

Woodville, South Derbyshire

Ground Investigation Report

Curtins Ref: 067895.101-CUR-00-XX-RP-GE-001

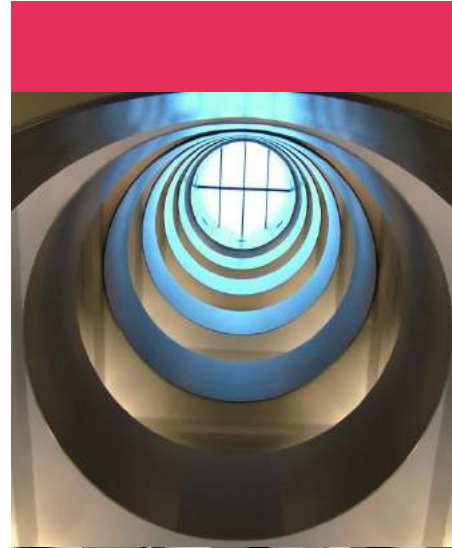
Revision: V02

Issue Date: 23 July 2019

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Rev	Description	Issued by	Checked	Date
-	Issue	LD	RGB	05 June 2019
V01	Final Issue	LD	ML	23 July 2019
V02	Revisions following client and NHBC comment	RA	ML	23 July 2019

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Executive Summary

Appointment	In November 2018, Curtins were instructed by Harworth Group to undertake a ground investigation of a parcel of land off Occupation Lane, Woodville, South Derbyshire. The redevelopment of the site is to consist of a proposed commercial/residential development, consisting of up to 300 dwellings with associated access roads, car parking, private gardens and areas of soft landscaping and several commercial units. A proposed bypass road is anticipated to dissect the site from south to north (outwith considerations of this report), with the eastern area comprising residential developments, and the western area comprising commercial developments.
Site Setting	The site generally comprises an area of roughly vegetated open space with localised areas of woodland. A large pond is located to the north west connected to a drainage channel, approximately 1.5m deep, which runs east to north west. The site covers an area of approximately 20 hectares that has undulating topography with a general fall in ground level from north east to south west. The site has an extensive legacy of mining and the majority of the site is underlain by filled opencast workings from the 1960s/ 70s..By the 1990s there is no longer reference to coal mining operations, with the pit backfilled to form current site levels.
Fieldworks	The site investigation fieldworks were undertaken in January and February 2019. The investigation comprised the following: 10 cored rotary boreholes, 10 open-hole rotary boreholes, 25 window sample boreholes, 44 machine excavated trial pits, gas and groundwater monitoring wells, together with the logging and representative sampling of the site soils and groundwater for environmental and geotechnical testing.
Ground Conditions	Inside Opencast Area The ground model within the opencast mine was characterised by the presence of made ground, in form of opencast backfill, to depths of up to 58.8m bgl. This material varied between a granular and cohesive stratum. Outside Opencast Area Outside of the opencast area the ground model was characterised by a thin veneer of topsoil overlying residual soils of the Pennine Middle Coal Measures bedrock.
In-Situ and Laboratory Testing	Representative samples of the shallow site soils (made ground and natural) were obtained and submitted to a suitably accredited laboratory for environmental chemistry analysis. The environmental chemistry results for soils have been compared with the Tier 1 criteria for soils with respect to human health for a Residential with homegrown produce end use reflecting the proposed end use of the site. To the west of the site where commercial properties are proposed, the results were compared with the Tier 1 criteria for soils for commercial properties. Geotechnical testing on representative soil samples was undertaken. The geotechnical testing comprised: Oedometer testing, Unconsolidated undrained triaxial, Atterberg, compaction testing and Particle Size Distribution (PSD) tests. In-situ testing comprising SPT and Hand Shear Vane Tests was also undertaken.
Generic Quantitative Risk Assessment	Human Health - The risk to future site users is considered Low/moderate with respect to a <i>Residential with homegrown produce</i>, end use, with remedial action required for the development. Controlled Waters - The risk to the underlying Secondary A Aquifer (bedrock) and surface waters is considered to be Low, with no remedial action required. Ground Gas - The risk presented by ground gases is assessed to be Moderate, with the requirement for ground gas protection measures, in line with an Amber 1/CS-2 (commercial) classification.

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Geotechnical Considerations	The main design hazards associated with the site are considered to be: the variable nature of the shallow fill; the inclusions of anthropogenic material in the fill; and, the potential for combustible coal seams in the southeast of the site (outside of the opencast area). The risks associated with these hazards comprise: • Poor/Insufficient bearing capacities • Intolerable total/differential settlement • Secondary consolidation • Requirement for higher classification of concrete
Recommendations	Recommendations for Site Enabling It is recommended that ground improvement is undertaken to regulate the shallow soils within the opencast fill area. Based on the findings of this ground investigation it is recommended that the most feasible option is a 'dig and turn' of the upper c. 3.00 m of the site followed by material sorting (removal of anthropogenic / unacceptable inclusions) and replacement to a suitable earthworks specification. Owing the scale of the required earthworks coupled with the variability of the fill and the likely requirement for some form of modification, e.g. lime addition, to control moisture content it is recommended that an earthworks trial is undertaken to inform the earthworks specification . The requirement for soil stabilisation, i.e. cement addition, may be required subject to the design performance. Recommendations for Development It is recommended that as part of the site enabling works a remediation strategy is developed to mitigate these risks to future site users. It is anticipated that these mitigation measures will be in the form of provision of clean capping to future residential properties and the provision of ground gas protections measures in accordance with BS8485:2019.

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067895.101-CUR-00-XX-DR-GE-003 – Depth to Base of Made Ground	Revision 00
067895.101-CUR-00-XX-DR-GE-004 – Depth to Base of Made Ground (heatmap)	Revision 00
067895.101-CUR-00-XX-DR-GE-005 – Groundwater Flow Direction	Revision 00
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1.0 Introduction

1.1 Project Background

In November 2018, Curtins was commissioned by Harworth Group to undertake a ground investigation on a site located off Occupation Lane, Woodville. The proposed works across the site comprise design of commercial/residential end use of the land, comprising:

- Up to 300 low rise residential dwellings
- Several commercial units
- Associated access roads, car parking, private gardens and areas of soft landscaping

Separate to the above Derbyshire City Council are, at the time of writing, designing a new link road which bisects the site running north south. The link road forms the boundary between the residential development plots (to the east of the link road) and the commercial development plots (to the west of the link road). Consideration of the design requirements of the proposed link road are outwith this report.

The aim of this Ground Investigation Report (GIR) is to present an account of the ground investigation works that have been undertaken and a review of the ground and groundwater conditions, geo-environmental limitations, constraints and ground hazards/risks. In addition, this report provides preliminary recommendations for future detailed design works.

1.2 Scope of Works

The Phase 2 Ground Investigation was undertaken to provide an assessment of the ground and groundwater conditions across the site with respect to:

- Potential ground/groundwater contamination
- Geotechnical ground and groundwater properties
- Potential geohazards/risks, in particular those likely due to the site's coal mining legacy.

As a part of this report, an assessment of the following items has been undertaken:

- Likely risk of adverse impact by potential shallow soils contamination on the end user, anticipated based on recent and historical land use.
- Likely risk of adverse impact of potential contaminated groundwater and/or surface water on the end user, anticipated based on recent and historical land use.
- The groundwater conditions within the made ground and the natural strata.

- Likely risk of adverse impact of soil gases including methane, carbon dioxide, oxygen and hydrogen sulphide, on the end user.
- Geohazards caused by historic coal mining.
- Geohazards due to presence of backfill material.

Following these assessments, recommendation comparing the following are provided:

- Recommendations for any site enabling and/or remediation works.
- Recommendations for the design of foundations and building ground floor slabs.
- Recommendations for the specification of sub-structure concrete.

1.3 Previous Reporting

A number of historical ground investigation reports have been made available by the client. These reports comprise both intrusive and desk-based investigation:

- May 2007 – Geo-Environmental Appraisal of Land off Occupation Lane, Woodville, Sirius (Sirius, 2007).
- October 2007 – Preliminary Geotechnical Interpretative Report – Swadlincote Regeneration Route, Scott Wilson Ltd (Scott Wilson Ltd., 2007).
- May 2012 - Preliminary Geo-Environmental Desk Study Report, Occupation Lane, Woodville, Atkins (Atkins, 2012).
- July 2013 – Factual Report on Site Investigation at the Former Dyson Site, Occupation Lane, Woodville, Ground Investigation & Piling Ltd (Ground Investigation & Piling Ltd., 2013).
- July 2013 – Preliminary Geo-Environmental Assessment Report, Woodville, Atkins (Atkins, 2013).
- October 2017 – Woodville Link Road, Settlement Calculations, AECOM (AECOM, 2017).

In addition to those listed above, a Preliminary Geo-Environmental Appraisal and Risk Register Report (Curtins, 2018) which also comprised a preliminary geotechnical risk assessment has been undertaken prior to the investigation.

2.0 Site Setting

This section presents a summary of the site setting based on readily available data and the information presented within the Curtins Geo-Environmental Appraisal Report (Curtins, 2018).

2.1 Current Setting

The development site (hereafter referred to as *the site*) is located off Occupation Lane, Woodville, on approximate National Grid Reference SK 31013 18716, see Figure 1. The site generally comprises an area of roughly vegetated open space with localised areas of woodland. A large pond is located to the north-west connected to a drainage channel, approximately 1.5m deep, which runs east to north west.

The site covers an area of approximately 20 hectares that has undulating topography with a general fall in ground level from north-east to south-west. The steepest topography is located in the south east of the site with a fall in ground level from east to west from approximately 135.7mAoD to 127.4mAoD.

The site's surrounding land use consists of: residential properties to the south and south-east and a mix of commercial and small industrial units surrounding it in all other directions.

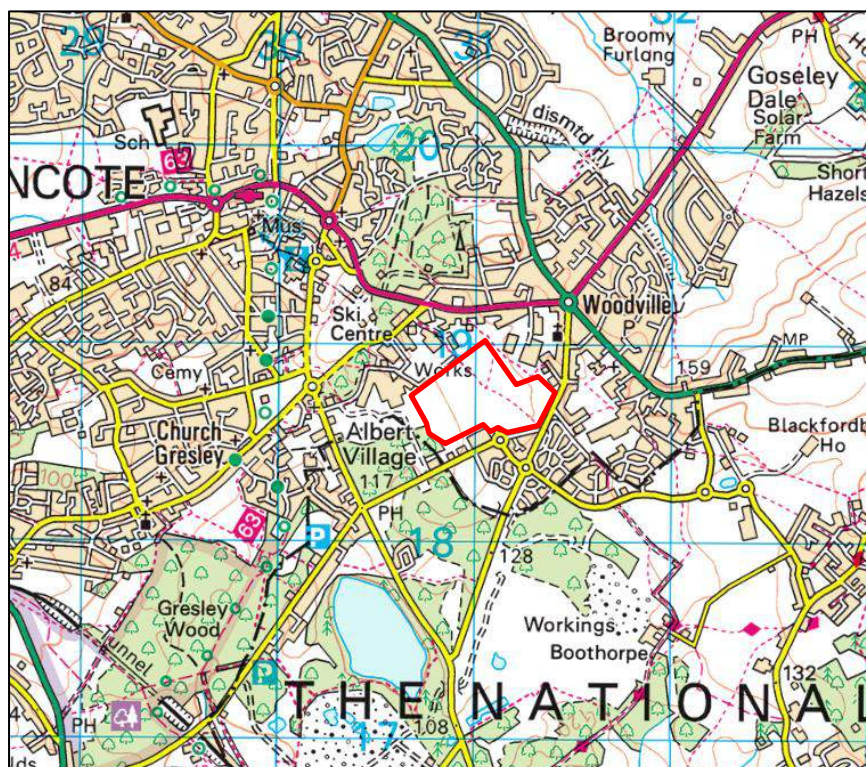


Figure 1 - Site Location Plan (approximate development site boundary in red (Wardell Armstrong, 2014), Google Earth Pro)

The majority of the site is known to have been used for open cast coal recovery, with operations now ceased and fully backfilled. It is anticipated that the ground and groundwater conditions could vary

inside and outside this opencast mine, as such for ease of reference hereafter, the site will be discussed for two separate sections as follows:

- Inside opencast mine: Majority of the site.
- Outside opencast mine: To far south-east.

The full location of the former opencast mine is illustrated on drawing ref: 067895-CUR-00-XX-DR-GE-002-Opencast Plan.

2.2 Site History

2.2.1 On-Site

Late 1800's

From the earliest available mapping the development site, can be split into eastern and western portion, with the eastern portion predominately comprising undeveloped fields, whilst the western portion consists of mining operations and a number of cross-boundary works.

In the eastern area of the development site are two former pits / quarries which at the time of mapping are vegetated and covered with trees. A number of footpaths transect the eastern portion, whilst a road is present in the south-eastern corner in a north to south alignment.

Within the central portion of the site a building (not shown by 1901) is present, no details of use are listed.

Two shafts are noted within the western portion consisting of a 'Old clay Shaft' annotated to the north west of the site and 'Shaft' noted adjacent to the mineral railway in the south-west. Mount Pleasant works are present cross-boundary of the site within the south-western corner in the current footprint of the Dyson Building, however no building footprints associated with the land use are present on the subject site.

1900 to 1955

The eastern portion of the site remains relatively unchanged during this period, whilst the unknown building is no longer present within the central portion, however outline of an unknown building is present further north, within a centrally located position.

Within the western portion during this period a clay pit (Milk Hill) is apparent immediately east of the mineral railway which extends to its maximum size in c.1925. Numerous air shafts are indicated to be present within the clay pit. The previously aforementioned shafts in Section 2.3.1 are no longer indicated on mapping.

Development of buildings in and around the Mount Pleasant works, including a pump house are noted, during the time period, with building footprints now present within the development site boundary. The area to the west of the Mineral Railway is presented as marsh land.

1955 to 1975

By 1955, the railway line within the western portion is indicated to have moved to a new position along the eastern edge of Milk Hill Clay Pit. The clay pit has extended to south-western portion to the former marsh area. To the east of the new railway alignment and along the central portion of the development site are suspected spoil heaps. The railway is shown to have been removed in the late 1960s.

No significant changes within the eastern portion during this period.

1975 to 2000's

The historical maps dating from 1975 show that the western portion of the site is entirely annotated as 'open cast' workings' (with mining records indicated opencast was operational from 1965 to 1978), whilst the majority of the eastern portion of the site is presented as a slag heap with the exception of the far south-eastern corner which remains undeveloped.

2000s to Present

Historical maps from 2006 show the majority of the site as 'Workings Disused' (with exception of far south-eastern corner) with minimal site features shown. Recent maps show the pond and drainage ditch on site, in the orientation noted at present.

2.2.2 Immediate Surrounding Area

From the earliest available mapping (1884) the development site is within a prominent colliery area, with shafts present west of the site and Granville Colliery and a number of 'works' and clay pits to the north and northwest with associated railway lines, spoil heaps and infrastructures.

By the 1970s the surrounding area was predominantly industrial/commercial units to the north and south, with residential properties to the east and an additional opencast mine to the west.

The present-day surroundings are not dissimilar to the 1970s however the opencast to the east is no longer present, a number of commercial properties have replaced this area.

2.3 Geology and Hydrogeology

The geological and hydrogeological setting of the site, as determined from the readily available information sources is summarised in Table 1 and is discussed within this section.

Table 1 - Summary of Geology and Hydrogeology Classifications within the development site

	Geology	Associated Hydrogeological Classification
Made Ground	Inside the opencast mine (Majority of the site): Opencast backfill that, based on mining records, is understood to extend to depths of between 35 to 40m below ground level (bgl). This material is likely to consist of reworked opencast arisings. Outside the opencast mine (Far south-eastern corner): Made ground deposits are unlikely to be present on the site due to lack of evidence of development on the site. No superficial deposits are recorded across the site.	N/A
Bedrock	Pennine Middle Coal Measures ¹ (Bedrock)	Secondary (A) Aquifer ²

Notes for Table 1:

1. These deposits comprise: Interbedded grey mudstone, siltstone, pale grey sandstone and commonly **coal** seams, with a bed of mudstone containing marine fossils at the base, and several such marine fossil-bearing mudstones in the upper half of the unit.
2. 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.

Review of the BGS map No.141, Loughborough, Solid and Superficial, 2003, scale 1:50,000, indicated that the site is underlain by a solid geology of Pennine Middle Coal Measures generally comprising interbedded mudstones and siltstones with occasional grey sandstone.

A review of the online BGS records (British Geological Society, 2019), identified three historical exploratory holes located within the site boundaries, with two located inside the opencast mine (SK31NW289 and SK31NW6) and one outside the opencast mine (SK31NW292). An off-site historical exploratory hole (SK31NW1) has been identified, located 100m north of the site boundaries. A summary of the recorded ground conditions is presented in Table 2.

Table 2 - Summary of on-site and off-site BGS historical borehole records

Location	BGS Reference	Encountered Ground Conditions	Depth [m bgl]
On-site			
North-western boundary	SK31NW289	Residual soils (clay) – Pennine Middle Coal Measures (PMCM)	1.67
		COAL	5.18
		PMCM	5.48
		COAL	6.70
		PMCM	6.88
		PMCM	8.25
		Fireclay	10.97
Western area	SK31NW6	Residual soils	3.06
		PMCM	3.66
		COAL	3.96
		PMCM	14.64
		COAL	14.95
		PMCM	17.39
		Fireclay	19.83
		COAL	19.84
		PMCM	25.02
		COAL	25.61
		PMCM	26.93
		COAL	26.85
		PMCM	27.14
		COAL	28.06
		Fireclay	28.98
PMCM	32.02		
Eastern area	SK31NW292	Residual soil	0.30
		PMCM	2.15
		COAL	2.46
		PMCM;	3.38
		COAL	3.68
		PMCM	5.82
		Fireclay	7.95
		PMCM	14.65
Off-site			
100m north	SK31NW1	Residual soil	2.59
		COAL	3.58
		PMCM	5.79
		COAL	7.26
		PMCM	7.52
		COAL	8.18
		Fireclay	8.43
		COAL	9.50
		Fireclay	9.70
		PMCM	10.72
		COAL	11.07
		PMCM	13.46

Location	BGS Reference	Encountered Ground Conditions	Depth [m bgl]
		COAL PMCM COAL <i>Fireclay</i> PMCM COAL PMCM COAL Further PMCM and coal seams including Dickey Gobbler (75m depth), Block Coal (88m depth), Little Coal (186m depth) and Cannel Coal (203m depth).	13.84 19.28 20.24 20.85 30.43 30.53 35.26 35.76

2.4 Hydrogeology

The development site is not listed within a groundwater Source Protection Zone (SPZ) and there are no groundwater abstractions within 1 km radius of the site.

The groundwater within the former opencast mine is anticipated likely to have accumulated or 'recovered' following the termination of coal mining activities and backfilling operations.

No pumping operations are known to be currently active locally to the site, therefore the groundwater levels within the opencast mining area are anticipated to reflect the natural groundwater table (potentiometric surface).

2.5 Hydrology

A large pond is located to the north-west of the site, connected to a drainage channel which runs east to north-west. A further drain bounds the site to the north.

There are no surface water abstractions recorded within 500 m of the site.

There are no discharge consents on the subject site.

2.6 Radon

The BGS Radon Mapping confirms that the site is situated in a lower probability radon area where less than 1% of homes are above the radon action level. On this basis radon protection measures are not considered necessary for future dwellings or extensions on the site.

2.7 Mining

As detailed within Section 2.2 and 2.3, the site is dominated by its mining legacy, specifically the former opencast coal mine that covers most of the site. This is guided by the underlying solid geology of the site, comprising the Pennine Middle Coal Measures which is known to contain numerous coal seams of extractable thickness and quality.

With reference to the Coal Authority records (Coal Authority, [accessed: 05/01/2018].), the whole site is located within a Coal Mining Development High Risk Area.

Mining and its associated risks across the site are discussed in detail in Section 8.0 of this report.

2.8 Unexploded Ordnance

Unexploded Ordnance (UXO) is a historical hazard that affects areas of the UK that have either been subject to former military use or have been historically bombed. To determine the likelihood of UXO being present on a site, a step-wise risk assessment process is followed. This process is outlined within CIRIA C681 '*Unexploded Ordnance: A Guide for the Construction Industry, 2009*'.

2.8.1 UXO Hazard Screen

The Hazard Screen ask two key questions:

Are there any indicators of former military use on the Sites? No (no evidence on historical mapping and internet searches).

Are there indicators of historical bombing on the Sites? No. Swadlincote was subject to at least one bomb strike during the Second World War (various internet sources), however, there is no evidence of the site itself having received direct strikes from ordnance (no change in footprint on historical mapping and internet searches).

It is further noted that the majority of the site was used as an active opencast mine, excavated to up to c. 40m bgl. The site's geology is characterised by opencast backfill, which was deposited in the following WWII, further reducing the likelihood of UXO being present on site.

Conclusion: No indicators of military land use or historical bombing are noted on site and therefore, no further risk assessment is recommended.

Recommendation: It is recommended that a generic emergency response plan is put in place, for all planned activities, to deal with any unforeseen UXO encounters.

3.0 Existing Ground Investigation

Two historic ground investigations have been undertaken by Sirius, 2006 and Atkins, 2013. This ground investigation information has been reviewed and considered in designing of the ground investigation works undertaken in January/February 2019.

3.1 Ground Conditions

Exploratory hole logs and geotechnical testing data, from both the Sirius Ground Investigation (Sirius, 2007) and the Atkins Ground Investigation (Atkins, 2013), has been reviewed. A summary of the findings can be found in Tables 3 and 4.

Table 3 - Summary of Ground Conditions, Sirius Investigation (2006)

Stratum	Depth to top of strata (m bgl)		Thickness (m)		General Description (Driller's descriptions only in rotary holes so depths not included from these)
	Min	Max	Min	Max	
Topsoil	0.0	0.0	0.0	0.5	Brown to black gravelly CLAY. Gravel is fine to medium angular to rounded sandstone, mudstone and siltstone.
Made Ground (Opencast backfill)	0.0	0.5	0.0	>43.0 ¹	Soft to stiff black, grey or brown occasionally mottled orange sandy gravelly CLAY. Gravel is fine to coarse angular to subangular ash, brick, clinker, coal, metal, mudstone, pottery, rope, sandstone, siltstone, timber, tyre and wire. Also encountered as a grey clayey sandy GRAVEL where the granular material was the same as encountered within the clays. Grey sandy gravelly SILT with gravel of siltstone. Grey fine to coarse SAND. Occasional brick, mudstone, sandstone and siltstone cobbles, and rare mudstone and concrete boulders. Occasional hydrocarbon odours.
Residual Soils *	15.5	18.4	0.1	1.2	Weak grey MUDSTONE, grey SILTSTONE and brown SANDSTONE recovered as angular gravel.

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Stratum	Depth to top of strata (m bgl)		Thickness (m)		General Description (Driller's descriptions only in rotary holes so depths not included from these)
	Min	Max	Min	Max	
Bedrock (Pennine Middle Coal Measures) *	4	>64.0 ²	-	-	Grey MUDSTONE; Grey SILTSTONE; and, Light brown-yellow SANDSTONE.

1 maximum base of the made ground sitewide has not been determined as the exploratory hole was terminated at max depth of 43m within this stratum.

2 The maximum depth of bedrock was not encountered.

Table 4 - Summary of Ground Conditions, Atkins Investigation (2013)

Stratum	Depth to top of strata (m bgl)		Thickness (m)		General Description (Driller's descriptions only)
	Min	Max	Min	Max	
Topsoil	0.0	0.0	0.2	0.3	Grass onto Topsoil. *
Made Ground (Opencast backfill)	0.0	0.3	1.7	>20 ¹	Firm to very stiff grey, brown or black sandy gravelly CLAY. Gravel is brick, coal, ironstone and mudstone with occasional ash, ceramic, concrete, metal and timber. Occasional hydrocarbon odour. Medium dense grey clayey sandy GRAVEL of mudstone. Grey COBBLES of mudstone.
Residual Soils	0.2	19.0	0.3	2.8	Grey or brown mottled orange or yellow sandy CLAY with mudstone and sandstone lithorelicts. Orange brown clayey or sandy GRAVEL of mudstone and sandstone.
Bedrock (Pennine Middle Coal Measures)	3.0	>21.8 ²	> 0.05	> 2	Grey MUDSTONE; and, Grey SILTSTONE.

1 maximum base of the made ground sitewide has not been determined as the exploratory hole was terminated at max depth of 20m within this stratum.

2 The maximum depth of bedrock was not encountered.

3.2 Laboratory Geotechnical Testing

3.2.1 Inside Opencast Mine

A summary of test results for this section of the site from the Sirius investigation (Sirius, 2007) is summarised in Table 5.

Table 5 – Summary of Test Results, Inside Opencast Mine, Sirius Investigation, 2007

Test	Quantity		Range of Data	
Standard Penetration Testing	Backfill	234	Range: 2 to >50 Average: 20	
	Bedrock	18	Range: 35 to 90 Average: 43	
Hand Vane	100		Cu	Range: 18 to 140 kPa Average: 67.6 kPa
Atterberg	28		MC	18.8%
			LL	48.2%
			PL	22.6%
			PI	25.6%
Compaction Testing	7		Max Dry Density	1.62 mg/m ³
			MC	19.1%

A summary of test results for this section of the site from the Atkins investigation (Atkins, 2013) is summarised in Table 6.

Table 6 - Summary of Test Results, Inside Opencast Mine, Atkins 2013

Test	Quantity		Range of Data	
Standard Penetration Testing	Backfill	64	Range: 3 to >50 Average: 21	
	Bedrock	7	Range: 40 to >83 Average: 60	
Hand Vane	4		Cu	Range: 42 to 120 kPa Average: 68.5 kPa
Atterberg	9		MC	19%
			LL	46.6

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Test	Quantity	Range of Data	
Compaction Testing	6	PL	21.4
		PI	25.1
		Max Dry Density	1.7 mg/m ³
		MC	18.8%

3.2.2 Outside Opencast Mine

A summary of test results for this section of the site from the Sirius investigation (Sirius, 2007) is summarised in Table 7.

Table 7 - Summary of Test Results, Outside Opencast Mine, Sirius 2007

Test	Quantity	Range of Data	
Standard Penetration Testing	3	7 to 52 with an average of 35.7	
Hand Vane	10	Cu	Range: 50 to 110 Average: 72.8
Atterberg	3	MC	34.3%
		LL	64.3%
		PL	29.3%
		PI	35%

A summary of test results for this section of the site from the Atkins investigation (Atkins, 2013) is summarised in Table 8.

Table 8 - Summary of Test Results, Outside Opencast Mine, Atkins 2013

Test	Quantity	Range of Data	
Standard Penetration Testing	5	Range: 10 to 83 Average: 52.4	
Compaction Testing	1	Max Dry Density	1.65 mg/m ³
		MC	18%

3.3 Laboratory Geo-Environmental Testing

3.3.1 Soil Testing

A summary of the geo-environmental soil testing from the Sirius Investigation (2007) is in Table 9.

Table 9 – Summary of Geo-environmental testing from Sirius Investigation (2007)

Parameter	Screening value (mg/kg, unless otherwise stated)	No. of samples above screening value	No. of samples tested	Maximum concentration (mg/kg, unless otherwise stated)
Metals/Metalloids				
Arsenic	20	21	126	190 TP154 1.00m
Cadmium	1 (pH 6) 2 (pH 7) 8 (pH 8)	13	126	5.4 TP18 0.60m
Chromium (Total)	130	0	126	
Lead	450	0	126	
Mercury	8	0	126	
Selenium	35	0	126	
Copper	80 (pH 5 to < 5.5) 100 (pH 5.5 to < 6) 135 (pH 6 to 7) 200 (pH > 7)	0	126	
Nickel	50	11	126	110 TP104 1.20m
Zinc	200 (pH 5 to 7) 300 (pH > 7)	3	126	
Inorganics				
pH	<5	3	126	
Total Sulphate	2,400	49	126	20,000 BH7 3.30M
Water Soluble Sulphate	0.5 g/l	76	126	2.3 TP106 0.60m
Organics				
Monohydric Phenol	78 (1% SOM) 150 (2.5% SOM) 280 (5% SOM)	0	126	NOTE: TOC/0.58 = SOM
Benzo(a)pyrene	1.1	4	126	12 TP116 0.10m
Naphthalene	3.5	0	126	
TOC	3 w/w%	81	126	15 TP137 2.90m
TPH, PRO/GRO	500	1	11	4500 TP8 2.90m
Others				
Calorific Value	2 MJ/Kg	3	13	3.3 TP137 2.90m

3.3.2 Groundwater Testing

A summary of the geo-environmental groundwater testing from the Sirius Investigation (2007) is in Table 10.

Table 10 – Summary of groundwater testing form the Sirius Investigation (2007)

Parameter	Screening value (µg/l, unless otherwise stated)	No. of samples above screening value	No. of samples tested	Maximum concentration (µg/l, unless otherwise stated)
Metals/Metalloids				
Arsenic	10 (50)	0	14	
Cadmium	5	0	14	
Chromium	250 (50)	0	14	
Lead	250 (25)	0	14	
Mercury	1	0	14	
Selenium	10	0	14	
Copper	28 (2,000)	0	14	
Nickel	200 (20)	1/8	14	250 BH1
Zinc	500 (3,000)	0	14	
Inorganics				
Sulphates	250 mg/l (400 mg/l)	12/10	14	2000 BH7
Organics				
Phenol	0.5 (30 [300])	0	14	
Total TPH	10	7	14	82 BH 10
Total PAH	0.1	6	14	1.6 R19
Benzo(a)pyrene	0.01	0	14	
Benzo(b)fluoranthene	0.1	0	14	
Benzo(k)fluoranthene	0.1	0	14	
Benzo(ghi)perylene	0.1	0	14	
Indeno(1,2,3cd)pyrene	0.1	0	14	
Others				
pH	6-9 pH units	1	14	5.8 R25

3.3.3 Leachate Testing

A summary of the geo-environmental leachate testing from the Sirius Investigation (2007) is in Table 11.

Table 11 – Summary of leachate testing from Sirius Investigation (2007)

Parameter	Screening value (µg/l, unless otherwise stated)	No. of samples above screening value	No. of samples tested	Maximum concentration (µg/l, unless otherwise stated)
Metals/Metalloids				
Arsenic	10 (50)	0	51	
Cadmium	5	0	51	
Chromium (Total)	250 (50)	0	51	

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Parameter	Screening value (µg/l, unless otherwise stated)	No. of samples above screening value	No. of samples tested	Maximum concentration (µg/l, unless otherwise stated)
Lead	250 (25)	0	51	
Mercury	1	0	51	
Selenium	10	0	51	
Copper	28 (2,000)	1/0	51	32 BH15 4.30
Nickel	200 (20)	0/4	51	200 BH15 4.30m 30 TP36 1.60m 29 TP48 0.10m 23 BH16 2.70m
Zinc	500 (5,000)	1/0	51	860 TP4 0.20m
Organics				
Phenol	0.5 (30 [300])	0	51	
Total PAH	0.1	17	51	8 TP141 0.10m
Benzo(a)pyrene	0.001	3	51	0.32 TP40 2.90m 0.06 TP123 0.10m 0.02 TP2 0.20m
Benzo(b)fluoranthene	0.1	1	51	0.26 TP40 2.90m
Benzo(k)Fluoranthene	0.1	1	51	0.16 TP40 2.90m
Benzo(ghi)perylene	0.1	0	51	
Indeno(1, 2, 3 cd)pyrene	0.1	1	51	0.18 TP40 2.90m
Others				
PH	6-9 pH	14	51	9.6 BH14A 4.00m 5.9 BH12 16.00m 5.9 BH16 2.70m 5.9 TP38 1.90m 3.1 TP120 0.50m

Table 12 – Summary of Sulphate testing in Atkins Investigation (2012)

Sample Ref.	Depth (m)	pH	SO ₄ (g/l)
CP5	1.00	7.59	0.903
TP1	2.00	7.35	0.0163
TP5	0.70	4.26	1.26
TP9	1.50	7.63	0.801
TP11	1.00	6.46	1.54
TP13	2.50	5.89	1.01

3.4 Summary of Ground Contamination

Review of the previous reporting is summarised in detail in Curtins Geo-Environmental Appraisal (Curtins, 2018). A brief summary is provided presenting a precis of the relevant findings which informed Curtins 2019 intrusive works.

