	-	-	Overbreak - 1.4m - 2.5m
D	TP018	2.3	2.3	0.3	0.5	1.2	2.3	-	-	-	-	-	-	-	-
D	TP019	3.0	3.0	0.25	0.45	3.0	2.4	-	-	-	-	-	-	-	Overbreak - 1.6m - 2.4m
B	TP020	2.4	2.4	0.3	0.5	2.4	-	-	-	-	-	-	-	-	Overbreak - 1.7m - 2.4m
B	TP021	3.1	2.0	0.3	0.5	1.0	2.0	-	3.0	-	-	-	3.0	0.1	Overbreak - 1.0m - 2.0m
B	TP022	2.6	1.3	0.3	0.4	1.3	-	-	1.6	2.6	2.2	-	-	-	-
B	TP023	3.3	1.4	0.3	1.0	1.4	-	-	2.3	3	-	-	3.0	0.3	-
B	TP024	3.3	2.0	0.3	0.4	2.0	-	-	2.5	3.2	-	-	3.2	0.1	-
B	TP025	4.2	2.3	0.3	0.4	1.7	2.3	-	3.1	4.2	-	-	-	-	Overbreak - 1.7m - 2.3m
B	TP026	3.3	1.8	0.3	0.4	0.8	1.8	-	3.3	3.2	2.1	2.4	-	-	-
B	TP027	3.4	1.8	0.3	0.6	1.1	1.8	-	2.5	-	-	-	2.5	0.9	-
D	TP028	3.5	3.5	0.3	-	-	3.5	-	-	-	-	-	-	-	-
D	TP029	3.8	3.8	0.35	-	-	3.8	-	-	-	-	-	-	-	Overbreak - 1.0m - 2.0m
D	TP030	2.8	2.8	0.25	0.45	2.8	-	-	-	-	-	-	-	-	-
D	TP031	1.5	1.5	0.25	0.4	-	1.5	-	-	-	-	-	-	-	-
D	TP032	3.1	3.1	0.3	0.6	3.1	2.1	-	-	-	-	-	-	-	Overbreak 0 1.5m - 2.1m
D	TP033	3.0	3.0	0.3	0.7	-	3.0	-	-	-	-	-	-	-	Overbreak -1.5m - 3.0m
D	TP034	3.1	3.1	0.3	0.6	2.3	3.1	-	-	-	-	-	-	-	-
D	TP035	2.4	2.4	0.25	0.5	-	2.4	-	-	-	-	-	-	-	-
D	TP036	2.6	2.6	0.4	0.5	2.6	-	-	-	-	-	-	-	-	Overbreak - 1.0m -= 2.6m
D	TP037	3.0	3.0	0.3	0.6	3.0	1.9	-	-	-	-	-	-	-	-
D	TP038	3.0	3.0	0.3	0.5	3.0	1.6	-	-	-	-	-	-	-	Overbreak - 0.5m - 1.6m
D	TP039	2.0	2.0	0.3	0.8	-	2.0	-	-	-	-	-	-	-	-
D	TP040	3.0	3.0	0.3	0.6	3.0	-	-	-	-	-	-	-	-	-
D	TP041	3.0	3.0	0.3	0.5	2.4	3.0	-	-	-	-	-	-	-	Overbreak - 0.5m - 1.5m
D	TP042	3.2	3.2	0.3	0.45	3.2	-	-	-	-	-	-	-	-	-
D	TP043	3.3	3.3	0.3	0.7	3.3	2.1	-	-	-	-	-	-	-	Overbreak 0 1.3m - 2.1m
D	TP044	3.4	3.4	0.3	0.7	3.4	1.7	-	-	-	-	-	-	-	Overbreak - 1.2m - 1.7m

Site Area	Hole ID	Final Depth (mbgl)	Total Made Ground (mblg)	Depth to base (mbgl)									Rock-head (mbgl)	Penetration (m)	Remarks
				Made Ground Topsoil	Cohesive Made Ground	Cohesive Opencast Backfill	Granular Opencast Backfill	Topsoil	Cohesive Residual Soil	Granular Residual Soil	Coal	Seat Earth			
D	TP045	3.3	3.3	0.3	1.0	-	3.3	-	-	-	-	-	-	-	-
D	TP046	1.2	1.2	0.3	0.8	-	1.2	-	-	-	-	-	-	-	-
D	TP047	3.7	3.7	0.3	-	3.7	-	-	-	-	-	-	-	-	-
D	TP048	3.1	3.1	0.3	0.9	3.1	-	-	-	-	-	-	-	-	-
D	TP049	3.4	3.4	0.3	1.0	1.9	3.4	-	-	-	-	-	-	-	-
A	TP050	2.7	0.9	0.3	0.9	-	-	-	2.3	2.5	-	-	2.5	0.2	-
A	TP051	2.8	0.6	0.3	0.6	-	-	-	1.8	2.7	-	-	2.7	0.1	-
D	TP052	3.2	3.2	0.3	1.5	3.2	-	-	-	-	-	-	-	-	-
D	TP053	3.5	3.5	0.3	1.1	1.4	3.5	-	-	-	-	-	-	-	Spalling - 1.9m - 3.4m
D	TP054	3.3	3.3	0.3	0.6	3.3	-	-	-	-	-	-	-	-	-
A	TP055	2.6	-	-	-	-	-	0.3	2.0	2.4	-	-	2.4	0.2	-
A	TP056	2.8	-	-	-	-	-	0.3	1.9	2.7	-	-	2.7	0.1	-
D	TP057	3.7	3.7	0.3	1.5		3.7	-	-	-	-	-	-	-	-
A	TP058	3.6	-	-	-	-	-	0.3	2.3	-	-	-	2.3	1.3	-
A	TP059	2.2	-	-	-	-	-	0.25	1.8	-	-	-	1.8	0.4	-
A	TP060	2.9	-	-	-	-	-	0.3	2.0	2.9	-	-	-	-	-
D	TP061	3.1	3.1	-	-	-	-	0.3	0.6	3.1	-	-	-	-	-
D	TP062	3.7	3.7	0.2	2.2	3.7		-	-	-	-	-	-	-	-
D	TP063	3.9	3.9	0.5	-	3.9	2.8	-	-	-	-	-	-	-	-
D	TP064	3.2	3.2	0.5	0.8	3.2	-	-	-	-	-	-	-	-	-
A	TP065	2.8	0.9	0.3	0.6	0.9	-	-	2.2	2.6	-	-	2.6	0.2	-
A	TP066	2.9	0.4	0.2	0.4	-	-	-	2.3	2.9	-	-	-	-	-
D	TP067	3.2	3.2	0.3	0.5	-	3.2	-	-	-	-	-	-	-	-
D	TP068	3.0	3.0	0.3	0.4	3.0	-	-	-	-	-	-	-	-	-
D	TP069	3.9	3.9	0.3	-	-	3.9	-	-	-	-	-	-	-	-
D	TP070	3.7	3.7	0.3	0.5	3.7	-	-	-	-	-	-	-	-	-
D	TP071	3.2	3.2	0.3	0.4	3.2	-	-	-	-	-	-	-	-	-
D	TP101	4.1	4.1	0.3	0.6	1.9	4.1	-	-	-	-	-	-	-	Spalling - 2.9m - 4.1m
D	TP102	3.9	3.9	0.3	0.7	3.9	1.6	-	-	-	-	-	-	-	Spalling - 0.7m - 1.6m
D	TP103	3.9	3.3	0.3	0.8	3.3	2.0	-	3.5		3.7	3.9	-	-	Overbreak - 0.8m - 1.8m
D	TP104	3.4	3.4	0.3	0.6	3.4	-	-	-	-	-	-	-	-	-
D	TP105	3.5	3.0	0.3	0.6	3.0	-	-	3.2		3.4	3.5	-	-	-
B	TP106	3.2	2.5	0.25	0.7	2.5	-	-	3.2	-	-	-	-	-	Overbreak - 1.0m - 2.2m

Site Area	Hole ID	Final Depth (mbgl)	Total Made Ground (mblg)	Depth to base (mbgl)									Rock-head (mbgl)	Penetration (m)	Remarks
				Made Ground Topsoil	Cohesive Made Ground	Cohesive Opencast Backfill	Granular Opencast Backfill	Topsoil	Cohesive Residual Soil	Granular Residual Soil	Coal	Seat Earth			
B	TP107	3.0	2.0	0.3	0.7	2.0	-	-	3.0	-	-	-	-	-	-
D	TP201	2.9	2.9	0.3	0.5	2.9	-	-	-	-	-	-	-	-	-
D	TP202	3.1	3.1	0.3	0.45	3.1	-	-	-	-	-	-	-	-	-
D	TP203	3.4	3.4	0.4	-	3.4	-	-	-	-	-	-	-	-	-
D	TP204	3.0	3.0	0.35	0.5	-	3.0	-	-	-	-	-	-	-	Spalling - 1.6m - 3.0m
D	TP205	2.9	2.9	0.3	0.4	-	2.9	-	-	-	-	-	-	-	Spalling - 1.8m - 2.9m
D	TP206	3.7	3.7	0.35	0.55	3.7	1.7	-	-	-	-	-	-	-	Spalling - 1.4m - 3.7m
D	TP207	3.4	3.4	0.3	1.8	3.4	-	-	-	-	-	-	-	-	-
D	TP208	3.3	3.3	0.3	-	3.3	-	-	-	-	-	-	-	-	-
D	TP209	3.8	3.8	0.25	0.5	3.8	-	-	-	-	-	-	-	-	-
D	TP210	3.4	3.4	0.3	0.6	1.6	3.4	-	-	-	-	-	-	-	-
B	TP211	3.2	1.1	0.3	0.55	-	1.1	-	2.3	-	2.9	3.2	-	-	-
B	TP212	3.6	2.1	0.4	0.6	2.1	0.9	-	2.8	-	3.3	3.6	-	-	-
D	TP213	2.7	2.7	0.3	0.4	2.7	-	-	-	-	-	-	-	-	-
D	TP214	3.3	3.3	0.3	-	-	3.3	-	-	-	-	-	-	-	-
D	TP215	3.3	3.3	0.35	0.45	3.3	-	-	-	-	-	-	-	-	-
C	TP216	3.4	2.7	0.3	0.6	2.7	-	-	3.4	-	-	-	-	-	Overbreak & spalling - 2.0m to 3.3m
C	TP217	3.4	3.3	0.3	0.9	3.3	-	-	-	-	-	-	3.3	0.1	-
C	TP218	3.3	3.3	0.3	0.8	3.3	-	-	-	-	-	-	-	-	-
C	TP219	3.6	3.6	0.3	0.5	3.6	-	-	-	-	-	-	-	-	-
C	TP220	3.3	3.3	0.3	0.7	3.3	2.3	-	-	-	-	-	-	-	-
D	TP221	3.5	3.5	0.3	0.5	3.5	1.5	-	-	-	-	-	-	-	-
D	TP222	4.4	4.4	0.3	0.5	4.4	1.4	-	-	-	-	-	-	-	-
C	TP223	3.4	3.4	0.3	0.6	3.4	-	-	-	-	-	-	-	-	-
C	TP224	3.0	3.0	0.35	0.6	3.0	2.2	-	-	-	-	-	-	-	-

11.5 Visual & olfactory evidence of organic contamination

11.5.1 No visual or olfactory evidence of contamination was noted during Lithos' investigation.

11.6 Groundwater

11.6.1 Groundwater ingress was encountered in 12 trial pits and trial trenches and during drilling of BH002 as summarised in the table below:

Hole	Depth of GW ingress		Description
	mbgl	mAoD	
BH002	3.0	110.20	Struck in Cohesive Opencast Backfill. Rose to 2.6mbgl in 20 minutes.
	8.0	105.20	Struck in Coal Measures Mudstone. Did not rise in BH.
TP007	1.8	111.95	Inflow from Granular Opencast Backfill.
TP011	0.3	105.15	Seepage from base of Topsoil.
TP015	3.3	106.40	Inflow from Granular Opencast Backfill.
TP019	2.6	111.10	Seepage from Cohesive Opencast Backfill.
TP025	0.3	121.55	Seepage from base of Topsoil.
TP031	1.1	107.50	Seepage from Granular Opencast Backfill.
TP036	2.4	101.30	Seepage from Cohesive Opencast Backfill.
TP224	1.2	94.40	Inflow from Granular Opencast Backfill.
TT010E	2.0	101.04	Seepage from Cohesive Opencast Backfill.
TT022NW	2.2	85.90	Inflow from Granular Opencast Backfill.
TT201	2.0	85.40	Inflow from Granular Opencast Backfill.
TT214N	2.2	90.05	Seepage from Cohesive Opencast Backfill.

11.6.2 Monitoring wells have been installed in 14 shallow probeholes and 20 deeper cable percussion boreholes. To date the wells have been monitored on two occasions on the 5th January and the 2nd February 2022. Groundwater levels recorded in the wells are presented in the table below:

Hole	Response zone (depth range & strata)	Groundwater body	Range of standing water levels	
			m bgl	m AoD#
BH001	2.0m – 4.7m (Opencast Backfill).	Shallow/perched.	Dry - 4.51	107.99
BH002	3.0m – 9.0m (Opencast Backfill).	Shallow/perched.	1.49 – 1.84	111.36 – 111.71
BH003	4.0m – 6.7m (Opencast Backfill).	Shallow/perched.	4.97 – 5.47	95.93 – 96.43
BH004	4.0m – 6.7m (Opencast Backfill).	Shallow/perched.	6.25 – 6.27	110.13 – 110.15
BH005	3.0m – 5.7m (Opencast Backfill).	Shallow/perched.	4.65 – 4.66	97.89 – 97.90
BH006	6.0m – 9.0m (Opencast Backfill).	Shallow/perched.	Dry	-
BH007	2.0m – 4.m (Opencast Backfill).	Shallow/perched.	Dry - 4.56	97.09
BH008	8.5m – 11.5m (Opencast Backfill).	Shallow/perched.	Dry - 10.95	116.45
BH009	3.0m – 5.7m (Opencast Backfill).	Shallow/perched.	3.70 - 3.71	92.34 - 92.35
BH010	7.0m – 11.0m (Opencast Backfill).	Shallow/perched.	Dry	-

Hole	Response zone (depth range & strata)	Groundwater body	Range of standing water levels	
			m bgl	m AoD#
BH011	5.0m – 11.0m (Opencast Backfill).	Shallow/perched.	Dry	-
BH012	4.5m – 7.2m (Opencast Backfill).	-	Dry	-
BH013	5.0m – 7.7m (Opencast Backfill).	Shallow/perched.	Dry - 7.41	88.89
BH014	3.0m – 5.7m (Opencast Backfill).	-	Dry	-
BH015	4.0m – 6.7m (Opencast Backfill).	Shallow/perched.	4.36 – 4.54	87.11 – 87.29
BH201	6.0m – 9.0m (Opencast Backfill).	Shallow/perched.	5.61 – 5.62	82.93 – 82.94
BH202	4.5m – 7.5m (Opencast Backfill).	Shallow/perched.	5.18 – 5.35	80.70 – 80.87
BH203	1.5m – 4.5m (Opencast Backfill).	Shallow/perched.	4.47 – 4.45	82.88 - 82.9
BH204	3.0m – 6.0m (Opencast Backfill).	-	Dry	-
BH205	2.5m – 5.5m (Opencast Backfill).	-	Dry	-
PH034	1.5m – 3.0m (Coal Measures).	Bedrock (secondary A Aquifer).	Dry – 0.82	85.78
PH035	1.5m – 3.0m (Opencast Backfill).	Shallow/perched.	2.98 – 2.99	89.91 – 89.92
PH036	1.5m – 3.0m (Coal Measures).	Bedrock (secondary A Aquifer).	0.88 – 0.98	96.67 – 96.77
PH037	1.5m – 3.0m (Opencast Backfill).	Shallow/perched.	2.85 – 2.98	92.72 – 92.85
PH038	1.5m – 3.0m (Opencast Backfill).	-	Dry	-
PH039	1.5m – 3.0m (Opencast Backfill).	Shallow/perched.	0.87 – 1.01	108.33
PH040	1.5m – 3.0m (Coal Measures).	Bedrock (secondary A Aquifer).	Dry – 1.40	119.1
PH041	1.5m – 3.0m (Coal Measures).	Bedrock (secondary A Aquifer).	Dry – 2.43	116.17
PH042	1.5m – 3.0m (Coal Measures).	Bedrock (secondary A Aquifer).	1.66 - 1.89	113.26 - 113.49
PH108	1.5m – 3.0m (Opencast Backfills).	Shallow/perched.	1.96 - 2.27	95.73 - 96.04
PH109	1.5m – 3.0m (Opencast Backfill).	Shallow/perched.	2.64 – 2.65	92.65 – 92.66
PH217	1.5m – 3.0m (Opencast Backfill).	Shallow/perched	2.25 – 2.45	88.40 – 88.60
PH218	1.5m – 3.0m (Opencast Backfill).	Shallow/perched.	1.15 – 2.21	84.84 – 85.90
PH219	1.5m – 3.0m (Opencast Backfill).	Shallow/perched.	Dry - 2.81	81.14

levelled-in by survey to enable groundwater risk assessment

11.6.3 The existing groundwater dip data would suggest that there isn't an overall groundwater level within Craven I opencast. It is possible that groundwater within the Opencast Backfill is perched within granular bands, layers and lenses, which in some areas may be interconnected, where as in other areas they may be discrete bodies of water.

11.6.4 In areas of the opencast where granular backfill is prevalent, the local permeability of the backfill may be higher than the surrounding Coal Measures bedrock. Consequently, the backfilled opencast may act as a sump, with surrounding groundwater within the bedrock draining towards the opencast.

11.6.5 In some parts of Craven I opencast, there may be a general groundwater flow towards the northeast, broadly parallel with the fall of topography, however there doesn't appear to be an even gradient on the groundwater flow, with some large local variations in groundwater level (m AOD), with groundwater even absent in some locations.

11.6.6 It should be noted that any excavations across the site which result in exposed highwalls, such as excavations required for site regrade, may encounter differing flow rates and groundwater levels where in-situ bedrock and Opencast Backfill is exposed. Careful consideration should be given to groundwater levels and flow directions during any regrade and earthworks design.

11.6.7 Further assessment of groundwater levels and flows will take place following completion of the monitoring.

11.7 Stability

11.7.1 The stability of excavations through natural Residual Soils and bedrock was generally good.

11.7.2 The stability of excavations through made ground was generally moderately good, however excavations through the Granular Opencast Backfill encountered overbreak and spalling; most notably where oversized materials (cobbles and boulders) were encountered.

11.8 Underground mining investigation

11.8.1 LT1 is underlain by 4 coal seams at shallow to intermediate depth; a Thin Coal, the Swallow Wood, the Top Haigh and the Low Haigh coals. Inside the footprint of the former Craven I opencast, the Thin and Swallow Wood Coals have been removed. Coal seam outcrops (based on BGS mapping) are shown on Drawing 3104/8.

11.8.2 Based on the findings of Lithos' desk study any underground workings in the Thin and/or Swallow Wood Coal could pose a risk to surface stability outside the former opencast and workings in the Top Haigh Coal could pose a risk to surface stability inside the former opencast.

11.8.3 Consequently, a mining investigation has been undertaken, comprising the drilling of 56 'deep' rotary open probeholes.

11.8.4 A summary of the probehole findings is presented in the table on pages 32 to 33.

11.8.5 The deep probeholes did **not** encounter any evidence (void, broken ground, soft push, loss of flush etc) of underground workings in the 4 shallow coal seams. Therefore, the risk posed to surface stability from underground shallow workings across LT1 is considered to be **insignificant**.

11.8.6 No evidence of underground workings for Ironstone was encountered during Lithos' mining investigation.

11.8.7 Although an insufficient cover of competent rock is present above shallow coal, given the absence of evidence of underground workings the risk of surface instability to the proposed development is considered **minimal**.

Summary of mining investigation

Hole ID	Final Depth (mbgl)	Depth to Rockhead (mbgl)	Thin Coal			Swallow Wood Coal			Top Haigh Coal			Low Haigh Coal			Evidence of workings?
			Depth to (mbgl)		Thickness (m)	Depth to (mbgl)		Thickness (m)	Depth to (mbgl)		Thickness (m)	Depth to (mbgl)		Thickness (m)	
			Top	Bottom		Top	Bottom		Top	Bottom		Top	Bottom		
PH001	32.0	3.1	-	-	-	11.6	12.7	1.1	-	-	-	-	-	-	No.
PH002	30.0	2.8	-	-	-	12.3	13.3	1.0	27.2	27.7	0.5	-	-	-	No.
PH003	30.0	2.0	2.0	2.4	0.4	14.2	15.1	0.9	24.1	24.6	0.5	-	-	-	No.
PH004	30.5	2.7	-	-	-	11.5	12.3	0.8	26.9	27.5	0.6	-	-	-	No.
PH005	33.7	2.5	3.6	4.1	0.5	17.2	18.2	1.0	30.2	30.7	0.5	-	-	-	No.
PH006	33.0	2.1	3.3	3.8	0.5	16.4	17.4	1.0	28.8	29.2	0.4	-	-	-	No.
PH007	33.2	2.9	3.0	3.25	0.25	15.4	16.5	1.1	29.7	30.2	0.5	-	-	-	No.
PH008	30.0	12.1	Removed by opencast			Removed by opencast			25.5	26.3	0.8	-	-	-	No.
PH009	28.2	1.7	1.7	2.1	0.4	13.8	14.4	0.6	24.4	25.2	0.8	-	-	-	No.
PH010	30.0	1.3	1.3	1.55	0.25	12.4	12.8	0.4	25.6	26.3	0.7	-	-	-	No.
PH011	33.0	3.6	Removed by opencast			3.6	3.7	0.1	15.1	16.2	1.1	28.1	29.1	1.0	No.
PH012	33.0	13.5	Removed by opencast			Removed by opencast			27.0	28.0	1.0	-	-	-	No.
PH013	33.0	3.8	-	-	-	9.4	10.1	0.7	24.1	24.6	0.5	28.3	28.9	0.6	No.
PH014	30.0	7.4	Removed by opencast			Removed by opencast			22.5	23.0	0.5	-	-	-	No.
PH015	30.0	7.9	Removed by opencast			7.9	8.0	0.1	22.3	22.9	0.6	-	-	-	No.
PH016	30.0	4.4	-	-	-	8.5	9.2	0.7	21.0	21.7	0.7	-	-	-	No.
PH017	30.0	8.8	Removed by opencast			Removed by opencast			21.9	22.75	0.85	-	-	-	No.
PH018	33.0	7.2	Removed by opencast			Removed by opencast			20.6	21.4	0.8	28.1	28.9	0.8	No.
PH019	33.0	7.1	Removed by opencast			Removed by opencast			20.8	21.6	0.8	28.2	29	0.8	No.
PH020	15.0	8.0	Removed by opencast			Removed by opencast			-	-	-	-	-	-	No.
PH021	30.0	7.9	Removed by opencast			Removed by opencast			22.1	23.0	0.9	-	-	-	No.
PH022	33.0	9.0	Removed by opencast			Removed by opencast			20.15	21.0	0.85	27.9	28.5	0.6	No.
PH023	33.0	5.9	Removed by opencast			5.9	6.0	0.1	21.3	22.3	1.0	28.0	28.7	0.7	No.
PH024	33.0	4.9	Removed by opencast			4.9	5.5	0.6	21.2	21.9	0.8	28.6	29.5	0.9	No.
PH025	33.0	7.0	Removed by opencast			7.0	7.3	0.3	21.2	22.1	0.9	28.6	29.3	0.9	No.
PH026	36.0	7.6	Removed by opencast			7.6	8.2	0.6	22.9	23.3	0.3	30.5	31.3	0.8	No.
PH027	36.0	7.8	Removed by opencast			7.8	8.2	0.4	22.9	23.2	0.4	30.5	31.3	0.8	No.
PH028	33.0	8.1	Removed by opencast			Removed by opencast			21.6	22.8	0.8	28.7	29.5	0.8	No.
PH029	36.0	10.2	Removed by opencast			Removed by opencast			25.5	26.4	0.9	33.6	34.3	0.7	No.
PH030	39.0	10.6	Removed by opencast			10.6	1.4	0.8	26.6	27.3	0.7	34.5	35.3	0.8	No.
PH031	36.0	9.0	Removed by opencast			9.0	9.5	0.5	24.7	25.7	1.0	32.6	33.3	0.7	No.
PH032	33.0	13.5	Removed by opencast			13.5	13.8	0.3	23.2	24.2	1.0	30.3	30.9	0.6	No.

Hole ID	Final Depth (mbgl)	Depth to Rockhead (mbgl)	Thin Coal			Swallow Wood Coal			Top Haigh Coal			Low Haigh Coal			Evidence of workings?
			Depth to (mbgl)		Thickness (m)	Depth to (mbgl)		Thickness (m)	Depth to (mbgl)		Thickness (m)	Depth to (mbgl)		Thickness (m)	
			Top	Bottom		Top	Bottom		Top	Bottom		Top	Bottom		
PH033	36.0	4.9	-	-	-	9.0	9.8	0.8	24.3	25.1	0.8	31.2	32.2	1.0	No.
PH101	30.0	4.5	Removed by opencast			Removed by opencast			19.0	20.0	1.0	27.0	27.6	0.6	No.
PH102	30.0	4.8	Removed by opencast			Removed by opencast			17.7	18.6	0.9	25.1	25.8	0.7	No.
PH103	30.0	4.7	Removed by opencast			Removed by opencast			17.7	18.6	0.9	25.1	25.8	0.7	No.
PH104	33.0	6.5	Removed by opencast			Removed by opencast			20.4	21.3	0.9	27.9	28.8	1.1	No.
PH105	33.0	7.8	Removed by opencast			Removed by opencast			21.3	22.1	0.8	28.9	29.7	0.8	No.
PH106	30.0	3.1	-	-	-	3.1	3.7	0.6	18.7	19.8	1.1	27.0	27.7	0.7	No.
PH107	30.0	2.9	Removed by opencast			Removed by opencast			17.8	18.6	0.8	25.2	26.1	0.9	No.
PH201	29.0	8.6	Removed by opencast			Removed by opencast			23.0	23.6	0.6	-	-	-	No.
PH202	28.0	1.2	-	-	-	9.2	10.0	0.8	24.1	25.0	0.9	-	-	-	No.
PH203	30.0	9.4	Removed by opencast			Removed by opencast			23.3	24.2	0.9	-	-	-	No.
PH204	30.0	8.9	Removed by opencast			Removed by opencast			23.5	24.5	1.0	-	-	-	No.
PH205	33.0	7.8	Removed by opencast			8.8	9.0	0.2	21.95	22.5	0.55	29.2	29.7	0.5	No.
PH206	33.0	7.8	Removed by opencast			Removed by opencast			21.7	22.5	0.8	29.8	30.5	0.7	No.
PH207	36.0	7.6	Removed by opencast			Removed by opencast			22.0	22.9	0.9	31.5	32.3	0.8	No.
PH208	33.0	7.4	Removed by opencast			Removed by opencast			21.0	21.9	0.9	28.2	29.0	0.8	No.
PH209	30.0	3.5	Removed by opencast			Removed by opencast			17.8	18.4	0.6	27.0	27.5	0.5	No.
PH210	30.0	2.2	Removed by opencast			2.2	2.7	0.5	18.3	19.1	0.8	26.2	26.8	0.6	No.
PH211	33.0	5.4	Removed by opencast			Removed by opencast			19.2	20.2	1.0	28.6	29.4	0.8	No.
PH212	30.0	4.5	Removed by opencast			Removed by opencast			17.9	18.6	0.7	25.3	26.1	0.8	No.
PH213	33.0	3.5	-	-	-	3.5	4.1	0.6	19.5	20.2	0.7	27.6	28.4	0.8	No.
PH214	33.0	6.9	Removed by opencast			Removed by opencast			20.15	21.0	0.85	28.8	29.6	0.8	No.
PH215	33.0	6.3	Removed by opencast			Removed by opencast			20.4	21.4	1.0	28.6	29.5	0.9	No.
PH216	33.0	7.5	Removed by opencast			Removed by opencast			22.8	23.8	1.0	30.7	31.7	1.0	No.

11.9 Opencast mining investigation

General

11.9.1 Based on the findings of Lithos' desk study about 60% of the total site area of LT1 has been subject to opencast coal extraction.

11.9.2 A key aim of Lithos' investigation was to determine the extents and profile of the Craven I and Craven II (where the proposed spine road crosses this area) opencasts. Consequently 20 cable percussion boreholes, 17 groups of stitched probeholes and 44 trial trenches were advanced to determine the depth to the base of the opencasts and the line and nature of buried highwalls.

Highwalls

11.9.3 Highwalls were encountered in 17 of the groups of stitch probeholes and in 32 trial trenches.

11.9.4 The lines of buried highwalls (proven and interpreted) are shown on Drawing 3104/12 and 12A. Highwalls follow the extents of the opencasts shown on the CA abandonment plans relatively closely, however the crest of the highwalls are usually set 1m to 3m back from the opencast boundary shown on the abandonment plans; the area surveyed during/after opencast extraction appears to represent the toe of the highwall and the extent of the area from which coal had been removed.

11.9.5 The Craven I opencast is an irregular shape and includes an 'island; in the centre-northwest. As discussed in Sections 3 and 11.3 the island corresponds to the approximate location of a former valley feature which was infilled on completion of the opencast.

11.9.6 The 'island' does not appear to have been removed during open-casting; the CA abandonment plan is essentially correct; however, the 'island' has been buried beneath between c. 1.0m and c. 3.5m of made ground (Cohesive Made Ground and Opencast Backfill) during site regrade.

11.9.7 Highwalls are present around the edge of the 'island' although given the depth of made ground across this area they have proved difficult to accurately locate and describe. Along the north eastern edge of the 'island' the feature has an irregular shape which appears to line up with the line of the former watercourse and the base of the former valley. It is likely that the irregular shape across this area has been influenced by this feature.

11.9.8 A 'shelf' is present in the west of the Craven I opencast which corresponds to the area where the shallower Thin Coal was extracted as shown in the CA abandonment plans. The shelf is bordered by a highwall along the western edge, and appears to have a second highwall which drops down into deeper areas of opencast to the east.

11.9.9 Highwalls are generally cut at 30° to 45° through Residual Soils and then at steeper angles (60° to 80°) through Coal Measures Bedrock. No evidence of terraces has been encountered to date suggesting that highwalls may have been cut in a single face around the boundary of the opencasts.

Base of opencasts

11.9.10 The Craven I opencast reaches depths of between 5.0m (BHs 001, 007 & 203) and 13.5m (PHs 012 & 032) with an average depth of 7.0 to 8.0m. The deepest backfill recorded in the cable percussive boreholes was 12.6m (BH002), which given the accuracy of measurement, when compared to openhole drilling (±1.0m) is taken as the typical maximum depth. The thickness of made ground is generally deepest in the southwest of the opencast and shallowest in the centre and east.

11.9.11 The level of the base of the Craven I opencast in mAOD is shown on Drawing 3104/15a.

11.9.12 The Craven II opencast reaches depths of between 7.5m (BH004) and 11.9m (BH010) with the deepest made ground in the south and the shallowest made ground in the north.

11.10 Revised conceptual ground model (ground conditions)

11.10.1 The Preliminary Conceptual Site Model has been revised in light of data obtained during the ground investigation, most notably with respect to:

- The nature and distribution of made ground, including the presence of significant buried obstructions
- The strength, nature and depth of underlying natural strata
- The absence of shallow underground coal and/or ironstone workings
- Presence of coal
- The extent of areas of former opencasts, including the depth of fill and line and nature of buried highwalls
- The nature and distribution of contamination (based on visual/olfactory evidence only)

11.10.2 Further refinement of the Conceptual Site Model is presented in Sections 12 and 13, where the results of laboratory testing for contaminants have been considered.

12 CONTAMINATION (ANALYSIS)

12.1 General

12.1.1 This site is essentially greenfield and remains is use as farmland. However about 60% of the total site area has been subject to historical opencast coal extraction with subsequent backfilling of the opencasts with Residual Soils and bedrock arisings.

12.1.2 The site's former usage is unlikely to have given rise to significant ground contamination, even though significant thicknesses of made ground were encountered in many of the exploratory locations during the ground investigation.

12.1.3 In the context of risks to human health associated with residential and commercial redevelopment, the Tier 1 Soil Screening Values referenced in this report have been derived via the CLEA default conceptual site model (CSM) used for generating SGVs, but amended, where appropriate, to be more specific to redevelopment within the planning process.

12.1.4 Where available, Category 4 Screening Levels (C4SL) have also been referenced.

12.1.5 Generic Note 04 in Appendix A provides further details with respect to current guidance and the interpretation of analytical data.

12.2 Testing scheduled

12.2.1 Based on the above assessment, Lithos submitted a test schedule (summarised in the table below) to a UKAS accredited laboratory.

Type of sample	No. of samples	Determinands
Topsoil (inc. Made Ground Topsoil)	32	pH, water soluble boron, and total metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium and zinc), Asbestos ID, Total organic carbon (TOC) & Speciated Polycyclic Aromatic Hydrocarbons (PAH)
	16	Banded Total Petroleum Hydrocarbons (TPH)

Type of sample	No. of samples	Determinands
Made Ground	44	pH, water soluble boron, and total metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium and zinc) & Asbestos ID Total organic carbon (TOC), Speciated Polycyclic Aromatic Hydrocarbons (PAH) & Banded Total Petroleum Hydrocarbons (TPH)
	39	Water soluble sulphate, chloride, nitrate and magnesium

12.3 Soil contamination results

12.3.1 The soil contamination test results are summarised in the tables on pages 38 to 43.

12.3.2 Laboratory test certificates as received from the laboratory are presented in Appendix J to this report.

Inorganic determinands

12.3.3 Of the 72 samples of made ground and Topsoil analysed for inorganic parameters, all can be classified as uncontaminated, with none classified as contaminated.

12.3.4 These samples have been classified by comparison with Tier 1 Soil Screening Values for an end use including domestic gardens and any area where plants are to be grown (the most sensitive of proposed end-uses).

Calorific value

12.3.5 The calorific value of a sample of the Thin Coal Seam has yielded a calorific value of 24.4MJ/kg. This confirms that the coal is almost certainly combustible and should not remain close to surface in gardens or areas of POS.

Asbestos

12.3.6 No asbestos fibres were identified in any of the 72 samples screened.

Organic determinands

12.3.7 This site is essentially greenfield and therefore for organic compounds, the Tier 1 Values used in this report have been derived with reference to a CSM that assumes a residential with gardens end use, with no clean soil cover will be placed in gardens/landscaped areas (Lithos Scenario A).

12.3.8 It should be noted that whilst some parts of the site are to be given to development with commercial buildings and a school all results have been compared to Tier 1 values assuming a residential end use as these values are more conservative than alternative screening values which assume a commercial/industrial end use.

12.3.9 Lithos have used the CLEA model 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. However, 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.

12.3.10 In order to check the validity of Lithos' Tier 1 Soil Screening Values, the average TOC for each common fill type (beyond any areas of obvious hydrocarbon impact) have been determined.

