

# Land at Barnsley West, Pogmoor Land For Strata

Report no: 4454/1

Date: December 2022



## SUMMARY OF GEOENVIRONMENTAL ISSUES

<b>Job No.</b>	4454	<b>Site area/ha</b>	7 ha
<b>Client:</b>	Strata	<b>NGR:</b>	SE 323 068
<b>Site:</b>	Barnsley West, Pogmoor Land	<b>Nearest postcode:</b>	S75 2LH

The site is located off Farmhouse Lane in Pogmoor, Barnsley and currently comprises a large cropped arable field and a smaller grassed field which is used for livestock grazing.

About 65% of the total site area, and about 80% of the total development footprint, has been subject to opencast coal extraction through historical quarrying from outcrop and opencast in the 1950's/60's. Outside the opencast the Barnsley Coal Seam lies close to surface and has been extracted by underground workings which are considered to pose a risk to surface stability.

Lithos were commissioned by Strata to provide a geoenvironmental appraisal of the site, which it is understood is to be redeveloped with residential dwellings. Lithos' investigation included a review of 3<sup>rd</sup> party reports, the site's history and environmental setting, and a ground investigation comprising 47 trial pits, 23 trial trenches, 10 cable percussion boreholes, three rotary cored boreholes, 29 rotary open probeholes and 13 groups of stitched rotary open 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, including the whole of the development footprint and typically comprises a veneer of Topsoil over Cohesive and Granular Opencast Backfill with some localised areas of Burnt Shale or Ash & Clinker, most notably across the west. The depth of made ground is predominantly dictated by the footprint of the former opencast which is shallowest (around 4.0m in the northwest to around 15.5m in the southeast).
Natural ground	Encountered outside areas of opencast comprising a veneer of Topsoil and Residual Soils over Coal Measures bedrock (interbedded sandstones, siltstones & mudstones).
Contamination	Localised Ash & Clinker has been found to be slightly contaminated with inorganic determinands and should be isolated from end users following development. Topsoil is chemically suitable for re-use.
Mining & quarrying	About 65% of the site (about 80% of the development footprint) has been subject to historical opencast coal extraction to depths of up to c. 15.5m. Beyond the areas of opencast, notably to the east, the site is underlain by shallow coal workings in the Barnsley Coal Seam which are considered to pose a risk to surface stability.
Hazardous gas	Site lies in an area where between 3% & 5% of homes are estimated to be above the action level. Monitoring wells have been installed in 20 boreholes/probeholes and monitoring for hazardous gasses is ongoing. A Hazardous Gas Risk Assessment will be issued on completion of the monitoring in May 2023.
Preparatory works	Topsoil strip & stockpile. Regrade of site levels to achieve required development platforms & levels. Turnover of the uppermost 3.0m of made ground across the development footprint & re-engineering of soils may allow for the adoption of rafts, semi-raft or reinforced beam foundations. Consolidation of underground workings where they underlie proposed plots or adoptable highways.
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.
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. 35mm and c. 55mm. In areas of typical backfill depths, the potential range of total settlement is between c. 30mm and c. 45mm. 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).

*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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<b>Site:</b>	Barnsley West, Pogmoor Land	<b>Nearest postcode:</b>	S75 2LH

Issue	Remarks
Groundwater & excavations	Excavations should remain dry in the short term. Excavations should remain relatively stable in the short term, however significant overbreak of excavation walls should be allowed for, notably where oversized materials are encountered.
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 abnormalities relating to geoenvironmental issues at the site are:

- Regrade of site levels to those specified in the final geotechnical design.
- Turnover of the uppermost 3.0m of made ground beneath the development footprint and re-engineering of the made ground to enable the use of raft/reinforced foundations.
- Consolidation of shallow mineworkings outside of the areas of opencast by means of drill & grout.

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).

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## APPENDICES

### Appendix A - General notes

01	Environmental setting
02	Ground investigation fieldwork
03	Geotechnical testing
04	Contamination laboratory analysis & interpretation
05	Hazardous gas

### Appendix B - Drawings

Drawing	Revision	Title
4454/1	-	Site location plan
4454/2	-	Proposed site layout
4454/3	-	Site features
4454/4	-	Site photographs
4454/5	-	Preliminary conceptual site model
4454/6	-	Exploratory hole locations
4454/7	-	Revised conceptual site model
4454/8A	-	Coal Authority abandonment plan ref. 5822
4454/8B	-	Coal Authority abandonment plan ref. 9196
4454/8C	-	Coal Authority abandonment plan ref. 11520
4454/8D	-	Coal Authority abandonment plan ref. FGB6
4454/8E	-	Coal Authority abandonment plan ref. FGB137
4454/8F	-	Coal Authority abandonment plan ref. DGB148
4454/8G	-	Coal Authority abandonment plan ref. N.E.145
4454/9	-	Geology & mining features
4454/10	-	3 <sup>rd</sup> party exploratory hole locations
4454/11	-	Line & location of buried highwalls
4454/12	-	Thickness of made ground (mbgl)
4454/13	-	Depth to natural ground (mAOD)
4454/14	-	Proposed site layout & buried highwall
4454/15	-	Line & location of buried highwalls & zone of differential settlement influence

### Appendix C - Commission

### Appendix D - Historical OS plans

### Appendix E - Search responses

From	Date	Content
Landmark	25/08/2022	Environmental search data
Coal Authority	25/08/2022	Mining report

### Appendix F to J - Exploratory records

Appendix F	TP01 to TP47
Appendix G	BH01 to BH10
Appendix H	PH01 to PH29
Appendix I	ST01 to ST13
Appendix J	RC01 to RC03

**Appendix K - Chemical test results**

**Appendix L - Geotechnical test results**

**Appendix M - Gas monitoring results**

## 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 pages 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.

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.

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.

Lithos standard terms and conditions apply to the report, a copy of the terms and conditions is available on request or can be found with our proposal in Appendix C.

**GEOENVIRONMENTAL APPRAISAL**  
**of land at**  
**BARNSELEY WEST, POGMOOR LAND**

## **1 INTRODUCTION**

### **1.1 The commission and brief**

1.1.1 Lithos Consulting Limited were commissioned by Strata to carry out a geoenvironmental appraisal of land at the parcel of land off Farm House Lane in Pogmoor, Barnsley.

1.1.2 The current area occupies 7.2 hectares in the southeast of a wider development area (c. 80 hectares) which is referred to as Barnsley West and is called Barnsley West, Pogmoor Land. In total the current area of interest (Pogmoor Land) makes up about 8% of the total Barnsley West development area.

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 47 trial pits, 23 trial trenches, 10 cable percussion boreholes, three rotary cored boreholes, 29 rotary open probeholes and 13 groups of stitched 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 consideration is being given to redevelopment of the site with 147 'traditional' two/three storey domestic dwellings with associated gardens, POS and adoptable roads and sewers.

1.2.2 A site layout has been provided by Strata (Pogmoor Parcel, Farm House Lane, Barnsley, S75 2LH, Viability Layout – Option 2', drawing ref. 21-CL4-SEGC-PBWO2-01 rev. C, dated 26/07/2022) which is reproduced as Drawing 4454/2 in Appendix B to this report.

## 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 4454/1 presented in Appendix B to this report. Site details are summarised in the table below:

Detail	Remarks
Location	2.2km west of Barnsley town centre
NGR	SE 323 068
Approximate area	7.2 hectares (17.8 acres)
Known services	Underground sewer (far north) & overhead communications (far-south)

## 2.2 Site features

2.2.1 Lithos completed a walkover survey of the site on the 13<sup>th</sup> September 2022.

2.2.2 Existing salient features, at the time of the walkover are presented on Drawing 4454/3 in Appendix B to this report and summarised in the table below:

Feature	Remarks
Current Access	Off Farm House Lane (in the south)
Topography	Slopes down to the north with steepest slopes in the north western corner.
Approximate areas	55,000m <sup>2</sup> ploughed arable farmland. 17,000m <sup>2</sup> grassland & overgrown areas
Nature of boundaries	Northwest – post & wire fencing, mature hedgerows & trees. Northeast & east – garden fences & hedgerows. South – garden fences & mature hedgerows & trees West – mature hedgerows, shrubs & post & wire fencing.
Surrounding land uses	Northeast, south & east – residential dwellings, associated gardens, estate roads etc. Northwest – Gawber primary school. West – grazing land.

2.2.3 A selection of site photographs is included on Drawing 4454/4.

2.2.4 The site can be divided into two areas based on usage and features. The majority of the site (centre, south & east) comprises two fields of arable farmland which had been ploughed awaiting crop sowing at the time of walkover. (Note; during Lithos' intrusive investigation in October 2022, see Section 10, the site had been levelled and seeded with an arable winter crop). The northwest comprises a single grassed field which was being grazed by horses.

2.2.5 Access can be gained to the ploughed field off Farm House Lane which runs east to west along the southern boundary. Access to the grassed field is available through adjacent fields to the west. No access is currently available between the ploughed field and the grassed field; the boundary between the two areas is secured by a post and wire fence and mature hedgerows.

2.2.6 A c. 0.6m deep drainage ditch (dry at the time of walkover) runs north to south through the centre-east and divides the two ploughed fields.

2.2.7 The general topography of the site slopes down to the north with a typical gradient of around 1v:20h. However, the north western corner slopes more steeply to the northwest with gradients of up to 1v:2.5h.

2.2.8 Land beyond the northern boundary slopes steeply up to the north resulting in the northern boundary comprising a valley.

2.2.9 Steeper slopes in the northwest were noted to be hummocky underfoot.

2.2.10 Several mature trees grow in the north western corner.

2.2.11 The northern boundary is overgrown with mature trees and shrubs. A surface watercourse flows west along the northern boundary and a second watercourse flows north just beyond the western boundary.

2.2.12 A public footpath runs along the western boundary.

### 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.

3.2 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. Well in centre of northern boundary. Footpaths/tracks cross the east & west.	Predominantly comprises farmland. Gawber village from 250m north. Hermit Wood immediately beyond north eastern boundary. Farm House Lane runs east to west along southern boundary. Buildings with attached yards/gardens immediately beyond southern boundary.
1891	Well no longer shown.	<b>Old shaft</b> shown in yard area c. 25m south.
1906	No significant changes.	No significant changes.
1931	Possible <b>earthworks/embankment</b> shown in west. Wet/marshy land shown in northwest.	Hermit wood predominantly shown as marshy land with occasional small buildings. Farm House Colliery with some earthworks & drift (adit) from 200m southeast.
1938	No significant changes.	Development of Gawber and Barnsley to the north & east.
1956		Farm house colliery shown as disused.
1961	Majority of site area shown as <b>opencast working</b> . Earthworks & marshy land no longer shown.	Further extensive opencast workings from 300m northeast. Further development of Barnsley to the east including dwellings, chapel & school from 100m east.
1973	<b>Opencast workings no longer shown</b> . Occupied by open fields.	No significant changes.
1983	No significant changes.	Residential dwellings developed immediately beyond southern & eastern boundaries. School developed immediately beyond northern boundary.
1999 (aerial photo)	North western area occupied by rough grasses & occasional shrubs & trees. Remainder of site comprises cropped arable farmland.	Residential dwellings with associated gardens, roads etc immediately south & east. Grassed fields to the west.
2022 (aerial photo)	No significant changes.	No significant changes.

3.3 The surrounding villages of Higham, Barugh Green and Gawber predominantly housed colliery workers throughout the 19<sup>th</sup> and early 20<sup>th</sup> centuries. Collieries were located across the wider surrounding area including Higham Colliery (c. 750m west, operated from 1854 to 1898), Beevers Colliery (c. 400m east, operated from 1888 to 1925) and Dodworth Colliery (c. 1km south, operated from 1855 to 1899).

3.4 Anecdotal evidence from surrounding residents suggests that a portion of the site may have been subject to underground combustion of soils or shallow coal recently after restoration of the opencast was completed. Treatment of the combustion comprised excavation of material from part of the site which were seen to smoke on exposure to the surface. Excavations were later backfilled to restore site levels and enable ongoing use of the land for agriculture.

- 3.5 Residents also suggested that some tipping of general spoil/soils took place at the site on completion of the opencasting, and consequently the site may include soils/materials which are not 'site-won' (backfill of the opencast would generally be expected to comprise site won arisings).
- 3.6 It should be noted that the Coal Authority do not record any known cases of underground combustion at this site, and there is no record of deposition of spoil, waste etc recorded in the Landmark Repot (see Section 4 below).

## 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, the BGS and the Environment Agency 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 87	Drift soils – none mapped; likely veneer of Residual Soils (gravelly clay) beyond areas of opencast. Solid (bedrock) – Middle Coal Measures (interbedded mudstones, siltstones & sandstones). Shallowest coal seam – Barnsley Coal & Thin (un-named) coals outcrop on site. Faults – fault runs east to west across the north of the site & downthrows to the south. Strata dip is 3° to the east.
Mining	Coal Authority	This site is located within a Coal Mining Development High Risk Area. Much of the site's area has been subject to opencast coal extraction. Recorded mine entries are present in the far-west. Shallow underground workings anticipated. Further details in Section 5.
Quarrying	Historical OS plans	Much of the site's area has been subject to opencast coal extraction, as has land to the northwest; see Section 5.
Landfills	Envirocheck Report Public Health England	No known landfills within 250m.
Radon		Site lies in an area where between 3% & 5% of homes are estimated to be above the action level. See Section 14.
Hydrogeology		Groundwater Source Protection Zone? None beneath site or wider area. Aquifer? Secondary A Aquifer (Solid). Groundwater abstractions? None within 1,000m. Soil leaching potential – Medium. Pollution incidents? None of significance.
Hydrology	Environment Agency electronic open data via QGIS	Nearest watercourse – un-named drainage ditch crosses the east. Un-named drainage ditch flows north along western boundary (flow into R. Dearne c. 2.1km north. Catchment of Cawthorne Dyke to R. Don & R. Rother). Water quality moderate ecological & failing chemical. Pollution incidents? Discharge of foam/soap suds to surface waters in centre-west of site August 1994 – Cat 3 minor incident. Abstractions? None within 1,000m. Discharge consents? 3 consents within 100m; all to the south & west comprising discharge of treated sewage/effluent to surface watercourses (tributaries of R. Dearne, operated by private residences & Yorkshire Water).
Flood risk	Environment Agency electronic open data via QGIS	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 14 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.

4.1.2 Geological features, including coal outcrops and faults are shown on Drawing 4454/9 in Appendix B.

## 4.2 Ground instability

4.2.1 An area of superficial landslip within the Coal Measures sandstone bedrock is shown along the north western edges of the site. At this stage it is unclear whether the slip is the result of oversteepening of slopes in the northwest of the site (a result of post-glacial erosion) or if the instability is driven by historical underground mining (see Section 5) decreasing the stability of the area.

4.2.2 The areas of landslip are shown on Drawing 4454/9.

4.2.3 Examination of the proposed layout (reproduced on Drawing 4454/2) shows that no development is proposed in the northwest. However, should Strata carry out any levels regrade or construction in this area, including placement of infrastructure, drainage, etc, then consideration should be given to an assessment of the long and short term stability of slopes in the northwest, including the potential impact of construction works and stabilising remediation works.

## 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 and further extraction is unlikely to be viable.

## 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.

## 4.5 Lithos' experience

4.5.1 Lithos has already completed a ground investigation across the LT1 area of the wider Barnsley West development site (c. 21.4 hectares located about 750m to the north) which comprised the excavation of 102 trial pits, 44 trial trenches, 20 cable percussion boreholes, to rotary cored boreholes, 70 rotary open probeholes and 17 stitched lines of probeholes.

4.5.2 The findings of Lithos' investigation are presented in our Report ref. 3104-1, dated March 2022.

4.5.3 Report 3104-1 focused on a separate area within the wider development which was underlain by a separate area of opencast (the Craven I site). However, given that opencasting at Craven I took place at a similar time and within similar geology to that beneath the current area of interest it is likely that ground conditions are analogous and a brief summary of Lithos' findings is given below.

4.5.4 About 60% of LT1 has been subject to opencast coal extraction targeting the Swallow Wood, Top Haigh and Low Haig Coal Seams (note these are not the same seams present beneath the current area of interest). No evidence of underground workings was encountered, however this is unlikely to be the case for the Pogmoor Land.

4.5.5 Backfill within the opencast comprised a veneer of Topsoil and a 'restoration layer' of Cohesive Made Ground (reworked Residual Soils) over Cohesive and Granular Opencast Backfill (clay with gravel, cobbles and boulders of mudstone) to a depth of up to 12.6m.

- 4.5.6 Natural ground comprised a veneer of medium to high strength Residual Soils (outside former opencast) over Coal Measures mudstone bedrock.
- 4.5.7 No evidence of gross contamination was encountered and Topsoil was considered to be chemically suitable for re-use (although visually quite clayey and of poor quality).
- 4.5.8 Foundations were expected to comprise 'traditional' strip footings outside of areas of opencast with competent Residual Soils or Coal Measures bedrock being the founding stratum. Inside of areas of opencast foundations were expected to comprised reinforced/stiffened strip footings and or rafts founding in re-engineered Opencast Backfill. Alternatively piled foundations might be considered.

## 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 Section 11.8) provides the necessary mining risk assessment required by the proposed planning application.
- 5.1.2 About 80% of the total site area is located in a Coal Authority Development **High Risk Area** – an area with specific mining legacy risks to the surface including mine entries, shallow coal workings etc. The remaining c. 20% of the site is located in a Development **Low Risk Area** – within the coalfield but no known defined risks have been identified; 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 4454/9.

#### 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:
- **Barnsley Coal: Outcrops in the centre-west** and along the western boundary and exposed in the sides of the former opencast, comprising a band of coal of between 2.9m and 3.1m thickness.
  - **Thin (un-named) Coal: Outcrops in the northwest** comprising a thin band of coal of low economic value.
  - **Dunsil Coal:** Outcrops c. 50m beyond the north western boundary with a thickness of 0.46m to 0.81m, and lies about 14m below the Barnsley Coal.
  - **Thin (un-named) Coal:** A thin band of coal of low economic value about 24m below the Barnsley Coal.
  - **Gawber Coal:** With a thickness of about 0.72m, about 32m below the Barnsley Coal.
  - **Swallow Wood Coal:** With a thickness of between a 0.3m and 1.15m, about 50m below the Barnsley Coal.
- 5.2.3 Seam outcrops are shown on Drawing 4454/9.

- 5.2.4 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 below the Swallow Wood Coal.
- 5.2.5 Geological mapping suggests that about 60% of the total site area is occupied by backfilled coal opencast sites.
- 5.2.6 The BGS report notes that the Swallow Wood Coal was worked from the Barugh Colliery, which was located c. 1.3km north as a 'house coal'. The Dunsil was worked locally (although not especially commonly) for a 'house coal'. The Barnsley Coal is the most important coal in this part of the coalfield, being consistently about 2.5m thick and worked exhaustively for use as a steam and manufacturing coal.
- 5.2.7 It should 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

- 5.2.8 A Coal Authority Consultants Mining Report has been obtained. The mining report states that:
- There are known underground workings in 6 seams of coal beneath this site. These seams are the;
    - Barnsley Coal, 4m bgl, extraction thickness up 2.97m, mined 1900 to 1926.
    - Flockton Thick Coal, 132m bgl, extraction thickness 0.76m, mined 1950 to 1954.
    - Top Fenton Coal, 171m bgl, extraction thickness 0.91, mined 1932 to 1936
    - Parkgate Coal, 200m bgl, extraction thickness 1.37m, mined 1921.
    - Silkstone Coal, 261m bgl, extraction thickness 1.76m, mined 1933 to 1977.
    - Whinmoor Coal, 349m bgl, extraction thickness of 1.10m, mined 1969 to 1977.
  - There are probable unrecorded shallow workings (*i.e. there are coal seams of economic value at shallow depth which are likely to have been worked from underground methods, although the CA hold no record of known workings*).
  - There are 7 known mine entries located within the site's boundary and a further 7 in the immediate surrounding area.
  - The Barnsley and Dunsil Coal Seams outcrop within the site's boundary.
  - Opencast coal extraction has taken place from one opencast site within the site's boundary.
  - There are no CA managed tips, mines gas emissions or mine water treatment schemes within 500m of the site's boundary.
  - The property is in an area where notices to withdraw support have been given in 1976. This entitlement to withdraw support has not been cancelled.
- 5.2.9 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

5.2.10 A total of 7 coal mining abandonment plans have been provided by the Coal Authority. The plans are reproduced on Drawings 4454/8 A to G and key findings from each plan are summarised in the table below:

Plan ref.	Drawing no.	Date	Coal seam & thickness (m)	Location of workings within site	Mine entries?	Remarks
5822	4454/8A	March 1912	Barnsley (2.84m)	Centre-south	Old shaft in centre-south. Adit at south eastern boundary & 3 further adits just beyond south eastern boundary.	Underground workings. Remarks state old workings present in the centre-south of the site. Remark that adit was driven through coal & goaf (backfilled old workings).
9196	4454/8B	Dec 1926	Barnsley (2.92m)	Centre & south	Adits along western periphery.	Underground workings including old workings. Coal shown as being quarried where close to outcrop.
11520	4454/8C	1917	Barnsley (2.92m)	Far south	Day hole in south.	Coal shown as being quarried where close to outcrop in 1926.
FGB6	4454/8D	-	(not stated – likely Barnsley)	Centre & south	Day holes along south & western periphery.	Fault crosses centre of site. Day holes & adits shown in west, but no details given in relation to areas worked.
FGB137	4454/8E	-	(not stated – likely Barnsley)	-	-	No workings shown beneath site; extensive workings to the east.
FGB148	4454/8F	-	(not stated – likely Barnsley)	south	Day holes along western periphery.	Pillars and galleries readily apparent.
NE415	4454/8G	1960	Barnsley (2.67m)	Centre, north & south.	-	Plan shows opencast extraction of coal. Plan states that c. 80% of coal had already been removed from underground methods. Old workings shown to extend beyond the opencast footprint to the east.

5.2.11 Based on examination of the above plans it is readily apparent that the Barnsley Coal Seam has been heavily worked by underground methods beneath the centre, south and east of the site as well as to outcrop in the west. The north and northwest does not appear to have been worked underground (this area lies beyond the Barnsley Coal outcrop), possibly due to the presence of a fault although there may well be workings beneath this area which the Coal Authority have no records of.

5.2.12 Abandonment Plan ref. NE415 records the extent of opencast coal extraction which covered the majority of the site's area, although not the northwest. Based on contours shown on the plan the base of the opencast lies at between about 125mAOD and 123mAOD. This suggests a maximum depth of opencast of about 17mbgl.

5.2.13 Several plans also show quarrying of the Barnsley Coal from outcrop towards the centre of the site and it is likely that coal between the opencast and the outcrop has been removed from surface by means of unlicensed and localised quarrying.

- 5.2.14 The approximate extent of quarrying appears to correlate with the line of earthworks shown on historical OS mapping in 1931 (see Section 3); the earthworks likely represent a highwall or backfilling of excavations.
- 5.2.15 Underground workings in the Barnsley Coal have been removed during opencast coal extraction, however beyond the areas of opencast they are almost certainly still in place beneath the ground.

### 5.3 Mine Entries

- 5.3.1 Of the 14 known mine entries recorded by the Coal Authority, 7 are located within the site's boundary and 7 are located in the surrounding area. A summary of mine entries is presented below, and the locations of the entries are shown on Drawing 4454/9.

Shaft Ref.	Co-ordinates	Entry type	Location	Remarks
432406-011	432302 , 406721	Adit	Southwest.	-
432406-014	432413 , 406745	Shaft	Centre-south.	Likely removed during opencasting.
432406-015	432298 , 406795	Adit	West.	-
432406-016	432305 , 406777	Adit	West.	-
432406-018	432324 , 406686	Adit	Southwest.	-
432406-019	432349 , 406680	Adit	Southwest.	-
432406-017	432280 , 406747	Adit	Immediately beyond western boundary.	-
432406-002	432364 , 406628	Shaft	20m southwest.	Unlikely to pose a significant risk to development.
432406-012	432423 , 406995	Shaft	31m north	Unlikely to pose a significant risk to development.
432406-013	432452 , 406972	Shaft	20m north	Unlikely to pose a significant risk to development.
432406-020	432507 , 406628	Shaft	55m southeast.	Searched for in 2007, but not located. Unlikely to pose a significant risk to development.
432406-021	432509 , 406615	Shaft	65m southeast.	Unlikely to pose a significant risk to development.
432406-031	432519 , 406627	Shaft	65m southeast.	Unlikely to pose a significant risk to development.
432407-019	432435 , 407008	Shaft	43m north.	Unlikely to pose a significant risk to development.

- 5.3.2 The Coal Authority have minimal data relating to any of the above shafts and adits.
- 5.3.3 Of the 7 entries which are located off-site only one (ref. 432046-017) is expected to pose a potential risk to development and the line of the adit should be located during the ground investigation.
- 5.3.4 The 7 mine entries located on site do pose a potential risk to the proposed development and should be located during the ground investigation with subsequent treatment prior to/during construction works.

### 5.4 Ironstone

- 5.4.1 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.
- 5.4.2 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.
- 5.4.3 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.

- 5.4.4 Consequently, it cannot be discounted that ironstone may have been extracted in underground workings located just above the Swallow Wood Coal.
- 5.4.5 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.
- 5.4.6 However, given the significant depth to the Swallow Wood Coal, and the thickness of competent cover present it is considered unlikely that any ironstone workings would pose a significant risk at this site.