Exceedances of the adopted Tier 1 thresholds were encountered within shallow soils. All of these exceedances, with the exception of two arsenic exceedance were of Poly Aromatic Hydrocarbons. Localised hot spots of contamination were encountered in the form of a barrel and localised visual and olfactory indicators of contamination

The controlled waters assessments found marginal exceedances for heavy metals and TPH fractions, with no identified exceedances for PAH determinants.

Ground gas monitoring of installed monitoring wells was assessed for inside the opencast area (majority of the site) and outside the opencast area (far south-eastern portion). These investigations found similar ground gas concentrations inside the opencast and outside the opencast and classified the site as CS-2/Amber 1 (NHBC Guidelines).

4.0 Preliminary Conceptual Site Model and Qualitative Risk Assessment

Following a review of the previous ground investigations and Curtins' Geo-Environmental Appraisal (Curtins, 2018), an updated preliminary Conceptual Site Model (CSM) and Qualitative Risk Assessment (QRA) are presented in Table 13 within this section.

The CSM details the source-pathway-receptor linkages or potential contaminant linkages (PCL) that have been identified for the site. The QRA details the associated level of risk relating to these potential contaminant linkages.

The CSM and QRA concern risk to human health and water environment with additional, more specific risk assessment protocols contained within the main body of this report, as detailed in Section 3.1.

The QRA follows the framework outlined within CIRIA C552 which is summarised within Appendix G.

The 'risk rating' within the QRA refers to the risk that the source, pathway, receptor linkage or PCL is complete. Unless specifically stated it does not necessarily refer to an immediate risk and is intended to be used as a tool to assess the necessity for further assessment/investigation.

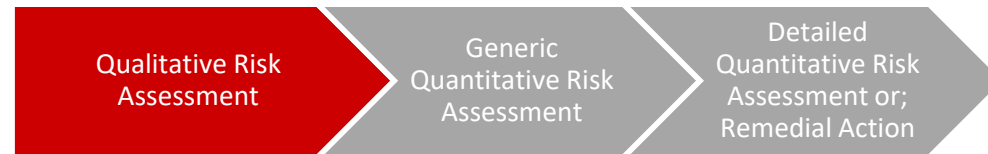
The CSM and the risk ratings within our QRA are informed by the available historic information and the findings of the previous ground investigations.

4.1 Additional Risk Assessments

The risk assessments listed below, are not included within the main CSM and QRA but none-the-less can be of critical importance to the onward development of the site.

- The risk presented by **Mining** is discussed and assessed in Section 9.0.
- The risk presented by **Radon** is discussed and assessed in Section 2.6.
- The risk presented by **Unexploded Ordnance** is discussed and assessed in Section 5.0.

Under current health and safety legislation, all involved parties are required to carry out their own appropriate risk assessments and mitigation measures to protect themselves and their employees, other human receptors and the environment, from potential contamination. Such risks must be adequately mitigated by law, specifically the Construction Design Management (CDM) Regulations (2015) which requires that potential risks to human health and the environment from construction activities are appropriately identified and all necessary steps taken to eliminate / manage the risk. It has been assumed that any future construction works on site will be undertaken in compliance with these requirements and therefore construction workers involved in the building works at the site have been discounted as a human receptor in the conceptual site model.



- The table below represents the first stage in the land quality risk assessment process: The Qualitative Risk Assessment.
- In order for a development site to be deemed 'suitable for use', the level of risk needs to be brought down to acceptable levels, i.e. low to negligible risk. The purpose of each stage of risk assessment is ultimately to establish, if there is a requirement for additional levels of assessment to be made to have sufficient confidence to support a risk characterisation or management decision, e.g. remedial action.

Table 13 – Preliminary Conceptual Site Model

Conceptual Site Model			Qualitative/Quantitative Risk Assessment			Recommended Action
Source	Pathway(s)	Receptor(s)	Consequence (Potential Severity)	Likelihood of Occurrence	Risk*	
Inorganic (arsenic) and organic (PAHs) contaminants within the Made Ground (opencast backfill) soils.	Direct contact, ingestion and inhalation (dust and vapours)	Future site users Residents and visitors.	Medium Chronic health risk	Likely Based on the concentrations of arsenic and PAHs within the Made Ground. Recommendation for clean capping within private gardens in areas of former opencast backfill.	Low to Moderate	GQRA as Part of Intrusive Ground Investigation
		Future site users Employees, visitors and the general public.	Medium Chronic health risk	Unlikely Based on testing of the Made Ground undertaken date, it is unlikely that shallow soils will present a risk to commercial end users.	Low	
	Leaching of contaminants from soils followed by horizontal migration, through superficial or bedrock deposits.	Controlled waters (Groundwater) Secondary A Aquifer in the bedrock deposits.	Mild Site not within a Source Protection Zone	Unlikely Based on concentrations of contaminants within the opencast backfill.	Very Low	
	Leaching of contaminants from soils followed by horizontal migration, through superficial or bedrock deposits.	Controlled waters (Pond on-site)	Mild Low sensitivity water body	Unlikely Based on concentrations of contaminants within the opencast backfill	Very Low	
	Direct contact (e.g. foundations corroded by acidic or alkaline soil or groundwater conditions).	Construction materials	Mild	Unlikely Assumes adoption of suitable materials in construction (e.g. appropriate class concrete and service construction). Current testing data indicates DS-1, AC-1 to DS-3, AC-3.	Very Low	
Ground gases – associated with opencast backfill and coal measure geology	Vertical and horizontal migration through existing superficial deposits.	Future users of site. Residents and visitors Employees, visitors and the general public.	Medium	Likely Assumes adoption of required gas protection measures in new dwellings and properties, based on previous testing data. It is anticipated that further monitoring potentially could reduce the likelihood of occurrence.	Low to Moderate	

5.0 Curtins 2019 Ground Investigation

The recent ground investigation has been undertaken by Geocore Site Investigation Limited in January and February 2019, under full time presence of a suitably qualified Curtins Engineer, to complement the existing information obtained from the historic ground investigations (as discussed in Section 3.0 of this report).

5.1 Fieldwork

5.1.1 General

A summary of the scope and rationale of the recent ground investigation is presented Table 14.

The ground investigation has been designed by Curtins with reference to the findings of the Phase 1 and Phase 2 reporting undertaken by Sirius (Sirius, 2007) and Scott Wilson Ltd. (Scott Wilson Ltd., 2007), to inform the design of the proposed works. The ground investigation has been undertaken in general accordance with the current UK best practice guidance including:

- CLR11 (Environment Agency (EA), September 2004)
- British Standard (BS) 10175 (British Standard Institution (BSI), 2011)
- BS 5930:2010 (British Standards (BS), 2010)
- BS EN 1997 – Parts 1 & 2 (British Standards Institution, 2006)

Table 14 - Ground Investigation Scope and Rationale

Activity	Quantity	Maximum Depth [m bgl]	Rationale
Rotary Open-Hole Exploratory Holes (referenced T1/T1a to T5/T5a)	10	60.0	To determine depth to and inform assessment of geometry of opencast highwall in transects across the site.
Rotary Cored Exploratory Holes (referenced RC01 to RC10)	10	30	To characterise ground profile within and to the east of the opencast area.
Machine Excavated Trial Pits (referenced TP201 to TP250)	45	3.7	To determine ground conditions across the opencast, backfill area and the northern section of the site.
Window Sample Exploratory Holes (referenced WS01 to WS25)	25	5.45	To determine shallow ground conditions across the northern section of the site outside the opencast area.
Description and Logging of Soil Arisings from Exploratory Holes.	N/A	N/A	To provide a characterisation of ground conditions and inform sample selection for laboratory analysis.
Collection of Representative Soil Samples from Exploratory Hole Arisings.	N/A	N/A	To enable laboratory Environmental and Geotechnical analysis of recovered soil samples.
Installation of Monitoring Wells in 30no. Exploratory Holes.	N/A	N/A	To enable a ground gas and groundwater level monitoring.
In-situ Testing.	N/A	N/A	To determine geotechnical properties of the strata revealed.

The exploratory hole locations are shown on the Curtins drawing ref. 067895.101-CUR-00-XX-DR-GE-001-V01_Exploratory Hole Location Plan, Appendix A.

5.1.2 Soil Logging and Sampling

Exploratory hole arisings were logged on site by a Curtins Engineer in accordance with BS 5930 (British Standards (BS), 2010). The visual and olfactory indications of contamination observed were recorded. The exploratory hole logs are provided in Appendix D1.

Representative soil samples were selected based on field observations, for geotechnical and geo-environmental testing, to ascertain information on the made ground and the natural strata encountered.

Selected soil samples for the purposes of geo-environmental testing were placed in laboratory provided containers and stored in cool boxes prior to being transported to the nominated laboratory, under the laboratory's chain of custody documentation. The laboratory selected by Curtins for chemical and geotechnical analysis was i2 Analytical, which is a UKAS and MCerts accredited laboratory. A summary of the environmental testing and samples are provided in Table 15.

Table 15 - Programme of Geo-Environmental Testing

Strata	Sample Numbers	Test Suite
Natural Strata (residual bedrock)	1	Soil Suite 1D
	1	BRE Suite D
Opencast Backfill (made ground)	8	Soil Suite 1C
	4	Soil Suite 1D
	8	WAC
	11	BRE Suite D

In-Situ Tests

The results of the in-situ testing undertaken as a part of this ground investigation is summarised in Table 16. The results of these tests will be used to ascertain the geotechnical properties of the encountered ground conditions at detailed design stage.

Table 16 - Programme of In-Situ Testing

Activity	Rationale
SPT Tests within Rotary and Window Sample Boreholes	Assess relatively density or consistency of various strata.
Hand Shear Vane Testing within Trial Pit Locations	To determine direct shear strength values of the cohesive strata.

5.1.3 Monitoring Well Installations

Gas and groundwater monitoring standpipes (50mm diameter) were installed within 30no. exploratory holes. A bentonite seal was placed above the screened section of the borehole (and below where relevant) to minimise potential for downward migration of contaminants and creation of a preferential migratory pathway. A gravel surround was installed in the annulus between the sides of the borehole and the slotted sections of the pipe. A summary of the exploratory hole's response zones is presented in Table 17.

Table 17 - Borehole Response Zones Summary

Borehole Reference	Response Zone(s) (m bgl)	Strata Description(s)
Inside Opencast Mine		
RC01	1 - 10	OPENCAST BACKFILL (Made ground)
RC02	1 – 8	OPENCAST BACKFILL (Made ground)
RC03	1 – 17	OPENCAST BACKFILL (Made ground)
RC04	1 – 20.5	OPENCAST BACKFILL (Made ground)
RC05	1 – 15.5	OPENCAST BACKFILL (Made ground)
RC06	1 – 17	OPENCAST BACKFILL (Made ground)
RC07	1 – 22	OPENCAST BACKFILL (Made ground)
RC08	1 – 35	OPENCAST BACKFILL (Made ground)
RC09	1 – 18	OPENCAST BACKFILL (Made ground)
RC10	1 - 20	OPENCAST BACKFILL (Made ground)
WS01	1 - 5	OPENCAST BACKFILL (Made ground)
WS02	1 - 5	OPENCAST BACKFILL (Made ground)
WS03	1 - 5	OPENCAST BACKFILL (Made ground)
WS04	1 - 5	OPENCAST BACKFILL (Made ground)
WS05	1 – 5	OPENCAST BACKFILL (Made ground)
WS06	1 – 3	OPENCAST BACKFILL (Made ground)
WS07	1 – 5	OPENCAST BACKFILL (Made ground)
WS08	1 – 5	OPENCAST BACKFILL (Made ground)
WS09	1 – 4	OPENCAST BACKFILL (Made ground)
WS10	1 – 5	OPENCAST BACKFILL (Made ground)
WS11	1 – 3.50	OPENCAST BACKFILL (Made ground)
WS12	1 – 4	OPENCAST BACKFILL (Made ground)
WS13	1 – 5	OPENCAST BACKFILL (Made ground)
WS14	1 – 5	OPENCAST BACKFILL (Made ground)
WS15	1 – 5	OPENCAST BACKFILL (Made ground)
WS16	1 – 5	OPENCAST BACKFILL (Made ground)
WS17	1 - 5	OPENCAST BACKFILL (Made ground)
WS18	1 - 5	OPENCAST BACKFILL (Made ground)
WS19	1 - 5	OPENCAST BACKFILL (Made ground)
WS20	1 - 5	OPENCAST BACKFILL (Made ground)
WS21	1 - 5	OPENCAST BACKFILL (Made ground)
Outside Opencast Mine		
WS24	1 - 5	Residual Bedrock (CLAY)

Notes for Table 17:

1. Copies of exploratory hole logs provided by Curtins are included in Appendix D1.

5.1.4 Post-Investigation Monitoring

Ground Gas and Groundwater Level Monitoring

An initial programme of six rounds of gas and groundwater monitoring over three months was proposed to confirm Preliminary Conceptual Site Model as presented in Section 3.0.

To better understand the groundwater conditions within the opencast backfill material, a data logger (Baro TROLL 100) was installed within exploratory hole RC10. The data logger will provide continuous groundwater level readings at hourly intervals, the results of which are demonstrated in the following sections.

Gas and groundwater level monitoring has been undertaken on the following 6 no. occasions, to date:

- 06/03/2019
- 21/03/2019
- 25/03/2019
- 11/04/2019
- 24/04/2019
- 14/05/2019.

The results of the groundwater monitoring data are summarised in Appendix E.

5.2 Laboratory Testing

5.2.1 Geo-Environmental Chemistry Testing

Geo-environmental testing was scheduled, with analytical suites developed, reflecting the preliminary CSM described in Section 3.0 and observations made during the ground investigation.

Given the potential for site wide source of contamination (made ground), the sampling positions (exploratory holes) were generally located in a semi- targeted/targeted array to give adequate and representative coverage of the site accounting for the historical site use and the immediate environmental setting.

5.2.2 Soil Analysis

The nature and type of soil contamination potentially present on the site was considered to include, amongst others: organic matter, ash and fill, slag, hydrocarbons (e.g. fuel oils), heavy metals and asbestos. The extent of these is captured by the broad environmental testing suite detailed in Table 18.

Copies of the environmental chemistry testing certificates can be referred to in Appendix D2 of this report.

Table 18 - Environmental Chemistry Analysis Suite: Soils

Analysis	LOD
Asbestos Screen	N/A
pH	N/A
Soil Organic Matter	0.1%
Arsenic	1 mg/kg
Boron (water soluble)	0.2 mg/kg
Cadmium	0.2 mg/kg
Chromium	1.2 mg/kg
Chromium VI	1 mg/kg
Copper	1 mg/kg
Lead	1 mg/kg
Mercury	0.3 mg/kg
Nickel	1 mg/kg
Selenium	1 mg/kg
Zinc	1 mg/kg
Sulphate (total)	1.25 mg/l
TPH (Aro/Alk Split)	0.01 to 10 mg/kg
BTEX	0.01 to 1 ug/kg
Waste Acceptance Criteria Testing	N/A

5.2.3 Groundwater Testing

Groundwater samples were taken from exploratory holes WS04, WS16, WS21 and RC03, all located within the backfilled opencast area, and tested for:

- General Inorganics (pH, Cyanide, Sulphate as SO₄, Ammonia as NH₃ and dissolved organic carbon)
- Speciated PAHs
- Heavy Metals (Ca, Cr, Fe, Se, As, Cd, Cu, Cr, Pb, Mn, Hg, Ni, Se and Zn.)

Groundwater testing results are discussed further in Section 7.2.

5.2.4 Geotechnical Testing

Geotechnical testing was scheduled to complement the existing ground and groundwater information and to inform the parametric analysis. A summary of the geotechnical testing undertaken is summarised in Table 19, the results of which are summarised in the following sections. The detailed results are presented in Appendix D2.

Table 19 - Geotechnical Tests

Geotechnical Tests	Standard
Water soluble sulphate & pH (24no.)	BS 1377-3: 1990 Clauses 3, 5.2, 5.5, 7.2 & 9
Moisture Content (16no.)	BS 1377: 1990: Part 2: 3.2
Plasticity testing (16no.)	BS 1377-2: 1990 Clauses 4.3 and 5
Particle Size Distribution (11no.)	BS 1377-2: 1990, Clause 9.2
Moisture Condition Value vs Moisture Content (2no.)	BS 1377-4:1990: Clause 5
Dry Density/Moisture Content Relationship (11no.)	BS 1377-4:1990: Clause 3.3
Particle Density	BS 1377: 1990: Part 2: 8.2
Quick Undrained Triaxial (5no.)	BS 1377-7: 1990 Clause 8
Oedometer Consolidation Testing (7no.)	BS 1377-5: 1990 Clause 3

5.3 Ground Conditions

The ground conditions encountered during the Curtins ground investigation are summarised in this section.

The site's ground model is dominated by the presence of the backfilled opencast coal mine occupying the majority of the site. Therefore, a significant variation in ground conditions inside and outside the opencast mine boundaries have been identified.

The speculated ground model for the area inside the opencast mine is summarised in Section 6.2.1, and the ground conditions for the area outside the opencast mine are summarised in Section 6.2.2.

5.3.1 Inside Opencast Mine

The ground conditions for areas inside the opencast mine are summarised in Table 20. 42 no. exploratory holes were undertaken within this section of the site.

Table 20 - Summary of Ground Conditions Encountered Inside the Former Opencast Coal Mine Area

Stratum	Depth to top of strata (m bgl)		Thickness (m)		General Description
	Min	Max	Min	Max	
Topsoil	0.0	0.0	0.05	0.30	Brown to black gravelly CLAY. Gravel is fine to medium angular to rounded of sandstone, mudstone and siltstone.
Opencast backfill	0.00	0.00	0.80	58.8	Soft to stiff black to dark grey occasionally mottled orange and brown sandy very gravelly CLAY. Gravel is fine to coarse angular to subangular brick, coal and mudstone. Very clayey GRAVEL. Gravel is as encountered in clay above. Occasional mudstone brick cobbles. Rare mudstone and concrete boulders. Occasional hydrocarbon odours.
Bedrock (Pennine Middle Coal Measures)	3.3	58.8	Base not encountered.		Grey MUDSTONE; Grey SILTSTONE; and, Light brown-yellow SANDSTONE.

Topsoil

Topsoil was encountered within all exploratory holes to depths of between 0.05m and 0.30m bgl, comprising a brown/red to black gravelly CLAY. Gravel is fine to medium, angular to rounded sandstone, mudstone and siltstone.

Geotechnical testing has not been undertaken on samples of topsoil.

Opencast Backfill Material

The opencast backfill material was encountered to depths of between 0.30m and 58.80m bgl. The presentation of this stratum correlated with the alignment of the opencast mine. The shallower depths of opencast backfill were encountered on the eastern to south-eastern extents of the site.

The unit comprised either:

- A soft to stiff black to dark grey occasionally mottled orange and brown sandy very gravelly CLAY. Gravel is fine to coarse angular to subangular of brick, coal and mudstone with occasional mudstone brick cobbles, and rare mudstone and concrete boulders. Olfactory

indicators of contamination was noted as a strong to mild hydrocarbon odours within TP01, TP03, TP09, TP10, TP28 and TP36. A mild 'rotten egg' odour was noted in TP14.

- Loose to dense black to dark grey occasionally mottled orange and brown sandy very clayey GRAVEL. Gravel is fine to coarse angular to subangular of brick, coal and mudstone with occasional mudstone brick cobbles, and rare mudstone and concrete boulders. Occasional hydrocarbon odours.

A summary of test results for the opencast backfill is summarised in Table 21. The results are relatively in consistent with those determined during the historical ground investigations, as summarised in Section 3.2.

Table 21 - Summary of Geotechnical Testing within Opencast Backfill, Backfill, Curtins 2019

Test	Quantity	Range of Data	
Standard Penetration Testing	147	Range: 0 to 52 Average: 13.7	
Oedometer consolidation Testing	11	C _v	Range: 4.6 to 32 m ² /yr Average: 15 m ² /yr
		M _v	Range: 0.11 to 1.0 m ² /MN Average: 0.3 m ² /MN
Moisture content	8	Mc	21.5%
Unconsolidated Undrained Triaxial	7	Cu	58.9%
Hand Vane	66	Cu	Range: 24 to 138 kPa Average: 59.6 kPa
Atterberg	1	MC	21.5%
		LL	59%
		PL	23.5%
		PI	22.5%

All trial pits encountered anthropogenic materials within the backfill material, comprising:

- Metals (sheet metal, nuts and bolts, wires and large cables)
- Timber (fence posts, timber fragments)
- Plastics (plastic sheets)
- Rubber (scraps of industrial belts)
- Brick (whole, fragments and partially intact walls)
- Concrete (as gravels, cobbles and occasionally boulders)
- Asbestos (TP12 only)

The majority of the anthropogenic material was encountered in the trial pits, in the top 5m bgl across site. Minor inclusions of anthropogenic material (i.e minor brick/ceramic inclusions) were encountered in the rotary boreholes to a maximum depth of 30m bgl. However, the majority of anthropogenic material was encountered within the top 5m bgl across site.



Figure 2 - Images displaying anthropogenic material in opencast mine backfill in TP17

Bedrock – Pennine Middle Coal Measures

The Pennine Middle Coal Measures was encountered from 5.8m to 58.8m bgl. The bedrock was encountered as a light grey siltstone, grey to dark grey mudstone and occasionally yellow sandstone.

Open Cast Highwall

Ten rotary openhole boreholes (referenced T1/T1a to T5/T5a) were designed and undertaken to depths between 5.8m and 26.0m bgl, in order to determine the highwall profile which is anticipated to form the boundary of the historical opencast mine. The exploratory holes were located in pairs or threes, positioned perpendicular to the inferred orientation of the highwall. The location and depths of backfill encountered within each of these exploratory holes was used to create the highwall profile providing information about height and its battering angle at various locations. Some Cross sections have been produced to demonstrate the variation in the anticipated highwall height and geometry. These cross sections are shown as Figures 4 to 7. Figure 4, shows the worst-case location identified following this investigation, located to the northwest of the site. The depth of the made ground was

shown to be greatest in this area. As shown on Figures 4 to 9, the transects elsewhere on the site indicated a much shallower profile of excavation across the site area.

For the purposes of assessment made within this report a highly conservative approach has been adopted using a highwall angle of 45°, Figure 10 shows the anticipated profile.