Fill type	Typical TOC (%)	Comparison of soil results with revised screening value necessary?
Topsoil	2.7%	Yes, but no significant organic contamination was recorded in this soil type. All determinands well below "6%" screening value; most below limit of detection.
Made Ground Topsoil	2.9%	
Cohesive Made Ground	1.0%	
Cohesive Opencast Backfill	1.5%	
Granular Opencast Backfill	1.3%	

Summary of degree of soils contamination (inorganics)

Site Area	Expl Hole	Depth (m)	Material	Concentrations in mg/kg unless otherwise stated. Results are quoted to 1 decimal place if <10, and whole numbers if >10. Trigger Level Concentrations are shown in BLUE and assume a **residential with gardens** end-use.													
				pH	As ∞	B~	Cd ∞	Cr x	Cu♣$	Pb ∞	Hg*	Ni	Se	Zn$	Vn	CV	Asbestos
					37	5	26	4000	100	200	199	109	434	200	584	2	
A	TP001	0.2	Topsoil	6.4	12	0.6	0.2	21	25	35	0.1	17	0.5	76	36	-	N.D.
A	TP010	0.2	Topsoil	6.7	11	0.7	0.2	22	25	32	0.1	18	0.5	76	35	-	N.D.
A	TP056	0.1	Topsoil	6.4	12	0.8	0.2	21	26	32	0.1	17	0.5	73	34	-	N.D.
A	TP061	0.1	Topsoil	6.0	11	0.4	0.2	21	27	32	0.1	18	0.5	72	37	-	N.D.
A	TP221	0.1	Topsoil	6.1	13	0.7	0.3	22	26	33	0.1	18	0.8	83	38	-	N.D.
A	TP002	0.1	Made Ground Topsoil	6.5	14	0.5	0.2	20	28	38	0.1	18	0.5	89	34	-	N.D.
B	TP005	0.1	Made Ground Topsoil	6.4	14	0.6	0.2	20	24	37	0.1	16	0.5	70	31	-	N.D.
B	TP006	0.2	Made Ground Topsoil	6.6	13	0.5	0.2	22	25	35	0.1	19	0.5	80	33	-	N.D.
B	TP008	0.2	Made Ground Topsoil	6.7	11	0.5	0.2	22	27	31	0.1	27	0.5	82	32	-	N.D.
D	TP015	0.2	Made Ground Topsoil	6.5	13	0.5	0.2	23	31	34	0.1	20	0.5	88	38	-	N.D.
D	TP018	0.1	Made Ground Topsoil	6.6	9.7	0.7	0.2	23	26	32	0.1	18	0.5	77	34	-	N.D.
D	TP019	0.1	Made Ground Topsoil	6.5	11	0.3	0.2	22	26	35	0.1	17	0.5	76	37	-	N.D.
B	TP025	0.2	Made Ground Topsoil	6.7	19	0.6	0.2	21	31	43	0.1	19	0.5	90	38	-	N.D.
B	TP027	0.2	Made Ground Topsoil	6.9	9.2	0.4	0.2	20	27	26	0.1	20	0.5	79	32	-	N.D.
D	TP028	0.1	Made Ground Topsoil	6.2	10	0.5	0.1	21	24	29	0.1	18	0.5	76	32	-	N.D.
D	TP032	0.1	Made Ground Topsoil	6.5	7.3	0.5	0.1	16	20	21	0.1	16	0.7	61	26	-	N.D.
D	TP034	0.1	Made Ground Topsoil	6.4	8.6	0.4	0.2	20	28	25	0.1	21	0.5	78	33	-	N.D.
D	TP036	0.1	Made Ground Topsoil	6.0	10	0.4	0.2	23	24	31	0.1	20	0.5	82	38	-	N.D.
D	TP048	0.1	Made Ground Topsoil	5.6	12	0.6	0.2	21	27	33	0.1	18	0.5	77	37	-	N.D.
A	TP050	0.1	Made Ground Topsoil	6.6	12	0.6	0.2	23	26	33	0.1	17	0.5	88	44	-	N.D.
D	TP054	0.1	Made Ground Topsoil	6.2	12	0.7	0.2	22	28	32	0.1	17	0.5	72	40	-	N.D.
D	TP062	0.1	Made Ground Topsoil	5.7	12	0.5	0.2	20	25	30	0.1	17	0.5	72	37	-	N.D.
D	TP064	0.1	Made Ground Topsoil	6.9	18	0.7	0.2	22	30	42	0.1	16	0.7	80	40	-	N.D.
D	TP070	0.1	Made Ground Topsoil	7.8	6.4	0.2	0.1	17	36	34	0.1	33	0.5	79	18	-	N.D.
D	TP105	0.2	Made Ground Topsoil	6.0	12	0.6	0.2	21	25	32	0.1	17	0.5	76	36	-	N.D.
B	TP107	0.1	Made Ground Topsoil	6.3	12	0.5	0.2	22	25	30	0.1	19	0.6	82	35	-	N.D.
D	TP201	0.1	Made Ground Topsoil	6.3	13	0.5	0.3	23	30	39	0.1	19	0.5	83	37	-	N.D.
D	TP205	0.1	Made Ground Topsoil	6.2	14	0.7	0.2	21	27	38	0.1	17	0.6	78	35	-	N.D.
D	TP208	0.1	Made Ground Topsoil	6.2	12	0.6	0.3	23	29	39	0.1	18	0.8	84	37	-	N.D.
D	TP214	0.1	Made Ground Topsoil	6.4	13	0.6	0.3	23	34	40	0.1	23	1.3	89	38	-	N.D.
B	TP005	0.4	Cohesive Made Ground	6.5	6.2	0.2	0.1	20	39	17	0.1	33	0.5	95	27	-	N.D.

Site Area	Expl Hole	Depth (m)	Material	Concentrations in mg/kg unless otherwise stated. Results are quoted to 1 decimal place if <10, and whole numbers if >10. Trigger Level Concentrations are shown in BLUE and assume a **residential with gardens** end-use.													
				pH	As ∞	B~	Cd ∞	Cr x	Cu♣$	Pb ∞	Hg*	Ni	Se	Zn$	Vn	CV	Asbestos
					37	5	26	4000	100	200	199	109	434	200	584	2	
D	TP019	0.3	Cohesive Made Ground	5.8	9.5	0.3	0.1	18	21	26	0.1	14	0.5	62	25	-	N.D.
D	TP031	0.3	Cohesive Made Ground	7.4	8.5	0.4	0.1	20	24	21	0.1	20	0.5	72	26	-	N.D.
D	TP033	0.4	Cohesive Made Ground	6.7	7.2	0.3	0.1	20	26	15	0.1	20	0.5	71	30	-	N.D.
D	TP052	0.8	Cohesive Made Ground	6.6	8.7	0.2	0.1	19	29	18	0.1	21	0.5	67	27	-	N.D.
D	TP057	0.4	Cohesive Made Ground	4.9	7.3	0.3	0.1	18	22	12	0.1	12	0.5	53	24	-	N.D.
D	TP062	0.5	Cohesive Made Ground	7.6	3.0	0.2	0.1	16	31	16	0.1	29	0.5	84	27	-	N.D.
D	TP064	0.6	Cohesive Made Ground	7.4	15	0.2	0.1	19	21	13	0.1	16	0.5	56	24	-	N.D.
D	TP201	0.4	Cohesive Made Ground	7.1	7.0	0.2	0.1	20	25	20	0.1	20	0.5	68	32	-	N.D.
B	TP211	0.4	Cohesive Made Ground	7.0	7.3	0.2	0.1	19	25	16	0.1	17	0.5	55	25	-	N.D.
D	TP215	0.4	Cohesive Made Ground	7.0	6.4	0.3	0.1	18	29	22	0.1	18	0.5	75	30	-	N.D.
B	TP004	0.5	Cohesive O'cast Backfill	6.0	11	0.4	0.1	19	21	28	0.1	14	0.5	68	30	-	N.D.
B	TP017	0.7	Cohesive O'cast Backfill	7.8	7.3	0.3	0.1	18	33	17	0.1	31	0.5	91	21	-	N.D.
D	TP019	0.7	Cohesive O'cast Backfill	7.5	6.1	0.2	0.1	18	36	14	0.1	34	0.5	110	17	-	N.D.
B	TP020	0.7	Cohesive O'cast Backfill	7.9	12	0.2	0.1	17	35	17	0.1	35	0.5	94	18	-	N.D.
B	TP021	0.6	Cohesive O'cast Backfill	6.1	9.0	0.2	0.1	17	30	22	0.1	31	0.5	76	23	-	N.D.
B	TP023	1.2	Cohesive O'cast Backfill	7.4	7.0	0.2	0.1	13	25	30	0.1	24	0.5	95	16	-	N.D.
B	TP026	0.5	Cohesive O'cast Backfill	7.8	12	0.2	0.1	18	37	32	0.1	40	0.5	110	19	-	N.D.
D	TP036	0.6	Cohesive O'cast Backfill	7.4	6.8	0.2	0.1	17	32	16	0.1	32	0.5	94	18	-	N.D.
D	TP040	2.5	Cohesive O'cast Backfill	7.4	6.1	0.2	0.1	17	36	19	0.1	34	0.5	92	20	-	N.D.
D	TP047	0.6	Cohesive O'cast Backfill	7.0	7.5	0.2	0.1	20	25	17	0.1	21	0.5	69	34	-	N.D.
D	TP048	1.6	Cohesive O'cast Backfill	7.8	6.0	0.2	0.1	18	35	16	0.1	35	0.5	97	20	-	N.D.
D	TP054	2.0	Cohesive O'cast Backfill	7.6	4.8	0.2	0.1	16	40	19	0.1	36	0.5	94	17	-	N.D.
A	TP065	0.8	Cohesive O'cast Backfill	7.4	4.9	0.2	0.1	17	27	15	0.1	30	0.5	81	20	-	N.D.
B	TP106	1.0	Cohesive O'cast Backfill	7.0	5.9	0.2	0.1	18	31	18	0.1	33	0.5	89	26	-	N.D.
D	TP202	0.6	Cohesive O'cast Backfill	7.2	4.8	0.2	0.1	16	38	16	0.1	31	0.5	77	19	-	N.D.
D	TP208	1.3	Cohesive O'cast Backfill	7.5	5.1	0.2	0.1	14	62	18	0.1	28	0.5	69	18	-	N.D.
D	TP216	0.8	Cohesive O'cast Backfill	7.3	6.8	0.2	0.1	16	38	20	0.1	35	0.5	120	19	-	N.D.
D	TP221	2.0	Cohesive O'cast Backfill	7.2	6.3	0.2	0.1	16	33	15	0.1	32	0.5	84	19	-	N.D.
D	TP007	0.9	Granular O'cast Backfill	7.8	5.9	0.3	0.1	22	41	18	0.1	46	0.5	120	20	-	N.D.
D	TP016	0.8	Granular O'cast Backfill	7.6	5.4	0.3	0.1	18	34	32	0.1	33	0.5	97	19	-	N.D.
B	TP021	1.3	Granular O'cast Backfill	8.0	6.0	0.2	0.1	16	31	13	0.1	30	0.5	84	15	-	N.D.
B	TP027	1.3	Granular O'cast Backfill	7.5	6.2	0.2	0.1	24	23	14	0.1	31	0.5	57	29	-	N.D.
D	TP029	0.7	Granular O'cast Backfill	7.7	6.0	0.2	0.1	16	38	24	0.1	31	0.5	100	18	-	N.D.

Site Area	Expl Hole	Depth (m)	Material	Concentrations in mg/kg unless otherwise stated. Results are quoted to 1 decimal place if <10, and whole numbers if >10. Trigger Level Concentrations are shown in BLUE and assume a **residential with gardens** end-use.													
				pH	As ∞	B~	Cd ∞	Cr x	Cu♣$	Pb ∞	Hg*	Ni	Se	Zn$	Vn	CV	Asbestos
					37	5	26	4000	100	200	199	109	434	200	584	2	
D	TP031	0.6	Granular O'cast Backfill	8.1	5.9	0.2	0.4	17	33	15	0.1	39	0.5	150	16	-	N.D.
D	TP044	1.2	Granular O'cast Backfill	7.9	5.7	0.2	0.1	17	32	14	0.1	32	0.5	88	20	-	N.D.
D	TP045	2.0	Granular O'cast Backfill	8.0	4.7	0.2	0.1	17	30	16	0.1	32	0.5	86	20	-	N.D.
D	TP069	0.6	Granular O'cast Backfill	7.3	6.9	0.2	0.1	18	32	15	0.1	35	0.5	92	20	-	N.D.
D	TP101	2.5	Granular O'cast Backfill	7.1	5.7	0.2	0.1	17	36	17	0.1	36	0.5	86	17	-	N.D.
D	TP204	0.6	Granular O'cast Backfill	7.3	6.1	0.2	0.1	17	34	17	0.1	33	0.5	84	18	-	N.D.
D	TP206	1.0	Granular O'cast Backfill	7.0	5.1	0.2	0.1	18	30	14	0.1	37	0.5	87	24	-	N.D.
B	TP211	0.7	Granular O'cast Backfill	6.4	17	1.0	0.3	22	42	42	0.1	20	0.5	98	47	-	N.D.
B	TP022	1.9	Thin Coal	-	-	-	-	-	-	-	-	-	-	-	-	**24.4**	-

Key	
36	Parameter tested for and found to be in excess of Tier 1 value.
179	Parameter tested for and found to be > 5 x Tier 1 value.
12	Parameter tested for but not found to be in excess of Tier 1 value.
-	Parameter not tested for.
♣	Tier 1 Value is pH dependent.
x	Assumes Cr is CrIII. If demonstrated Cr is CrVI Tier 1 would be 21mg/kg.
ND	No fibres detected (asbestos screen)
~	Engineering judgement (Lithos). Boron is a phytotoxic, although most phytotoxic compounds can pose a risk to human health if sufficient concentrations are present. However, plants represent the most sensitive receptor, and a Tier 1 value which is protective of flora is therefore also protective of human health.

Source of guidance trigger level	
With the exception of those annotated with one of the symbols below (∞, $, ~), all Soil Screening Values in brackets above have been derived using CLEA v1.071.	
∞	Category 4 Screening Level – SP1010, December 2013 (CL:AIRE/Defra).
$	MAFF. Code of Practice for Agricultural Practice for the Protection of Soil, 1998.
*	Assumes mercury present as an inorganic compound (cf elemental metal or within organic compound). See Science Report SC050021/Mercury SGV.

Summary of degree of soils contamination (organics)

Site Area	Expl Hole	Depth (m)	Material	Concentrations in mg/kg. Results are quoted to 1 decimal place if <10, and whole numbers if >10. Trigger Level Concentrations are shown in BLUE and assume a **residential with gardens (and no cover)** end use					
				% TOC	PAH		TPH - C6 to C40		
					B(α)P ∞	Naphthalene	GRO~ C_6 to C_{10}	DRO◊ C_{10} to C_{21}	LRO C_{21} to C_{40}
					5	6	22	215	3299
A	TP001	0.2	Topsoil	3.6	0.1	0.1	0.1	30	20
A	TP010	0.2	Topsoil	2.9	0.1	0.1	0.1	30	20
A	TP056	0.1	Topsoil	2.7	0.1	0.1	-	-	-
A	TP061	0.1	Topsoil	2.0	0.1	0.1	-	-	-
A	TP221	0.1	Topsoil	2.7	0.1	0.1	-	-	-
A	TP002	0.1	Made Ground Topsoil	3.4	0.1	0.1	0.1	30	20
B	TP005	0.1	Made Ground Topsoil	5.3	0.1	0.1	0.1	30	20
B	TP006	0.2	Made Ground Topsoil	2.7	0.1	0.1	0.1	30	20
B	TP008	0.2	Made Ground Topsoil	2.4	0.1	0.1	0.1	30	20
D	TP015	0.2	Made Ground Topsoil	2.3	0.1	0.1	0.1	30	20
D	TP018	0.1	Made Ground Topsoil	2.3	0.1	0.1	0.1	30	20
D	TP019	0.1	Made Ground Topsoil	2.8	0.1	0.1	0.1	30	20
B	TP025	0.2	Made Ground Topsoil	4.1	0.1	0.1	0.1	30	20
B	TP027	0.2	Made Ground Topsoil	20	0.1	0.1	0.1	30	20
D	TP028	0.1	Made Ground Topsoil	1.9	0.1	0.1	0.1	30	20
D	TP032	0.1	Made Ground Topsoil	2.0.	0.1	0.1	0.1	30	20
D	TP034	0.1	Made Ground Topsoil	2.1	0.1	0.1	0.1	30	20
D	TP036	0.1	Made Ground Topsoil	2.4	0.1	0.1	0.1	30	20
D	TP048	0.1	Made Ground Topsoil	2.6	0.1	0.1	-	-	-
A	TP050	0.1	Made Ground Topsoil	2.8	0.1	0.1	-	-	-
D	TP054	0.1	Made Ground Topsoil	2.5	0.1	0.1	-	-	-
D	TP062	0.1	Made Ground Topsoil	3.3	0.1	0.1	-	-	-
D	TP064	0.1	Made Ground Topsoil	3.5	0.1	0.1	-	-	-
D	TP070	0.1	Made Ground Topsoil	1.5	0.1	0.1	-	-	-
D	TP105	0.2	Made Ground Topsoil	2.6	0.1	0.1	-	-	-
B	TP107	0.1	Made Ground Topsoil	2.1	0.1	0.1	-	-	-
D	TP201	0.1	Made Ground Topsoil	3.0	0.1	0.1	-	-	-
D	TP205	0.1	Made Ground Topsoil	4.0	0.1	0.1	-	-	-
D	TP208	0.1	Made Ground Topsoil	3.0	0.1	0.1	-	-	-
D	TP214	0.1	Made Ground Topsoil	6.2	0.1	0.1	-	-	-

Site Area	Expl Hole	Depth (m)	Material	Concentrations in mg/kg. Results are quoted to 1 decimal place if <10, and whole numbers if >10. Trigger Level Concentrations are shown in BLUE and assume a **residential with gardens (and no cover)** end use					
				% TOC	PAH		TPH - C6 to C40		
					B(a)P ∞	Naphthalene	GRO~ C_6 to C_{10}	DRO◊ C_{10} to C_{21}	LRO C_{21} to C_{40}
					5	6	22	215	3299
B	TP052	0.8	Cohesive Made Ground	0.9	0.1	0.1	0.1	30	20
D	TP057	0.4	Cohesive Made Ground	0.5	0.1	0.1	0.1	30	20
D	TP062	0.5	Cohesive Made Ground	1.3	0.1	0.1	0.1	30	20
D	TP064	0.6	Cohesive Made Ground	0.5	0.1	0.1	0.1	30	20
D	TP201	0.4	Cohesive Made Ground	0.8	0.1	0.1	0.1	30	20
D	TP211	0.4	Cohesive Made Ground	2.0	0.1	0.1	0.1	30	20
D	TP215	0.4	Cohesive Made Ground	1.0	0.1	0.1	0.1	30	20
D	TP004	0.5	Cohesive Opencast Backfill	1.9	0.1	0.1	0.1	30	20
D	TP017	0.7	Cohesive Opencast Backfill	0.9	0.1	0.1	0.1	30	20
B	TP019	0.7	Cohesive Opencast Backfill	0.5	0.1	0.1	0.1	30	20
D	TP020	0.7	Cohesive Opencast Backfill	1.4	0.1	0.1	0.1	30	20
B	TP021	0.6	Cohesive Opencast Backfill	4.4	0.1	0.1	0.1	30	20
B	TP023	1.2	Cohesive Opencast Backfill	1.4	0.1	0.1	0.1	30	20
D	TP026	0.5	Cohesive Opencast Backfill	1.3	0.1	0.1	0.1	30	20
B	TP036	0.6	Cohesive Opencast Backfill	1.2	0.1	0.1	0.1	30	20
B	TP040	2.5	Cohesive Opencast Backfill	1.5	0.1	0.1	0.1	30	20
B	TP047	0.6	Cohesive Opencast Backfill	0.9	0.1	0.1	0.1	30	20
B	TP048	1.6	Cohesive Opencast Backfill	1.3	0.1	0.1	0.1	30	20
D	TP054	2.0	Cohesive Opencast Backfill	1.6	0.1	0.1	0.1	30	20
D	TP065	0.8	Cohesive Opencast Backfill	0.7	0.1	0.1	0.1	30	20
D	TP106	1.0	Cohesive Opencast Backfill	0.7	0.1	0.1	0.1	30	20
D	TP202	0.6	Cohesive Opencast Backfill	1.9	0.1	0.1	0.1	30	20
D	TP208	1.3	Cohesive Opencast Backfill	2.4	0.1	0.1	0.1	30	20
A	TP216	0.8	Cohesive Opencast Backfill	1.5	0.1	0.1	0.1	30	20
B	TP221	2.0	Cohesive Opencast Backfill	1.1	0.1	0.1	0.1	30	20
D	TP044	1.2	Granular Opencast Backfill	1.0	0.1	0.1	0.1	30	20
D	TP007	0.9	Granular Opencast Backfill	1.2	0.1	0.1	0.1	30	20
D	TP016	0.8	Granular Opencast Backfill	1.3	0.1	0.1	0.1	30	20
D	TP021	1.3	Granular Opencast Backfill	0.7	0.1	0.1	0.1	30	20
D	TP027	1.3	Granular Opencast Backfill	0.8	0.1	0.1	0.1	30	20
D	TP029	0.7	Granular Opencast Backfill	0.9	0.1	0.1	0.1	30	20
B	TP031	0.6	Granular Opencast Backfill	1.0	0.1	0.1	0.1	30	20

Site Area	Expl Hole	Depth (m)	Material	Concentrations in mg/kg. Results are quoted to 1 decimal place if <10, and whole numbers if >10. Trigger Level Concentrations are shown in BLUE and assume a **residential with gardens (and no cover)** end use					
				% TOC	PAH		TPH - C6 to C40		
					B(α)P ∞	Naphthalene	GRO~ C_6 to C_{10}	DRO◊ C_{10} to C_{21}	LRO C_{21} to C_{40}
					5	6	22	215	3299
B	TP045	2.0	Granular Opencast Backfill	0.7	0.1	0.1	0.1	30	20
D	TP069	0.6	Granular Opencast Backfill	0.5	0.1	0.1	0.1	30	20
D	TP101	2.5	Granular Opencast Backfill	1.9	0.1	0.1	0.1	33	20
D	TP204	0.6	Granular Opencast Backfill	1.3	0.1	0.1	0.1	30	20
D	TP206	1.0	Granular Opencast Backfill	0.7	0.1	0.1	0.1	30	20
D	TP211	0.7	Granular Opencast Backfill	3.7	0.1	0.1	0.1	30	20

Key		**Source of guidance trigger level**	
60	Parameter tested for and in excess of Tier 1 concentration.	∞	Category 4 Screening Level – SP1010, December 2013 (CL:AIRE/Defra).
0.3	Parameter tested for but not in excess of Tier 1 concentration.	~	Assumes all GRO is aromatic fraction C7 to C8.
-	Contaminant not tested for.	◊	Assumes all DRO is aliphatic fraction C10 to C12.
All Soil Screening Values in brackets above have been derived using CLEA v1.071. Values assume contaminants located in a sandy loam, with 6% soil organic matter (SOM).			

Hydrocarbons (TPH & PAH)

12.3.11 Given the previous uses of the site and absence of visual/olfactory evidence of any hydrocarbon contamination, only a simple banded TPH (cf full speciation) was initially scheduled on 57 samples.

12.3.12 Assessment of TPH associated with a fuel/oil source would normally be undertaken in accordance with a 3-step approach, (outlined in Generic Note 04 in Appendix A) on fully speciated TPH results. However, although only banded TPH analysis has been scheduled here, none of the fractions exceed their respective Tier 1 criteria, even if it is conservatively assumed all of each fraction is either aliphatic or aromatic.

12.3.13 Consequently, no significant petroleum hydrocarbon concentrations have been identified, and there is no risk to human health from these hydrocarbons.

Polycyclic Aromatic Hydrocarbons (PAH)

12.3.14 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.

12.3.15 The analytical data for this site has been compared against Tier 1 screening values for the most problematic (16 USEPA) PAHs. All concentrations are below Tier 1 screening values, therefore whilst a range of PAHs may be present, these are not considered to pose a risk to health.

12.3.16 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).

12.3.17 Speciated analysis has confirmed the absence of significant concentrations of both benzo(a)pyrene and naphthalene in the soils beneath this site.

12.4 Topsoil

12.4.1 Topsoil (and made ground topsoil), typically 300mm thick is present across most of the site. Testing suggests this material is chemically suitable for re-use.

12.4.2 Given the nature of the topsoil present on this site it would be expected to be suitable to support plant growth.

Topsoil grading

12.4.3 The clay/sand/silt content and visible contaminants, sharps (glass etc) of 14 samples of Made Ground Topsoil and one sample of 'natural' Topsoil have been determined to check compliance with BS3882[1] requirements. BS3882 considers visual contaminants to comprise 'undesirable potentially injurious foreign object(s) visible to the naked eye'.

12.4.4 It should be noted that this is a reduced suite of analysis, and no N-P-K etc. testing has been undertaken.

12.4.5 The results are summarised below:

Hole ID & depth (mbgl)	Retained on (%)			Sand content %	Silt content %	Clay content %	Visible contaminants
	50mm sieve	20mm sieve	2mm sieve				
	<0%	<10%	<30%	0% to 90%	0 to 65%	5 to 35%	<0.5%
TP004 – 0.1	0	0	9	17	43	31	-
TP007 – 0.1	0	1	5	2	51	**42**	-
TP017 – 0.1	0	0	5	14	46	35	-
TP031 – 0.1	0	1	10	8	47	35	-
TP035 – 0.1	0	0	7	11	47	35	-
TP043 – 0.1	0	0	9	23	46	22	-
TP068 – 0.1	0	0	0	35	40	18	-
TP071 – 0.1	0	8	19	21	41	19	-
TP102 – 0.2	0	5	15	12	42	31	-
TP105 – 0.2	0	0	6	17	51	26	-
TP207 – 0.1	0	0	7	18	53	22	-
TP216 – 0.1	0	0	6	30	44	20	-
TP219 – 0.1	0	1	15	22	42	21	-
TP059 – 0.1 (Topsoil)	0	4	10	51	26	13	-

Note: Values in **bold** type fail the required specification for multipurpose topsoil

12.4.6 The above results suggest that Topsoil and Made Ground across this site predominantly falls within the standards set out in BS3882. In terms of textural classification, the Topsoil generally falls into the 'Silty Clay Loam' class.

12.4.7 Large undeveloped sites typically generate a surplus of topsoil, and there might be implications here with export of surplus topsoil to other development sites.

[1] *BS3882:2015. Specification for topsoil. Published by BSI Standards Limited.*

13 CONTAMINATION (QUALITATIVE RISK ASSESSMENT)

13.1 Summary of significant contamination

13.1.1 No significant evidence of contamination has been encountered during Lithos' ground investigation or following chemical testing of the samples recovered.

13.1.2 However, the Opencast Backfill includes a number of opencast materials (cobbles and boulders) which would be undesirable as near-surface materials in gardens and areas of POS. Furthermore, the Opencast Backfill would not generally be desirable near surface as it is not expected to provide a favourable growing medium for trees and plants.

13.1.3 Both the Cohesive Made Ground and Made Ground Topsoil are considered suitable to remain near surface in gardens and areas of POS.

13.1.4 Therefore, where Opencast Backfill remains below gardens and areas of POS and is not modified during site regrade or turnover works (see Section 17) it should be isolated below a **450mm** thick surface cover of "clean" soils comprising at least 300mm of subsoil and at least 150mm of Topsoil.

13.1.5 Alternatively, where the Opencast Backfill has been re-engineered (and oversized materials removed) it should be isolated beneath a **300mm** thick surface cover of "clean" soil comprising at least 200mm of subsoil and at least 100mm of Topsoil. This is expected to be the case at this site. This thickness is in accordance with NHBC Standards, Chapter 10.2.

13.1.6 Waterlogging of garden areas within 3m of the habitable parts of the home should be prevented by appropriates soil selection and management and if necessary by drainage or other suitable means (NHBC Standards, Chapter 10.8.2)

13.2 Topsoil

13.2.1 Made Ground Topsoil and Topsoil, typically 300mm thick underlies the entire site. Testing suggests this material is chemically suitable for re-use.

13.2.2 Given the nature of the topsoil present on this site it would be expected to be suitable to support plant growth.

13.3 Revised conceptual ground model (contamination)

13.3.1 No plausible contaminant linkages have been identified.

Combustibility

13.3.2 Shallow coal is considered to be potentially combustible and, in accordance with current guidance, the following remediation measures should be adopted if it is left on site:

- Garden areas: isolate beneath a minimum 1,000mm thickness of inert soil, comprising 850mm of "clean" subsoil plus 150mm topsoil.
- Services: utility trenches (especially those carrying potential heat sources e.g. electric cables) should be cut oversize and backfilled with clean, inert material. This applies to any utility trenches that run beneath estate roads or extend under houses. It is strongly recommended that further advice be sought from all statutory service bodies with respect to the ground conditions within which they will lay services.
- Estate roads: no action required (although generally less than 1,000mm thick, the road construction is considered to provide adequate isolation as there will be no heat source). Local Authority Highways approval should be sought.
- Houses: Where foundation excavations do come into contact with coal, the foundation should be taken through the coal seam, into underlying natural in-situ strata

of adequate bearing. The full thickness of coal should then be sealed with concrete to create a trench fill foundation. To prevent the ingress of air, the mass concrete fill should be placed as soon as possible after exposing the seam. Building Control body and Warranty Provider approval should be sought.

13.4 Waste classification

13.4.1 Disposal of the made ground off site is generally not considered appropriate, economically viable, nor in line with current Government philosophy regarding sustainable development. However, some excess arisings may be generated by excavations for foundations, sewers etc.

13.4.2 Following excavation and stockpiling, sampling will be required prior to disposal.

13.4.3 As there is no WRAP protocol for soils, the characterisation, sampling and classification of soils arising from brownfield sites has been incorporated within the Environment Agency's Technical Guidance WM3[2]. Classification of soils as non-hazardous or hazardous in accordance with WM3 is quite a complex process, although it ultimately results in a simple classification as hazardous or non-hazardous. Note: inert is not a class under WM3; WAC testing is required to determine whether a waste soil can be considered inert.

13.4.4 If waste soil is classed as hazardous following classification under WM3, and destined for landfill, waste acceptance criteria (WAC) leachate testing will need to be undertaken. Similarly, if waste soil destined for landfill is classed as non-hazardous under WM3, and suspected to be inert, WAC leachate testing will need to be undertaken. However, non-hazardous soil waste can go to a non-hazardous landfill facility; no further testing (e.g. WAC) is required.

13.4.5 WAC analysis is different to the 'routine' laboratory testing (such as that included earlier in this Section) undertaken in order to determine hazardous properties. Lithos typically only include WAC analysis if significant off-site disposal (of soil classified as hazardous waste) is anticipated.

13.4.6 It is critical if material is to be exported from site that this is allocated an appropriate waste code, following the steps within WM3. Waste carriers transporting, and sites accepting, this material should have a corresponding code within their permits. It is the responsibility of those generating the waste (i.e. the site), to ensure that the waste is handled and disposed of appropriately.

13.4.7 Soil treatment facilities (STFs) provide an alternative to landfill. STFs are regulated by the Environment Agency and allow soils to be treated and screened (effectively recycled to be used at other sites). Export to an STF does not require WAC testing and suitability of various soil types will be dependent on material waste codes, which may be allocated after consideration of the data in Section 12 but will often need supplementing with further testing after soils have been stockpiled (see also advice in Section 17.3).

13.4.8 Most STFs are permitted to accept soils with waste code 17 05 04 (i.e. soils which do not exhibit hazardous properties). Lithos has a list of permitted STFs and can help identify one local to this development site.

[2] *Technical Guidance WM3 – Guidance on the classification and assessment of waste. Environment Agency 2015*

14 HAZARDOUS GAS

14.1 General

14.1.1 Consideration of the conceptual site model and potential linkages has enabled a preliminary qualitative assessment of risks associated with gas:

Source	Receptors	Hazard	Pathway	Initial risk
Coal seams / workings	Human health	Asphyxiation & explosion	Vertical migration, ingress & accumulation	**Low**: no evidence of shallow coal workings encountered
	Buildings	Explosion		
On-site made ground	Human health	Asphyxiation & explosion	Vertical migration, ingress & accumulation	**Low**: made ground essentially inert, with little degradable matter
	Buildings	Explosion		
Off-site landfill	Human health	Asphyxiation & explosion	Lateral migration, ingress & accumulation	**Low**: natural strata to at least 5m depth are generally of low permeability
	Buildings	Explosion		

14.1.2 Given the above gas monitoring wells have been installed in 20 boreholes and 14 probeholes across the site. Details of the installations are given on the exploratory hole logs presented in Appendix G (boreholes) and Appendix I (probeholes) to this the report.

14.1.3 The generation potential of the gas source was initially considered to be Low and this has been confirmed by the site investigation undertaken. Consequently, in accordance with CIRIA Report C665, given the proposed residential end use, 9 visits have been scheduled over a 6-month period.

14.2 Scope of works

14.2.1 To date, the wells have been monitored on two occasions, on the 5th January and the 2nd February 2022, for groundwater levels and soils-gases, and the results are presented in Appendix L.