## 5.5 Summary of coal & mining

- 5.5.1 The Barnsley Coal (around 2.9m thick) underlies this site at shallow depth and has been heavily worked in the surrounding area. CA data shows that the Barnsley Coal has been worked beneath this site from both underground and opencast methods.
- 5.5.2 Seams beneath the Barnsley Coal are considered to lie deep enough to not pose a risk to surface stability even if worked.
- 5.5.3 However, any underground workings in the Barnsley Coal (where not removed by quarrying/opencast) are considered to pose a significant risk to surface and to the proposed development.
- 5.5.4 Opencast extraction of the Barnsley Coal from outcrop to the eastern periphery poses a significant constraint to the proposed development; see Section 6 below.
- 5.5.5 Mine entries comprise several adits and a shaft located along the western edge and the centre-south respectively. At this stage it seems likely that mine entries have been removed by opencasting and quarrying, however if any entries remain this poses a significant potential risk to surface and the proposed development.
- 5.5.6 An intrusive mining investigation is required to determine the potential risk posed to the proposed development; see Section 11.8.

## 6 POTENTIAL ISSUES ASSOCIATED WITH DEEP BACKFILL

### 6.1 Opencast

- 6.1.1 It is considered likely that the backfill within the Pogmoor opencast 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.
- 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. 10 to 15m) anticipated. Fill thicknesses mean that consideration could 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 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 reports cover a larger area than the current site; land to the north and west (Barnsley West LT1 & LT2) and an area of commercial development to the southwest.

7.1.3 Third party exploratory hole locations are shown on Drawing 4454/10.

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 18.

### 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 Pogmoor Land 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, with one borehole (BH05) falling 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 area of interest 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 borehole is relevant to this site; BH05, which encountered made ground comprising clay with gravel and cobbles of mudstone and rare brick and coal to a depth of 8.3m (where the BH refused in siltstone/sandstone bedrock).

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 the current area of interest as well as land to the north, west 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, although given JPGs scope covered a much larger area much of the information is not relevant to the current site.
- 7.3.4 JPG highlight that localised ironstone mining could have taken place, most notably 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 the current area of interest, 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, 10 boreholes and two trial pits were located in the current area of interest.
- 7.4.2 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 the current area of interest varied between 2.0m to 11.5m deep and typically comprises a veneer of clayey Topsoil over Colliery Spoil (clay with gravel, cobbles & occasional boulders of Coal Measures bedrock). Locally areas of Ash were described, however based on the site's setting and field descriptions this could actually be Burnt Shale.
- 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 area of interest.
- 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 entire site.

## 7.5 Report 4

### Scope of works

- 7.5.1 JPG's report relates to an area of c. 70 hectares, but only the westernmost c. 40% of the current area of interest.
- 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 data presented in Report 3.
- 7.5.4 Several mine entries were identified, excluding those located within the current area of interest (which lie beyond JPG's site boundary).
- 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.

## 7.6 Lithos comments

- 7.6.1 All 4 of the above reports cover a significantly larger area than the current site and consequently include ground related data and interpretations which are not of significance. However, data relating to land outside of this site 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 the current area of interest.
- 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.

### Summary table of 3<sup>rd</sup> party exploratory holes

Rept 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	TP111	2.9	>2.9	0.2	0.8	>2.9	-	-	-	-	Farm House Lane	Unstable from 1.5m.
	TP115	3.0	>3.0	0.25	-	>3.0	-	-	-	-		-
JPG	BH111	30.0	-	-	-	-	2.0	2.0	28.0	3.8 – 6.3, 20.3 – 20.6 & 25.1 – 25.4	Farm House Lane	No evidence of u/g workings.
	BH111A	9.0	5.7	0.3	-	5.8	-	5.7	3.3	5.7 – 7.4		-
	BH111B	20.5	10.1	0.3	-	1.1	-	10.1	10.4	-		Occasional boulders in MG.
	BH111C	9.0	3.5	0.2	1.5	3.5	-	3.5	5.5	3.5 – 4.9		-
	BH112	15.0	11.4	0.2	-	11.4	-	11.4	3.6	-		MG inc. ash (possible burnt shale)
	BH113	15.0	11.5	0.2	1.5	11.5	-	11.5	3.5	-		Extensometers installed.
	BH113A	8.0	5.0	0.2	-	5.0	-	5.0	3.0	-		-
	BH113B	7.0	4.0	0.2	1.5	4	-	4.0	3.0	-		-
BH124	30.0	2.0	0.2	-	2.0	-	2.0	28.0	16.5 – 19.5	-	No evidence of u/g workings.	
East-wood	BH05	18.6	8.3	0.25	0.9	8.3	-	8.3	0.3	-	Farm House Lane	Located roughly in the centre of the current area of interest.

## 8 PRELIMINARY CONCEPTUAL SITE MODEL

- 8.1.1 The site comprises arable farmland and is essentially greenfield. However about 65% of the site (and about 80% of the development footprint) has been subject to opencast coal extraction with subsequent backfilling of all excavations. Based on the findings of 3<sup>rd</sup> party investigations, as well as Lithos' experience across the wider site, it appears that excavations were backfilled with site-won arisings (reworked Coal Measures bedrock) rather than imported soils, landfill waste etc. However, in the absence of a detailed ground investigation this cannot be guaranteed.
- 8.1.2 A preliminary conceptual site model, presented as Drawing 4454/5 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 8, anticipated ground conditions are expected to comprise:

Anticipated condition	Remarks
Made ground	Made Ground up to c. 17m deep cross area of opencast/coal quarrying comprising reworked Coal Measures soils & bedrock.
Natural soils	Veneer of Topsoil & Residual Soils (gravelly clays).
Bedrock	Lower Coal Measures (interbedded mudstones, siltstones & siltstones) from shallow depth (where outside of opencast).
Mineworkings	Barnsley Coal is expected to be heavily worked by underground methods (c. 80% extraction) outside of opencast & wholly removed inside of opencast.
Groundwater	Anticipated at depth within bedrock (Secondary A Aquifer), flowing to the north.

- 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	<ol style="list-style-type: none"> <li>Made Ground</li> <li>Agriculture</li> <li>Mineworking</li> </ol>	<ol style="list-style-type: none"> <li>Made ground backfill within former opencast.</li> <li>Discharge of chemicals, burial, spreading have all taken place on agricultural land.</li> <li>Potential generation &amp; migration of hazardous gasses.</li> </ol>
Potential off-site contamination sources	<ol style="list-style-type: none"> <li>Adjacent deep made ground</li> <li>Off-site mineworkings</li> </ol>	<ol style="list-style-type: none"> <li>Generation &amp; migration of hazardous gasses.</li> <li>Generation &amp; migration of hazardous gasses.</li> </ol>
Potential geotechnical hazards	<ol style="list-style-type: none"> <li>Deep made ground</li> <li>Buried highwalls</li> <li>Shallow mineworkings</li> <li>Mine entries</li> </ol>	<ol style="list-style-type: none"> <li>Potential for settlement, oversized obstructions, excavation instability.</li> <li>Differential settlement across highwalls.</li> <li>Outside areas of opencast.</li> <li>Along the western periphery.</li> </ol>
Other potential constraints	<ol style="list-style-type: none"> <li>Steep slopes</li> </ol>	<ol style="list-style-type: none"> <li>Northwest has moderately steep slopes &amp; BGS mapped instability.</li> </ol>

## 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 45 trial pits	To determine the general nature of soils underlying the site, including the: <ul style="list-style-type: none"> <li>• Nature, distribution and thickness of made ground.</li> <li>• Nature, degree and extent of contamination.</li> <li>• Proportion of undesirable elements e.g. biodegradable matter, foundations etc.</li> <li>• Suitability of the ground for founding structures and highways.</li> </ul>
About 25 trial trenches	To determine the line and nature of buried highwalls around the opencast edges.
10 cable percussion boreholes	To retrieve geotechnical data and samples from depth, to enable description of made ground at depth and to install monitoring wells in order to: <ul style="list-style-type: none"> <li>• Monitor for hazardous gas.</li> </ul>
3 rotary cored boreholes	To retrieve samples of bedrock from the opencast base in order to enable detailed logging and retrieval of geotechnical samples.
About 20 rotary open probeholes	To determine the depth and profile of the opencast. To determine the depth to coal seams outside and beneath the opencast and to determine the presence and nature of any underground workings. To install monitoring wells in order to: <ul style="list-style-type: none"> <li>• Monitor for hazardous gas.</li> <li>• Determine groundwater levels and assess flow direction.</li> </ul>
About 10 groups of stitched rotary open probeholes	To determine the line and profile of buried highwalls.

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 9 above. A nominal 50m grid spacing was proposed. 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 9.2 above.

### 10.2 Exploratory hole location constraints

10.2.1 No access was available over the line of an underground sewer which crosses the northeast of the site.

10.2.2 No access was available in the far-northeast due to steeply sloping topography.

### 10.3 Scope of works

10.3.1 Fieldwork was supervised by Lithos between the 30<sup>th</sup> September and the 14<sup>th</sup> October 2022 and comprised the exploratory holes listed below:

Technique	Exploratory holes	Final depth(s)	Remarks
Trial pitting (machine dug)	TP 01 to TP47	2.0m to 4.7m	Hand vane tests undertaken in cohesive soils.
Trial trenching (machine dug)	TT01 to TT23	1.2m to 4.4m	Trenches advanced across the inferred line of highwalls based on CA plans.
Cable percussion boreholes	BH01 to BH10	3.4m to 15.5m	SPT tests undertaken & undisturbed samples retrieved at c. 1.0m intervals. Monitoring wells installed.
Rotary cored boreholes	RC01 to RC03	13.2m to 19.4m	Samples of rock submitted for strength testing.
Rotary open probeholes	PH01 to PH29	8.3m to 54.0m	Monitoring wells installed in 10no. PHs.
Groups of stitched probeholes	ST01 to ST13	6.0m to 18.0m	Stitches advanced across the inferred line of highwalls based on CA plans.

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 J 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 4454/6 presented in Appendix B; exploratory holes were 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 J.

11.1.2 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 25 and 26.

### 11.2 Made ground

11.2.1 The made ground on 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 bulk of the made ground can be categorised as one of 4 broad types:

- **Made Ground Topsoil:** Encountered in all exploratory holes except TPs 13 to 18 from surface to between 0.2m and 0.45m (typically 0.3m) depth comprising silty/clay with some gravel of mudstone, siltstone, sandstone, occasional coal, pottery, brick burnt shale and rare glass.
- **Burnt Shale:** Encountered in 8 exploratory holes along the northern and western peripheries and in the east typically from below Made Ground Topsoil to between 0.8m and 3.8m depth (ave. 2.3m) comprising gravel with cobbles of burnt shale and some mudstone, siltstone and occasional coal and clinker.
- **Opencast Backfill:** Encountered in 65 exploratory holes from the base of Made Ground Topsoil or Burnt Shale typically to the base of the former opencast/to natural ground (between 0.6m and 15.5m). The Opencast Backfill can be subdivided into two categories which are loosely intermixed across the site:
  - **Cohesive Opencast Backfill:** Comprising stiff clay with gravel and a low cobble content of mudstone, siltstone, sandstone and occasional burnt shale, coal, brick and pottery.
  - **Granular Opencast Backfill:** Comprising clayey slightly sandy gravel with a low to medium cobble content and occasionally a low boulder content of mudstone, siltstone and sandstone and occasional coal, burnt shale, pottery and brick. Rarely with fragments of metal.
- **Coal Arisings:** Encountered occasionally in 6 exploratory holes in the very base of the opencast comprising sand and gravel of dull ashy coal and some mudstone.

11.2.2 Opencast backfill along the western boundary appeared to be of the same composition as the Opencast Backfill across the wider site, but was generally darker in colour; likely containing a greater proportion of coal dust and coal gravel. It is tentatively inferred that Opencast backfill along the western edge of the site was deposited at an earlier stage than the opencasting and subsequent backfilling across the wider site (see Section 11.9).

11.2.3 It should be noted that localised beds of Burnt Shale and areas of Opencast Backfill with a higher proportion of gravel/cobbles of burnt shale were frequently encountered, typically around the outer edges of the former opencast.

11.2.4 A localised area of ash sand with gravel of clinker and occasional coal, mudstone and brick and occasional fragments of plastic, wire and metal was encountered in TP39 from 1.2m to 1.7m.

- 11.2.5 Made Ground was absent across the north western area of grazing land, but present across the remainder of the site.
- 11.2.6 The depth of made ground at this site is predominantly dictated by the presence of the former opencast; inside the opencast depths of made ground range from around 4.0m to 15.5m depth with the deeper opencast and made ground being located in the southeast.
- 11.2.7 Outside of the opencast made ground ranges from around 1.3m to 1.9m thickness which suggests that levels outside of the opencast have been raised following opencasting.
- 11.2.8 The thickness of made ground across the site (in mbgl) is shown on Drawing 4454/12 and the level of natural ground is shown in mAOD on Drawing 4454/13.
- 11.2.9 Whilst not encountered during this investigation it should be noted that the possibility of some more hazardous materials (eg. deposited waste, degradable materials, contaminated soils, asbestos etc) cannot be discounted. Backfilling and restoration of this site is understood to have taken place in c. 1960, prior to the Control of Pollution Act 1974 and consequently the control and regulation of materials deposited into an open excavation (i.e. an exhausted opencast) was very poorly regulated.
- 11.2.10 It would be prudent to allow for the presence of some further made ground types than those described above in localised areas across this site.

### 11.3 Obstructions

- 11.3.1 It is apparent from review of historical mapping that no buildings have been placed across this site and consequently it is unlikely that relict foundations, floor slabs etc will be encountered during the proposed development works.
- 11.3.2 However occasional medium to large **boulders** were encountered during Lithos' works and it is highly likely that more boulders are present at depth within the Opencast Backfill. Further it cannot be discounted that some obstructions have been placed within the Opencast Backfill such as old plant, equipment, scrap metals etc which may pose a potential obstruction to excavations, earthworks and foundations.

### 11.4 Natural ground

- 11.4.1 Natural Ground was encountered **in the parcel of grazing land** in the northwest and comprises the following succession:
- **Topsoil:** Encountered in TPs 13 to 18 from surface to 0.2m depth comprising sandy silt with occasional gravel of siltstone and sandstone
  - **Cohesive Residual Soil:** Encountered in TPs 15 to 18 from the base of Topsoil to between 1.4m and 2.1m depth comprising stiff closely fissured clay occasionally with gravel of mudstone and siltstone lithorelicts.
  - **Granular Residual Soil:** Encountered in TPs 13, 14 and 18 from the base of Topsoil to between 0.7m and 2.6m depth comprising clayey gravel of sandstone or mudstone and siltstone lithorelicts.
  - **Lower Coal Measures Bedrock:** Encountered in TPs 13 to 18 from the base of Residual Soils (between 0.7m and 2.6m) comprising medium strong sandstone or moderately weak siltstone.
- 11.4.2 Across the **remainder of the site** natural ground was encountered locally below the base of the opencast or below Made Ground outside the opencast.

- 11.4.3 Outside of the opencast natural ground comprised Cohesive Residual Soils (as described above) over Lower Coal Measures bedrock. Inside of the opencast natural ground comprised Lower Coal Measures Bedrock (as described above).
- 11.4.4 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.
- 11.4.5 Trial pitting and the rotary cored boreholes has allowed detailed description of **bedrock**. All bedrock at this site falls within the Lower Coal Measures Group, a deposition of sedimentary rocks laid down about 318 million years ago and which comprises an interbedded succession of mudstones, siltstones and sandstones with beds of iron-rich layers, coals and seatearths.
- 11.4.6 Bedrock was encountered in 15 trial pits (in the grazing land/outside the opencast) in all three rotary cored boreholes and all 10 cable percussion boreholes (inside of the opencast) and in all of the rotary open probeholes and stitched probeholes.
- 11.4.7 It should be noted that all rotary cored boreholes were advanced within the former opencast and the rock descriptions refer to the ground immediately below the base of the opencasts.
- 11.4.8 Bedrock described in the rotary cored boreholes (Area D) comprises one of three types:
- **Mudstone:** Encountered in thin beds in RCs 01, 02 and 03 and rarely in trial pits, comprising very weak mudstone with discontinuities which are very closely spaced, sub-horizontal, planar, closed and with clay on surfaces. The Rock Quality Designation (RQD) of mudstone is typically around 10% to 30%.
  - **Siltstone:** Encountered in RCs 01, 02 and 03 as well as several trial pits which encountered bedrock, comprising moderately weak to weak (occasionally medium strong) cross laminated siltstone with discontinuities which are very closely to closely spaced, sub-horizontal, smooth, planar, closed and clean or rarely with up to 5mm of clay fill on surfaces. In excavations siltstone is typically recovered as a slightly clayey slightly sandy medium gravel. The RQD of siltstone is typically around 50%, but locally much lower.
  - **Sandstone:** Encountered in RCs 01 and 02 as well as the majority of trial pits which encountered bedrock, comprising medium strong cross laminated fine grained sandstone with discontinuities which are closely to medium spaced, sub-horizontal, rough, planar and/or stepped and closed. Often with penetrative brown staining. In excavations sandstone is typically recovered as slightly sandy subangular medium gravel. The RQD of sandstone is typically between c. 40% and 70%.
- 11.4.9 Some red colouration of bedrock was noted during excavations in the northwest of the site, notably TT14 and TPs 02 and 03. It is tentatively suggested that this could be the result of localised heating of the in-situ bedrock from combustible/smouldering made ground placed above rockhead; this would support anecdotal evidence of combustion at this site which is outlined in Section 3. **No** evidence of ongoing combustion was noted during Lithos' investigation.

## 11.5 Stability

- 11.5.1 The stability of excavations through both natural and made ground soils were generally good, however some overbreak of excavation walls should be anticipated where oversized materials (cobbles and boulders) are encountered.

### Summary of Ground Conditions

Hole ID	Final Depth (mbgl)	Depth to Base (mbgl)										Depth to rockhead (mbgl)	Penetration (m)	Remarks
		Made Ground							Natural Ground					
		Total Made Ground	Made Ground Topsoil	Ash & Clinker	Burnt Shale	Cohesive Opencast Backfill	Granular Opencast Backfill	Coal Arisings	Topsoil	Cohesive Residual Soil	Granular Residual Soil			
TP01	3.5	>3.5	0.25	-	>3.5	1.7	-	2.6	-	-	-	-	-	-
TP02	3.6	3.1	0.3	-	-	3.1	-	-	-	-	-	3.1	0.5	-
TP03	2.4	1.9	0.3	-	1.9	1.0	-	-	-	-	-	1.9	0.5	-
TP04	4.0	>4.0	0.25	-	-	>4.0	-	-	-	-	-	-	-	-
TP05	3.8	>3.8	0.3	-	-	>3.8	-	-	-	-	-	-	-	-
TP06	3.4	>3.4	0.3	-	-	>3.4	-	-	-	-	-	-	-	-
TP07	3.3	>3.3	0.25	-	-	-	>3.3	-	-	-	-	-	-	-
TP08	2.7	>2.7	0.25	-	-	1.6	>2.7	-	-	-	-	-	-	Overbreak of pit walls during excavation.
TP09	1.2	>1.2	0.25	-	-	0.9	>1.2	-	-	-	-	-	-	-
TP10	1.9	1.0	0.3	-	1.0	-	-	-	-	1.5	-	1.5	0.4	-
TP11	3.5	>3.5	0.3	-	>3.5	-	-	-	-	-	-	-	-	-
TP12	3.2	>3.2	0.3	-	0.8	-	>3.2	-	-	-	-	-	-	Overbreak of pit walls during excavation.
TP13	2.0	-	-	-	-	-	-	-	0.2	-	1.2	1.2	0.8	-
TP14	2.0	-	-	-	-	-	-	-	0.2	-	0.7	0.7	1.3	-
TP15	2.5	-	-	-	-	-	-	-	0.2	1.8	-	1.8	0.7	-
TP16	2.9	-	-	-	-	-	-	-	0.2	2.1	-	2.1	0.8	-
TP17	2.2	-	-	-	-	-	-	-	0.2	1.6	-	1.6	0.6	-
TP18	3.4	-	-	-	-	-	-	-	0.2	1.4	2.6	2.6	0.8	-
TP19	3.5	>3.5	0.35	-	-	-	>3.5	-	-	-	-	-	-	-
TP20	3.8	>3.8	0.3	-	-	-	>3.8	-	-	-	-	-	-	Overbreak of pit walls during excavation.
TP21	2.9	>2.9	0.25	-	-	-	>2.9	-	-	-	-	-	-	-
TP22	3.7	>3.7	0.3	-	-	>3.7	2.4	-	-	-	-	-	-	-
TP23	4.0	>4.0	0.25	-	-	>4.0	-	-	-	-	-	-	-	-
TP24	4.0	>4.0	0.3	-	-	-	>4.0	-	-	-	-	-	-	Overbreak of pit walls during excavation.
TP25	3.7	>3.7	0.3	-	-	>3.7	1.9	-	-	-	-	-	-	Overbreak of pit walls during excavation.
TP26	4.0	>4.0	0.4	-	-	>4.0	-	-	-	-	-	-	-	Overbreak & spalling of pit walls during excavation.
TP27	2.9	>2.9	0.3	-	-	-	>2.9	-	-	-	-	-	-	Overbreak of pit walls during excavation.
TP28	3.5	>3.5	0.35	-	-	>3.5	-	-	-	-	-	-	-	-
TP29	2.5	0.6	0.35	-	-	0.6	-	-	-	2.1	-	2.1	0.4	-
TP30	3.5	0.5	0.45	-	-	-	-	-	-	2.7	-	-	-	-
TP31	2.7	>2.7	0.3	-	-	>2.7	-	-	-	-	-	-	-	Overbreak of pit walls during excavation.
TP32	3.2	>3.2	0.3	-	-	1.0	>3.2	-	-	-	-	-	-	-
TP33	3.8	>3.8	0.35	-	>3.8	1.6	-	-	-	-	-	-	-	-
TP34	2.6	1.6	0.3	-	-	1.6	-	-	-	2.2	-	2.2	0.4	-
TP35	3.0	>3.0	0.3	-	-	>3.0	-	-	-	-	-	-	-	-
TP36	3.4	>3.4	0.35	-	-	>3.4	-	-	-	-	-	-	-	-
TP37	2.5	>2.5	0.3	-	-	-	>2.5	-	-	-	-	-	-	Overbreak of pit walls during excavation.
TP38	3.5	>3.5	0.3	-	-	-	>3.5	-	-	-	-	-	-	Overbreak of pit walls during excavation.
TP39	2.2	1.7	0.25	1.7	-	-	-	1.2	-	-	-	1.7	0.5	-
TP40	3.0	>3.0	0.35	-	-	-	>3.0	-	-	-	-	-	-	Overbreak of pit walls during excavation.
TP41	2.7	1.8	0.25	-	-	1.8	-	-	-	2.3	-	2.3	0.4	-
TP42	3.5	>3.5	0.3	-	-	>3.5	1.8	-	-	-	-	-	-	Overbreak of pit walls during excavation.

Hole ID	Final Depth (mbgl)	Depth to Base (mbgl)										Depth to rockhead (mbgl)	Penetration (m)	Remarks	
		Made Ground							Natural Ground						
		Total Made Ground	Made Ground Topsoil	Ash & Clinker	Burnt Shale	Cohesive Opencast Backfill	Granular Opencast Backfill	Coal Arisings	Topsoil	Cohesive Residual Soil	Granular Residual Soil				
TP43	3.0	>3.0	0.25	-	-	1.6	>3.0	-	-	-	-	-	-	-	Overbreak of pit walls during excavation.
TP44	2.5	1.4	0.25	-	-	1.4	-	-	-	2.0	-	2.0	0.5	-	
TP45	2.7	1.3	0.3	-	-	1.3	-	-	-	2.5	-	2.5	0.2	-	
TP46	3.5	>3.5	0.3	-	-	>3.5	-	-	-	-	-	-	-	-	
TP47	4.2	>4.2	0.3	-	-	>4.2	-	-	-	-	-	-	-	-	
BH01	11.0	10.8	0.2	-	-	10.8	-	-	-	-	-	-	-	-	Monitoring well installed.
BH02	15.5	15.3	0.3	-	-	13.5	-	15.3	-	-	-	15.3	0.2	Monitoring well installed.	
BH03	7.3	7.3	0.2	-	-	7.3	-	-	-	-	-	7.3	0.0	Monitoring well installed.	
BH04	3.4	>3.4	0.2	-	-	>3.4	-	-	-	-	-	-	-	Monitoring well installed. Refused on unknown obstruction (likely boulder or similar)	
BH05	6.7	6.4	0.3	-	1.6	4.2	-	6.4	-	-	-	6.4	0.3	Monitoring well installed.	
BH06	10.7	9.4	0.2	-	-	9.4	-	-	-	-	-	10.6	0.1	Monitoring well installed.	
BH07	8.7	8.3	0.2	-	-	8.3	-	-	-	-	-	8.3	0.4	Monitoring well installed.	
BH08	14.0	14.0	0.2	-	-	14.0	-	-	-	-	-	14.0	0.0	Monitoring well installed.	
BH09	10.2	9.0	0.2	-	-	9.0	-	10.2	-	-	-	-	-	Monitoring well installed.	
BH10	14.5	13.9	0.2	-	-	12.0	-	13.9	-	-	-	14.4	0.1	Monitoring well installed.	
RC01	13.2	0.2	0.2	-	-	7.8	-	-	-	-	-	7.8	5.4	-	
RC02	19.4	15.3	0.2	-	1.6	14.3	-	14.5	-	-	-	14.5	4.9	-	
RC03	16.5	0.2	0.2	-	-	11.5	-	-	-	-	-	11.5	5.0	-	

## 11.6 Visual & olfactory evidence of organic contamination

- 11.6.1 No visual or olfactory evidence of gross contamination was noted during any of Lithos' exploratory holes.
- 11.6.2 However, several made ground types, notably the Ash & Clinker and Burnt Shale, are commonly associated with a number of organic and inorganic determinands. Natural Coal Measures bedrock/Residual Soils can also be associated with a number of inorganic determinands (notably lead and arsenic).
- 11.6.3 Consequently, it cannot be discounted that some contamination is present within the made ground at this site.