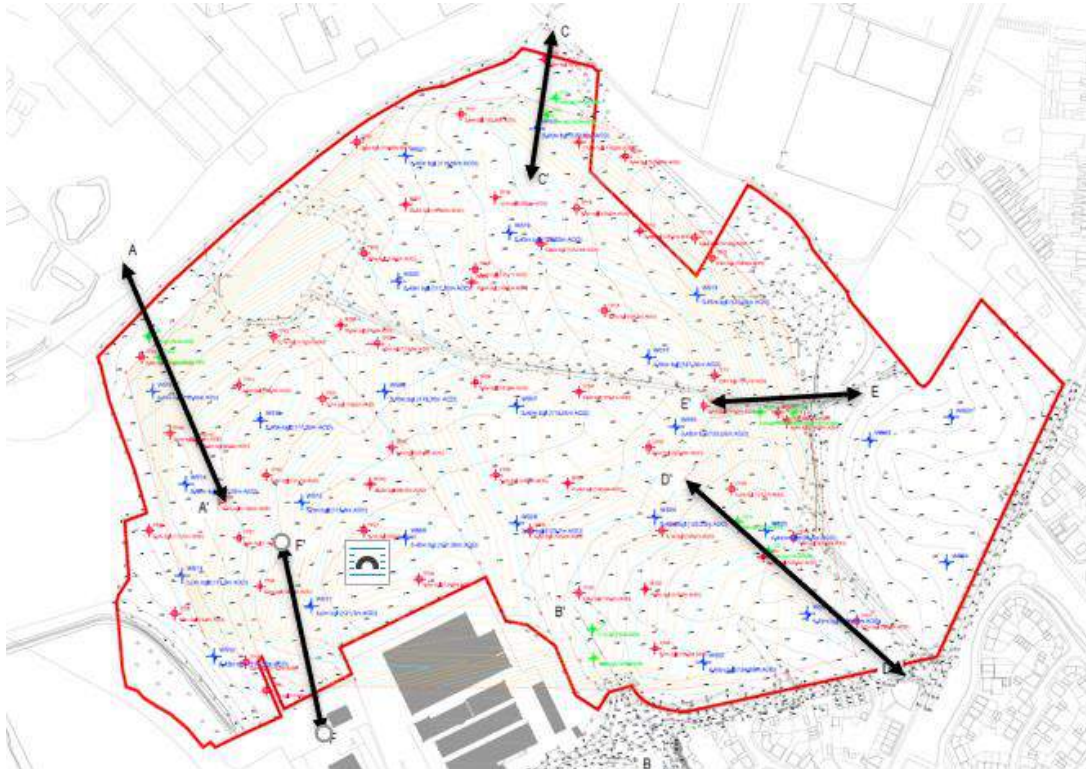


Figure 3 – Cross Section Locations

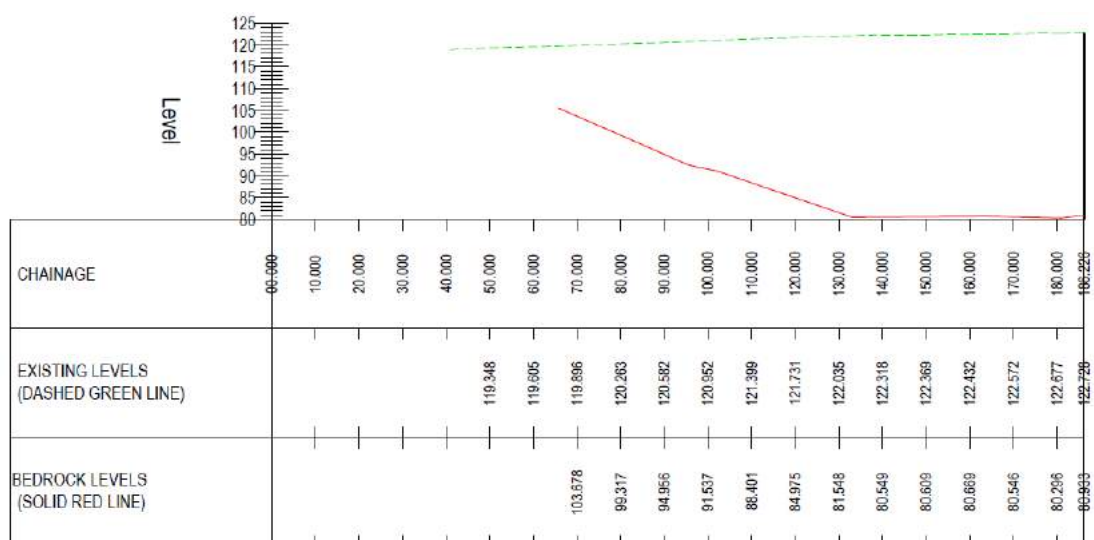


Figure 4 - Cross Section Through Highwall – AA', Scale 1:1000 H&V Datum:80.000

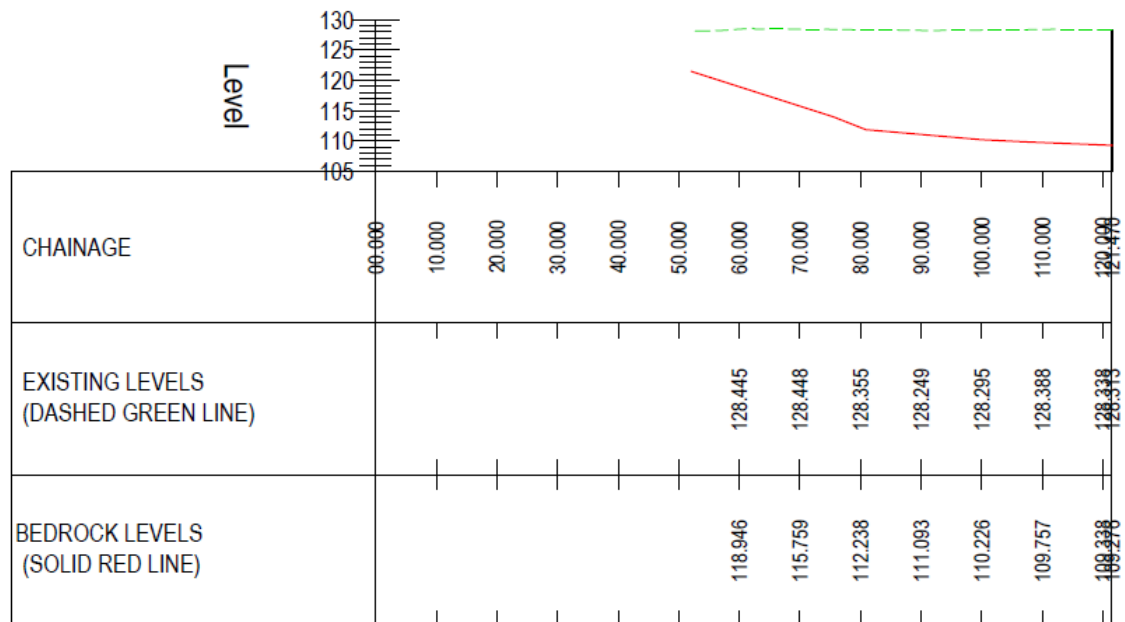


Figure 5 - Cross Section Through Highwall – BB', Scale 1:1000 H&V Datum:105.000

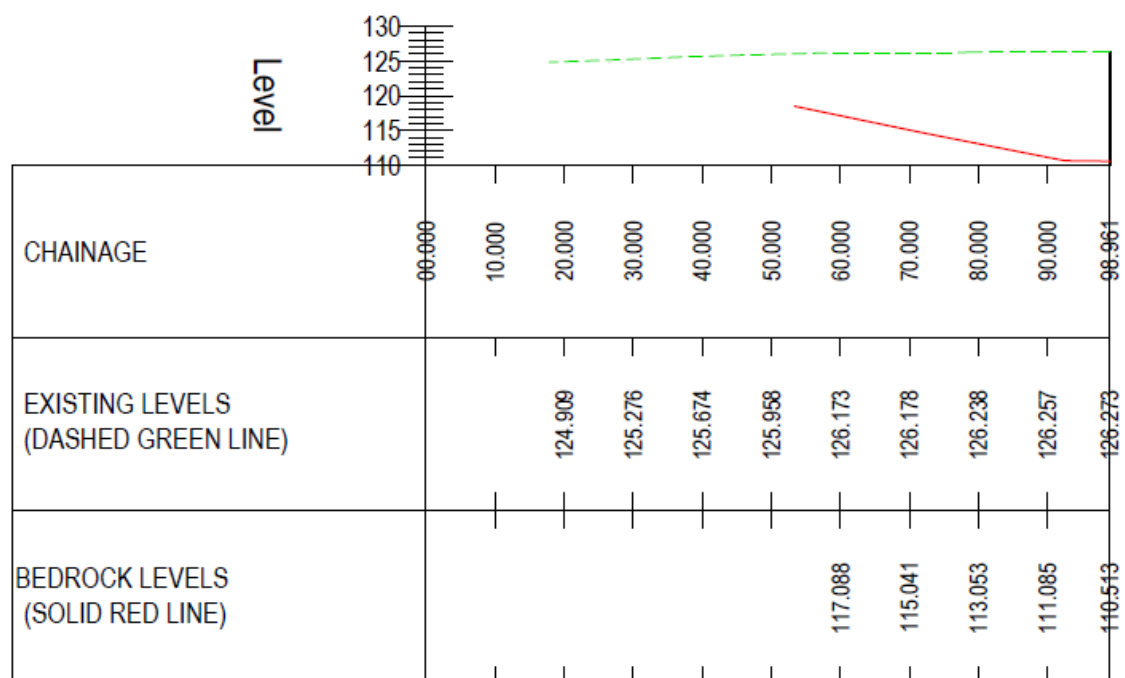


Figure 6 - Cross Section Through Highwall – CC', Scale 1:1000 H&V Datum:110.000

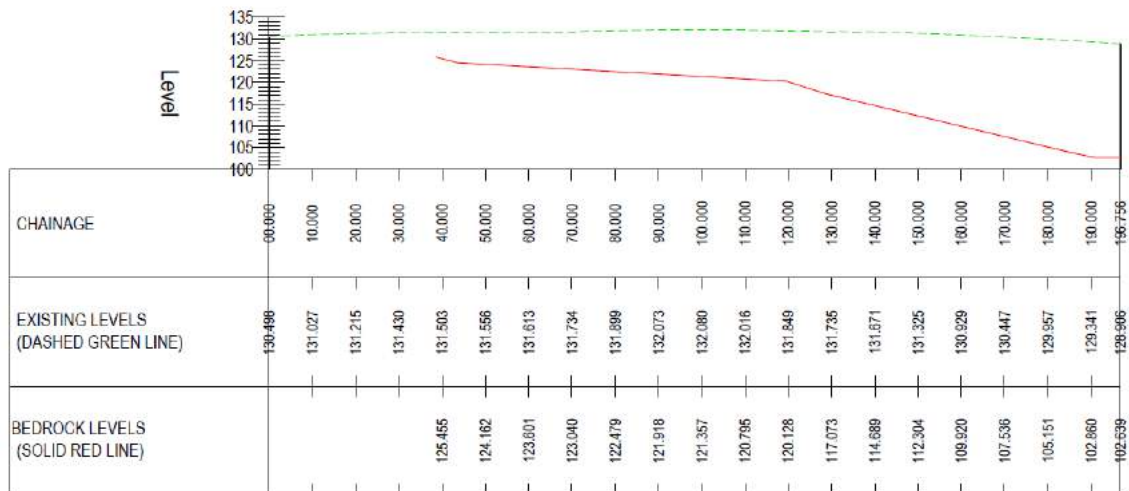


Figure 7 - Cross Section Through Highwall – DD', Scale 1:1000 H&V Datum:100.000

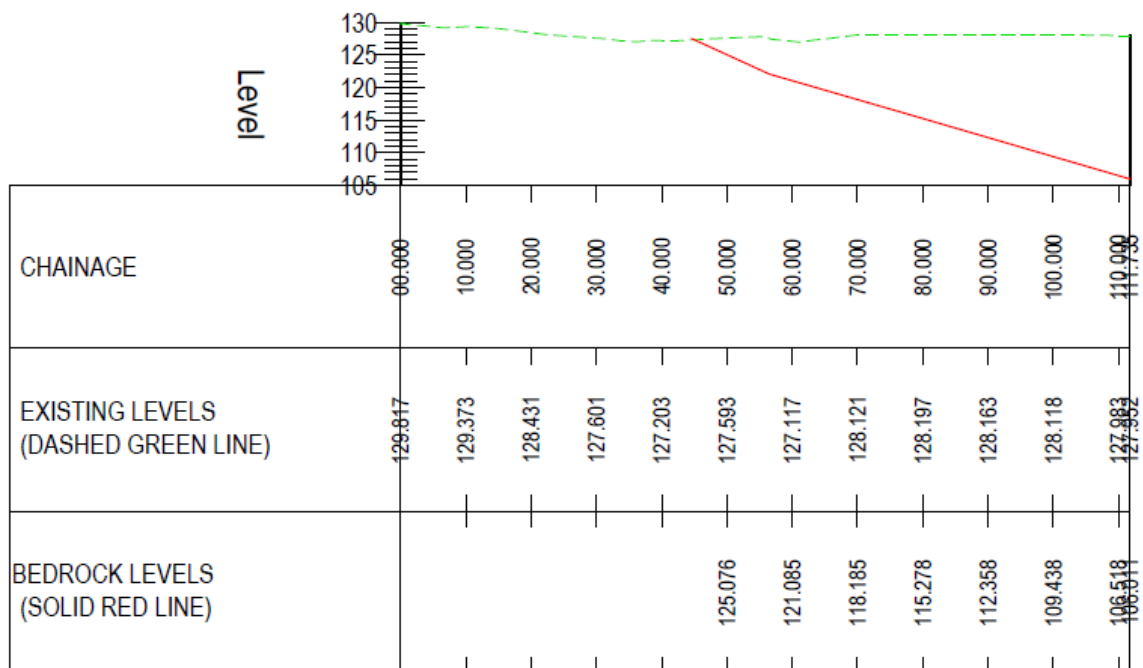


Figure 8 - Cross Section Through Highwall – EE', Scale 1:1000 H&V Datum:105.000

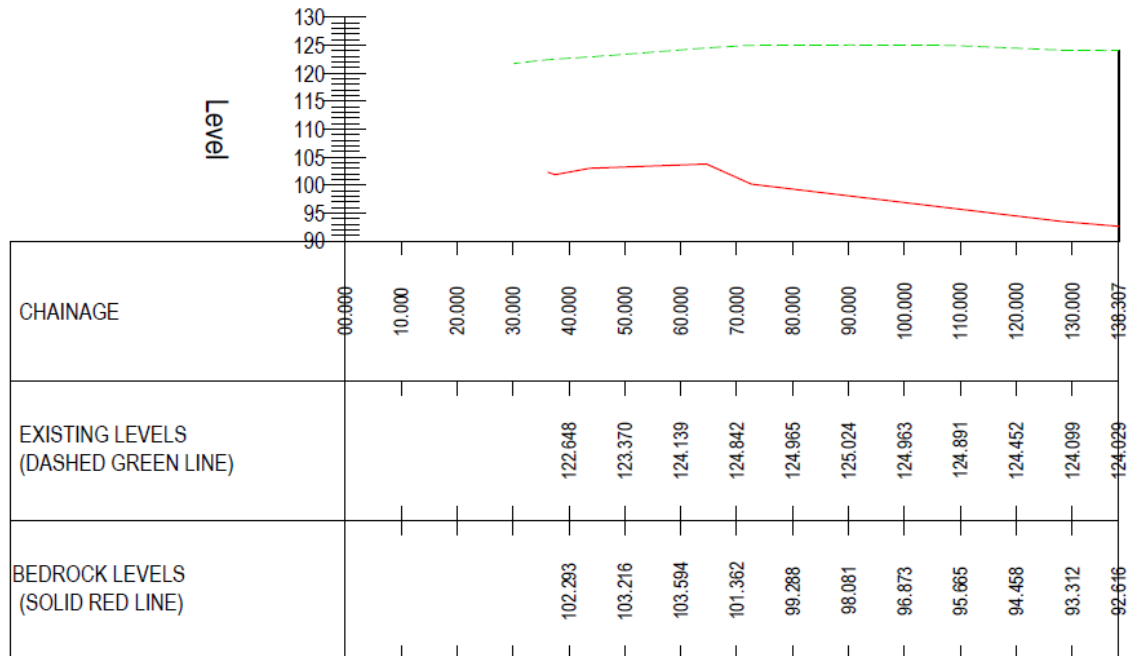


Figure 9 - Cross Section Through Highwall – FF', Scale 1:1000 H&V Datum:90.000

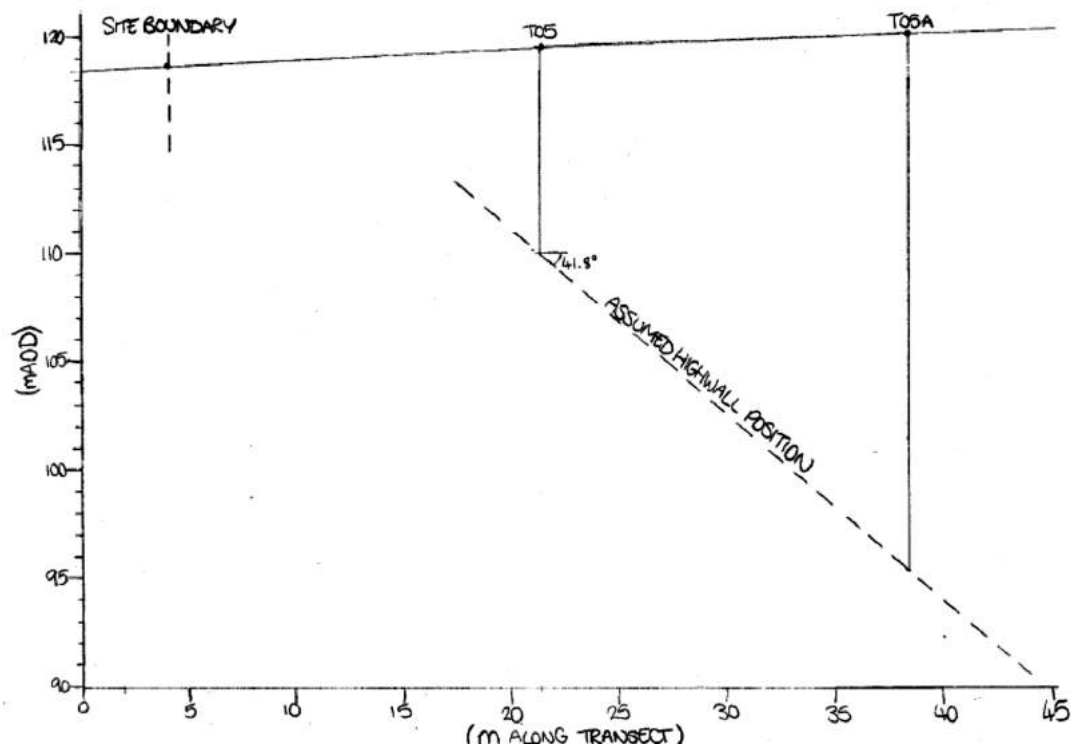


Figure 10 - Cross Section Through Highwall - Northwest of Site

The estimated location of the highwall is illustrated on Curtins drawing ref. 067895.101-CUR-00-XX-DR-GE-001 found in Appendix A.

Obstructions

Obstructions in the form of concrete, siltstone and mudstone boulders were encountered within the opencast backfill material to a maximum length of 900mm. No obstructions resulted in the termination of an exploratory hole.

Seven of the machines excavated trial pits encountered boulders within the pits from depths of between 0.4m and 2.7m bgl.

5.3.2 Outside Opencast Mine

The ground conditions for areas outside the opencast mine is summarised in Table 22. Three exploratory holes were undertaken within this section of the site.

Table 22 - Summary of Ground Conditions, Outside Opencast Mine, Curtins 2019

Stratum	Depth to top of strata (m bgl)		Thickness (m)		General Description
	Min	Max	Min	Max	
Topsoil	0.00	0.00	0.15	0.25	Brown gravelly CLAY. Gravel is fine to medium subangular to rounded of sandstone and mudstone.
Residual Soil	0.15	0.25	3.1	5.45	Stiff light brown mottled grey sandy gravelly CLAY. Gravel is fine to coarse angular to subangular of mudstone, sandstone and siltstone. Black gravelly SILT. Gravel is fine to medium angular coal.

Topsoil

Topsoil has been encountered from the surface to depths of 0.25m bgl. It comprised a brown gravelly clay with a gravel of mudstone and sandstone.

Geotechnical testing has not been undertaken on samples on topsoil.

Residual Soils

Weathered bedrock was encountered to underlie the topsoil within the eastern section of the site, from 0.15m bgl to 0.25m bgl. Generally, the unit consisted of a stiff brown mottled grey slightly gravelly very sandy CLAY. Gravel of sub-angular to angular, fine to coarse, mudstone and sandstone.

A summary of test results undertaken on residual soils within this section of the site is summarised in Table 23.

Table 23 - Summary of Geotechnical Test Results, Residual Soils, Outside Opencast Mine, Curtins 2019

Test	Quantity	Range of Data	
Standard Penetration Testing	12	Range: 6 to 50 Average: 31.3	
Atterberg	1	MC	17%
		LL	57%
		PL	23%
		PI	34%

5.4 Site Wide Groundwater

5.4.1 During Investigation

Groundwater strikes were observed only within the trial pits undertaken in the opencast backfill (made ground) during the ground investigation. A summary of the groundwater strikes encountered in trial pits during the investigation is included in Table 24.

Table 24 - Groundwater Strike Summary, Curtins 2019

Exploratory Hole	Depth Strike [m bgl]	Comments
TP02	2.80	Slow groundwater seepage
TP03	0.80	Slow groundwater seepage
	2.70	Slow groundwater seepage
TP04	2.80	Slow groundwater seepage
TP05	1.50	Slow groundwater seepage
TP08	0.65	Slow groundwater seepage
TP09	2.90	Slow groundwater seepage
TP10	0.50	Slow groundwater seepage
TP11	2.00	Steady groundwater flow
TP14	2.70	Slow groundwater seepage
TP15	1.10	Steady groundwater flow
TP16	1.60	Steady groundwater flow
TP23	2.80	Slow groundwater seepage
TP24	1.80	Slow groundwater seepage
TP26	0.50	Slow groundwater seepage
TP27	2.50	Slow groundwater seepage
TP28	2.80	Slow groundwater seepage

Exploratory Hole	Depth Strike [m bgl]	Comments
TP30	2.80	Slow groundwater seepage
TP37	1.30	Slow groundwater seepage
TP38	2.80	Slow groundwater seepage
TP39	1.00	Slow groundwater seepage
TP43	1.80	Heavy groundwater flow

5.4.2 Return Monitoring Visits

During the return monitoring visits, groundwater was only encountered within the backfill strata. A summary is presented in Table 25 and within Appendix E.

Table 25 - Summary of Post-Investigation Groundwater Monitoring (m bgl), Curtins 2019

Location	Visit 1 06/03/2019	Visit 2 21/03/2019	Visit 3 25/03/2019	Visit 4 11/04/2019	Visit 5 24/04/19	Visit 6 14/05/19	Maximum Reading (m bgl)	Minimum Reading (m bgl)
Outside Opencast Mine								
WS24	Dry	0.85	-	Dry	Dry	Dry	Dry	0.85
Inside Opencast Mine								
RC01	3.73	6.35	-	6.47	8.66	5.95	3.73	8.66
RC02	1.00	1.05	-	1.38	1.61	1.49	1.00	1.61
RC03	8.99	9.55	9.64	9.85	9.74	10.21	9.55	10.21
RC04	5.64	5.62	3.20	5.52	5.50	5.05	3.20	5.64
RC05	4.33	4.42	4.50	4.46	4.52	4.64	4.33	4.64
RC06	4.56	3.92	4.30	4.24	4.26	4.59	3.92	4.59
RC07	2.91	3.64	3.80	3.92	3.78	4.06	2.91	4.06
RC08	5.85	6.24	6.25	2.20	5.82	6.19	2.2	6.19
RC09	1.95	2.18	-	2.23	2.02	2.40	1.95	2.40
RC10	4.05	Unable to monitor / data logger within well.						
WS01	Dry	Dry	2.75	Dry	Dry	Dry	Dry	2.75
WS02	5.45	5.37	5.39	5.38	5.38	Dry	Dry	5.45
WS03	1.23	0.90	-	3.93	3.85	4.14	0.9	4.14
WS04	3.09	3.00	-	3.01	3.07	3.01	3.01	3.09
WS05	Dry	4.40	4.50	4.10	5.38	Dry	Dry	5.38
WS06	2.57	2.31	2.37	2.61	2.65	2.69	2.31	2.69
WS07	4.2	4.06	-	4.05	4.09	4.29	4.05	4.29
WS08	3.01	2.97	2.99	2.99	3.11	3.17	2.97	3.17
WS09	3.01	2.27	-	3.44	3.54	3.74	2.27	3.74
WS10	3.15	2.97	3.01	3.13	3.08	3.07	2.97	3.15
WS11	2.79	2.45	-	2.54	2.58	2.59	2.45	2.79
WS12	3.09	3.08	-	3.24	3.35	3.34	3.08	3.34

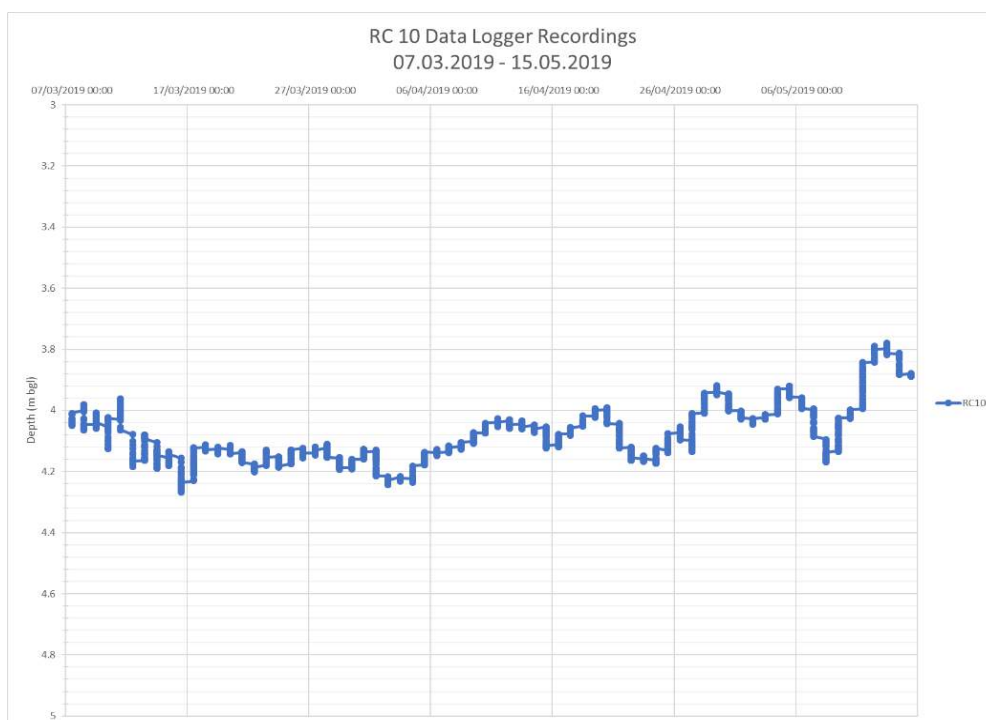
Location	Visit 1 06/03/2019	Visit 2 21/03/2019	Visit 3 25/03/2019	Visit 4 11/04/2019	Visit 5 24/04/19	Visit 6 14/05/19	Maximum Reading (m bgl)	Minimum Reading (m bgl)
WS13	Dry	5.31	-	5.32	5.33	Dry	Dry	5.33
WS14	4.52	3.15	-	5.21	5.19	5.19	4.52	5.21
WS15	4.53	4.24	-	4.74	4.65	4.68	4.24	4.74
WS16	4.71	2.47	3.20	2.73	2.76	2.78	2.47	4.71
WS17	4.90	2.71	3.10	3.10	2.69	3.24	2.71	4.90
WS18	4.48	Dry	4.20	5.35	5.30	Dry	Dry	5.35
WS20	5.08	3.25	3.50	3.41	3.40	4.09	3.25	5.08
WS21	5.02	3.16	3.50	3.23	3.01	3.09	3.01	5.02

The results of the post-investigation groundwater monitoring undertaken over a two months period, infer no significant change (i.e. rise or fall). Therefore, it is anticipated that the groundwater within the opencast backfill is relatively stable. The groundwater monitoring is designed over the period of Winter/Spring to record the anticipated higher levels of groundwater fluctuations.

5.4.3 Data Logger

Due to the sensitivity of the underlying backfill to changes in groundwater, on 6th March 2019, a data logger was installed to measure groundwater levels and downhole water pressures at hourly intervals within RC10, for a period of four months. The results of this is presented on figure 11.

Figure 11 - Data Logger Recordings, Curtins 2019



The level logger data shows relatively minor fluctuations in groundwater level over the monitoring period with a difference between the minimum and maximum depths of c 0.5m. This is in keeping with the spot monitoring which shows average minimum and maximum differences across the monitoring period of less than 1m. Select wells indicate a higher variance however given the density of data afforded by the logger it is considered that some of the spot levels monitored are due to instrument error.

5.5 Concrete Design

In accordance with BRE Special Digest 1 (BRE, 2005) the site has been classified as 'brownfield land unlikely to contain pyrite and laboratory testing undertaken accordingly within the made ground and natural deposits.

The results of chemical tests in the made ground (opencast backfill deposits) are summarized in Table 26.

Table 26 - BRE Suite D Aggressive Ground Classification Testing

Testing Undertaken	Number of Tests	Range (mg/kg) (mg/l)
pH	31 no.	3.4 – 7.8
Water Soluble SO ₄ 16hr extraction (2:1) (leachate equivalent) (mg/l)	31 no.	57.7 - 2770
Water Soluble Chloride (2:1) (leachate equivalent) (mg/l)	11 no.	2.5 - 190

It is recommended that the groundwater should be regarded as mobile for shallow ground conditions.

Following these considerations and in accordance with BRE Special Digest 1, 2005 (BRE, 2005), the development site concrete classification is a DS-3, AC-3 and buried concrete should be designed accordingly.

6.0 Geochemical Ground and Groundwater Risk Assessment

This section covers an assessment undertaken on the potential contamination, solid, liquid and gas identified across the site, which may present a risk to the potential end users, associated utilities and the wider environment.

In accordance to the guidance published by the Environment Agency, the risk to human health or controlled waters is determined through an assessment of contaminant linkages between a source of contamination (within the ground or groundwater either on or off site) and a sensitive receptor such as end users of the site, building materials, edible plants grown in gardens or groundwater abstracted for drinking. This is termed a source-pathway-receptor relationship. The same model is applied to the assessment of risk arising from ground gases as detailed within BS 8576:2013 (British Standards (BS), 2013)

These models have a common approach, which is one of a tiered assessment. At each stage of the assessment further detail can be applied to the conceptual site model to provide a detailed interpretation on a site by site basis. As part of the planning process this approach is adopted in order to establish either if the site is 'suitable for use' or whether additional work or else remedial work is required in order for the site to be deemed so.

The sub-sections hereafter therefore incorporate the first tier (Tier 1) of this approach otherwise referred to as the Generic Quantitative Risk Assessment (GQRA). The GQRA builds on the qualitative risk assessment presented in Section 3.0, in conjunction with observations made during the ground investigation and is based solely on the results of the chemical and other testing data obtained as part of Curtins ground investigation.

The following sections present more detail on the risk assessment methodology rationale for the main receptors.

6.1 Human Health GQRA

Detailed guidance on human health risk assessment is available within a number of documents, published by both the Environment Agency and Defra. Guidance includes Contaminated Land Exposure Assessment (CLEA) v1.07 model (Environment Agency, September 2009), Science Report 2 (Environment Agency, 2009) and Science Report 3 (Environment Agency, January 2009).

A generic quantitative risk assessment (GQRA) has been carried out for the Potential Contaminant Linkages (PCLs), investigated by screening of soil contamination data against relevant Generic Assessment Criteria (GAC) or 'Tier 1 Thresholds' where available, including:

- i) **Soil Guideline Values (SGVs):** These have been published by the Environment Agency and are trigger values for screening out low risk areas of land contamination. SGV's give an indication of representative average concentrations of chemicals in soil, below which long-term health risks are likely to be minimal. SGVs have been published for a number of contaminants including arsenic, cadmium, mercury, nickel, selenium, BTEX, phenols and dioxins, furans and dioxin-like PCB substances for land uses including residential,

allotments and commercial. The SGVs have been developed for a sandy loam soil with 6% soil organic matter (SOM) content;

- ii) **Supplementary Screening Values:** In addition to the SGVs developed by the EA other third-party organisations have derived GACs for a wider range of contaminants and land uses using the CLEA Model. Curtins have adopted these numbers where applicable, including those developed by Atkins AtriskSoil™, the LQM/CIEH Suitable for Use Levels (S4UL) and EIC/AGS/CL:AIRE published thresholds.
- iii) **Category 4 Screening Levels (C4SLs):** In March 2014 Defra published C4SLs for arsenic, benzene, benzo(a)pyrene, cadmium, hexavalent chromium and lead. These values were derived to support the revised Part 2A Statutory Guidance issued in 2012 in which four categories of contaminated land are included, ranging from Category 1 (significant/high risk) to Category 4 (low risk). C4SLs are not representative of significant possibility of significant harm (SPoSH) and are values of low risk levels. As such, where the C4SLs are not exceeded, land can be demonstrated to be in Category 4 and therefore cannot be determined as contaminated land.

Given the proposed mixed end use of low rise residential with private gardens (east of proposed bypass road) and commercial (west of proposed bypass road), a *Residential with Homegrown Produce* land use scenario has been utilised for the purposes of this assessment for results relating to the east of the site (proposed residential development plots. To the west of the proposed link road results have been compared to *Commercial* values to reflect the end use in that area of the site.

Details of the GAC's or 'Tier 1 Thresholds' adopted for the GQRA are provided in Appendix F.

6.1.1 Soils

Representative samples of made ground and natural soils were taken from exploratory holes across the site and tested for either Soil Suite C or D with a total of 17 No. samples tested.

As discussed within the previous section, comparison of the soil analysis results has been undertaken against Generic Assessment Criteria (GAC) or 'Tier 1 Thresholds' for a *Residential with Homegrown Produce* land use scenario and *Commercial*.

Soil organic matter (SOM) has a strong bearing on the availability of potential contaminants and therefore influences the Tier 1 Thresholds. The SOM typically ranged from 1.2% to 11%, with an average of 7.2%. As such, the comparison has been made against GACs developed for a sandy soil with a SOM of 6%.

The results of the environmental testing can be referred to in Appendix D2. Copies of the adopted Tier 1 Thresholds are contained within Appendix F.

With respect to the proposed end use of the site, the soil samples submitted for testing did exceed the Tier 1 Thresholds adopted in the development area as 3no. samples had exceedances of Arsenic within TP01, TP07 and TP11. Asbestos was not identified within the 17 No. soil samples submitted for Asbestos presence and screen testing. Asbestos was identified in one sample that was scheduled for asbestos identification, this sample was from TP12 where visual evidence of asbestos containing materials was encountered (asbestos cement sheets).

There were no exceedances within the samples compared against the GACs for commercial developments.

Whilst the levels of testable contamination are assessed to be relatively **Low** across the site, the presence of anthropogenic materials encountered across the main site area make shallow soils physically unsuitable for use in future gardens and soft landscaping without remedial action. Furthermore, visual and olfactory indicators of contamination were identified in shallow soils. Although tests results returned concentrations of contaminants below the adopted screening criteria these soils stand to cause a nuisance to future occupiers without appropriate mitigation.

6.1.2 Remedial Actions– Human Health

Based on the environmental testing results and the physical condition of shallow soils encountered the ground investigation, there is requirement for remedial action to be undertaken to ensure the site is 'suitable for use' in terms of human health risk.

There will be requirement for provision of clean capping for private gardens across the site. The provision of this clean capping layer should be designed to the landscape architect's design and engineer's requirements.

The provision of appropriate Personal Protective Equipment (PPE) and welfare/sanitary facilities for construction workers with respect to soils quality is considered adequate to mitigate the potential risk presented by the groundwater encountered on site.

6.2 Controlled Waters - GQRA

The controlled waters GQRA has been designed to assess the risks posed to the identified controlled waters receptors namely the on-site Secondary (A) Aquifer from the potential migration of contaminants. There is a surface drainage feature on site and a pond, however these are not considered sensitive receptors as they are not controlled waters.

Controlled waters GQRA comprises a comparison of chemical analysis results for shallow groundwater samples against appropriate water quality standards (WQS) to assess the risk.

WQS selection depends on the controlled waters (surface and groundwater) receptors identified at the site and in general, the Generic Assessment Criteria (GAC) for the principal or most sensitive

controlled waters receptor are used. Groundwater is present beneath the site within the PMCM Secondary A Aquifer, with no known active groundwater abstractions within the local vicinity.

The Secondary A Aquifer within the PMCM is considered the primary receptor. As such surface waters are considered to represent the primary controlled waters receptor and freshwater Environmental Quality Standards (EQS) (13) have been used as the GAC.

6.2.1 Groundwater Testing Results

Three samples of groundwater were obtained from the subject site and scheduled for testing as discussed in Section 5.2.

A summary of the groundwater exceedances above the EQS thresholds are presented in Table 27.

Table 27 - Summary of Groundwater Exceedances - EQS

Location	Determinant	Concentration (µg/l)	EQS Value (µg/l)
WS04	Nickel	91 & 54	4
	Iron	5600	1000
	Copper	1.2	1
	Sulphate	1890 & 2770 (mg/l)	400 (mg/l)
WS16	Nickel	4.1 & 23 & 23	4
	Cadmium	0.21	0.08
	Copper	1.1	1
	Sulphate	1530 & 1380 & 1210 (mg/l)	400 (mg/l)
WS21	Nickel	6.1	4
	Iron	2800 & 2300	1000
	Sulphate	1160 & 1980 (mg/l)	400 (mg/l)
RC03	Nickel	25 & 66	4
	Copper	2.8	1
	Sulphate	1500 & 1570 (mg/l)	400 (mg/l)
RC07	Nickel	150	4
	Copper	1.9	1
	Zinc	18	10.9
	Sulphate	2410 (mg/l)	400 (mg/l)

*USEPA RSL values used as GAC.

6.2.2 Assessment of Bioavailability

Table 23 identifies exceedances of the adopted screening values for four heavy metals, namely Copper, Nickel, Zinc and Manganese.

The UK Technical Advisory Group (UKTAG) under the Water Framework Directive (WFD) have produced an assessment methodology to indicate the bioavailability of heavy metals within the environment, based upon the environmental conditions at the site.

Utilising this methodology, the bioavailable concentration of Nickel, Copper, Zinc and Manganese have been calculated as per Table 28.

Table 28 - Summary of Bioavailable metal concentrations

Location	Determinant	Bioavailable Concentration (µg/l)	EQS Value (µg/l)
WS04	Copper	0.14 & 0.39	1
	Manganese	243.11 & 336.33	123
	Nickel	11.69 & 6.93	4
	Zinc	2.53 & 3.37	10.9
WS16	Copper	0.04 & 0.04 & 0.22	1
	Manganese	94.98 & 104.28 & 67.84	123
	Nickel	0.71 & 4.23 & 4.61	4
	Zinc	0.38 & 1.87 & 1.71	10.9
WS21	Copper	0.2 & 0.3	1
	Manganese	104.02 & 241.50	123
	Nickel	0.60 & 0.83	4
	Zinc	1.03 & 1.17	10.9
RC03	Copper	0.03 & 0.16	1
	Manganese	316.76 & 175.03	123
	Nickel	9.88 & 3.21	4
	Zinc	2.72 & 1.62	10.9
RC07	Copper	0.33	1
	Manganese	285.69	123
	Nickel	18.71	4
	Zinc	8.91	10.9

Note: All exceedances are in bold and red.