14.2.2 A standard procedure was followed, in accordance with CIRIA guidance:

- Ambient oxygen concentration
- Atmospheric temperature & pressure
- Methane, oxygen and carbon dioxide concentrations and flow rates using a Gas Data GFM436 infra-red gas analyser
- Standing water level using a dipmeter
- Ambient oxygen concentration (check for instrument drift)

14.3 Monitoring results

14.3.1 The results of the monitoring completed to date are summarised below.

Well	Response zone	Range of methane concentrations (% v/v)	Range of carbon dioxide concentrations (% v/v)	Range of steady flow rates (litre/hour)
BH001	2.0m – 4.7m (Opencast Backfill).	0.0	7.0 – 8.4	0.0 – 1.5
BH002	3.0m – 9.0m (Opencast Backfill).	0.0	0.0 – 2.9	0.0 – 0.1
BH003	4.0m – 6.7m (Opencast Backfill).	0.0	0.4 – 5.2	0.0 – 0.8
BH004	4.0m – 6.7m (Opencast Backfill).	0.0	0.0 – 8.9	0.1

Well	Response zone	Range of methane concentrations (% v/v)	Range of carbon dioxide concentrations (% v/v)	Range of steady flow rates (litre/hour)
BH005	3.0m – 5.7m (Opencast Backfill).	0.0	1.8 – 5.6	0.1
BH006	6.0m – 9.0m (Opencast Backfill).	0.0	0.0 – 1.7	0.1
BH007	2.0m – 4.0m (Opencast Backfill).	0.0	6.9 – 7.2	0.1 – 0.9
BH008	8.5m – 11.5m (Opencast Backfill).	0.0	0.0	0.1
BH009	3.0m – 5.7m (Opencast Backfill).	0.0	5.4 – 8.8	0.0 – 0.1
BH010	7.0m – 11.0m (Opencast Backfill).	0.0	0.2 – 6.1	0.0 – 0.1
BH011	5.0m – 11.0m (Opencast Backfill).	0.0	0.0 – 3.6	0.1
BH012	4.5m – 7.2m (Opencast Backfill).	0.0	0.1 – 6.0	0.0 – 0.1
BH013	5.0m – 7.7m (Opencast Backfill).	0.0	0.9 – 18.5	0.0
BH014	3.0m – 5.7m (Opencast Backfill).	0.0	2.3 – 10.2	0.0
BH015	4.0m – 6.7m (Opencast Backfill).	0.0	8.4 – 21.8	0.0
BH201	6.0m – 9.0m (Opencast Backfill).	0.0	0.8 – 3.5	0.1
BH202	4.5m – 7.5m (Opencast Backfill).	0.0	16.9 – 18.6	0.1
BH203	1.5m – 4.5m (Opencast Backfill).	0.0	11.3 – 12.2	0.1
BH204	3.0m – 6.0m (Opencast Backfill).	0.0	8.9 – 9.3	0.0
BH205	2.5m – 5.5m (Opencast Backfill).	0.0	9.6 – 12.5	0.1
PH034	1.5m – 3.0m (Coal Measures).	0.0	0.0 – 0.8	0.0 – 5.5
PH035	1.5m – 3.0m (Opencast Backfill).	0.0	0.0	0.0
PH036	1.5m – 3.0m (Coal Measures).	0.0	0.1	0.0 – 0.4
PH037	1.5m – 3.0m (Opencast Backfill).	0.0	7.2 – 10.8	0.0
PH038	1.5m – 3.0m (Opencast Backfill).	0.0	0.8 – 17.2	0.0 – 0.1
PH039	1.5m – 3.0m (Opencast Backfill).	0.0	14.1	0.0
PH040	1.5m – 3.0m (Coal Measures).	0.0	0.0 – 3.3	0.0 – 0.9
PH041	1.5m – 3.0m (Coal Measures).	0.0	0.0 – 3.6	0.0 – 0.1
PH042	1.5m – 3.0m (Coal Measures).	0.0	0.4 – 2.4	0.0 – 0.3
PH108	1.5m – 3.0m (Coal Measures).	0.0	7.6 – 9.1	0.1 – 0.6
PH109	1.5m – 3.0m (Coal Measures).	0.0	8.7 – 11.4	0.0
PH217	1.5m – 3.0m (Coal Measures).	0.0	0.2 – 0.5	0.1 – 4.5
PH218	1.5m – 3.0m (Coal Measures).	0.0	0.3 – 0.8	0.0
PH219	1.5m – 3.0m (Coal Measures).	0.0	4.7 – 8.2	0.0 – 0.1

14.4 Discussion

14.4.1 Generic Note 05 in Appendix A outlines how monitoring results are interpreted.

14.4.2 Both the gas concentrations for carbon dioxide and the flow rates presented in the monitoring results above are variable from monitoring well to monitoring well.

14.4.3 Variable groundwater levels may be the result of some higher flow rates.

14.4.4 Further monitoring will be required to generate a larger dataset and enable a Gas Risk Assessment to be carried out. Monitoring is ongoing and a completed Gas Risk Assessment will be issued on completion of the monitoring in June 2022.

14.4.5 However, based on the results obtained to date it would be prudent to assume that some gas protective measures will be required for all plots across the site; possibly equating to Amber 1 or Amber 2, which will be confirmed in the finished Gas Risk Assessment.

14.5 Radon

14.5.1 Requirements with respect radon measures are set out in Building Regulations Approved Document C. Probability bandings (based on the proportion of properties in a given area that exceed the Action Level; currently 200 $Bq.m^{-3}$) are used to determine whether a property requires no, basic or full measures.

14.5.2 At present Approved Document C advocates basic measures for the probability banding 3% to 10% (full measures if >10%). However, Public Health England would like to see all new build include basic measures.

14.5.3 The Public Health England UK radon map and the Landmark report indicate that the site is in an area where **between 1% and 3%** of homes are estimated to be above the action level.

14.5.4 Consequently, basic radon protection measures are not required. However, in light of Public Health England advice, the Developer might consider providing all new dwellings with basic radon protection measures.

15 GEOTECHNICAL TESTING

15.1 General

15.1.1 A total of 228 samples of natural soil were delivered to a suitably accredited laboratory with a schedule of geotechnical testing drawn up by Lithos.

15.1.2 The geotechnical laboratory test results are presented in Appendix K to this report.

15.2 Atterberg limits

15.2.1 The plasticity indices of 106 samples of cohesive soil have been determined; results are summarised below:

Soil type	No. samples tested	Moisture content range % (average)	Range of Plasticity Indices % * (average)	Shrinkability
Cohesive Made Ground	17	14.0 – 34.0 (23.0)	16 – 35 (28)	Medium
Cohesive Opencast Backfill	58	4.7 – 33.0 (13.0)	8 - 33 (21)	Medium
Granular Opencast Backfill (with high fines portion)	10	6.4 – 15.0 (10.1)	8 – 16 (11)	Low
Cohesive Residual Soil	17	14.0 – 38.0 (21.0)	16 – 39 (26)	Medium
Coal Measures (weathered bedrock)	4	7.8 – 14.0 (11.0)	10 – 20 (16)	Low

* Modified where appropriate in accordance with Chapter 4.2 of the NHBC Standards

Note. The term Shrinkability is equivalent to the term Volume Change Potential used in Chapter 4.2.

15.2.2 For the purposes of foundation design, it is recommended that all cohesive soils (made ground and natural) be regarded as being of **medium** shrinkability. The shrinkability of Granular Opencast Backfill and weathered Coal Measures bedrock is discussed further in Section 15.3 below.

15.3 Particle size distribution

15.3.1 The gradings of 40 samples have been determined by wet sieving and the results are summarised in the table below:

Sample & depth	Field description	% pass' 37.5mm sieve	% pass' 20mm sieve	% pass' 2mm sieve	% fines	Material description (based on grading & plasticity)
BH006 – 0.0m – 1.0m	**Cohesive Made Ground** (CLAY)	100	100	90	74	Slightly gravelly slightly sandy CLAY
BH009 – 0.0m – 1.0m	**Cohesive Made Ground** (CLAY)	100	100	93	84	Slightly sandy slightly gravelly CLAY.
BH011 – 0.4m	**Cohesive Made Ground** (CLAY)	78	75	66	48	Slightly gravelly slightly sandy CLAY.
BH202 – 0.0m – 1.0m	**Cohesive Made Ground** (slightly gravelly CLAY)	100	100	84	53	Slightly sandy slightly gravelly CLAY.
BH204 – 0.0m – 1.0m	**Cohesive Made Ground** (slightly gravelly CLAY)	100	96	85	68	Slightly sandy slightly gravelly CLAY.
BH002 – 12.0m	**Cohesive Opencast Backfill** (very gravelly CLAY)	100	98	89	68	Clayey slightly sandy slightly gravelly SILT
BH008 – 8.0m	**Cohesive Opencast Backfill** (very gravelly CLAY)	97	93	88	83	Gravelly clayey SILT with rare sand.
BH010 – 9.0m	**Cohesive Opencast Backfill** (very gravelly CLAY)	80	68	44	29	Very clayey sandy GRAVEL.
BH011 – 3.0m	**Cohesive Opencast Backfill** (very gravelly CLAY)	86	81	57	39	Gravelly Sandy CLAY.
BH014 – 4.0m	**Cohesive Opencast Backfill** (very gravelly CLAY)	96	86	65	46	Very gravelly slightly sandy CLAY.
BH015 -3.0m	**Cohesive Opencast Backfill** (very gravelly CLAY)	92	86	65	51	Gravelly slightly sandy CLAY.
BH015 – 5.0m	**Cohesive Opencast Backfill** (very gravelly CLAY)	94	89	72	52	Slightly gravelly slightly sandy CLAY.
BH201 – 2.0m	**Cohesive Opencast Backfill** (very gravelly slightly sandy CLAY)	95	87	48	37	Gravelly slightly sandy CLAY.
BH201 – 6.5m	**Cohesive Opencast Backfill** (very gravelly slightly sandy CLAY)	100	94	74	59	Slightly gravelly slightly sandy CLAY.
BH204 – 2.0m	**Cohesive Opencast Backfill** (very gravelly CLAY)	88	83	68	49	Slightly gravelly slightly sandy CLAY.
BH204 – 5.0m	**Cohesive Opencast Backfill** (very gravelly CLAY)	89	81	50	38	Gravelly slightly sandy CLAY.
TP003 – 0.8m	**Cohesive Opencast Backfill** (very gravelly silty CLAY)	98	90	59	54	very gravelly slightly sandy clayey SILT
TP014 – 3.2m	**Cohesive Opencast Backfill** (silty slightly gravelly CLAY)	100	100	87	83	Slightly gravelly CLAY, rare sand.
TP015 – 3.5m	**Cohesive Opencast Backfill** (gravelly silty CLAY)	92	84	62	47	Gravelly sandy clayey SILT.
TP017 – 1.0m	**Cohesive Opencast Backfill** (very gravelly slightly sandy CLAY)	86	70	47	36	Very gravelly slightly sandy CLAY.
TP020 – 0.9m	**Cohesive Opencast Backfill** (very gravelly CLAY)	74	40	23	15	Silty sandy slightly clayey GRAVEL, low cobble content.
TP024 – 0.6m	**Cohesive Opencast Backfill** (very gravelly silty CLAY, medium cobble content)	77	65	54	41	Very gravelly slightly sandy CLAY.
TP030 – 0.7m	**Cohesive Opencast Backfill** (very gravelly slightly sandy CLAY)	95	77	58	55	Gravelly clayey SILT, rare sand.

Sample & depth	Field description	% pass' 37.5mm sieve	% pass' 20mm sieve	% pass' 2mm sieve	% fines	Material description (based on grading & plasticity)
TP047 – 1.0m	**Cohesive Opencast Backfill** (very gravelly silty CLAY)	100	93	58	45	Gravelly slightly sandy CLAY.
TP064 – 2.0m	**Cohesive Opencast Backfill** (very gravelly slightly sandy CLAY)	41	35	22	15	Clayey slightly sandy GRAVEL, high cobble content.
TP103 – 2.9m	**Cohesive Opencast Backfill** (gravelly silty CLAY)	95	87	70	52	Very gravelly sandy clayey SILT.
TP105 – 1.0m	**Cohesive Opencast Backfill** (gravelly silty CLAY, high cobble content)	90	77	51	35	Very clayey sandy GRAVEL.
TP217 – 1.5m	**Cohesive Opencast Backfill** (gravelly silty CLAY)	100	97	82	63	Clayey slightly sandy GRAVEL.
TP007 – 1.0m	**Granular Opencast Backfill** (silty clayey GRAVEL)	67	40	26	24	Clayey GRAVEL, medium cobble content, rare sand.
TP007 – 1.8m	**Granular Opencast Backfill** (silty clayey GRAVEL)	84	65	34	23	Silty clayey sandy GRAVEL.
TP027 – 1.2m	**Granular Opencast Backfill** (clayey GRAVEL)	55	43	29	22	Very clayey slightly sandy GRAVEL, high cobble content.
TP037 – 1.0m	**Granular Opencast Backfill** (clayey slightly sandy GRAVEL)	80	53	29	24	Very clayey slightly sandy GRAVEL, low cobble content.
TP057 – 1.6m	**Granular Opencast Backfill** (very clayey GRAVEL, low cobble content)	74	44	19	14	Clayey slightly sandy GRAVEL.
TP069 – 0.7m	**Granular Opencast Backfill** (silty clayey GRAVEL, low cobble content)	93	64	37	30	Very clayey sandy GRAVEL.
TP101 – 2.4m	**Granular Opencast Backfill** (silty clayey GRAVEL, high cobble content)	82	63	42	26	Silty clayey sandy GRAVEL.
TP205 – 0.8m	**Granular Opencast Backfill** (very clayey GRAVEL, low cobble content)	80	74	52	35	Very clayey slightly sandy GRAVEL.
TP039 – 1.0m	**Granular Opencast Backfill** (silty clayey GRAVEL, low cobble content)	82	62	33	24	Very clayey slightly sandy GRAVEL.
TP044 – 0.8m	**Granular Opencast Backfill** (silty clayey GRAVEL, medium cobble content)	84	50	27	17	Clayey sandy GRAVEL.
TP046 – 1.0m	**Granular Opencast Backfill** (silty clayey GRAVEL, high cobble content)	100	83	59	41	Gravelly slightly sandy CLAY.
TP051 – 0.8m	**Cohesive Residual Soil** (gravelly silty CLAY)	100	100	93	91	Slightly gravelly CLAY, rare sand.

Note: soils with greater than 35% fines highlighted in red.

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

15.3.3 A single sample of soil which was described as being granular in the field (TP046 at 1.0m; Granular Opencast Backfill), which would be described as cohesive based on the results of the gradings, however the results above generally support the field descriptions of made and natural soils beneath this site.

15.3.4 Whilst some samples of Granular Opencast Deposits returned a plasticity index of greater than 10, almost all samples submitted for gradings had a portion of fines less than 35% and therefore the Granular Opencast Backfill can generally be considered to be non-shrinkable.

15.4 Soluble sulphate and pH

15.4.1 In accordance with BRE SD1[3], this site has been classified as brownfield with a mobile groundwater regime. Groundwater flows to the northeast and preferentially drains into/flows through the former opencast.

15.4.2 At this stage final levels and design details have not been made available, however it is envisaged that foundations will extend to depths up around 1.0m (in natural soils) and up to c. 15m through made ground; samples have been taken from this depth range and submitted for pH and water-soluble sulphate (2:1 soil/water extract).

15.4.3 The concentrations of sulphate in the aqueous natural soil extracts of 36 samples were determined. In addition, 54 samples of made ground were tested as part of the contamination suite. The pH value of each sample has also been determined.

15.4.4 The highest water-soluble sulphate concentration and the lowest pH value for each soil type analysed are shown in the table below:

Soil type	No. samples tested	Lowest pH values	Highest soluble sulphate concentration (mg/l)
Cohesive Made Ground	13	5.8	280
Cohesive Opencast Backfill	32	6.1	1,322* (typically <300)
Granular Opencast Backfill	9	7.5	1,200* (typically <200)
Cohesive Residual Soil	14	5.3* (typically >6.0)	230
Granular Residual Soil	9	6.2	169
Coal Measures (bedrock)	10	7.5	145
Thin Coal	3	5.9	215

15.4.5 pH values were all above 5.5 with the exception of a single sample of Cohesive Residual Soil recovered from TP211 at 1.5m depth. Given none of the other 13 samples of Cohesive Residual Soil tested, or indeed 89 samples from the wider dataset, returned results of less than 5.5 (or indeed generally less than 6.0) this result is considered an outlier and can be discounted.

15.4.6 Consequently, concentrations of chloride and nitrate are considered insignificant.

15.4.7 Two samples returned results for water soluble sulphates in excess of the threshold for DS-1 AC-1 concrete classification; one sample of Cohesive Opencast Backfill; and, one sample of Granular Opencast Backfill. In accordance with the guidance presented in BRE SD1 these results have been assessed in the following ways; Cohesive Opencast Backfill = the mean of the highest 20% of values (rounded up to 100mg/l) has been taken; and, Granular Opencast Backfill = the mean of the highest two results has been taken.

15.4.8 Based on the above 'corrections' the following typical soluble sulphate results can be adopted: Cohesive Opencast Backfill; 600mg/l; and, Granular Opencast Backfill; 700mg/kg.

15.4.9 Consequently, in accordance with Tables C1 and C2 of SD1, sub-surface concrete which is in contact with **natural soils and bedrock** should be Design Sulphate Class **DS-1**, with the site allocated an ACEC Classification of **AC-1**. Concrete which is in contact with **Made Ground** should be **DS-2** and **AC-2**.

[3] *BRE Special Digest 1 (2005) – Concrete in aggressive ground.*

15.5 Compaction tests

15.5.1 Laboratory compaction tests are useful wherever ground improvement is anticipated, for example to provide a satisfactory CBR beneath proposed highways.

15.5.2 In accordance with BS5930[4] engineered fill is defined as material which is selected, placed and compacted to an appropriate specification so that it will exhibit the required engineering behaviour.

15.5.3 Grading and moisture content control the degree to which materials can be effectively compacted. If the grading or moisture content of an in-situ material is not suitable to facilitate its compaction then screening, wetting, or lime addition may be required.

15.5.4 Laboratory compaction testing was scheduled on 37 samples of made ground and 7 samples of natural soil and rock (using a 4.5km rammer) to determine their suitability for re-engineering.

15.5.5 Laboratory compaction tests are only appropriate if:

- At least 90% of the material passes the 37.5mm sieve; and/or
- At least 70% of the material passes the 20mm sieve

15.5.6 It is apparent from the results of the gradings (see Section 15.3) that whilst Cohesive Soils at this site broadly fall within the gradings envelope for compaction tests, the granular soils are generally too coarse (without processing).

15.5.7 Regardless, compaction tests can be useful in order to indicate target densities, but the results should be treated with caution and used for guidance only. However, if a particular material type is significantly coarser than the above limits allow, the results of laboratory compaction testing would be meaningless and a field trial would be necessary.

15.5.8 The material particle density (Gs) is required in order to plot the 0, 5 and 10% air voids lines on the compaction graph for each material type.

15.5.9 The results are summarised in the tables below:

Sample location & depth	Geology type	Gs (Mg/m^3)	MDD (Mg/m^3)	OMC (%)	Allowable mc range for 95% MDD & <5% air voids		As received moisture content (%)
					from	to	
BH014 – 0.4m	Cohesive Made Ground	2.66	1.76	17	16.0	22.0	23.0
BH201 – 0.0m – 1.0m	Cohesive Made Ground	2.63	1.65	20	19.5	25.0	23.0
TP012 – 0.1m	Cohesive Made Ground	2.64	1.71	19	17.5	23.0	31.0
TP015 – 0.2m	Cohesive Made Ground	2.64	1.71	18	18.0	22.0	33.0
TP020 – 0.4m	Cohesive Made Ground	2.65	1.79	16	15.5	20.0	22.0
TP105 – 0.5m	Cohesive Made Ground	2.63	1.79	15	15.0	20.5	22.0
TP207 – 0.7m	Cohesive Made Ground	2.63	1.93	11	11.0	16.5	14.0
TP210 – 0.5m	Cohesive Made Ground	2.65	1.81	16	15.0	20.0	19.0
BH014 – 2.0m	Cohesive Opencast Backfill	2.65	1.86	14	13.0	19.0	17.0
BH015 – 3.0m	Cohesive Opencast Backfill	2.62	1.93	12	11.0	16.5	15.0

[4] *BS5930 (2015) - Code of practice for ground investigations.*

Sample location & depth	Geology type	Gs (Mg/m³)	MDD (Mg/m³)	OMC (%)	Allowable mc range for 95% MDD & <5% air voids		As received moisture content (%)
					from	to	
BH015 – 5.0m	Cohesive Opencast Backfill	2.59	1.92	11	11.0	16.0	14.0
BH201 – 2.0m	Cohesive Opencast Backfill	2.59	2.04	9	8.0	13.0	11.0
BH203 – 2.0m	Cohesive Opencast Backfill	2.62	1.88	13	12.5	17.5	16.0
BH204 – 5.0m	Cohesive Opencast Backfill	2.63	1.99	10	10.0	15.0	15.0
BH205 – 4.0m	Cohesive Opencast Backfill	2.63	1.80	16	15.0	19.5	20.0
TP018 – 0.6m	Cohesive Opencast Backfill	2.67	1.88	15	13.0	18.0	15.0
TP022 – 0.5m	Cohesive Opencast Backfill	2.67	2.11	8	7.5	13.0	7.8
TP023 – 1.3m	Cohesive Opencast Backfill	2.69	2.02	12	10.5	15.5	12.0
TP062 – 3.0m	Cohesive Opencast Backfill	2.59	1.84	13	13.0	18.0	16.0
TP101 – 1.2m	Cohesive Opencast Backfill	2.65	1.87	14	13.0	18.0	17.0
TP104 – 1.5m	Cohesive Opencast Backfill	2.59	1.97	10	9.5	15.0	13.0
TP201 – 0.8m	Cohesive Opencast Backfill	2.64	1.96	11	10.5	15.5	14.0
TP213 – 0.6m	Cohesive Opencast Backfill	2.63	1.99	10	10.0	15.0	16.0
TP220 – 1.0m	Cohesive Opencast Backfill	2.64	1.96	11	10.5	16.0	14.0
TP043 – 2.4m	Cohesive Opencast Backfill	2.6	1.92	11	11.0	15.0	12.0
TP071 – 1.0m	Cohesive Opencast Backfill	2.61	1.86	14	13.0	18.0	14.0
TP071 – 2.0m	Cohesive Opencast Backfill	2.68	1.93	12	12.0	16.0	18.0
TP005 – 1.0m	Granular Opencast Backfill	2.65	2.03	10	9.0	14.0	10.0
TP011 – 2.0m	Granular Opencast Backfill	2.67	2.12	8	7.5	13.0	7.9
TP013 – 0.9m	Granular Opencast Backfill	2.64	2.11	8	7.0	12.0	6.4
TP016 – 0.8m	Granular Opencast Backfill	2.67	2.09	8	8.0	13.0	10.0
TP016 – 1.4m	Granular Opencast Backfill	2.64	2.05	9	8.5	14.0	15.0
TP026 – 0.9m	Granular Opencast Backfill	2.63	1.99	10	10.0	15.0	7.2
TP035 – 0.8m	Granular Opencast Backfill	2.66	2.08	10	8.5	13.0	7.6
TP049 – 2.5m	Granular Opencast Backfill	2.6	1.95	11	10.0	16.0	14.0
TP067 – 0.9m	Granular Opencast Backfill	2.6	1.98	10	9.5	14.5	14.0
TP102 – 1.2m	Granular Opencast Backfill	2.67	2.09	10	8.5	12.5	7.8
TP066 – 0.9m	Cohesive Residual Soil	2.63	1.73	19	17.0	22.5	25.0
TP104 – 1.5m	Cohesive Residual Soil	2.65	1.79	17	16.0	21.0	20.0
TP106 – 2.8m	Cohesive Residual Soil	2.62	1.83	15	14.0	19.0	21.0
TP001 – 1.4m	Granular Residual Soil	2.69	2.03	10	9.5	15.0	12.0
TP002 – 1.0m	Granular Residual Soil	2.69	2.03	11	10.0	14.5	13.0
TP022 – 2.3m	Granular Residual Soil	2.57	1.99	9	8.9	12.6	9.4
BH203 – 5.0m	Coal Measures	2.63	2.03	9	9.0	14.0	14.0

Note: As received moisture contents which fall outside of the allowable moisture content range are shown in red.

15.5.10 It is apparent that soils across the site fall broadly within or 'close to' the allowable moisture content range to achieve 95% MDD and less than 5% air voids; although the Cohesive Made Ground is often slightly too wet and the Granular Opencast Backfill is on occasion slightly too dry.

15.5.11 Therefore, correction of soil moisture contents should be allowed for during earthworks at this site, notably drying of the Cohesive Made Ground.

15.5.12 Drying out of these soils will require careful management on site. They should be placed in sealed stockpiles during periods of wet weather, or while the site is unattended. During periods of favourable weather (ideally warm & windy) the soils should be spread in thin layers over as wide an area as possible and aerated by turning with an excavator. Alternatively, consideration could be given to lime modification, using nominal lime percentages of 0.5% to 2% (maximum).

15.5.13 The Granular Opencast Backfill may also need to be screened in order to remove any unsuitable and oversized materials (i.e. cobbles and boulders).

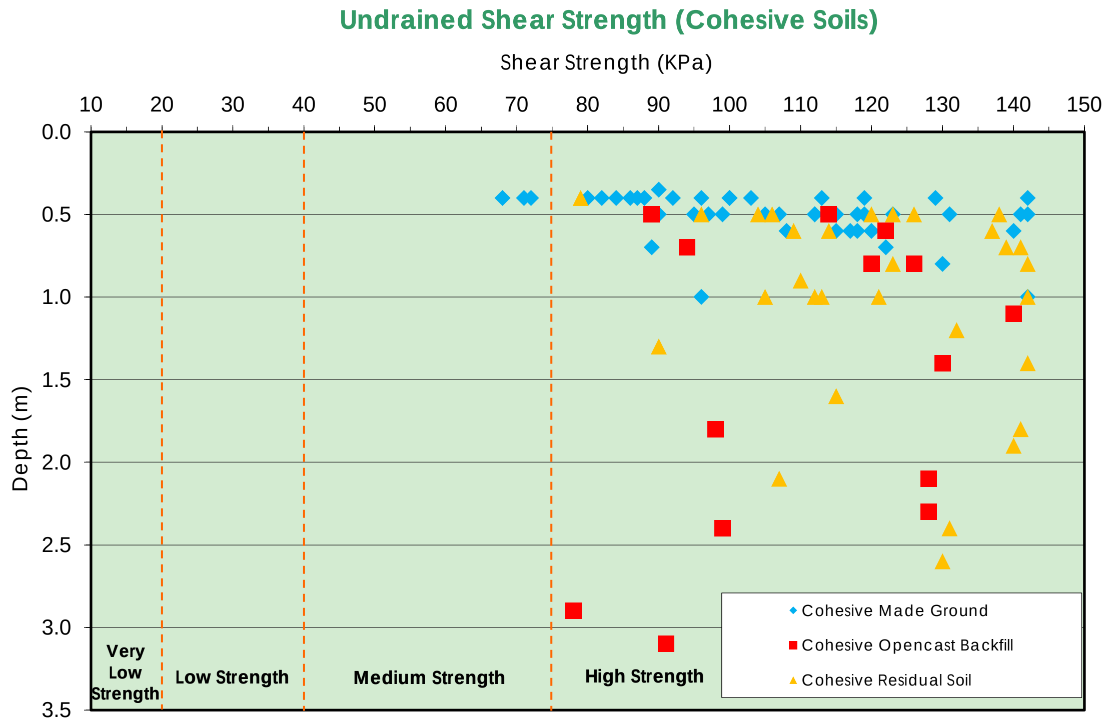
15.5.14 Acceptability of the soils for use in the proposed controlled earthworks will need detailed appraisal by the Earthworks Designer in light of the required performance characteristics.

15.6 Undrained shear strength testing

Hand shear vane testing

15.6.1 Hand shear vane testing was undertaken on 'clean' (i.e. not sandy/gravelly) cohesive soils within trial pits in-situ to around 1.2m depth and from larger blocks of excavated clay below that depth.

15.6.2 The results are summarised in the plot below:



15.6.3 The results show that both made and natural cohesive soils beneath the site are of at least medium strength, generally high strength, and have a broad trend of increasing strength with depth.

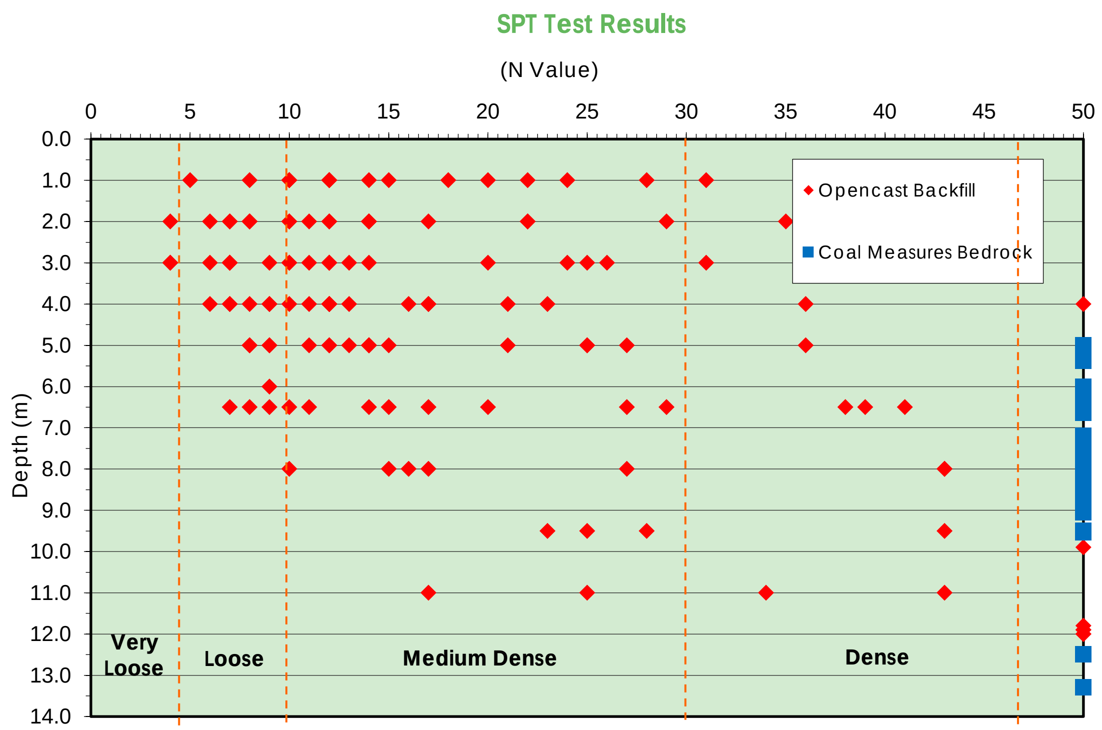
15.7 Standard penetration test (SPT)

15.7.1 The in-situ relative density of Opencast Backfill and Coal Measures was established by carrying out Standard Penetration Tests (SPTs) during the drilling of the cable percussion boreholes.

15.7.2 The SPT results are summarised in below:

Stratum	Range of SPT 'N' values (ave.)	Estimated strength or density	Remarks
Opencast Backfill	4 - >50 (17)	High strength/Medium dense	-
Coal Measures	>50	Very high strength.	SPT's refused before 450mm

15.7.3 SPT N values are shown against depth in the plot below:



15.7.4 The reported blow counts suggest that the Opencast Backfill is variable in terms of it's in-situ compaction but is generally of high strength/medium density. The in-situ strength broadly increases with depth.

15.7.5 All SPT tests undertaken on bedrock refused before reaching 450mm of penetration.

15.8 Rock strength testing

General

15.8.1 A total of 147 samples of rock recovered from the rotary cored boreholes were submitted for point load and unconfined compressive strength (UCS) testing to determine the rocks in-situ strength. Results of rock testing are presented in the tables on pages 59 to 61.

15.8.2 Samples submitted for point load testing and Unconfined Compressive Strength testing were typically carried out on Mudstone, as this was the dominant rock type, with Siltstone and typically 'stronger' Sandstone samples also tested where encountered.

15.8.3 Point Load testing in an axial orientation (i.e. vertical/perpendicular to bedding) produces a value for I_s50 in MPa. This value is not a direct reflection on the strength of the in-situ rock due to the concentrated area of force applied to the rock sample by the testing tool (the point). In order to gain a value in MPa comparable to the strength of the rock sample, and directly equivalent to the unconfined compressive strength, a correction factor must be applied.

15.8.4 Whilst a variety of correction factors have been published. Mark and Rusnak[5] published a conversion factor of 21 following a case study of Coal Measures bedrock across North America.

15.8.5 Therefore, Lithos have adopted a correction factor of 21 to convert the I_s50 into a uniaxial Compressive Strength equivalent in MPa.

Summary of Point Load Testing

15.8.6 A total of 127 samples were submitted for point load testing. Each point load test was undertaken along an axial (perpendicular to bedding) and diametral (parallel to bedding) orientation. The result of each test is reported in an Is50 format which makes corrections based on the diameter of each sample. Results are summarised in the table below, and presented more fully in the table overleaf:

Material	Range of PL results (Is50)	
	Parallel (ave)	Perpendicular (ave)
Mudstone	0.01 – 0.53 (0.19)	0.07 – 1.36 (0.51)
Siltstone	0.04 – 0.95 (0.30)	0.30 – 1.66 (0.69)
Sandstone	0.16 – 4.50 (1.63)	0.48 – 5.98 (2.46)

15.8.7 All results show a marked difference in strength axially (parallel) and diametrically (perpendicular), as would be expected in thinly bedded sedimentary rocks.

Hole ID	Rock Type	Sample Depth (mbgl)	Test orientation #	Is50	Strength (MPa) +	Strength description (BS5930)
RC001	Coal Measures; Mudstone	9.5	Par	0.05	1.05	Very weak.
RC001			Perp	0.25	5.25	Weak.
RC001	Coal Measures; Mudstone	9.7	Par	0.06	1.26	Very weak.
RC001			Perp	0.33	6.93	Weak.
RC001	Coal Measures; Sandstone	11.5	Par	0.80	16.80	Weak.
RC001			Perp	1.03	21.63	Weak.
RC001	Coal Measures; Siltstone	10.4	Par	0.12	2.52	Very weak.
RC001			Perp	0.38	7.98	Weak.
RC001	Coal Measures; Siltstone	13.8	Par	0.43	9.03	Weak.
RC001			Perp	0.82	17.22	Weak.
RC002	Coal Measures; Mudstone	8.0	Par	0.11	2.31	Very weak.
RC002			Perp	0.39	8.19	Weak.

[5] *Using the point load test to determine the uniaxial compressive strength of Coal Measure Rock. J Rusnak & C Mark. August 200. Proceedings on the 19th international conference on ground control in mining. Pgs. 362 - 371*

Hole ID	Rock Type	Sample Depth (mbgl)	Test orientation #	Is50	Strength (MPa) +	Strength description (BS5930)
RC002	Coal Measures; Mudstone	8.6	Par	0.11	2.31	Very weak.
RC002			Perp	0.36	7.56	Weak.
RC002	Coal Measures; Mudstone	9.4	Par	0.09	1.89	Very weak.
RC002			Perp	0.30	6.30	Weak.
RC002	Coal Measures; Mudstone	9.8	Par	0.07	1.47	Very weak.
RC002			Perp	0.31	6.51	Weak.
RC002	Coal Measures; Mudstone	10.4	Par	0.20	4.20	Very weak.
RC002			Perp	0.52	10.92	Weak.
RC002	Coal Measures; Siltstone	11.3	Par	0.04	0.84	Extremely weak.
RC002			Perp	0.31	6.51	Weak.
RC002	Coal Measures; Siltstone	11.4	Par	0.13	2.73	Very weak.
RC002			Perp	0.50	10.50	Weak.
RC002	Coal Measures; Siltstone	11.6	Par	0.18	3.78	Very weak.
RC002			Perp	0.51	10.71	Weak.
RC002	Coal Measures; Siltstone	12.3	Par	0.41	8.61	Weak.
RC002			Perp	0.90	18.90	Weak.
RC002	Coal Measures;	13.0	Par	0.35	7.35	Weak.
RC002			Perp	0.82	17.22	Weak.
RC003	Coal Measures; Mudstone	12.1	Par	0.45	9.45	Weak.
RC003			Perp	0.90	18.90	Weak.
RC003	Coal Measures; Mudstone	12.8	Par	0.48	10.08	Weak.
RC003			Perp	0.96	20.16	Weak.
RC003	Coal Measures; Mudstone	14.7	Par	0.53	11.13	Weak.
RC003			Perp	1.36	28.56	Medium Strong.
RC003	Coal Measures; Sandstone	9.6	Par	2.63	55.23	Strong.
RC003			Perp	4.22	88.62	Strong.
RC003	Coal Measures; Sandstone	10.5	Par	1.17	24.57	Weak.
RC003			Perp	1.84	38.64	Medium Strong.
RC004	Coal Measures; Mudstone	11.1	Par	0.01	0.21	Extremely weak.
RC004			Perp	0.08	1.68	Very weak.
RC004	Coal Measures; Mudstone	11.2	Par	0.03	0.63	Extremely weak.
RC004			Perp	0.17	3.57	Very weak.
RC004	Coal Measures; Mudstone	11.7	Par	0.03	0.63	Extremely weak.
RC004			Perp	0.10	2.10	Very weak.
RC004	Coal Measures; Mudstone	16.0	Par	0.24	5.04	Weak.
RC004			Perp	0.50	10.50	Weak.
RC004	Coal Measures; Mudstone	16.1	Par	0.35	7.35	Weak.
RC004			Perp	0.75	15.75	Weak.
RC004	Coal Measures; Sandstone	14.4	Par	1.86	39.06	Medium Strong.
RC004			Perp	2.89	60.69	Strong.
RC005	Coal Measures; Mudstone	12.2	Par	0.06	1.26	Very weak.
RC005			Perp	0.21	4.41	Very weak.
RC005	Coal Measures; Mudstone	12.6	Par	0.20	4.20	Very weak.
RC005			Perp	0.73	15.33	Weak.