## 11.7 Groundwater

- 11.7.1 No inflows of groundwater were encountered during the investigation.
- 11.7.2 Groundwater levels recorded to date (two visits) in the monitoring wells are summarised below.

Hole	Response zone (depth range & strata)	Groundwater body	Typical standing water level	
			m bgl	m AoD#
PH01	4.70m to 7.70m, Opencast Backfill	Perched in backfill	5.40 to 5.70	125.65 to 125.35
PH04	3.0m to 4.5m, Coal Measures Sandstone	Bedrock	4.30	137.75
PH08	4.50m to 7.50m, Opencast Backfill	Perched in backfill	7.20	128.1
PH26	1.50m to 3.0m, Residual soil	Shallow	2.0 to 2.80	135.8 to 135
PH27	9.5m to 14.0m, Opencast Backfill	Perched in backfill	14.15	121.8

# levelled-in by survey to enable groundwater risk assessment

- 11.7.3 Dip data to date suggests there is locally a shallow perched water table within the opencast backfill, with a deeper 'true' water table in the bedrock at depth beneath the base of the backfilled opencast.

## 11.8 Underground mining investigation

- 11.8.1 The site is underlain at shallow depth by the Barnsley Coal Seam, with further coals below (the Dunsil; c. 14m below Barnsley Coal; &, Gawber; c. 32m below Barnsley).
- 11.8.2 Review of Coal Authority information and abandonment plans shows that known workings have taken place within the Barnsley Coal beneath this site and the wider surrounding area from underground means. Several mine entries (adits/day-holes) are located along the western edge and beyond the western boundary as well as a shaft in the centre-south.
- 11.8.3 Based on the findings of Lithos' Desk Study (see Section 5) workings in the Barnsley Coal could pose a risk to surface stability where present.
- 11.8.4 Workings in the Dunsil Coal might pose a risk to surface stability (although at the desk study stage this is considered unlikely) where opencast coal extraction has significantly reduced the thickness of competent cover over this seam.
- 11.8.5 Consequently, a mining investigation has been undertaken comprising the drilling of 28 'deep' rotary open probeholes. A summary table of the probehole findings is presented on Page 28.

### Summary table of underground mining investigation

Hole ID	Final Depth (mbgl)	Depth to Base (mbgl)		Depth to rockhead (mbgl)	Barnsley Coal Seam				Dunsil Coal Seam				Remarks
		Opencast Backfill	Residual Soil		top (mbgl)	Bottom (mbgl)	thickness (m)	10h present?	top (mbgl)	Bottom (mbgl)	thickness (m)	10h present?	
PH01	51.0	7.7	-	7.7	Removed by opencast				23.5	24.1	0.6	Yes	Thin Coal from 10.8 - 11.3 (0.5m thick). Gawber Coal from 47.8m to 48.3m (0.5m thick) 10h present for both seams.
PH02	21.0	2.0	2.0	2.0	Removed by opencast				17.0	17.4	0.4	Yes	-
PH03	21.0	2.8	2.8	2.8	Removed by opencast				17.5	18.0	0.5	Yes	-
PH04	21.0	3.0	3.0	3.0	Removed by opencast				18.0	18.6	0.6	Yes	-
PH05	24.0	2.8	2.8	2.8	2.8	3.3	0.5	No	18.3	18.8	0.5	Yes	-
PH06	24.0	1.6	-	1.6	Removed by opencast				20.6	21.1	0.5	Yes	-
PH07	27.0	8.1	-	8.1	Removed by opencast				23.6	24.1	0.5	Yes	-
PH08	27.0	7.5	-	7.5	Removed by opencast				23.2	23.8	0.6	Yes	-
PH09	30.0	8.1	-	8.1	8.1	8.3	0.2	No	-	-	-	-	-
PH10	30.0	11.2	-	11.2	Removed by opencast				26.4	27.0	0.6	Yes	-
PH11	54.0	10.2	-	10.2	Removed by opencast				26.2	26.7	0.5	Yes	Thin Coal from 41.1m to 41.3m (0.2m thick). Gawber Coal from 50.2m to 50.7m (0.5m thick) 10h present for both seams.
PH12	30.0	12.6	-	12.6	12.6	12.9	0.3	No	27.3	27.9	0.6	Yes	-
PH13	13.3	13.3	-	-	Removed by opencast				-	-	-	-	-
PH14	8.3	8.3	-	-	Removed by opencast				-	-	-	-	-
PH15	14.2	14.1	-	-	Removed by opencast				-	-	-	-	-
PH16	27.0	12.5	-	12.5	Removed by opencast				23.1	23.5	0.4	Yes	-
PH17	24.0	-	3.7	4.2	3.7	4.2	0.5	No	19.0	19.4	0.4	Yes	-
PH18	15.0	13.6	-	13.9	13.6	13.9	0.3	No	-	-	-	-	-
PH19	11.0	-	2.7	2.7	9.7	11.0	2.3	No	-	-	-	-	-
PH20	18.0	-	2.0	2.0	12.0	15.5	3.5	No	-	-	-	-	-
PH21	15.0	-	2.8	2.8	8.5	11.8	3.3	No	-	-	-	-	-
PH22	18.0	-	2.5	2.5	10.1	13.5	3.4	No	-	-	-	-	-
PH23	30.0	-	2.0	2.0	14.2	15.7	1.5	No	27.8	28.3	0.5	Yes	-
PH24	18.0	15.5	-	15.5	Removed by opencast				-	-	-	-	-
PH25	18.0	-	2.1	2.1	12.1	15.3	3.2	No	-	-	-	-	-
PH26	21.0	-	3.0	3.0	13.1	16.5	3.4	No	-	-	-	-	-
PH29	15.0	12.5	-	12.8	Removed by opencast				-	-	-	-	-

- 11.8.6 In the table above depths of coal highlighted in **red** indicate evidence of underground workings were encountered during Lithos' investigation. Evidence of workings comprised a loss of flush returns and soft push during drilling.
- 11.8.7 It is apparent that the Barnsley Coal Seam has been removed from about 65% of the total site area (c. 80% of the development footprint) during opencasting. Opencasting mitigates the risk posed from underground workings as the coal and any cavities, roadways, mine entries, void collapsed etc are removed during excavations.
- 11.8.8 However outside of the area of opencast, evidence of underground workings in the Barnsley Coal Seam has been recorded in 6 of 7 relevant (i.e. located beyond the opencast) probeholes. Workings are recorded as typically being greater than 3.0m thick and an insufficient cover of competent bedrock is present to negate the risk posed to the surface.
- 11.8.9 Outside of the area of opencasting workings in the Barnsley Coal Seam shall require consolidation (most likely by means of Drill & Grout) should they underlie proposed plots or highways.
- 11.8.10 The Dunsil and Gawber Coal Seams have a sufficient cover of competent rock above them to negate the risk to surface stability posed by any underground workings. Further, no evidence of underground workings was encountered in either the Dunsil or Gawber Coal Seams during Lithos' mining investigation.
- 11.8.11 No evidence of underground workings for Ironstone was encountered during Lithos' mining investigation.

## 11.9 Opencast mining investigation

### General

- 11.9.1 Based on the findings of Lithos' investigations to date, about 65% of the total site area, and c. 80% of the development footprint, has been subject to opencast coal extraction with subsequent backfilling off all excavations. Historical mapping, CA plans and Lithos' findings to date (see below) also suggests that some localised and unlicensed quarrying of coal took place close to outcrop along the western edge of the site.
- 11.9.2 Consequently, one of the key aims of Lithos' scope of works was to determine the extents and profile of the former opencast beneath the site including the line and nature of buried highwalls. A total of 10 cable percussion boreholes, 29 probeholes, 13 groups of stitched probeholes and 23 trial trenches were excavated to determine the depth to the base of the opencast and the line and nature of the buried highwalls.

### Highwalls

- 11.9.3 Highwalls were encountered in 9 trial trenches and 9 of the groups of stitched probeholes.
- 11.9.4 The lines of the buried highwalls (interpreted and proven) are shown on Drawing 4454/11, and overlain the proposed lay out on Drawing 4454/14. Highwalls loosely follow the extents of the opencast shown on the Coal Authority abandonment plan.
- 11.9.5 Highwalls appear to be cut at around 45° through residual soils at are close to vertical (c. 80°) through bedrock. Evidence of an intermittent terrace has been encountered along the eastern edge of the site, notably in stitch probehole groups 08, 10, 11 and 12.

- 11.9.6 Highwalls are typically well formed and easy to identify around the opencasts southern and eastern edges where the depth of excavation is deepest. However, along the northern and western edges (close to the coal outcrop) highwalls appear poorly defined, shallow and locally absent. Given the proximity of the opencast to the coal outcrop it is considered likely that the opencast boundary comprised a relatively shallow slope rather than a steep drop-off across this area, although localised steps and highwalls cannot be discounted.
- 11.9.7 During excavation of TT22 a 'highwall' was noted which had been cut at about 45° into an older darker Opencast Backfill rather than bedrock. It is likely that this highwall represents the extent of the 1950's opencast which cut into an area of historical unlicensed coal quarrying.
- 11.9.8 Historical quarrying of coal from outcrop is highly likely to result in deeper made ground extending further to the west than would be suggested on CA plans, possibly all the way to outcrop.

### **Base of opencast**

- 11.9.9 The opencast reaches depths of between 6.4m (BH05) and 15.5m (PH24). The base of the opencast typically shallows to the northwest and deepens to the southeast which reflects the angle of dip within the underlying Coal Measures geology.
- 11.9.10 The average depth of the opencast is around 11.0m, and is generally shallower (around 4m deep) in the northwest and deeper (around 15m deep) in the east. The level of the base of the opencast in mAOD is shown on Drawing 4454/13.

## **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 presence of coal and shallow workings
  - 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 13.2, where the results of laboratory testing for contaminants have been considered.

## 12 CONTAMINATION (ANALYSIS)

### 12.1 General

- 12.1.1 The site is essentially greenfield arable farmland, however, has been subject to historical coal mining and opencasting with backfilling of the resultant excavations. Backfill material appears to predominantly comprise reworked (likely site-won) natural soils and rock, however does also include some Burnt Shale and Ash & Clinker. Further made ground types sourced from off-site may well be present.
- 12.1.2 There is some anecdotal evidence of historical combustion of soils beneath the west of the site and this is supported by the presence of Burnt Shale and in-situ bedrock in the northwest being coloured red, likely as a result of heating.
- 12.1.3 In the context of risks to human health associated with residential 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. Account has also been taken of visual and olfactory evidence recorded during the ground investigation.

Type of sample	No. of samples	Determinands
Made Ground Topsoil	10	pH, water soluble boron, and total metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium and zinc) & Asbestos ID. Total Organic Carbon (TOC) & Poly Aromatic Hydrocarbons (PAH) & Total Petroleum Hydrocarbons (TPH).
Topsoil	3	pH, water soluble boron, and total metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium and zinc) & Asbestos ID. TOC & PAH.
Made Ground	26	pH, water soluble boron, and total metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium and zinc) & Asbestos ID. TOC, PAH & Total Petroleum Hydrocarbons (TPH).
	8	Calorific Value (CV).

### 12.3 Soil contamination results

- 12.3.1 The soil contamination test results are summarised in the tables on pages 32 to 35.
- 12.3.2 Laboratory test certificates as received from the laboratory are presented in Appendix K to this report.

### Summary of degree of soils contamination (inorganics)

Expl Hole	Depth (mbgl)	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 <b>BLUE</b> and assume a <b>residential with gardens</b> end-use.													
			pH	As ∞	B~	Cd ∞	Cr x	Cu ⚡\$	Pb ∞	Hg*	Ni	Se	Vn	Zn\$	CV	Asbestos
				37	5	26	4000	100	200	199	109	434	584	200	2	
TP13	0.1	Topsoil	5.9	25	0.5	0.2	11	33	54	0.1	10	0.5	23	61	-	N.D.
TP15	0.1	Topsoil	6.1	13	0.4	0.2	13	34	34	0.1	18	0.5	26	61	-	N.D.
TP17	0.1	Topsoil	5.6	11	0.8	0.2	15	27	44	0.1	16	0.5	25	92	-	N.D.
TP03	0.1	Made Ground Topsoil	6.3	14	0.4	0.2	16	31	47	0.1	17	0.5	27	79	-	N.D.
TP06	0.1	Made Ground Topsoil	6.2	13	0.4	0.2	17	35	31	0.1	26	0.5	28	82	-	N.D.
TP19	0.1	Made Ground Topsoil	6.3	11	0.4	0.2	16	28	29	0.1	22	0.5	24	75	-	N.D.
TP22	0.1	Made Ground Topsoil	6.0	12	0.4	0.2	17	31	40	0.1	20	0.5	27	84	-	N.D.
TP26	0.1	Made Ground Topsoil	6.3	14	0.6	0.2	17	30	49	0.1	17	0.5	27	72	-	N.D.
TP28	0.1	Made Ground Topsoil	6.6	14	0.4	0.2	17	34	43	0.1	19	0.5	29	84	-	N.D.
TP30	0.1	Made Ground Topsoil	6.1	31	0.6	0.2	17	41	62	0.1	18	0.7	36	89	-	N.D.
TP37	0.1	Made Ground Topsoil	6.9	14	0.5	0.2	15	33	47	0.2	17	0.8	27	80	-	N.D.
TP40	0.1	Made Ground Topsoil	6.6	17	0.6	0.2	16	36	57	0.1	17	0.6	29	85	-	N.D.
TP43	0.1	Made Ground Topsoil	6.5	17	0.6	0.2	17	37	60	0.1	17	0.6	30	85	-	N.D.
TP39	1.5	Ash & Clinker	7.7	17	0.6	0.4	22	72	<b>270</b>	0.1	30	0.5	41	<b>250</b>	<b>3.2</b>	N.D.
TP01	2.0	Burnt Shale	7.3	31	0.5	0.1	21	28	31	0.1	23	0.5	46	49	1.0	N.D.
TP10	0.6	Burnt Shale	6.8	18	0.6	0.2	18	35	51	0.1	19	0.5	33	87	-	N.D.
TP11	0.6	Burnt Shale	7.4	5.4	0.4	0.1	16	20	19	0.1	31	0.6	20	92	1.0	N.D.
TP12	0.6	Burnt Shale	6.9	8.1	0.4	0.1	15	36	20	0.1	30	0.7	20	83	-	N.D.
TP33	1.8	Burnt Shale	6.6	6.1	0.5	0.2	16	30	21	0.1	31	0.5	22	99	1.0	N.D.
TP02	0.5	Cohesive Opencast Backfill	5.3	9.8	0.6	0.1	16	32	28	0.1	20	0.8	24	73	1.0	N.D.
TP04	0.4	Cohesive Opencast Backfill	6.6	5.4	0.3	0.1	14	25	20	0.1	25	0.5	18	75	-	N.D.
TP22	0.5	Cohesive Opencast Backfill	6.2	12	0.2	0.1	15	29	15	0.1	28	0.5	20	75	1.0	N.D.
TP26	0.7	Cohesive Opencast Backfill	7.2	11	0.3	0.1	16	25	19	0.1	27	0.5	19	85	-	N.D.
TP29	0.5	Cohesive Opencast Backfill	6.9	11	0.4	0.1	16	31	44	0.1	18	0.5	30	81	-	N.D.
TP32	0.8	Cohesive Opencast Backfill	7.0	10	0.3	0.1	16	31	34	0.1	27	0.5	26	83	-	N.D.
TP34	0.5	Cohesive Opencast Backfill	6.8	7.7	0.3	0.1	15	28	24	0.1	27	0.5	20	88	-	N.D.
TP36	0.7	Cohesive Opencast Backfill	6.3	6.4	0.2	0.2	15	27	28	0.1	31	0.7	19	120	-	N.D.
TP42	2.0	Cohesive Opencast Backfill	6.9	6.6	0.2	0.1	16	31	17	0.1	32	0.5	20	91	-	N.D.
TP44	0.5	Cohesive Opencast Backfill	6.6	7.9	0.3	0.1	15	28	20	0.1	28	0.7	21	87	-	N.D.
TP46	1.8	Cohesive Opencast Backfill	6.8	6.5	0.2	0.1	15	29	16	0.1	31	0.6	18	84	-	N.D.
TP07	0.5	Granular Opencast Backfill	6.8	6	0.3	0.1	15	26	19	0.1	27	0.5	19	85	1.0	N.D.

Expl Hole	Depth (mbgl)	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 <b>BLUE</b> and assume a <b>residential with gardens</b> end-use.													
			pH	As ∞	B~	Cd ∞	Cr x	Cu♣\$	Pb ∞	Hg*	Ni	Se	Vn	Zn\$	CV	Asbestos
				37	5	26	4000	100	200	199	109	434	584	200	2	
TP19	0.6	Granular Opencast Backfill	7.1	6.2	0.3	0.1	16	28	19	0.1	29	0.5	19	89	-	N.D.
TP20	0.6	Granular Opencast Backfill	7.6	10	0.3	0.1	15	29	15	0.1	30	0.5	19	72	-	N.D.
TP24	0.5	Granular Opencast Backfill	6.6	12	0.5	0.1	16	31	40	0.1	19	0.6	28	78	1.0	N.D.
TP25	0.6	Granular Opencast Backfill	6.2	15	0.5	0.2	17	37	44	0.1	19	0.9	28	79	-	N.D.
TP27	0.5	Granular Opencast Backfill	7.0	6.9	0.3	0.2	15	28	21	0.1	29	0.5	21	90	-	N.D.
TP37	0.5	Granular Opencast Backfill	7.7	6.4	0.2	0.2	14	28	21	0.1	26	0.5	18	91	-	N.D.
TP38	0.6	Granular Opencast Backfill	7.0	6.4	0.3	0.1	15	34	21	0.1	30	0.5	20	82	-	N.D.
TP40	1.5	Granular Opencast Backfill	8.4	4.9	0.2	0.1	16	26	24	0.1	28	0.5	18	82	-	N.D.

Key		Source of guidance trigger level	
36	Parameter tested for and found to be in excess of Tier 1 value.	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.	
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.	∞	Category 4 Screening Level – SP1010, December 2013 (CL:AIRE/Defra).
-	Parameter not tested for.	\$	MAFF. Code of Practice for Agricultural Practice for the Protection of Soil, 1998.
♣	Tier 1 Value is pH dependent.	*	Assumes mercury present as an inorganic compound (cf elemental metal or within organic compound). See Science Report SC050021/Mercury SGV.
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.		

### Summary of degree of soils contamination (organics)

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 <b>BLUE</b> and assume a <b>residential with gardens (and no cover)</b> end use					
			% TOC	PAH		TPH - C <sub>6</sub> to C <sub>40</sub>		
				B(a)P ∞	Naphthalene	GRO~ C <sub>6</sub> to C <sub>10</sub>	DRO∅ C <sub>10</sub> to C <sub>21</sub>	LRO C <sub>21</sub> to C <sub>40</sub>
				5	6	22	215	3299
TP13	0.1	Topsoil	5.0	0.1	0.1	-	-	-
TP15	0.1	Topsoil	3.2	0.1	0.1	-	-	-
TP17	0.1	Topsoil	3.9	0.1	0.1	-	-	-
TP03	0.1	Made Ground Topsoil	4.7	0.1	0.1	10	20	20
TP06	0.1	Made Ground Topsoil	6.3	0.1	0.1	10	20	20
TP19	0.1	Made Ground Topsoil	4.4	0.1	0.1	10	20	20
TP22	0.1	Made Ground Topsoil	3.2	0.1	0.1	10	20	20
TP26	0.1	Made Ground Topsoil	4.6	0.1	0.1	10	20	20
TP28	0.1	Made Ground Topsoil	4.0	0.1	0.1	10	20	20
TP30	0.1	Made Ground Topsoil	8.7	0.1	0.1	10	20	20
TP37	0.1	Made Ground Topsoil	5.4	0.1	0.1	10	20	20
TP40	0.1	Made Ground Topsoil	6.1	0.1	0.1	10	20	20
TP43	0.1	Made Ground Topsoil	6.2	0.1	0.1	10	20	20
TP39	1.5	Ash & Clinker	9.5	0.1	0.1	10	20	20
TP01	2.0	Burnt Shale	2.3	0.1	0.1	10	20	20
TP10	0.6	Burnt Shale	6.9	0.1	0.1	10	20	20
TP11	0.6	Burnt Shale	1.1	0.1	0.1	10	20	20
TP12	0.6	Burnt Shale	4.2	0.1	0.1	10	20	20
TP33	1.8	Burnt Shale	1.0	0.1	0.1	10	20	20
TP02	0.5	Cohesive Opencast Backfill	4.5	0.1	0.1	10	20	20
TP04	0.4	Cohesive Opencast Backfill	1.2	0.1	0.1	10	20	20
TP22	0.5	Cohesive Opencast Backfill	1.7	0.1	0.1	10	20	20
TP26	0.7	Cohesive Opencast Backfill	1.3	0.1	0.1	10	20	20
TP29	0.5	Cohesive Opencast Backfill	3.1	0.1	0.1	10	20	20
TP32	0.8	Cohesive Opencast Backfill	3.9	0.1	0.1	10	20	20
TP34	0.5	Cohesive Opencast Backfill	3.6	0.1	0.1	10	20	20
TP36	0.7	Cohesive Opencast Backfill	2.0	0.1	0.1	10	20	20
TP42	2.0	Cohesive Opencast Backfill	2.6	0.1	0.1	10	20	20
TP44	0.5	Cohesive Opencast Backfill	3.6	0.1	0.1	10	20	20
TP46	1.8	Cohesive Opencast Backfill	1.8	0.1	0.1	10	20	20

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 <b>BLUE</b> and assume a <b>residential with gardens (and no cover)</b> end use					
			% TOC	PAH		TPH - C6 to C40		
				B(a)P ∞	Naphthalene	GRO~ C6 to C10	DRO◇ C10 to C21	LRO C21 to C40
				5	6	22	215	3299
TP07	0.5	Granular Opencast Backfill	2.4	0.1	0.1	10	20	20
TP19	0.6	Granular Opencast Backfill	1.2	0.1	0.1	10	20	20
TP20	0.6	Granular Opencast Backfill	0.8	0.1	0.1	10	20	20
TP24	0.5	Granular Opencast Backfill	3.6	0.1	0.1	10	20	20
TP25	0.6	Granular Opencast Backfill	5.8	0.1	0.1	10	20	52
TP27	0.5	Granular Opencast Backfill	2.4	0.1	0.1	10	20	20
TP37	0.5	Granular Opencast Backfill	1.3	0.1	0.1	10	20	20
TP38	0.6	Granular Opencast Backfill	1.1	0.1	0.1	10	20	20
TP40	1.5	Granular Opencast Backfill	1.4	0.1	0.1	10	20	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).

### Inorganic determinands

- 12.3.3 Of the 39 samples of ground analysed for inorganic parameters, 38 can be classified as uncontaminated and a single sample of Ash & Clinker recovered from 1.5m in TP39 could be 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).
- 12.3.5 Significant contaminants in the ash & Clinker are lead and zinc.

### Calorific value

- 12.3.6 The calorific value of one sample of Ash & Clinker and 7 samples of Opencast Backfill have been determined; the Opencast Backfill yielded a result of less than 1MJ/kg.
- 12.3.7 The Ash & Clinker yielded a result of 3.2MJ/kg. Materials whose CVs exceed 10MJ/kg are almost certainly combustible, while those with values below 2MJ/kg are unlikely to burn. Therefore, whilst the Opencast Backfill can be considered essentially 'inert' in terms of combustion, the Ash & Clinker could have the potential to combust (although the result reported lies at the 'lower end' of the relative spectrum).

### Asbestos

- 12.3.8 No asbestos fibres were identified in any of the 39 samples screened.

### Organic determinands

- 12.3.9 Whilst this site has not been previously developed, the majority of the area has been subject to opencast coal extraction and underground mining and a significant thickness of made ground is present beneath the entire development footprint.
- 12.3.10 Whilst made ground has been found to be essentially 'clean;' in terms of inorganic determinands (with the exception of localised Ash & Clinker) it contains a number of undesirable near-surface materials and consequently some clean cover is anticipated.
- 12.3.11 However, at this stage the Tier 1 Values used in this report have been conservatively 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).
- 12.3.12 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.
- 12.3.13 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.