Table 23 identifies that heavy metal exceedances within each tested location do not fall below the EQS value when bioavailability is considered but do decrease in severity. Therefore, it is assessed that these concentrations do present a risk to controlled waters at the site.

The full M-BAT assessment is presented in Appendix D

6.2.3 Controlled Waters Risk Assessment

The results of the screening of 10no. groundwater samples against EQS values identified determinants in select samples above the adopted thresholds. The determinants above the EQS threshold are encountered within each tested location.

It should be noted that the results of the groundwater testing in the final visit were more elevated than that of previous visits. This is likely due to the methodology adopted in the final visit. In the first two visits, groundwater was sampled using the 'low-flow' method, which causes minimal disturbance to the water column. During the final visit, the 'bulk purge' methodology was adopted, where water from the well is purged. This methodology can often result in silt within the water sample, due to the disturbance of the water column. It is plausible that the addition of this silt to the samples is the reason for the elevated exceedances.

Given that the site itself has been utilised historically for coal mining purposes the presence of heavy metals is not unexpected. On this basis it is considered that the minor exceedance is indicative of groundwater quality across this area and as such does not represent a significant point source risk to controlled waters. Furthermore the site is considered to be in a low sensitivity setting with regard to controlled water.

Development of the site will lead to reduced infiltration potential and aid in the betterment of the on-site soils.

6.2.4 Remedial Measures

On the basis of the above, it is considered that site wide remedial action is unnecessary to mitigate the risk to controlled waters from heavy metal contamination.

6.3 Ground Gas GQRA

The assessment of risk presented by ground gases is assessed with reference to guidance published by CIRIA (Assessing Risks Posed by Hazardous Ground Gases to Buildings, C665 (CIRIA, December 2007) , BSI Publication (Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings BS8485:2015 (British Standards, June 2015), BSI Publication (Guidance on Investigations for Ground Gas-Permanent gases and Volatile Organic Compounds (VOCs) (British Standards (BS), 2013) and other broadly accepted references such as the Ground Gas Handbook 2009 (S.Wilson, G.Card and S.Haines, 2009).

The gas risk assessment adopts a tiered approach. In the first instance, this involves a re-evaluation of the Conceptual Site Model described within the previous reporting and thereafter validating this conceptual model with the ground gas data, the semi-quantitative risk assessment.

6.3.1 Conceptual Site Model

The Preliminary Conceptual Site Model (PCSM) presented within Section 4.0 noted the overall low to moderate potential for ground gases based on the identified sources, primarily Made Ground used to backfill the opencast workings and gases originating from mining legacy and the adjacent landfill cell to the west.

With respect to ground gas sources:

Made Ground

The ground investigation encountered Made Ground deposits within the area of the former opencast were in excess of 5m. Made Ground was predominantly encountered as either a soft to stiff black to dark grey occasionally mottled orange and brown sandy very gravelly CLAY or a loose to dense black to dark grey occasionally mottled orange

and brown sandy very clayey GRAVEL. Gravel is fine to coarse angular to subangular of brick, coal and mudstone with occasional mudstone brick cobbles, and rare mudstone and concrete boulders. Anthropogenic inclusions were noted across the site, predominantly in the upper 5m and typically comprising inert fragments of brick concrete, metal. In addition, coal was noted throughout the made ground, likely representative of lower quality coal extracted and not recovered as part of the opencasting operations. Timber was noted in several locations however widespread encountering of household or other putrescible waste was not observed. Samples of the opencast colliery spoil, predominantly in the near surface samples (<3m, where anthropogenic inclusions were more frequent) have reported Soil Organic Matter at an average of 7.26% with a converted TOC ($\text{SOM} \times 0.58$) content ranging from 0.70% to 11.02% with an average of 4.21%. Descriptions of samples reporting TOC greater than 3% were all noted to have coal inclusions with a several also recording timber. It is considered unlikely that the timber content has resulted in the elevated TOC reported due to the targeting of the soils rather than larger inclusions with samples where coal only was recorded report comparable TOC readings. As such it is considered that the TOC concentrations recorded are reflections of the presence of coal within the made ground.

Mine Workings

Intact coal seams have been identified in previous rotary boreholes and sub crops identified in shallow boreholes and trial pits advanced outside of the opencast area. However, no evidence of shallow mine workings has been identified in any exploratory hole advanced (discussed in detail in Section 8).

With respect to ground gas pathways:

Direct gassing of ground gas from the shallow soils to the near surface is considered the main pathway for ground gas migration on site.

6.3.2 Monitoring Results Discussion

In order to characterise the site's gas regime and validate the qualitative assessment of ground gas risk, standpipe installations were incorporated within 32 No. exploratory borehole locations as detailed in Table 4.4 within Section 4.0.

Gas monitoring has been undertaken on the following occasions to date; 06/03/2019, 21/03/2019, 25/03/2019, 11/04/2019, 24/05/2019 and 14/05/2019.

Gas monitoring to date has been undertaken during both falling and rising atmospheric pressures with barometric pressure ranging from 964mb and 1021mb.

A summary of the soil gas monitoring results to date is presented in Table 29 and copies of the log sheets presented in Appendix E.

Table 29 - Summary of Soil Gas Monitoring Results

Location	Flow (l/hr)		CO ₂ Range of Peak Values (%vol/vol)	CO ₂ Range of Steady State (%vol/vol)	CH ₄ Range (%vol/vol)	Strata Description
	Max	SS				
WS24	0.0	0.0	0.2 – 1.1	0.0 – 1.1	0.0	Residual Bedrock (CLAY)
RC01	0.1	0.0	1.4 – 8.7	1.4 – 12.6	0.0	Opencast Backfill (Made ground)
RC02	0.3	0.2	0.4 – 2.7	0.4 – 7.1	0.0	Opencast Backfill (Made ground)
RC03	0.0	0.0	2.5 – 15.6	2.5 – 22.7	0.0	Opencast Backfill (Made ground)
RC04	4.5	0.0	0.0 – 4.2	0.0 – 4.2	0.0	Opencast Backfill (Made ground)
RC05	3.3	0.0	0.7 – 4.0	0.7 – 6.0	0.0	Opencast Backfill (Made ground)
RC06	2.2	0.0	1.7 – 9.3	0.0 – 9.3	0.0 – 0.4	Opencast Backfill (Made ground)
RC07	2.8	0.0	0.0 – 4.9	0.0 – 0.8	0.0	Opencast Backfill (Made ground)
RC08	5.4	0.4	29.1 – 39.5	27.3 – 39.2	0.8 – 1.9	Opencast Backfill (Made ground)
RC09	0.0	0.0	0.4 – 5.6	0.1 – 3.7	0.0	Opencast Backfill (Made ground)
RC10	Unable to monitor due to level logger installation.					
WS01	0.2	0.0	5.2 – 20.7	5.2 – 20.6	0.0	Opencast Backfill (Made ground)
WS02	2.4	0.0	0.0 – 12.4	0.0 – 12.4	0.0	Opencast Backfill (Made ground)
WS03	0.7	0.5	0.1 – 14.7	0.1 – 8.3	0.0	Opencast Backfill (Made ground)
WS04	3.6	0.0	0.9 – 9.2	0.6 – 9.2	0.0	Opencast Backfill (Made ground)
WS05	2.4	0.4	1.6 – 9.6	1.3 – 9.6	0.1 – 2.0	Opencast Backfill (Made ground)
WS06	0.0	0.0	0.2 – 9.6	0.2 – 9.4	0.3 – 1.7	Opencast Backfill (Made ground)
WS07	2.1	1.8	0.6 – 2.2	0.0 – 2.2	0.0 – 0.4	Opencast Backfill (Made ground)
WS08	0.5	0.0	0.2 – 8.8	0.1 – 8.8	0.0 – 4.1	Opencast Backfill (Made ground)
WS09	2.1	0.0	0.3 – 8.4	2.7 – 8.1	0.9 – 3.0	Opencast Backfill (Made ground)
WS10	0.2	0.0	0.3 – 9.5	0.3 – 9.7	0.0 – 0.2	Opencast Backfill (Made ground)
WS11	0.4	0.0	0.1 – 0.8	0.1 – 1.0	0.0	Opencast Backfill (Made ground)
WS12	0.0	0.0	1.5 – 6.8	1.5 – 7.4	0.0	Opencast Backfill (Made ground)
WS13	0.4	0.0	0.8 – 10.4	0.8 – 10.4	0.0	Opencast Backfill (Made ground)
WS14	0.0	0.0	0 – 10.8	0.0 – 10.8	0.0 – 0.3	Opencast Backfill (Made ground)

Location	Flow (l/hr)		CO ₂ Range of Peak Values (%vol/vol)	CO ₂ Range of Steady State (%vol/vol)	CH ₄ Range (%vol/vol)	Strata Description
	Max	SS				
WS15	0.2	0.0	0.9 – 9.7	0.9 – 9.6	0.0 – 0.3	Opencast Backfill (Made ground)
WS16	0.1	0.0	0.7 – 7.3	0.7 – 7.3	0.0 – 0.5	Opencast Backfill (Made ground)
WS17	3.1	0.0	0.3 – 8.2	0.5 – 8.9	0.0 – 1.6	Opencast Backfill (Made ground)
WS18	4.2	0.0	0.6 – 9.8	0.6 – 9.8	0.0	Opencast Backfill (Made ground)
WS20	8.6	0.0	0.4 – 11.9	0.4 – 11.9	0.0	Opencast Backfill (Made ground)
WS21	3.1	0.0	0.8 – 20.3	0.0 – 1.1	0.0 – 1.2	Opencast Backfill (Made ground)

Neither hydrogen sulphide nor carbon monoxide was recorded within any of the monitoring installations during the gas monitoring visits undertaken to date.

Maximum concentrations of carbon dioxide and methane were recorded at 39.5% vol/vol and 3.9 % vol/vol respectively. These ground gas concentrations are consistent with the on-site ground gas sources, i.e. made ground (opencast backfill) greater than 5m in thickness, predominately consisting of inert material (i.e. coal, sandstone and mudstone) with inclusions of anthropogenic material (i.e. brick, metals, plastics, timber) and underlying coal measures geology. In addition, carbon dioxide concentrations greater than 5% were recorded in the area of opencast backfill on-site. However, it was noted that generally carbon dioxide and methane concentrations would record at higher concentrations in early monitoring rounds i.e 20.7% (WS01) and reduce during subsequent monitoring visits i.e 6.3% (WS01). This decrease over the course of the monitoring period can be better illustrated by highlighting the mean CO₂ concentration during the first visit (9.9% vol/vol) and the final visit (5.4% vol/vol). Typically, levels of CO₂ recorded indicate the construction of monitoring wells within the opencast backfill has caused a chimney effect and the introduction of oxygen into an anaerobic environment with the monitoring visits essentially 'venting' the ground gas source.

RC08 (located to the west of the proposed link road) is noted to record elevated CO₂ during all monitoring rounds which does not follow the pattern noted in other wells as discussed above. Groundwater was typically reported at c. 6m bgl, with the unflooded section of the well screening Made Ground including 'frequent timber inclusions. It is considered likely that the source of the ground gas in RC08 is associated with these inclusions, noted to be more frequent than the rest of the site, causing localised elevated CO₂.

RC08 (located to the west of the proposed link road) is noted to record elevated CO₂ during all monitoring rounds which does not follow the pattern noted in other wells as discussed above. Groundwater was typically reported at c. 6m bgl, with the unflooded section of the well screening Made Ground including 'frequent timber inclusions'. It is considered likely that the source of the ground gas in RC08 is associated with these inclusions, noted to be more frequent than the rest of the site, causing localised elevated CO₂.

Gas flow rates during the monitoring visits, whilst variable, displayed a gradual decrease over the course of the monitoring period. The peak flows in the first two visits were 8.6l/hr and 5.4 l/r, these visits were undertaken at 964-968mb and 1009-1017mb respectively. A decrease in the peak flow rates was noted over the remainder of the monitoring period, with the following visits displaying flows of 2.5l/hr, 0.5l/r, 2.0l/hr and 2.1l/hr. There are two salient factors which explain the gradual reduction in flow rates over the course of the monitoring period. The first has been discussed above and is the 'venting' of the ground gas source. The installation of the monitoring wells creates a pathway from the ground gas source to the surface, which, due to the variability in the ground of cohesive and granular material, could have caused a release of gas pockets within the fill. This was likely displayed during the construction of RC10; upon completion of the borehole and the removal of the rods and casing, water would occasionally rise to the surface and exit the hole at speed. This was likely caused as a result of our adopted drilling methodology. For the rotary boreholes, a 'wireline' Geobore-S method of rotary coring was adopted to allow for the best possible recovery. As a flushing medium, a combination of air and water were pumped down the hole at high pressures to help lubricate the drilling bit as well as to mitigate against any potential pockets of mine gas. This air and water can travel laterally into the surrounding strata, especially here where the strata alternated between cohesive and granular regularly. The escape of water upon the completion of RC10 was likely a depiction of the borehole attempting to reach a pressure equilibrium.

This phenomenon is likely the reason that the gas flow rates are at their highest, and also most fluctuating, in the first two visits. Peak steady state flows during the first two visits were difficult to achieve as the flow rates were fluctuating a lot during these visits. The number of wells that displayed fluctuating flow rates fell off after the 2nd visit which is a sign that the ground is approaching an equilibrium. The mean maximum flow rate for the first two visits is 7.00l/hr, whilst the flow rate over the final four visits is 1.77l/hr.

The above concentrations indicate the construction of monitoring wells within the opencast backfill has caused a chimney effect and the introduction of oxygen into an anaerobic environment with the monitoring visits essentially 'venting' the ground gas source.

6.3.3 Assessment

Considering both a 'worst credible scenario' (maximum 'absolute' flow rate, maximum gas concentration within a single borehole location) and 'worst possible scenario' (maximum 'absolute' flow rate, maximum gas concentration across all borehole locations) the Hazardous Gas Flow Rates (Q_{hg}) for the site are evaluated as 2.1 (carbon dioxide) and 0.162 (methane).

In this site situation, the calculated Hazardous Gas Flow Rates (Q_{hg}) are not considered reflective of a conservative assessment of Gas Screening Values (GSV) with generally very low to negligible flow rates and low to moderate concentrations of carbon dioxide and very low concentrations of methane recorded.

Peak and steady state flow rates display a similar pattern to the ground gas concentrations. The first monitoring visit, undertaken with atmospheric pressures ranging between 964mb and 968mb displayed a range of peak flows between 5.4l/hr and 0.0l/hr. The 4th visit was undertaken with atmospheric pressures ranging from 973mb to 981mb and the flow values during this visit ranged from 2.0l/hr to 0.0l/hr with a mean flow across site of 0.27l/hr. The initial assessment above has assessed the site assuming a flow rate across the site of 5.4l/hr. This is considered a highly conservative assessment, with this flow level not representative of the flow rates recorded across the site as a whole.

In order to obtain more realistic GSV values from across the site, the GSVs have been recalculated using a mean flow across the site of 0.27l/hr. The adoption of an average peak is considered to be more realistic. In general flows were recorded at a steady state below the detection limit of the gas analyser, however given that peak flows were recorded (albeit lower in later rounds) during all monitoring visits the average peak has been adopted. Utilising an averaged flow with peak carbon dioxide and methane provides a GSV of 0.1 for carbon dioxide and 0.0081 for methane.

With reference to BS8485:2016, the proposed residential development area of the site is considered to represent a Type B development, i.e. low-rise building (two-storey) with minimal ventilation in the sub-floor void. Whilst the proposed commercial development area of the site is considered to represent a Type C, i.e. commercial buildings with small to large rooms and good passive ventilation.

Utilising averaged flow ground gas classifications for NHBC Traffic Light system for the residential section of the site and a Characteristic Situation value for the commercial development area classes the site as Amber 1 for the residential developments and CS2 for the commercial development.

7.0 Revised Conceptual Site Model

The preliminary conceptual site model (PCSM) presented and discussed in Section 3.0 of this report has been revised following the GQRA in Section 7.0. The revised Conceptual Site Model (CSM) is presented in the Table 30.

The CSM details the source-pathway-receptor linkages or potential contaminant linkages (PCL) that have been identified for the site. The GQRA details the associated level of risk relating to these potential contaminant linkages.

The CSM concerns risk to human health, Water and Environment with additional and more specific risk assessment protocols contained within the main body of this report as detailed in Section 8.1.

The CSM follows the framework outlined within CIRIA C552 which is summarised within Appendix G.

The 'risk rating' within the CSM refers to the risk that the source, pathway, receptor linkage or PCL is complete. Unless specifically stated that it does not necessarily refer to an immediate risk and is intended to be used as a tool to assess the necessity for further assessment/investigation.

7.1 Additional Risk Assessments

The following risk assessments, listed below, are not included within the main CSM and GQRA but none-the-less can be of critical importance to the onward development of the site.

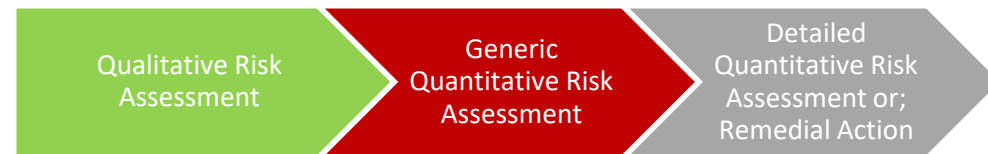
The risk presented by **Mining** is discussed and assessed in Section 9.0.

The risk presented by **Unexploded Ordnance** is discussed and assessed in Section 2.8.

The risk presented by **Radon** is discussed and assessed in Section 2.6.

Under current health and safety legislation, employers are required to carry out their own appropriate risk assessments and mitigation to protect themselves and their employees, other human receptors and the environment from potential contamination. Such risks must be adequately mitigated by law, specifically the Construction Design Management (CDM) Regulations, 2015 which require that potential risks to human health and the environment from construction activities are appropriately identified and all necessary steps taken to eliminate / manage that risk. It has been assumed that any future construction works on site will be undertaken in compliance with these requirements and therefore construction workers involved in the building works at the site have been discounted as a human receptor in the conceptual site model. Reference should be given to the environmental testing results discussed within Section 7.0 and presented within Appendix D2.

Ground Investigation Report



- The table below represents the second stage in the land quality risk assessment process: The Quantitative Risk Assessment.
- In order for a development site to be deemed 'suitable for use', the level of risk needs to be brought down to acceptable levels, i.e. low to negligible risk. The purpose of each stage of risk assessment is ultimately to establish, if there is a requirement for additional levels of assessment to be made to have sufficient confidence to support a risk characterisation or management decision, e.g. remedial action.

Conceptual Site Model			Qualitative Risk Assessment			Recommended Actions
Source	Pathway(s)	Receptor(s)	Consequence	Likelihood of Occurrence	Risk Rating	
Soils Residential Arsenic exceedances noted in three samples to the east of the proposed bypass road (residential development area). Commercial No exceedances of adopted commercial GACs Groundwater Exceedances of iron, sulphate, manganese and nickel encountered. Manganese and nickel have been assessed with the Metals Bioavailability Assessment Tool (M-BAT).	Direct contact, ingestion, inhalation (dust and vapours)	End users of site Residents, visitors and trespassers.	Medium Chronic health risk	Low Likelihood Due to the presence of elevated arsenic levels, the shallow soils are considered not suitable for use within the residential area of the site. Additionally, despite the exceedances, the volume of anthropogenic material encountered across the site would be unsuitable to be used in a residential setting.	Low/Moderate	Clean capping of private gardens and areas of soft landscaping. Discussed further in Section 11.2.1
	Vertical migration through the backfill material and residual (soils) May occur due to processes including; capillary action, burrowing animals inducing soil mixing and downwards into the natural deposits through infiltration.	Controlled waters Bedrock - Secondary A Aquifer Not within a Source Protection Zone.	Medium Pollution of sensitive water resources (bedrock aquifer)	Unlikely The risk to the underlying Secondary A Aquifer (bedrock) is considered to be Low owing to; the overall limited nature of mobile contamination revealed on site and no abstractions (groundwater) within 500m of the subject site. Despite the presence of elevated contaminants in the groundwater, there are no sensitive receptors as there are no abstractions. On this basis, no further investigation/assessment or specific remedial action is recommended.	Low	No further action required.
	Horizontal migration through the backfill material and residual (soils) May occur due to processes including; capillary action, burrowing animals inducing soil mixing and downwards into the natural deposits through infiltration	No abstractions within 500m of the site. No surface water abstractions within 250m of the subject site.	Medium Pollution of sensitive water resources (surface waters)			
Off-site sources of potential contamination: Off-site sources of potential contamination are similar to the subject site, with a number of historical collieries and industrial units to the north and the west.	Horizontal migration through the shallow soils and air (dust/particulates) Followed by... Direct contact, ingestion, inhalation (dust and vapours)	End users of site Residents, visitors and trespassers.	Medium Chronic health risk	Unlikely Overall the potential off-site sources of contamination are considered no greater than the subject site, given the similar historical use. In addition, the potential for mobile phase contamination to be generated based on these past off-site uses and have the potential to migrate onto the subject is considered unlikely.	Low	No further action required.
On-site and off-site sources of ground gas: Made ground associated with opencast backfill area on-site	Vertical and horizontal migration through the superficial (incl. made ground) and bedrock deposits	End users of site Residents and visitors	Severe Acute health risk, e.g. asphyxiation or risk from explosion	Likely The calculated gas screening values for Carbon Dioxide are considered sufficient to warrant the adoption of gas protection measures in future properties and buildings.	Moderate	Adoptions of protection measures in line with Amber 1 for the residential developments and CS2 for the commercial development.

Table 30 – Revised Conceptual Site Model

8.0 Coal Mining Risk Assessment

A Consultants Coal Authority Mining Report and the relevant Abandonment Search Results have been obtained for the site, Appendix B. The Report states that the site is in the likely zone of influence from workings in numerous coal seams (30no.), ranging from 11m to 359m deep. The Consultants Coal Authority Mining Report indicates that seams have been last worked between 1844 and 1951. The Abandonment Search Result indicates that the last opencast mine within an approximate 500m radius from the centre of the site has been last worked in early 1990's. However, the exact location of this opencast mine is not indicated. The last known opencast mine within the site boundaries is indicated to have been abandoned in 1978.

Based on the Consultants Coal Authority Mining Report, 27 no. mine entries are recorded across the site. The indicative location of these are illustrated on Coal Authorities Summary of Findings Map, Appendix B.

The following sections provides a summary of information obtained from the Consultants Coal Authority Mining Report, the Abandonment Search Results and historic/ recent ground investigations.

8.1 Past and Present Mining

The site is within an area of previous interest. It is close to where the Coal Authority or licensed mine operator has investigated and where necessary, remediated issues relating to:

- Coal mining subsidence
- The effects of mine or ground gas emissions following specific reported hazards

Based on the Consultants Coal Authority Mining Report, the seams listed below have been mined within the site boundaries as shallow¹, deep and opencast mines. Fireclay Seam is recorded as the only shallow seam, in accordance with guidance provided by CIRIA Special Publication 32).

- Fireclay
- Upper Kilburn
- **Main Coal²**
- Block
- Yard

¹ Only the past underground workings, where the site boundary is within 0.7 times the depth of the workings (zone of likely physical influence) allowing for seam inclination, are included.

² Main Coal Seam is listed as combustible seams, albeit the risk of spontaneous combustion is nevertheless likely for all the underlying seams.

- Little Kilburn
- Kilburn
- Little
- Stockings
- Woodfield
- Euroka
- Stanhope

8.2 Future Mine Workings

According to the Consultants Coal Authority Mining Report, no future underground mining is anticipated for the site. No coal mining licenses are available within a 200m radius around site boundaries.

8.3 Shallow Workings

Shallow mining is defined as mining that has occurred within 50m bgl (CIRIA Special Publication 32). Due to site's opencast mining history, this report has considered that provided depths in the Consultants Coal Authority Mining Report are based on the historic ground levels, and therefore mine workings within 50m depth from the historical ground level (as presented within the Coal authority Report) are considered as 'shallow'. One shallow worked seam of "Fireclay" is recorded on the Consultants Coal Authority Mining Report. The depth of this seam is recorded as 11m bgl with a 3.8° dip to west. The worked thickness of this seam is recorded as 167cm.

The historical exploratory holes advanced outside of the opencast area have previously identified numerous intact seams between 2.6m to 32.8m bgl. No evidence of workings e.g. voids or broken ground was recorded in any exploratory hole advanced in this area. Therefore, the risk of extensive shallow working within the areas outside the opencast mine to south/southeast is considered to be low.

The recorded shallow seams are located at depths which may have been exploited in bell pitting. No evidence of bell pitting has been noted in any exploratory hole advanced in the area however the presence cannot be precluded at this stage. Overall, the presence of the bell pits in this area of the site is considered a low likelihood and it is recommended that vigilance is adopted by groundworks contractor during the development of this area of the site, with any change in identified geological conditions (discussed in Section 5.0) to be noted and further investigated.

8.4 Deep Workings

Deep mining is defined as mining that has occurred below 50m bgl (CIRIA Special Publication 32).

The Consultants Coal Authority Mining Report has recorded numerous deep coal seams across the site (listed in section 8.1). These seams are recorded to generally dip to west/south-west at a depth generally ranging from 60m to 441m bgl.

Within the opencast mine area, where >50 m of backfill material has been placed for the past 30 years, either the thickness of backfill or, in shallower areas, the presence of sufficient competent cover (bedrock) would mitigate against the effects of potential collapses occurring in any potential unrecorded mine workings within these deeper coal seams.

Similarly, for the area outside the opencast mine area the presence of sufficient competent cover (bedrock) would mitigate against the effects of potential collapses occurring in any potential unrecorded mine workings within these deeper coal seams (>50m bgl).

8.5 Opencast

The evidence indicates that the majority of the site is a part of the former open cast mine, which is indicated to have been worked between 1965 and 1978.

It is assumed that following removal of the coal, the coal measure rock fragments (mudstone, siltstone and sandstone) along with other fill and man-made materials have been re-deposited within the site boundaries. The Curtins Ground Investigation has recorded highly variable ground conditions within the layer of backfill which confirms this assumption. Locally, boulder sized fragments have been recorded. This indicates that the backfill material has not been placed in a controlled engineered manner.

The area outside the opencast mine have not been significantly affected by the backfilling activities. However, the exact limits of fill placement are not recorded, as such encountering local shallow made ground across this section of the site is anticipated likely.

8.6 Shafts/ Mine Entries

The Consultants Coal Authority Mining Report indicates that 27 no. shafts are recorded within the site boundaries. These shafts are generally shown to be located to the north and north-west of the site.

The Consultants Coal Authority Mining Report indicates that many of these shafts, across the opencast mine, have been fully or partially removed by the previous opencast mining operations. With reference to the Summary of Findings Map, provided by Coal Authority, the majority of the shafts are located near the opencast mine boundaries. Therefore, it is likely that the shafts located across the opencast mine highwall may have been only partially removed.

No voids or significant core loss have been recorded within the bedrock, during the Curtins ground investigation or earlier investigations however it is noted that these investigations, by their nature, cover only a very limited proportion of the bedrock surface, where evidence of mine entries would manifest. Notwithstanding this, the risk presented by these relic mine entries (within the opencast area) is considered low given that they would have been subjected to significant disturbance during the opencasting operations (that occurred after the mine entries were formed), likely partially of fully filled as a result of this disturbance (to avoid them being hazards to the opencasting works) and, at the depths they are present (within the base of the opencast), unlikely to result in significant surface disturbance / subsidence through self-arrest or self-filling of any residual voids. However, the likelihood of encountering uncapped/untreated shafts cannot be fully discounted, however it may be considered a low risk.

It must be noted that these records may be incomplete, and as such the presence of more local unidentified shafts cannot be discounted, outside of the opencast. As with the potential for bell pits (Section 8.3) the risk of unrecorded mine entries is considered Low and it is recommended that vigilance is adopted by groundworks contractor during the development of this area of the site, with any change in identified geological conditions (discussed in Section 5.0) to be noted and further investigated.

8.7 Subsidence

The site is in an area where there has been reporting of subsidence associated with the extraction of coal. The Coal Authority Report states that one damage notice or claim has been received, relevant to a property within 50m of the site boundaries, although the location of this property in relation to the site is not clarified.

The risk of subsidence caused by settlement characteristics of the opencast fill is discussed in detail in Section 9. The assessed ground model outside of the opencast area (residual soils over coal measures with intact seams) presents a low risk of subsidence

8.8 Mine Gases

In accordance to the Guidance on Managing the Risk of Hazardous Gases when Drilling or Piling Near Coal, issued by the Coal Authority, Appendix B, most often mine gas is a mixture of atmospheric air and various pollutants, the pollutants in some cases completely displacing the air. No evidence of gases typical of mine gases (e.g. Carbon Monoxide) were recorded in any of the monitoring undertaken as part of the recent ground investigation and no evidence of shallow workings has been noted outside of the opencast. Therefore, the risk posed by mine gases is considered low, or at least, comparable with the wider ground gas risk (Section 6.3).

8.9 Spontaneous Combustion

In accordance with the Coal Seams with a History of Spontaneous Combustion list issued by Coal Authority, Appendix B, none of the identified coal seams underlying the site are classed as combustible. However, Main Coal Seam located outside the site boundary, within the region influencing the stability of the site is listed as susceptible to spontaneous combustion. However, it is not anticipated that this seam will be exposed during the proposed works and as such not considered to present a risk.

It must be noted that all coal seams are at a risk of spontaneous combustion, therefore this risk cannot be fully discounted. There is a risk of combustion, if the coal is exposed to air during the development works through direct excavation. It is likely that coal seams will be revealed during excavation across south/southwest of the site, outside the opencast mine, where shallow coal seams are anticipated (see Section 8.3). This is likely both within the cut and fill and during excavation for foundations/utilities. If coal is revealed it is recommended that access to the air is limited and that the exposed coal face is blinded with cement as soon as possible.

In accordance with the Guidance on Managing the Risk of Hazardous Gases when Drilling or Piling Near Coal, issued by the Coal Authority, any historical monitoring boreholes identified outside of the opencast fill must be backfilled to ensure that these potential conduits are sealed.

At any point, where spontaneous combustion has occurred the Coal Authority must be notified and consulted.

8.10 Exploratory hole Data

Exploratory holes from the following sources have been reviewed and assessed for areas where coal, voids or poor recovery have been recorded:

- BGS Exploratory Holes
- Historical Investigations including:
 - Sirius (Sirius, 2007)
 - Atkins (Atkins, 2013)
 - Ground Investigation & Piling Limited (Ground Investigation & Piling Ltd., 2013)
- Curtins Ground Investigation

Distinct layers of coal, no recovery zones or voids have not been recorded in the exploratory holes undertaken during the recent Curtins Ground Investigation.

Zones of no recovery or voids have not been recorded during the historical or BGS exploratory holes. However, distinct layers of coal have been recorded at various locations. A summary of these are provided in Appendix H.

8.11 Geotechnical Hazard/Risk Assessment

A summary of geotechnical risks associated with historic mining across the site are presented in Table 31 along with preliminary mitigation recommendations. Geo-environmental risks associated with mining are discussed in detail in Section 6.0 of this report.