Hole ID	Rock Type	Sample Depth (mbgl)	Test orientation #	Is50	Strength (MPa) +	Strength description (BS5930)
RC005	Coal Measures; Mudstone	12.9	Par	0.24	5.04	Weak.
RC005			Perp	0.55	11.55	Weak.
RC005	Coal Measures; Mudstone	13.4	Par	0.31	6.51	Weak.
RC005			Perp	0.66	13.86	Weak.
RC005	Coal Measures; Sandstone	9.0	Par	2.04	42.84	Medium Strong.
RC005			Perp	3.29	69.09	Strong.
RC005	Coal Measures; Sandstone	11.1	Par	1.84	38.64	Medium Strong.
RC005			Perp	2.89	60.69	Strong.
RC005	Coal Measures; Siltstone	7.8	Par	0.08	1.68	Very weak.
RC005			Perp	0.30	6.30	Weak.
RC006	Coal Measures; Mudstone	13.1	Par	0.29	6.09	Weak.
RC006			Perp	0.64	13.44	Weak.
RC006	Coal Measures; Mudstone	13.6	Par	0.30	6.30	Weak.
RC006			Perp	0.68	14.28	Weak.
RC006	Coal Measures; Mudstone	14.7	Par	0.41	8.61	Weak.
RC006			Perp	0.94	19.74	Weak.
RC006	Coal Measures; Mudstone	15.1	Par	0.45	9.45	Weak.
RC006			Perp	0.88	18.48	Weak.
RC006	Coal Measures; Mudstone	15.5	Par	0.19	3.99	Very weak.
RC006			Perp	0.71	14.91	Weak.
RC006	Coal Measures; Mudstone	16.4	Par	0.34	7.14	Weak.
RC006			Perp	0.70	14.70	Weak.
RC201	Coal Measures; Mudstone	8.8	Par	0.08	1.68	Very weak.
RC201			Perp	0.42	8.82	Weak.
RC201	Coal Measures; Mudstone	11.2	Par	0.19	3.99	Weak.
RC201			Perp	0.48	10.08	Weak.
RC201	Coal Measures; Mudstone	11.5	Par	0.15	3.15	Weak.
RC201			Perp	0.39	8.19	Weak.
RC201	Coal Measures; Mudstone	12.2	Par	0.25	5.25	Weak.
RC201			Perp	0.62	13.02	Weak.
RC201	Coal Measures; Mudstone	13.5	Par	0.11	2.31	Very weak.
RC201			Perp	0.59	12.39	Weak.
RC201	Coal Measures; Mudstone	15.6	Par	0.18	3.78	Very weak.
RC201			Perp	1.22	25.62	Medium Strong.
RC201	Coal Measures; Mudstone	15.9	Par	0.04	0.84	Extremely weak.
RC201			Perp	0.42	8.82	Weak.
RC202	Coal Measures; Mudstone	7.9	Par	0.05	1.05	Very weak.
RC202			Perp	0.16	3.36	Very weak.
RC202	Coal Measures; Mudstone	8.5	Par	0.01	0.21	Extremely weak.
RC202			Perp	0.07	1.47	Very weak.
RC202	Coal Measures; Mudstone	9.4	Par	0.02	0.42	Extremely weak.
RC202			Perp	0.10	2.10	Very weak.
RC202	Coal Measures; Mudstone	11.2	Par	0.05	1.05	Very weak.
RC202			Perp	0.26	5.46	Weak.

Hole ID	Rock Type	Sample Depth (mbgl)	Test orientation #	Is50	Strength (MPa) +	Strength description (BS5930)
RC202	Coal Measures; Sandstone	13.9	Par	4.50	94.50	Strong.
RC202			Perp	5.98	125.58	Very strong.
RC202	Coal Measures; Sandstone	15.5	Par	0.22	4.62	Very weak.
RC202			Perp	0.48	10.08	Weak.
RC203	Coal Measures; Mudstone	10.9	Par	0.20	4.20	Very weak.
RC203			Perp	0.49	10.29	Weak.
RC203	Coal Measures; Mudstone	11.0	Par	0.15	3.15	very weak.
RC203			Perp	0.37	7.77	Weak.
RC203	Coal Measures; Mudstone	12.6	Par	0.32	6.72	Weak.
RC203			Perp	0.58	12.18	Weak.
RC203	Coal Measures; Mudstone	13.1	Par	0.41	8.61	Weak.
RC203			Perp	0.84	17.64	Weak.
RC203	Coal Measures; Sandstone	9.6	Par	1.92	40.32	Medium Strong.
RC203			Perp	2.84	59.64	Strong.
RC203	Coal Measures; Siltstone	14.5	Par	0.95	19.95	Weak.
RC203			Perp	1.66	34.86	Medium Strong.
RC204	Coal Measures; Mudstone	11.5	Par	0.05	1.05	Very weak.
RC204			Perp	0.11	2.31	Very weak.
RC204	Coal Measures; Sandstone	8.2	Par	1.34	28.14	Medium Strong.
RC204			Perp	1.56	32.76	Medium Strong.
RC204	Coal Measures; Sandstone	8.6	Par	0.16	3.36	Weak.
RC204			Perp	0.52	10.92	Weak.
RC204	Coal Measures; Sandstone	9.5	Par	1.06	22.26	Weak.
RC204			Perp	1.98	41.58	Medium Strong.
RC204	Coal Measures; Sandstone	12.5	Par	1.63	34.23	Medium Strong.
RC204			Perp	2.49	52.29	Strong.

** Type: A = axial, D = diametral, I = Irregular*
 # With respect to bedding plane & from vertical
+ See comments with regards to conversion from Is50 to UCS in text of Section 13.8

Summary of UCS testing

15.8.8 A total of 21 samples were submitted for UCS testing. In addition to each UCS value, the density of each sample has also been reported. Results are summarised in the table below:

Material	Range of Unconfined Compressive Strength (MPa) (ave)	Strength description (BS5930)
Mudstone	4.8 – 19.2 (12.4)	Weak.
Siltstone	14.3 – 21.3 (17.7)	Weak.
Sandstone	21.1 – 88.5 (39.3)	Medium strong.

Hole ID	Rock Type	Sample depth (mbgl)	UCS (MPa)	Failure Mode	Strength description (BS5930)
RC001	Coal Measures; Siltstone	10.00	14.3	Brittle	Weak
RC001	Coal Measures; Sandstone	11.70	28.5	Brittle	Medium Strong
RC001	Coal Measures; Siltstone	13.50	17.4	Brittle	Weak

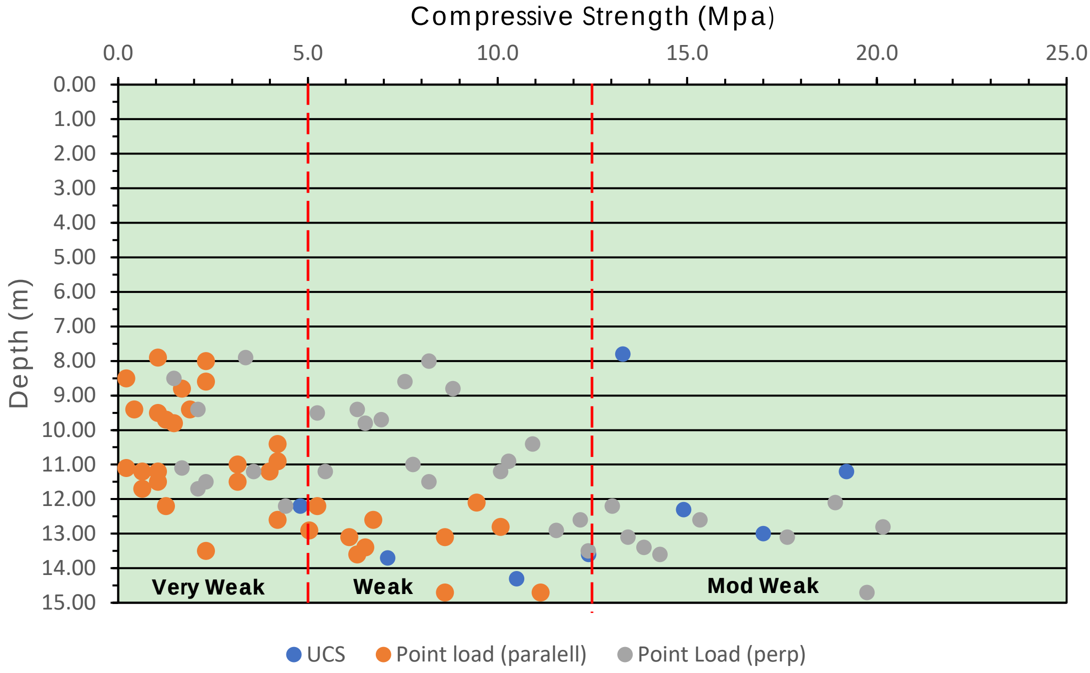
Hole ID	Rock Type	Sample depth (mbgl)	UCS (MPa)	Failure Mode	Strength description (BS5930)
RC003	Coal Measures; Sandstone	9.70	25.5	Brittle	Medium Strong
RC003	Coal Measures; Mudstone	13.60	12.4	Brittle	Weak
RC003	Coal Measures; Mudstone	14.30	10.5	Brittle	Weak
RC004	Coal Measures; Sandstone	14.00	25.7	Brittle	Medium Strong
RC004	Coal Measures; Sandstone	14.50	21.1	Brittle	Weak
RC005	Coal Measures; Sandstone	8.20	56.1	Brittle	Strong
RC005	Coal Measures; Sandstone	9.20	24.0	Brittle	Weak
RC005	Coal Measures; Mudstone	12.30	14.9	Brittle	Weak
RC006	Coal Measures; Mudstone	11.20	19.2	Brittle	Weak
RC006	Coal Measures; Mudstone	12.20	4.8	Brittle	Very weak
RC006	Coal Measures; Mudstone	13.70	7.1	Brittle	Weak
RC201	Coal Measures; Mudstone	13.00	17.0	Brittle	Weak
RC202	Coal Measures; Mudstone	7.80	13.3	Brittle	Weak
RC202	Coal Measures; Sandstone	14.00	88.5	Brittle	Strong
RC203	Coal Measures; Sandstone	9.40	27.1	Brittle	Medium Strong
RC203	Coal Measures; Siltstone	14.00	21.3	Brittle	Weak
RC204	Coal Measures; Sandstone	8.30	47.9	Brittle	Medium Strong
RC204	Coal Measures; Sandstone	12.30	49.0	Brittle	Medium Strong

Summary of rock strength

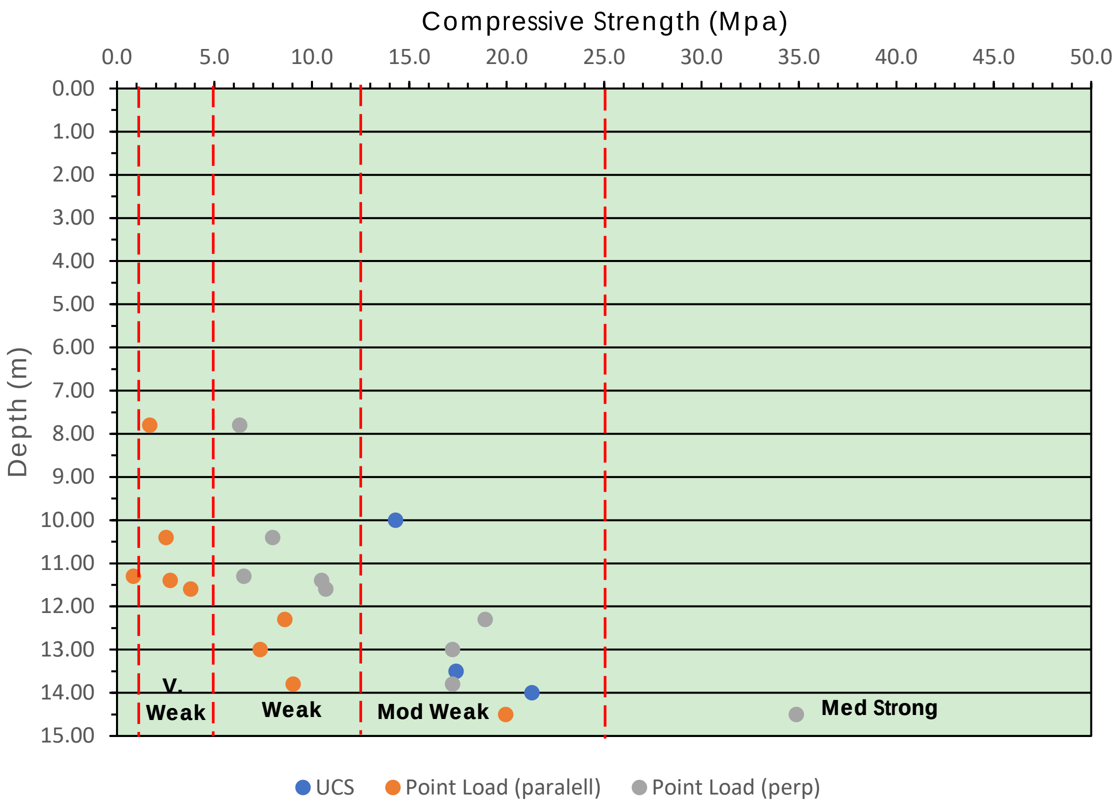
15.8.9 Coal Measures Mudstone is typically very weak to weak, the Siltstone is typically weak whilst the sandstone is generally medium strong to strong. This supports the field descriptions shown in the exploratory logs. All rock types tested are weaker when tested parallel to horizontal (and relict bedding planes) and stronger when tested perpendicular to horizontal, as would be expected.

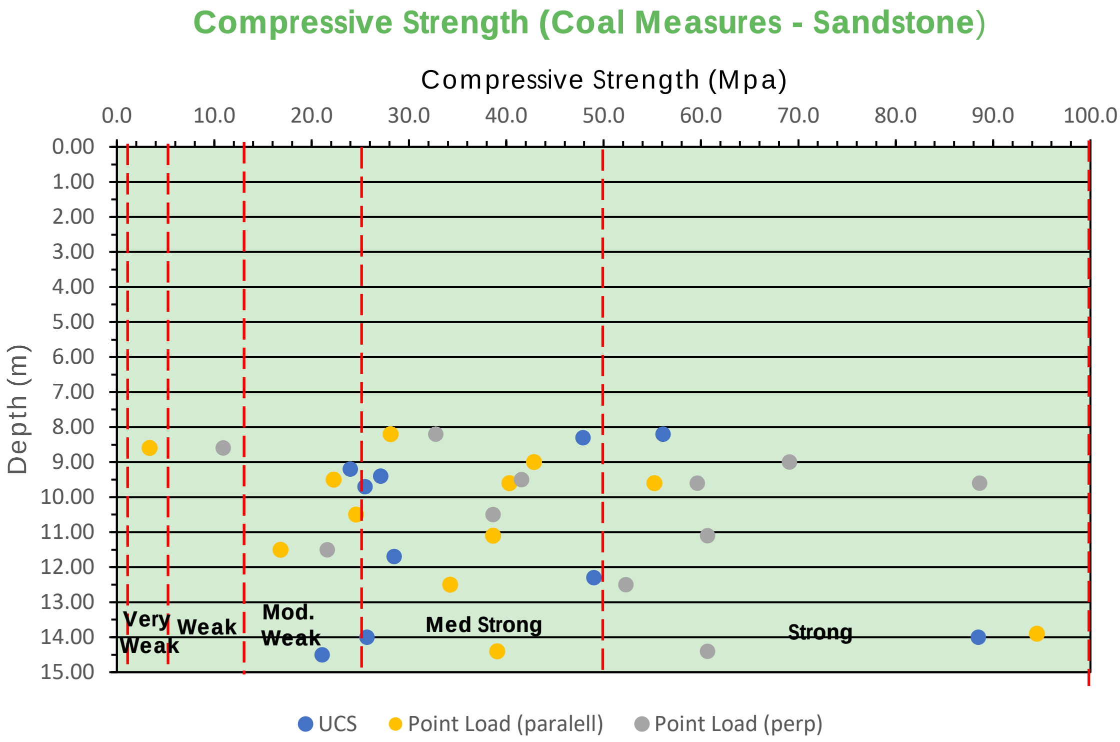
15.8.10 A plot of compressive rock strengths is presented in the graphs below:

Compressive Strength (Coal Measures - Mudstone)



Compressive Strength (Coal Measures - Siltstone)





15.8.11 Strength across all rock types shows a slight increase with depth.

16 GEOTECHNICAL ISSUES

16.1 Conceptual site model

16.1.1 The Conceptual Site Model has been revised to reflect the nature and depths of made and natural soils across the site, notably in terms of the depth and in-situ characteristics of Opencast Backfill and Cohesive Made Ground across the footprint of the former opencasts.

16.2 Mining & quarrying

16.2.1 Much of the site's area is located within a Coal Mining Development High Risk Area.

16.2.2 About 60% of the total area has been subject to opencast coal extraction; the Development Areas are underlain by the Craven I opencast which reaches depths of up to around 13m; the spine road is underlain by the Craven II opencast which reaches depths of around 30m to 40m, although to date exploratory holes have refused before reaching the base of the Craven II opencast.

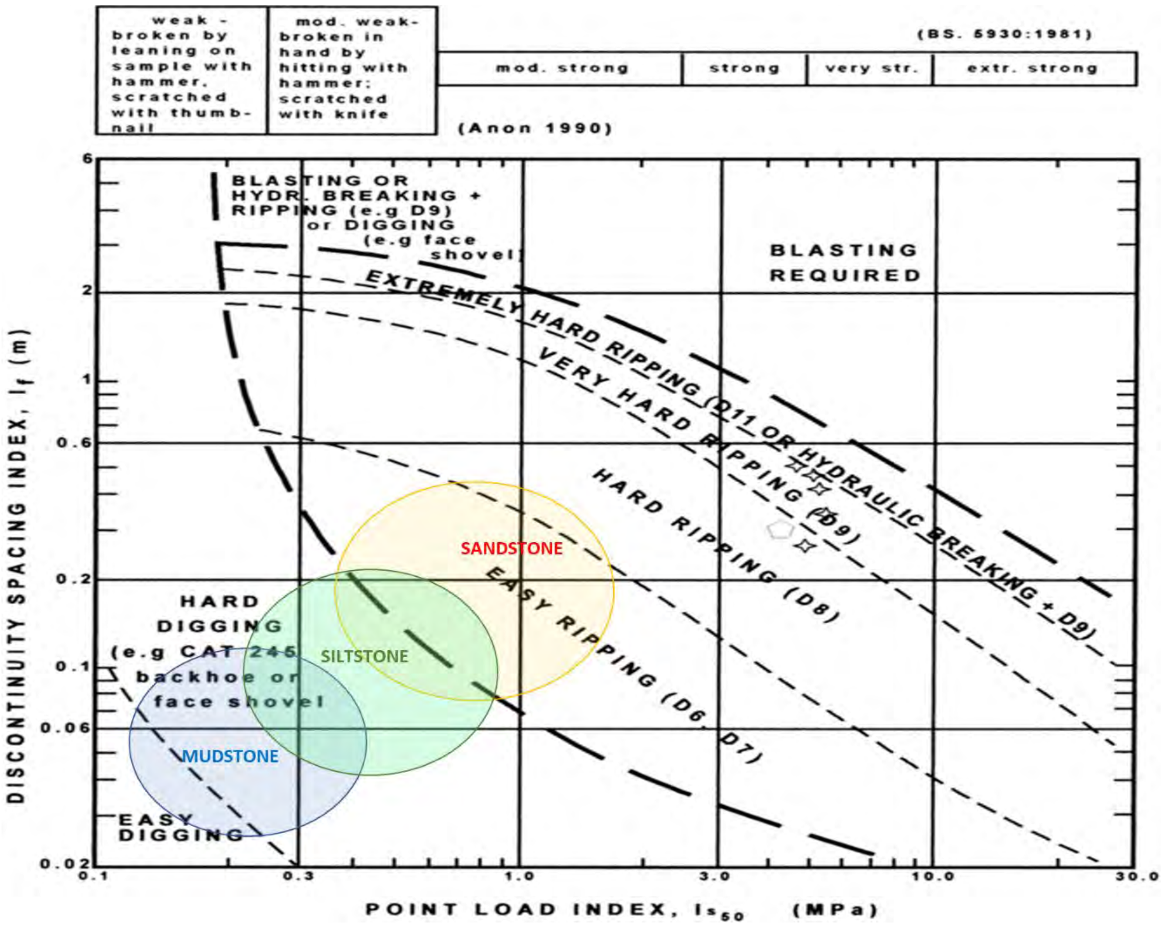
16.2.3 Shallow coal seams underlay the opencasts and land outside of the opencasts. However, no evidence of shallow underground workings have been encountered during Lithos' ground investigation.

16.3 Excavatability

16.3.1 As outlined in Section 17.2 below some levels regrade is anticipated across this site, although final levels have yet to be confirmed. Based on the existing topography, in order to create the development platform, cut is likely in the west and upfill most likely in the east of the site.

16.3.2 Cut, across the west of LT1, may result in excavations through bedrock which comprises interbedded mudstones, siltstone and sandstones of the Lower Coal Measures; the dominant near-surface rock type is mudstone.

16.3.3 Excavatability can be characterised by plotting point load results (in Is50) against fracture spacing on the Pettifer-Fookes chart. Indicative excavatability of rock from levels above the proposed finished floor levels (ie material to be cut) is plotted in this way below:



16.3.4 The Pettifer-Fookes chart suggests that the mudstones and siltstones are likely to be excavatable using normal excavating machinery, ranging from easy to hard digging. However, excavations through sandstone (if encountered) may require ripping (D6, D7 & D8 Dozers)and more specialised equipment.

16.4 Foundation recommendations

General

16.4.1 Foundation recommendations assume that development will be of two or three storey construction and that line loads will not exceed 90kN/m run. If this is not the case significant alteration to these recommendations will be required.

16.4.2 In the absence of detailed design information, no foundation recommendations can be given for the proposed school buildings or commercial buildings; design specific assessment and possibly ground investigation will be required for these developments.

16.4.3 For the purpose of foundation recommendations, and in the absence of detailed final design levels and parameters, it has been assumed that final levels will not alter significantly from existing levels; however, this is unlikely to be the case, at least for some areas of the site as a levels regrade is anticipated. Any digital terrain modelling undertaken, or commissioned, by Strata should consider implications for the foundation recommendations outlined below.

16.4.4 Foundation depths (and types) will depend on thicknesses of fill following the anticipated earthworks regrade.

16.4.5 Following the anticipated turnover earthworks, replaced fill materials will not contain obstructions and should be relatively stable with little overbreak. At this stage, it is assumed that fill will be placed with nominal compaction only, and reinforced footings on engineered fill are not currently anticipated.

16.4.6 Made ground is not considered a suitable foundation material and foundations should therefore be taken through these materials into underlying natural strata of adequate bearing capacity.

16.4.7 sub-surface concrete which is in contact with **natural soils and bedrock** should be Design Sulphate Class **DS-1**, with the site allocated an ACEC Classification of **AC-1**. Concrete which is in contact with **Made Ground** should be **DS-2** and **AC-2**.

16.4.8 Foundation solutions are subject to the nature and thickness of made ground beneath the site and can be categorised on site areas based on ground conditions (see Section 11.1.2 and Drawing 3104/13).

Areas A & B

Strip/trench fill footings

16.4.9 It is considered that shallow strip or deepened trench fill footings will be the most suitable foundation solution for plots constructed in Areas A and B subject to the thickness of made ground following any levels regrade.

16.4.10 Footings will be founded in Residual Soils or upon competent bedrock.

16.4.11 Reinforcement, as a precaution against differential settlement, is recommended only where foundation excavations encounter significant lateral and vertical variations in strata. One layer of B385 mesh placed 75mm above the base of the footing is likely to provide suitable reinforcement, but further advice should be sought from the Structural Engineer.

16.4.12 Foundations will be required to be placed below a line drawn up at 45^{o} from the base of any service or similar excavation.

16.4.13 Deepened foundations should be stepped in accordance with NHBC Standards, Chapter 4.3.

16.4.14 In order to minimise softening and swelling of cohesive soils or loosening of granular soils, it is recommended that footings are cast as soon as formation level is reached (or alternatively formation could be blinded using concrete with as low a water:cement ratio as possible).

16.4.15 Strata or their groundworker should seek further advice from Lithos if unexpected ground conditions are encountered in foundation or sewer excavations, including any conflict between soft ground associated with a backfilled trial pit excavation and the line of a proposed footing.

16.4.16 The **Granular Residual Soil** is assumed to have a relative density of at least medium dense (in accordance with BS5930).

16.4.17 A safe bearing capacity of at least 150kPa, allowing a maximum foundation line load of 90kN/m run, can be assumed if the following are true:

- A foundation length of 8m
- A foundation breadth of 0.6m
- A foundation thickness of 225mm
- A foundation depth of 0.6m depth
- An angle of shearing resistance of ϕ=33° for the granular deposits

16.4.18 Assuming the foundation geometry detailed above, minimal settlements would be anticipated. This is considered likely to be acceptable, however, further advice should be sought from the Structural Engineer responsible for foundation design.

16.4.19 In accordance with NHBC Standards, a minimum founding depth of 450mm (due to potential frost susceptibility) is required in granular soils.

16.4.20 However, in order to reduce the risk of unacceptable amounts of settlement a minimum depth of 600mm is recommended at this site.

16.4.21 This depth should be taken from finished ground level to the underside of the footing. If finished ground level is to be above existing ground level then the foundation excavation simply needs to ensure that there is sufficient depth of excavation to allow casting of the footing entirely within natural ground (not made ground or topsoil). However, if the excavation is dug from original ground level in cold conditions when freezing is expected, then foundation depth should be taken from the existing, not finished, ground level.

16.4.22 Where ground level is being raised, it would be prudent to proof roll the exposed granular soils after stripping topsoil (to mitigate any near-surface disturbance), and ideally fill should be placed prior to construction (otherwise the Developer will need to consider the potential for movement associated with placement of the fill).

16.4.23 It should also be noted that the footing may require deepening or stepping in order to allow plot drainage to exit the plot footprint (either over or under the footing).

16.4.24 Clay classification tests suggest that the **Cohesive Residual Soils** at the site are of medium shrinkability. A minimum founding depth of 900mm (not accounting for any existing or proposed vegetation) is therefore recommended for all soils on the site where strip footings are proposed.

16.4.25 In accordance with NHBC Standards, founding depths in cohesive soils should be taken from original or finished ground level, whichever is the lower, to the underside of the footing.

16.4.26 Foundations should be deepened near trees in accordance with NHBC Standards Chapter 4.2. It is estimated that up to 20% of the site may be affected by trees.

16.4.27 The current layout suggests some plots will be built on ground from which hedgerows will be removed. Whilst the hedgerows at the site are relatively low (<2.5m height) and appear to have been maintained at that height by trimming, it is often difficult to definitively prove that they have not desiccated soils to significant depth. In theory, if mature Hawthorn is removed from within the footprint of a plot, founding depth (in low shrinkability clay) would be >2.5m.

16.4.28 Trench fill foundations should be designed in accordance with NHBC Standards, Chapter 4.2. Heave precautions (a suitable approved compressible void former) should be used on the internal face of all external walls where the foundation is within the zone of influence of trees and greater than 1.5m deep.

16.4.29 Any trench fill foundation deeper than 2.5m will need to be designed by a Chartered Engineer, whose status is accepted by NHBC (NHBC Standards, Technical Requirement R5).

16.4.30 It would therefore be prudent to prepare a detailed foundation schedule and seek approval from NHBC in order to determine likely foundation abnormals.

16.4.31 A safe bearing capacity of at least 150kPa, allowing a maximum foundation line load of 90kN/m run, can be assumed if the following are true

- A foundation length of 8m
- A foundation breadth of 0.6m
- A foundation thickness of 225mm
- A foundation depth of 0.9m depth
- An undrained shear strength of 70kPa for the firm clay (typical minimum recorded on site)

16.4.32 Assuming the foundation geometry detailed above, minimal settlements would be anticipated. This is considered likely to be acceptable, however, further advice should be sought from the Structural Engineer responsible for foundation design.

16.4.33 The Coal Measures Bedrock is generally considered to have a safe bearing capacity of at least 250kPa and minimal settlements would be anticipated.

16.4.34 Where rock is encountered at shallow depth foundations should be placed entirely on rock and not partially on rock and partially on soil. This may, depending on surface gradient, necessitate significant deepening of foundations.

16.4.35 Bedrock at the site comprises mudstone which can be easily excavated using a backhoe excavator and will be recovered as a tabular gravel. Where in-situ mudstone is encountered at founding depth (minimum of 450mm), it will provide a suitable founding stratum for two or three storey dwellings and need only be penetrated by the proposed foundation thickness. Note: any overlying residual soil (typically clay with gravel-sized lithorelicts of mudstone) is likely to be a shrinkable soil; Mudstone is not.

16.4.36 Some excavations for foundations in the west of the site may come into contact with coal. Care should be taken not to unnecessarily overdeepen foundations, in order to minimise the chance of encountering coal.

16.4.37 Where foundation excavations do come into contact with coal, the foundation should be taken through the coal seam, into underlying natural in-situ strata of adequate bearing. The full thickness of coal should then be sealed with concrete to create a trench fill foundation. To prevent the ingress of air, the mass concrete fill should be placed as soon as possible after exposing the seam.

16.4.38 By virtue of the provisions of the Coal Industry Act 1994 interests in unworked coal and coal mines previously vested in the British Coal Corporation are now vested in the Coal Authority. The developer will need to contact the Coal Authority to dig or carry away such coal as they encounter in connection with redevelopment of the site (this is often referred to as incidental coal).

Areas C and D

Raft or reinforced beam foundations (on engineered fill)

16.4.39 As discussed in Section 17, turnover of the uppermost 3.0m of Made Ground is recommended across Areas C and D in order to remove any obstructions/oversized materials, to enable earthworks to form the required development levels and to improve the ground beneath plots and highways. Ground improvement associated with turnover (placement of screened, and re-engineered fill) may provide an opportunity to establish new dwellings on raft or reinforced ring-beam foundations.

16.4.40 In areas where raft foundations are proposed, the uppermost 3.0m of made ground should be excavated, screened and placed in engineered layers (turned over) to an **End Product** specification. Excavation and screening will enable the removal of all oversize material and any grossly contaminated soil/fill (not encountered to date).

16.4.41 Deep excavations to remove made ground could result in "hollows" in the natural ground surface. The natural ground around these "hollows" should be overdug in order to ensure that the thickness of fill below each proposed plot does not vary by more than 15%. Where this requires benching of the natural ground, each bench should have a maximum vertical height not exceeding 500mm.

16.4.42 The suitability of made ground for placement as engineered fill should be confirmed by field trials and laboratory testing.

16.4.43 The field trials should be carried out in accordance with Lithos' Specification for Engineered Fill. The field trial will enable estimation of tolerable settlement characteristics and an achievable safe bearing capacity, with a view to establishing new dwellings on raft foundations. It will also yield the following information:

- Number of passes with the compaction plant (to be used during subsequent earthworks)
- Maximum and minimum layer thickness (plant dependent)
- Acceptance criteria; minimum dry density and moisture content range

16.4.44 The engineered fill should achieve at least 95% maximum dry density (4.5kg rammer), with air voids comprising less than 5%; as determined by appropriate laboratory compaction tests (refer to Lithos' Specification for Engineered Fill).

16.4.45 Raft, or beam-grillage, design should be in accordance with NHBC Standards, Chapter 4.4. Granular sub-base product should be placed in accordance with Table 8/1 of the Highways Agency Specification for Highway Works (1998).

16.4.46 NHBC generally require any spread foundation on Opencast Backfill to be capable of achieving a minimum spanning capability of 3m and a minimum cantilever capability of 1.5m. For reinforced strip foundations, NHBC also require continuity of reinforcement across orthogonal beams, ensuring a "grillage type" (not a true grillage) arrangement with cross wall / stiffening beams.

16.4.47 For reinforced strip foundations, NHBC typically require the aspect ratios (in plan) of all 'cells' of the 'grillage' to be no greater than 2:1, to ensure there is sufficient rigidity to the foundation. The maximum permissible angular distortion (tilt) is typically 1:400.

16.4.48 Should any long terraces/blocks be proposed they should incorporate structural movement joints to mitigate the risk of differential settlement across the block/terrace.

16.4.49 NHBC generally recommend that rafts be founded on a minimum 150mm thickness of DoT granular sub-base product. Granular sub-base should extend laterally for at least 0.5m beyond the raft. The base of the granular sub-base must be at least 600mm below original or finished level, whichever is the lower. At most reclaimed brownfield sites, original level is generally equivalent to the top of engineered fill.

16.4.50 Where plots are within the influence of mature trees, the depth of crushed stone placed should be equal to 50% of the trench fill foundation depth determined in accordance with NHBC Chapter 4.2.

16.4.51 Placement of blankets of a granular sub-base, directly on top of engineered fill would normally be acceptable immediately after placement of the final layer of fill. However, if placement is delayed, climatic factors can lead to a deterioration of the near surface fill.

16.4.52 Where the engineered fill is cohesive, rainfall, (softening) or sunshine (desiccation) may cause deterioration. Cohesive fill should therefore be "blinded" with granular sub-base within 48 hours of placement of the final layer of fill. Wherever this is not possible, it is recommended that a minimum 300mm depth of fill is excavated from beneath the plot footprint, prior to placement of the granular sub-base. Furthermore, it may be necessary to remove any desiccated material if the engineered fill is left exposed during a prolonged spell of dry weather.