- 12.3.14 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	4.0%	No.
Made Ground Topsoil	5.0%	
Ash & Clinker	9.0%	
Burnt Shale	3.0%	Yes, but no significant organic contamination was recorded in this soil type. All determinands well below "6%" screening value; most below limit of detection.
Cohesive Opencast Backfill	2.5%	
Granular Opencast Backfill	2.0%	

### Hydrocarbons (TPH & PAH)

- 12.3.15 Given the absence of visual/olfactory evidence of any hydrocarbon contamination, only a simple banded TPH (cf full speciation) was initially scheduled on 36 samples of made ground.
- 12.3.16 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.

### Polycyclic Aromatic Hydrocarbons (PAH)

- 12.3.17 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.
- 12.3.18 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).
- 12.3.19 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 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.

### BS3882 Topsoil testing

- 12.4.3 The presence of visible contaminants, sharps (glass etc) was assessed by the Engineer in the field (inspection of initial trial pit arisings and inspection of the recently ploughed surface); none were identified. BS3882 considers visual contaminants to comprise 'undesirable potentially injurious foreign object(s) visible to the naked eye'.

- 12.4.4 The clay/sand/silt content of 4 topsoil samples have been determined to check compliance with BS3882<sup>1</sup> requirements.
- 12.4.5 It should be noted that this is a reduced suite of analysis, and no N-P-K etc. testing has been undertaken.
- 12.4.6 The results are summarised below:

Parameter	BS3882 Specification	TP01 – 0.1m	TP23 – 0.1	TP36 – 0.1	TP14 – 0.1
Retained on 2mm sieve	< 30%	14	8	22	10
Retained on 20mm sieve	< 10%	3	2	<b>10</b>	0
Retained on 50mm sieve	0%	0	0	0	0
Clay content	5 to 35%	25	30	20	23
Silt content	0 to 65%	43	47	41	47
Sand content	0 to 90%	18	15	17	20

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

- 12.4.7 The above results suggest that the topsoil at this site complies to the standards set out in BS3882. In terms of textural classification, the topsoil falls into the 'silty clay' class.
- 12.4.8 However, it should be noted that during Lithos' trial pitting fragments of undesirable materials (notably glass, but also pottery and some gravel to cobble sized fragments of brick etc) were encountered during the trial pitting (glass encountered in 4 of 47 TPs). The presence of sharp and undesirable fragments within a Topsoil result in a failure to comply with BS3882 and consequently some site-won Topsoil at this site might be considered unsuitable for use.
- 12.4.9 Arable farmland sites typically generate a surplus of topsoil, and there might be implications here with export of surplus topsoil to other development sites.

## 13 CONTAMINATION (QUALITATIVE RISK ASSESSMENT & REMEDIATION)

### 13.1 Summary of significant contamination

- 13.1.1 Made ground underlies the majority of the site, and the entire development footprint, which is typically less than around 2.0m to 4.0m deep outside of the former opencast and between c. 4.0m and 15.5m deep inside the former opencast.
- 13.1.2 Made Ground predominantly comprises a veneer of Made Ground Topsoil over Cohesive and Granular Opencast Backfill. Some Burnt shale and localised Ash & Clinker has been encountered in the west and some coal arisings have been encountered at the base of the opencast from depths of around 9.0m.
- 13.1.3 Some inorganic contamination has been encountered in localised Ash & Clinker at depth (c. 1.5m in TP39). However, the bulk of the made ground tested has been found to be essentially 'clean'.
- 13.1.4 Whilst being chemically 'clean' the Made Ground at this site contains a number of undesirable near surface materials (oversized obstructions, brick etc) which are considered unsuitable to remain at/near surface in gardens and/or areas of POS following development.

<sup>1</sup> BS3882:2015. Specification for topsoil. Published by BSI Standards Limited.

13.1.5 No significant remediation should be necessary, but some preparatory works will be necessary to render the site suitable for development; see Section 18.2.

13.1.6 No significant groundwater contamination has been encountered during this ground investigation.

### 13.2 Revised conceptual ground model (contamination)

13.2.1 The Preliminary Conceptual Site Model has been amended in light of data obtained during the ground investigation, most notably with respect to the distribution of made ground and contaminants.

### 13.3 Environmental setting & end use

13.3.1 It is apparent from Section 13.1 above, that only limited contamination has been identified to date in the soils beneath this site.

13.3.2 In order to assess the significance of this contamination, consideration must be given to the site's environmental setting and the proposed end use.

13.3.3 The underlying Coal Measures are classified as a Secondary A Aquifer. The nearest surface watercourses are the un-named drainage ditches which flow along the northern boundary and through the east. Therefore, the site's environmental setting is considered to be **moderate sensitivity**.

13.3.4 With respect to human health, the proposed end use (residential) is considered **sensitive**.

13.3.5 Transient risks to construction workers can be addressed by the adoption of appropriate health and safety measures, see Section 18.6.

### 13.4 Contaminant linkages

13.4.1 In terms of a proposed redevelopment of this site, plausible contaminant linkages can be summarised as follows.

#### Contaminants

13.4.2 Contaminants have been summarised in Section 13.1 above and comprise a number of inorganic determinands in localised deposits of Ash & Clinker.

#### Pathways

13.4.3 Potential contaminant pathways include:

- Ingestion
- Dermal contact

#### Receptors

13.4.4 Potential contaminant receptors include:

- End users of the site (residents)

13.4.5 It can be concluded that there are plausible pathways between the soil contaminants summarised in Section 13.1 above. Consequently, some remediation will be required; either treatment/removal of the contaminant, or "breakage" of the pathway.

## 13.5 Potential remediation options

### General

13.5.1 Approval of the recommendations given below should be sought from the appropriate regulatory authorities prior to commencement of site redevelopment.

### Combustibility

13.5.2 The Ash & Clinker at this site yielded an average CV of 3.2 MJ/kg. This is at the lower end of the range where the potential for combustion exists but 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 **600mm** thickness of inert soil, comprising 450mm 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: no action required (the floor slab will include insulation and therefore heat transfer into the ground will be negligible). Local Authority Building Control and Warranty Provider approval should be sought.

13.5.3 As further mitigation against the risk of spontaneous combustion, the ash could be excavated, replaced in approximate 300mm thick layers, wetted and subjected to nominal compaction, comprising at least 2 passes with a towed vibratory roller of at least 2,900 kg per metre width. Compaction will help to prevent the material drying out and reduce the ingress of oxygen.

### Inorganic contamination

13.5.4 The Ash & Clinker has yielded elevated concentrations of a number of metals; lead and zinc. Therefore, where residual made ground remains beneath garden and landscaped areas (i.e. not beneath hardstanding) a **600mm** thick surface cover of "clean" soil comprising 500mm subsoil and 100mm topsoil is recommended. This cover will break potential contaminant linkages between the contaminated made ground and future end-users.

13.5.5 Alternatively, the Ash & Clinker is considered suitable for redistribution beneath concrete oversite or areas of hardstanding, where they would be satisfactorily isolated from end users.

13.5.6 The majority made ground has been found to be essentially "clean" (i.e. it has not yielded elevated concentrations of any contaminants), but it does include "unsuitable" materials (e.g. they contain a significant proportion e.g. demolition rubble, colliery spoil, brick, pottery, and locally tin, rope, timber and plastic etc.). Therefore, where residual made ground remains beneath garden and landscaped areas (i.e. not beneath hardstanding) a **450mm** thick surface cover of "clean" soil is recommended. This thickness is in accordance with NHBC Standards, Chapter 10.2. Any obstructions should be removed from within 450mm of the finished ground surface in proposed garden areas.

## Organic contamination

- 13.5.7 No areas of gross organic contamination were encountered during the site works. However, localised areas of more onerous contamination than that identified to date may be present on site.

## Groundwater & surface water

- 13.5.8 As discussed in Section 13.1 above, no significant groundwater or surface water contamination has been encountered.
- 13.5.9 Regardless groundworkers should make all necessary arrangements to prevent off-site migration of contaminants via surface water runoff, inadvertent groundwater disturbance and airborne dust.

## 13.6 Summary of potential contaminant linkages & mitigation

- 13.6.1 In terms of the proposed redevelopment plausible contaminant linkages, and feasible remediation options, can be summarised as follows:

Receptors	Pathways	Contaminants	Plausible contaminant linkage? (and remediation options where required)
Human health (Future residents) ◊	Consumption of contaminated vegetables	Metals in Ash & Clinker	Isolation beneath at least 600mm clean soil cover in garden and landscaped areas.
	Ingestion		
	Dermal contact		
Buildings	Migration & accumulation of explosive gas	Methane/carbon dioxide	To be assessed on completion of monitoring and gas risk assessment.
Surface watercourses	Surface water run-off	Metals, hydrocarbons in the made ground	Yes. Silt and surface water management plan (SWMP) required.

◊ transient risks to construction workers will be addressed by the adoption of appropriate health and safety measures in accordance with the Health and Safety at Work Act 1974 and regulations made under the Act including for example the COSHH Regulations.

## 13.7 Waste classification

- 13.7.1 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. Disposal to landfill (or an appropriate soil / aggregate transfer station) may be the most practical solution, if redistribution and retention on site is not feasible.
- 13.7.2 Following excavation and stockpiling, sampling will be required prior to disposal.
- 13.7.3 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<sup>2</sup>. 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.

<sup>2</sup> Technical Guidance WM3 – Guidance on the classification and assessment of waste. Environment Agency 2015

- 13.7.4 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.
- 13.7.5 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.
- 13.7.6 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 Developer), to ensure that the waste is handled and disposed of appropriately.
- 13.7.7 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 13 but will often need supplementing with further testing after soils have been stockpiled (see also advice in Section 18.2.3).
- 13.7.8 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.
- 13.7.9 With respect to **asbestos**, waste soils will be classed hazardous if the soil mass contains more than 0.1% asbestos fibres that are free and dispersed. However, WM3 states that where the waste contains identifiable pieces of asbestos (i.e. any particle of a size that can be identified as potentially being asbestos by a competent person if examined by the naked eye), then the waste is hazardous if the concentration of asbestos in the pieces alone is 0.1%. If a stockpile of soil contained rare fragments of broken asbestos-cement sheeting, the whole stockpile would be classed as hazardous unless all the fragments could be picked-out (even though the concentration of asbestos in the soil mass might be orders of magnitude less than 0.1%).
- 13.7.10 Contractors exporting waste from the site should review the site investigation data and make their own assessment. Alternatively, Lithos could undertake this assessment once exported waste streams have been identified.

## 14 HAZARDOUS GAS

### 14.1 General

14.1.1 The site may be affected by sources of hazardous gas generation as it is:

- Underlain by significant thicknesses of made ground (Opencast Backfill)
- Located within 250m of further areas of deep made ground
- Underlain by shallow coal and mineworkings

14.1.2 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
On-site made ground	Human health	Asphyxiation & explosion	Vertical migration, ingress & accumulation	<b>Low:</b> made ground essentially inert, with little degradable matter
	Buildings	Explosion		
Off-site made ground	Human health	Asphyxiation & explosion	Lateral migration, ingress & accumulation	<b>Low:</b> likely to be of similar composition to on-site made ground; little degradable matter.
	Buildings	Explosion		
Shallow mineworkings	Human health	Asphyxiation & explosion	Vertical migration, ingress & accumulation	<b>Moderate:</b> no significant thickness of low permeability drift or bedrock above workings
	Buildings	Explosion		

14.1.3 Given the above gas monitoring wells have been installed in 20 boreholes across the site. Details of the installations are given on the borehole and probehole logs presented in Appendices G and H to this the report.

14.1.4 The generation potential of the gas source was initially considered to be moderate. Consequently, in accordance with CIRIA Report C665<sup>3</sup>, 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 for groundwater levels and soils-gases, and the results are presented in Appendix M.

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)

<sup>3</sup> CIRIA C665: *Assessing risks posed by hazardous ground gases to buildings (2007)*.

## 14.3 Monitoring results

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

Hole ID	Response zone	Range of methane concentrations (% v/v)	Range of carbon dioxide concentrations (% v/v)	Range of steady flow rates (litre/hour)
BH01	2.7m to 5.7m; Cohesive Opencast Backfill.	0.0	1.3 - 1.5	0.0
BH02	2.7m to 5.7m; Cohesive Opencast Backfill.	0.0	0.9 - 1.1	0.0
BH03	2.7m to 5.7m; Cohesive Opencast Backfill.	0.0	4.5 - 5.3	0.0
BH04	2.7m to 5.7m; Cohesive Opencast Backfill.	0.0	0.8 - 1.6	0.0
BH05	2.7m to 5.7m; Cohesive Opencast Backfill.	0.0	3.5 - 4.1	0.0
BH06	2.7m to 5.7m; Cohesive Opencast Backfill.	0.0	1.8 - 4.2	0.0
BH07	2.7m to 5.7m; Cohesive Opencast Backfill.	0.0	2.0 - 3.4	0.0
BH08	2.7m to 5.7m; Cohesive Opencast Backfill.	0.0	2.4 - 9.2	0.0
BH09	2.7m to 5.7m; Cohesive Opencast Backfill.	0.0	1.2 - 2.3	0.0
BH10	2.7m to 5.7m; Cohesive Opencast Backfill.	0.0	1.9 - 2.3	0.0
PH01	4.5m to 7.5m; Opencast Backfill.	0.0	13.6 - 20.0	0.0
PH04	3.0m to 4.5m; Coal Measures Sandstone.	0.0	4.9 - 5.7	0.0
PH08	4.5m to 7.5m; Opencast Backfill.	0.0	0.1 - 2.3	0.0
PH13	7.0m to 13.0m; Opencast Backfill.	0.0	0.9 - 2.4	0.0
PH14	5.3m to 8.3m; Opencast Backfill.	0.0	3.7 - 4.1	0.0
PH15	8.1m to 14.1m; Opencast Backfill.	0.0	0.7 - 1.5	0.0
PH17	1.5m to 3.0m; Cohesive Residual Soil.	0.0	1.4 - 1.8	0.0
PH21	1.5m to 3.0m; Cohesive Residual Soil.	0.0	2.4 - 2.5	0.0
PH26	1.5m to 3.0m; Cohesive Residual Soil.	0.0	0.5	0.0
PH27	9.5m to 140m; Coal Measures Sandstone.	0.0	0.8	0.0

## 14.4 Discussion (methane & carbon dioxide)

- 14.4.1 Generic Note 05 in Appendix A outlines how monitoring results are interpreted.
- 14.4.2 A hazardous gas risk assessment incorporating all of the results will be issued on completion of monitoring in May 2023.

## 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<sup>-3</sup>) 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 UK Health Security Agency radon map indicate that the site is in an area where **between 3% and 5%** of homes are estimated to be above the action level. Note, the radon maps were revised and updated on the 1<sup>st</sup> December 2022.

14.5.4 The Landmark report indicates that 1 to 3% of homes are estimated to be above the action level, however, the Landmark report is dated before 1<sup>st</sup> December 2022, and therefore is derived from an out-of-date data source.

14.5.5 Consequently, following the update to the radon maps, basic radon protection measures **are** required.

## 15 GEOTECHNICAL TESTING

### 15.1 General

15.1.1 A total of 85 samples of Made Ground and 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 L to this report.

### 15.2 Atterberg limits

15.2.1 The plasticity indices of 24 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 Opencast Backfill	14	6 – 21 (13)	9 – 21 (14)	Low
Cohesive Residual Soil	10	13 – 24 (18)	19 – 29 (22)	Medium

\* 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 be regarded as being of **medium** shrinkability.

### 15.3 Particle size distribution

15.3.1 The gradings of 16 samples of made ground have been determined by wet sieving and the results are summarised in the table below:

Sample & depth	Field description	% passing 37.5mm sieve	% passing 20mm sieve	% passing 2mm sieve	% fines	Material description (based on grading & plasticity)
TP01 – 1.9m	(Burnt Shale) clayey gravelly SAND.	91	89	51	17	Very sandy clayey GRAVEL low cobble content.
TP10 – 0.7m	(Burnt Shale) clayey GRAVEL low cobble content.	62	55	34	20	Clayey sandy GRAVEL medium cobble content.
TP33 – 2.0m	(Burnt Shale) clayey GRAVEL medium cobble content	57	41	24	16	Clayey sandy GRAVEL medium cobble content.
TP13 – 1.5m	(Coal Measures) rec as sand GRAVEL	68	51	24	9	Sandy clayey GRAVEL medium cobble content.
TP16 – 2.5m	(Coal Measures) rec as GRAVEL medium cobble content.	37	19	5	4	Slightly clayey GRAVEL rare sand high cobble content.

Sample & depth	Field description	% passing 37.5mm sieve	% passing 20mm sieve	% passing 2mm sieve	% fines	Material description (based on grading & plasticity)
TP18 – 3.0m	(Coal Measures) rec as slightly clayey GRAVEL.	43	14	7	6	Slightly clayey GRAVEL rare sand high cobble content.
TP44 – 2.2m	(Coal Measures) rec as slightly clayey slightly sandy GRAVEL.	50	35	19	12	Clayey sandy GRAVEL medium cobble content.
TP26 – 1.0m	(Cohesive Opencast Backfill) very gravelly slightly sandy CLAY.	100	100	85	70	Slightly sandy slightly gravelly clayey SILT.
TP42 – 3.0m	(Cohesive Opencast Backfill) gravelly CLAY medium cobble content.	84	76	45	30	Sandy silty clayey GRAVEL rare cobbles.
TP10 – 1.2m	(Cohesive Residual Soil) CLAY.	100	100	91	78	Slightly gravelly slightly sandy silty CLAY.
TP15 – 0.6m	(Cohesive Residual Soil) gravelly CLAY.	100	100	92	75	Slightly sandy slightly gravelly clayey SILT.
TP07 – 0.7m	(Granular Opencast Backfill) clayey slightly sandy GRAVEL.	70	59	26	15	Clayey sandy GRAVEL medium cobble content.
TP08 – 1.9m	(Granular Opencast Backfill) slightly clayey GRAVEL medium cobble content.	46	34	18	11	Clayey sandy GRAVEL high cobble content.
TP20 – 0.5m	(Granular Opencast Backfill) sandy GRAVEL low cobble content.	58	46	19	12	Clayey sandy GRAVEL high cobble content.
TP27 – 0.8m	(Granular Opencast Backfill) very clayey slightly sandy GRAVEL low cobble content.	90	87	69	37	Sandy gravelly CLAY rare cobbles.
BH09 – 9.0m	(Coal Arisings) very sandy GRAVEL.	100	98	83	56	Slightly sandy slightly gravelly CLAY.

15.3.2 The gradings reported above generally supported the field descriptions which are shown on the exploratory hole logs although samples recovered from TP27 at 0.8m and at BH09 at 9.0m which were found to be cohesive rather than granular as described in the field.

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

## 15.4 Soluble sulphate and pH

15.4.1 In accordance with BRE SD1<sup>4</sup>, this site has been classified as brownfield with a mobile groundwater regime.

15.4.2 It is envisaged foundations will extend to depths of about 1.0m through made ground and natural strata and samples taken from this depth range have been submitted for pH and water-soluble sulphate (2:1 soil/water extract).

15.4.3 The pH and the concentrations of sulphate in the aqueous natural soil extracts of 45 samples of made and natural ground has 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.

<sup>4</sup> BRE Special Digest 1 (2005) – Concrete in aggressive ground.

Soil type	No. samples tested	Lowest pH values	Highest soluble sulphate concentration (mg/l)
Barnsley Coal Seam	1	3.6	23
Burnt Shale	3	6.4	150
Coal Arisings	4	4.4	840
Coal Measures	11	4.0	430
Cohesive Opencast Backfill	12	4.3	150
Cohesive Residual Soil	9	4.6	250
Granular Opencast Backfill	3	6.4	16
Granular Residual Soil	3	7	54

15.4.5 In total, 11 of the 45 samples tested yielded pH values below 5.5, therefore supplementary analysis to determine the concentrations of magnesium, chloride and nitrate was scheduled. The 11 samples yielded magnesium, chloride and nitrate results of greater than 10mg/l and consequently the equivalent sulphate concentrations have been calculated and added to the initial results in accordance with BRE SD-1:2005.

15.4.6 In accordance with Tables C1 and C2 of SD1, sub-surface concrete should be Design Sulphate Class **DS-2**, with the site allocated an ACEC Classification of **AC-3z**.

## 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<sup>5</sup> 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 16 samples (using a 4.5kg 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 If particle sizes are only slightly in excess of the above limits, 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.

15.5.7 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.

15.5.8 The results are summarised in the tables below:

<sup>5</sup> BS5930 (2015) - Code of practice for ground investigations.

Sample location & depth	Material description	Gs (Mg/m <sup>3</sup> )	MDD (Mg/m <sup>3</sup> )	OMC (%)	Allowable mc range for 95% MDD & <5% air voids	Typical in-situ moisture content (%)
TP01 – 1.9m	Burnt Shale	2.4	1.75	13	13.0 – 18.0	<b>19</b>
TP10 – 0.7m	Burnt Shale	2.6	1.96	11	10.0 - 14.0	11
TP33 – 2.0m	Burnt Shale	2.65	1.98	11	10.0 - 15.0	13
TP13 – 1.5m	Coal Measures	2.65	1.97	11	10.0 - 15.0	<b>8.3</b>
TP16 – 2.5m	Coal Measures	2.65	1.97	11	11.0 - 16.0	11
TP18 – 3.0m	Coal Measures	2.6	2.03	9	8.0 - 13.0	9
TP44 – 2.2m	Coal Measures	2.7	2.02	11	10.0 - 15.0	<b>6.7</b>
TP26 – 1.0m	Cohesive Opencast Backfill	2.5	1.73	16	15.0 - 20.0	19
TP42 – 3.0m	Cohesive Opencast Backfill	2.45	1.81	12	14.0 - 17.0	15
TP10 – 1.2m	Cohesive Residual Soil	2.65	1.81	16	15.0 - 20.0	19
TP15 – 0.6m	Cohesive Residual Soil	2.6	1.86	14	13.0 - 17.0	14
TP07 – 0.7m	Granular Opencast Backfill	2.55	1.93	11	10.0 - 14.0	14
TP08 – 1.9m	Granular Opencast Backfill	2.65	2.03	10	9.0 - 14.0	12
TP20 – 0.5m	Granular Opencast Backfill	2.7	2.03	11	10.0 – 14.0	<b>8.8</b>
TP27 – 0.8m	Granular Opencast Backfill	2.55	1.88	13	11.0 - 16.0	13
BH09 – 9.0m	Coal Arisings	2.1	1.57	14	13.0 – 19.0	<b>29</b>

**Note:** Values in **bold** have an in-situ moisture content beyond the allowable moisture content envelope.

- 15.5.9 It is apparent from the results above that the moisture contents of made ground and natural soils are generally either within or close to the allowable moisture contents to achieve 95% MDD and >5% air voids, and on this basis it is considered that site won materials are generally suitable for reengineering subject to careful management and occasional drying or wetting where required.
- 15.5.10 The Coal Arisings recovered from BH09 were considerably above the allowable moisture range and this material would not be considered suitable for re-use as an engineering fill.
- 15.5.11 Acceptability of site won materials for use in the proposed controlled earthworks will need detailed appraisal by the Earthworks Designer in light of the required performance characteristics.

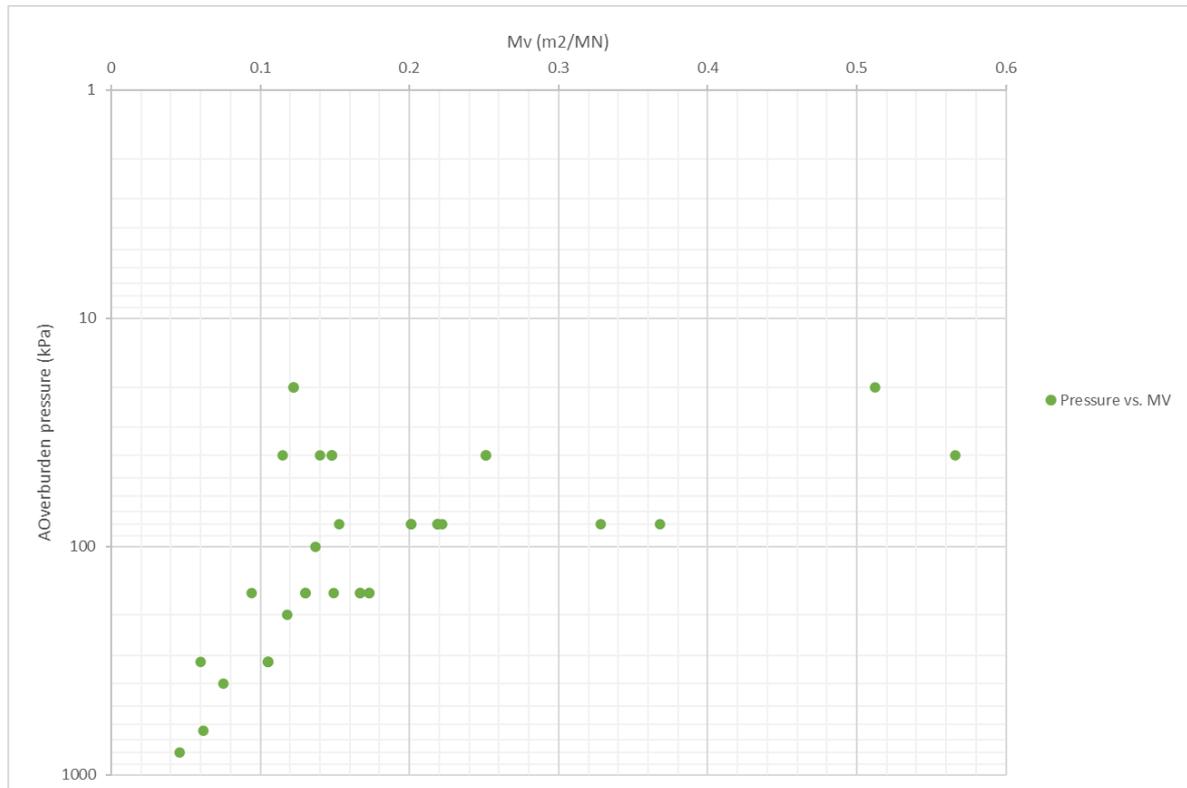
## 15.6 One dimensional consolidation tests

- 15.6.1 To assess the settlement characteristics of the natural cohesive strata, one-dimensional consolidation tests were carried out on 7 samples of Cohesive Opencast Backfill. Four loading pressures and one unloading pressure were specified in accordance with BS1377<sup>6</sup>.
- 15.6.2 Laboratory certificates are included in Appendix L. The results are provided as plots of voids ratio and coefficient of consolidation against applied pressure. The coefficient of volume compressibility ( $m_v$ ) has been derived for each test in accordance with BS1377 at a pressure range starting close to overburden ( $p_0$ ).
- 15.6.3 Tests are summarised in the table below.