Table 31 - Hazard/Risk summary

Coal Mining Hazard	Risk	Preliminary Mitigation Recommendations
Backfilled Opencast Coal Mining	- Highly variable ground conditions resulting in intolerable ground movements - Poor/soft ground conditions resulting in intolerable ground movements - Poor bearing capacity - Aggressive ground conditions - Spontaneous combustion	- Suitable ground improvement techniques to stabilise the ground - Classification of concrete to consider aggressive ground conditions - Best practice guidance provided by Coal authority on combustible seams to be used
Shallow Coal Mining Risk	Anticipated to only effect areas outside the opencast mine, resulting in: - Poor ground conditions resulting in intolerable ground movements - Reduced bearing capacity - Aggressive Ground Conditions - Spontaneous Combustion	- More robust structural design or adoption of suitable ground improvement techniques to stabilise the ground - Best practice guidance provided by coal authority on combustible seams to be used - Classification of concrete to consider aggressive ground conditions
Shafts and Mine Entries	- Likely presence of voids - Poor ground conditions resulting in intolerable ground movements - Ground gas - Aggressive Ground Conditions	- More robust structural design or adoption of suitable ground improvement techniques to stabilise the ground, where required - Classification of concrete to consider aggressive ground conditions

Note for Table 31:

- It must be noted, where voids and combustible seams are encountered, coal authority must be notified immediately.*

9.0 Geotechnical Assessment

The recommendations provided within this section, are based on the recent and historical ground conditions encountered across the site, considering the geotechnical and geo-environmental limitations and hazards identified.

9.1 Foundation Recommendation

No structural development plans have been provided at the time of writing this report. Therefore, the advice provided within this section is based on the assumption that the structures will comprise conventional two-story residential properties and 'traditional' commercial industrial units (sheds).

9.1.1 Inside the Opencast Mine Area

Made ground in form of opencast mine backfill is determined to cover this section of the site to depths locally in excess of 50m bgl. The backfill is found to be non-engineered and as such it is anticipated to be highly variable, both laterally and vertically. The backfill is anticipated to have been placed approximately 30 years ago, however it has not been historically subject to any loading, therefore significant risks associated with ground movement, particularly at shallower depths, are anticipated likely and will be considered further in the following sections.

In accordance with the Coal Authority Consultants Mining report, numerous shafts and worked seam are likely to underlie the site. It is anticipated likely that the shafts across the opencast mine have been removed during the opencast mining activities. In addition, the seams and shafts have been underlying significant thickness of fill material for a period of approximately 30 years, as such been significantly loaded and therefore ground movements caused by loading on these features is likely to have been ceased.

The associated risks with construction are generally assumed to be due to presence of backfill material and it comprises: poor bearing capacities, intolerable total/differential settlement and collapse failures.

The fill has been placed on site approx. 30 years ago. The groundwater monitoring data undertaken reflected the anticipated seasonal groundwater changes across the site. The findings of the groundwater monitoring indicate that the fill is generally underwater and as such it is likely that that most of the collapse settlement likely, due to inundation has already occurred. As such collapse failure is not considered further.

It is recommended that for adoption of likely most sustainable foundation solution, i.e. shallow foundations of appropriate reinforcement and thickness, ground improvements should be adopted. Ground improvement techniques for the encountered ground conditions generally comprise:

- Band drain and surcharging along with appropriate observational method monitoring
- Shallow soil mixing compaction (SSM)
- Refilling in thin layers with compaction in accordance with best practice guidance and method or performance earthworks specification.

The band drains and surcharging method is not considered cost effective or time efficient. In addition, due to high variation in ground conditions within the fill, the behavior of the ground cannot be thoroughly predicted. This method also requires a long programmed period, as such this solution is not considered to be suitable for the purposes of the works.

Shallow soil mixing compaction will result in improved ground conditions to approximately 7m bgl, utilizing a suitable hardening agents mixed with the soils, such as those used in deep soil mixing. However, due to made ground's variable nature and likely presence of unsuitable materials, the suitability of this method is not confirmed. However, this method could be investigated further during the detailed design stage.

Refilling the site using the existing backfill material, following and processing, appears to be the most suitable, viable option. This is assuming that the existing materials will pass the required criterion for re-use. The refilling will be undertaken in suitably sized layers compacted in accordance with the best practice guidance. For the purposes of the works, refilling of the top c.3.0 m of the materials is anticipated to be suitable. This method will be further assessed at detailed design stage. It is recommended that suitable observational monitoring methods, in accordance with BS EN 1997 – Part 1 are adopted.

The minimum founding depths in line with NHBC standards should be adopted, following ground treatment, with reference to existing and proposed trees.

9.1.2 Outside the Opencast Mine Area

The ground conditions outside the opencast area are generally shown to comprise up to two meters of firm cohesive residual soils overlaying weathered bedrock of Pennine Middle Coal Measures predominantly recovered as firm to very stiff clay. To mitigate the risk of intolerable total/differential settlement it is anticipated likely that the local dig and replacement of soft to firm/compressible materials maybe required. Provided that the bearing capacity of the underlying weathered bedrock of Pennine Middle Coal Measures satisfies the serviceability and ultimate limit state requirements for design, suitably designed shallow foundations (incl. Spread and Raft Foundations) are likely to be practical.

It must be noted that where coal is encountered, formation levels must be reduced to below coal and/or any co-deposited soft material such as seatearth or fireclay.

It is anticipated likely that conventional shallow foundation founded at reasonable levels can be adopted across this area. It is assumed that if the layer of soft to firm clay is removed, the stiff to very stiff clay would have an allowable bearing capacity of between 75 kN/m² and 100 kN/m² for a 600mm strip footing, which is founded at 0.75m bgl. However, this must be further reviewed at detailed design stage and if the imposed loads exceed the bearing capacity of the underlying ground, more robust foundation design solutions such as: shallow foundations founded at a deeper ground over competent ground conditions or adoption of deep foundations such as piles may be required.

In accordance with the Consultants Coal Authority Mining Report, no shafts within this area are recorded. The historical and recent ground investigations have not encountered any voids or significant core loss. However historical ground investigations have encountered layers of coal at shallower depths between 2.46 and 35.76 bgl, some of which are likely to be of extractable thickness. With reference to Section 9.1, risk of presence of unrecorded shafts cannot be discounted. As such it is advised that further location by location ground assessment, comprising watching brief during the constructions works is adopted.

Due to low to moderate plasticity, with a low volume change potential of the residual soils, it is recommended that, outside the zone of trees influence (and the localized deeper area of made ground), a minimum foundation depth of 0.75 m bgl is adopted in line with NHBC guidance.

9.1.3 Foundations Spanning the High Wall

The approximate location of the opencast mine high wall is presented on Drawing 067895-CUR-00-XX-DR-GE-002-Opencast Plan. The risks associated with construction of plots spanning the high wall comprise: intolerable total/differential settlement caused by total and secondary consolidation. A detailed assessment of the settlement must be undertaken at detailed design stage.

The secondary consolidation is anticipated to be a high risk. As such the secondary consolidation profile, for an assumed cross section taken perpendicular to the highwall is analysed. The assumption about the geometry of the wall is made based on the ground investigation information obtained and anticipated historical methods of construction. For the purposes of design, the high wall is assumed to be at a conservative 45° angle (discussed in Section 5.1.1). For the purposes of this assessment, two methods of analysis using equations 1 and 2, assuming 10m increase in depth, laterally, have been reviewed:

$$S_2 = H \cdot \frac{C\alpha}{1+e_0} \text{Log} \frac{t_2}{t_1} \quad \text{Equation 1}$$

$$S_2 = H \cdot \frac{\varepsilon\alpha}{100} \text{Log} \frac{t_2}{t_1} \quad \text{Equation 2}$$

The Void Ratios used in design were determined from laboratory testing. As a moderately conservative assumption value of 0.6 was deemed suitable for the purposes of preliminary calculations.

The values of C_α has been estimated after Terzaghi et al, 1996. Correlating with the C_c values. The C_c values were determined from the one-dimensional Oedometer testing graphs. For affirmation, three values of C_α were also estimated after Mesri, 1973, correlating with natural moisture content values. As such a moderately conservative C_α value of 0.04 was selected. The value was chosen such that >90% of the values estimated are lower than the moderately conservative value determined, providing a higher degree of confidence, See Figure 12.

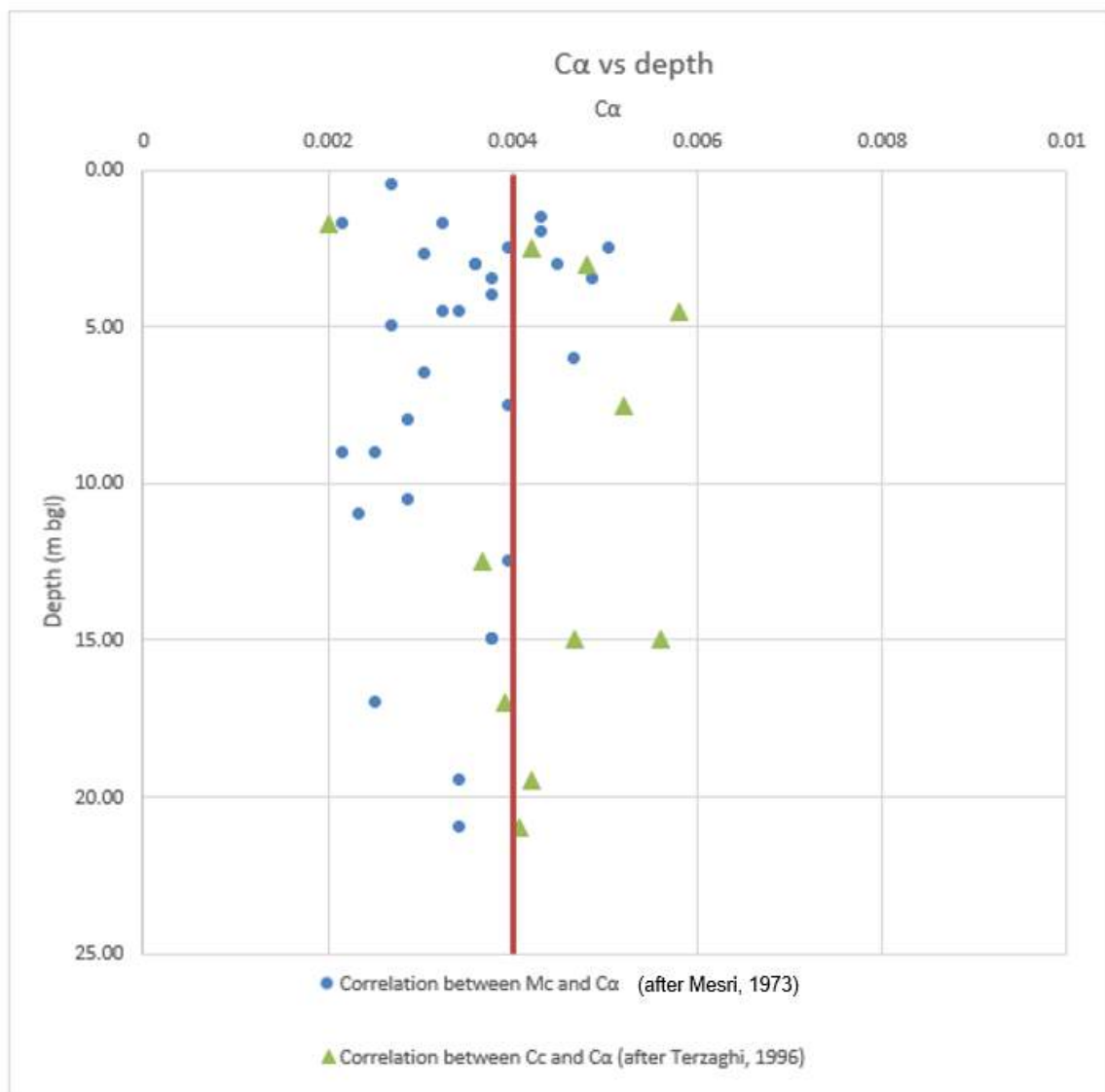


Figure 12 – C_α Vs. Depth

To ascertain a more representative understanding of creep at the location of the site, the creep was also calculated utilising Equation 2, where the $\epsilon\alpha$ values were obtained from correlation with natural moisture content after Mesri, 1973 for the representative ground conditions. As such a moderately conservative $\epsilon\alpha$ value of 0.22 was selected. The value was chosen such that >90% of the values estimated are lower than the moderately conservative value determined, providing a higher degree of confidence, See Figure 13.

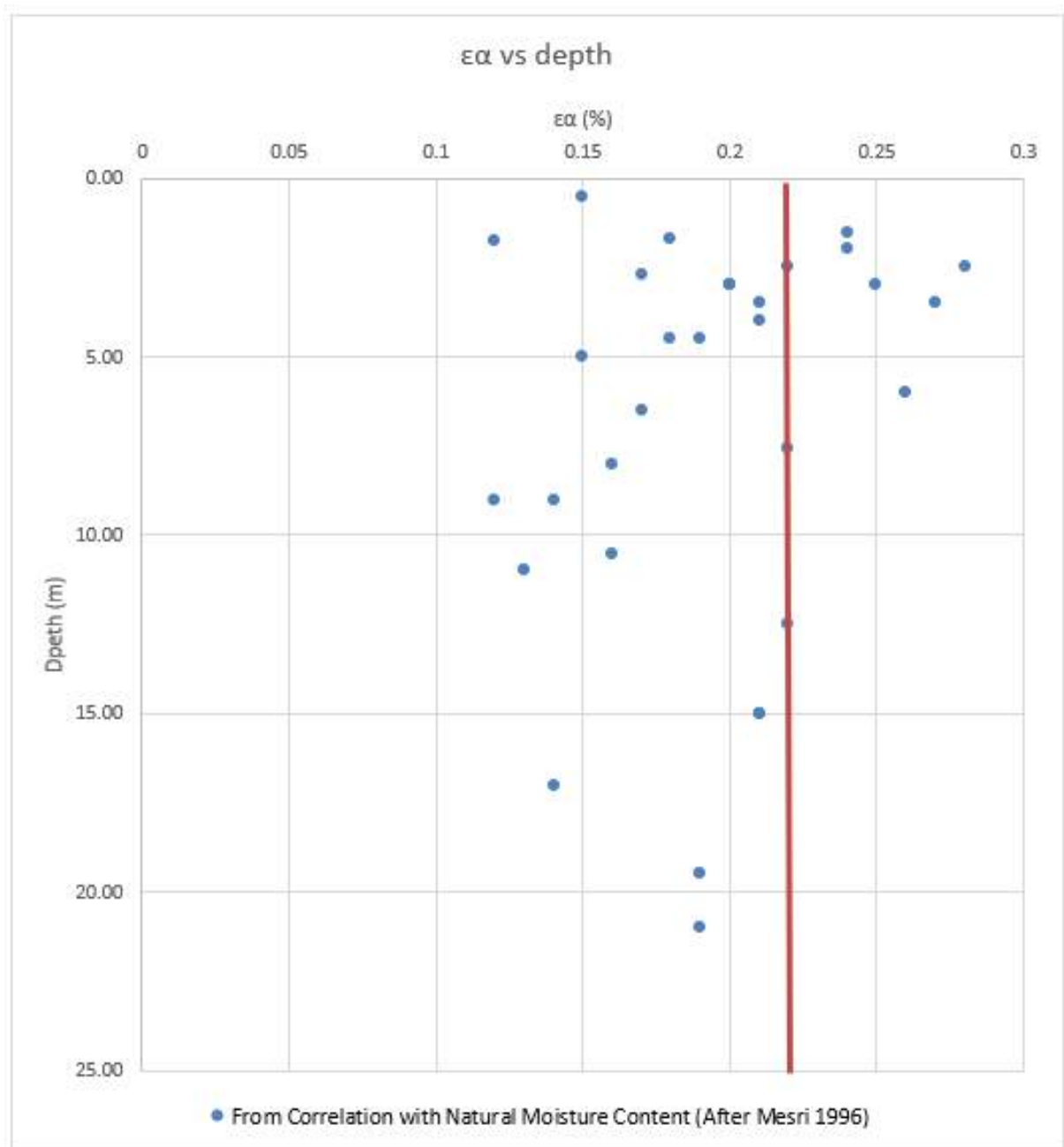


Figure 13 - $\epsilon\alpha$ Vs. Depth

The calculation adopts the fill to have been in place for 30 years and to have a design life of 120 years as a conservative assumption.

Figure 7, presents the anticipated secondary consolidation profile along this assumed cross section.

The results of the analysis are shown on Figure 14.

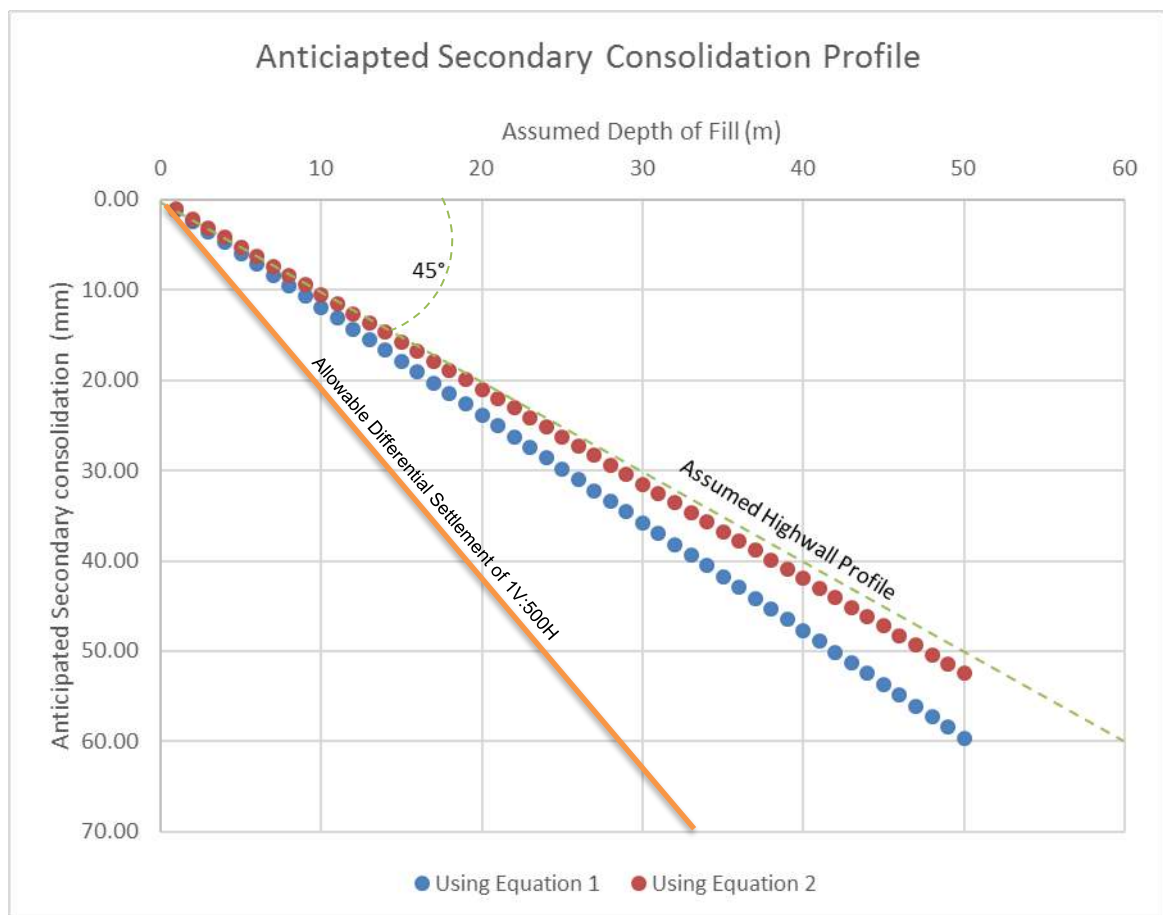


Figure 7 - Anticipated Secondary Consolidation Profile

As demonstrated on Figure 14, the secondary consolidation gradient across the assumed highwall profile is within the range considered acceptable. Generally, for these structures a 1V:500H gradient is assumed suitable.

It must be noted that **only for the purposes of affirmation**, calculations with the highest limits of ϵ_a and C_a (where 100% of results are lower than the design value) estimated from the Figures 12 and 13 were used, where ϵ_a of 0.3 and C_a of 0.006 were adopted. The results indicated that the creep will remain within the acceptable tolerances of 1V:500H.

However, it must be noted that due to highly variable nature of the backfill material, the calculated behavior of the ground as shown on Figure 14 is preliminary. It is recommended that following design of the ground improvement works, secondary consolidation analysis is undertaken in more detail.

9.1.4 Ground Floor Slabs

It is anticipated that outside the opencast mine, where outside of the zone of influence of trees, ground bearing floor slabs may be adopted.

It is anticipated that following suitable ground improvement works and approval of NHBC, ground bearing floor slabs may be adopted within the area inside the opencast coal mine.

Please refer to Section 9.1 for more information on founding stratum.

9.2 Excavations

It is anticipated likely that excavations will be required during the construction phase. These are likely to be for achieving required founding levels, ground improvement, remediation or localised dig and replacement works.

Shallow excavations (<1.2m bgl deep) for the purposes of dig and replacement of surface materials are likely to be relatively stable, as such, in general it is not anticipated that ground support for short term excavations within these regions would be required. Local instability should be expected where greater proportions of degradable or unsuitable material are encountered, e.g. rope wire. Attention should be given to limiting the duration over which excavations remain exposed to water ingress as both the residual soils and bedrock deposits may undergo rapid loss of strength and possible heave if wetted excessively.

In accordance with Health and Safety Regulations, side support for safety purposes should be provided to all excavations which appear unstable and those more than 1.2m deep. Excavations shallower than 1.2m deep, requiring personnel access, will require closed side support.

Seepage through walls of excavations could result in instability, as such where encountered, suitable measures such as side supports should be adopted. Noticeable amounts of standing water are encountered within the excavations could result in weakening of the founding soils, as such where encountered, the water should be removed facilitating suitable methods. However, groundwater conditions are not anticipated to impose a major risk, albeit, if following the assessment at detailed design stage, dewatering is deemed to be required, general advice on de-watering in accordance with CIRIA Report C750: Groundwater Control (CIRIA, 2016) should be taken into consideration.

Excavation through coal seams, shafts or coal is anticipated likely, outside of the opencast area, therefore, Coal Authority permit and advice on these works are anticipated to be required.

9.3 Unexploded Ordnance

A Preliminary Unexploded Ordnance Risk Assessment was undertaken, as detailed in Section 2.8 which concluded an overall low likelihood of UXO risk for the proposed works.

In any event, the following procedure should be adopted should any unexploded ordnance be encountered on site: **stop work immediately, prevent access to the area and inform the police.**

9.4 Re-use of Site Soils

It is assumed that re-use of soils will be considered as a part of the development works.

Based on the environmental testing and visual evidence, there is no reason for the site soils to be removed from the site, provided they are treated on site. The volume of anthropogenic material within the site soils means they are not suitable for use in areas of soft landscaping or private gardens. However, as there are proposed level changes and earthworks required as part of the development, the re-use of site soils is considered viable providing the soils are screened first to be made suitable for use. On that basis, with respect to their quality, all site-won soils are considered suitable for re-use across the development, subject to the re-use of the material being discussed with a suitably qualified Environmental Engineer.

In addition to quality, the re-use of site-won soils is governed by the following principles:

- The geotechnical suitability of the material needs to be confirmed;
- The re-use of the material needs to be covered as part of the planning approval, e.g. site levels maintained within agreed limits;
- The volume of the material being re-used needs to be confirmed and traceable
- Regulatory approval from the relevant authorities should be sought.

These principles are outlined within the CL: AIRE Code of Practice (v2) and if and where the re-use of site-won soils is proposed as part of the development works, it is recommended that a Materials Management Plan is produced in line with the Code of Practice to detail and document the process.

9.4.1 Waste Classification of Soils

It is the responsibility of the contractor and/or their appointed groundworks contractor to confirm waste classifications of soils requiring disposal off site.

Where any site soils are to be disposed of off-site guidance on the disposal of contaminated soils is provided within the following documents published by the Environment Agency.

- a) Guidance on the Classification and Assessment of Waste Technical Guidance WM3 (1st Edition 2015) (Environment Agency, May 2015).

Guidance states that the principal contractor (or any other sub-contractor undertaking excavations) should, in conjunction with the proposed disposal facility, use where possible the relevant environmental chemistry analyses results to classify any surplus material identified for off-site disposal. However, it should be noted that this information is for guidance only and material identified for disposal should be tested and assessed in accordance with WM3 to enable classification during the works.

An initial assessment for the waste classification of the made ground (opencast backfill) encountered on site has been carried out through a comparison of the soil testing results using the Waste Soils Characterisation Assessment Tool, Cat-Waste^{Soil}, developed by M^cArdle and Atkins. This online tool gives a rapid assessment of contaminated soils and their classification as either hazardous or non-hazardous waste.

The initial CAT Waste assessment has revealed that the made ground (opencast backfill) may be considered non-hazardous for off-site disposal as a preliminary classification.

Additionally, WAC tests have been undertaken on the made ground (opencast backfill) and suggest that the material is generally unlikely to be classified as inert. Each sample displayed levels of TOC and loss on ignition as being above the inert thresholds, and two displayed elevated sulphate levels.

9.5 Roads and Hard-standing Design

In-situ or laboratory CBR testing was not undertaken as a part of the ground investigation, however given the predominant presence of shallow fine-grained soils (opencast backfill and residual soils), it is recommended that a CBR value of no more than 1.5% is assumed for preliminary design purposes across the development site.

Through the completion of the recommended programme of ground improvement works, higher CBR values will be attained including the removal of potential hard-spots (cobble and boulders).

For the purposes of pavement designed and in accordance with Interim Advice Note 73/06, 2009, a minimum CBR of 2.5% must be adopted. This guidance indicates that pavements founded on ground with a minimum CBR of 2.5% will not require regular maintenance.

All soft/compressible spots must be excavated and replaced with suitably compacted granular material in accordance with best practice guidance.

10.0 Recommendations

Review of all available sources of information as discussed in detail in Section 1 to 8 indicates that the site ground conditions inside the opencast mine and outside the opencast mine are dissimilar.

The ground conditions outside the opencast mine are generally determined to comprise residual soils overlaying weathered bedrock of Pennine Middle Coal Measures. The ground conditions within the opencast mine are encountered to comprise significant thickness of made ground consisting of opencast mine backfill material placed as a non-engineered fill. As such the ground conditions within this area are anticipated to be highly variable. In addition, an opencast highwall is anticipated to be around the perimeter of the site, with greatest influence noted across the north western section of the site.

The main design hazards associated with the site are considered to comprise the variable nature of the shallow fill, the inclusions of anthropogenic material in the fill and the potential to combustible seams in the southeast of the site (outside of the opencast area). The associated prominent risks with these hazards comprise:

- Poor/Insufficient bearing capacities
- Intolerable total/differential settlement
- Secondary consolidation
- Requirement for higher classification of concrete

10.1 Recommendations for Site Enabling Works

To accomplish a sustainable design solution, it is desirable to achieve ground conditions which allow adoption of shallow foundations of suitable reinforcement and dimensions.

Following assessment of the risks and to achieve this criterion, it recommended that ground improvement is undertaken to regulate the shallow ground model within the opencast fill area.

Based on the recent ground investigation findings it is recommended that the most feasible option is a 'dig and turn' of the upper c. 3m of the site followed by material sorting (removal of anthropogenic/unacceptable inclusions) and replacement following a suitable earthworks specification.

Owing the scale of the required earthworks coupled with the variability of the fill and the likely requirement for some form of modification (e.g. lime addition, to control moisture content), it is recommended that an earthworks trial is undertaken to inform the earthworks specification. The requirement for soil stabilisation, i.e. cement addition, may be required subject to the design performance.

It is recommended that the ground improvement works are assessed using suitable observational methods as per guidance provided by BS EN 1997- Part 1, including: Skip Load Testing, Plate Bearing Testing accompanied by monitoring. It is assumed likely that this method will improve the ground

conditions and decrease the associated risks with intolerable ground movements and further inform the assessment of secondary creep potential of the fill as assessed in Section 9.1.

It is recommended that discussion with NHBC should be held, to obtain approval for an acceptable ground improvement technique along with a suitable foundation solution.

The ground conditions outside the opencast mine are anticipated to provide suitable shallow foundations founding stratum, following removal and replacement of soft/compressible spots with suitably compacted granular material. Locally removal of up to 2m of unsuitable materials may be required. In addition, in accordance with the Consultants Coal Authority Mining Report, to locate any likely unrecorded shafts and worked seams, further location by location ground assessment, consisting of strip of the surface soil and observation to be adopted.

10.2 Recommendations for the Proposed End Uses

The quantitative risk assessment has identified that the risk to future site users is considered Low/Moderate with respect to a Residential with homegrown produce.

The risk presented by ground gases is assessed as Moderate with ground gas protection measures recommended across the proposed development site.

It is recommended that as part of the site enabling a Remediation Strategy is developed to mitigate these risks to future site users. It is anticipated that these mitigation measures will be in the form of provision of clean capping to future residential properties and the provision of ground gas protections measures in accordance with BS8485:2019.