16.4.53 Where the engineered fill is granular, deterioration may be caused by frost (unless the fill contains less than 10% fines). Granular fill should therefore be "blinded" with granular sub-base prior to frosty weather.

Piled foundations

16.4.54 Piled foundations may be an option for plots across Areas C and D.

16.4.55 The following general comments relating to piling are provided for guidance, and further advice should be sought from a specialist-piling contractor. Piles are likely to be end bearing and socketed into bedrock, therefore in accordance with BS 8004[6] and EC7[7], rotary cored boreholes have been advanced into the base of the former opencast (see Section 10) and samples of bedrock have been submitted for geotechnical testing (see Section 15.8).

16.4.56 Sandstone cobbles and boulders were encountered during excavation of the trial pits and trenches. Further boulders were noted at depth during drilling of the rotary open probeholes (although cable percussion boreholes across Craven I did not refuse on obstructions, boreholes in Craven II did).

16.4.57 Given the presence of **obstructions** the use of driven piles may be problematic (subject to type); obstructions may deflect or refuse piles during installation and there may be a need for pre-boring prior to pile placement.

16.4.58 Turnover of the made ground should remove some obstructions and increase confidence on driven piles, however it cannot be guaranteed that further obstructions might not remain in any residual made ground beneath the turnover.

16.4.59 Away from buried highwalls, driven precast concrete piles are likely to encounter problems with terminating on obstructions. An allowance would need to be made for changing piling locations and ground beam design to account for any difficulties encountered with piles terminating on boulders. Further advice should be sought from a specialist-piling contractor regarding the most appropriate pile type for the ground conditions encountered.

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6 *BS 8004 (2015) - Code of practice for foundations.*

7 *BS EN 1997-1:2007. Eurocode 7: Geotechnical design – Part 2: Ground investigation & testing*

16.4.60 Subject to final levels it may be that the site could be zoned into areas where driven piles can be adopted and areas where pre boring will be required.

16.4.61 Given the presence of highwalls and variable depths to bedrock across the site (see Drawings 3104/14A & B and 3104/15A & B), care should be taken to ensure that piles are not allowed to deflect off any steep under-ground gradients within the rock. This could be achieved by socketing and will likely require pre-drilling and casing of piles. An allowance should also be made for changing piling locations and ground beam design to account for any difficulties encountered with steep rock gradients associated with the former opencast.

16.4.62 In order to ensure that piles are founded within natural bedrock, especially over the opencast highwall (and not any overlying quarry backfill), it may be necessary to advance piles to greater depth, so that they have a suitable rock socket (length subject to design and pile type).

16.4.63 Warranty providers generally require pile lengths to be at least 3m (measured from pile cut off level to pile toe level). Short piles are likely to become dislodged during pile trimming operations, creating additional costs associated with remedial works. Where depths to bedrock vary significantly beneath a plot, pre-boring of piles may be necessary to reach required depths.

16.4.64 Piled foundations should extend into the underlying bedrock. The safe working load that may be supported on a pile is dependent on the pile diameter, its founding depth and the method of installation.

16.4.65 Bedrock lies at depths of between c. 2.5m and 5.0m (Area C) and up to c. 12.6m (Area D) below current ground levels. The depth to, and level of, natural ground (bedrock) inside of the former opencast is shown on Drawings 3104/14A and 3104/15A.

16.4.66 As piles would be founded in bedrock, they will be essentially end bearing, although there may also be some shaft adhesion in the engineered made ground.

16.4.67 Consequently, preliminary estimates for pile lengths (based on existing ground levels) are in the order of between 5.0m and c. 14.0m.

16.4.68 Any plots that straddle the buried highwall zone of influence (as shown on Drawing 3104/16) will require a more robust foundation type, such as bored piles and possibly the use of a stiff raft (subject to detailed design).

16.4.69 Given the significant depth of made ground, and the potential for further raising of levels across existing made ground, it is essential that pile design allows for down-drag (negative skin friction).

16.4.70 In accordance with NHBC Standards, Chapter 4.2, heave precautions should be provided where a plot is within the zone of influence of trees. Table 3b in Chapter 4.2 defines the zone of influence as a function of tree height (between 0.5 and 1.25) dependant on the water demand. Figure 6 in Chapter 4.2 shows where heave precautions are required for pile foundations.

16.4.71 There is the potential for **settlement** (see Section 16.6) of the ground in external areas around any piled plots, and consideration should be given to mitigation, including:-

- Extending facing brickwork so that ground settlement does not result in exposing the underground portions of walls and foundations. Two additional courses should be more than adequate.
- Threshold issues
- Flexible connections (e.g. rocker pipes) in drainage and service pipes passing through the buildings.

- Ensuring drainage is laid with generous falls.

16.4.72 Driven piles can induce some ground vibration. Assessment of any vibration risk to adjacent structures and/or existing site features should be undertaken by pile designer.

16.4.73 New houses can be built off ring beams designed to span the piles. In order to bond them to the piles, the tops of the piles must be broken out to expose the reinforcement, which can then be tied to that of the beams.

16.4.74 Ground conditions at this site are considered likely to require provision of a piling mat (working platform) and further advice should be sought from the appointed specialist-piling contractor regarding the proposed plant loadings and resulting pressures. This data, together with a knowledge of the strength and variability of the near-surface ground conditions is required in order that design of a mat can be undertaken in accordance with guidance provided in the 2004 BRE document, “BR 470: Working platforms for tracked plant”.

16.4.75 The design of working platforms for tracked plant is a geotechnical design process and should be carried out by a competent person. The following parties should have input into the design:

- Permanent works designer, to consider additional uses for platform material as part of the overall development
- Principal contractor, to define any other purposes for which the platform might be used
- Contractor or subcontractor, to specify requirements for the platform, including gradients, ramps and edges

16.4.76 The number of plots affected by piling will depend on final levels, layout proposals, and Strata’s/the developers preferred foundation solution following an appraisal of cost, speed of construction and perceived risk.

16.4.77 It may be more practical and economic to pile all plots in Areas C and D the plots on this site, since mobilisation charges are likely to be similar regardless of how many plots are piled. A piled solution would also result in less disturbance than strip footings and negate the need to dispose of contaminated arisings.

16.4.78 Piles can provide an enhanced pathway for the vertical migration of mobile contaminants. The Environment Agency may therefore object to the adoption of piles as a foundation solution. However, objection is considered unlikely given the lack of any significant contamination being encountered to date, and the fact that quarry backfill is currently resting directly on the underlying mudstone bedrock.

Summary of foundation recommendations

16.4.79 In summary, the following foundation solutions are likely to be most appropriate (subject to Strata preferences regarding site preparatory works, final levels & costs associated with each foundation option):

Site Area	Foundation solution(s)	Remarks (influencing factors)
A	Strips at 0.9m (Cohesive Residual Soil) & 0.6m (Granular Residual Soil)	Foundations in Cohesive Residual Soil deepened where influenced by trees
B	Deep strips/trench fill to between 0.9m & 2.5m.	Passing through made ground & founding in underlying Residual Soil or bedrock.
C	Piles to between c. 5.0m & 8.0m or rafts/beams on engineered fill.	Piles passing through made ground & founding in bedrock.
D	Piles to between c. 8.0m & 14.0m or rafts/beams on engineered fill.	Piles passing through made ground & founding in bedrock at the base of the former opencast.

16.4.80 The foundation solutions outlined in the above table assume that ground levels will not change significantly from those existing at present, and will require revision once proposed levels have been finalised.

Geological fault

16.4.81 Drawing 3104/8 shows the approximate lines of geological faults which cross the site.

16.4.82 It should be noted that the line of a fault on a geological map is often very approximate, and it may be inaccurate by 10m or more. Furthermore, the presence of a fault is usually 'masked' by overlying drift or residual soils; they can only be seen where long trenches are excavated into bedrock.

16.4.83 At this site, no movement associated with past, present or future mining is anticipated, therefore building can take place over the faults, without the need to search for the fault, and without the need to adopt special precautions in the footings of those plots suspected to lie in the vicinity of the fault.

16.4.84 However, NHBC like to see reinforcement of footings with one layer of B385 mesh placed 75mm above the base of the footing. Given the uncertainty regarding the precise line of the faults, it would be prudent to reinforce the footings of all plots within 25m of their assumed lines.

16.4.85 Further advice should be sought if a significant weak zone is encountered (e.g. ground comprising loose, broken or soft 'gouge' material) during the excavation of footings. If associated with a fault, the weak zone is likely to form a fairly continuous "linear belt", rather than a localised "pocket", and be anything from a few centimetres to a few metres in width.

16.5 Floor slabs

16.5.1 Floors for low rise housing (2-3 storeys) constructed on piled foundations typically utilise reinforced concrete ground beams which rest on pre-cast or in-situ pile caps. A suspended 'Beam and Block' ground floor is then usually constructed using concrete or polystyrene blocks placed between further concrete beams suspended across the ring beams.

16.5.2 Suspended floor slabs should be utilised where the depth of made ground or engineered stone exceeds 600mm in accordance with NHBC Standards Chapter 5.1 (to negate potential settlement problems).

16.5.3 It is estimated that the thickness of made ground is likely to exceed 600mm beneath the majority of proposed plots.

16.5.4 Where shallow foundations are within the influence of existing or proposed trees (and are underlain by shrinkable soils), NHBC require a suspended floor slab, with sub-floor void. The floor slab is most commonly a precast block and beam construction, but alternatively could comprise a suspended timber floor, or a slab cast on a suitable compressible void former. Ground-bearing and cast in-situ suspended slabs (other than those cast on a void former) are not acceptable where foundations are within the influence of trees.

16.5.5 In accordance with NHBC Standards Chapter 4.2, a minimum void height of 250mm should be adopted for a precast block and beam (or suspended timber) floor; this includes a 150mm ventilation allowance. If a suspended, cast in-situ slab (on a void former) is proposed, a minimum clear void height of 100mm should be adopted; of course, the actual thickness of the void former will be significantly greater.

16.5.6 In the event that coal is exposed beneath the floor void, it would be prudent to prevent air ingress and the potential for spontaneous combustion by blinding with concrete or removing the coal.

16.5.7 Floor slab design should be finalised/take account of the results of the gas monitoring and protection measures required, which will be detailed in Lithos' gas risk assessment, to be issued on completion of monitoring in June 2022.

16.6 Settlement of Opencast Backfill

16.6.1 Settlement of deep made ground, such as at this site, is initially (first 5 years or so) predominantly associated with consolidation, early creep and inundation. After this initial period, creep is usually the dominant mechanism.

16.6.2 **Consolidation** settlement is associated with a reduction in volume caused by expulsion of water from soil pores and transfer of load from excess porewater pressure to soil particles. Consolidation of opencast backfill under self-weight largely occurs during placement but may continue for a short period thereafter.

16.6.3 Such movements are likely to be variable between plots due to fill heterogeneity. Nonetheless, some predictions can be made using published coefficient of volume compressibility (Mv) correlations (e.g. Carter & Bentley 1991). The Opencast Backfill was found to be typically firm / medium dense, equating to a moderately compressible soil. The range of Mv used for this preliminary assessment is 0.1 to 0.25 m^2/MN. Loadings from proposed plots were initially estimated to be a maximum of c.100kPa.

16.6.4 **Creep** compression occurs as the particles of fill become more closely packed, under conditions of constant effective stress (arising from self-weight of the fill). Although the movements caused by creep can be relatively small, often it is these long-term movements that are of most interest to foundation performance. Shallow fills show an approximately linear relationship between settlement and the logarithm of the time that has elapsed since the fill was placed (i.e. settlement that occurs during the first 10 years is similar to that from years 10 to 100).

16.6.5 Using published data from ICE Earthworks; a guide 2nd Edition, which references Hodgetts et al. (1993), Hills and Denby (1996), the following range of alpha values are provided:

- Full scheme of backfill compaction, alpha = **0.2%**
- Partial backfill compaction, alpha = **0.4%**
- Uncompacted backfill, alpha = **0.8%**

16.6.6 Although the strength / density of the Opencast Backfill was found to be typically firm / medium dense, to allow for potential variability, and local differences, the ICE alpha values selected in this preliminary assessment are 0.4% (partial), 0.8% (uncompacted) and an average of the two values 0.6%.

16.6.7 For this preliminary assessment, t0, t1 and t2 were assumed to be 1952 (date of backfill), 2022 and 2082 respectively (allowing for NHBC's expected 60-year design life). The tables below provide a summary of the preliminary settlement assessment:

Depth of Fill (m)	Alpha α (%)			Potential creep settlement by 2082 (mm)			Initial compression & consolidation (mm)	
	Partial [C]	Uncompacted [C]	Ave [C]	Partial [C]	Uncompacted [C]	Ave [C]	Mv = 0.1 [D]	Mv = 0.25 [D]
13 [A]	0.4	0.8	0.6	15	30	20	15	35
7 [B]	0.4	0.8	0.6	10	15	12	15	35

Notes

[A] = Typical maximum depth of Opencast Backfill

[B] = Typical depth of Opencast Backfill

[C] = ICE Earthworks: a guide (2nd Edition) p62, partial compaction, no compaction and the average of partial and no compaction.

[D] = Carter & Bentley (1991) Table 5.1 - Firm Clays of Medium Compressibility

Depth of Fill (m)	Total potential settlement (mm)					
	α=0.4[C], Mv=0.1[D]	α=0.4[C], Mv=0.25[D]	α=0.8[C], Mv=0.1[D]	α=0.8[C], Mv=0.25[D]	α=0.6[C], Mv=0.1[D]	α=0.6[C], Mv=0.25[D]
13 [A]	30	50	45	65	35	55
7 [B]	25	45	30	50	27	47

Notes

[A] = Typical maximum depth of Opencast Backfill

[B] = Typical depth of Opencast Backfill

[C] = ICE Earthworks: a guide (2nd Edition) p62, partial compaction, no compaction and the average of partial and no compaction.

[D] = Carter & Bentley (1991) Table 5.1 - Firm Clays of Medium Compressibility

16.6.8 The above preliminary settlement assessment indicates that the potential range of total settlement for the deepest area of backfill post development over the 60-year design life of the properties is between c. 30mm and c. 65mm. In areas of typical backfill depths, the potential range of total settlement is between c. 25mm and c. 50mm.

16.6.9 Settlements of this magnitude are greater than is normally accepted by NHBC (25mm), however, on deep fille sites, there is an understanding that total settlement in excess of 25mm is not necessarily of concern, provided it is uniform, it is differential settlement that causes structural defects. Differential settlement will be of greatest concern in the highwall zone of influence (Drawing 3104/16), however, this will be mitigated via the use of a more robust foundation type. Away from the highwall zone of influence, differential settlement beneath individual plots is not expected to be more than c. 15mm (c. 25% of total maximum settlement).

16.6.10 The settlement predictions above should not be considered absolute, rather they represent predictions of the potential range of consolidation and creep settlement that may occur across the site, following construction of the proposed residential properties. Predictions will need to be verified by post earthworks monitoring.

16.6.11 Settlement due to **inundation** is caused by changes in the water table depth (e.g. groundwater rebound) and/or surface water infiltration. Given the time since the opencasting was complete (c. 70 years), groundwater rebound is expected to have reached equilibrium with pre-opencasting levels.

16.7 Plots constructed over/near highwalls

16.7.1 An area of former opencast underlies about 60% of the total site area. The opencast has an irregular ‘doughnut’ shape with boundaries which are marked by highwalls around the external and internal peripheries.

16.7.2 Made Ground beyond the highwalls is generally less than c. 2.5m thick, whilst made ground inside the highwalls is generally greater than 5.0m thick.

16.7.3 Should any plots be proposed close to or spanning the highwall then extra consideration should be given to foundations and structural design. Foundations will require additional reinforcement, to ensure a more robust solution is adopted, with either bored piles or stiff rafts likely to be required..

16.7.4 An illustrative zone of influence has been determined which is shown on Drawing 3104/16. The zone of influence conservatively assumes that differential settlement could occur across the line of the highwalls based on the highwall profiles determined during the Lithos' ground investigation.

16.7.5 The zone of influence for the buried highwalls encountered has been calculated in general accordance with BRE[8] guidance, conservatively assuming there is the potential for significant vertical compression (Cotβ = 1). The overall width of the zone of influence and the offset from the crest of the highwall are summarised in the table below.

Location	Depth to crest of highwall (m)	Height of highwall (m)	Overall width of zone of influence (m)	Distance back from highwall to start of zone of influence (m)
Craven I				
Centre [A]	3	6	9	0.75
Southeast	1	8	12	0.5
Northwest	1	8	12	0.5
Southwest	3	10	15	1.0
Internal Highwall [B]	6	8	16	2.5
Notes: A = 'Island' within Craven I B = 'Shelf' present in the west of the Craven I				

16.7.6 It would be prudent to allow for a plot-specific assessment and foundation for all plots within the stand-off zone.

16.7.7 However, it should be noted that the proposed earthworks and levels regrade will have an effect on the extent of the zone of influence and significant revision will likely be required once final levels have been determined.

16.8 Designated concrete mixes

16.8.1 Designated mixes are considered in BRE SD1[9] and BS 8500[10]. However, in addition to soil chemistry (sulphate class), there are a number of other considerations relating to structural design that need to be taken into account when determining an appropriate concrete mix. Consequently, Strata should seek advice from their appointed Structural Engineer.

8 *BRE Building on fill: geotechnical aspects 3rd edition 2015 – Appendix D: Delineation of exclusion zone over a highwall*

9 *BRE Special Digest 1 (2005) – Concrete in aggressive ground.*

10 *BS 8500-1&2:2015+A2:2019. Concrete. Complementary British Standard to BS EN 206. Method of specifying and guidance for the specifier (1) & Specification for constituent materials and concrete (2).*

16.9 Excavations

16.9.1 Based on the results of the investigation it is considered unlikely that major groundwater ingress will occur in excavations of up to c. 2.0m depth. However deeper excavations required as part of a levels regrade and turnover might encounter some groundwater inflows. It would be prudent to allow for some pumping works during any deep excavations.

16.9.2 Furthermore it would be prudent to include consideration of groundwater levels in any earthworks design and to avoid the finished level intercepting groundwater levels beneath the site to avoid the risk of springs and weeping on any cut/terrace faces and the need for careful management, toe drains etc.

16.9.3 Groundwater should be controlled in accordance with CIRIA Report R113[11].

16.9.4 Excavations should remain stable in the short term but if left open for any significant period of time may require shoring most notably in granular soils and made ground.

16.9.5 Bedrock was encountered in exploratory holes across Areas A and B. Based on the exploratory hole logs, excavation beyond around 2.0m is likely to prove difficult across the western edge of the site and it would be prudent to allow for excavation of hard rock in any deep excavations such as those that may be required for drainage etc, see Section 16.3.

16.10 Drainage

16.10.1 Given the significant thicknesses of made ground encountered on-site soakaway construction will be highly problematic. It should be noted that soakaways cannot be allowed to infiltrate into made ground due to the risk of settlement caused by wash out of fine soil particles.

16.10.2 Alternative SUDS options (see CIRIA C753[12] for further details) include:

- Swales – linear grassed features in which surface water can be stored or conveyed. Where suitable, swales can be designed to allow infiltration.
- Pervious Pavements – provide a surface suitable for pedestrian and/or vehicular traffic, while allowing rainwater to infiltrate into subsurface storage, with subsequent infiltration or controlled discharge. Pavement could be porous (water able to infiltrate across entire surface material; e.g. reinforced grass), or permeable (water infiltrates via joints between concrete blocks).
- Ponds – designed to have permanent pool of water, but with capacity to provide temporary storage-controlled discharge.

16.10.3 Yorkshire Water have published a guide[13] for developers and designers outlining their design requirements for surface water attenuation assets.

16.10.4 With respect to detention basins, which should normally be dry, water table levels should be taken from borehole monitoring wells over 4 consecutive seasons, for at least 3 points in the basin area. The detention basin should be designed to ensure that there is a minimum of 1m of unsaturated soil between the maximum groundwater level and the lowest part of the structure.

16.10.5 It is recommended that the developer contact Yorkshire Water Services with respect to capacity in existing foul and surface water sewers in the vicinity of the development area.

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[11] *CIRIA Report R113 (1986) - Control of Groundwater for Temporary Works.*
[12] *CIRIA C753 (2015) – The SuDS Manual.*
[13] *Design Requirements for Surface Water Attenuation Assets, February 2017.*

16.11 Highways

General

16.11.1 Deep Made ground is present across the site, notably Areas C and D, and consultation with the adopting authority, regarding the specification of the highways, is strongly recommended.

16.11.2 The made ground present beneath this site is highly variable in terms of both composition, and strength/density. Furthermore, it often contains a significant amount of oversize materials (boulders etc), which represent potential 'hard-spots'.

16.11.3 Consequently, where made ground is present its full thickness (up to a maximum of 3m (in line with development platform earthworks) from existing ground level or proposed highway formation, whichever is the lower) should be excavated and either:

- Replaced with suitable aggregate in accordance with Series 600 (Earthworks) of The Highways Agency (HA) "Specification for Highway Works" 1998; or
- Screened, to allow selection of suitable material, before being replaced in engineered layers (in accordance with Series 600). Unsuitable materials include any soft or wet materials, biodegradables including topsoil, wood, scrap metal, frozen material and oversize.

16.11.4 Some refinement of the above advice might be possible after highways design (with consideration of the proposed formation level cf existing ground level), and via inspection (and usually CBR testing) of the proposed formation during site preparatory groundworks.

16.11.5 Any residual made ground materials in the base of the excavation should be inspected and (where necessary) any soft spots removed and replaced with suitable engineered fill.

16.11.6 Where the made ground is re-engineered it is considered that a CBR value of at least 3% should be achievable. However, this should be verified by field trials.

16.11.7 Crushing of demolition/hardstand/foundation arisings will generate aggregate, which (subject to confirmatory testing) should be suitable for use as unbound pavement materials within the highways.

Highways crossing highwalls

16.11.8 Examination of the proposed layout shows that adoptable highwalls shall cross the line of buried highwalls both across the area of the proposed development and along the proposed spine road.

16.11.9 At all locations where highways cross a buried highwall, the following precautions are recommended to protect highway and drainage infrastructure from damage due to differential settlement.

- The made ground should be excavated over the full width of the adoptable highway to at least 1.0m below deepest sewer invert
- The base of the excavation (1.5m below sewer invert) should be reinforced with two layers of Tensar Triax TX160 (or equivalent) geogrid sandwiched within at least 300mm of suitable aggregate (i.e. nominally 75mm aggregate, geogrid, 150mm aggregate, geogrid and then another 75mm aggregate).

16.11.10 A minimum length of 10m either side of any highwalls associated with the former quarry should be treated to the above specification, although the final specification should be agreed with the adopting authority.

16.11.11 If any deep excavation beneath a highway results in sub-formation slopes greater than 1v:5h, the sub-formation should be stepped (max. 0.5m high) and benched (min. 1m wide). Where excavation works exceed 1m in depth, the footprint of earthworks should be extended beyond the highway footprint a minimum of 1m, plus the depth of excavation. The Engineer will keep records of any such work undertaken.

16.11.12 Some refinement of the above advice might be possible after highways design (with consideration of the proposed formation level cf existing ground level), and via inspection (and usually CBR testing) of the proposed formation during site preparatory groundworks.

16.12 External works

16.12.1 Any digital terrain modelling undertaken, or commissioned, by Strata should be made available to their Engineering Designer prior to issue of an External Works Drawing.

16.12.2 When designing retaining walls, consideration should be given clause 10.2.3 of NHBC standards which states that flexible retaining walls such as gabion and timber structures should not be used to provide support to homes, garages, roads, drives, car parking areas or drainage systems.

17 EARTHWORKS & GROUND IMPROVEMENT

17.1 General

17.1.1 Natural ground underlying LT1 is often clayey, therefore consideration should be given to the implication of undertaking earthworks in poor/wet weather when the ground surface is likely to become difficult to cross with heavy machinery.

17.1.2 Excavation of the Cohesive Made Ground (present beneath Topsoil across the majority of the site) could be undertaken to generate a sufficient volume of ‘clean’ subsoil for placement across the proposed development in gardens and landscaped areas. This subsoil would be best placed during the construction phase; i.e. it should be left in stockpile(s) on completion of the site preparatory works.

17.1.3 Wherever possible, Lithos recommend that excavated soils are retained on site. However, if this is not possible the comments in Section 13.3 should apply.

17.1.4 The below solution is considered to be in line with current government philosophy regarding sustainable development.

17.2 Site regrade

17.2.1 The site slopes down to the northwest with a typical gradient of about 1v:40h and a total fall of about 40m.

17.2.2 Given the topography of the site some regrade is anticipated to create development platforms and terraces, although levels have yet to be finalised.

17.2.3 Careful consideration will need to be given to earthworks design, and implications for slope stability, induced settlement, retaining walls, foundations, highway gradients and drainage

17.2.4 Any digital terrain modelling undertaken, or commissioned, by Strata should consider implications for the foundation recommendations.

17.3 Turnover & ground improvement

17.3.1 Made Ground is present across the majority of LT1: Area A comprising a veneer of Made Ground Topsoil beyond areas of opencast; Area B comprising Cohesive Made Ground and Opencast Backfill to between 1.1m and 2.5m; Area C comprising Cohesive Made Ground and Opencast Backfill to greater than 2.5m; and, Area D (footprint of former opencast) comprising Cohesive Made Ground and Opencast Backfill to between 5.0m and 12.6m depth.

17.3.2 Made Ground across Areas B and C are the result of regrade of site levels after completion of the opencast, notably the backfilling of a former valley feature which ran northeast to southwest through the site. Made Ground across Area D is the result of backfilling of the former Craven I opencast.

17.3.3 The made ground is of variable and poor strength and is therefore not considered a suitable foundation material in its current state. Opencast Backfill is also considered undesirable as a near-surface material due to the presence of oversized inclusions (cobbles and boulders).

17.3.4 Given the substantial volume of made ground present, export to landfill is not considered economically viable.

17.3.5 The uppermost 3.0m of made ground within areas C and D, and the full thickness of made ground in Area B should be subjected to "turnover" (excavation, screening/sorting and replacement in engineered layers, with compaction) across the LT1 development platform.

17.3.6 Turnover is considered an appropriate ground improvement solution since re-engineering of the made ground should enable the adoption of ‘spread’ (rafts or heavily reinforced strips) foundations or should improve the feasibility of the use of piled foundations.

17.3.7 Turnover and engineering of near surface made ground will also allow for a reduction of the clean cover from 450mm to 300mm.

17.3.8 Because turnover enables inspection of the full thickness of fill, the developer and their prospective property purchasers, are provided with the reassurance that no significant hazard is left undetected. This is considered advantageous from a perception viewpoint. Furthermore, any potential for surface water infiltration, which would drive potential leaching of contaminants, should be reduced by compaction.

17.3.9 Screened and engineered fill should yield CBR values in excess of 3%, thereby reducing abnormals associated with the construction of estate roads and car parking areas. Excavations through the engineered fill, for drainage etc and foundations will not encounter significant obstructions or grossly contaminated ground and should be stable with little overbreak.

17.3.10 Groundworkers should make all necessary arrangements to prevent off-site migration of pollutants via surface water run-off, inadvertent groundwater disturbance and airborne dust. Groundwater shall be controlled in accordance with CIRIA report 113 “Control of Groundwater for Temporary Works”.

17.4 Backfill of excavations

17.4.1 In areas where raft / reinforced strip foundations are proposed, the uppermost 3.0m/full thickness (whichever is less) of made ground should be excavated, screened and placed in engineered layers (turned over) across the LT1 development platform. Excavation and screening/sorting will enable the removal of all relict foundations, oversize material and any grossly contaminated soil/fill.

17.4.2 Deep excavations could result in "hollows" in the natural ground surface. The natural ground around these "hollows" should be overdug in order to ensure that the thickness of fill below each proposed plot does not vary by more than 15%. Where this requires benching of the natural ground, each bench should have a maximum vertical height not exceeding 500mm.

17.4.3 Clearly, such works will be undertaken in accordance with the final development layouts and it is essential that the earthworks and geotechnical designers are provided with the most recent (and proposed final) scheme. Any subsequent revisions to the plot layout could result in rafts straddling a 'high wall', and any layout revisions should take account of the potential to conflict with completed earthworks.

17.4.4 Where it is not possible to provide an even thickness of fill beneath proposed plots, raft foundations are unlikely to be acceptable, and consideration should be given to an alternative foundation solution.

17.4.5 On-site compaction trials will be required for each material type, prior to the commencement of any compaction works. The trial shall be conducted using the same compaction plant as is proposed for the main compaction works.

17.4.6 Control testing (in situ dry density & moisture content) will be required during the earthworks to confirm compliance with the Earthworks Specification. As part of the verification process, Load Tests, Surface Monuments and Rod & Plate settlement monitoring may be required.

18 REDEVELOPMENT ISSUES

18.1 General

18.1.1 This report has presented options with respect to foundation solutions, re-use of topsoil etc that are considered technically feasible and in line with current good practice. Consequently, we would expect to obtain regulatory approval for whichever option is adopted, although this cannot be guaranteed. Copies of this report should be forwarded to the relevant regulatory authorities (Warranty Provider & Local Authority) for their comment/approval.

18.1.2 Even after an appropriate preliminary investigation and ground investigation, with exploratory holes on a closely spaced grid (say trial pits at 30m centres), a geoenvironmental appraisal is typically based on inspection of the ground underlying less than 0.5% of the total site area (and much less at depths in excess of about 3.5m). Consequently, there is always a possibility that unanticipated ground conditions will be encountered during the construction phase.

18.1.3 If unanticipated ground is encountered during the construction phase, the Contractor should immediately seek further advice from the Engineer.

18.2 Remediation strategy

18.2.1 Given the absence of any significant contamination, a remediation strategy is not considered necessary. Nonetheless, some preparatory works will be required, most notably:

18.2.2 Whilst a detailed remediation strategy report is unlikely to be required, preparation of a Remediation Statement would be prudent and should include:

- General background information, including site location, site description and a summary of ground investigation data
- An overview of existing constraints on development and the aims of the proposed remediation works

- Specific details of the anticipated site remediation/preparatory works
- Details of site supervision and verification
- A summary of implications for redevelopment

18.2.3 The Remediation Statement will describe what is required, but not how it is achieved; the appointed Contractor would normally be expected to undertake an Options Appraisal, and then prepare a Method Statement.

18.2.4 The anticipated remediation works are summarised below:

- General site clearance of surface materials and vegetation
- Turnover (excavation, screening and replacement in engineered layers, with nominal compaction) of the uppermost 3.0m of made ground to enable:
  - Inspection of the made ground
  - Removal of below ground obstructions
  - Preparation of the ground for highway construction
- Excavation of natural soils from beneath made ground to source 'clean' subsoil for use in gardens and landscaped areas
- Backfill of all resultant excavations, with appropriate compaction
- Re-grade of site to levels specified by the detailed geotechnical designer (approximately 450mm below final "soft" end use areas and 600mm below proposed slab levels)
- Excavation of up to a maximum depth of 3m beneath proposed adoptable road footprints and controlled re-engineering of selected materials in layers to approximately 650mm below final road levels
- Provision of a minimum 450mm thick cover layer of 'clean' soils in all garden and landscaped areas comprising Subsoil (which could comprise site-won Cohesive Made Ground) and Topsoil.

18.2.5 The remediation contractor should survey reduced levels during the proposed turnover, prior to the placement of any fill.

18.2.6 Natural Residual Soils excavated during the site preparatory works for subsequent use as cover in gardens and landscaped areas, would be best placed during the construction phase; i.e. it should be left in stockpile(s) on completion of the site preparatory works.

18.2.7 A minimum 200mm thickness of suitable granular fill (i.e. a "blanket" of 6F2) could be placed along the line of proposed haul roads to provide a firm and stable running layer for the subsequent construction works.

18.3 Control of excavation arisings

18.3.1 Excavations into made ground are likely to yield contaminated arisings. The groundworker should carefully segregate (and stockpile separately) made ground arisings from arisings of "clean" natural soils, in order that an excessive volume of unsuitable material is not generated.

18.3.2 The groundworker should appreciate the need for good materials management. Most notably the importance of not mixing different materials within a given stockpile; i.e. there should be separate stockpiles of: topsoil; made ground arisings; excess clean, natural soil arisings; general construction waste etc.

18.3.3 Further characterisation of stockpiled materials is likely to be required if off-site disposal is proposed. See also comments in Section 13.4.

18.3.4 Made ground arisings could be:

- Placed in area deliberately left low on completion of the remediation works in order to accommodate construction arisings
- Isolated beneath the 450mm thick cover layer in garden or landscaped areas
- Exported from site to a suitably licensed landfill facility

18.3.5 Natural ground and Cohesive Made Ground arisings should be suitable for use as subsoil in the proposed soil cover.

18.4 Good practice guidance

18.4.1 The construction phase groundworker should follow good environmental practice to minimise the risks of spillage, leakage etc with reference, but not limited, to the following documents:

- CIRIA C741[14]
- EA Pollution Prevention Guidelines[15]:
    - PPG6 - Working at construction and demolition sites
    - PPG2 - Above ground oil storage tank
    - PPG7 – The safe operation of refuelling facilities.
    - PPG21 – Incident Response Planning

18.4.2 Site preparatory works associated with this project are likely to involve the re-use of both natural and made ground soils on site.

18.5 New utilities

18.5.1 It is strongly recommended that all statutory service bodies are consulted at an early stage with respect to the ground conditions within which they will lay services in order to enable them to assess at an early stage any potential abnormal costs.

18.5.2 Drainage and other utilities should not be placed within any coal seam; the seam should either be removed to below the base of the lowest service, or services should be placed in oversize trenches cut into the seam & backfilled with inert material.

18.5.3 This site is greenfield, and no previous or current usage of the site or its immediate surroundings is likely to have resulted in ground contamination. .

18.5.4 Consequently, the use of 'standard' polyethylene water supply pipes should be acceptable, although Strata should consult Yorkshire Water at the earliest opportunity to confirm this.

18.6 Health & safety issues - construction workers

18.6.1 Access into excavations etc. must be controlled and undertaken in accordance with the CDM Regulations 2015, most notably Regulation 22, to mitigate risk of collapse or asphyxiation.

18.6.2 Before site operations are started, the necessary COSHH statements and Health & Safety Plan should be drafted in accordance with the CDM regulations.

18.6.3 The bulk of the made ground will be retained on site. . Workers involved in excavations for foundations, drainage, utilities etc are likely to come into direct contact with the made ground.

[14] *CIRIA C741 (2015) - Environmental Good Practice on Site*

[15] *Whilst this has formally been withdrawn it can still be accessed via the EA archives and provides useful information on managing risks.*

18.6.4 Although workers will only be exposed to the made ground for a relatively short time, and simple precautionary measures are required, i.e. good personal hygiene and basic personnel protective equipment.

18.6.5 Consequently, during the remediation and construction phases it will be necessary to protect the health and safety of site personnel. General guidance on these matters is given in the Health and Safety Executive (HSE) document "Protection of Workers and the General Public during the Redevelopment of Contaminated Land".