Hole	Depth (m)	Material	$m_v$ ( $m^2/MN$ )*	Compressibility assessment
BH10	4.0	Cohesive Opencast Backfill	0.173	Medium.
BH02	1.0	Cohesive Opencast Backfill	0.148	Medium.
BH03	2.0	Cohesive Opencast Backfill	0.219	Medium.
BH04	1.0	Cohesive Opencast Backfill	0.566	High.
BH06	1.0	Cohesive Opencast Backfill	0.115	Medium.
BH06	5.0	Cohesive Opencast Backfill	0.118	Medium.
BH08	2.0	Cohesive Opencast Backfill	0.153	Medium.

\* Design  $m_v$  value calculated for a stress increment starting at the approximate overburden pressure.

- 15.6.4 The graph below shows variation in  $m_v$  with depth (increasing overburden pressure; as plotted on a log scale):



<sup>6</sup> BS1377 (1990) – Methods of test for Soils for civil engineering purposes. Part 5: Compressibility, permeability & durability tests.

## 15.7 Undrained shear strength testing

### Undrained triaxial compression tests

- 15.7.1 Unconsolidated undrained triaxial compression tests were carried out at a single cell pressure, roughly equal to the overburden pressure, on 6 undisturbed samples of Cohesive Opencast Backfill.
- 15.7.2 Fully saturated conditions were assumed and the apparent undrained cohesion  $S_u$ , was taken as half the deviator stress at failure. Results are summarised in the table below.

Hole	Depth (m)	Material	Field description	Laboratory Shear strength/kPa	Strength term
BH10	1.0	Cohesive Opencast Backfill	Firm	127	High strength
BH03	4.0	Cohesive Opencast Backfill	Firm	130	High strength
BH05	2.0	Cohesive Opencast Backfill	Firm	104	High strength
BH07	1.0	Cohesive Opencast Backfill	Firm	47	Medium strength
BH08	6.5	Cohesive Opencast Backfill	Firm	89	High strength
BH09	4.0	Cohesive Opencast Backfill	Firm	92	High strength

### Hand shear vane testing

- 15.7.3 Hand shear vane testing was undertaken within trial pits in-situ to around 1.2m depth and from larger blocks of excavated clay below that depth. Test results are summarised in the table below:

Material	no. of tests	Range of test results & ave. (kPa)	Strength (BS5930:2015)
Cohesive Opencast Backfill	24	92 – 150 (130)	High strength.
Cohesive Residual Soil	1	84	High strength.

## 15.8 Standard penetration test (SPT)

15.8.1 The in-situ relative density of soils was established by carrying out Standard Penetration Tests (SPTs) during the drilling of the cable percussion boreholes and results are presented in the graph below:



15.8.2 The results are summarised within the plot below and illustrate a loose linear increase in undrained shear strength ( $S_u$ ) with depth within the Cohesive Opencast Backfill materials. Bedrock and the Coal Arisings typically refused before SPT tests were completed.

## 15.9 Rock strength testing

### General

15.9.1 A total of 25 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 page 52.

15.9.2 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.

### Summary of Point Load Testing

15.9.3 A total of 17 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.

- 15.9.4 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.
- 15.9.5 Whilst a variety of correction factors have been published. Mark and Rusnak<sup>7</sup> published a conversion factor of 21 following a case study of Coal Measures bedrock across North America.
- 15.9.6 Therefore, Lithos have adopted a correction factor of 21 to convert the  $I_{s50}$  into a uniaxial Compressive Strength equivalent in MPa.
- 15.9.7 Results are summarised in the table below:

Material (no of samples)	Range of PL results ( $I_{s50}$ )			
	Parallel (ave)	UCS (MPa) Parallel	Perpendicular (ave)	UCS (MPa) Perpendicular
Mudstone (5)	0.06 – 1.34 (0.36)	1.26 – 28.14	0.13 – 2.95 (0.98)	2.73 – 61.95
Siltstone (7)	0.13 – 0.72 (0.32)	2.73 – 15.12	0.29 – 1.93 (0.81)	6.09 – 40.53
Sandstone (5)	0.15 – 0.84 (0.52)	3.15 – 17.64	0.29 – 1.95 (1.28)	6.09 – 40.95

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

### Summary of UCS testing

- 15.9.9 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:

Hole ID	Rock Type	Sample depth (mbgl)	UCS (MPa)	Failure Mode	Strength description (BS5930)
RC01	Sandstone.	10.4	44.7	Brittle	Medium strong.
RC01	Mudstone.	10.7	7.7	Brittle	Weak.
RC02	Sandstone.	15.0	47.9	Brittle	Medium strong.
RC02	Sandstone.	17.1	47.0	Brittle	Medium strong.
RC02	Siltstone.	18.9	50.6	Brittle	Strong.
RC03	Siltstone.	13.2	41.7	Brittle	Medium strong.
RC03	Siltstone.	13.7	44.1	Brittle	Medium strong.
RC03	Siltstone.	15.3	43.4	Brittle	Medium strong.

### Summary of rock strength

- 15.9.10 Coal Measures Mudstone is typically weak, the Siltstone and Sandstone is typically medium strong. This broadly 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.

<sup>7</sup> Using the point load test to determine the uniaxial compressive strength of Coal Measure Rock. J Rusnak & C Mark. August 200. Proceedings on the 19<sup>th</sup> international conference on ground control in mining. Pgs. 362 - 371

## 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 across the footprint of the former opencasts.

### 16.2 Mining & quarrying

16.2.1 This site is located within a Coal Mining Development High Risk Area.

16.2.2 About 65% of the total site area (and about 80% of the proposed development footprint) has been subject to opencast coal extraction of the Barnsley Coal Seam. Opencasting has taken place historically (likely c. 1920) across the west of the site (close to the seam outcrop) and in the late 1950's across the majority of the site, with the deepest areas of opencast being in the southeast and reaching around 15.5m depth.

16.2.3 Outside the footprint of the opencast, notably to the south and east, the Barnsley Coal Seam remains in place at between around 10.0m and 16.0m depth and has been heavily worked by underground methods. Underground workings are considered to pose a significant potential risk to surface stability.

16.2.4 Mine entries comprising day holes/adits may remain in place along/beyond the western boundary (along Farm House Lane), although it is likely that many of these, including a shaft in the centre-south) have been removed by opencasting.

16.2.5 The next shallowest coal is the Dunsil Coal Seam which lies about 14.0m below the Barnsley Coal and the base of the former opencast. No evidence of underground workings have been encountered in the Dunsil Coal and, given the seam thickness (c. 0.5m) any workings (if present) would not be considered likely to pose a significant risk to surface stability.

#### Shallow mineworkings

16.2.6 CIRIA SP32:1984<sup>8</sup> suggests voids resulting from mineral extraction are unlikely to migrate more than 10 times the seam thickness through competent bedrock. CIRIA C758D<sup>9</sup> notes that the use of this 10 times 'rule-of-thumb', as the design basis for treatment depth, has been observed to be successful over many years for a wide range of mineworkings and overlying rock/soil strata scenarios. However, consideration must always be given to site specifics such as nature of roof strata, strata dip, groundwater, extraction ratio etc.

16.2.7 Mitigation against the risk of subsidence associated with the shallow mineworkings will be required across about 20% of the site's total area (likely Plots 5, 10, 11 & 24 to 33, possibly also for some of plots 67 to 78 based on current layout as shown on Drawing 4454/2). This will likely involve consolidation by drilling and grouting.

16.2.8 Based on the findings of this investigation and the anticipated nature of the workings, it is considered that the necessary consolidation (grouting) would require drilling holes on a 3m grid. A viscous grout composed of appropriate proportions of OPC, PFA, sand or pea gravel would then be injected into the workings via these holes.

16.2.9 Further holes would need to be drilled in areas of high grout take (to confirm filling of void space), and in areas where several adjacent holes encountered solid coal (to confirm that the local area is underlain by no workings, rather than pillars).

<sup>8</sup> CIRIA SP32 (1984) - Construction over abandoned mine workings

<sup>9</sup> CIRIA C758D (2019) - Abandoned mine workings manual

16.2.10 Drilling and grouting operations should be carried out with engineering supervision and be undertaken in accordance with a revision of Lithos' "General Specification for the Treatment of Shallow Mineworkings" tailored to the site-specifics.

### **Mine entries**

16.2.11 As discussed in Section 5.3.1 there are 7 known mine entries within the site's boundary.

16.2.12 To date no mine entries have been located as part of Lithos' investigation due to the significant thicknesses of made ground across the site making a shaft search impractical.

16.2.13 However, based on the findings of Lithos' work to date, it seems highly likely that the majority of mine entries across the site (notably shaft refs. 432406-014, 015, 016 & 019) have been removed during historical and 1950's opencasting works. Consequently, there is a limited risk posed by these features.

16.2.14 the CA will expect Strata's layout to assume a no-build "zones of influence" around each remaining mine entry.

16.2.15 It is possible that unrecorded "shallow" shafts (possibly bell pits) may be present at this site (likely bell pits/day holes along the western periphery & deeper shafts along the eastern boundary), and consideration could be given to a geophysical survey, although success would be dependent on the "contrast" between shaft backfill and the surrounding ground (i.e. the survey is likely to be more successful if shaft backfill is significantly different material or less dense than the surrounding ground). Follow-up intrusive investigation (pitting) would be recommended to determine the cause of any anomalies identified by the geophysics.

16.2.16 Given the absence of loose superficial deposits, it is considered unlikely that such mine entries would have been lined.

16.2.17 A topsoil strip could also be considered, however deep made ground, notably across the west would make this highly problematic.

16.2.18 Turnover of made ground is anticipated and it would be prudent to incorporate examination of natural ground below the turnover for evidence of mine entries along the western periphery (notably beneath Plots 67 to 78).

16.2.19 Where build over a shaft(s) is proposed, Strata will need to discuss proposed treatment (which is likely to include both grouting of the shaft backfill, and a cap at rockhead) and bespoke foundation design, by a suitably qualified structural engineer, with the Coal Authority. A Permit to Enter or Disturb Coal Authority Mining Interests will be required prior to construction of any shaft cap.

16.2.20 Proposals to treat the mineworkings and shafts will need to be discussed with both the Local Authority (most notably Highways), the Coal Authority and NHBC well in advance of starting works on site.

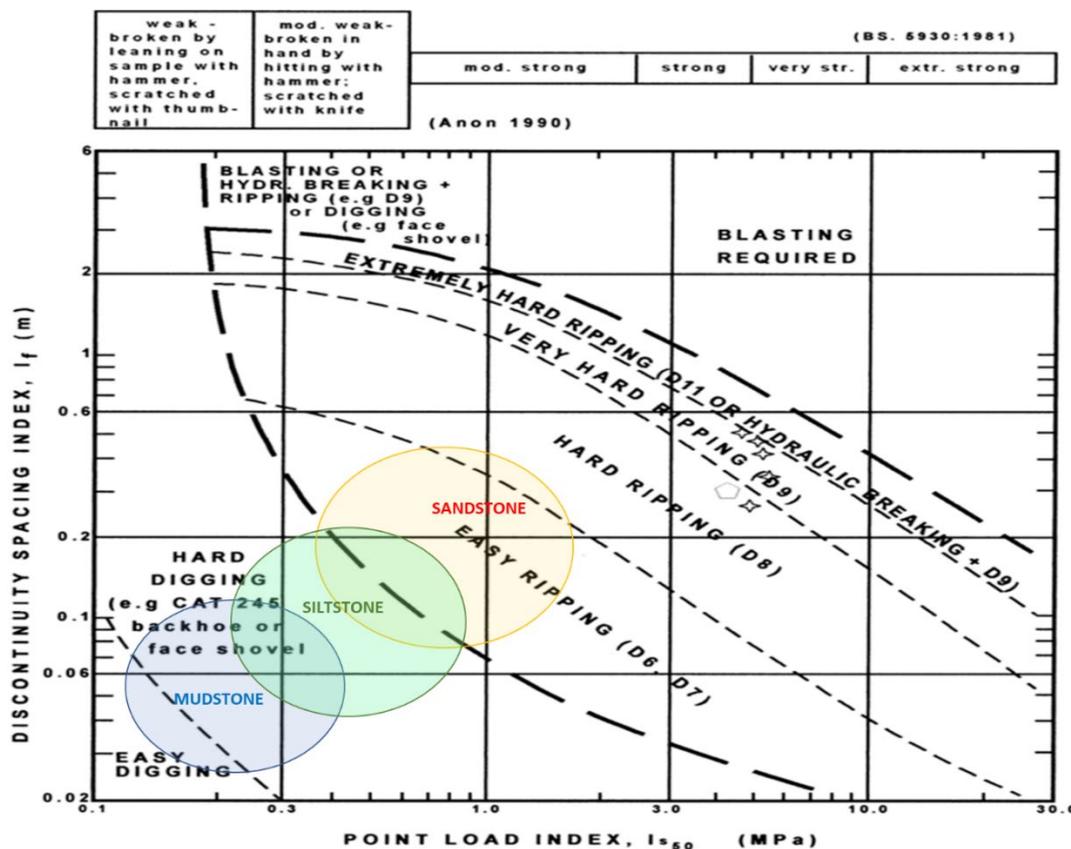
16.2.21 Any shafts encountered during the development of this site should be made safe by treatment in accordance with an appropriate Specification (Lithos can prepare this) and a Coal Authority Permit to Enter or Disturb Coal Authority Mining Interests.

### **16.3 Excavatability**

16.3.1 As outlined in Section 16.3 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 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 Siltstone.

16.3.3 Excavatability can be characterised by plotting point load results (in  $I_{s50}$ ) against fracture spacing on the Pettifer-Fookes chart. Indicative excavatability of rock from levels above the proposed finished floor levels (i.e. 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 some siltstones and sandstone (if encountered) may require ripping (D6, D7 & D8 Dozers) possibly with more specialised equipment.

## 16.4 Foundation recommendations

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 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.

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

- 16.4.4 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.
- 16.4.5 Made ground in its current condition is not considered a suitable foundation material and foundations should therefore be taken through these materials into underlying natural strata of adequate bearing capacity.
- 16.4.6 Sub-surface concrete should be Design Sulphate Class **DS-2**, with the site allocated an ACEC Classification of **AC-3z**.
- 16.4.7 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 Drawing 4454/12). It should be noted that the thickness of made ground will be subject to change following the anticipated remediation and regrade earthworks.

### Less than 2.5m total Made Ground

#### Strip/trench fill footings

- 16.4.8 It is considered that shallow strip or deepened trench fill footings will be the most suitable foundation solution for plots constructed in areas where the thickness of made ground is less than about 2.5m.
- 16.4.9 Footings will be founded in Residual Soils or upon competent bedrock.
- 16.4.10 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.
- 16.4.11 Foundations will be required to be placed below a line drawn up at 45° from the base of any service or similar excavation.
- 16.4.12 Deepened foundations should be stepped in accordance with NHBC Standards, Chapter 4.3.
- 16.4.13 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).
- 16.4.14 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.
- 16.4.15 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.
- 16.4.16 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.
- 16.4.17 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.

- 16.4.18 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.
- 16.4.19 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.
- 16.4.20 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).
- 16.4.21 It would therefore be prudent to prepare a detailed foundation schedule and seek approval from NHBC in order to determine likely foundation abnormalities.
- 16.4.22 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)
- 16.4.23 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.
- 16.4.24 The **Coal Measures Bedrock** is generally considered to have a safe bearing capacity of at least 250kPa and minimal settlements would be anticipated.
- 16.4.25 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.
- 16.4.26 Shallow bedrock (outside of the opencast) at the site predominantly comprises mudstones and some siltstones which can be relatively 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.
- 16.4.27 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.
- 16.4.28 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.

- 16.4.29 It should be noted that the Barnsley Coal Seam reaches a thickness of about 3.0m and this could result in excavations having to be overdeepened to in excess of 5.0m below FFL (although to date the thickness of coal close to outcrop has typically been much thinner). Therefore, it cannot be discounted that where coal is encountered in foundation excavations, the use of trench fill foundations may become impractical and uneconomical.
- 16.4.30 Consequently, it would be prudent to allow for some localised abandoning and backfilling of foundation excavations and piling of plots across the west of the site should a significant thickness of coal be encountered.
- 16.4.31 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).

### Strip footings over grouted workings

- 16.4.32 Along the western edge of the site strip footings are anticipated which will overlay underground workings which have been consolidated by means of drill & grout.
- 16.4.33 Even after consolidation, foundations should be “beefed-up” to accommodate any potential time dependant differential settlement.
- 16.4.34 Further advice regarding reinforcement should be sought from the appointed Structural Engineer, but in the meantime reference should be made to the table below.

Rock cover above grouted seam	Preferred Foundation
<5 x seam thickness <sup>10</sup>	Raft - designed to span 3m over potential soft spots and cantilever 1.5m at corners. Either stiffened, flat-bottomed rafts a minimum of 300mm thick, on 450mm of compacted Type 1 material, with reinforcement top and bottom. Or, rafts could be of 300mm concrete with a 150mm upstand to allow for wall construction provided that the base of compacted type 1 material lies at a depth of at least 600mm
>5 x seam thickness – 10m	Strip footing OK, but thickened (300mm), and reinforced top and bottom
>10m	Strip footing OK, but needs to be 300mm thick reinforced with one layer of mesh

### Greater than 2.5m total Made Ground

#### Raft or reinforced beam foundations (on engineered fill)

- 16.4.35 As discussed in Section 17, turnover of at least the uppermost 3.0m of Made Ground is recommended 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 -beam “grillage” type foundations.
- 16.4.36 In areas where ground bearing foundations (rafts and or beam “grillage”) are proposed, at least 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).

<sup>10</sup> See s5.6 of *Structural Foundations Manual* (M F Atkinson) 2<sup>nd</sup> Ed.

- 16.4.37 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.
- 16.4.38 The suitability of made ground for placement as engineered fill should be confirmed by field trials and laboratory testing.
- 16.4.39 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
- 16.4.40 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.
- 16.4.41 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).
- 16.4.42 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.
- 16.4.43 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.
- 16.4.44 Should any long terraces/blocks be proposed they should incorporate structural movement joints to mitigate the risk of differential settlement across the block/terrace.
- 16.4.45 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.
- 16.4.46 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.
- 16.4.47 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.

- 16.4.48 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.
- 16.4.49 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

- 16.4.50 Piled foundations may be an option for plots where the total thickness of made ground exceeds 2.5m, and for plots where a significant thickness of coal is encountered within foundation excavations (see Section 16.4.30).
- 16.4.51 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<sup>11</sup> and EC7<sup>12</sup>, rotary cored boreholes have been advanced into the base of the former opencast (see Section 11.4.5) and samples of bedrock have been submitted for geotechnical testing (see Section 15.9).
- 16.4.52 Given the potential for **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.
- 16.4.53 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.
- 16.4.54 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.
- 16.4.55 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.
- 16.4.56 Given the presence of highwalls and variable depths to bedrock across the site (see Drawings 4454/10, /12, /13 and /14), 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.
- 16.4.57 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).

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<sup>11</sup> BS 8004 (2015) - Code of practice for foundations.

<sup>12</sup> BS EN 1997-1:2007. Eurocode 7: Geotechnical design – Part 2: Ground investigation & testing

- 16.4.58 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.
- 16.4.59 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.
- 16.4.60 Bedrock lies at depths of between c. 4.5m and 15.5m below current ground levels. The depth to, and level of, natural ground (bedrock) inside of the former opencast is shown on Drawings 4454/12.
- 16.4.61 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.
- 16.4.62 Consequently, preliminary estimates for pile lengths (based on existing ground levels) are in the order of between 7.0m and c. 19.0m.
- 16.4.63 Any plots that straddle the buried highwall zone of influence (as shown on Drawing 4454/14) will require a more robust foundation type, such as bored piles and possibly the use of a stiff raft (subject to detailed design).
- 16.4.64 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).
- 16.4.65 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.
- 16.4.66 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.
- 16.4.67 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.
- 16.4.68 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.

- 16.4.69 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".
- 16.4.70 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
- 16.4.71 The number of plots affected by piling will depend on final levels, layout proposals, and Strata's preferred foundation solution following an appraisal of cost, speed of construction and perceived risk.
- 16.4.72 It may be more practical and economic to pile all 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.
- 16.4.73 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.

#### Piles over grouted workings

- 16.4.74 Piling over shallow mineworkings (even after grouting) is not common practice. In addition, it would be prudent to discuss proposals with specialist piling contractor and seek their views.
- 16.4.75 Current UK guidance is provided in CIRIA C758D<sup>13</sup>, which provides information and guidance for engineers and geologists with respect to the design of: mining investigations; foundations; and remedial measures. It describes: past methods of mining employed in the UK; their short and long-term effects on surface stability; techniques for the consolidation of old mine workings; and remedial measures for mine shafts.
- 16.4.76 CIRIA C758 provide advice:

*If workings occur within 20m of surface it would be unusual to find a satisfactorily thick and rigid founding stratum for highly-loaded piles above, and sufficiently isolated from, the workings. When loadings are light (e.g. for houses), a suitable horizon might be available, but often piles will need to penetrate the workings to found in a stable stratum adequately below the disrupted floor of the workings.*

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<sup>13</sup> CIRIA C758D:2019. Abandoned mine workings manual

Whatever the depth of workings, even if they are thought to be fully filled or the roof strata to be rigid, piles should not be terminated immediately above an untreated worked horizon because this could concentrate load on a potentially unstable stratum which may initiate eventual collapse.

The objective of a conventionally spaced, over-site grout treatment grid is to ensure against surface settlements. It will not adequately serve below ground support for individual piles. Experience shows that grid separations exceeding 3m in partially collapsed or back-stowed workings are prone to uneven grout distribution and leaving isolated untreated areas or discrete void pockets. These circumstances heighten the risks of pile construction defects and differential performance which need to be minimised by enhanced treatment.

It should be recognised that pressurised grout treatments (even if enhanced) are unlikely to achieve full closure or permeation of randomly distributed or occluded voids, especially if water-filled. This consequence of earthworks treatments is well known, but also it is industry wisdom that grout acceptance maximises at about 90-95% of voidage. Therefore, the pile designer may need to examine additional means to negate residual voids, perhaps by the pile-head detailing and group interconnection measures.

It is recommended that all improvements to the workings themselves, whether by grouting or other filling takes place before piling. All improvement work should be allowed to attain the requisite strength before piling.

When there is a continuing risk of subsidence or residual movements, piles should be taken into competent strata below any seam floor disruption and heave consequential on the workings. Ground treatments should be scheduled to mitigate both installation effects and future settlements.

Particular attention should be given in design to accommodating consequential loads and down-drag generated from ongoing consolidation or reactivated subsidence potential.

- 16.4.77 Founding piles above a system of **untreated** workings is not recommended because collapsed workings are rarely in a permanently stable condition and so have some form of residual settlement potential. Thus, either creep settlement, strata relaxation or collapse migration remain intermittent subsidence possibilities. In which case, structure vulnerability can be an issue if its settlement performance and distortion criteria are too restrictive.
- 16.4.78 Piling above workings might be possible where sufficiently reliable strata (e.g. a substantial massive and competent bed of sandstone) are present to enable a detachment zone to be defined, or created by enhanced ground treatment. The thickness of this zone will depend on the pile installation method and the size and loading of the pile group.
- 16.4.79 When a prospective horizon is present, the following key issues, should be examined before deciding if the proposal is viable:
- depths, dip and thickness of the subsidence restricting horizon
  - geotechnical and geomechanical properties of the restricting horizon
  - separation between pile toe level and the restricting horizon (i.e. the detachment zone)
  - establishing that past collapses have arrested at the restricting horizon
  - specific connectivity arrangements at pile heads/caps.
- 16.4.80 To enable piles to found at a higher level than a significantly stressed worked seam, bulk filling of open workings or grout treatment should be carried out beforehand as standard practice. If grouting, a more comprehensive treatment regime than for spread foundations will be required to produce reliable higher strength characteristics in the intensely stressed zones. These strengths should be specified via the grout mix and validated afterwards.