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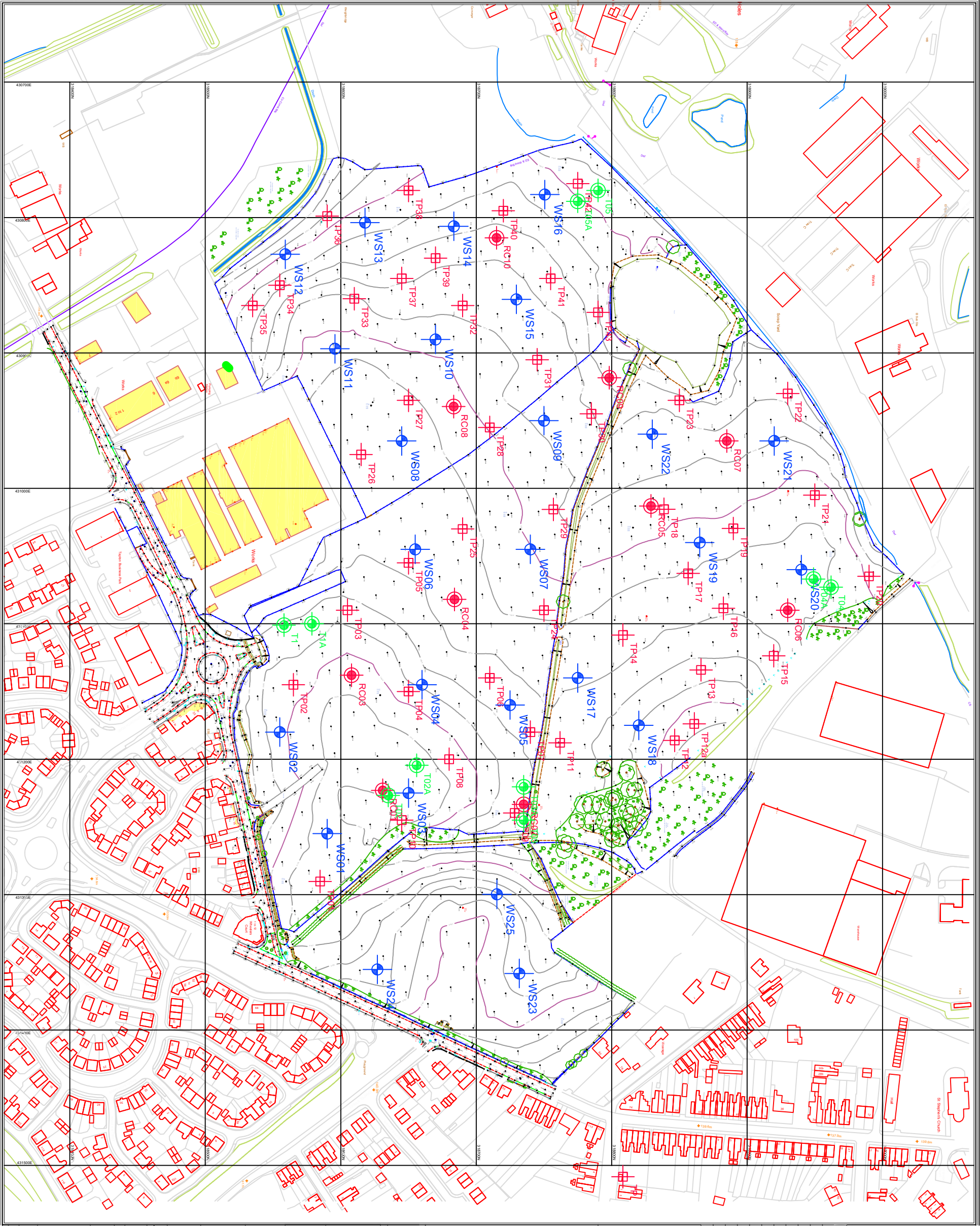
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Appendices

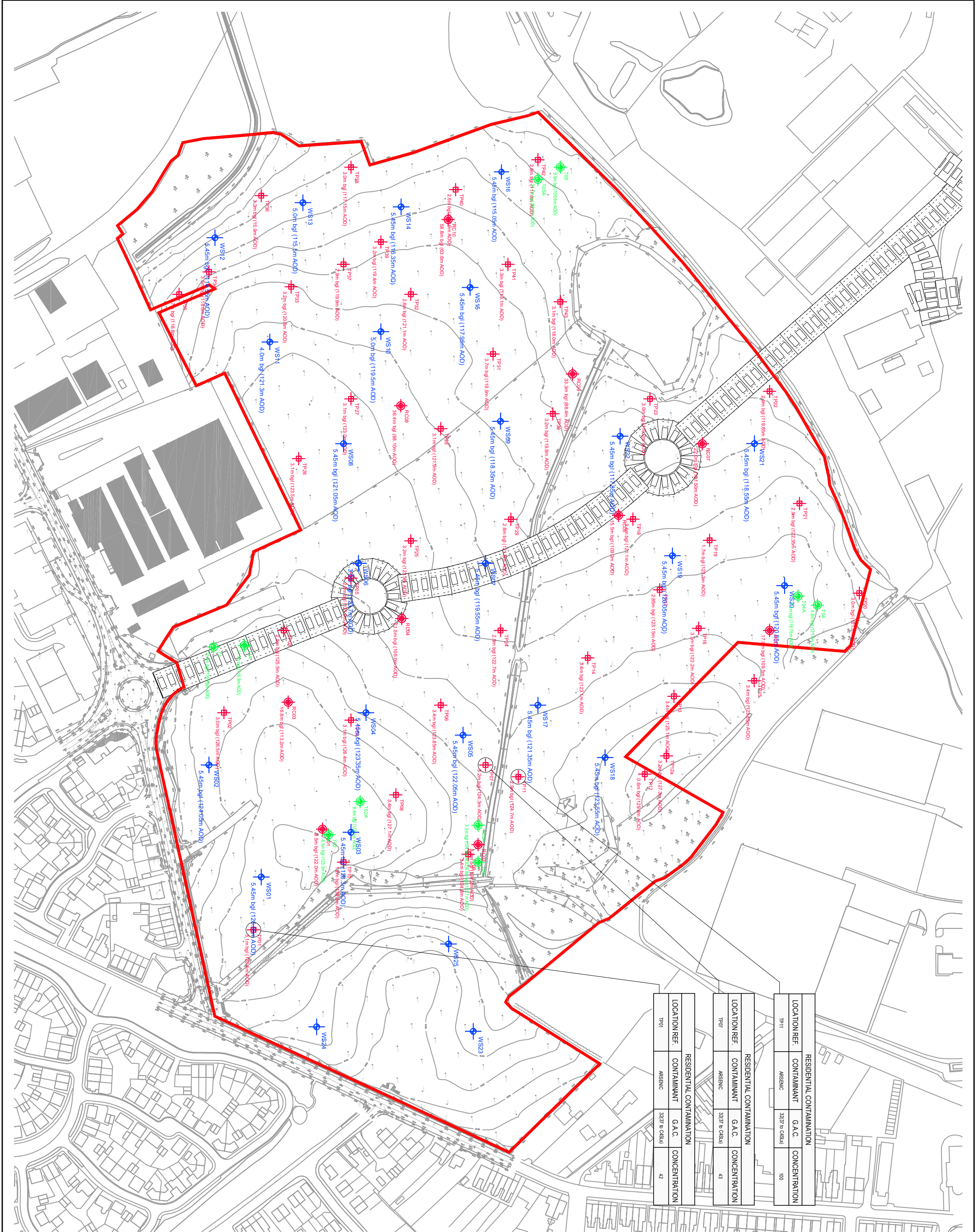
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Appendix A Drawings

- 067895.101-CUR-00-XX-DR-GE-001-V01_Exploratory Hole Location Plan



902	RECEIVED BY LOCATION	3/20/2014	06
901	INVEST INSIDE	6/6/13	10
	Company	Date	By
			
Rick Wyl, General Mgr., 78 301 1st Street, Unit 128 Etc. linn@curtins.com www.curtins.com 408 478 0000			



RESIDENTIAL CONTAMINATION			
LOCATION REF.	CONTAMINANT	G.A.C.	CONCENTRATION
TP11	ARSENIC	32.07 b CRLSJ	100
RESIDENTIAL CONTAMINATION			
LOCATION REF.	CONTAMINANT	G.A.C.	CONCENTRATION
TP07	ARSENIC	32.07 b CRLSJ	43
RESIDENTIAL CONTAMINATION			
LOCATION REF.	CONTAMINANT	G.A.C.	CONCENTRATION
TP01	ARSENIC	32.07 b CRLSJ	42

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KEY:

WS

WSW

TP

RC

T

SITE LOCATION BOUNDARY

WINDOWLESS SAMPLER LOCATION

TRIAL PIT LOCATION

ROTARY HOLE DRILLING LOCATION

ROTARY PROBE TRANSECT LOCATION

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GROUND INVESTIGATION SECTIONS & CONTAMINATION PLAN

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4. FOR GENERAL NOTES REFER TO DRAWING.

- SYMBOLS
- SITE LOCATION BOUNDARY
 - ROTARY HOLE DRILLING LOCATION
 - HISTORICAL ROTARY HOLE DRILLING LOCATION
 - HISTORICAL BORE HOLE DRILLING LOCATION

SURFACE LEVEL DATA			
NUMBER	MINIMUM LEVEL	MAXIMUM LEVEL	COLOR
1	-50.00	-40.00	Red
2	-40.00	-30.00	Orange
3	-30.00	-20.00	Yellow
4	-20.00	-10.00	Light Green
5	-10.00	0.00	Dark Green
6	0.00	1.00	Blue

NO	REVISION	DATE	BY	CHK
1	ISSUED FOR CONSTRUCTION	2024/01/15	JD	ML



Woodville Swadlincofte

SUITABLE FOR INFORMATION

S2

GROUND INVESTIGATION
SECTIONS & CONTAMINATION
PLAN

NO	REVISION	DATE	BY	CHK
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067896 - CUR - 00 - XX - DR - GE - 04001 - V01

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- Coal Authorities Summary of Findings Map
- Coal Seams with a History of Spontaneous Combustion
- Guidance on Managing the Risk of Hazardous Gases when Drilling or Piling Near Coal



Guidance on Managing the Risk of Hazardous Gases when Drilling or Piling Near Coal



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Management of Health and Safety at Work Regulations 1999

Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR)

The Building Regulations 2010

The Building (Scotland) Amendment Regulations 2010

Confined Spaces Regulations 1997

Provision and Use of Work Equipment Regulations 1998 (PUWER), as amended

The Lifting Operations and Lifting Equipment Regulations 1998 (LOLER), as amended

British Standards

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C. Regulatory Agencies and Trade Bodies

Health and Safety Executive

Coal Authority

Environment Agency

Scottish Environmental Protection Agency

Local Government

British Drilling Association

Association of Geotechnical & Geoenvironmental Specialists

D. Useful Contacts & Addresses

Acknowledgements

Working Group

Acknowledgement is made to the following members of the working group who are responsible for the co-authorship of this publication.

Keith Banton	The Coal Authority + Chairman & Editor
Steve Kershaw	The Coal Authority
Marcus O'Connor	Health & Safety Executive
David Allan	British Drilling Association & Raeburn Drilling & Geotechnical Ltd
Brian Stringer	British Drilling Association

Others who have collaborated in the compilation of this guidance are:

Jon Ball	Federation of Piling Specialists & Roger Bullivant Ltd
Neil Parry	The Association of Geotechnical and Geoenvironmental Specialists & Geotechnical Engineering Limited
Louise Clarke	The Coal Authority
Ian Smith	The Coal Authority
Bill Denton	Formerly The Coal Authority

Reviewers

Acknowledgement is also made to the following organisations and individuals that have reviewed this guidance:

Wolverhampton Council & Black Country Geotechnical Association (Clive Roper et al.); BAM Ritchies (Rod Edser et al.); SYMAS (Paul James et al.); Highways Agency (Andrew Jukes et al.); Geotechnics (Keith Nicholls); Halcrow (Ray Kenny); Glasgow Council (Donald Linn); Forkers Ltd (Peter Watson); M & J Drilling Services Ltd (Steve Rule et al.); HM Specialist Inspector - Construction Engineering Specialist Team (Martyn Ostcliffe); NHBC (Ruth Easterbrook et al.); Coal Authority (Joe Dearden)

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Definitions

Act	An Act of Parliament, a statute (commonly called a law), primary legislation
ACoP	Approved Code of Practice. Code that provides practical guidance on how to comply with the legal requirement of an Act
Adit	Non vertical mine access roadway (usually walkable) driven from the surface and used for removal of mineral, ventilation, pumping water etc. See also Drift; Sough, Level; Day Level
Admixture	Something produced by incorporating an item into something else
Afterdamp	A mixture of gases primarily nitrogen, carbon monoxide and carbon dioxide, left in a mine after a fire or an explosion
Alkanes	Any gas in a group that contains only carbon and hydrogen atoms, with the carbon atoms joined together in a simple chain, such as butane and propane. Often very flammable. Methane is the simplest single carbon alkane
Asphyxiation	To deprive of oxygen often leading to unconsciousness or death
ATEX	From the French – Atmospheres Exposable. European directive for explosive atmospheres
Blackdamp	A mixture of gases formed when oxygen is removed from mine air and is replaced by carbon dioxide, also known as 'stythe' or 'chokedamp'
Broken Ground	Area of disturbed ground usually associated with the collapse of overlying strata into former coal workings
Cap	A strong slab or block of concrete placed over a shaft and capable of supporting both overburden and, exceptionally, a structure
Carbonaceous	Consisting of, containing, relating to, or yielding carbon
Casing	Open tubes inserted into a borehole to prevent the hole from collapsing
CDM	The Construction (Design & Management) Regulations 2007
CFA Piling	Piles formed by drilling using a hollow stem continuous flight auger through which concrete is pumped as the auger is withdrawn
Coalfield	An area in which deposits of coal are found
Coal Measures	Coal-bearing part of the Upper Carboniferous System
Coal Workings	Areas of underground strata from which coal is being or has been mined. Coal workings can be open and void, partially collapsed

	and semi void, or totally collapsed with little void space. See also - Broken Ground
Comminuted	Powdered; pulverized, divided into small parts
Competent Authority	Person or organisation that has the legally delegated or invested authority, capacity, or power to perform a designated function.
CPCS	Construction Plant Competence Scheme
CSCS	Construction Skills Certification Scheme
Day Level	Non vertical mine access roadway driven from the surface. See also 'Adit'
Desorption	The release of gas from coal where it has been stored on the surfaces of the internal structure
Dip	Angle at which a stratum or other planar body is inclined to the horizontal
Discontinuity	Fracture or break in soil or rock fabric in the form of bedding, faults, joints, cleavage or fissure
Dissociate	The breaking of a chemical (molecular) bond
Drift	See also 'Adit'. Non vertical mine access roadway. Particularly known as a drift when driven as a major access
Drilling	The intrusive process by which ground is penetrated by percussive, rotary or rotary percussive or resonance techniques to obtain samples or data, provide access for installations and ground stabilisation etc
Drill Rig	A powered drilling machine for investigating sub surface ground conditions, stabilising ground, geothermal drilling and other such activities
Face	A surface exposed by excavation usually for mineral extraction
Fault	A fracture or fracture zone in rock along which there has been an observable displacement
Firedamp	Mining term used for methane and associated alkanes
Groundwater	Aqueous liquid present in the cavities and spaces in soils and rocks
Ground Investigation	Exploration and recording of the location and characteristics. Specialist intrusive investigation on a site with the associated monitoring, testing and reporting. This may comprise boreholes, trial pits, penetration tests, laboratory tests and geophysical methods

Grout	A mixture of cementitious material and aggregate to which sufficient water is added to produce pouring consistency without segregation of the constituents but will gain strength over time
Guidance	Technical information on a particular work arena provided by the HSE and others e.g. Trade Associations, based on good practice
Hydrocarbon	A chemical combination of hydrogen and carbon, e.g. oil or methane
Heating	Colloquial name for a spontaneous combustion fire in coal
Level	See also 'Adit'. Non vertical mine access roadway. Often known as a level when driven for mine drainage
LOLER	Lifting Operations and Lifting Equipment Regulations 1998, as amended
L.E.L	Lower Explosive Limit
L.T.E.L	Long Term Exposure Limit
NVQ	National Vocational Qualification (NVQ diploma)
Outcrop	The area over which a coal seam (or other rock type) occurs at bedrock level – whether exposed at ground surface, or buried beneath drift
Oxidation	To convert into an oxide; combine with oxygen
Pelistor	Gas sensor used to detect flammable gases
Permeable Ground	Rock or superficial deposits that will allow gas and/or water to pass through it with relative ease
Piling	Construction of deep foundations by driving a preformed pile (usually concrete or steel) into the ground or by casting concrete in a pre-bored shaft which may be cased or uncased
Piling Rig	Machine used for the installation of piles by drilling boreholes or driving or vibrating preformed piles
ppm	Parts per million
PUWER	Provision and Use of Work Equipment Regulations 1998, as amended
Pyrite or Iron Pyrite	An iron sulphide with the formula FeS_2 . Nicknamed “fool's gold” due to its resemblance to gold. Often found in association with coal seams
Rockhead	Interface between soil (superficial deposits) and the underlying solid rock
Regulations	Legal duties made under the Health & Safety at Work etc Act

	1974 and any other enabling Act. Generally compulsory and are more specific than Acts
Shaft	Vertical or almost vertical opening used for access to the mine, removal of mineral, ventilation of a mine, or pumping water etc
Site	The bounds of an area of ground designated for a project
Site Investigation	The overall process of determination of the physical characteristics of sites as they affect design, construction and stability of neighbouring ground or structures
Sough or Slough	Non vertical mine access roadway. Particularly known as a sough when driven for mine drainage. See also 'Adit'
S.T.E.L	Short Term Exposure Limit
Stinkdamp	A mining term for hydrogen sulphide
Stythe	See blackdamp
Superficial deposits	Soil materials overlying rockhead. The most recent deposits, mostly unconsolidated (e.g. sand, silt, clay, mud, etc)
SVQ	Scottish Vocational Qualification
Toxic	Poisonous / deadly
Tremie Pipe	Device that carries materials, usually grout or concrete, to a designated depth in a borehole or void.
U.E.L	Upper Explosive Limit
Unworked Coal	In situ coal, of any thickness, which has not been mined
Whitedamp	A mining term for carbon monoxide
% v/v	Percentage by volume

Guidance on Managing the Risk of Hazardous Gases when Drilling or Piling Near Coal

1. Introduction

Serious incidents, which have occurred during geotechnical drilling operations to investigate and treat former coal mine workings, have highlighted the need for guidance to ensure the safety of operatives and the public whilst undertaking such work.

Of particular concern are incidents where carbon monoxide has been measured or inferred as entering houses contemporaneously with adjacent drilling operations, in one instance affecting the health of the residents and in another the loss of two lives. The source of the carbon monoxide in both cases was not clear, but possibilities are that the gas was either in the workings due to existing or previous spontaneous combustion or that the drilling operations themselves, which were air flush drilling into a spontaneous combustion prone seam, produced the gas.

Subsequent research carried out by the Coal Authority led to a group, comprising Health and Safety Executive, British Drilling Association, Association of Geotechnical and Geoenvironmental Specialists and the Coal Authority, being formed to produce guidance, in conjunction with the industry, on how coal mine workings and unworked coal can be drilled, treated and piled through, without creating or displacing hazardous gases.

Entering former coal mine workings, coal mine entries and unworked coal can present many hazards for both site operatives and properties adjacent and in close proximity to the site. Operations to investigate, treat or disturb such features should only be considered by suitably competent persons. Moreover physical (manned) entry to such environments can only be undertaken by persons qualified to do so under the Management and Administration of Safety and Health at Mines (Masham) Regulations 1993.

Where proposed works will intersect, enter or disturb the Coal Authority's property it is a pre-requisite that prior consent is obtained. In the case of an accident occurring, if it is established that a contractor has knowingly undertaken work which was advised against by a competent authority, or that he has knowingly circumvented authorised schemes designed to ensure safety, this may be seen as an aggravating factor in any potential prosecution of the company.

This document gives guidance on the general procedures to be adopted when drilling or piling into former coal mine workings (including shafts and adits) and unworked coal. If you follow this advice then the likelihood of an incident will be reduced.

However this guidance does not preclude the use of alternative strategies and arrangements which provide equivalent or higher standards of safety.

2. Scope

This document is designed and published in order to provide guidance with respect to hazardous gases for the safe drilling and piling through Coal Measures up to a maximum depth of 200m. These gases include the most common such as methane, hydrogen sulphide, carbon dioxide and carbon monoxide but also less common such as hydrogen. It also includes oxygen deficient air.

This guidance will only apply in the coalfield areas of Great Britain where the proposed activity will or is likely to intersect areas of unworked coal seams and former coal mine workings (including shafts and adits), henceforward referred to as just unworked coal and former coal workings, (which are in most instances the property of the Coal Authority).

Coalfield areas are identified by the Coal Authority Gazetteer which can be viewed at www.groundstability.com and where a coal mining report or ground stability report can also be obtained. Furthermore the Coal Authority has defined specific 'Coal Mining Development Referral Areas'. These are areas, based upon Coal Authority records, where the potential for instability and other safety risks associated with former coal mining activities are likely to be greatest. These areas can be viewed at <http://coal.decc.gov.uk/en/coal/cms/services/planning/strategy/strategy.aspx>

All drilling applications are included within the scope. Principally these are ground investigation, piling, drilling and grouting, geothermal, waterwell and processes which are geotechnical in nature. Driving precast piles is also included.

The scope of this document is limited to and includes all matters concerning health and safety in relation to hazardous gases associated with unworked coal and coal workings. These include identifying the hazards, evaluating the risks and taking protective measures both on and in close proximity to sites. The responsibilities and duties of Clients, Designers and Contractors are covered in this document.

Specialist advice is always recommended in providing a balance to the often conflicting demands of safety, economy and durability, particularly for sites with complex histories and geology. Such sites are often affected by contamination and expert specialist advice based on adequate site investigation data is therefore essential, preferably at a very early stage

Not included in the scope of this document are hazardous gases in landfills, hazardous gases in contaminated land, and naturally occurring gases as a result of non coal geology. These are covered by BDA (British Drilling Association), ESA (Environmental Services Association) and other authoritative publications. However the guidance within this document may be useful in other areas.

The document does not cover the activities involved in hydraulic fracturing (also called "fracking") or exploration drilling for oil and gas,

3. Disclaimer

The information contained in this guidance has been compiled by the British Drilling Association Ltd, the Coal Authority, the Health and Safety Executive, the Federation of Piling Specialists and the Association of Geotechnical and Geoenvironmental Specialists and reviewed by those listed under acknowledgements above and is supplied to the recipient on the following terms:-

- 1) The authors and compilers of this guidance are not responsible for the results of any actions taken on the basis of the information contained in this guidance, or for any errors or omissions from this guidance.
- 2) The authors and/or compilers of this guidance are not engaged in rendering professional services, except when acting on a personal consultancy basis.
- 3) The authors and/or compilers of this guidance shall not be liable to any recipients of this guidance in respect of any damage, loss, proceedings or expenses incurred in consequence of this guidance. No liability is accepted in respect of any act or omission by the recipient in reliance on the information contained in this guidance. All recipients of this guidance are advised to seek expert advice, where required, from a relevant competent professional.
- 4) This guide is only intended for use in the stated context and should not be used otherwise. The guidance is compiled from the authorship team's knowledge of current good professional practice and standards. Any limitations are identified where possible but the guidance may require amendment should additional information become available.

In this document reference is made to various National Regulations, European, International and British Standards and other appropriate reference documents. Some of the major aspects of these

have been summarised. This is done only to assist users of this guidance by drawing their attention to these regulations and standards.

It is the responsibility of those who use this guidance to make themselves thoroughly conversant with all the appropriate legislation and standards and not to rely on any reference or summary contained in this document that may be incomplete or incomprehensive. It is not intended that this document should replace any Acts, Codes of Practice, Regulations or other documents having legal or contractual standing.

Of necessity this document addresses the broad principles that should be adopted. Advice in respect of specific equipment or operations should be obtained from the appropriate body or technical reference source.

The recognition of the various and individual responsibilities are fundamental to the application of this guidance and the principle of **"Identify the Hazard, Assess the Risk and Take the Appropriate Control Measures"** should always be applied.

4. Legal Duties/ Competence Requirements for those Undertaking Drilling or Piling Work

General legal duties for those undertaking applicable construction works are defined under Construction (Design and Management) Regulations. This section deals with those specific areas that relate to the drilling process. For more general information refer to the CDM ACoP.

Competence is a combination of aptitude, training, experience and familiarisation of the work to be undertaken. As such, each task should be done only when the employer is confident that those performing the task are competent to do so. Below is an outline of minimum attributes necessary to undertake work involving the drilling or piling activities that may be affected by hazardous gases.

4.1 Client

A client is someone who is having construction or building work carried out. The Client has one of the biggest influences over the way a project is run and their approach may help to define the structure and safety culture of the work. Clients are not required or expected to plan or manage projects themselves, nor do they have to develop expertise in construction health and safety, unless it is central to their business. Clients must ensure that various things are done, but are not normally expected to do them themselves. There are two types of client - a domestic client and a commercial client.

4.1.1 Domestic Client

A domestic client is someone who lives, or will live, in the premises where the work is carried out. The premises must not relate to any trade, business or other undertaking. Although a domestic client does not have duties under CDM, those who work for them on construction projects will. A contractor engaged by a domestic client, takes on the responsibilities of the Client to make arrangements for the management of health, safety and welfare issues on the project.

4.1.2 Commercial Client

Client duties apply to any business that seeks or accepts the services of architects, builders, and workers etc. to carry out construction project work. This definition is very wide and includes companies, partnerships and sole traders. Client duties apply on all projects and there are additional requirements on notifiable projects. Client duties apply from project conception through to completion. Most Client duties require action well before work starts on site.

The Client is critical to securing project safety and achieving compliance with all other aspects of CDM

2007. The extent of Client duties will be affected by the scale and nature of the project. Clients must ensure that those appointed or engaged on the project are competent to comply with health and safety requirements.

In practical terms, this means the Client must implement procedures that check the CDM Competence of others. The Client must ensure that CDM co-ordinators, designers and contractors are promptly provided with pre-construction information (PCI).

The PCI consists of all the information which is relevant to the health and safety of those engaged in, affected by the work or using the structure as a future workplace. It will provide designers and contractors who may be bidding for the work (or who they intend to engage), with the project-specific health and safety information needed to identify hazards and risks associated with the design and construction work. This could include the information in any relevant existing health and safety file but where there are gaps in this information, the Client should ensure that these are filled by commissioning surveys or by making other reasonable enquiries (see [section 8](#) – Desk Study). It is not acceptable for clients to make general reference to hazards which might exist. The PCI should be sufficient to ensure that significant risks during the work can be anticipated and planned for. It should concentrate on those issues that designers and contractors could not reasonably be expected to anticipate or identify.

For notifiable work the Client must appoint a project CDM Co-ordinator (CDM-C) at an early stage and subsequently appoint a Principal Contractor (PC). If others are not appointed the project client becomes both CDM-C and PC and takes on the duties of both roles.

The Client must also:

- Take steps to ensure that these arrangements are maintained and reviewed throughout the project.
- Allow sufficient time and resources for all stages of the work.
- Co-ordinate their own work with others involved with the project in order to ensure the safety of those carrying out the construction work, and others who may be affected by it.

4.2 Designer

Designers are defined under CDM as those who have a trade or business which involves them in:

“Preparing designs for construction work, including variations. This includes preparing drawings, design details, specifications, bills of quantities and the specification of articles or substances, as well as all the related analysis, calculations and preparatory work.” (see CDM ACoP para’s 115-118).

This definition includes contract engineers who have responsibility for analysis of the site, including the location of the coal workings and the calculations for the work. Designers have a general duty to eliminate risk within the work, where reasonably practicable by design. For example, if the design calls for a borehole to be drilled in an area which makes it impractical to use guards on a machine and it is possible to relocate the hole then a designer has a duty to do so. Similarly, if the drilling process presents a risk of gas migration and the process can be designed out, so far as is reasonably practicable, then this is a legal duty.

The Designer in providing advice and plans for drilling and piling works into coal measures should be able to demonstrate their familiarity and competence in the following areas;

- Health and Safety at Work Act and the accompanying relevant regulations.
- CDM requirements.
- Contractual matters.
- Coal Authority permissioning regime.

- Desk study principles and practice.
- Coal Measures geology and hydrogeology.
- Historical coal mining.
- Risks from hazardous gases.
- Migration of gases on and off site.
- Influence of atmospheric conditions.
- Monitoring for hazardous gases on and off site.
- Drilling and/or piling processes.
- Emergency procedure for coal seam fires, blow outs and evacuation.

4.3 CDM Co-ordinator

The CDM coordinator (CDM-C) is an enabling role. A CDM-C has to be appointed to advise the Client on projects that last more than 30 days or involve 500 person days of construction work. A Client engages a CDM-C to liaise and advise all parties before and during the construction phase. They may assess the competence of Principal Contractors on behalf of the Client, discuss design implications with designers and give advice on additional control measures for tasks. Their legal duties are to:

- Advise and assist the Client with its duties; and thus be up to date with safety issues surrounding specific work activity, such as the dangers of drilling into unworked coal and coal workings.

With this in mind the CDM-C's should have an intimate knowledge of the issues and hazards involved within the drilling and /or piling industry, including sufficient knowledge of potential difficulties and solutions to engage designers in a meaningful dialogue regarding these issues.

4.4 Contractor

The drilling or piling contractor shall be able to demonstrate its competence to undertake and manage the risk arising from the work. This may be shown by:

- Experience of similar work (References).
- Using only competent, assessed and authorised personnel.
- Having appropriate insurance cover.
- Using only suitable plant with:
 - Rig certification (LOLER).
 - Compliance with PUWER (Dangerous rotating parts).
- A Health & Safety Policy for their organisation.
- Having a Construction Phase (Health and Safety) Plan.
- Or additional documentation demonstrating expertise and experience.

4.5 Drilling and Piling Operatives

Drilling and Piling Operatives shall be able to demonstrate their competence.

For drilling this should be all of the following:

- NVQ/SVQ certificate in Land Drilling (or proof of an equivalent level of experience and continuous development).
- A current and valid Audit card as issued by the British Drilling Association or an equivalent body in a State of the European Union.
- CSCS Land Drilling card.
- Or have proof of an equivalent level of training and experience.

The certificates and cards for Lead Drillers shall be applicable to the work and specific boring / drilling operation on which they are engaged.

For Piling this should be:

- NVQ/SVQ certificate in Piling Operations (or proof of an equivalent level of experience and continuous development).

4.6 Plant Operatives

Operatives using plant covered by Construction Plant Competence Scheme (CPCS) e.g. piling rigs, excavators, dumpers etc employed on the contract should hold an appropriate card (or proof of equivalent training and experience of operating this category of machine).

4.7 Site Supervisors

Site Supervisors shall be able to demonstrate their competence.

This should be all of the following:

- NVQ/SVQ certificate or equivalent proof of experience and continuous development of knowledge and skills.
- Appropriate CSCS card.
- Safe site supervision training.
- Or have proof of an equivalent level of training and experience.

4.8 Site Engineers

Site Engineers shall be able to demonstrate their competence

This should be all of the following:

- Appropriate degree.
- Appropriate CSCS card.
- Safe site supervision training when acting in supervisory role.
- Or have proof of an equivalent level of training and experience.

4.9 Site Managers

Site Managers shall be able to demonstrate their competence.

This should be all of the following:

- Appropriate CSCS card (or proof of equivalent training/ experience).
- Site manager's safety training when acting in a managerial role.
- Or have proof of an equivalent level of training, experience and familiarisation of the processes to be undertaken on site.

5. Gases – Properties and Problems

5.1 Coal Mine Gases and their Principal Hazards

5.1.1 Atmospheric Air

Atmospheric air is often a component of gas emitted from mines. Most often mine gas is a mixture of atmospheric air and various pollutants, the pollutants in some cases completely displacing the air.

5.1.2 Oxygen (O₂)

Oxygen makes up 21% of air and is the dominant reactive gas in the atmosphere. The remaining 79% comprises of 78% nitrogen and 1% argon along with other trace gases.

Hazardous conditions can arise from excess levels of oxygen, but such conditions are extremely unlikely to be encountered. On the contrary, hazardous conditions due to reduced levels of oxygen, usually as a result of oxidation of carbonaceous material, are likely to be encountered. Operations should not be carried out where workers are consistently exposed to concentrations of oxygen below 19% v/v (percentage by volume). Once oxygen levels approach 17% v/v breathing can become laboured and judgement impaired. Once oxygen concentrations approach 10% v/v there is a high probability of unconsciousness and death.

Low oxygen levels are most often found in conjunction with elevated levels of carbon dioxide (see below), although high concentrations of methane can also produce oxygen deficiency.

Sometimes coal mine atmospheres contain excess levels of nitrogen, which are due to oxygen being removed, usually by conversion into carbon dioxide which is then dissolved in water.

5.1.3 Methane (CH₄)

Methane is present in mine workings due to desorption from the coal seams. Methane was produced during the conversion of organic matter to coal due to heat and pressure and some of the gas produced remains within the structure of coal. In general, the methane content of coals increases with depth. As a consequence, where only shallow seams have been mined or deeper seams have become flooded by rising mine waters, high methane concentrations are unlikely to be present. Conversely, where deep mined seams are connected either directly to the surface or through shallow workings, methane may be a significant constituent in mine gas.