18.7 Coal extraction

18.7.1 This site has already been subject to opencast coal extraction and consequently shallow coal of economic value has already been removed from the majority of the site's area.

18.8 Shallow coal in garden areas

18.8.1 Whilst there is no explicit guidance in NHBC Standards, liaison with NHBC suggests their stance is essentially the same as that they would apply to potentially combustible fills (such as Ash & Clinker). So where significant coal is present at very shallow depth in garden areas (uppermost 1m), it should either be removed, or covered with inert subsoil/topsoil so that it lies at greater than 1m depth.

18.8.2 In theory this could be an issue for about 5% of the total site area.

18.8.3 The most pragmatic way of dealing with shallow coal in gardens will be to inspect foundation excavations, and where coal is recorded within the uppermost 1m or so then excavate an inspection pit in the rear garden. Further advice should be sought from Lithos during the construction phase.

18.8.4 As with foundation arisings, the developer will need to contact the Coal Authority to dig or carry away excavated (incidental) coal.

18.9 Potential development constraints

18.9.1 The site slops down to the northeast with a typical gradient of about 1v:40h and a total fall of about 40m. Some regrade of site levels comprising cut and fill is anticipated to create level development terraces, although to date final levels have not been confirmed.

18.9.2 Some deterioration of the surface is likely to be caused by trafficking, especially after topsoil has been stripped and during/after periods of significant rainfall. Consequently, it would be prudent to consider placement of a minimum 200mm thickness of suitable granular fill (i.e. a "blanket" of 6F2) along the line of proposed highways and any temporary haul roads to protect formation during the construction phase.

18.9.3 It would be prudent to allow flexibility in the groundworks programme to take advantage of any prolonged dry\warm weather (typically between May and September) to enable footings to be cast and blockwork brought up to DPC level well in advance of the build programme (i.e. so it is never necessary to dig deep footings in winter/early spring, when the groundwater table is likely to be higher).

18.9.4 Overhead electrical utilities cross the south of the site and these present development constraint unless they can be relocated. Additional enquiries are required to ascertain the feasibility of such diversionary works and the particular easement required by each service undertaker if they remain in-situ.

18.9.5 Areas of former opencast coal extraction are present with made ground of up to 12.6m depth beneath the proposed development footprint. Deep made ground shall require alternative foundation solutions for plots inside the area of opencast. Further areas of deep (>2.5m) made ground are present outside the former opencast which shall also require alternative foundation solutions.

18.9.6 The former opencast is bound by buried highwalls and any plots close to/spanning the highwall will require additional consideration and design of their foundations to allow for differential settlement.

19 SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

19.1 General

19.1.1 The site is located to the south of Barugh Green Road to the west of Barnsley town centre and comprises c. 21.4 hectares of arable and grazing farmland.

19.1.2 The site is referred to as Barnsley West Land Transfer One (LT1) and makes up about 20% of a wider development site called Barnsley West (a further c. 80 hectares to the south).

19.1.3 The site is to be given to development across 4 sub-areas: Development Area1; 9.38ha, 229 plots constructed by Strata Homes; Area 2; 4.42ha, 137 plots constructed by Miller Homes; Area 3; 0.5ha developed with retail buildings and associated parking; and, Area 4; 1,7ha developed with a new school.

19.1.4 About 60% of LT1 has been subject to opencast coal extraction at the former Craven I and Craven II sites, although only the shallower Craven I site underlies LT1. Both opencasts have been backfilled with site-won arisings comprising a veneer of Made Ground Topsoil and Cohesive Made Ground over Cohesive and Granular Opencast Backfill.

19.1.5 Made Ground inside the former opencasts ranges from c. 5.0m to c. 12.6m deep whilst made ground outside of the opencasts ranges from absent to about 5.0m thick with the deepest made ground (outside the opencast) aligned along the line of the former valley feature.

19.2 Mining

19.2.1 The majority of LT1 is located within a Coal Mining Development High Risk Area due to the presence of areas of open-casting. Beyond the opencasts, the remaining land lies in a Development Low Risk Area.

19.2.2 Both inside and outside of the opencasts the site is underlain by shallow coal. However, no evidence of underground workings (voids, broken ground, soft push etc) have been encountered during Lithos' desk study or intrusive mining investigation and consolidation of underground workings is not expected to be required.

19.3 Hazardous gas

19.3.1 The site is in an area where between 1% and 3% of homes are estimated to be above the radon action level. Radon protection is not required, but the Developer might consider providing new dwellings with basic measures in light of Public Health England advice.

19.3.2 There are areas of known landfill from 70m to the north and the site and surrounding land is underlain by shallow coal and deep made ground associated with open casting.

19.3.3 Gas monitoring wells have been installed in 34 probeholes and boreholes across the site. Monitoring is ongoing and on completion a Hazardous Gas Risk Assessment shall be issued.

19.4 Contamination & remediation

19.4.1 Made Ground Topsoil, typically 300mm thick, underlays the site. Testing suggests that this material is chemically and physically suitable for re-use in gardens and areas of POS.

19.4.2 To date no evidence of significant contamination has been encountered in made or natural soils beneath this site. However, the Opencast Backfill is not considered desirable as a near surface material due to the presence of oversized inclusions in this soil type (cobbles and boulders).

19.4.3 Therefore, where the Opencast Backfill has been re-engineered (and oversized materials removed) it should be isolated beneath a **300mm** thick surface cover of "clean" soil is recommended.

19.5 Foundations

19.5.1 The site has been divided into four areas (A to D) based on ground conditions.

19.5.2 Foundations across Areas A and B could comprise strips and/or deep trench footings with the founding stratum being either medium strength Residual Soils, or competent Coal Measures bedrock.

19.5.3 Areas C and D will require alternative foundations due to the presence of deep made ground across these areas.

19.6 Flooding

19.6.1 The site lies in Flood Zone 1, where the risk of flooding from rivers or the sea is classified as low.

19.7 Drainage

19.7.1 Due to deep made ground being present across much of the site, soakaways will not provide a suitable means of surface water disposal and alternative drainage solutions will be required.

19.8 Highways

19.8.1 Based on visual inspection of the shallow natural materials and published guidance, the Residual Soils should provide a CBR value of at least 3%. This value should be verified prior to or during construction.

19.8.2 However, made ground is present across the majority of the site and consultation with the adopting authority, regarding the specification of the highways, is strongly recommended.

19.8.3 Where made ground is present it should be excavated and either replaced with suitable aggregate, or screened, to allow selection of suitable material, before being replaced in engineered layers. Where the made ground is re-engineered it is considered that a CBR value of at least 3% should be achievable. However, this should be verified by field trials.

19.9 Further works

19.9.1 Completion of the monitoring and completion and issue of a Hazardous Gas Risk Assessment.

19.9.2 Preparation of a Remediation Statement.

19.9.3 Preparation of an Earthworks Specification.

19.9.4 Preparation of a Materials Management Plan (MMP) if import of materials is required.

19.9.5 Further settlement assessment once proposed final ground levels are known, taking into account areas of cut (net stress reduction) and fill (net stress increase).

Appendix A

General Notes

General

Third party information obtained from the British Geological Survey (BGS), the Coal Authority, the Local Authority etc is presented in the "Search Responses" Appendix of this Geoenvironmental Report.

Geology, mining & quarrying

In order to establish the geological setting of a site, Lithos refer to BGS maps for the area, and the relevant geological memoir. Further information is sourced by reference to current and historical OS plans.

In July 2011, the Coal Authority (CA) formalised their requirements in relation to planning applications and introduced some new terminology. The CA, using its extensive records has prepared plans for all coalfield Local Planning Authorities, which effectively refines the defined coalfield areas into High Risk and Low Risk areas. **High Risk** areas are likely to be affected by a range of legacy issues that pose a risk to surface stability, including: mine entries; shallow coal workings; workable coal seam outcrops; mines gas; and previous surface mining sites. **Low Risk** areas comprise the remainder of the defined coalfield, and are areas where no known defined risks have been recorded; although there may still be unrecorded issues. Where a site lies within either a High or Low Risk area, a mining report is obtained from the CA.

Landfills

Reference is made to publicly available Government held digital data via **QGIS** (an Open Source Geographic Information System), data from Landmark or Groundsure, and sometimes the Environment Agency and the Local Authority with respect to known areas of landfilling within 250m of the proposed development site.

Historical OS plans are also inspected for evidence of backfilled quarries, railway cuttings, colliery spoil tips etc.

Radon

Radon is a colourless, odourless gas, which is radioactive. It is formed in strata that contain uranium and radium (most notably granite), and can move though fissures eventually discharging to atmosphere, or the spaces under and within buildings. Where radon occurs in high concentrations, it can pose a risk to health.

In order to assess potential risks associated with radon gas, Lithos refer to BRE Report BR211[1], and the Public Health England website. Advice on the limitation of exposure of the population to radon in buildings was originally published in 1990 by the National Radiological Protection Board (NRPB), which joined the Health Protection Agency (HPA) in 2005; the HPA updated NRPB advice in July 2010[2]. The HPA became part of Public Health England in 2013.

The HPA recommended that the NRPB radon Action Level for homes be retained, and a new Target Level for radon in homes be introduced. The values of the Action Level and Target Level, expressed as the annual average radon concentration in the home, are 200 Bqm^{-3} and 100 Bqm^{-3} respectively. The Target Level was to provide an objective for remedial action in existing homes and preventive action in new homes.

The term 'radon Affected Area' is defined as those parts of the country with >1% of homes estimated to be above the Action Levels. The NRPB first indicated which parts of the country should be regarded as radon Affected Areas in 1990. A more detailed mapping method was developed by the HPA in conjunction with the British Geological Survey in 2007[3]. The level of protection needed is site-specific and can be determined by reference to this mapping on the Public Health England website, which indicates the highest radon potential within each 1km grid square. Each 1km grid square is classified on the basis of the percentage of existing homes within that grid square estimated to have radon concentrations above the Action Level. There are 6 'bands': <1%; 1 to 3%; 3 to 5%; 5 to 10%; 10 to 30%; and >30%.

The NRPB advised that action should be taken to reduce radon concentrations in existing homes if the radon concentration exceeded the Action Level of 200 Bqm^{-3} in room air averaged over a year; ten times the average UK domestic radon concentration. NRPB advice informed changes in the requirements for radon protection in new buildings.

- **Basic** preventive measures are required in new buildings, extensions, conversions and refurbishments if the probability of exceeding the Action Level is **>3%** in England and Wales, and >1% in Scotland and Northern Ireland.
- Provision for further preventive (**Full**) measures is required in new buildings if the probability of exceeding the Action Level is **>10%**.

At present Building Regulations Approved Document C advocates basic measures for the probability banding 3% to 10%, and full measures if >10%. However, Public Health England would like to see all new build include basic measures.

Action & Target Levels should also be applied to non-domestic buildings with public occupancy exceeding 2,000 hrs/yr and to all schools.

Hydrogeology

Reference is made to publicly available Government held digital data via QGIS, and Landmark or Groundsure with respect to:

- Groundwater quality
- Recorded pollution incidents
- Licensed groundwater abstractions

From April 2010 the EA's Groundwater Protection Policy uses aquifer designations that are consistent with the Water Framework Directive. These designations reflect the importance of aquifers in terms of groundwater as a resource (drinking water supply), but also their role in supporting surface water flows and wetland ecosystems. The aquifer designation data is based on geological mapping provided by the British Geological Survey. The maps are split into two different types of aquifer designation:

- Superficial (Drift) - permeable unconsolidated (loose) deposits. For example, sands and gravels
- Bedrock - solid permeable formations e.g. sandstone, chalk and limestone

The maps display the following aquifer designations:

Principal aquifers: These are layers of rock or superficial deposits that have high intergranular and/or fracture permeability - meaning they usually provide a high level of water storage. They may support water supply and/or river base flow on a strategic scale. In most cases, principal aquifers are aquifers previously designated as major aquifer.

Secondary aquifers: These include a wide range of rock layers or superficial deposits with an equally wide range of water permeability and storage. Secondary aquifers are subdivided into three types:

- **Secondary A** - permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers. These are generally aquifers formerly classified as minor aquifers
- **Secondary B** - predominantly lower permeability layers which may store and yield limited amounts of groundwater due to localised features such as fissures, thin permeable horizons and weathering. These are generally the water-bearing parts of the former non-aquifers
- Secondary undifferentiated - In most cases, this is because the rock type in question has previously been designated as both a minor and non-aquifer in different locations due to the variable characteristics.

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[1] BRE Report BR211, 2015: "Radon: guidance on protective measures for new buildings.

[2] Limitation of Human Exposure to Radon, Documents of the Health Protection Agency - Radiation, Chemical and Environmental Hazards, RCE-15. July 2010.

[3] Miles JCH, Appleton JD, Rees DM, Green BMR, Adlam KAM and Myers AH (2007). Indicative Atlas of Radon in England and Wales. Chilton, HPA-RPD-033.

Unproductive strata: These are rock layers or superficial deposits with low permeability that have negligible significance for water supply or river base flow.

The EA maps only display the principal and secondary aquifers as coloured areas. All uncoloured areas on the map will be unproductive strata. However, for uncoloured areas on the superficial (drift) designation map it is not possible to distinguish between areas of unproductive strata and areas where no superficial deposits are present; to do this, it is necessary to consult the published geological survey maps.

For the purposes of the EA's Groundwater Protection Policy the following default position applies, unless there is site specific information to the contrary:

- If no superficial (drift) aquifers are shown, the bedrock designation is adopted
- In areas where the bedrock designation shows unproductive strata (the uncoloured areas) the superficial designation is adopted
- In all other areas, the more sensitive of the two designations is used (e.g. If secondary superficial overlies principal bedrock, an overall designation of principal is assumed)

The EA have also designated groundwater Source Protection Zones, which are based on proximity to a groundwater source (springs, wells and abstraction boreholes). The size of a Source Protection Zone is a function of the aquifer, volume of groundwater abstracted and the effective rainfall, and may vary from tens to several thousand hectares.

Hydrology

Reference is made to publicly available Government held digital data via QGIS, and Landmark or Groundsure with respect to:

- Surface water quality
- Recorded pollution incidents
- Licensed abstractions (groundwater & surface waters)
- Licensed discharge consents
- Site susceptibility to flooding

The EA have set **water quality** targets for all rivers. These targets are known as River Quality Objectives (RQOs). The water quality classification scheme used to set RQO planning targets is known as the River Ecosystem scheme. The scheme comprises five classes (RE1 to RE5) which reflect the chemical quality requirements of communities of plants and animals occurring in our rivers.

General Quality Assessment (GQA) grades reflect actual water quality. They are based on the most recent analytical testing undertaken by the EA. There are 6 GQA grades (denoted A to F) defined by the concentrations of biochemical oxygen demand, total ammonia and dissolved oxygen.

The susceptibility of a site to **flooding** is assessed by reference to a Flood Map on the Environment Agency's website. These maps show natural floodplains - areas potentially at risk of flooding if a river rises above its banks, or high tides and stormy seas cause flooding in coastal areas. There are two different kinds of area shown on the Flood Map:

1. Dark blue areas (Flood Zone 3) could be flooded by the sea by a flood that has a 0.5% (1 in 200) or greater chance of happening each year, or by a river by a flood that has a 1% (1 in 100) or greater chance of happening each year
2. Light blue areas (Flood Zone 2) show the additional extent of an extreme flood from rivers or the sea. These outlying areas are likely to be affected by a major flood, with up to a 0.1% (1 in 1000) chance of occurring each year

These two colours show the extent of the natural floodplain if there were no flood defences or certain other manmade structures and channel improvements. Where there is no blue shading (Flood Zone 1), there is less than a 0.1% (1 in 1000) chance of flooding occurring each year.

The maps also show all flood defences built in the last five years to protect against river floods with a 1% (1 in 100) chance of happening each year, or floods from the sea with a 0.5% (1 in 200) chance of happening each year, together with some, but not all, older defences and defences which protect against smaller floods.

The Agency's assessment of the likelihood of flooding from rivers and the sea at any location is based on the presence and effect of all flood defences, predicted flood levels, and ground levels.

It should also be noted that as the floodplain shown is the 1 in 100 year, areas outside this may be flooded by more extreme floods (e.g. the 1 in 1000 year flood). Also, parts of the areas shown at risk of flooding will be flooded by lesser floods (e.g. the 1 in 5 year flood). In some places due to the shape of the river valley, the smaller floods will flood a very similar extent to larger floods but to a lesser depth.

If a site falls within a floodplain, it is recommended that a flood survey be undertaken by a specialist who can advise on appropriate mitigating measures; i.e. raising slab levels, provision of storage etc. In accordance with Chapter 10 of the National Planning Policy Framework, a site-specific flood risk assessment is required for: proposals of 1 hectare or greater in Flood Zone 1, or in an area within Flood Zone 1 which has critical drainage problems (as notified to the local planning authority by the Environment Agency); and any new development in Flood Zones 2 and 3.

COMAH & explosive sites

Lithos obtain information from Landmark or Groundsure with respect to Control of Major Accident Hazards (COMAH) or explosive sites within 1km of the proposed development site. Lithos' report refers to any that are present, and recommends that the Client seeks further advice from the HSE.

Areas around COMAH sites (chemical plants etc) are zoned with respect to the implementation of emergency plans. The HSE are a statutory consultee to the local planning authority for all COMAH sites. The COMAH site may have to revise its emergency action plan if development occurs. This might be quite straightforward or could entail significant expenditure. Consequently, the COMAH site may object to a proposed development (although it is the Local Authority who have final say, and they are likely to place more weight on advice from the HSE).

Preliminary conceptual site model

The site's environmental setting (and proposed end use) is used by Lithos to assess the significance of any contamination encountered during the subsequent ground investigation.

Assessment of contaminated land is based on an evaluation of pollutant linkages (source-pathway-receptor). Contaminants within the near surface strata represent a potential source of pollution. The environment (most notably groundwater), site workers and end users are potential receptors.

Potential pollutant linkages are shown on a preliminary conceptual site model (pCSM). A CSM is essentially a cross-section through a site that reflects both the surface topography and underlying geology, and shows surface features of interest. The most significant sources of contamination are then superimposed onto this cross-section together with potential receptors (human health & controlled waters), and plausible pathways between the two. In addition to environmental issues, the CSM should also highlight geotechnical issues.

A pCSM is prepared after consideration of all available "desk study" data, and before design of the ground investigation. Data reviewed should include historical plans (with superimposition on a current-day plan), previous SI reports, geological maps etc. The pCSM, in conjunction with knowledge of site constraints (buildings, services, slopes etc) is used to design the ground investigation.

The revised CSM takes account of data obtained during the ground investigation, including the distribution of made ground, the nature and distribution of contamination etc.

General

Lithos Ground Investigations are undertaken in accordance with current UK guidance including:

- BS5930:2015 "Code of practice for site investigation"
- Eurocode 7: BS EN 1997-1:2004. Geotechnical design - Part 1: General rules
- Eurocode 7: BS EN 1997-2:2007. Geotechnical design - Part 2: Ground investigation and testing
- BS10175:2013 "Code of practice for the identification of potentially contaminated sites"
- "Technical Aspects of Site Investigation" – EA R&D Technical Report P5-065/TR (2000)
- "Development of appropriate soil sampling strategies for land contamination" – EA R&D Technical Report P5-066/TR (2001)
- Contaminated Land Reports 1 to 6, most notably CLR Report No. 4 "Sampling strategies for contaminated land"
- "Guidance on the protection of housing on contaminated land" – NHBC & EA R&D Publication 66 (2000)
- AGS: 1996 "Guide to the selection of Geotechnical Soil Laboratory Testing"

Exploratory hole locations

Exploratory hole locations are selected by Lithos, prior to commencement of fieldwork, to provide a representative view of the strata beneath the site and to target potential contaminant sources identified during the preliminary investigation (desk study). Additional exploratory locations are often determined by the site engineer in light of the ground conditions actually encountered; this enables better delineation of the depth and lateral extent of organic contamination, poor ground, relict structures etc.

Investigation techniques

Ground conditions can be investigated by a number of techniques; the procedures used are in general accordance with BS5930: 2015 and BS1377: 1990. Techniques most commonly used by Lithos include:

- Machine excavated **trial pits**, usually equipped with a backactor and a 0.6m wide bucket. Allows a thorough inspection of the ground; especially the uppermost 1m or so (but able to reach depths of up to c. 4m), with the recovery of representative, disturbed samples. Also used to conduct soakaway testing.
- **Window or windowless** sampling boreholes (**dynamic sampling**). Constraints associated with existing buildings, operations and underground service runs can render some sites partly or wholly inaccessible to a mechanical excavator. In such circumstances, window sampling is often the most appropriate technique. A window sampling drilling rig can be manoeuvred in areas of restricted access and results in minimal disturbance of the ground (a 150mm diameter tarmac/concrete core can be lifted and put to one side). However, it should be noted that window sampling allows only a limited inspection of the ground (especially made ground with a significant proportion of coarse material).
- **Cable percussive** (Shell & Auger) boreholes, typically using 150mm diameter tools and casing. Enables the recovery of soil samples and data from greater depth than is possible via trial pitting or a mini-percussive drill rig. Also enables the installation of better/deeper monitoring wells (cf use of a mini-percussive drill rig) due to the utilisation of temporary steel casing during drilling.
- **Rotary percussive** open-hole probeholes are typically drilled using a tri-cone rock roller or polycrystalline diamond compact (PDC) bit with air as the flushing medium. Probeholes are generally lined through made ground with temporary steel casing to prevent hole collapse. Often used to penetrate bedrock to investigate abandoned shallow mineworkings
- **Rotary cored** boreholes. A rock core is cut by a bit, passes up into the inner barrel and, at the end of the coring run, the core barrel assembly is lifted to the surface. Core drilling is relatively expensive, but essential if quality data is required to assess issues associated with deep excavation, rock slope stability etc.

Where installed, gas\groundwater monitoring **wells** typically comprise a lower slotted section, surrounded by a filter pack of 10 mm non-calcareous gravel and an upper plain section surrounded in part by a bentonite seal and in part by gravel or arisings. The top of the plain pipe is cut off below ground level and the monitoring well protected by a square, stopcock type manhole cover set in concrete, or the plain pipe is cut off just above ground level and the well protected by 100mm diameter steel borehole helmet set in concrete. Monitoring well details, including the location of the response zone and bentonite seal are presented on the relevant exploratory hole logs.

In-situ testing

Relative densities of granular materials given on the trial pit logs are based on visual inspection only, they do not relate to any specific bearing capacities.

The relative densities of granular materials encountered in cable percussive boreholes are based on Standard Penetration Test (SPT) results. SPTs are carried out boreholes, in accordance with BS 1377 1990, Part 9 Section 3.3. Where full penetration (600mm) is not possible, N values are calculated by linear extrapolation and are shown on the logs as N* = x. The strength of cohesive deposits is determined using a hand shear vane.

Shear strength test results (hand vane readings) reported on trial pit logs are considered to be more reliable than those reported on window sample logs. Significant sample disturbance occurs during window sampling and consequently shear strength results on disturbed window samples are generally lower than results obtained during trial pitting, in-situ or in large excavated blocks.

Sampling

Typically Lithos collect at least three soil samples from each exploratory hole, although in practice a greater number are often taken. The collection of a sufficient number of samples provides a sound basis upon which to schedule laboratory analysis, ensuring:

- A sufficient number of samples from each (common) site material are tested
- Horizontal and vertical coverage of the site is adequate, thereby providing a robust data set for use in the conceptual ground model
- Any localised, significant, but non-pervasive conditions are considered

Made ground and natural soils encountered in the field during a ground investigation often contain a significant proportion of coarse grained material (e.g. brick etc). Soil samples obtained during most investigations are often only truly representative of the in-situ soil mass where there is an absence of particles coarser than medium gravel; i.e the entire soil mass would pass a 20mm sieve.

Representative bulk samples of the **soil mass** are retrieved from coarse soils for specific geotechnical tests (most notably grading and compaction); this typically requires the collection of at least 10kg of soil, and occasionally >50kg. However, in the context of assessing land contamination, it is generally accepted that samples should be representative of the **soil matrix** of the stratum from which they are taken. Consequently, truly representative samples of coarse soils for subsequent contaminant analysis are not obtained - only the finer fraction is placed in sample containers. Coarse constituents not sampled would typically comprise any 'particles' with an average diameter greater than about 20mm (i.e. coarse gravel, cobble and boulder).

At present, neither ISO/IEC 17025 nor MCERTS specify sample pre-treatment with respect to stone removal. Unsurprisingly therefore UKAS accredited testing laboratories do not adopt the same approach to stones[1] – some crush and test the "as received" soil, whilst others sieve out stones and analyse only the residual soil (the sieve size used varies depending on the laboratory).

In essence, samples taken from coarser soils for contaminant analysis are "screened" by the geoenvironmental engineer in the field, and often sieved again by the laboratory during sample preparation. Geoenvironmental engineers do not typically re-calculate soil mass contaminant concentrations by taking account of the unsampled coarse fraction. Likewise, laboratories that remove stones typically report contaminant concentrations based on the dry weight of soil passing the sieve. In the context of land contamination and human health risk assessment, this is considered reasonable, because it is the soil matrix which is of greatest concern. Stones are unlikely to:

- Provide a significant source for plant uptake (consumption of vegetables)
- Remain on vegetables after washing (consumption of vegetables)
- Be eaten (accidentally by an adult, or deliberately by a child)
- Be whipped-up by the wind for dust generation (inhalation)
- Stick to the skin for any length of time (dermal contact)
- Yield toxic vapour (inhalation)

Consequently, Lithos instruct labs to remove all stones >10mm, and to report the results as dry-weight based on the mass of matrix tested. However, the laboratory are given site-specific instruction where coarse stones are coated in say oil, or impregnated with mobile contaminants such as diesel. Where the stones are predominantly natural, or inert (e.g. brick, concrete etc), removal will clearly result in higher reported concentrations, than if the stones were crushed and added to the matrix.

Where the stones include a significant proportion of contaminant-rich material (e.g. slag, fragments of galvanised metal etc) an argument could be made for crushing and analysing. However, provided the stones are stable (i.e. unlikely to disintegrate or degrade) they should not pose a significant risk to human health for the reasons stated above.

Sometimes it is necessary to obtain samples that are not representative of the wider soil matrix, for example when investigating localised, significant, but non-pervasive conditions. Any such unrepresentative samples are annotated with the suffix '*' (eg 2D*, or 4G*). Lithos' site engineer describes both the unrepresentative sample, and the soil mass from which it was been taken.

Sample Containers (for contaminant analysis). Samples of soil for contaminant testing are placed into appropriate containers (see below). Soil samples for organic analysis are stored in cool boxes, at a temperature of approximately 4°C, until delivery to the selected laboratory.

Anticipated testing	Container(s)
Asbestos identification	1000ml plastic tub
pH & metals	1000ml plastic tub or 250ml glass jars
non-volatile organics	250ml glass jars
Speciated TPH	250ml & 50ml glass jars
VOCs (incl. naphthalene and\or GRO)	50ml glass jar

Sample Containers (for geotechnical analysis). The majority of samples are only scheduled for PI and sulphate testing, for which 500g of sample is required (a full 0.5-litre plastic tub). However, bulk bags are taken where scheduling of compaction or grading tests is proposed.

Groundwater

Where encountered during fieldwork, groundwater is recorded on exploratory hole logs. If monitoring wells are installed, groundwater levels are also recorded on one or more occasions after completion of the fieldwork. Long-term monitoring of standpipes or piezometers is always recommended if water levels are likely to have a significant effect on earthworks or foundation design.

It should be borne in mind that the rapid excavation rates used during a ground investigation may not allow the establishment of equilibrium water levels. Water levels are likely to fluctuate with season/rainfall and could be substantially higher at wetter times of the year than those found during this investigation.

Description of strata

Soils encountered during a Lithos investigation are described (logged) in general accordance with BS 5930:2015. The descriptions and depth of strata encountered are presented on the exploratory hole logs and summarised in the Ground Conditions section within the main body of text. The materials encountered in the trial pits are logged, samples taken, and tests performed on the in-situ materials in the excavation faces, to depths of up to 1.2m; below this depth these operations are conducted at the surface on disturbed samples recovered from the excavation.

[1] *Mark Perrin. Stoned – Sample Preparation for Soils Analysis. Ground Engineering, April 2007.*

General

Soil samples are delivered to the laboratory for testing along with a schedule of testing drawn up by Lithos. All tests are carried out in accordance with BS 1377:1990. The following laboratory testing is routinely carried out on a selection of samples:

- Atterberg limits & moisture contents
- Soluble sulphate & pH

Where soft, cohesive soils are encountered, one-dimensional consolidation tests are scheduled in order to assess settlement characteristics, and unconsolidated undrained triaxial compression tests to assess shear strength.

The additional tests are typically only scheduled where significant earthworks regrade is anticipated:

- Grading
- Compaction tests
- Particle density

Test results are presented as received in an Appendix to the Geoenvironmental Report.

Atterberg limits & moisture content

The Liquid and Plastic Limits of samples of natural in-situ clay are determined using the cone penetrometer method and the rolling thread test. These tests enable determination of an average Plasticity Index (PI) for each "type" of clay, although judgement is applied where variable results are reported.

PI can be related to shrinkability (low, medium or high) and then to minimum founding depth. Lithos typically only consider a soil to be shrinkable if the proportion finer than 63µm is >35%. PI results are compared against guidance given in the NHBC Standards, Chapter 4.2 (revised April 2003), which advocates the use of modified Plasticity Index (I'p), defined as:

I'p = Ip * (%< 425µm/100)

i.e. if PI is 30%, but the soil contains 80% < 425µm, then: I'p = 30 * 80/100 = 24%.

It should be noted that in accordance with the requirements of BS 1377, the % passing the 425µm sieve is routinely reported by testing labs. Lithos apply engineering judgment where PI results are spread over a range of classifications. Consideration is given to:

- The average values for each particular soil type (ie differentiate between residual soil and alluvium)
- The number of results in each class and
- The actual values

Unless the judgment strongly indicates otherwise, Lithos typically adopts a conservative approach and recommends assumption of the higher classification.

Soluble sulphate and pH

Sulphates in soil and groundwater are the chemical agents most likely to attack sub-surface concrete, resulting in expansion and softening of the concrete to a mush. Another common cause of concrete deterioration is groundwater acidity.

The rate of chemical attack depends on the concentration of aggressive ions and their replenishment at the reaction surface. The rate of replenishment is related to the presence and mobility of groundwater.

Lithos refer to BRE Special Digest 1 (SD1) "Concrete in aggressive ground. Part 1: Assessing the aggressive chemical environment" (2005). SD 1 provides definitions of:

- The nature of the site (greenfield, brownfield or pyritic)
- The groundwater regime (static, mobile or highly mobile)
- The design sulphate class (DS class) and
- The aggressive chemical environment for concrete (ACEC class)

Lithos reports clearly state each of the above for the site being considered.

The concentrations of sulphate in aqueous soil/fill extracts are determined in the laboratory using the gravimetric method. The results are expressed in terms of SO_4 for direct comparison with BS 5328:1997. The pH value of each sample was determined by the electrometric method.

SD1 also discusses determination of "representative" sulphate concentration from a number of tests. Essentially if <10 samples of a given soil-type have been tested, the highest measured sulphate concentration should be taken. If >10 samples have been tested, the mean of the highest 20% of the sulphate test results can be taken. With respect to groundwater, the highest sulphate concentration should always be taken.

With respect to pH (soil & groundwater) the value used is the lowest value if <10 samples have been tested and the mean of the lowest 20% if >10 samples have been tested.

Oedometer (Consolidation) tests

Oedometer tests measure a soil's consolidation properties, and are performed by applying different loads to a soil sample and measuring the deformation response. Typically the sample is subject to 5 incremental pressures (4 loading & 1 unloading), and the convention is for each subsequent pressure to be double the previous pressure. BS1377 suggests the **initial** pressure should be:

a) For stiff soils the effective overburden pressure*
b) For firm soils "somewhat less" than the effective overburden pressure
c) For soft soils "appreciably less" than the effective overburden pressure, usually 25 kPa or less
d) For very soft soils very low, typically 5 kPa or 10 kPa

* Effective **overburden pressure** (kNm^{-2}) = depth (m) x soil bulk unit weight (kNm^{-3})

Results from these tests are used to predict how a soil in the field will deform in response to a change in effective stress.

Triaxial tests

This test measures the mechanical properties of a soil by placing the sample between two parallel platens which apply stress in one (usually vertical) direction, with fluid used to apply a confining pressure in the perpendicular directions. During the test, the surrounding fluid is pressurized, and then stress on the platens is increased until the material in the cylinder fails.

From triaxial test data, it is possible to extract fundamental material parameters, including its angle of shearing resistance, apparent cohesion, and dilatancy angle. These parameters are then used in computer models to predict how the material will behave in a larger-scale engineering application.

Quick (single stage, Unconsolidated, Undrained tests) are most appropriate for foundation design**.** This is because load is applied relatively quickly, and shear strength of the clay will be lowest initially; after the applied load causes some consolidation of the ground (after drainage results in dissipation of short-term excess pore water pressure), the in-situ clays will become progressively stronger and hence the factor of safety will increase. Confining pressure is specified as equivalent to overburden pressure (kNm^{-2}).

Foundations on granular soils would use effective shear strength parameters (c' and phi') to assess safe bearing capacity, as the soil would fully drain quickly. These effective shear strength parameters could be determined from Consolidated Undrained (or sometimes the more expensive Consolidated Drained) triaxial tests, but often correlations to the SPT are used.

Unconsolidated Undrained triaxial tests are most appropriate for assessment of the stability of fill slopes on clays. Similar to foundations, the application of load gradually increases the strength of the clays and hence the critical case is the short term undrained condition.

Consolidated Undrained (or sometimes **Consolidated Drained**) triaxial tests are most appropriate for assessment of the stability of cut slopes in clays. This is because unloading of the ground leads to short term reduction in pore pressures that approximately balance the unloading, hence the soil strength is largely unchanged. Over time the reduced pore pressures suck water in, which leads in to the progressive increase in pore pressure and loss of strength. The fully drained state is critical, which must be modelled using effective strength parameters and a reasonable estimate of the long term water table conditions.

Slopes formed in granular soils would use effective shear strength parameters (c' and phi') to assess safe bearing capacity, as the soil would fully drain quickly. These effective shear strength parameters could be determined from Consolidated Undrained (or sometimes the more expensive Consolidated Drained) triaxial tests, but often correlations to the SPT are used.

Determination of analytical suite

An assessment of potential contaminants associated with the former usages of the site is undertaken with reference to CLR 8 "Potential contaminants for the assessment of land" and the relevant DETR Industry Profile(s).

Common contaminants

Common **Inorganic** Contaminants include:

- Metals, most notably cadmium, copper, chromium, mercury, lead, nickel, and zinc
- Semi-metals, most notably arsenic, selenium, and (water soluble) boron
- Non-metals, most notably sulphur
- Inorganic anions, most notably cyanides (free & complex), sulphates, sulphides, and nitrates

With respect to the terminology used by most analytical laboratories:

Total cyanide = Free cyanide + Complex cyanide

Total cyanide (CN) is determined by acid extraction; whereas free cyanide is the water soluble fraction. Complex cyanide is "bound" in compounds and is hard to breakdown. Laboratory determination of complex CN involves subjecting the sample to UV digestion for determination of both free and total CN.

