APPENDIX 9.1

Earth Science Partnership

Consulting Engineers | Geologists | Environmental Scientists

Cosmeston Farm, Penarth

Proposed Residential Development

Exploratory Geo-Environmental and Geotechnical Assessment

Ref: 7061b.3166 Rev5

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Earth Science Partnership

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Cosmeston Farm, Penarth
Proposed Residential Development

Geo-Environmental and Geotechnical Assessment

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2) *This report may not be used for any purpose other than that for which it was commissioned.*

3) *We have taken reasonable efforts to ensure the accuracy and reliability of the information presented herein. Some of this information has been obtained from third party sources and they are referenced as appropriate. Nevertheless, no guarantee is provided on the authenticity or reliability of this information.*

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Executive Summary

The Earth Science Partnership were instructed to undertake an integrated geotechnical and geo-environmental at the site, with the objective of the investigation, as provided by the Client, *"To undertake a geoenvironmental ground investigation and associated interpretive reporting to inform the masterplan and drainage strategy for the development of the site at Cosmeston Farm, Penarth for residential housing and a proposed primary school"*.

We understand the proposed masterplan will include residential housing, schools., community space, public open space and associated areas of access roads, hardstanding and landscaping. The objectives and scope were altered on a number of occasions during discussions and meetings with the project team and this is outlined in Section 1.4.

The site has been split into four areas which are discussed throughout this report and a brief summary of the ground conditions and hazards within each area are discussed below.

Area A, comprises the West fields that make up the winter paddocks and fields associated with a livery business. Here the ground model identified relatively shallow bedrock, with limited contamination features identified.

Area B, a former and now infilled quarry. Here the ground model comprised up to 12m of reworked soils, with frequent occurrences of man made materials, such as brick, concrete and ash etc. Laboratory testing has indicated exceedances of some determinands.

Area C, comprises a former quarry and historic landfill. In this area, up to 7m of variable, domestic and commercial landfill waste has been identified. This area poses a significant hazard with regard to both geotechnical and geoenvironmental hazards.

Area D, comprises the north/north-east fields which are predominantly used for crop growth. In this area, shallow bedrock was encountered and no obvious sources of contamination were identified.

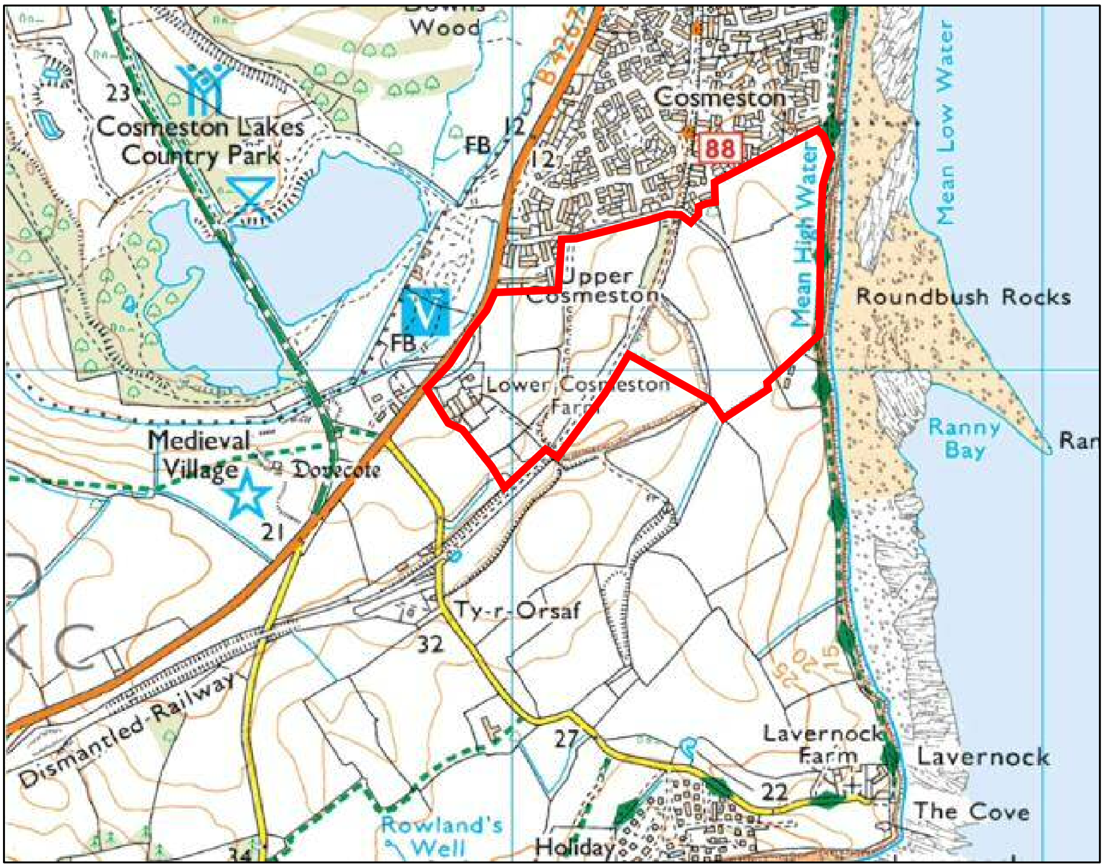
Each area of the site will require detailed consideration with regard to foundation and floor slab design and ground gas protection measures. Reference should be made to this full report for content and context, with risk drivers discussed in Section 2.0, Ground Models and findings in Sections 4.0 and 5.0, and an assessment of risk posed by geoenvironmental and geotechnical hazards undertaken in Sections 6.0 – 8.0.