The principal danger arising from methane is fire and explosion. The explosive range for methane in air is 5% to 15% methane by volume (v/v) (50,000-150,000 ppm). Sometimes gas concentrations are quoted in terms of percentages of the Lower Explosive Limit (%LEL), where 100% LEL is 5% v/v. So, for example, 1% methane by volume is equal to 20% LEL. Because of the wide disparity in values care must be taken when reading gas monitors as to which scale is being used. Although concentrations higher than 15% v/v (the Upper Explosive Limit or UEL) cannot be directly ignited they can dilute into the explosive range or represent a risk of ignition as they will burn at the interface of the gas and air.

Even small quantities of gas can produce significant damage and risk to people, especially if the gas volume is confined at the time of ignition. A particular aspect of gas ignitions is the fact that the size of the flame is much larger than the volume of the gas before ignition, due to the temperature of the

flame. This means that the flame can impact on a much wider area than might be expected and may mean that an ignited flame might be hard to avoid. Ignitions within confined spaces can produce significant overpressures causing harm both to operators and structures. For these reasons it is especially important that monitoring is undertaken where methane might be encountered. If detected moving away from the source is also an important safety precaution.

Methane is ignited relatively easily by either naked lights or sparks from electrical equipment such as switches. Great care needs to be exercised in not allowing methane to come into contact with electrical equipment, or taking electrical equipment into atmospheres potentially containing methane. Any equipment which may come into contact with methane must be suitably ATEX compliant. This also applies to any equipment used to monitor for the presence of methane and other mine gases.

Methane has a density of about 0.7 kg/m^3 , compared to the density of air of about 1.2 kg/m^3 . Being lighter than air, mixtures of methane and air, especially at high methane concentrations, will tend to rise in air. Methane mixtures may also form layers when rising gas encounters horizontal barriers, such as ceilings, and especially where the gas is emitted close to such a horizontal barrier.

Methane is not toxic, but can act as an asphyxiant by displacing oxygen from the air. For a pure mixture of air and methane, every 10% of methane will produce a 2% reduction in oxygen.

5.1.4 Carbon Dioxide (CO₂)

Carbon dioxide in mines originates predominantly as a result of oxidation processes. These processes are generally as a result of oxidation of carbonaceous material, but biological processes could also be involved. In oxidation processes a unit volume of oxygen will produce an equal volume of carbon dioxide. Consequently, an increase in the concentration of carbon dioxide will be at the expense of an equal reduction in the concentration of oxygen. In many cases the sum of the concentrations of oxygen and the concentration of carbon dioxide will be close to 21% v/v - the atmospheric concentration of oxygen. However, solution of carbon dioxide in water can result in atmospheres which are predominantly nitrogen. In the mining industry, a mine air mixture rich in carbon dioxide and poor in oxygen is also known as blackdamp or stythe.

Carbon dioxide has a density close to 2 kg/m^3 , which is significantly higher than air. As a result, blackdamp emissions have a tendency to layer at ground level, especially if the mine gas is cold, which enhances the density difference. Blackdamp is therefore particularly dangerous in cases such as cellars, trenches, cuttings and any other confined low lying ground. The gas can also flow downhill and collect in low lying ground at a distance from the point of emission.

Carbon dioxide is toxic, but the principal danger arising from emissions is asphyxiation due to the associated reductions in oxygen. The 8 hour long term exposure limit (LTEL) is 0.5% v/v or 5000ppm and the 15 minute short term exposure limit (STEL) is 1.5% v/v. (See 6.2). The STEL and LTEL figures included here and in the Table of Characteristics and Effects of Toxic Mine Gases (6.2), are set out in EH40 Occupational Exposure Limits published by the HSE.

5.1.5 Carbon Monoxide (CO)

Carbon monoxide is produced as a result of incomplete combustion of fuel. In domestic situations the main danger arises from problems with heating appliances and leaking flues. In mines the gas is generally associated with spontaneous combustion of the coal seams (see Section 6.2). Indeed, the presence of carbon monoxide has long been used as an indicator of the probable presence of an in-seam heating or combustion.

Carbon monoxide is normally found in low levels, at a few ppm, in abandoned mine workings which does not represent a risk to health. However, the Coal Authority has found carbon monoxide at one location, at a level of about 200ppm where historically there had been spontaneous combustion. This suggests that carbon monoxide could remain for substantial periods underground. In contrast, carbon monoxide has a lifetime of about four months in the general atmosphere.

Carbon monoxide is toxic at very low levels. The LTEL for CO is 30ppm and the STEL is 200ppm. For

further details see the Table in 6.2, but severe effects will result from spending short times in concentrations as low as 0.1% v/v (1000ppm).

The density of carbon monoxide is 1.25 kg/m^3 , but because it is generally found in low concentrations, it does not have any effect on the physical behaviour of the gas, such as layering.

5.1.6 Hydrogen Sulphide (H_2S)

The principal characteristic of hydrogen sulphide is its smell, which may be perceived at levels as low as 0.003 ppm. The short term exposure limit for H_2S is 10ppm and the long term exposure limit is 5ppm.

Hydrogen Sulphide is produced either as a by product of degradation of organic material or due to the action of acidic mine water on sulphide materials, such as pyrites. Hydrogen sulphide is highly soluble in water and dangerous conditions can arise from gas release due to disturbance of standing pools containing saturated solutions of the gas. It is heavier than air and although flammable, at between 4.3% – 46% v/v, its principal danger is its toxicity.

Although very pungent at first, it quickly deadens the sense of smell, so potential victims may be unaware of its presence until it is too late. The gas is toxic and is likely to result in unconsciousness at concentrations over 250 ppm and death at over 1000 ppm.

5.1.7 Hydrogen (H_2)

Hydrogen is not normally encountered within abandoned workings although it has sometimes been found where there have been signs of spontaneous combustion. Hydrogen can also be formed by concrete when aluminium is part of the admixture when, for example, incinerator bottom ash is used. Hydrogen may be produced from the dissociation of water (H_2 and O_2) if used in an attempt to put out a spontaneous combustion fire, resulting in an explosion.

The principal danger of Hydrogen is that it is explosive in the range 4% to 75% v/v in air.

5.1.8 Other Gases

- Although methane is the principal hydrocarbon gas found in mine workings there will also be lower levels of other **alkanes** especially **ethane** (C_2H_6). Because the concentration of ethane is usually about two orders of magnitude less than that of methane it does not represent a significant increase in risk. However, it affects infrared methane detectors disproportionately and so, where present, it can give misleading readings which are too high.
- **Radon** is an inert but radioactive gas which is derived from the decay of naturally radioactive elements in the strata. The problem from radon arises from its daughters which are other radioactive elements produced as a result of the decay chain and which can become deposited in the lungs. In operating mines the build up of radon is prevented by ventilation of the mine which dilutes and removes the gas from the mine. In closed workings, there is a potential to build up levels of radon although radon's half life is only 3.8 days. There is limited information on the general levels encountered within old workings and it will depend on the types and composition of rocks exposed by mining. However, some measurements from metal mines suggest that radon levels can be measured in the tens of thousands of becquerels per metre cubed (Bq/m^3).

The principal risk from radon is lung cancer, usually as a result of prolonged exposure to elevated levels of the gas in homes or workplaces, caused by emissions from radioactive decay in the underlying rocks. The risk is a combination of the level of radioactivity with the exposure time. The Health Protection Agency recommends that radon levels should be reduced in homes where the average is more than 200 Bq/m^3 over a 12 month period. The target level of 100 Bq/m^3 is the ideal outcome for remediation works in existing buildings and protective measures in new buildings. In a drilling context, prolonged exposure is unlikely, due to the limited times when drillers are likely to encounter undiluted airflows from mining voids and therefore the risk will be low. For example, continuous acceptable exposure (100 Bq/m^3) in a building for one year would be about 50 million

Bq.minutes/m⁻³, whereas 10 minutes exposure to say 50,000 Bq/m⁻³ would be 500,000 Bq.minutes/m⁻³ or 100 times less. Where these instances do occur it is likely that other mine gases, created in stagnant mine atmospheres, will also be present and detectable.

5.2 Table of Characteristics and Effects of Toxic Mine Gases

GAS	CHARACTERISTICS	CONCENTRATION		EFFECT
		% v/v	ppm	
Oxygen	Colourless and odourless	21	210,000	Normal Atmospheric Concentration
		17	170,000	Heavier and faster breathing and possible impaired judgement
		16	160,000	The first signs of hypoxia appear
		15	150,000	Dizziness, buzzing noise, headache and blurred vision may develop
		12 -16	120,000 - 160,000	Breathing and pulse rate increases; muscular coordination impaired
		10 -12	100,000 - 120,000	Emotional upset and abnormal fatigue on exertion are evident; a person may remain conscious
		6 -10	60,000 - 100,000	Nausea and vomiting may occur; victims may lose consciousness
Methane	Flammable, colourless and odourless	5	50,000	Lower Explosive Limit in air
		15	150,000	Upper Explosive Limit in air
Carbon Dioxide	Colourless, sharp odour, sour taste. Toxic.	0.5	5,000	LTEL
		1.5	15,000	STEL
		5.0	50,000	Breathing laboured
		7 - 10	70,000 - 100,000	Unconsciousness after a few minutes; a high concentration will eventually cause death
Carbon Monoxide	Colourless and odourless. Highly Toxic	0.003	30	LTEL
		0.02	200	STEL
		0.04	400	Headache and discomfort with possibility of collapse after 2 hours at rest or 45 minutes work
		0.12	1,200	Palpitations after 30 minutes at rest or 10 minutes work
		0.20	2,000	Unconsciousness after 30 minutes rest or 10 minutes work
Hydrogen Sulphide	Smell of rotten eggs. Highly Toxic	0.0005	5	LTEL
		0.001	10	STEL
		0.003	30	Eye irritation
		0.005 - 0.015	50 -150	Irritation of eyes and respiratory tract, leading to nausea, vomiting and headaches
		0.015	150	Olfactory (sense of smell) fatigue occurs
		0.1	1000	Immediate unconsciousness
Hydrogen	Flammable, colourless and odourless	4	40,000	Lower Explosive Limit in air
		75	750,000	Upper Explosive Limit in air
LTEL - Long Term Exposure Limit (8 hour) STEL - Short Term Exposure Limit (15 minute)				From EH40 Occupation Exposure limits, HSE

5.3 Spontaneous Combustion ('Spon Com')

Spontaneous combustion of coal is the process where coal catches fire without an external heat source. Spontaneous combustion usually occurs in coal as a result of air flowing over it. Coal will oxidise in the presence of air releasing carbon dioxide and, importantly, heat. Where the flow of air is insufficient to carry away the generated heat the coal will warm and increase the rate of oxidation. In this way the coal's temperature can increase until it auto-ignites. However, where the airflow is very low there will be insufficient oxygen for oxidation and the process will be stopped. The process of spontaneous combustion therefore requires sufficient air to allow oxidation/combustion, but not so much as to cool the coal.

Spontaneous combustion of coal is most often associated with former coal workings. In operating mines it is usually found in collapsed ground, which contains coal, or in fractured coal around roadways. In these situations it is the replenishment of potentially oxidising gas conditions by ventilation air in the workings which allows continued heating. It is also found where coal outcrops at the surface especially where it has been disturbed by mining operations which allows air to come into close contact with the coal.

As the temperature of the coal increases, gases other than carbon dioxide are produced. These include hydrogen, higher hydrocarbons and carbon monoxide. Carbon monoxide is produced in conditions of incomplete combustion caused by a limited supply of oxygen. These gases are produced, albeit at lower concentrations, at temperatures well below those at which the coal actually catches fire.

There appears to be very little in the literature regarding spontaneous combustion of coal in air flush boreholes. Nevertheless, details of known examples of this happening, along with anecdotal evidence, suggest that there have been potentially many other cases where such events have not been reported.

The production of spontaneous combustion, or heating, of coal by air flush drilling is probably a combination of two factors. These are the production of heat by the mechanical action of the drill on the coal and the oxidation of the coal due to the injected air. The presence of broken coal and fines may also increase the rate of oxidation as it is a surface process and comminution of coal leads to an increase in its surface area.

Whatever the cause, ignition of a coal seam can have dangerous consequences. Where associated with underground workings there is a danger of the fire spreading through the workings and threatening the safety of any properties lying above them. There is also the potential to spread hazardous gases, including carbon monoxide, through the workings to locations where they might escape at the surface, especially up dip.

A list of seams which have had incidents of spontaneous combustion in the past is available on the Coal Authority website at <http://coal.decc.gov.uk/en/coal/cms/services/permits/permits.aspx>. However this list is by no means comprehensive and some of these incidents have occurred within deep mines where the condition of the coal may be materially different to its condition when near the surface. It should not be assumed that because a seam is not on the list it is not capable of spontaneous combustion.

5.4 Atmospheric Pressure

Atmospheric pressure is usually the most important factor controlling the movement of gases within abandoned mine workings. Where water levels are rising within an area of workings gas will be displaced and potential pressurisation can occur. Nevertheless, even in these circumstances changes in atmospheric pressure can still have an effect on the movement of gas and the concentrations of gas in the workings.

If the atmospheric pressure falls below that in an abandoned mine and there are connections between the mine and the surface then there will be a flow from the mine to the surface, until the pressure becomes equal. If the connection to the surface is good, which is most common for shallow workings,

then the pressure in the mine is usually close to atmospheric pressure and the rate of emission from the mine is related to the rate of fall in atmospheric pressure. The time of greatest risk of surface emissions of mine gas is therefore when deep depressions are moving across the country where pressure fall rates of 4mb/hr are possible.

Rising atmospheric pressure, by the same argument, will tend to push air into the workings. In this case, the air will either dilute the pollutants or completely displace them in a zone close to the point of ingress. On falling pressure, gas from deeper in the mine will displace any fresh air drawn into the mine, but may still contain atmospheric air as part of its composition.

If the connection to the surface is poor, which is the usual case with deeper workings, the rate of flow will be related to the difference between atmospheric pressure and the pressure in the mine. Such differences can be substantial, especially where pressurisation due to rising mine water is present.

5.5 Migration and Pathways

5.5.1 Migration

The concept of migration of gases due to pressure differences and the existence of connections between workings and the surface were raised in the previous section. Pressure differences may be produced by:

- Rising water levels.
- Atmospheric pressure.
- Differences in gas density.
- Injection of fluids and gases.

The first two have been discussed already. The movement of gas due to differences in density is sometimes referred to as natural ventilation. Where there are two points of access to a mine void and the density of the gas in the void is higher than that of the atmosphere then, due to gravity, the denser air will flow from the lower connection and draw fresh air into the higher connection. If, alternatively, the density of the gas in the void is lighter than that of the atmosphere, then, by gravity, the atmospheric air will displace the lighter air by entering by the lower connection and forcing the lighter mine gas out of the higher connection.

The density of the gas will be a function of its temperature and composition. The density of a gas will decrease as its temperature increases, which means that warmer air tends to rise. The density of a gas mixture is made up of that of its constituents, so if it contains gases of a lower molecular weight its density will tend to be lower. For example, mine atmospheres with high levels of carbon dioxide are likely to be more dense than the surrounding atmosphere. Nevertheless the effect of temperature can be important. Because the mine atmosphere is less prone to temperature change, but the outside temperature can change substantially, especially overnight, the flow of gas from the mine can vary over a 24 hour period or even reverse.

The most likely case where fluids are injected into workings is during drilling or piling operations where air or water flush drilling are utilised. The extent to which injection of fluids, such as air and water, into workings will influence the movement of the mine atmosphere will be a function of the flow of the fluids, the void volume and the resistance to the flow.

Where there is a very large open interconnected void the induced pressures are likely to be small and this has been borne out by experiment. However, if the connected void is small it is possible that it could become pressurised. In the case of air flush, the maximum pressure will be the back pressure exerted by the resistance of the air returning up the annulus between the drill string and the side of the drilled hole. In the case of water flush, higher pressures could be exerted if void volumes were very small and the volume of water injected was to fill a significant portion of it.

In comparison the low pressure and relatively low flow methods employed in open or closed bore

piling techniques do not lend themselves to ground pressurisation.

Areas of broken ground, although offering greater resistance to flow, will also allow better transmission of pressure over short distances as the pressures can less easily dissipate.

Beyond pressurising the workings the injection of air or other materials will also displace gas within the workings, potentially moving dangerous gases into places they did not previously occupy. In general, air flush, as it uses much larger volumes, has a greater potential to displace mine gases over larger distances. Measurements to date have shown that normal air flush drilling is capable of having an effect on the gases in voided mine workings at distances up to 60m although flows were low (see Case Study 4)

5.5.2 Pathways

Pathways between mine workings and the surface can be of a number of forms although they are all weaknesses within the intervening ground which present a lower resistance to movement of gases. The mine workings themselves also represent a pathway through which gas can move considerable distances.

Examples of pathways are:

- Mine entries (shafts and adits).
- Shallow mine workings.
- Previous boreholes.
- Water wells.
- Service ducts and trenches.
- Faults / break lines.
- Permeable strata.

The most obvious form of pathway is a shaft or an adit constructed to access the workings. Although such mine entrances are usually filled to some degree, they may still represent a weak point through the strata due to containing permeable fill. Gas is also able to move along the interface between the strata and the lining of the mine entry.

Collapses of ground over coal workings are also a potential route for gas migration. In some cases the movement of the developing void to the surface may not be complete, but the weakening of the strata may be sufficient to allow movement of gas. In general, fracturing of the strata, either mining induced or natural, such as faults, are potential lines of weakness which can provide pathways.

It should be noted that, where it is unknown whether pathways exist, the risk assessment must err on the side of caution and assume that they might be present. As such a layer of clay in the superficial deposits cannot be classed as impermeable if it is not known whether pathways exist.

Where mine gas gets close to the surface it has the potential to run through ground which might have a higher permeability than the natural ground surrounding or underlying it. Examples are made ground and service runs.

Colliery spoil as placed is frequently high in sulphides. Upon exposure to air and moisture these have the potential to generate significant sulphate and low pH conditions which are aggressive to concrete. Over time the corrosion of piles formed using concrete may, in addition to detrimentally affecting load bearing characteristics, lead to the formation of a new pathway. It is therefore important to design the concrete to resist such attack.

5.6 Monitoring and Testing

Refer also to [Section 10.5](#)

5.6.1 General

If carrying out works or investigations in areas which may be affected by mine gas, then suitable safeguards must be in place to ensure a safe working environment. The risk assessment for the drilling operations should identify any significant risks from gas and should make sure that a suitable drilling method is being used along with adequate testing and monitoring procedures and that the appropriate equipment is in place before commencement of operations.

Monitors are readily available which will detect the gases described in Section 6.1 and alarm if trigger gas levels are exceeded. The most likely gases to be encountered are methane and carbon dioxide (usually associated with low oxygen). An ability to measure carbon monoxide can also be of great benefit in identifying potential spontaneous combustion. **This guide recommends that monitors / alarms should routinely sample for carbon dioxide, carbon monoxide, methane and oxygen.** The presence of hydrogen sulphide is very rare and is apparent by its smell even at very low levels.

All gas monitors being used need to be calibrated and tested with copies of supporting certificates available on site. Provision needs to be made to ensure that monitors are operational at all times whilst in use on site.

When using gas monitors, it is important to remember that monitors measure gas properties and not the gases directly. Because of the nature of the gas detection cells, some gases can affect cells other than those for which they were designed. This cross sensitivity effect can cause monitors to provide false readings. Some examples of this are:

- Infrared methane cells will also record ethane, and other hydrocarbons, at an enhanced level. This means that small levels of ethane mixed in with methane will show methane levels potentially well in excess of actual levels.
- Electrochemical cells used to detect gases such as oxygen, carbon monoxide, hydrogen and hydrogen sulphide often show cross sensitivity to the other gases. Known examples include both hydrogen and an unsaturated hydrocarbon (e.g. ethyne/acetylene) registering as carbon monoxide and resulting in a misdiagnosis of the particular problems encountered.
- Pelistors, sometimes used to detect methane, are also cross sensitive to other flammable gases, so that hydrogen will register as methane.

When unusual readings are being detected during operations and cross sensitivity is suspected another instrument using a different type of cell may help, but laboratory analysis of a gas sample will be required to provide certainty.

5.6.2 On Site monitoring

Gas monitors may be carried by individuals or a single monitor placed in a suitable position, where appropriate. The key guideline for siting monitors and alarms is that they must be located close to those who might be affected. For example, on a drilling rig the monitors should be sited close to the drill string and the operators, to ensure that the atmosphere being tested is the same as that to which the workers are exposed.

A monitoring regime needs to be designed to address the works being undertaken. The following are suggested criteria:

- a) When drilling in confined spaces where pathways exist or potentially exist into underground workings (e.g. mine entries and boreholes), continuous monitoring in the working area close to the source is recommended. Additionally, further tests should be carried out to check for layering of cold gas or blackdamp at ground level or methane in the roof of an enclosed area or at any open boreholes within the confined space. Exit routes from the confined space should be well defined,

clear of obstruction and identified to those working in the confined space. Evacuation should take place in these circumstances, in the first instance, at gas concentrations at the trigger level rather than the action level due to the enhanced risk in these situations.

- b) When drilling boreholes into shafts or mine workings, for the purposes of investigation, grouting etc, the following points should be considered:-
- Continuous monitoring at the drilling rig location (with appropriate alarm) at 1.2m height near the drill string.
 - If steel casings are being inserted and welded, then prior to each section of casing being attached, the contractor needs to monitor for gas within the mouth of the casing. The main risk is an explosion of flammable gas caused by contact with a flame. It is suggested monitoring 0.5m down the casing to obtain a meaningful reading. It is also suggested that any other adjacent boreholes should be monitored for flammable gas to indicate whether there is any in the immediate vicinity before drilling commences.
- c) Boreholes which are left open temporarily for operational reasons (see **d** below) and which are in contact with workings, represent a potential route for gas and so should be checked periodically for potentially hazardous conditions. The interval for inspections should be based on the findings of the initial and ongoing risk assessment. It should be remembered that gas composition can change with time due to atmospheric pressure effects.
- d) When a series of holes are being drilled such as when mine workings are being grouted or on a piling scheme prior to cast then pathways (boreholes) can be left open for short periods until the grout is injected or the concrete is poured. However the time between drilling and sealing should be kept to a minimum and where these two operations cannot be achieved concurrently temporary caps or bungs should be inserted into the hole.
- e) Air flush drilling is the technique most likely to displace gases which may emit from adjacent pre drilled holes, or other pathways to the surface.

Monitoring of specific perimeter holes is unlikely to protect properties adjacent to the site. Whilst these holes may intersect mineworkings, other unconnected mineworkings and pathways may exist elsewhere.

All parties involved in the works need to be aware of atmospheric conditions and realise that under falling or low atmospheric pressure, gas more readily emits from the ground (usually during adverse weather conditions).

The following table suggests trigger levels of gases, measured within the general working area, at which the drilling supervisor should be informed and he/she should make an assessment of the situation and determine suitable actions to take. The table also includes suggested action levels where drilling should cease and all personnel withdrawn from the affected working area. If withdrawal takes place there should be no return to the affected area until a competent person has investigated and assessed that it is safe to do so. Methane has a low suggested trigger level, because it is rarely contacted and is a particular danger due to its explosivity. Oxygen has a suggested trigger level of 19% v/v as the effects are unlikely to be felt, but it is very close to 17% v/v at which effects are likely to be felt. The action level has therefore been set at 18%. The carbon monoxide Action level has been suggested as 100ppm rather than the STEL to take some account of the cumulative effects of the gas. The trigger level for hydrogen sulphide has been suggested as 1ppm which, although only 20% v/v of the LTEL, would represent a very strong unpleasant smell.

Gas	Trigger Level	Action Level
Methane	≥0.1% v/v	≥1% v/v (20% LEL)
Carbon Dioxide	≥0.5% v/v (LTEL)	≥1.5% v/v (STEL)
Oxygen	≤19% v/v	≤18% v/v
Carbon Monoxide	≥30 ppm (LTEL)	≥100ppm (50% STEL)
Hydrogen Sulphide	≥1ppm (20% LTEL)	≥5ppm (50%STEL)

5.6.3 Off Site Monitoring

There will necessarily be less control over off site locations, because they will be in land owned by others. A risk assessment should be carried out, based on a **source – pathway – receptor** model (see [section 9.2](#)), to determine whether there is a medium to high risk of gas migrating off site which might cause harm. If so the working method should be reviewed to determine whether the risk can be reduced. If not, then the contractor should arrange for monitors to be installed in adjacent, off site, occupied buildings which are assessed as being at risk.

Off site monitoring will normally be in the form of alarms to provide immediate warning to those potentially affected. All those provided with alarms should be provided with clear instructions on what to do in the event of an alarm sounding. The precise actions will vary with the type of risk, but the instructions should set out:

- What they should do to make themselves safe in the first instance.
- Who they should contact for further assistance. During operations this should be the site supervisor, but there should also be an out of hours contact in case of problems after work has stopped on site. The out of hours contact should be able to arrange for someone to quickly attend the site to investigate the problem.

Alarms could be backed up with monitoring by staff visiting properties at intervals during the day and/or by continuously monitoring and logging results using a suitable instrument to provide a full picture of conditions during the full period of working including out of hours.

Depending on the particular risks, suitable alarms will be flammable gas alarms, carbon monoxide alarms and carbon dioxide alarms. The first two are available through retail outlets, but carbon dioxide alarms are usually more expensive and need to be obtained through specialist suppliers. In all cases the alarms should be calibrated where appropriate and within their approved lifetime.

6. The Influence of Flush and Injected Materials

6.1 Introduction

Any material that is injected into mineworkings will have the effect of displacing any gas that is already present within the workings. The amount of gas displaced will depend upon the volume of the displacing agent being injected.

The selection of a particular drilling fluid is normally based on the formations to be drilled, required fluid functions for the selected drilling process and method, fluid efficiency and cost (including disposal) and its contribution to productivity. Part of the selection process shall also include whether it will have harmful effects on persons, property or the environment – either directly or indirectly.

Before final selection of a particular drilling fluid, the project risk assessment shall consider whether hazardous gases are likely to be present; could be created, or could be mobilised to cause harm by any of the preferred drilling fluids. A selected drilling fluid shall eliminate or minimise the risk of harm.

The flushing mediums most generally used are air and water. Beyond the potential oxidisation of the coal, using large air volumes also has the capability of displacing large volumes of gas, as large pressures are required to flush out the spoil from the hole. Nevertheless, air can be more practical where water supplies are limited.

Conversely, water will have a cooling action and displace much smaller volumes of hazardous gases. It does have the disadvantages that a water supply needs to be available and in weak strata can cause erosion of the borehole. Although rare, the use of water has also been known to precipitate mine working collapses in nearby ground due to the washing out of supporting material.

Whilst the highest degree of displacement during drilling will come from the injection of compressed air, the effect of inserting large volumes of non compressible materials, such as grout, should also be considered.

6.2 Drilling Fluid

Drilling Fluid is a fluid circulated through the in-hole drilling assembly. Its basic constituent may be air, water or oil or a combination of these. Main functions include carrying the cuttings from the drill bit to surface; cooling and cleaning the drill bit; suspending the cuttings; reducing friction between the drill rods and the sides of the borehole; stabilising the borehole, and preventing fluid loss to the formation. The drilling fluid may also have the function of transmitting power to a bottom hole drilling tool e.g. DTH hammer, mud motor etc.

Many types of drilling fluid are used but they generally fall into a few broad classifications and variations.

6.2.1 Air Flush

Compressed air is often chosen as the drilling fluid for rotary and rotary percussive drilling methods. It is supplied generally by mobile compressors, either owned or hired in by the drilling contractor. Some rigs have compressors mounted on board e.g. quarry and large waterwell rigs. It is efficient in cleaning the hole due to its self expanding property but has a low specific gravity of close to zero.

To effectively flush the borehole the compressor must supply a sufficient volume of compressed air at an adequate pressure. The compressor capacity that is necessary is a function of the uphole velocity required to lift the cuttings to surface. An optimum uphole velocity is approximately 1200 metres / minute but will vary depending upon cutting size and density. If the drill bit produces large, high density cuttings then either the uphole capacity has to increase i.e. larger compressor required or the cuttings will be reground by the bit to a smaller size for uplifting.

Uphole velocity is calculated with reference to cutting size and density; annular space between rod outside diameter and hole diameter, and compressor free air discharge (FAD).

Note: Discharge volumes of compressed air i.e. compressor volume rating are always given as FAD which means that the air will occupy equivalent volume when the air pressure drops to that of standard atmospheric air.

Air Flush - hazardous gas risk assessment - Factors to be considered are:

- Fire needs an ignition source. Will the drill bit generate heat and / or sparks to cause ignition of coal? Air is not particularly effective as a substantial coolant.
- Will the introduction of compressed air (which contains oxygen) fuel a fire e.g. coals already smouldering or liable to spontaneous combustion thus having the potential for creating hazardous gases?
- Air heats up when compressed. Compressors cool the air before discharge and normally have a discharge temperature gauge. Is the air delivered to the drill bit of sufficiently low temperature to cool the bit i.e. is the compressor working correctly?

- High volumes of compressed air will expand into voids e.g. old workings, broken ground etc. and may displace / drive existing hazardous gases in those voids. Where and how far will those gases be displaced to?
- Is the compressor of a greater capacity than required to achieve sufficient uphole velocity? If so more air than necessary may be being introduced into the formation. This may be achieving greater drilling productivity at the expense of driving hazardous gases further away from the borehole.
- Does the Coal Authority normally allow the use of this drilling flush for the type of project and the strata that is to be drilled?

6.2.2 Air Mist Flush

This is a variant of air flush. The principal constituent of the drilling fluid is still compressed air but water is added to increase the fluid viscosity, provide more cooling, assist in dust suppression, and provide a little more lubrication. A water injection pump injects small amounts of water into the compressed air delivery hose thus raising the specific gravity of the drilling fluid to about 0.2.

Because the air mist drilling fluid has higher viscosity than air it is more capable of “lifting” cuttings than compressed air. Cuttings of similar size and weight will not require the same uphole velocity as that required for air flush given that everything else is equal. Compressor capacity to generate the lower uphole velocity will therefore be less. One reason that air mist is selected for coring, for example, is that with the decrease in velocity at the bit face there is less erosion of the core.

Air Mist Flush - hazardous gas risk assessment - Factors to be considered are:

Those in 8.2.1 Air Flush as above plus the following:

- What safeguards are to be employed if the water injection pump fails or the water supply is cut off?

6.2.3 Foam Flush

This is a variant of air flush in that the principal constituent is compressed air. However it can be considered to be a significant improvement in safety terms in that a significantly smaller capacity compressor is employed. Foam flush has the benefit of reducing the uphole velocity to as little as 15 metres / minute due to its great cutting carrying capacity.

Air is combined with a foam fluid. The latter comprises a small quantity of water and foaming agent which is prior mixed and then injected into the compressed air delivery hose by an injection pump. The ratio of foam fluid to air is about 1:150, and foam fluid usually consists of about 1% by volume of foaming agent mixed with water. The foaming agent may incorporate high molecular weight polymers which increase the foam bubble strength. The consistency of the foam flush is much like shaving foam when it emerges from the top of the borehole. It has an interlocking bubble structure of encapsulated air that provides its high lifting capacity. Some skill is necessary to adjust the consistency – too little foam fluid injection will result in the bubble structure not being formed and thereby loss of cutting carrying capacity.

One major disadvantage is the volume of foam that emerges at surface. This takes time to settle and drop its cuttings unless sprayed with water. Handling of the foam / cuttings waste is a major exercise which may explain why it is not more generally used especially in high production open holing.