- 16.4.81 Further advice should be sought from a specialist piling contractor(s), and discussions held with the pile designer before committing to a contract to grout mineworkings beneath the proposed new build.

### Summary of foundation recommendations

- 16.4.82 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):

Ground Conditions	Foundation solution(s)	Remarks (influencing factors)
<0.9m total made ground	Strips at 0.9m (Cohesive Residual Soil) & 0.6m (Granular Residual Soil)	Foundations in Cohesive Residual Soil deepened where influenced by trees
<2.5m total made ground	Deep strips/trench fill to between 0.9m & 2.5m.	Passing through made ground & founding in underlying Residual Soil or bedrock.
>2.5m total made ground	Piles to between c. 8.0m & 15.0m or rafts/beams on engineered fill.	Piles passing through made ground & founding in bedrock at the base of the former opencast.

- 16.4.83 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

- 16.4.84 Drawing 4454/9 shows the approximate lines of geological faults which cross the site.
- 16.4.85 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.
- 16.4.86 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.
- 16.4.87 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.
- 16.4.88 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 April 2023.

## 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 site specific laboratory data and published coefficient of volume compressibility ( $M_v$ ) correlations (e.g. Carter & Bentley 1991). The Opencast Backfill was found to be typically firm / medium dense, equating to a moderately compressible soil.
- 16.6.4 The range of  $M_v$  used for this preliminary assessment is 0.1 to 0.20  $m^2/MN$  to reflect the range of values recorded by the one-dimensional consolidation tests. Loadings from proposed plots were initially estimated to be a maximum of c.100kPa.
- 16.6.5 **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 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).
- 16.6.6 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%**

16.6.7 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%.

16.6.8 For this preliminary assessment, t<sub>0</sub>, t<sub>1</sub> and t<sub>2</sub> were assumed to be 1960 (date of backfill), 2023 and 2083 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 $\alpha$ (%)			Potential creep settlement by 2082 (mm)			Initial compression & consolidation (mm)	
	Partial <sup>c</sup>	Uncompacted <sup>c</sup>	Ave <sup>c</sup>	Partial <sup>c</sup>	Uncompacted <sup>c</sup>	Ave <sup>c</sup>	Mv = 0.1 <sup>D</sup>	Mv = 0.20 <sup>D</sup>
15.5 <sup>A</sup>	0.4	0.8	0.6	20	35	30	15	20
11.0 <sup>B</sup>	0.4	0.8	0.6	15	25	20	15	20

Notes

<sup>A</sup> = Typical maximum depth of Opencast Backfill

<sup>B</sup> = Typical depth of Opencast Backfill

<sup>c</sup> = ICE Earthworks: a guide (2nd Edition) p62, partial compaction, no compaction and the average of partial and no compaction.

<sup>D</sup> = Carter & Bentley (1991) Table 5.1 - Firm Clays of Medium Compressibility & site-specific one-dimensional consolidation tests

Depth of Fill (m)	Total potential settlement (mm)					
	$\alpha=0.4^c, Mv=0.1^D$	$\alpha=0.4^c, Mv=0.20^D$	$\alpha=0.8^c, Mv=0.1^D$	$\alpha=0.8^c, Mv=0.20^D$	$\alpha=0.6^c, Mv=0.1^D$	$\alpha=0.6^c, Mv=0.20^D$
15.5 <sup>A</sup>	35	40	50	55	45	50
11.0 <sup>B</sup>	30	35	40	45	35	40

Notes

<sup>A</sup> = Typical maximum depth of Opencast Backfill

<sup>B</sup> = Typical depth of Opencast Backfill

<sup>c</sup> = ICE Earthworks: a guide (2nd Edition) p62, partial compaction, no compaction and the average of partial and no compaction.

<sup>D</sup> = Carter & Bentley (1991) Table 5.1 - Firm Clays of Medium Compressibility & site-specific one-dimensional consolidation tests

16.6.9 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. 35mm and c. 55mm. In areas of typical backfill depths, the potential range of total settlement is between c. 30mm and c. 45mm.

16.6.10 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 4454/14), 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).

16.6.11 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.

- 16.6.12 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. 60 years), groundwater rebound is expected to have reached equilibrium with pre-opencasting levels.
- 16.6.13 Note – along the western edge there is likely to be a ‘modern’ backfill (dating from 1960s) overlaying older quarrying backfill (more coal, ash etc, dating from c. 1920s) which is likely to be less ‘well placed’ – probably placed by hand cf. rolled in with plant, but has had more time (c. 40 years) to consolidate. There is the possibility for differential settlement locally within the made ground along the western part of the site. However turnover of made ground (see Section 17) should homogenise this, thereby reducing the risk.

## 16.7 Plots constructed over/near highwalls

- 16.7.1 An area of former opencast underlies about 65% of the total site area (about 80% of the development footprint). The opencast's extents are marked by highwalls which are most well defined along the eastern boundary, and **poorly defined** along the western periphery where some historical quarrying of coal has taken place prior to ‘formal’ opencast in the 1950's/60's.
- 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<sup>14</sup> guidance, conservatively assuming there is the potential for significant vertical compression ( $Cot\beta = 1$ ). 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)
West	2	4	7	0.75
East	3	12	21	1.5

- 16.7.6 It would be prudent to allow for a plot-specific assessment and foundation for all plots within the highwall zone of influence (Drawing 4454/15).
- 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.

<sup>14</sup> BRE Building on fill: geotechnical aspects 3<sup>rd</sup> edition 2015 – Appendix D: Delineation of exclusion zone over a highwall

## 16.8 Designated concrete mixes

- 16.8.1 Designated mixes are considered in BRE SD1<sup>15</sup> and BS 8500<sup>16</sup>. 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.
- 16.8.2 Consequently, Strata should seek advice from their appointed Structural Engineer.

## 16.9 Excavations

- 16.9.1 Based on the results of the investigation it is considered unlikely that major groundwater flows will be encountered in shallow excavations.
- 16.9.2 Groundwater should be controlled in accordance with CIRIA Report R113<sup>17</sup>.
- 16.9.3 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.
- 16.9.4 Bedrock was encountered in several exploratory holes, especially around the sites peripheries. Based on the exploratory hole logs, excavation greater than 3.0m is likely to prove difficult across about 20% of the site. It would therefore be prudent to allow for excavation of hard rock in any deep excavations such as those that may be required for drainage etc.

## 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<sup>18</sup> for further details) include:
- 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).
  - Swales – linear grassed features in which surface water can be stored or conveyed. Where suitable, swales can be designed to allow infiltration.
  - Basins - a ground depression designed to store surface water that is normally dry, except during and immediately following a rainfall event. There are two types:
    - Infiltration – basin designed to store runoff and infiltrate it gradually into the ground.
    - Detention – an outlet restricts flows, so that the basin fills and provides attenuation.
  - 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<sup>19</sup> for developers and designers outlining their design requirements for surface water attenuation assets.

<sup>15</sup> BRE Special Digest 1 (2005) – Concrete in aggressive ground.

<sup>16</sup> 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).

<sup>17</sup> CIRIA Report R113 (1986) - Control of Groundwater for Temporary Works.

<sup>18</sup> CIRIA C753 (2015) – The SuDS Manual.

<sup>19</sup> Design Requirements for Surface Water Attenuation Assets, February 2017.

- 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 Lithos' understanding that ground does not have to be free-draining (i.e. sands/gravels), but where clay is present the basin needs to be designed to prevent waterlogging - because this renders maintenance (grass cutting) difficult. It would be prudent to seek confirmation of this from Yorkshire Water and/or the appointed drainage designer.
- 16.10.6 Appropriate design usually comprises a fall across the short axis (to centre of basin), and then along the long axis (possibly inclusive of a pipe in gravel trench) to the outfall.
- 16.10.7 The guide also discusses required access to flow control chambers, large diameter (i.e. >900mm) surface water storage pipes, and surface water storage tanks.
- 16.10.8 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.

## 16.11 Highways

### General

- 16.11.1 Deep Made ground is present across the site 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 an 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.

### Highways crossing highwalls

- 16.11.7 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.

- 16.11.8 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).
- 16.11.9 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.
- 16.11.10 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.
- 16.11.11 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 Both natural ground and the Opencast Backfill underlying the site 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 13.7 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:20h and a total fall of about 30m, although the steepest slopes and the majority of the 'loss in height' is located in the northwest of the site outside of the proposed development footprint.
- 17.2.2 Given the topography of the site some relatively minor 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 the site, including the whole of the development footprint, comprising a veneer of Made Ground Topsoil over Opencast Backfill with localised Burnt Shale and Ash & Clinker (in the west) to between around 2.0m and 15.5m depth.
- 17.3.2 Made Ground across the whole development area is the result of backfilling of opencasting operations and a general raising of site levels during/following completion of the opencasting. Some made ground in the west appears to predate the more 'modern' recorded opencast (1950's) and is likely a result of historical unlicensed quarrying of coal in c. 1920 where the Barnsley Seam is at/close to outcrop.
- 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 could be subjected to "turnover" (excavation, screening/sorting and replacement in engineered layers, with compaction) across the 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 by allowing for screening and crushing/removal of undesirable near surface obstructions.
- 17.3.8 Because turnover enables inspection of the full thickness of fill (up to 3m), 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 abnormalities 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 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, treatment of contamination, 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 unexpected 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:
- 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.
- 18.2.2 The remediation contractor should survey reduced levels during the proposed turnover, prior to the placement of any fill.
- 18.2.3 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.
- 18.2.4 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; Ash & Clinker; fuel-contaminated soil; 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 13.7 regarding asbestos.
- 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 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<sup>20</sup>
  - EA Pollution Prevention Guidelines<sup>21</sup>:
    - 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 oversized trenches cut into the seam & backfilled with inert material.
- 18.5.3 It is recommended that trenches for services including site drainage and water supply are cut over size in order to isolate pipe materials from potential contaminants and to enable maintenance to be conducted in "clean" material.

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<sup>20</sup> CIRIA C741 (2015) - Environmental Good Practice on Site

<sup>21</sup> Whilst this has formally been withdrawn it can still be accessed via the EA archives and provides useful information on managing risks.

- 18.5.4 Water Companies have a statutory duty to supply wholesome water, which could be compromised by the selection of an inappropriate pipe material. For example, compounds such as petroleum hydrocarbons and solvents can permeate commonly used plastics pipes, and/or corrosive chemicals can reduce the service life of metallic pipes. Guidance has been developed for the selection of pipes in brownfield sites and is contained in a UKWIR Report<sup>22</sup>.
- 18.5.5 This site is brownfield, and therefore consideration of soil contaminant concentrations is required. Samples taken must be representative of the soil conditions in which the water pipes are proposed to be laid; normally water pipes are laid 0.7m to 1.3m below finished ground level.
- 18.5.6 At the time of writing, the proposed route(s), and total length, of water supply pipes were unknown. Consequently, to date laboratory testing of soil samples in line with UKWIR guidance has not been undertaken.
- 18.5.7 However, given the site's size, history, and ground conditions encountered, Yorkshire Water may require sampling within 15m of proposed water supply pipes, once infrastructure design has been completed. In the meantime, it is considered likely that Yorkshire Water will request the use of Protectaline mains, with plastic coated copper house connections, given that residual organic contaminants will still be present post-remediation, albeit at acceptable concentrations.

## 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. This made ground contains contaminants at concentrations above the guidance threshold values for an end use that includes domestic gardens. Workers involved in excavations for foundations, drainage, utilities etc are likely to come into direct contact with the made ground.
- 18.6.4 Although workers will only be exposed to the contaminated soil for a relatively short time, the contaminants represent a risk, and simple precautionary measures are required, i.e. good personal hygiene and basic personal protective equipment.
- 18.6.5 Consequently, during the remediation and construction phases of the site development 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.

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<sup>22</sup> UKWIR Report 10/WM/03/21 – 'Guidance for the Selection of Water Supply Pipes to be used in Brownfield Sites'.

## 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 15% of the total site area. However, given seam dip and topography it seems unlikely that coal will be present at such shallow depth.
- 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 slopes down to the northwest with a typical gradient of about 1v:20h and a total fall of about 30m, although the steepest slopes and the majority of the 'loss in height' is located in the northwest of the site outside of the proposed development footprint.
- 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 Areas of former opencast coal extraction are present with made ground of up to 15.5m 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.
- 18.9.5 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 off Farm House Lane in Pogmoor Barnsley and comprises a single parcel of farmland of c. 7.2 hectares. The majority of the site is given to arable farming, however a c. 1.7 hectare 'spur' of steeply sloping grassland to the northwest is given to livestock grazing.
- 19.1.2 The current area of interest comprises about 8% of a wider development area (c. 80 hectares) which is called Barnsley West. The current area occupies 7.7 hectares in the southeast of the wider development area and is called Barnsley West, Pogmoor Land.
- 19.1.3 It is understood that consideration is being given to redevelopment of the site with 147 'traditional' two/three storey domestic dwellings with associated gardens, POS and adoptable roads and sewers.
- 19.1.4 About 65% of the total site area and about 80% of the proposed development footprint has been subject to historical opencast coal extraction. Backfilling of opencast excavations has resulted in made ground comprising a mixture of Cohesive and Granular Opencast Backfill, along with localised Burnt Shale and Ash & Clinker, being present to depths of between 2.0m and 15.5m depth with steep highwalls around the opencast peripheries.

### 19.2 Mining

- 19.2.1 This site is located within a Coal Mining Development High Risk Area. Several mine entries are located within the site's boundary, although opencasting is likely to have removed the majority of these.
- 19.2.2 Deep opencast backfill is present across about 65% of the site's area and about 80% of the development footprint.
- 19.2.3 Shallow underground workings are present in the Barnsley Coal Seam with thicknesses of greater than 3.0m at a depth of around 10.0m along the eastern periphery of the site. Workings shall require consolidation by means of drill and grout where development is proposed above them.

### 19.3 Hazardous gas

- 19.3.1 The site is in an area where between 3% and 5% of homes are estimated to be above the radon action level. Consequently basic radon protection is required.
- 19.3.2 The site is underlain by deep made ground and shallow coal and workings. Consequently, there is a potential risk of hazardous ground gasses migrating beneath the site.
- 19.3.3 Monitoring wells have been installed in 20 boreholes across the site and monitoring for hazardous ground gasses is ongoing. A Hazardous Gas Risk Assessment shall be issued on completion of the monitoring in May 2023.
- 19.3.4 At this stage it would be prudent to assume that some protective gas measures might be required for new plots across the site.

### 19.4 Contamination & remediation

- 19.4.1 Made ground underlies the majority of the site, and the entire development footprint, which is typically less than around 2.0m to 4.0m deep outside of the former opencast and between c. 4.0m and 15.5m deep inside the former opencast.

- 19.4.2 Some inorganic contamination has been encountered in localised Ash & Clinker at depth (c. 1.5m in TP39). However, the bulk of the made ground tested has been found to be essentially 'clean'.
- 19.4.3 All made ground at the site should be isolated by a clean cover of at least 450mm comprising at least 300mm of 'clean' and suitable subsoil and at least 150mm of clean and suitable Topsoil.
- 19.4.4 Consequently, the Ash & Clinker should be isolated at greater than 0.6m depth (beneath 600mm of clean cover or beneath other made ground types) or beneath roads, floor slabs or concrete oversite where it will be sufficiently isolated from end users.

## 19.5 Foundations

- 19.5.1 Foundations will be determined by the thickness of made ground across the site following any turnover and levels regrade.
- 19.5.2 Where the total thickness of made ground is less than c. 2.5m deepened strip/trench footings, seated on competent Residual Soils or bedrock, are likely to be the most suitable means of foundation solution for plots.
- 19.5.3 Where made ground is greater than c. 2.5m deep there will be a need for alternative foundation solutions (likely piles or reinforced strips/rafts founding on re-engineered fill).
- 19.5.4 Foundations may require reinforcement or deepening (if piles) to allow for some settlement of underground workings which have been consolidated by drill & grout, notably along the eastern edge of the site.

## 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 significant thicknesses of Made Ground across the majority of this site soakaways are unlikely to provide a suitable means of surface water disposal and there may be a need for an alternative SuDS solution.

## 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 (up to 3m depth) 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 The following further works are ultimately required prior to finalisation of the geotechnical design of the proposed development:

- Completion of the monitoring and completion and 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).

**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 through 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<sup>1</sup>, 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<sup>2</sup>. 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 Bq<sup>m</sup>-<sup>3</sup> and 100 Bq<sup>m</sup>-<sup>3</sup> 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<sup>3</sup>. 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 Bq<sup>m</sup>-<sup>3</sup> 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.

<sup>1</sup> BRE Report BR211, 2015: "Radon: guidance on protective measures for new buildings.

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

<sup>3</sup> 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<sup>1</sup> – 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 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 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.

<sup>1</sup> 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:

$$I'p = I_p * (\% < 425\mu\text{m} / 100)$$

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<sub>4</sub> 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<sup>-2</sup>) = depth (m) x soil bulk unit weight (kNm<sup>-3</sup>)

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 ( $\text{kNm}^{-2}$ ).

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<sub>4</sub>), 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<sub>6</sub> to C<sub>10</sub>). Also referred to as PRO – Petroleum Range Organics
- DRO – Diesel Range Organics (typically C<sub>10</sub> to C<sub>28</sub>)
- LRO - Lubricating Oil Range Organics (typically C<sub>28</sub> to C<sub>40</sub>)
- MRO – Mineral Oil Range Organics (typically C<sub>18</sub> to C<sub>44</sub>)

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<sub>5</sub>-C<sub>40</sub>, whereas others define TPH as C<sub>10</sub>-C<sub>30</sub>.

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<sub>4</sub> to C<sub>5</sub> 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<sub>10</sub> to C<sub>40</sub> (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<sub>6</sub> to C<sub>8</sub>, aromatic C<sub>10</sub> to C<sub>12</sub> 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)	<ul style="list-style-type: none"> <li>• Direct ingestion of soil</li> <li>• Dermal contact</li> <li>• Consumption of vegetables &amp; soil attached to vegetables</li> <li>• Inhalation of indoor vapours and dust</li> <li>• Inhalation of outdoor vapours and dust</li> </ul>	Minimal cover – insufficient to break any pathways therefore all exposure pathways are relevant.
B	Residential with garden minimum 600mm cover	<ul style="list-style-type: none"> <li>• Inhalation of indoor vapours</li> <li>• Inhalation of outdoor vapours</li> </ul>	The 600mm cover removes the risk from all pathways other than inhalation.
C	Residential apartments with landscaped areas and minimum 300mm cover	<ul style="list-style-type: none"> <li>• Direct ingestion of soil</li> <li>• Dermal contact</li> <li>• Inhalation of indoor vapours and dust</li> <li>• Inhalation of outdoor vapours and dust</li> </ul>	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.

## 04 - Contamination analysis & interpretation (including WAC)

### Generic notes – geoenvironmental investigations



Scenario	Land use	Pathways	Justification
D	Commercial/ industrial with landscaped areas no cover	<ul style="list-style-type: none"> <li>Direct ingestion of soil</li> <li>Dermal contact</li> <li>Inhalation of indoor vapours and dust</li> <li>Inhalation of outdoor vapours and dust</li> </ul>	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	<ul style="list-style-type: none"> <li>Direct ingestion of soil</li> <li>Dermal contact</li> <li>Consumption of vegetables &amp; soil attached to vegetables</li> <li>Inhalation of outdoor vapours and dust</li> </ul>	Material used as cover to break existing pathways therefore all direct and indirect pathways relevant; however cover is <b>not</b> 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 CrIII
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	
Cu			100		100	100	100	Based on phytotoxic risks as plants are the more sensitive receptor (Cu is pH dependant)
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 <sup>^</sup>	<1 <sup>^</sup>	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	Scenario E based on professional judgement and lower than calculated value.
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
Diesel Range Organics			215	218	215	^5,000	1,429	^Based on professional judgement and lower than calculated value
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<sup>1</sup>

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.

<sup>1</sup> 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 physicochemical 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.

$$HI = \sum_{F_i=1}^{16} HQ F_i = \frac{\text{Measured concentration } F_i \text{ (mg kg}^{-1}\text{)}}{SGV F_i \text{ (mg kg}^{-1}\text{)}}$$

where HI = Hazard Index  
 HQ = Hazard Quotient  
 F<sub>i</sub> = Fraction<sub>i</sub>  
 SGV = Soil Guideline Value

### Statistical Assessment

Current UK guidance is provided by CL:AIRE<sup>2</sup>, 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.

<sup>2</sup> 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 ICRC 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 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)<sup>i</sup> 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)<sup>ii</sup> advocates two methodologies for characterising sites:

**A** – All developments except low rise housing. The advocated methodology is that proposed by Wilson & Card, 1999<sup>iii</sup>

**B** – Low rise housing. An alternative (traffic light) methodology, derived by Boyle and Witherington, 2006<sup>iv</sup> 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)<sup>v</sup> revised Table 28 of CIRIA 149<sup>v</sup> 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 <sub>4</sub> or CO <sub>2</sub> (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 <sup>1</sup>		Carbon Dioxide <sup>1</sup>	
	Typical Maximum Concentration <sup>5</sup> (%v/v)	Gas Screening Value <sup>2,4,6</sup> (l/hr)	Typical Maximum Concentration <sup>5</sup> (%v/v)	Gas Screening Value <sup>2,3,4,6</sup> (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:

- 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.
- 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.
- 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<sup>3</sup> has been considered.
- 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.
- 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.
- The GSV thresholds should not generally be exceeded without completion of a detailed gas risk assessment taking into account site-specific conditions.

<sup>i</sup> Harries CR, Witherington PJ and McEntee JM (1995). Interpreting measurements of gas in the ground. CIRIA Report 151

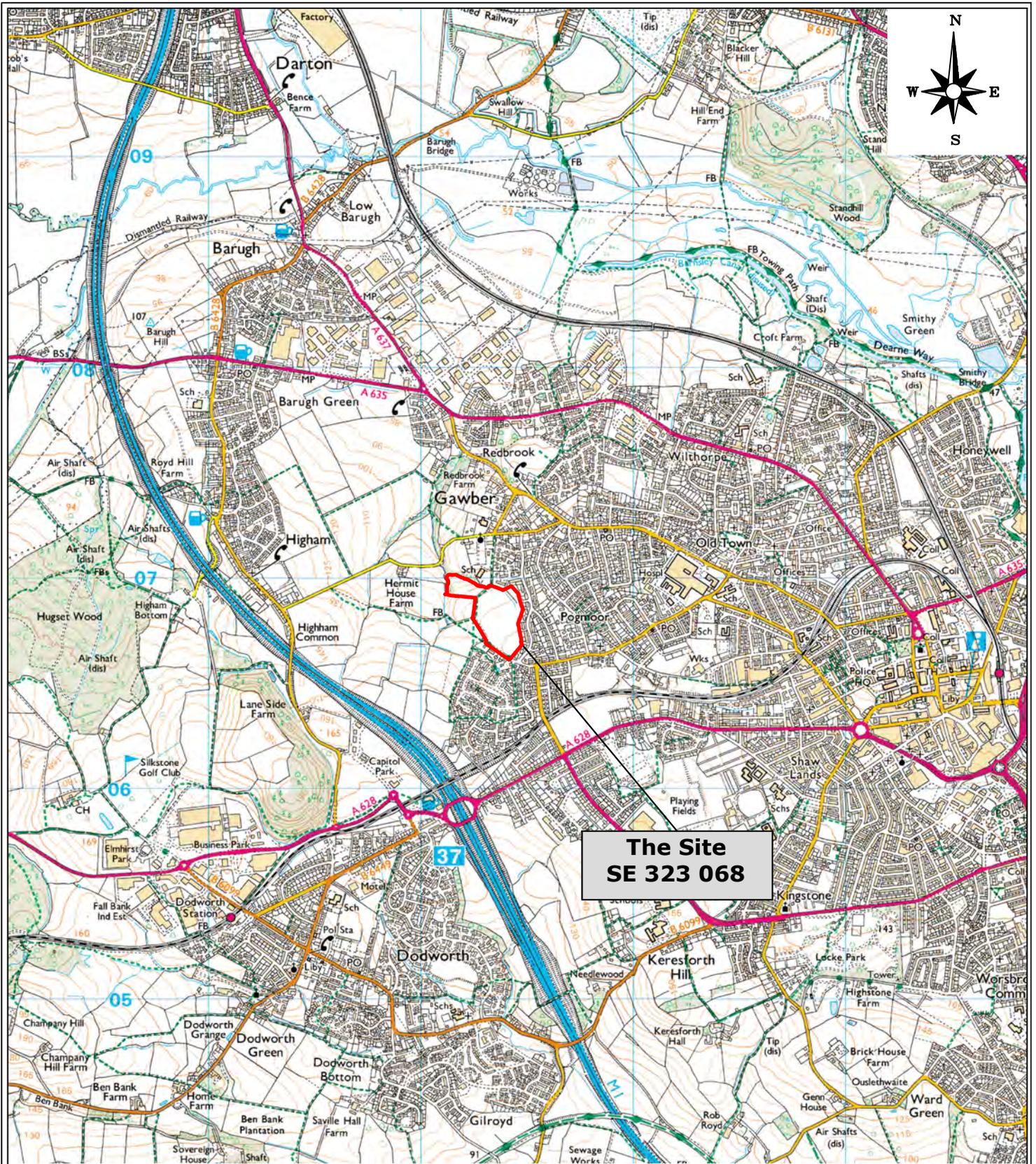
<sup>ii</sup> CIRIA (2007) – Assessing risks posed by hazardous ground gases to buildings.