1 Introduction

1.1 Background

Welsh Government (hereafter known as the Client) are proposing to market the site for redevelopment, with the intended end use to include residential housing, schools., community space, public open space and associated areas of access roads, hardstanding and landscaping.

The Earth Science Partnership Ltd (ESP), Consulting Engineers, Geologists and Environmental Scientists, were instructed by Welsh Government via Austin-Smith:Lord and Cambria Consulting Ltd on the behalf of the Client to undertake an integrated geotechnical and geo-environmental investigation and assessment to identify and evaluate potential ground hazards which could impact on the proposed development Masterplan that is being compiled as part of the marketing process. The site location is shown on Insert 1.



Insert 1: Site Location Plan 1:25,000 (Ordnance Survey License No.: AL100015788).

We understand the preferred Masterplan options will include residential housing, schools., community space, public open space and associated areas of access roads, hardstanding and landscaping.

1.2 Objective and Scope of Works

The objective of the investigation as provided by the Client was *"To undertake a geoenvironmental ground investigation and associated interpretive reporting to inform the masterplan and drainage strategy for the development of the site at Cosmeston Farm, Penarth for residential housing and a proposed primary school"*.

The objectives and scope were altered on a number of occasions during discussions and meetings with the project team and this is outlined in Section 1.4.

1.3 Report Format

This report includes the third party report review and field reconnaissance reports (Section 2), and details of the investigation undertaken of Eurocode EC7 and BS5930:2015 (Section 4), along with the Preliminary Risk Assessment stage (Section 3) and Generic Quantitative Risk Assessment (Section 5) of CLR11. A preliminary evaluation of the resulting risks and any remedial measures potentially required to mitigate identified unacceptable risks from contamination and hazardous ground gas is included in Sections 6 and 7. It should be appreciated that this is a preliminary evaluation, which meets the requirement of the Risk Assessment chapters of CLR11.

A preliminary risk register, identifying potential geotechnical hazards from the desk study review, is presented as Section 2.9, with a full assessment of the geotechnical conditions including foundation and floor slab options, the feasibility of soakaways, etc. in Section 8 – this complies the relevant elements of the Geotechnical Design Report of BS EN 1997-2 (Eurocode 7) and BS5930:2015. The geotechnical risk register is updated using the findings of the intrusive investigation and assessment in Section 8.2. The report concludes with a summary of any further surveys/ investigations/ assessments recommended (Section 9).

The assessment of the potential for hazardous substances (contamination) or conditions to exist on, at or near the site at levels or in a situation likely to warrant mitigation or consideration appropriate to the proposed end use has been undertaken using the guidance published by CIRIA (2001). This is discussed in more detail in Section 3.2.1 and in Appendix A.

1.4 Limitations of Report

This report represents the findings of the brief relating to the proposed end use and geotechnical category of structure(s) as detailed in Section 1.1. The brief did not require an assessment of the implications for any other end use or structures, nor is the report a comprehensive site characterisation and should not be construed as such. Should an alternative end use or structure be considered, the findings of the assessment should be re-examined relating to the new proposals.

It is understood that this investigation is required to inform a Masterplan and provide recommendations for further investigation and assessment in areas of the site as necessary. The scoping, sourcing and implementation of this phase of works, has been undertaken with multi-party input and has been impacted by a prescriptive scope of works provided by the Client and subsequently reviewed and modified by the project team to minimise disruption.

The undertaking of the investigation has been affected by access restrictions as discussed in Section 4.0. The findings of this investigation are considered suitably robust to inform the Masterplan and provide recommendations for further assessment and we understand that further works for detailed design will occur in the future.

Where preventative, ameliorative or remediation works are required, professional judgement will be used to make recommendations that satisfy the site specific requirements in accordance with good practice guidance. Consultation with regulatory authorities will be required with respect to proposed works as there may be overriding regional or policy requirements which demand additional work to be undertaken. It should be noted that both regulations and their interpretation by statutory authorities are continually changing.

This report represents the findings and opinions of experienced geo-environmental and geotechnical specialists. Earth Science Partnership does not provide legal advice and the advice of lawyers may also be required.

1.5 Digital Copy of Report

This report is issued as a digital version only.

2 Desk Study And Field Reconnaissance Visit

The information presented in this section primarily comprises a review of the Third Party information presented in the Arcadis Desk Study Report (Ref: February 2016-03). Whilst the site description is based on ESP's approach to the site and implemented assessment, the factual Desk Study information comprises a summary of Arcadis information only and their full reports should be referred to (see Appendix B).