Foam Flush - hazardous gas risk assessment - Factors to be considered are:

- In general, foam flush when done correctly does not comprise the risks associated with air flush or air mist flushing with regard to hazardous gases.
- However there is the possibility that incorrect operation will effectively convert the flushing into air mist or air flush. This may happen if the mixing of the foam fluid is done incorrectly e.g. foam fluid is omitted or insufficient. It could also occur if the injection pump fails. Incorrect operation will

usually be detected fairly quickly as no foam will emerge at the surface.

- Environmental considerations and COSHH assessments.

6.2.4 Water Flush

Water by itself is often used in drilling. Being far more viscous than air it can lift cuttings at an optimum uphole velocity of 30 metres / minute, some 40 times less than air. A water flush pump is employed with capacity suitable to obtain this velocity for the specific drilling application. The capacity will vary between 45 litres / minute up to approximately 220 litres / minute. The water flush pump will also be able to generally provide up to 50 bar pressure.

While water is readily available in developed locations and relatively cheap, it does have the disadvantage of being expensive to provide in locations at relatively short distances from the water network. Unlike air flush and air mist it also has greater problems of control, containment and waste management on emergence from the borehole. It can be re-circulated in that the borehole returns are taken to cutting settling pits or tanks and the water (less cuttings) is then pumped back into the drill rods.

Water Flush - hazardous gas risk assessment - Factors to be considered are:

- Water flush is a major coolant and therefore the drilling bit will remain relatively cold during drilling. It will also have the effect of damping any sparks.
- Water flush will not contribute to the creation of hazardous gases as air is not being introduced into the unworked coal or coal workings.
- Water flush is non compressible and will therefore only displace a volume, equivalent to its own, of gases that may be present within any voids or broken ground.

6.2.5 Mud Flush

Mud flush for the purpose of this guidance is the combination of adding any substance, other than foaming agent, to water to improve the latter's capabilities during the drilling process. The substances may be naturally occurring e.g. bentonite, and / or naturally occurring polymers e.g. starches, guar gum etc., and / or synthetic polymers. There may be other chemicals e.g. potassium formate introduced into mud flush to achieve various effects. This guidance does not consider oil-based mud or synthetic-based mud, both of which are employed mainly in off-shore oil and gas operations.

Mud flush involves the mixing of substances with water and should be performed in accordance with the manufacturer's / supplier's recommendations. This will often include mixing plant. The mud drill fluid is then supplied to a mud pump which pumps the fluid into the drill rods (or borehole annulus on occasions). Mud flush is mainly selected because it has a high density which permits a low uphole velocity, and obviates the need for casing because it prevents hole collapse; prevents fluid loss to the formation, and is economical in use with re-circulation.

Mud Flush - Hazardous Gas risk assessment - Factors to be considered are:

- Mud flush is a major coolant and therefore the drilling bit will remain relatively cold during drilling. It will also have the effect of damping any sparks.
- Mud flush will not contribute to the creation of hazardous gases as air is not being introduced into the unworked coal or coal workings.
- Mud flush is non compressible and will therefore only displace a volume, equivalent to its own, of gases that may be present within any voids or broken ground.
- Environmental considerations and COSHH assessments.

6.2.6 Summary - Drilling Fluid Influence

In conclusion, the selection of any drilling fluid with regard to hazardous gases is of prime importance. The "lighter" drilling fluid of air flush has the greatest potential to provide conditions for the ignition and

/ or support of an underground fire creating hazardous gases and / or the displacement / mobilisation of existing underground hazardous gases. Air mist shares some of the same potential but if well controlled is not considered to be a major risk. Foam flush contains a very slight risk if not controlled but is unlikely to create a hazard. Water and mud flush will have a negligible effect and can therefore be classed as having minimal risk.

6.2.7 Table of Risks for Different Drilling Scenarios						
Situation	Air flush	Mist flush	Foam flush	Water flush	Mud flush	Additional controls
- Unworked coal or coal workings - High or unknown risk of hazardous gases being present / created - Occupied property within risk area	HIGH	HIGH / MED'M	HIGH / MED'M	LOW	LOW	- Monitoring at rig and other open holes. - Seal boreholes as soon as possible.
- Unworked coal or coal workings - High or unknown risk of hazardous gases being created or displaced - NO occupied property within risk area	MEDIUM	MED'M / LOW	MED'M / LOW	LOW	LOW	- Monitoring at rig and other boreholes. - Ensure materials are on site to extinguish any heating - Seal boreholes as soon as possible.
- Unworked coal or coal workings - Defined low risk of hazardous gases being present / created - Occupied property within risk area	MEDIUM	LOW	LOW	LOW	LOW	- Monitoring at rig and other open holes. - Seal boreholes as soon as possible.
- Unworked coal or coal workings - Defined low risk of hazardous gases being present / created - No occupied property within risk area	LOW	LOW	LOW	LOW	LOW	- Monitoring at rig and other open holes. - Seal boreholes as soon as possible.
Key / Notes						
High / High Medium drilling operations should not be undertaken if there is a safer, practicable, alternative. Stringent control measures, such as monitoring inside occupied properties within the risk area, would be required to mitigate this level of risk to an acceptable level.						
Medium / Medium Low drilling operations can be undertaken but only with sufficient control measures to ensure that the work can undertaken without endangering the public or the workforce.						
Low risk drilling operations can be undertaken with standard control measures i.e. monitoring for hazardous gases at the drill rig						
This table provides general guidance and does not and cannot represent every circumstance. Each drilling operation must have a unique, robust and appropriate risk assessment and this table should not be used as a substitute for this.						

6.3 Grout and Other Filling Materials

Most bulk infilling of mine working voids and broken ground is undertaken with grout. However, expanding foams are becoming more prevalent for smaller voids. Most grouts are essentially non-compressible and will therefore displace and move volumes of gases that are equal to the amount of fluid injected. Where grout is being used as bulk filler the volumes injected can be quite considerable.

With grout introduced through a gravity feed it is possible that any displaced gas will eventually migrate back to the surface through weaknesses or boreholes and as the process of infilling is gradual the effects are likely to be negligible. However if gases become trapped by the grout they could become pressurised and force a route to the surface. Grouting is usually carried out from the 'down dip' side of the site in an up dip direction which will displace any gases in an 'up dip' direction. Properties on the 'up dip' side of the site could therefore face an increased risk at this time and this should be accounted for in the risk assessment. The creation of a grouted perimeter curtain around the site could limit the 'off site' movement of any gas and allow for controlled 'on site' venting of any displaced gas.

Pressure grouting could also have the effect of pressurising and mobilising any gases within the voids, driving them to the surface, should a suitable pathway exist. Grout injected into the workings via a tremie with an open annulus between it and the casing could provide a preferential pathway back up the injection hole for any displaced gases.

Foaming agents are designed to expand as they are injected and will initially displace gases in a similar way to pressure grouting. However its use within former coal mine workings is generally limited to surface based collapses at the moment.

It should be noted that sand or aggregate may need to be strategically placed in mine workings as a barrier prior to the injection of grout. It is unlikely that the placing of these materials will have any substantial displacing effect on the mine atmosphere.

The potential hazards involved with the injection of any bulk filling material should always be considered as part of the risk assessment.

6.4 Piling

It would be good practice for any mine working stabilisation work, using grout injection, to take place in advance of any piling technique. Piling can be split into three global groups, open bore, closed bore and driven methods. Where the method involves the introduction of uncured concrete to the bore it should be remembered that this operation is carried out at relatively low pressures when compared with grouting; analogous to gravity feed methods. Secondly the concrete consistency used is relatively low in comparison. It should be noted that piling methods will only have the potential to act as a pathway when they come into contact with existing closed or open pathways. Should the technique remain within a zone unaffected by pathways, for example where a significant thickness of impermeable strata exists between the piling works and any mine workings, then no potential for ingress of gas exists.

6.4.1 Open bore piling

Sometimes known as bored or segmental flight auger, the boring and concreting are two distinct parts of the operation, As such in the time between boring or augering of the void and concrete placement there may be a period where the pile is left open and the possibility of a temporary pathway dependant upon conditions, especially if temporary or permanent casing is used.. Where pile holes are in contact with unworked coal or mine workings they should be temporarily plugged or sealed at the earliest practicable opportunity pending permanent sealing when the concrete is introduced,

Open bore piling - hazardous gas risk assessment - factors to be considered are:

- Will the introduction of atmospheric conditions containing oxygen during the open bore phase fuel

a fire?

- Are the gases likely to vent through the open bore?
- Once concrete has been introduced the pathway will close.

6.4.2 Closed bore piling

Continuous Flight Auger and auger displacement piling form part of this category. The operation differs from the above in that once at the required depth, concrete is introduced to the base of the bore under pressure and the tool only withdrawn when sufficient head of concrete has developed around the tool which effectively protects the pile from the ingress of gases. This operation continues until the pile is fully cast to final level. It is not anticipated that a significant pathway exists during this operation provided that sufficient head of concrete is present to outweigh any gas influx.

Closed bore piling - hazardous gas risk assessment - factors to be considered are:

- Closed bore piling will not contribute to the creation of hazardous gases as air is not being introduced into the unworked coal or coal workings.
- The method will only displace a volume equivalent to its own of gases that may be present within any voids or broken ground.
- As the concrete or grout is introduced at low pressure there a lesser risk of gas migration.

6.4.3 Driven piling

This method usually takes the form of using a piling hammer to install preformed elements of either concrete or steel. In the same way casing can allow a pathway to develop so a driven steel tube has an increased potential for gas migration. Precast concrete units do not have this disadvantage. Where the pile driving is protracted due to the slow progress of the pile there is potential for a limited pathway to arise due to the small lateral movement of the pile, known as pile whip.

Driven piling - hazardous gas risk assessment - factors to be considered are:

- Will prolonged pile driving lead to pile whip increasing the potential for a pathway to develop?
- Will prolonged driving of steel tubular sections result in heating of the element sufficiently to aid combustion?
- Will the introduction of the hollow tube allow contact between the mine gases and the atmosphere fuelling a fire e.g. coals already smouldering or liable to spontaneous combustion?
- The method will only displace a volume, equivalent to its own, of gases that may be present within any voids or broken ground.
- Are the gases likely to vent through the hollow section?

7. Coal Authority Permission

7.1 Introduction

During privatisation of the coal industry in 1994 the Coal Industry Act transferred ownership of unworked coal and coal workings, including shafts and adits, (previously vested in the NCB & British Coal) to the Coal Authority. In the interests of public safety and to ensure the proper exchange of relevant information, the Coal Authority, as owners, requires that any activity which intersects, disturbs or enters any of its property interests requires its prior written authorisation.

This authorisation can take the form of a Licence, an Agreement, or a Permit, depending upon the nature of the activity to be carried out.

The following activities may require a Permit and are dealt with by the Authority's Licensing and

Permissions department:

- Site investigation boreholes.
- Treatment of abandoned coal mine workings for ground stability purposes.
- Investigation and treatment of coal mine entries (shafts and adits).
- Piling.
- Geothermal boreholes.
- Water wells.
- Ground anchors.
- Trial pits and other activities which intrude into unworked coal or coal workings.

Incidental digging of coal and commercial coal mining are dealt with by Licenses and Agreements.

7.2 Application Process

Applicants requiring the Authority's permission are required to complete a pro-forma which sets out who is involved, what intrusive activity is being proposed and how any risks are being mitigated. The process also requires that a set of terms and conditions are agreed to which effectively makes the applicant responsible for any adverse consequences which occur to Authority property as a result of their actions for a period of 12 years. As an agreement is being entered into it is expected that applicants should have some interest in the surface property, e.g. owner or developer.

Application forms supported by notes of guidance can be viewed and downloaded at the Authority's web site: <http://coal.decc.gov.uk/en/coal/cms/services/permits/permits.aspx>. Submissions should include the appropriate application fee (see Coal Authority website for current fees. Fees are levied on a cost recovery basis for the running of the service as per Treasury guidelines).

7.3 Requirements

The MHSWR require a suitable and sufficient assessment to be made of the risks to health and safety of their employees to which they are exposed at work. This includes looking at appropriate sources of information, such as relevant legislation, appropriate guidance and seeking advice from competence sources.

HSE consider that it is a reasonably practicable step for companies planning to undertake work in the vicinity of mineworkings to have undertaken a desk study prior to the proposed works. This study should consider the mining circumstances of the site and the immediate surrounding area, based upon, amongst other things, the information contained within a Mining Report available from the Coal Authority and other reputable coal mining information suppliers.

Applicants should reduce risks to public safety arising from their proposed works by considering the layout of proposed works in relation to potential receptors, method of work, inherent hazards of the site, the sequencing of the work and any additional risk mitigation measures.

When considering applications, the Coal Authority will review the coal mining information available and carry out a risk assessment of the proposed works based upon the Source, Pathway, Receptor principle and any proposals deemed to be high risk will be referred back to the applicant for further consideration. Only where the residual risk has been determined to be low or medium will the Authority consider allowing access to its mining estate.

Under no circumstance should any intrusive activities take place which knowingly enter or disturb the Authority's property without its permission. Undertaking works without permission will result in trespass, the potential for court action and could adversely affect property sales. Furthermore home warranty and household insurances could be affected and planning permission may be prejudiced. In the case of an accident occurring, if it is established that a contractor has knowingly

undertaken work which was advised against by a competent authority, or that he has knowingly circumvented authorised schemes designed to ensure safety, this may be seen as an aggravating factor in any potential prosecution of the company.

Upon completion of the proposed works, applicants are required to submit details of the actual site works carried out, in the form of a recommendation, completion or validation report, to the Coal Authority in order that its records can be updated, where required, and the information referred to in its Mining Reports. Site works are considered to be ongoing until this report is received by the Coal Authority.

8. Desk Study

8.1 Elements to be Considered

A desk study should be carried out before any drilling or piling operations take place and should form part of the pre-construction information (PCI). Beyond the normal requirements to establish the location of services, identify any environmental issues etc, the drilling location needs to be assessed for potential risks from unworked coal and coal workings, especially mine gas.

The desk study needs to identify, amongst other things:

- The depth and position of any known or possible unrecorded mine workings.
- Whether the seams are prone to spontaneous combustion. A list of seams that are known to have had spontaneous combustion incidents in the past is available on the Coal Authority's website at: http://coal.decc.gov.uk/en/coal/cms/services/permits/coal_seams/coal_seams.aspx.
- Whether there is a history of mining related gas problems in the area.
- The nature of the strata above the workings including layers of clay and any made or permeable ground.
- Zones of geological disturbance.
- The location of any mine entries.
- The location of any existing properties close to operations.
- Other underground features e.g. ground water levels and mine water levels.
- Are the mine workings dry, flooded or partially flooded with water?

Further information on what is required from a desk study is available through the AGS publication 'A Client's Guide to Desk Studies': <http://www.ags.org.uk/site/clientguides/clientguides.cfm>.

The information gathered from the desk study should be used to formulate a conceptual site model to gain an holistic view of both the surface and the underground environment.

8.2 Sources of Coal Mining Information

The Coal Authority holds an archive of approximately 118,000 old mining plans and a register of approximately 170,000 former mine entries. This information is disseminated to the public via its mining reports service. The information provided by these reports is a fundamental building block for the start of any desk top or other feasibility studies and any risk assessments necessary when planning proposed works.

Furthermore the Coal Authority has defined specific 'Coal Mining Development Referral Areas'. These are areas, based upon Coal Authority records, where the potential for land instability and other safety risks associated with former coal mining activities are likely to be greatest. They include, for example, areas of known or suspected shallow coal mining, recorded mine entries, past surface hazards and areas affected by mine gas. Further information is available at <http://coal.decc.gov.uk/en/coal/cms/services/planning/strategy/strategy.aspx>

The Coal Authority's abandoned mine plans and other mining records can also be viewed, by prior appointment, at its Mansfield offices. Further information is available at <http://coal.decc.gov.uk/en/coal/cms/services/records/records.aspx>

It should be noted however that a significant proportion of shallow mineworkings have no plan record of their existence. There was no obligation on mine owners to make plans and deposit them with the Mines Records Office until 1872 by which time many millions of tonnes of coal had been mined. Furthermore many of the early mine plans are of variable accuracy and standards and their interpretation can require considerable expertise.

As a general rule it should be assumed that if coal of a workable thickness exists then there is a good chance that it may have been mined at some time in the past.

As part of the process of obtaining the Coal Authority's permission to enter or disturb its coal and mining interests, known mining hazards, which may influence the site, will be brought to the attention of the applicant.

Other important sources of information include:

- Ordnance Survey plans.
- Geological plans.
- British Geological Survey.
- Local Authority plans / records.
- Aerial photo's.
- Network Rail / British Waterways.
- Private / Local companies: Mining Reports / Ground Investigations / Geotechnical Consultants / Mining Engineers and Surveyors.
- Public libraries.
- Local History groups.
- Public Records Office.
- Mining and Speleological societies.
- Internet sites.
- Local publications.
- Deputy Gaveler (Forest of Dean).

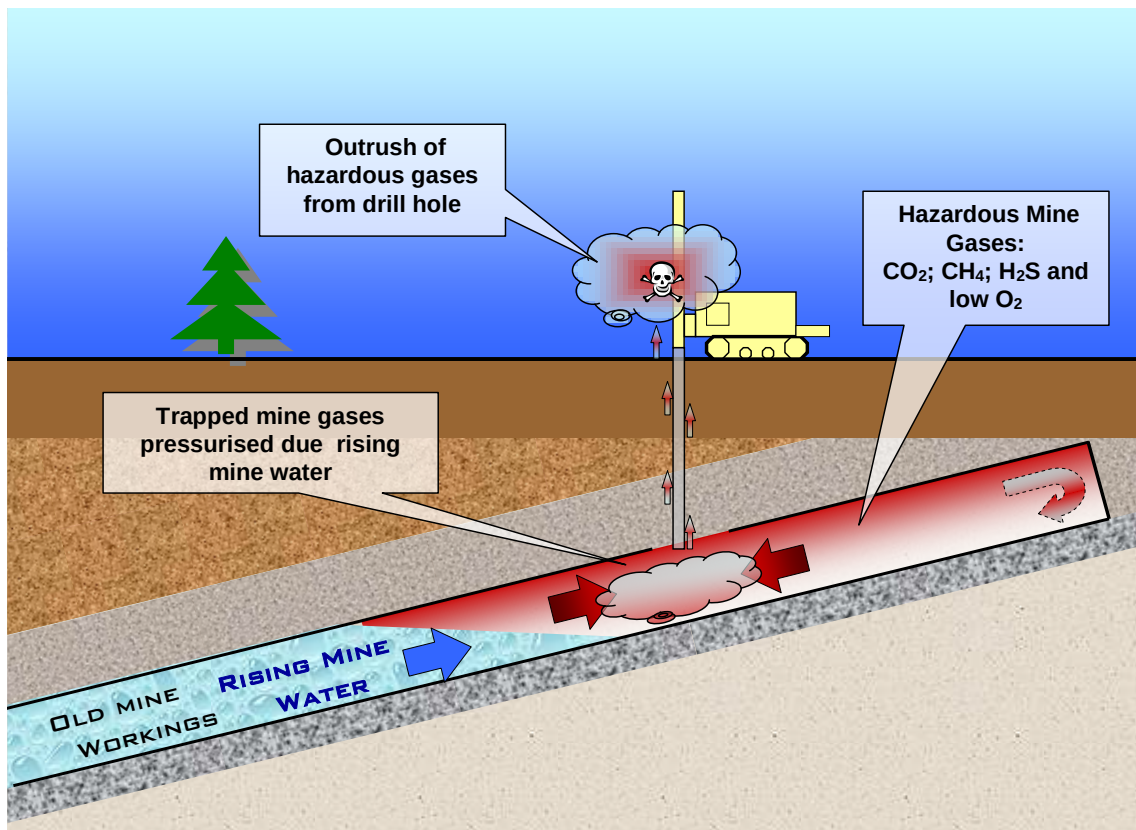
9. Risk Assessment

9.1 On Site Risks

There are three principal hazardous gas risks associated with drilling and piling works. These are:

- Emissions at the rig during or immediately after drilling or piling operations.
- Emissions from previously drilled boreholes and other pathways between the unworked coal and coal workings and the surface.
- Spontaneous combustion of coal (not a gas risk as such, but does present the risk of the creation of carbon monoxide) – [See section 5.3](#).

9.1.1 Emissions at the Rig



Whilst drilling or using open bore or some driven piling techniques, the greatest risk comes from entering a void or permeable ground containing a volume of gas at pressure. In this case there could be an outrush of gas into the working area. The possibility of this is difficult to exclude unless it is known that there are open connections to the workings which are being drilled into. The risk is likely to be higher in areas where mine water levels are known to be rising. The risk is also likely to increase with depth as the likelihood of a connection to the surface is likely to decrease with depth. Clearly working within a confined area will greatly increase the risk and suitable arrangements would be required to provide protection in these circumstances.

Where blackdamp is contacted, this can give rise to the risk of asphyxiation. In low oxygen atmospheres unconsciousness can occur very rapidly and it is important that people are removed from such an atmosphere as soon as possible. This is particularly the case where the working area is a confined space, such as within a building. In these circumstances a dangerous atmosphere would remain in place for a long time rather than being dispersed as it would be in an outside environment. Care should be taken to ensure that routes of egress are clear and short. In certain circumstances where the risks merit it, breathing sets may be appropriate. The risks in these types of situations should be controlled by a Permit to Work procedure.

The risk from flammable gas, of which methane is the most likely to be contacted, is an ignition or explosion. Where high concentrations are found above the Upper Explosive Limit of 15% v/v it should not be assumed that the gas is safe. The gas will still burn at the interface and can be diluted into the explosive mixture due to mixture with air. The effects of such an event can be very sudden and it is therefore very important that people move to a point of safety at the first sign of flammable gas. It should also be borne in mind that the volume of the flame produced by an ignition is many times that of the volume of flammable gas that produced it. Again the risks are increased where working within a confined area as egress may be more difficult and the effects of an ignition in a confined area more damaging. Beyond the risk of the direct effect of an ignition on those within range there is the potential to cause secondary burning of the operatives clothing or other equipment and property. There has been a recorded instance where a rig and operative was set on fire when a smoker ignited methane near an open hole which had just been drilled. Where flammable gases are possible no naked lights, smoking, or storage of flammable liquids should be permitted within a minimum of 15m of the borehole (see also [section 10.4](#))

9.1.2 Emissions from Previously Drilled Boreholes and Other Pathways

Previously drilled open boreholes are a potential contact to dangerous atmospheres below ground. While drilling using air flush the mine atmosphere is likely to be displaced and diluted in the vicinity of the hole once air is introduced into the workings. Nevertheless, after a period of time gas can migrate to the surface through these holes due to naturally induced pressures or through convection of the gas in the holes. Alternatively, if the holes contact workings, drilling of another hole in the vicinity can displace gas up the holes through injection of water or more especially air. For this reason it is important to monitor any open holes during drilling operations that could pose a risk to the Public or operatives. It should not be assumed that holes are safe because they have been safe at some time previously. Again this is particularly the case in a confined environment if there are open holes within a building for example. Where holes need to be left open, temporary caps or seals should be considered to reduce the risk.

Where other possible pathways are likely to exist on site, between the mine workings being drilled and the surface e.g. mine shafts, the risk of gases being displaced via these pathways should be considered and monitoring undertaken as required. However it is likely that in many cases the location of such pathways will be unknown or uncertain and in such cases monitoring may not be practicable.

9.1.3 Spontaneous Combustion

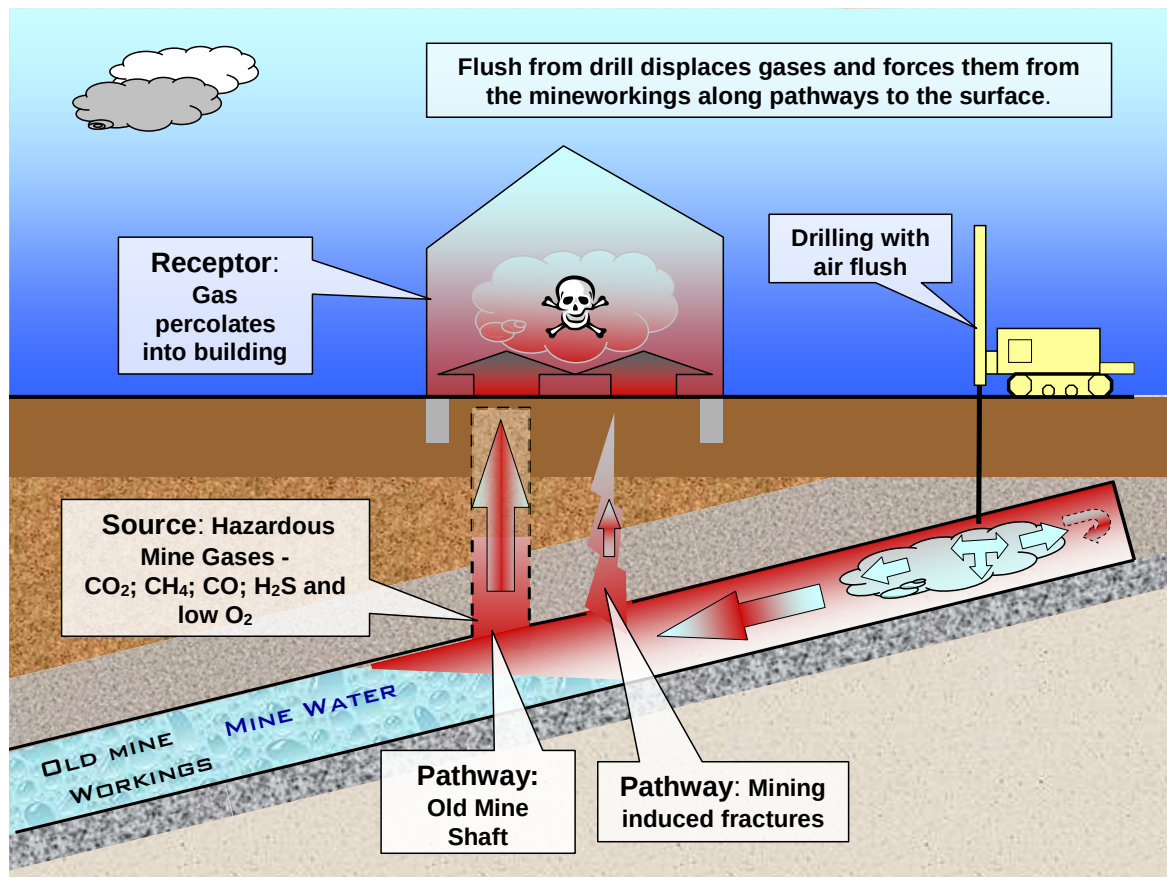
Before any drilling operations commence which may contact an unworked or remnant coal, efforts should be made to establish whether a particular seam is known to be prone to spontaneous combustion. The Coal Authority website contains a list of those known in the mining industry and those which recent laboratory tests have been shown to represent a medium to high risk. [See section 5.3](#) for more details.

9.2 Off Site Risks

Off site risks arise principally from the movement of dangerous mine gases onto adjacent land and into properties. Such gases can move through the atmosphere, but this is only likely to represent a problem where there are very large flows of gas. The more relevant risk is produced by the movement of gas through coal workings and other pathways and its subsequent displacement into adjacent properties

The risk of off site gas emission as a result of drilling operations arises primarily as a result of displacing the mine atmosphere by use of the flushing medium used in drilling.

Although carbon monoxide has been identified as a real and significant hazard, other mine gases could migrate in a similar fashion and provide the risk of methane, carbon dioxide or low oxygen atmospheres entering property. It should not be assumed that the use of air as a flushing medium will clear away other gas and therefore provide a clean environment. Tests have shown that even over short distances injecting air into a borehole moves existing mine atmospheres rather than replacing them.



The aim of the risk assessment is to identify whether there is an increased risk of gas entering adjacent properties due to operations: If there is a source, a potential pathway and a potential receptor then the necessary preconditions are in place. In these circumstances gas could potentially migrate naturally. However, the risk assessment should identify any increased risk due to the presence of additional motive force created by drilling operations. In the case of piling it is unlikely that this will have significant influence due to the relatively low flow and high stiffness of the grout or concrete.

A motive force can be produced by injection of fluids such as air, water and grout into permeable ground and mine workings. The injection of these fluids has the potential to displace volumes of gas and increase pressure to allow the flow of gas through pathways.

Areas of ground which are at highest risk of mine gas are those which lie:

- On or in close proximity to a mine entry.
- On fractured or broken ground connected to mine workings.
- On a collapse which results in connection to mine workings or ground which is prone to such a collapse.
- On opencast backfill.
- On made ground and permeable strata directly above mine workings.

Lower risks will be associated with an absence of these factors. Also if it is known that potential pathways, such as mine workings, are totally flooded it would have a large mitigating effect on the risk. However in reality it is very difficult to definitively prove that mine workings are totally flooded and that no pockets of dry roadways exist without detailed knowledge of the workings and a thorough understanding of the hydrogeology in the area. It should be noted that ground water levels will not, in many cases, correspond with the water levels in the mine workings.

The risk assessment should estimate the likelihood of:

- Whether there is a risk of mine gases being present in any unworked coal or coal workings contacted during operations.
- Whether carbon monoxide might be created.
- The existence of pathways from source to surface which might allow the passage of gas.
- Gas entering properties if it were to reach the surface.

It should be based on a **source – pathway – receptor** model and needs to identify if the necessary conditions are in place and whether the proposed operation might enable the gas to enter properties at concentrations which will cause harm.

Where it is not possible to define whether there is a likelihood of any of the above conditions then it must be assumed that there is a potential for them to exist.

9.3 Residual Risks

Although we have so far considered the risks associated with the processes of drilling, there is also potential for the drilling operations to leave the area at a higher risk once those operations have ceased.

The process of drilling into mine workings creates a pathway between those workings and the surface through which gases can escape to the surface and air can enter the workings. The area covered by the drilling is therefore at an enhanced risk of gas emissions to the surface unless an absolute seal against the workings can be established. For example, a close pattern of holes may be drilled over an area to be stabilised by grout in order to allow construction of buildings over it. Although grout placed in the workings will provide increased stability, it is not likely to provide a good seal against the movement of gas. The process of drilling can therefore provide a route for mine gas to enter beneath such properties and put the occupiers at risk.

Boreholes provided with an inadequate seal could also produce risks from spontaneous combustion, especially where contacted seams are prone to this phenomenon. Air drawn into abandoned workings during periods of rising atmospheric pressure could potentially lead to a heating especially where the flow is restricted to low velocities.

For these reasons it is imperative that where drilling contacts unworked coal and coal workings the boreholes should be properly sealed (see [section 10.8](#)). If buildings are constructed over such boreholes they should have suitable gas protection installed in case of failure of the seals. Gas protection is usually afforded by means of ventilation and sealing. Ventilation beneath properties can help dissipate and dilute any gases, reducing the risk from any gases that enter the property. Sealing is usually carried out by placing a gas proof membrane across the whole footprint of the building and creating a seal around any service entries.

Another potential risk caused by grouting operations is where they restrict the normal flow of gas (or water) through the workings, leading to uncontrolled emissions at another location. Although grouting will not provide a perfect seal against gas (and thereby allow gas to leak to the surface) it is capable of restricting flow. Placing a barrier of grout, therefore, between gas filled mine workings and a normal point of contact with the surface could place the land above those workings at increased risk, especially if any points of weakness are present. If the Coal Authority has specific knowledge regarding relevant gas or water problems at the site of operations or in the surrounding area, this will be provided as part of their permission granting procedures.