Thiocyanate (SCN) is a different species combined with sulphur.

Elemental sulphur (S) and free sulphur are the same. Total sulphur is all forms, including that present in sulphates (SO_4), sulphides etc.

There are 2 forms of chromium (Cr), chromium VI and chromium III. Chromium VI is the more toxic of these. In soils, total chromium is determined by a strong aqua regia acid digestion. Chromium VI is an empirical method based on a water extract test.

Common **Organic** Contaminants include hydrocarbons, phenols, and polychlorinated biphenyls.

Petroleum is a mixture of hydrocarbons produced from the distillation of crude oil, and includes aliphatics (alkanes, alkenes and cycloalkanes), aromatics (benzene and derivatives) and hydrocarbon-like compounds containing minor amounts of oxygen, sulphur or nitrogen. Petroleum hydrocarbons can be grouped based on the carbon number range:

- GRO – Gasoline Range Organics (typically C_6 to C_{10}). Also referred to as PRO – Petroleum Range Organics
- DRO – Diesel Range Organics (typically C_{10} to C_{28})
- LRO - Lubricating Oil Range Organics (typically C_{28} to C_{40})
- MRO – Mineral Oil Range Organics (typically C_{18} to C_{44})

However, it should be borne in mind that the terms "GRO" and "DRO" analysis are purely descriptive terms, the exact definition of which varies. Total Petroleum Hydrocarbons (TPH) is also a poorly defined term; some testing laboratories regard TPH as hydrocarbons ranging from C_5-C_{40}, whereas others define TPH as C_{10}-C_{30}.

The composition of a TPH plume migrating through the ground can vary significantly; this is primarily dictated by the nature of the source (e.g. petrol, diesel, engine oil etc). Furthermore, different hydrocarbons are affected differently by weathering processes, and this can result in further variation in the chemical composition of the TPH.

Gasoline contains light aliphatic hydrocarbons (especially within the C_4 to C_5 range) that are volatile. The aromatic hydrocarbons in gasoline are primarily benzene, toluene, ethylbenzene and xylenes, referred to as BTEX. Small amounts of polycyclic aromatic hydrocarbons (PAHs) such as benzo(a)pyrene may also be present. Diesel and light fuel oils have higher molecular weights than gasoline. Consequently, they are less volatile and less water soluble. About 25 to 35% is composed of aromatic hydrocarbons. BTEX concentrations are generally low.

Heavy Fuel Oils are typically dark in colour and considerably more viscous than water. They contain 15 to 40% aromatic hydrocarbons. Polar nitrogen, sulphur and oxygen-containing compounds (NSO) compounds are also present. Lubricating Oils are relatively viscous and insoluble in groundwater. They may contain 10 to 30% aromatics, including the heavier PAHs. NSO compounds are also common.

Polycyclic Aromatic Hydrocarbons (PAHs) have two or more fused benzene rings as a structural characteristic. PAH compounds are present in both petrol and diesel, although in significantly lower concentrations than in coal tars. Certain PAH compounds are carcinogenic (benzo(a)pyrene) and\or mobile in the environment (naphthalene).

Volatile Organic Compounds (VOCs) are organic chemicals, and most are liquids that readily evaporate on exposure to air. Examples include benzene, toluene, xylene, chloroform etc. Semi-Volatile Organic Compounds (sVOCs) include phenol and benzo(a)pyrene, and have relatively low boiling points. Both groups of chemicals are readily absorbed through skin and some, such as benzene, are believed to be linked to tumour growth.

Phenols are compounds that have a hydroxyl group (-OH) attached to an aromatic ring (ie include a benzene ring and an –OH group). Most are colourless solids. A solution of phenol in water is known as carbolic acid, and is a powerful antiseptic. However, phenol vapour is toxic, and skin contact can result in burns.

Polychlorinated Biphenyls (PCBs) were used in pre-1974 transformers as dielectric fluids. PCB's are of increasing toxicity relative to the degree of chlorination. Acute symptoms of PCB poisoning are irritation of the respiratory tract leading to coughing and shortness of breath. Nausea, vomiting and abdominal pain are caused by ingestion of PCB's.

Dioxins and furans (polychlorinated dibenzodioxins and polychlorinated dibenzofurans) are some of the most toxic chemicals known; in the environment, they tend to bio-accumulate in the food chain. Dioxin is a general term that describes a group of hundreds of chemicals that are highly persistent in the environment. The most toxic compound is 2,3,7,8-tetrachlorodibenzo-p-dioxin or TCDD.

Dioxin is formed by burning chlorine-based chemical compounds with hydrocarbons. The major source of dioxin in the environment comes from waste-burning incinerators and also from backyard burn-barrels. Dioxin pollution is also affiliated with paper mills which use chlorine bleaching in their process and with the production of Polyvinyl Chloride (PVC) plastics and with the production of certain chlorinated chemicals (like many pesticides).

Methods of analysis (organic compounds)

TPH by GC-FID is an analytical technique which only detects hydrocarbons (aliphatic and aromatic) in the range C_{10} to C_{40} (volatiles, heavy tars, humic material and sulphur are not detected). The laboratory can provide a broad, 'banded' breakdown of the TPH results into gasoline range organics (GRO), diesel range organics (DRO) and heavier lubricating oil range organics (LRO), or fully speciated results with the reporting of hydrocarbon concentrations in 14 specific carbon bandings based upon behavioural characteristics, e.g. aliphatic C_6 to C_8, aromatic C_{10} to C_{12} etc.

Speciated VOC (by GC-MS) analysis quantifies the concentrations of 30 USA-EPA priority compounds. These include chlorinated alkanes and alkenes (in the molecular weight range chloroethane to tetrachloroethane); trimethylbenzenes; dichlorobenzenes; and the 4 BTEX compounds (benzene, ethyl-benzene, toluene & xylene).

Speciated sVOC by (GC-MS) analysis quantifies the concentrations of a variety of organic compounds, including the 16 USA-EPA priority PAHs, phenols, 7 USA EPA priority PCB congeners, herbicides & pesticides.

Note: PAHs are hydrocarbons and consequently (where present) will be picked-up when scheduling TPH by GC-FID.

Note: Risk assessment models require physiochemical properties (solubilities, toxicities etc) of compounds in order to model their behaviour in the environment. These physiochemical properties cannot be derived from a single "TPH", "GRO" or "DRO" value. However, the carbon banded fractions can be used in risk assessment models.

Current UK guidance

The UK approach to contaminated land is set out in Land Contamination Risk Management (2020). The approach is based upon risk assessment, where risk is defined as the combination of the probability of occurrence of a defined hazard and the magnitude of the consequences of the occurrence.

In the context of land contamination, there are three essential elements to any risk: (1) a contaminant source; (2) a receptor (eg controlled water or people); and (3) a pathway linking (1) and (2). Risk can only exist where all three elements combine to create a pollutant linkage. Risk assessment requires the formulation of a conceptual model which supports the identification and assessment of pollutant linkages.

Lithos adopt a tiered approach to risk assessment, consistent with UK guidance and best practice. The initial step of such a risk assessment (or Tier 1) is the comparison of site data with appropriate UK guidance levels, Lithos risk-derived screening values, or remedial targets. It should be noted that exceedance of Tier 1 does not necessarily mean that remedial action will be required.

Soil screening values used by Lithos

In March 2002 DEFRA and the Environment Agency published a series of technical papers (R&D Publications CLR 7, 8, 9 & 10) outlining the UK approach to the assessment of risk to human health from land contamination. In 2008 CLR 7, 9 & 10 and all corresponding SGV and Tox reports were withdrawn and superseded by new guidance including:

- Guidance on Comparing Soil Contamination Data with a Critical Concentration - CL:AIRE and CIEH, May 2008
- Evaluation of models for predicting plant uptake of chemicals from soil - Science Report – SC050021/SR
- Human health toxicological assessment of contaminants in soil - Science Report: SC050021/SR2
- Updated technical background to the CLEA model - Science Report: SC050021/SR3
- CLEA Software Handbook, Science report: SC050021/SR4
- Compilation of data for priority organic pollutants for derivation of Soil Guideline Values - Science Report: SC050021/SR7

In December 2013 Defra published the results of research project SP1010 – Development of Category 4 Screening Levels (C4SLs) for Assessment of Land Affected by Contamination. The objective of this project was to provide technical guidance in support of Defra's revised Statutory Guidance for Part 2A of the Environmental Protection Act 1990 (Part 2A). The revised Statutory Guidance, published in April 2012, introduced a new four-category system for classifying land under Part 2A, where Category 1 includes land where the level of risk is clearly unacceptable, and Category 4 includes land where the level of risk posed is acceptably low. Project SP1010 aimed to deliver:

- A methodology for deriving C4SLs for four generic land-uses comprising residential, commercial, allotments and public open space; and
- Demonstration of the methodology, via derivation of C4SLs for 6 substances – arsenic, cadmium, chromium IV, lead, benzene & benzo(a)pyrene.

The methodology for deriving both the previous Soil Guideline Values and the Category 4 Screening Levels is based on the Environment Agency's Contaminated Land Exposure Assessment (CLEA) methodology. Development of C4SLs has been achieved by modifying the toxicological and\or exposure parameters used within CLEA (while maintaining current exposure parameters).

Part 2A Statutory Guidance was developed on the basis that C4SLs could be used under the planning regime. Defra anticipate that, where they exist, C4SLs will be used as generic screening criteria, and Lithos consider C4SLs to be suitable for use as Tier 1 Screening Values. Lithos have discussed this matter with both NHBC and YALPAG (collection of Yorkshire & Lincolnshire local authorities) and received confirmation that they are satisfied with this approach.

The CLEA conceptual site model assumes a source located in a sandy loam, with 6% soil organic matter (SOM) - equivalent to 3.5% total organic carbon (TOC). However, many organic contaminants are more mobile when the SOM is lower, and consequently comparison of soil results with revised, lower screening values may be required. Other CLEA default characteristics adopted by Lithos are:

Sandy Loam characteristics (source)	Default values adopted
Total porosity (fraction)	0.53
Water filled porosity (fraction)	0.33
Air filled porosity (fraction)	0.2

Lithos have derived Screening Values for five different CSMs (scenarios); these are:

A - Residential with gardens, but no cover (or only up to 300mm)

B - Residential with gardens and 600mm 'clean' cover

C - Residential apartments with landscaping (i.e. no home grown produce)

D - Commercial/industrial with landscaping

E – Importation of soil cover

The **exposure** pathways considered for each scenario are detailed in the table below.

Scenario	Land use	Pathways	Justification
A	Residential with garden, but no cover (or only up to 300mm)	• Direct ingestion of soil • Dermal contact • Consumption of vegetables & soil attached to vegetables • Inhalation of indoor vapours and dust • Inhalation of outdoor vapours and dust	Minimal cover – insufficient to break any pathways therefore all exposure pathways are relevant.
B	Residential with garden minimum 600mm cover	• Inhalation of indoor vapours • Inhalation of outdoor vapours	The 600mm cover removes the risk from all pathways other than inhalation.
C	Residential apartments with landscaped areas and minimum 300mm cover	• Direct ingestion of soil • Dermal contact • Inhalation of indoor vapours and dust • Inhalation of outdoor vapours and dust	All pathways applicable due to possible exposure from landscaped areas. However consumption of home grown produce not included as unlikely to be grown in landscaped areas. Where vegetables are to be grown site specific QRA may be required.

Scenario	Land use	Pathways	Justification
D	Commercial/ industrial with landscaped areas no cover	• Direct ingestion of soil • Dermal contact • Inhalation of indoor vapours and dust • Inhalation of outdoor vapours and dust	All pathways applicable due to possible exposure from landscaped areas. Assumed the commercial development consists of offices to provide a conservative assessment.
E	Importation of soil for cover in garden and landscaped areas	• Direct ingestion of soil • Dermal contact • Consumption of vegetables & soil attached to vegetables • Inhalation of outdoor vapours and dust	Material used as cover to break existing pathways therefore all direct and indirect pathways relevant; however cover is **not** placed below plots therefore indoor inhalation is not relevant.

Lithos have assumed the source of contamination is directly below the building foundation; i.e. a depth to source of 0.15m as opposed to the CLEA default of 0.65m. This assumption provides for a more conservative approach than the UK default.

Lithos have derived Tier 1 values for a number of inorganic and organic determinands in the context of the five Scenarios A to E. The Tier 1 values are **not** intended to be used when considering potential risks associated with:

- Existing land uses in the context of Part 2A of the Environment Protection Act 1990;
- End uses such as allotments, sports fields, children's playgrounds, care homes, hospitals etc; or
- Groundwater and surface water

Inorganic Tier 1 values for scenarios A to E

Inorganic contaminant	Tier 1 assessment criteria (mg/kg) for Scenarios A to E							Comments/notes
	SGV*	C4SL*	A	B	C	D	E	
As	32	37	37	Use (A) in SI Report for initial "screen" If >5 x A, then consider increase of cover to 1,000mm	40	640	37	C4SL adopted
Cd	10	26	26		149	410	26	C4SL adopted
Cr			4,000		4,000	28,767	4,000	Assumes Cr is CrII
Pb	450	200	200		314	2,330	200	C4SL adopted
Ni	130		109		123	892	109	Assessment of health risk only
Se	350		434		596	13,018	434	
Hg	170		199		244	3,603	199	Assumes in an inorganic compound
Vn			584		586	4,994	584	
B			5		5	5	5	Based on phytotoxic risks as plants are the more sensitive receptor (Cu is pH dependant)
Cu			100		100	100	100	
Zn			200		200	200	200	

Organic Tier 1 values for scenarios A to E

Organic contaminant (all sourced via CLEA)	Tier 1 assessment criteria (mg/kg) for Scenarios A to E							Comments/notes
	SGV*	C4SL*	A	B	C	D	E	
Benzene	0.33	0.87	0.7	<1^	<1^	63	<1	<1 based on professional judgement and lower than calculated value.
Toluene	610		836	2,048	1,912	5,000	<1	Scenario D based on professional judgement and lower than calculated value.
Ethyl Benzene	350		379	592	566	5,000	<10	
Xylenes	240		535	590	585	5,000	<10	Scenario E based on professional judgement and lower than calculated value.
Phenol	420		1,434	3,360	2,264	5,000	<10	
PCBs			2	8	2	38	N/A	Based on toxicity of EC7
Benzo(a)pyrene		5	5	25	5	76	5	C4SL adopted. Scenario B 5 times scenario A
Naphthalene			6	6	6	619	<10	Scenario E based on professional judgement and lower than calculated value
Gasoline Range Organics			22	23	23	2178	626	See 3-step assessment of TPH below ^Based on professional judgement and lower than calculated value
Diesel Range Organics			215	218	215	^5,000	1,429	
Lubricating Range Org			3,299	5,000	3,829	^5,000	3,299	

* *For a residential end use*

The significance of PAHs can be determined by considering indicator compounds. In most cases benzo(a)pyrene (BaP) is adopted as an indicator due to the amount of toxicological data available and has been used by various authoritative bodies to assess the carcinogenic risk of PAHs in food. A surrogate marker approach can be used to estimate the toxicity of a mixture of PAHs in soil using toxicity data for individual indicator compounds within that mixture. Exposure to the surrogate marker is assumed to represent exposure to all PAHs in that matrix. The surrogate marker approach relies on a number of assumptions:

- Surrogate marker (BaP) must be present in all soil samples
- Profile of the different PAH relative to BaP should be similar in all samples
- PAH profile in the soil samples should be similar to that used in the pivotal toxicity study[1]

To assess the PAH profile in a soil sample, the ratio of the seven genotoxic PAHs (benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[g,h,i]perylene, chrysene, dibenz[a,h]anthracene and indeno[1,2,3-c,d]pyrene), relative to BaP, should be calculated. The ratio relative to BaP should lie within an order of magnitude above and below the mean ratio to BaP.

[1] SP1010 Appendix E, Provisional C4Sls for benzo(a)pyrene as a surrogate marker for PAHs, CL:AIRE 2013

Naphthalene should also be considered separately against its generic screen. Whilst classed as a PAH, naphthalene is more volatile and mobile in the environment than most other PAHs. As such the significance of naphthalene cannot be considered within the surrogate marker approach.

Similarly, **TPH** cannot be assessed as a single "total" value, and reference has been made to the Environment Agency's document P5-080/TR3, "The UK approach for evaluating human health risks from petroleum hydrocarbons in soils". This document supports the assumptions and recommendations made by the US Total Petroleum Hydrocarbons Criteria Working Group (TPHCWG). The TPHCWG have broken down "TPH" into representative constituent fractions or "EC Bandings". The TPHCWG have derived a series of physiochemical and toxicological parameters for each of the bandings.

The significance of speciated TPH results can be assessed by following the 3 steps outlined in the tables below.

Step	Result	Action
1. Consider indicator compounds: Are BTEX, naphthalene, benzo(a)pyrene above their respective Tier 1 values?	Yes	Remediation or dQRA required
	No	Proceed to Step 2
2. Consider individual TPH fractions: are they above respective screening values?	Yes	Remediation or dQRA required
	No	Proceed to Step 3
3. Assess Cumulative effects: Is the calculated Hazard Index for each source >1	Yes	Remediation or dQRA required
	No	TPH compounds pose no significant risk

The equation used to assess cumulative effects in step 3 is shown below.

$$HI = \sum_{F_i=1}^{16} HQ\,F_i = \frac{Measured\ concentration\ F_i\ (mg\,kg^{-1})}{SGV\ F_i\ (mg\,kg^{-1})}$$

where HI = Hazard Index
HQ = Hazard Quotient
F_i = Fraction $_i$
SGV = Soil Guideline Value

Statistical Assessment

Current UK guidance is provided by CL:AIRE[2], and uses two-way confidence intervals and graphical summaries, to assist assessors when determining whether or not a dataset is adequate to answer the question posed; e.g. "is existing site topsoil suitable for retention & re-use?". To answer such a question, it is necessary to recover and test a large number of samples (a minimum of 10; ideally 20+) in order to undertake meaningful statistical analysis.

However, in the context of site investigation to assess the significance of contamination on brownfield sites which are typically underlain by **heterogenous made ground**, some remediation is almost always required (placement of soil cover, excavation of gross contamination etc). Consequently, in such circumstances, it is not necessary to demonstrate that made ground soils are "clean" and therefore there is no need to test large numbers of samples and undertake statistical analysis. Sample results can simply be compared directly with appropriate screening values (e.g. Lithos Tier 1 values).

The CL:AIRE (2020) guidance replaces the withdrawn "Guidance on Comparing Soil Contamination Data with a Critical Concentration" (2008).

The old approach to statistical analysis was based on a definitive yes/no answer which required limited consideration of the dataset and Conceptual Site Model. It was widely accepted that this did not allow sites or risk to be adequately assessed. The updated approach requires a comprehensive understanding of the datasets within the context of the Conceptual Site Model.

Current guidance requires that:

- A robust CSM is in place which identifies source areas, averaging areas and averaging zones
- Sampling locations are relatively evenly spread across the site and were selected using simple or stratified random sampling with no targeting being undertaken
- The field data and CSM do not suggest the presence of a hotspot of contamination which should be treated as a separate zone
- The samples are all taken from a similar same depth and within the same material type across the zone being assessed
- A minimum of 10 samples have been taken. It should be appreciated that confidence in a dataset increases as the number of samples obtained and tested from a zone increases.

The statistical analysis assumes a homogenous distribution of strata and contamination and therefore the dataset will be normally distributed (symmetric, log symmetric or fat tailed).

A normally distributed dataset is assessed using a number of statistical tools to generate a Dot and Box Plot which includes summary statistics and confidence intervals. The review of statistical data enables the assessor to make a decision, with an associated level of confidence, where the true mean of the sample population lies in relation to the critical concentration.

It is essential when using statistics to assess sample data that all decisions relate back to the conceptual site model. Statistics cannot indicate if contamination on a site is likely to present a risk to the end user, this is the role of the 'competent person' i.e. Lithos.

However, broadly speaking the following applies:

- Mean and UCL below the critical concentration – no further assessment required.
- Mean below the critical concentration, but UCL above – consider the CSM and likely sources.
- Mean and UCL above the critical concentration – further assessment required, remediation likely depending on the CSM.
- LCL, Mean & UCL above the critical concentration – further assessment required, remediation likely.

[2] *CL:AIRE, 2020.Professional Guidance: Comparing Soil Contamination Data with a Critical Concentration.*

Other screening values used by Lithos

Tier 1 risk assessment of **hazardous gas** is undertaken through reference to the following documents (and further information is presented in Generic Note No. 5 – Hazardous Gas):

- Approved Document C, Building Regulations 2000
- Boyle & Witherington (2007) – Guidance on evaluation on development proposals on sites where methane and carbon dioxide are present, incorporating "traffic lights". Report Ref. 10627-R01-(02), for NHBC
- CIRIA C665 (2007) – Assessing risks posed by hazardous ground gases to buildings
- BS 8485:2015 – Code of Practice for the characterisation & remediation from ground gas in affected developments

With respect to the assessment of potential **phytotoxic effects** of contaminants, Lithos refer to The Sewage Sludge in Agriculture: Code of Practice 2018 for copper and zinc (at pH 5.5 to 6.0). The CLEA derived Tier 1 value is adopted for nickel due to its human health effects.

The potential risk to **building materials** is considered through reference to relevant BRE Digests, with particular emphasis on BRE Special Digest 1, 'Concrete in aggressive ground', 2005.

With respect to the interpretation of the **calorific values**, at present there are no accepted methods to assess whether a sample is combustible and under what circumstances it might smoulder. Some guidance is given in ICRCL Note 61/84 "Notes on the fire hazards of contaminated land" which states that: *"In general … it seems likely that materials whose CV's exceed 10MJ/kg are almost certainly combustible, while those with values below 2MJ/kg are unlikely to burn"*.

Tier 1 **groundwater risk assessments** are always site specific and compare leachate or groundwater concentrations with the appropriate water quality standard based on the CSM and consideration of relevant water quality impacts and assessments.

Waste classification & WAC

In the context of waste soils generated by remediation and\or groundworks activities on brownfield sites, the following definitions (from the Landfill Regulations 2002) apply:

- Inert (e.g. uncontaminated 'natural' soil, bricks, concrete, tiles & ceramics)
- Non-Hazardous (e.g. soil excavated from a contaminated site which contains dangerous substances, but at concentrations below prescribed thresholds)
- Hazardous (e.g. soil excavated from a contaminated site which contains dangerous substances at concentrations above prescribed thresholds)

Dangerous substances include compounds containing a variety of determinants commonly found in contaminated soils on brownfield sites, for example arsenic, lead, chromium, benzene etc.

Landfill operators require Waste Acceptance Criteria (WAC) laboratory data, if soil waste is classified as **hazardous**. However, subject to WAC testing it may be possible to classify it as stable, non-reactive hazardous waste, which can be placed within a dedicated cell within the non-hazardous landfill.

Lithos typically only include WAC analysis in site investigation proposals and reports, if significant off-site disposal (of soil classified as hazardous waste) is anticipated, for example where redevelopment proposals include basement construction etc. If off-site disposal of soils classified as hazardous waste during redevelopment is anticipated, then WAC analysis should be scheduled at an early stage in the remediation programme. However, organic compounds (BTEX, TPH, PAH etc) are the most common contaminants that result in soils being classed as hazardous, and these contaminants can often be dealt with by alternative technologies (e.g. by bioremediation or stabilisation) and consequently retention on site is often possible.

It should be noted that **non-hazardous** soil waste can go to a non-hazardous landfill facility; no further testing (e.g. WAC) is required.

Possible action in event of Tier 1 exceedance

Should any of the Tier 1 criteria detailed above be exceeded, then three potential courses of action are available. (The first is only applicable in terms of human health, but the second and third could also be applied to groundwater or landfill gas).

1. Undertake further statistical analysis following the approach set out in Professional Guidance: Comparing Soil Contamination Data with a Critical Concentration, 2020 (see above) in order to determine whether contaminant concentrations of inorganic contaminants within soil\fill actually present a risk (only applicable to assessing the risk to human health).
2. Carry out a more detailed quantitative risk assessment in order to determine whether contamination risks actually exist.
3. Based on a qualitative risk assessment, advocate an appropriate level of remediation to "break" the pollutant linkage - for example the removal of the contaminated materials or the provision of a clean cover.

Prior to undertaking any statistical analysis the issue of the **averaging area** requires further consideration. Professional Guidance: Comparing Soil Contamination Data with a Critical Concentration, 2020 provides some guidance on averaging areas noting that they are the area within which a receptor may be exposed to contamination but leaving the site assessor to determine the appropriate averaging area for their site.

Lithos consider the entire site needs to be characterised by reference to the Conceptual Site Model. Consequently, Lithos gather and analyse sample results by fill type, and\or by former use in a given sub-area of the site, before undertaking statistical analysis; i.e. the averaging area is associated with the extent of a particular fill type, or an area affected by spillage\leakage.

In terms of brownfield redevelopment, this is considered a more appropriate methodology which provides a more representative sample population for statistical analysis. As such the entire site is considered in terms of the proposed end use, be this residential with, or without gardens.

Analysis by soil\fill type is appropriate for essentially immobile contaminants associated with a particular fill type, for example arsenic in colliery spoil, metals in ash & clinker, sulphate in plaster-rich demolition rubble etc.

Analysis by former use is appropriate where more mobile contaminants have entered the ground, for example diesel associated with leakage from a former fuel tank, downward migration of leachable metals through granular materials, various soluble contaminants present in a wastewater leaking into the ground via a fractured sewer etc. In these circumstances, it may be appropriate to undertake statistical analysis of sample results from a variety of different soil\fill types. However, consideration would have to be given to factors such as porosity which might influence impregnation of a mobile contaminant into the soil mass, i.e. contamination would normally be more pervasive and significant in granular soils than cohesive soils

General

Hazardous gas is considered to be any mixture of potentially explosive, toxic or asphyxiating gases, most notably methane, carbon dioxide and oxygen (deficiency). In addition, radon, a naturally occurring radioactive gas is also considered. Further information about radon is included in Notes 01 – Environmental Setting.

Assessment of potential risks associated with hazardous gas are based on a review of data obtained from the Landmark Information Group, the Environment Agency and the Local Authority and the British Geological Survey. Reference is also made to historical OS plans, which are inspected for evidence of backfilled quarries, railway cuttings, colliery spoil tips etc.

Where landfilling has occurred within 250m of the site boundary, the Local Planning Authority may request a landfill gas investigation in accordance with the Town and Country Planning General Development Order, 1988.

Sources

Potential sources of hazardous gas include:

- Landfill sites
- Made ground, especially where significant depths are present
- Shallow mineworkings associated with coal extraction
- Geological strata, including peat, organic silts, coal and limestone (reaction with acidic waters), granite (radon)
- Groundwater can sometimes act as a "carrier" for hazardous gas
- Leakages from pipelines or storage tanks
- Sewers, septic tanks and cess pits

Generation

Wherever biodegradable material is deposited, landfill gas (principally a mixture of methane and carbon dioxide) is likely to be generated by microbial activity. Carbon dioxide is an asphyxiant and toxic; methane is flammable and a mixture containing between 5% and 15% methane by volume in air is explosive. Landfill gas in the ground is unlikely in itself to pose a significant risk, though it may damage vegetation. However, infiltration of landfill gas into confined spaces (e.g. cellars, services, etc) may give rise to considerable risk.

There is no typical figure for the length of time that landfill gas will be evolved, but at many sites significant gas generation continues for at least 15 years after the last deposit of waste.

Migration

Gas migration from a landfill site may occur in several ways. It may migrate through adjacent strata; the distance of migration being dependent on the pressure gradients, volume of gas and permeability of the strata. Where there are faults, cavities and fissures within the strata, gas may move considerable distances. Other migration pathways for gas include man-made features such as mine shafts, roadways and underground services.

Gas migration is influenced by a number of climatic factors, such as atmospheric pressure variations, water table level variations and the influence of a covering of snow or ice over the surface of the site and surrounding area.

Gas monitoring procedure

Lithos adopt a standard gas monitoring procedure, in accordance with CIRIA guidance. This procedure involves the measurement, in the following order of:

- Atmospheric temperature, pressure and ambient oxygen concentration
- Gas emission rate
- Methane, oxygen and carbon dioxide concentrations using an infra-red gas analyser
- Standing water level using a dipmeter.

In addition, ground conditions at each sampling location are recorded together with prevailing weather conditions and any other observations such as any vandalism. Where samples of gas are required for laboratory analysis, Gresham Tubes or multi-layer Tedlar / ALTEF sampling bags are used. Gas concentrations in the well are typically recorded immediately before and after retrieval of a sample.

Current guidance

CIRIA Report 151 (1995)[i] identified that there was inadequate guidance on trigger concentrations for ground gases. CIRIA concluded that the most important aspect of a gas regime below or adjacent to a site was the surface emission rate, i.e. how quickly the gas is coming out of the ground. The lower the surface emission rate the lower the risk. CIRIA Report C665 (2007)[ii] advocates two methodologies for characterising sites:

A – All developments except low rise housing. The advocated methodology is that proposed by Wilson & Card, 1999[iii]

B – Low rise housing. An alternative (traffic light) methodology, derived by Boyle and Witherington, 2006[iv] for NHBC

Both methodologies refer to Gas Screening Values (GSV); previously referred to as limiting borehole gas volume flow.

Other relevant UK guidance includes:

- BS8485:2015+A1:2019 – Code of Practice for the characterisation & remediation from ground gas in affected developments.
- BS8576:2013 Guidance on investigations for ground gas – permanent gases and volatile organic compounds
- Boyle & Witherington (2007) – Guidance on evaluation on development proposals on sites where methane and carbon dioxide are present, incorporating "traffic lights". Report Ref. 10627-R01-(02), for NHBC
- Wilson, Card & Haines (CIEH, 208) The Local Authority Guide to Ground Gas
- CL:AIRE Research Bulletin RB17 (November 2012) A Pragmatic Approach to Ground Gas Risk Assessment
- CL:AIRE Research Bulletin RB13 (February 2011) The Utility of Continuous Monitoring in Detection & Prediction of 'Worst-Case' Ground Gas Concentration
- BRE\Environment Agency Report BR 414 (2001) – "Protective Measures for housing on gas-contaminated land".
- YALPAG (December 2016) - Verification Requirements for Gas Protection Systems - Technical Guidance for Developers, Landowners and Consultants.
- Environment Agency Report LFTGN 03 - Guidance on the management of landfill gas, June 2014

A – All developments except low rise housing

(Wilson & Card, 1999)[v] revised Table 28 of CIRIA 149[v] in terms of borehole gas volume flow rate (now GSV) in order to achieve a more consistent design of protection measures. This was done to reflect the importance of recognising the gas surface emission rate. Wilson & Card then developed a method for classifying gassing sites (Table 1 below), which took into account the combined gas concentration and GSV.

Characteristic Situation	Gas Screening Value, CH_4 or CO_2 (l/hr)	Additional limiting factors	Typical source of generation
1	<0.07	Methane not to exceed 1% v/v and carbon dioxide not to exceed 5% v/v	Natural soils with low organic content
2	<0.7	Borehole air flow rate not to exceed 70 litre/hr otherwise increase to Characteristic Situation 3	Natural soil, high peat/organic content
3	<3.5		Old landfill, inert waste, mineworkings flooded.
4	<15	Quantitative Risk Assessment required to evaluate scope of protection measures.	Mineworkings – susceptible to flooding, completed landfill, inert waste
5	<70		Mineworkings unflooded, inactive
6	>70		Recent landfill site

Notes: Borehole flow rate = volume of gas (regardless of composition) which is escaping from well (l/hr). Gas Screening Value (litre/hour) = gas concentration (%) / 100 x borehole flow rate (l/hr). To facilitate design implementation, the limiting values for both methane and carbon dioxide are identical.

B – Low rise housing.

NHBC have developed a characterisation system similar to that of Wilson & Card above, but specific to low-rise housing development (Boyle and Witherington) (Table 8.7). This approach compares measured gas emission rates with generic "Traffic Lights". The Traffic Lights include "Typical Maximum Concentrations" for initial screening, and risk-based Gas Screening Values (GSVs) for consideration of situations where the Typical Maximum Concentrations are exceeded. Calculations are carried out for both methane and carbon dioxide and the worst case adopted in order to establish the appropriate protection measures.

Table 8.7 NHBC Traffic light system for 150 mm void

Traffic Light Classification	Methane[1]		Carbon Dioxide[1]	
	Typical Maximum Concentration[5] (%v/v)	Gas Screening Value[2,4,6] (l/hr)	Typical Maximum Concentration[5] (%v/v)	Gas Screening Value[2,3,4,6] (l/hr)
Green				
	1	0.16	5	0.78
Amber 1				
	5	0.63	10	1.56
Amber 2				
	20	1.56	30	3.13
Red				

Notes:

1. The worst gas-regime identified at the site, either methane or carbon dioxide, recorded from monitoring in the worst temporal conditions, will be the decider for which Traffic Light and GSV is allocated.
2. Generic GSVs are based on guidance contained within "The Building Regulations: Approved Document C" (2004) and assume a sub-floor void of 150 mm thickness.
3. A leak of gas from the sub-floor void into a small room (e.g. downstairs toilet with soil pipe potentially passing into sub-floor void) of dimensions 1.50m × 1.50m × 2.50m, with a total room volume of 5.63m^3 has been considered.
4. The GSV, in litres per hour, is as defined in Wilson and Card (1999) as the borehole flow rate multiplied by the concentration in the air stream of the particular gas being considered.
5. The Typical Maximum Concentrations can be exceeded in certain circumstances should the conceptual site model indicate it is safe to do so. This is where professional judgment will be required, based on a thorough understanding of the gas regime identified at the site where monitoring in the worst temporal conditions has occurred.
6. The GSV thresholds should not generally be exceeded without completion of a detailed gas risk assessment taking into account site-specific conditions.