<sup>iii</sup> Wilson SA and Card GB (February 1999). Reliability and Risk in Gas Protection Design. Ground Engineering.

<sup>iv</sup> 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

<sup>v</sup> Wilson SA and Card GB (February 1999). Reliability and Risk in Gas Protection Design. Ground Engineering.

**Appendix B**  
**Drawings**



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CLIENT

STRATA HOMES

JOB TITLE

BARNSELY WEST  
(POGMOOR  
LAND)

DRAWING TITLE

SITE LOCATION  
PLAN

DRAWN

GLM

DATE

21/09/2022

CHECKED

AG

DATE

21/09/2022

STATUS

FOR COMMENT

DRAFT

FOR APPROVAL

FINAL

SCALE

1:25,000

SHEET

A4

DRAWING NO.

4454/1

REVISION



NOTES

— APPROXIMATE SITE BOUNDARY

REPRODUCED FROM STRATA HOMES@  
DRAWING 'POGMOOR PARCEL, FARM  
HOUSE LANE, BARNSELY S72 2JH -  
VIABILITY LAYOUT, OPTION 2' DRAWING  
NO. 21-CL4-SEGC-PBW02-02, REV. C,  
DATED 26/07/2021.

REV.	DESCRIPTION	DATE



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JOB TITLE

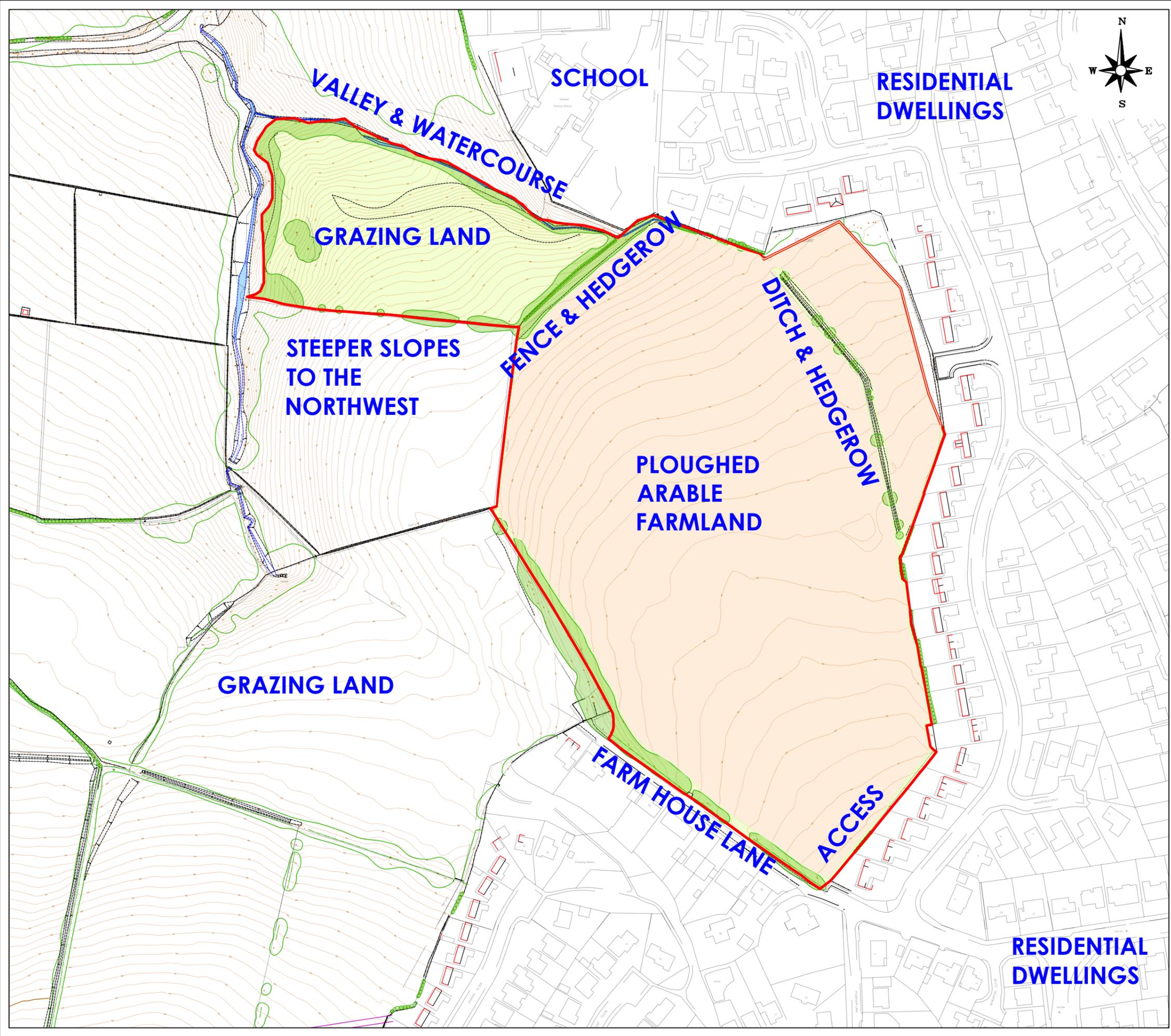
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(POGMOOR  
LAND)

DRAWING TITLE

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NOTES

	GRASS & GRAZING LAND
	ARABLE FARMLAND (PLOUGHED)
	TREES, SHRUBS & WOODLAND
	SURFACE WATERCOURSE
	APPROXIMATE SITE BOUNDARY

REV.	DESCRIPTION	DATE



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**STRATA HOMES**

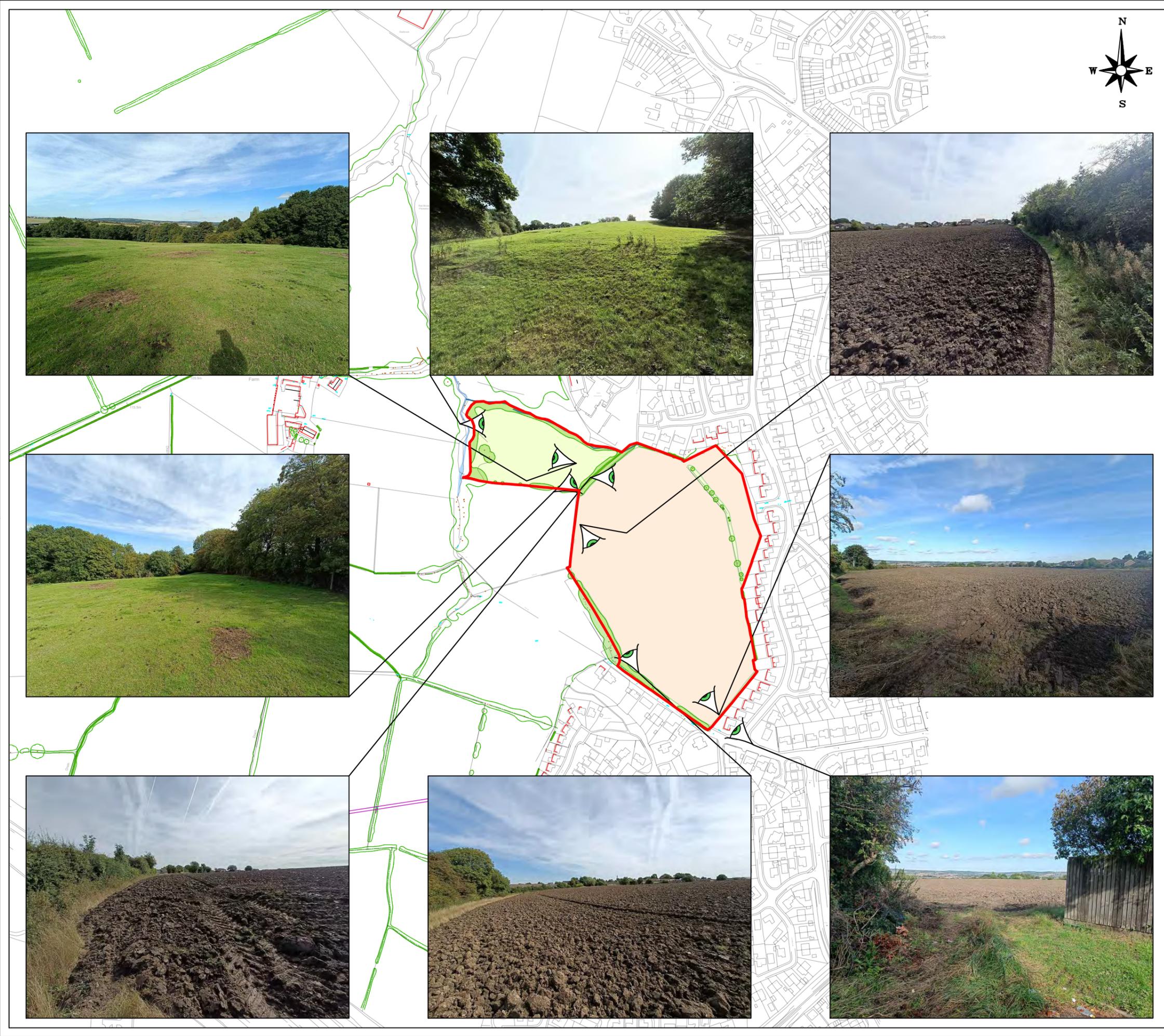
JOB TITLE  
**BARNSELY WEST (POGMOOR LAND)**

DRAWING TITLE  
**SITE FEATURES**

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CHECKED AG	DATE 21/09/2022	

SCALE 1:2,000	SHEET A3	DRAWING NO. 4454/3	REVISION
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**RESIDENTIAL DWELLINGS**



- NOTES
- GRASS & GRAZING LAND
  - ARABLE FARMLAND (PLOUGHED)
  - TREES, SHRUBS & WOODLAND
  - SURFACE WATERCOURSE
  - APPROXIMATE SITE BOUNDARY
  - LOCATION & ORIENTATION OF PHOTOGRAPH

REV.	DESCRIPTION	DATE



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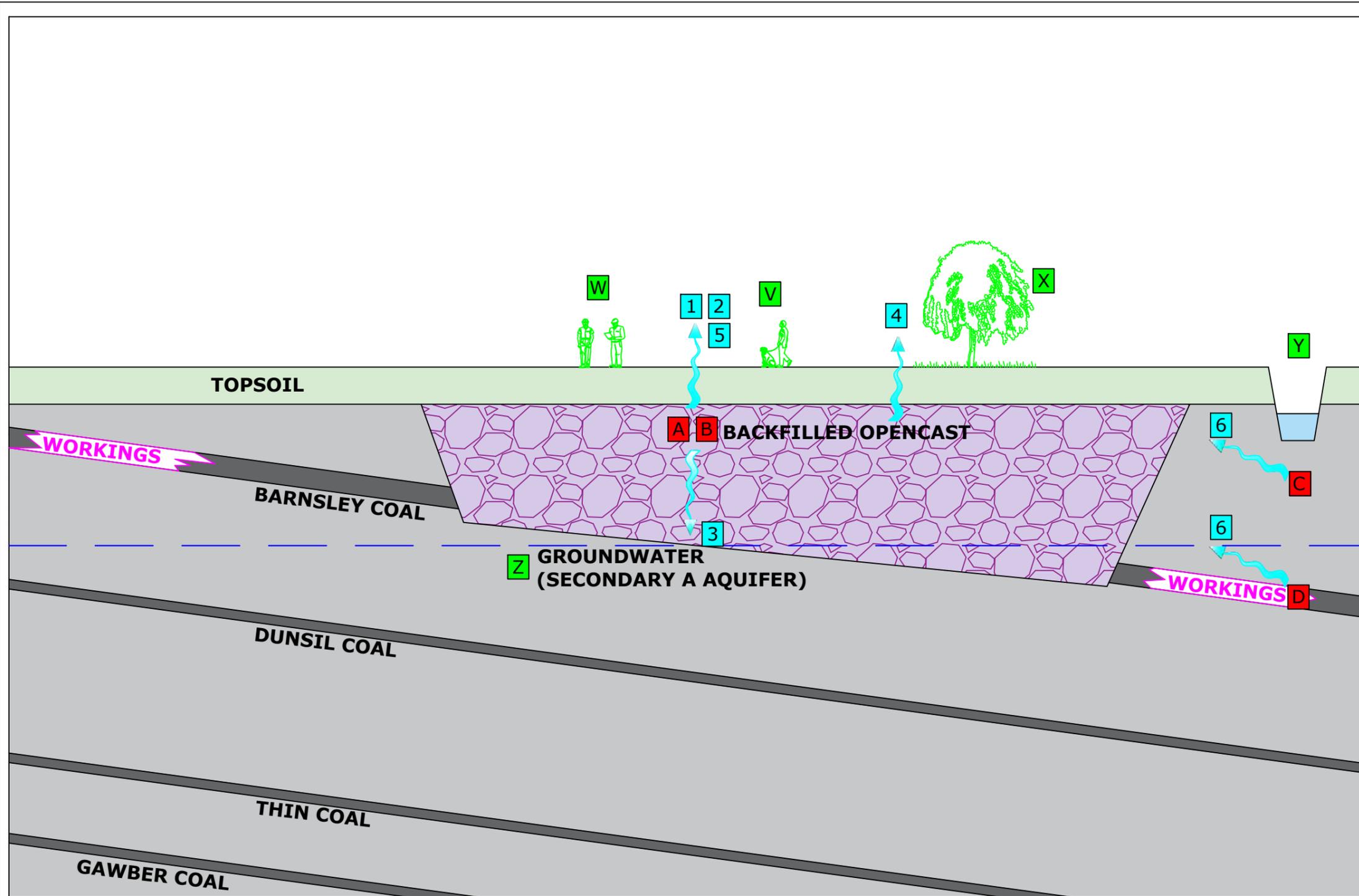
CLIENT  
  
**STRATA HOMES**

JOB TITLE  
  
**BARNSELY WEST  
(POGMOOR  
LAND)**

DRAWING TITLE  
  
**SITE PHOTOGRAPHS**

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NOTES

REV.	DESCRIPTION	DATE



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JOB TITLE

BARNSELEY WEST  
(POGMOOR LAND)

DRAWING TITLE

PRELIMINARY CONCEPTUAL SITE MODEL

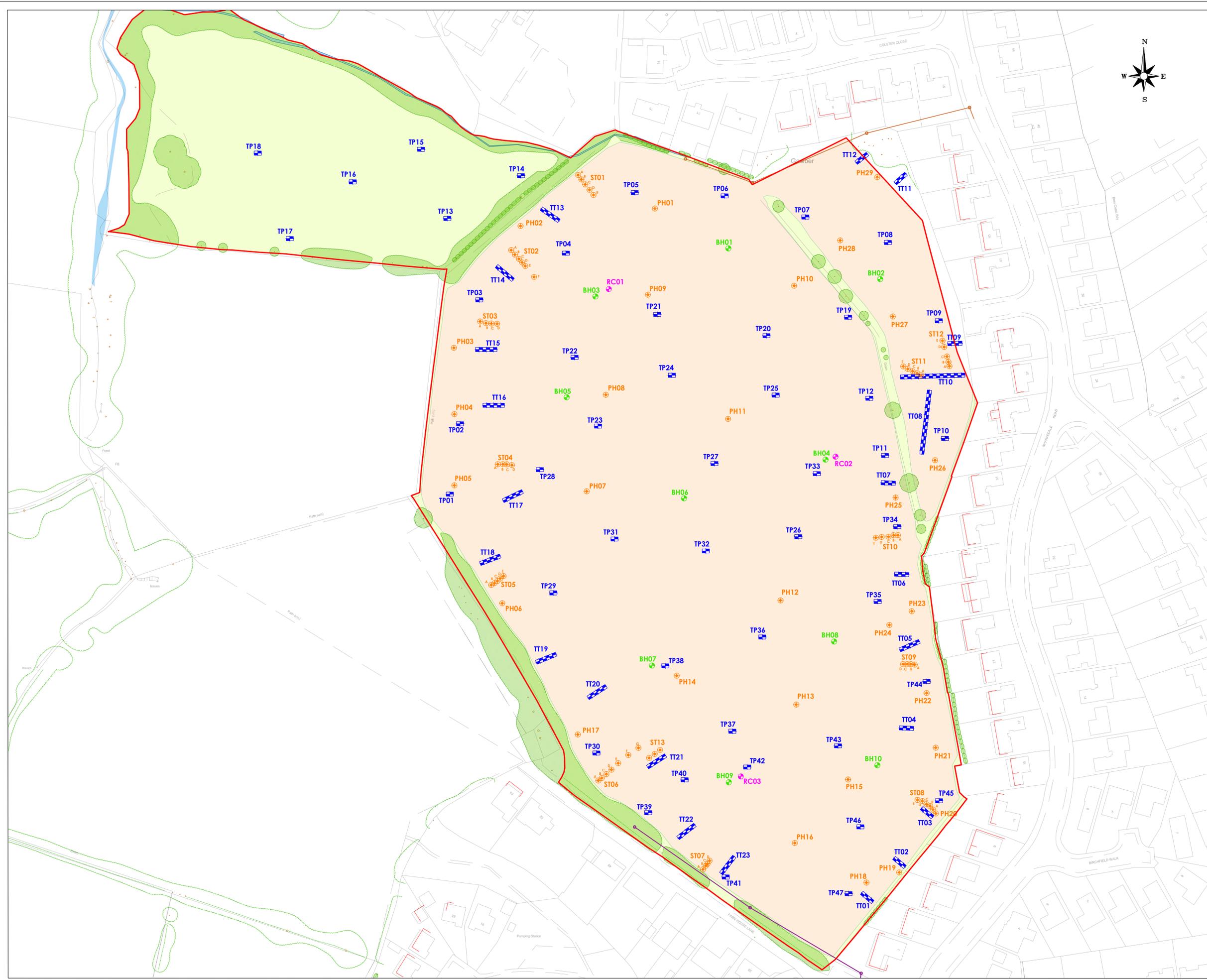
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SCALE	Not to scale	SHEET	A3	DRAWING NO.	4454/5	REVISION	
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SOURCES	
<b>A</b>	MADE GROUND (INORGANICS)
<b>B</b>	LEAKAGE/SPILLAGE (ORGANICS)
<b>C</b>	OFF-SITE MADE GROUND
<b>D</b>	SHALLOW COAL & WORKINGS

PATHWAYS	
<b>1</b>	DERMAL CONTACT
<b>2</b>	INGESTION/INHALATION
<b>3</b>	LEACHING OF CONTAMINANTS
<b>4</b>	UPTAKE BY PLANTS
<b>5</b>	VOLATILISATION
<b>6</b>	MIGRATION OF GAS

RECEPTORS	
<b>V</b>	END USERS (RESIDENTS)
<b>W</b>	SITE WORKERS
<b>X</b>	VEGETATION
<b>Y</b>	SURFACE WATERS
<b>Z</b>	GROUNDWATER



- NOTES**
- TRIAL PIT LOCATION
  - TRIAL TRENCH LOCATION
  - ROTARY CORED BOREHOLE LOCATION
  - CABLE PERCUSSION BOREHOLE LOCATION
  - PROBEHOLE LOCATION
  - LINE OF STITCHED PROBEHOLES
  - APPROXIMATE SITE BOUNDARY
- EXPLORATORY HOLE LOCATIONS HAVE BEEN SURVEYED IN (COORDINATES & GROUND LEVEL) ON COMPLETION

REV.	DESCRIPTION	DATE

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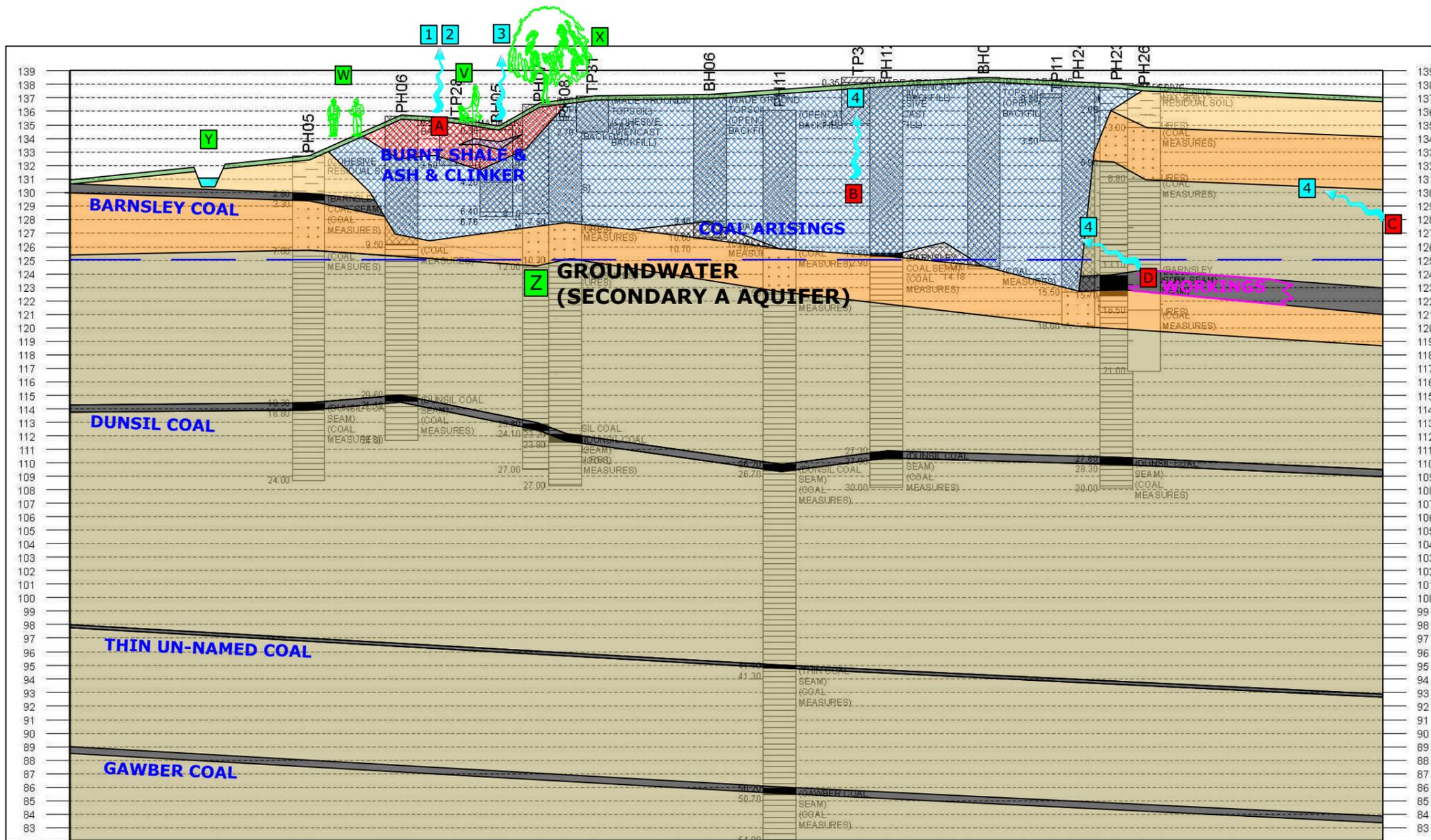
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DRAWING TITLE

**EXPLORATORY HOLE LOCATIONS**

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SCALE	SHEET	DRAWING NO.	REVISION
1: 750	A1	4454/6	



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BARNSELY WEST  
(POGMOOR LAND)

DRAWING TITLE

REVISED CONCEPTUAL SITE MODEL

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SCALE	Not to scale	SHEET	A3	DRAWING NO.	4454/7	REVISION	
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**KEY**

	ASH & CLINKER/BURN'T SHALE
	OPENCAST BACKFILL
	TOPSOIL
	RESIDUAL SOIL
	COAL MEASURES - SANDSTONE
	COAL MEASURES - MUD/SILTSTONE