---

i *Harries CR, Witherington PJ and McEntee JM (1995). Interpreting measurements of gas in the ground. CIRIA Report 151*

ii *CIRIA (2007) – Assessing risks posed by hazardous ground gases to buildings.*

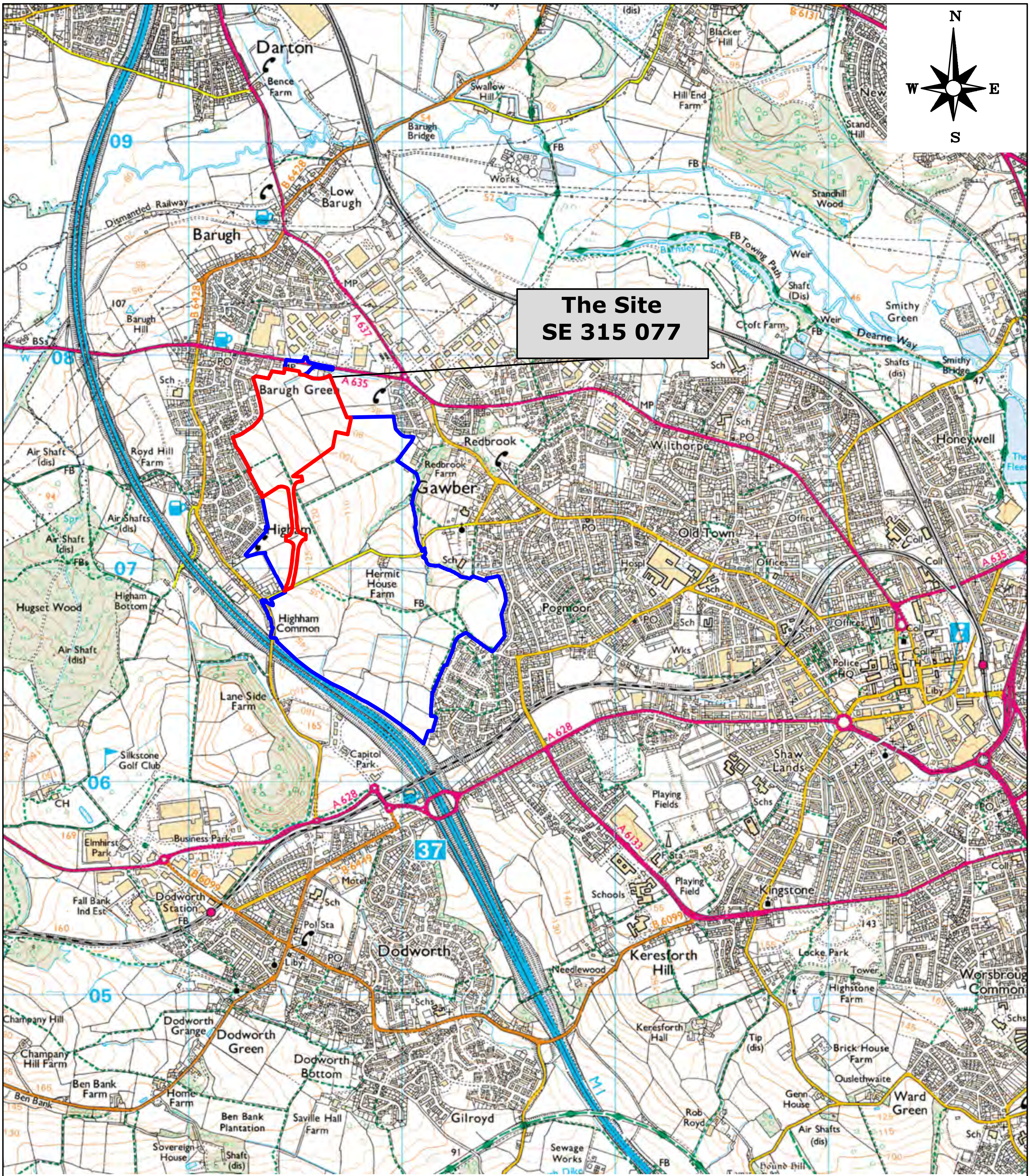
iii *Wilson SA and Card GB (February 1999). Reliability and Risk in Gas Protection Design. Ground Engineering.*

iv *Boyle & Witherington (2006) – Guidance on evaluation on development proposals on sites where methane and carbon dioxide are present, incorporating "traffic lights". Report Ref. 10627-R01-(02), for NHBC*

v *Wilson SA and Card GB (February 1999). Reliability and Risk in Gas Protection Design. Ground Engineering.*

Appendix B

Drawings



Reproduced from OS Explorer map 1:25,000 scale by permission of Ordnance Survey on behalf of The Controller of Her Majesty's Stationery Office.

APPROXIMATE LAND TRANSFER ONE BOUNDARY — APPROXIMATE WIDER BARNSLEY WEST DEVELOPMENT BOUNDARY

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CLIENT	JOB TITLE	DRAWING TITLE	DRAWN	DATE
STRATA HOMES	BARNSLEY WEST, LAND TRANSFER ONE	SITE LOCATION PLAN	GLM	06/10/2021
			CHECKED: AG	DATE: 06/10/2021

STATUS: FOR COMMENT ☐ FOR APPROVAL ☐ DRAFT ☐ FINAL ☑

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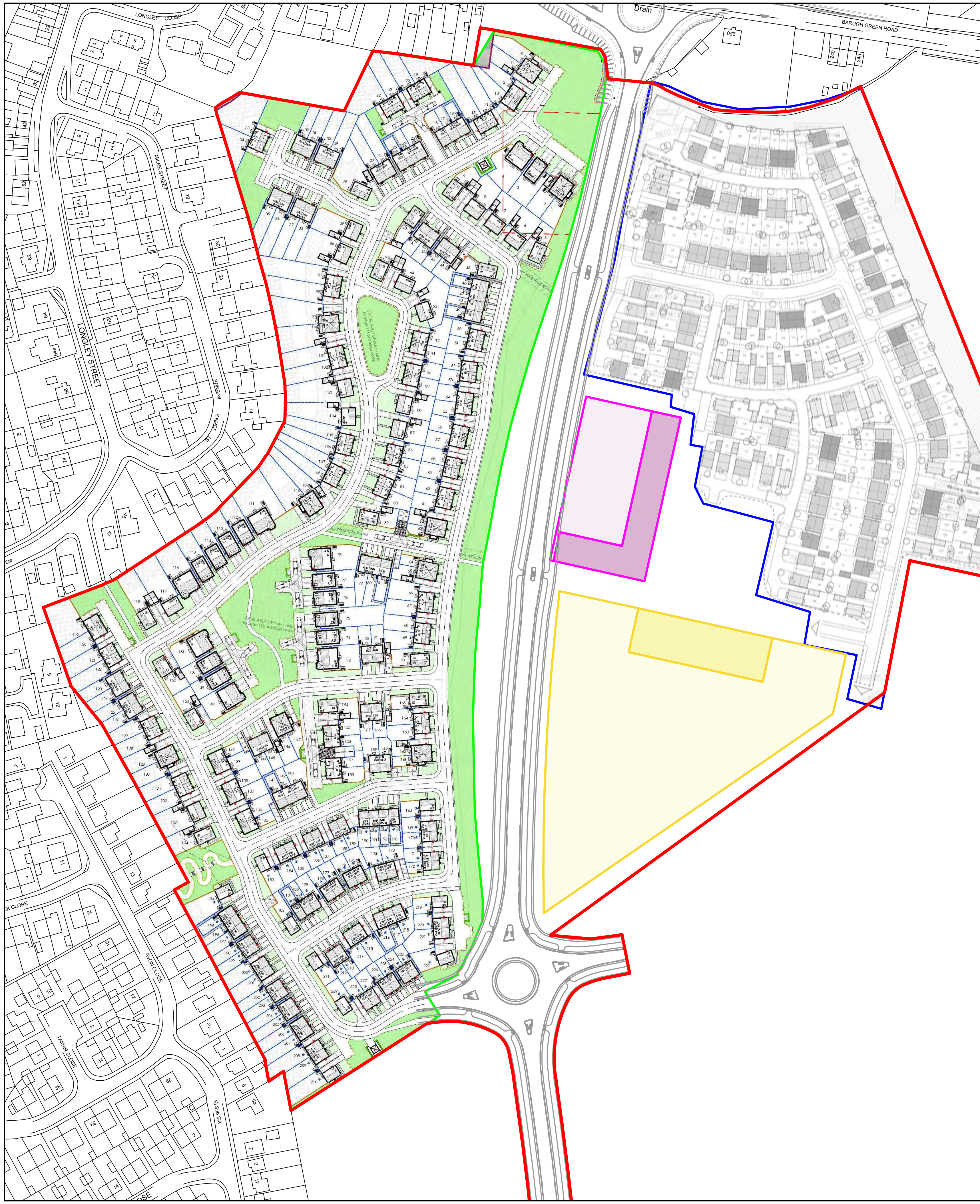
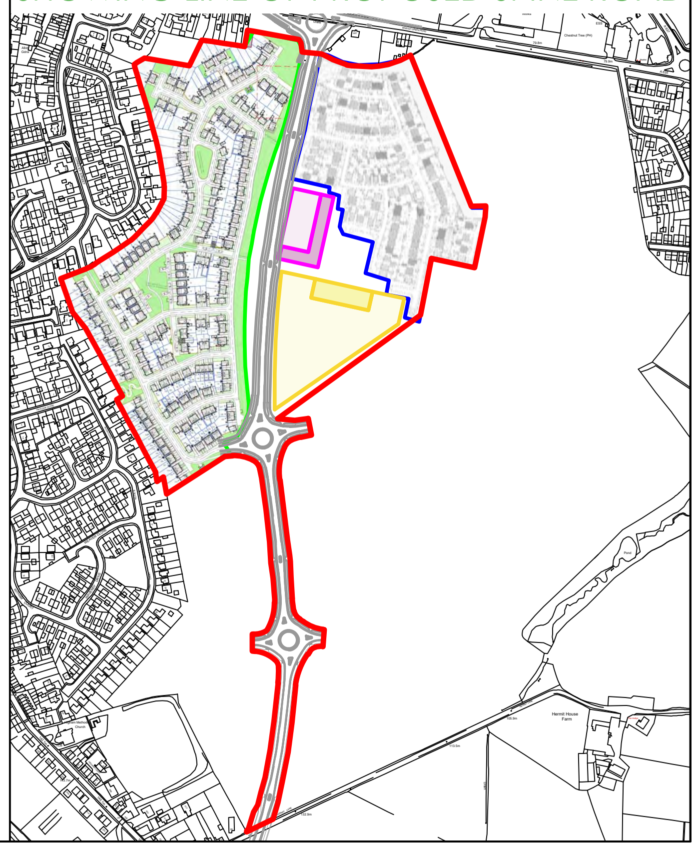


NOT TO SCALE: EXPANDED VIEW SHOWING LINE OF PROPOSED SPINE ROAD



NOTES

DEVELOPMENT AREA 1

REPRODUCED FROM STRATA HOMES' DRAWING 'BARNSLEY WEST PHASE 1, S75 1 - SKETCH LAYOUT' REF. 20-CL4-SEGB-BWP1-02 REV. J, DATED 18/06/2021

DEVELOPMENT AREA 2

REPRODUCED FROM MILLER HOMES' DRAWING 'BARNSLEY WEST SK04, REF. SK04, ISSUED BY STEN ARCHITECTURE IN MARCH 2021

DEVELOPMENT AREA 3 (RETAIL)

DEVELOPMENT AREA 4 (SCHOOL)

APPROXIMATE SITE BOUNDARY

REV.	DESCRIPTION	DATE

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CLIENT

STRATA HOMES

JOB TITLE

BARNSLEY WEST, LAND TRANSFER ONE

DRAWING TITLE

PROPOSED SITE LAYOUT

DRAWN	DATE	STATUS
GLM	06/10/2021	FOR COMMENT ☐ FOR APPROVAL ☐
CHECKED AG	DATE 06/10/2021	DRAFT ☐ FINAL ☑

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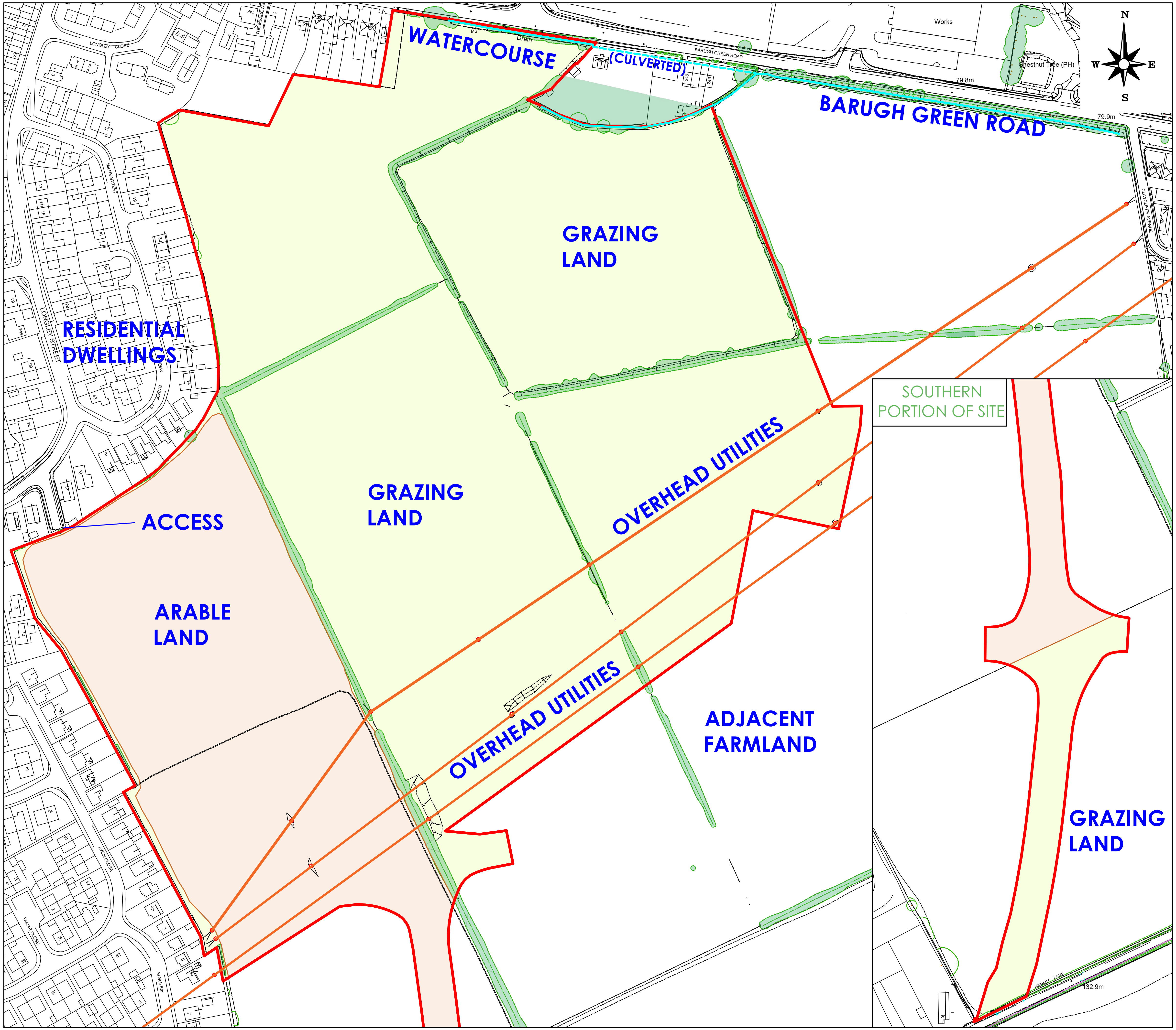

NOTES

- GRASS & OVERGROWN AREAS
- ARABLE FARMLAND (STUBBLE)
- OVERHEAD UTILITY
- LINE OF WATERCOURSE
- APPROXIMATE SITE BOUNDARY

REV.	DESCRIPTION	DATE

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JOB TITLE
BARNSLEY WEST, LAND TRANSFER ONE

DRAWING TITLE
SITE FEATURES

DRAWN	DATE	STATUS
GLM	28/10/2021	FOR COMMENT ☐ FOR APPROVAL ☐
CHECKED	DATE	DRAFT ☐
AG	28/10/2021	FINAL ☑

SCALE	SHEET	DRAWING NO.	REVISION
1:1,250	A3	3104/3	

NOTES

- GRASS & OVERGROWN AREAS
- ARABLE FARMLAND (STUBBLE)
- APPROXIMATE SITE BOUNDARY
- LOCATION & ORIENTATION OF PHOTOGRAPH

REV.	DESCRIPTION	DATE

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JOB TITLE

BARNSLEY WEST, LAND TRANSFER ONE

DRAWING TITLE

SITE PHOTOGRAPHS

DRAWN	DATE	STATUS
GLM	23/12/2021	FOR COMMENT ☐ FOR APPROVAL ☐
CHECKED	DATE	DRAFT ☐
AG	23/12/2021	FINAL ☑

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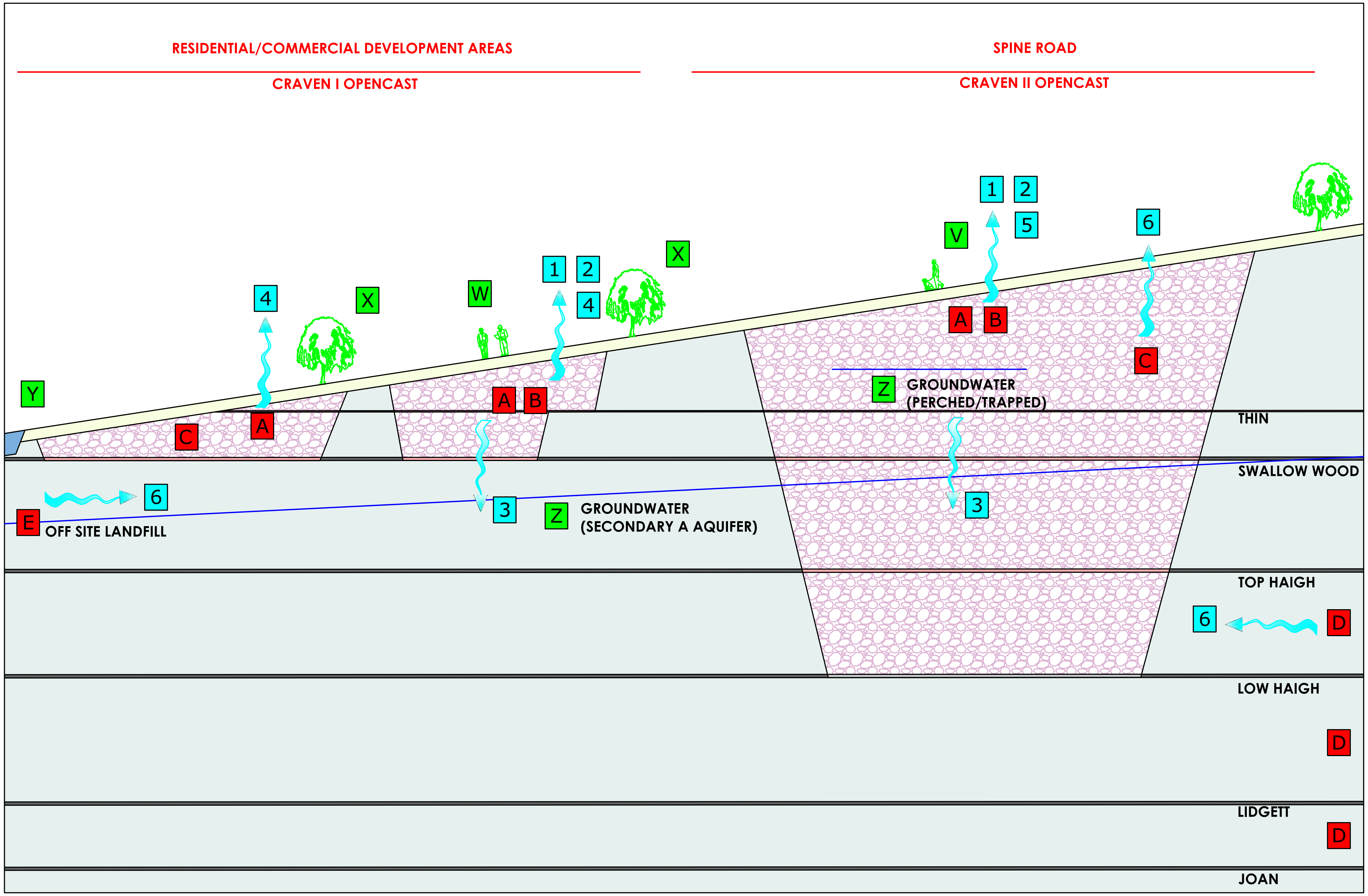

KEY

- TOPSOIL
- MADE GROUND (OPENCAST BACKFILL)
- COAL
- LOWER COAL MEASURES

SOURCES

- A MADE GROUND (INORGANICS)
- B LEAKAGE/SPILLAGE (ORGANICS)
- C DEEP MADE GROUND (GAS)
- D COAL/MINEWORKINGS (GAS)
- E OFF SITE LANDFILL(GAS)

PATHWAYS

- 1 DERMAL CONTACT
- 2 INGESTION/INHALATION
- 3 LEACHING OF CONTAMINANTS
- 4 UPTAKE BY PLANTS
- 5 VOLATILISATION
- 6 MIGRATION OF GAS

RECEPTORS

- V END USERS (RESIDENTS)
- W SITE WORKERS
- X VEGETATION
- Y SURFACE WATERS
- Z GROUNDWATER

NOTES

REV.	DESCRIPTION	DATE

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CLIENT: STRATA HOMES

JOB TITLE: BARNSLEY WEST, LAND TRANSFER ONE

DRAWING TITLE: PRELIMINARY CONCEPTUAL SITE MODEL

DRAWN	DATE	STATUS
GLM	01/11/2021	FOR COMMENT ☐ / FOR APPROVAL ☐
CHECKED: AG	DATE: 01/11/2021	DRAFT ☐ / FINAL ☑

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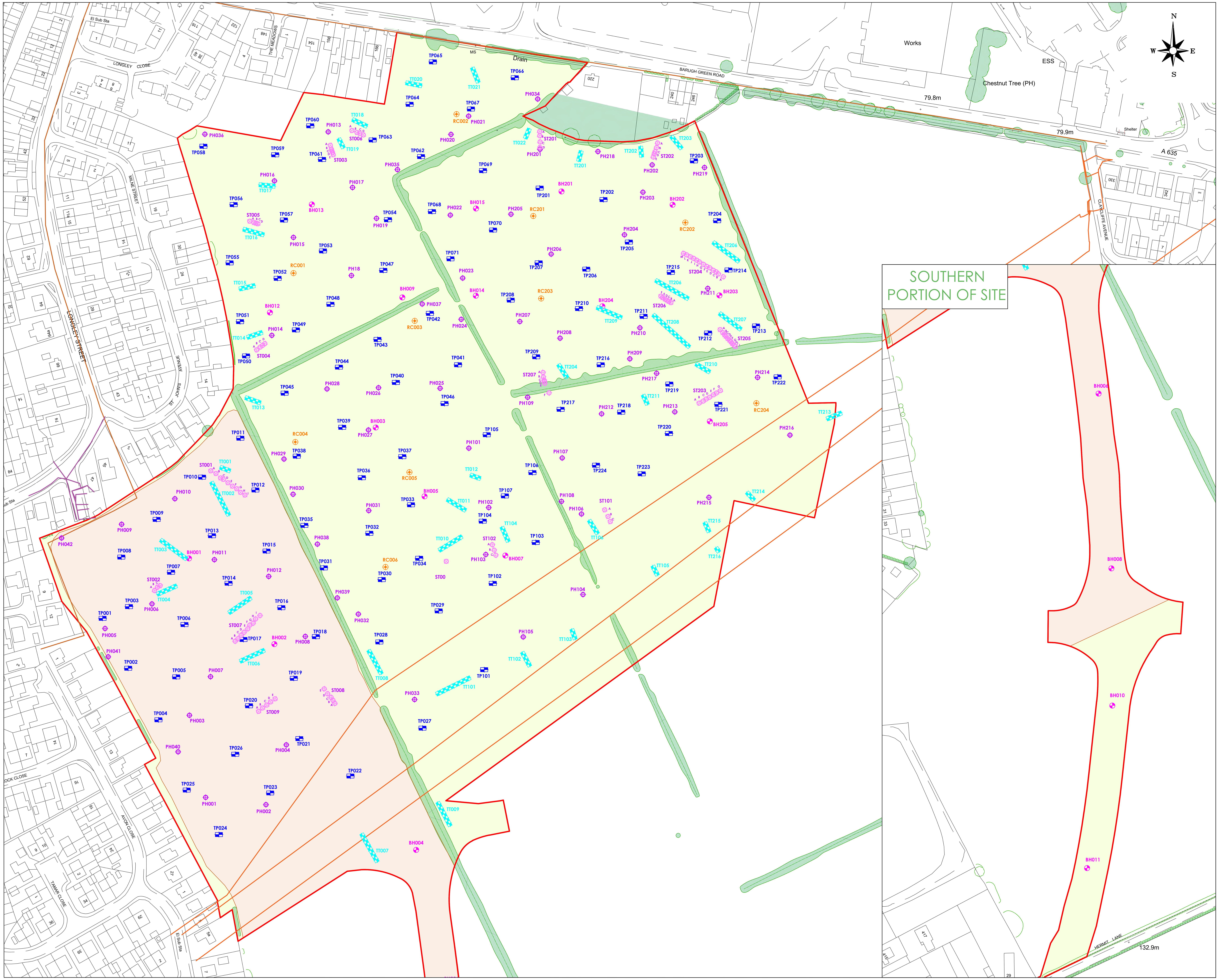

NOTES

- TRIAL PIT LOCATION
- TRIAL TRENCH LOCATION
- CABLE PERCUSSION BOREHOLE LOCATION
- ROTARY CORED BOREHOLE LOCATION
- PROBEHOLE LOCATION
- STITCH PROBEHOLE LOCATION
- GRASS & OVERGROWN AREAS
- ARABLE FARMLAND (STUBBLE)
- LINE OF OVERHEAD UTILITY
- APPROXIMATE SITE BOUNDARY

REV.	DESCRIPTION	DATE

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JOB TITLE

BARNSLEY WEST, LAND TRANSFER ONE

DRAWING TITLE

EXPLORATORY HOLE LOCATION PLAN

DRAWN	DATE	STATUS
GLM	23/12/2021	FOR COMMENT ☐ FOR APPROVAL ☐
CHECKED	DATE	DRAFT ☐ FINAL ☑
AG	23/12/2021	

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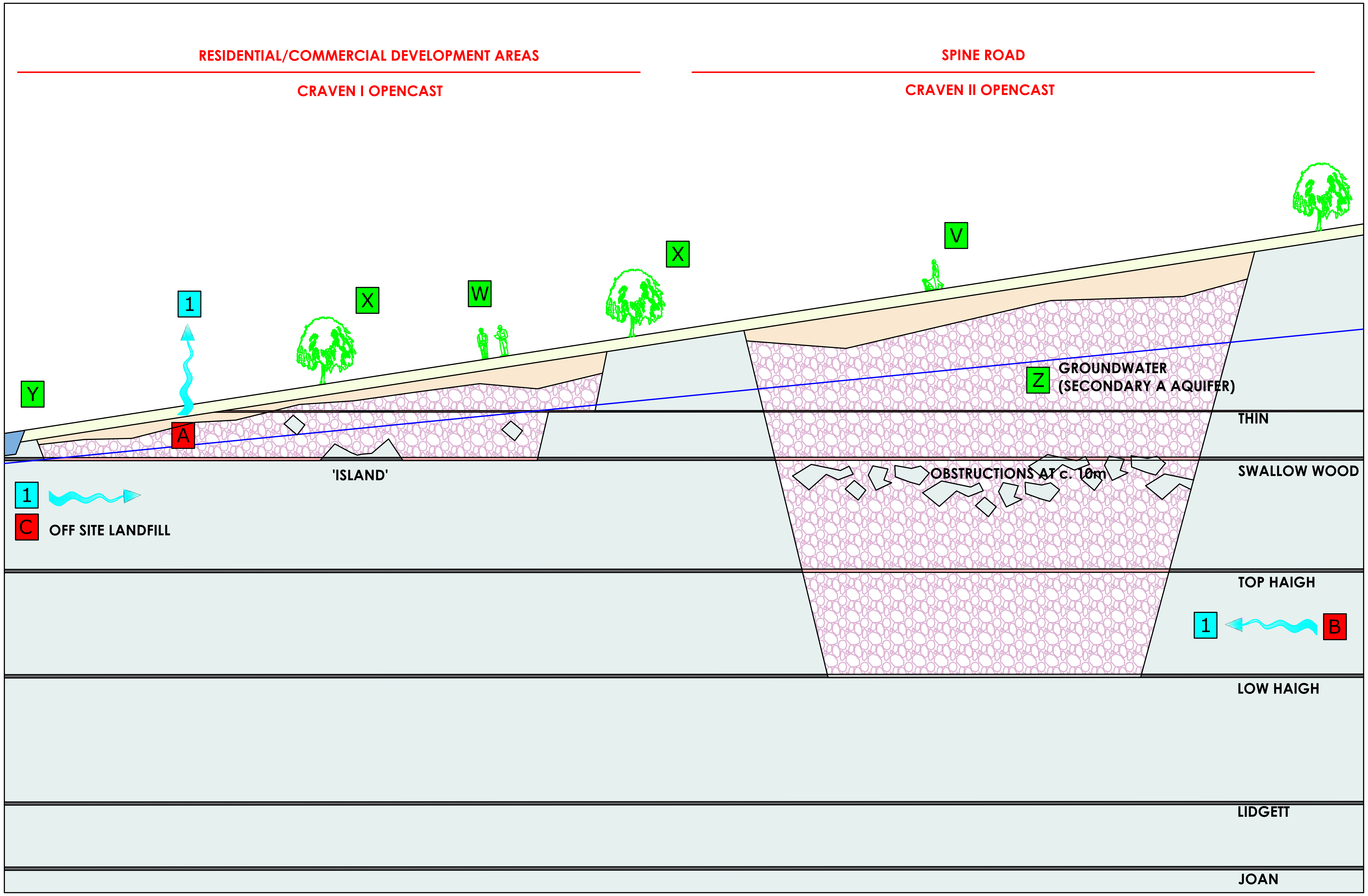

KEY
TOPSOIL
COHESIVE MADE GROUND
COHESIVE/GRANULAR OPENCAST BACKFILL
COAL
LOWER COAL MEASURES

SOURCES	
A	DEEP MADE GROUND (GAS)
B	COAL (GAS)
C	OFF SITE LANDFILL (GAS)

PATHWAYS	
1	MIGRATION OF GAS

RECEPTORS	
V	END USERS (RESIDENTS)
W	SITE WORKERS
X	VEGETATION
Y	SURFACE WATERS
Z	GROUNDWATER

NOTES

REV.	DESCRIPTION	DATE

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JOB TITLE

BARNSLEY WEST, LAND TRANSFER ONE

DRAWING TITLE

REVISED CONCEPTUAL SITE MODEL

DRAWN	DATE	STATUS
GLM	22/02/2022	FOR COMMENT ☐ FOR APPROVAL ☐
CHECKED: AG	DATE: 22/02/2022	DRAFT ☐ FINAL ☑

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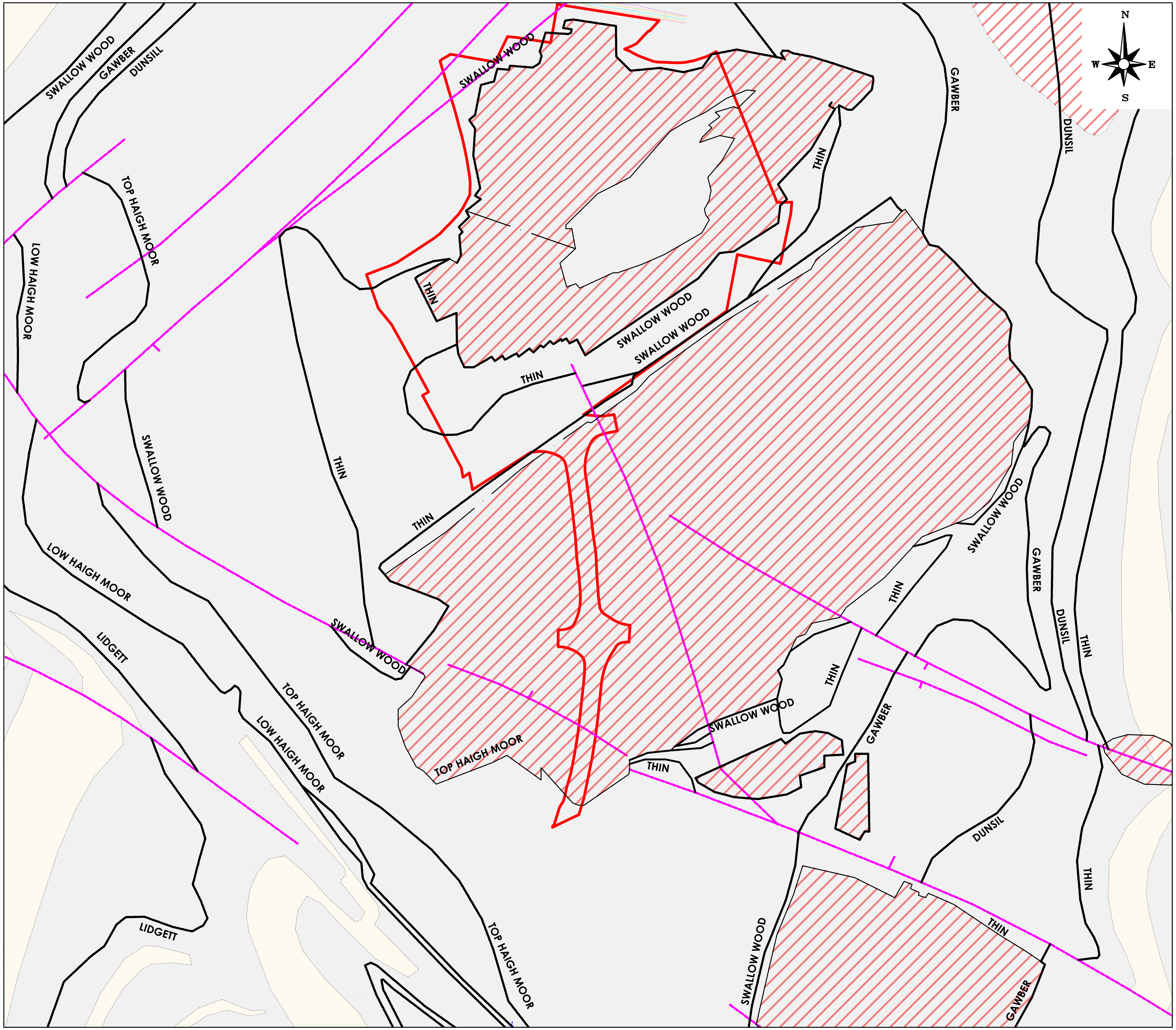

NOTES

- AREA OF MADE GROUND
- LOWER COAL MEASURES; INTERBEDDED MUDSTONE, SILTSTONE & SANDSTONE
- LOWER COAL MEASURES; SANDSTONE UNIT
- APPROXIMATE LINE OF FAULT
- APPROXIMATE COAL SEAM OUTCROP
- APPROXIMATE SITE BOUNDARY

REV.	DESCRIPTION	DATE

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JOB TITLE

BARNSLEY WEST, LAND TRANSFER ONE

DRAWING TITLE

SITE GEOLOGY

DRAWN	DATE	STATUS
GLM	06/10/2021	FOR COMMENT ☐ FOR APPROVAL ☐
CHECKED	DATE	DRAFT ☐
AG	06/10/2021	FINAL ☑

SCALE	SHEET	DRAWING NO.	REVISION
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