**SOURCES**

	MADE GROUND (INORGANICS)
	MADE GROUND
	OFF-SITE LANDFILL
	SHALLOW COAL & WORKINGS

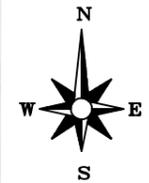
**PATHWAYS**

	DERMAL CONTACT
	INGESTION/INHALATION
	UPTAKE BY PLANTS
	MIGRATION OF GAS

**RECEPTORS**

	END USERS (RESIDENTS)
	SITE WORKERS
	VEGETATION
	SURFACE WATERS
	GROUNDWATER

Mr. John Smith Owner. Clauber

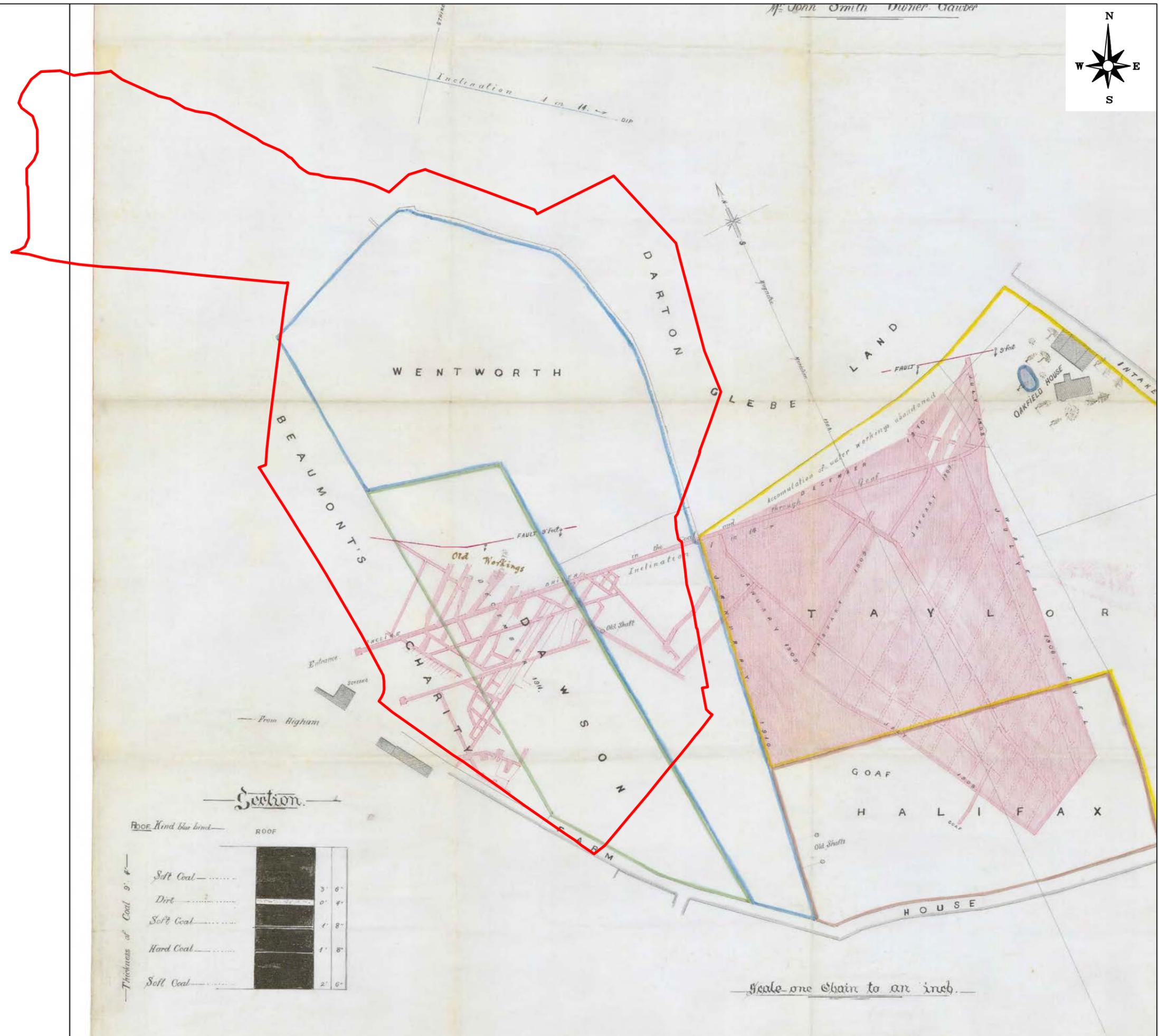


NOTES

— APPROXIMATE SITE BOUNDARY

REPRODUCED FROM THE COAL AUTHORITY'S ABANDONMENT PLAN REF. 5822 SHOWING WORKINGS IN THE BARNSELY COAL SEAM, DATED DECEMBER 1911

REV.	DESCRIPTION	DATE



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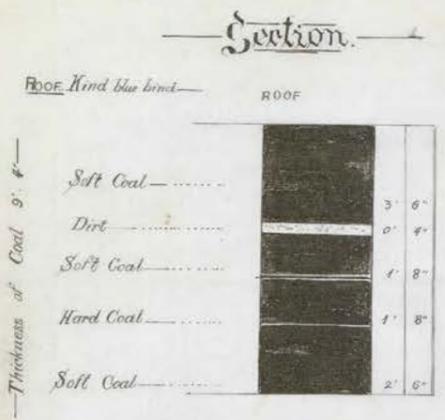
BARNSELY WEST (POGMOOR LAND)

DRAWING TITLE

COAL AUTHORITY ABANDONMENT PLAN 5822

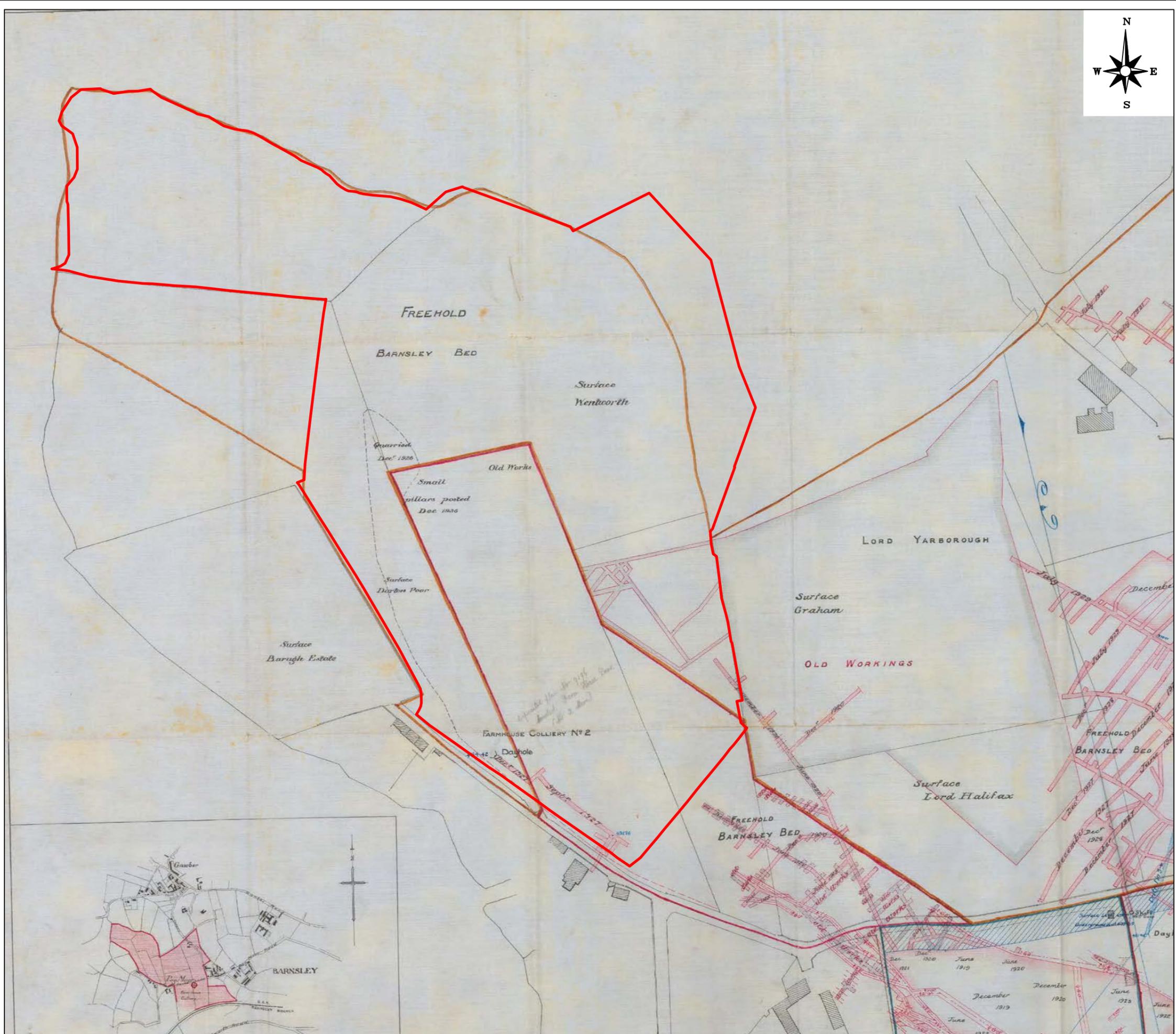
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SCALE	1:2,00	SHEET	A3	DRAWING NO.	4454/8A	REVISION	
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Scale one chain to an inch.





NOTES

— APPROXIMATE SITE BOUNDARY

REPRODUCED FROM THE COAL AUTHORITY'S ABANDONMENT PLAN REF. 11520 SHOWING WORKINGS IN THE BARNSELY COAL SEAM, DATED 1917

REV.	DESCRIPTION	DATE



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JOB TITLE

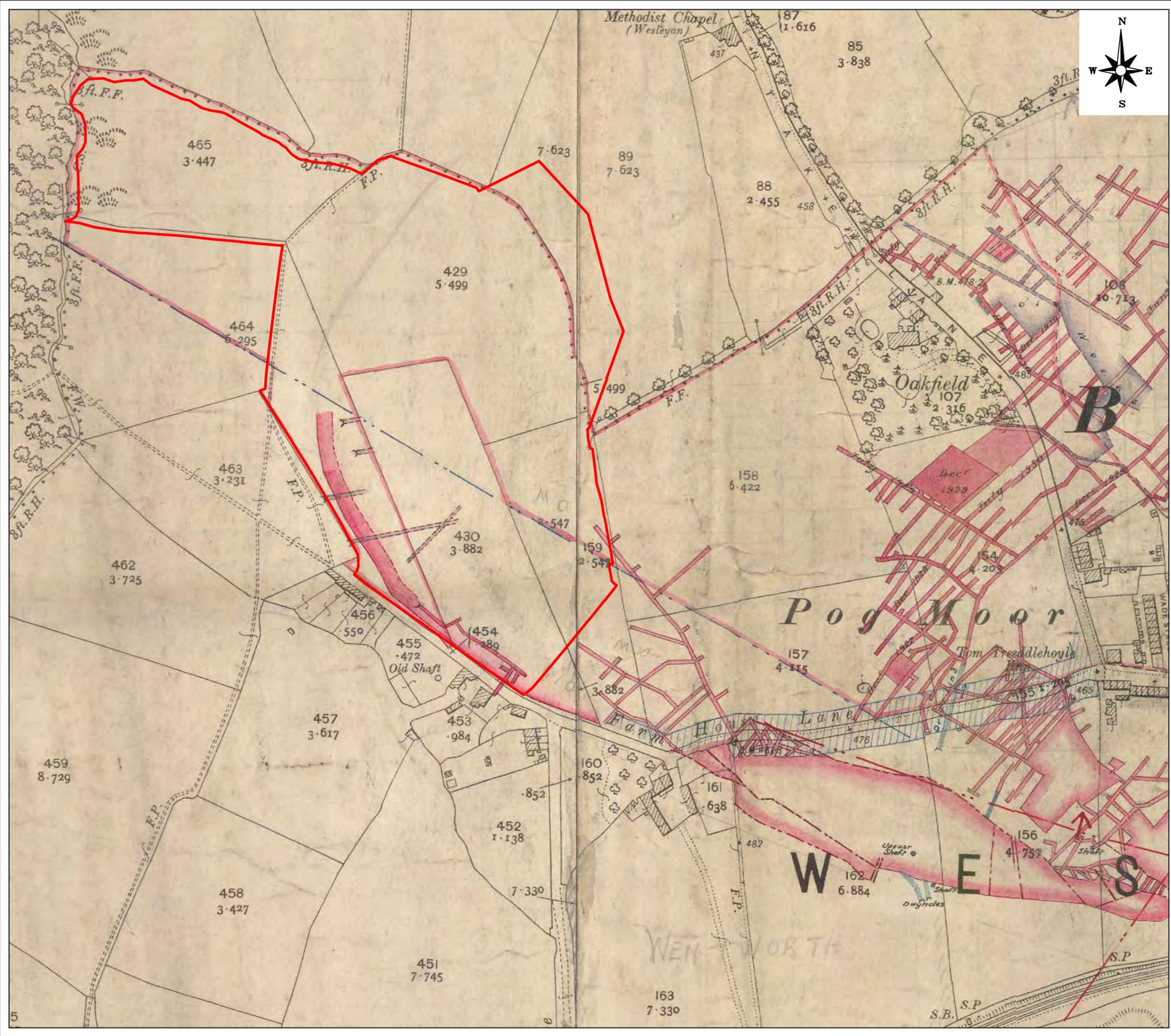
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NOTES

— APPROXIMATE SITE BOUNDARY

REPRODUCED FROM THE COAL AUTHORITY'S ABANDONMENT PLAN REF. FGB6 SHOWING WORKINGS IN THE BARNSELY COAL SEAM.

REV.	DESCRIPTION	DATE



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JOB TITLE

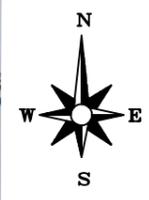
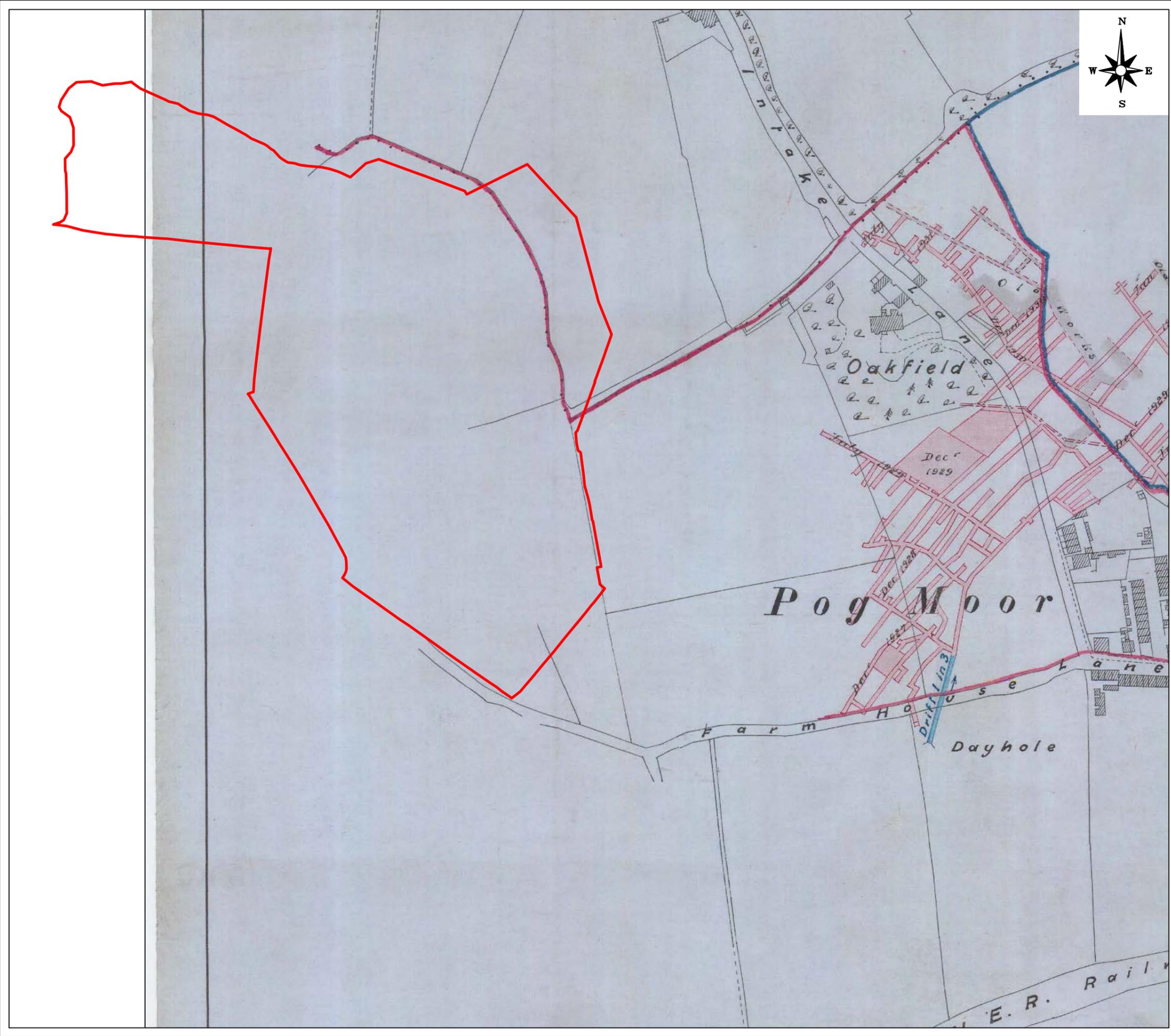
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(POGMOOR LAND)

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COAL AUTHORITY ABANDONMENT  
PLAN FGB6

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NOTES

— APPROXIMATE SITE BOUNDARY

REPRODUCED FROM THE COAL AUTHORITY'S ABANDONMENT PLAN REF. FGB137 SHOWING WORKINGS IN AN UNSPECIFIED SEAM (LIKELY BARNSELY SEAM).

REV.	DESCRIPTION	DATE



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JOB TITLE

BARNSELY WEST  
(POGMOOR LAND)

DRAWING TITLE

COAL AUTHORITY ABANDONMENT PLAN FGB137

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SCALE	1:2,500	SHEET	A3	DRAWING NO.	4454/8E	REVISION	
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NOTES

— APPROXIMATE SITE BOUNDARY

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ABANDONMENT PLAN REF. FGB148  
SHOWING WORKINGS IN THE BARNESLEY  
COAL SEAM.

REV.	DESCRIPTION	DATE



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STRATA HOMES

JOB TITLE

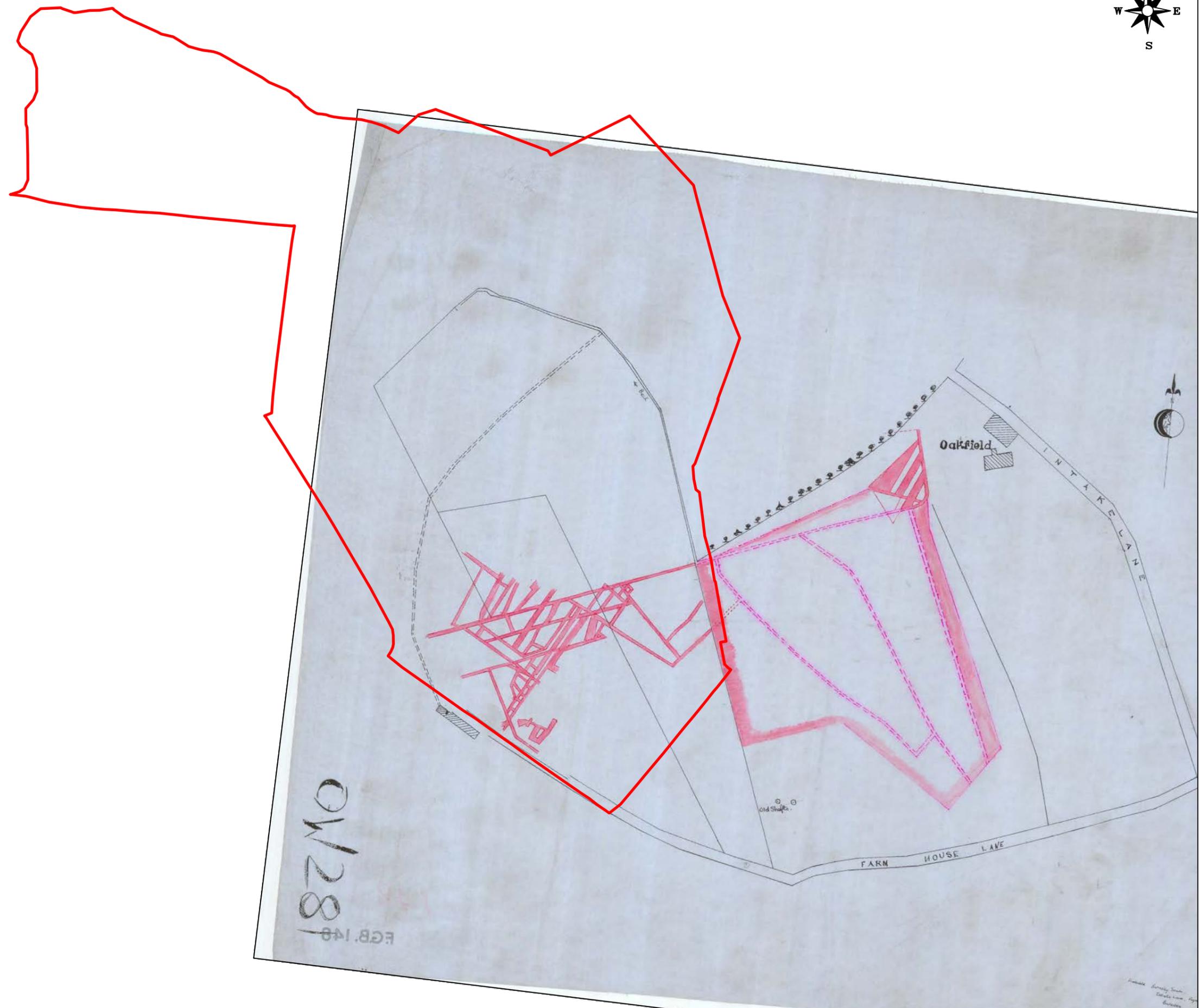
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(POGMOOR  
LAND)

DRAWING TITLE

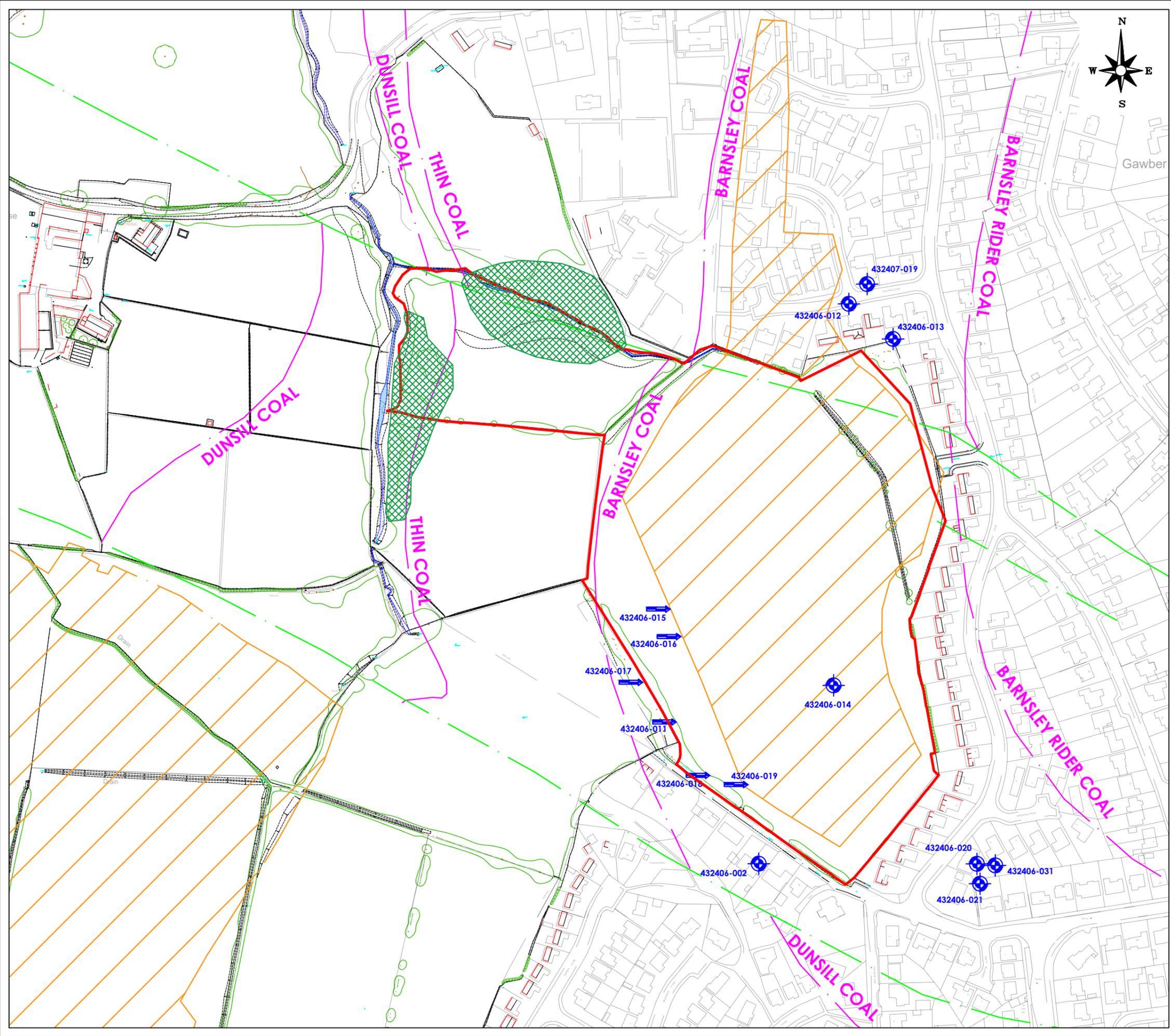
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NOTES

- MINE SHAFT LOCATION (BASED ON CA DATA)
- MINE ADIT LOCATION (BASED ON CA DATA)
- AREA OF SLOPE INSTABILITY (BASED ON BGS MAPPING)
- AREA OF OPENCAST (BASED ON BGS MAPPING)
- COAL SEAM OUTCROP
- LINE OF FAULT
- APPROXIMATE SITE BOUNDARY

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JOB TITLE

BARNSELY WEST (POGMOOR LAND)

DRAWING TITLE

GEOLOGY & MINING FEATURES

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