2.1 Site Location and Description (Areas A – D)

The site is located within the boundaries of Lower Cosmeston Farm, Cosmeston, accessed from Lavernock Road (B4267) and entrance through the Livery Yard that occupies the west/south west portion of the site. Access to other areas is along trackways and through farm gates, once within the confines of the site boundary. Due to the overall size of the site and differing anticipated geologies, the site has been split into five areas which are discussed throughout this report. These areas comprise the following and are shown on Figure 1:

- Area A – Comprising the West fields that make up the winter paddocks and fields associated with the livery;
- Area B – The historic former quarry/infilled land now used as summer paddocks;
- Area C – The historic former quarry and part of a former landfill;
- Area D – The North/North East fields that are currently used for crop growth.
- Area E - The "Old Quarry". This area was not accessible during the investigation, due to ecological constraints.

A historic railway embankment trends roughly north east to south west through the central portion of the site and forms a boundary line between Areas B and Areas C and D. The remaining boundaries between the areas, generally comprise soft boundaries, such as hedgerows and trees. At the north of the site and noted adjoining Areas B and D, a vertical rock face is present, beyond which a residential housing estate is identified (see Figure 3).

The south part of Area B is used to store a number of materials, including fencing, signage, cones and metal containers. A number of other man made materials such as plastic tubs, cement, lubricants and tarmacadam products were stored directly on the ground along with bottles of propane gas bottles, farm machinery and fly tipped materials.

Anecdotal evidence from the farm tenant indicates that this area was also used as a pyre for cattle, during the foot and mouth outbreak of 2001. A pyre is generally identified as a mound of material set aside to burn. However it is unknown if this pyre was at or below the surface.

2.2 Site History

2.2.1 Published Historical Maps

A review of the site history presented in the Arcadis Desk Study has indicated that from the late 1800s the site was occupied by agricultural fields. By 1900, a railway is noted to roughly bisect the site (between Areas B, C and D).

Between 1900 and 1920, a quarry is noted in the west of the site (Area B), with a small section of this quarry extending into Area C. Another small quarry is present in the north of the site (Area E). By 1940 the quarry excavations are noted to expands into Area C, whilst the quarries in Area B and Area E appear to have been infilled. By 1965, the quarry in Area C is indicated to have been infilled. By 1970, the site appears to have reverted back to agricultural land use, with no significant changes after this time.

Whilst the railway is no longer indicated after around 1960, the embankment remains and has been observed on site.

Areas A and D predominantly remain agricultural fields throughout the available historical mapping, with no significant development and/or features identified.

2.2.2 Archaeological Setting

A full archaeological assessment was not included within ESP's brief, but we understand that areas of archaeological importance are present in Areas A and C, with all aspects of archaeological identification and protection being implemented by a third party. The areas of archaeological importance communicated to ESP, prior to site attendance are shown on Figure 3.

2.2.3 Ecological Setting

A full ecological assessment was not included within ESP's brief, however, a number of areas of the whole site are ecologically sensitive. All aspects of ecology are being undertaken by a third party (The Environmental Dimension Partnership). All intrusive investigation have been implemented in line with their guidance email of 28th November 2018 which stated:

- *"Tracking of machinery and trail pits should be confined to areas of short, grassland habitat where the ground layer is visible, avoiding tall and rank grassland habitats in addition to areas of dense scrub, woodland and tall ruderal vegetation;*
- *Machinery/vehicles should follow the same route out of the field as in to the field in order to minimise the extent of ground disturbance;*
- *Tracking of machinery and trial pits should be offset from woodland and hedgerow boundaries by a minimum 5m to avoid damage to root protection zones of such features. This is particularly warranted given that dormouse have previously been identified on site;*
- *In respect of confirmed presence of dormouse, there should be no clearance of woody habitats including dense scrub;*
- *Tracking of machinery and trial pits should be offset from any waterbodies (ponds, wet ditches, watercourses) by a minimum 7-8m to avoid potential pollution incidents cause by the mobilisation and runoff of sediment;*
- *Trial pit locations and access routes across the site should be checked for suitable hibernacula that can harbour hibernating reptiles – these include piles of rocks/boulders, brash piles – such features provide potential cavities in which*

reptiles can hibernate. If found, access routes/machinery should retain and avoid these features;

- *In the event any badger setts are identified, a minimum 15m buffer should be established around the sett in which no excavations or movement of machinery will be permitted."*

2.3 Previous Investigations and Assessments

A series of previous investigation works have been undertaken by Arcadis and full digital copies are provided in Appendix B. Where "Areas" are referred to in Section 2.3, they refer to the ESP designation of Areas outlined in Section 2.1.

- Geo-environmental Desk Study (Ref: February 2016-03)
- Ground Investigation Report (Ref: 001-UA008386-UP32R-01 – February 2018)
- Geoenvironmental and Geotechnical Assessment Report (Ref: 002-UA008386-UP32R-03 – July 2018).

Arcadis Consulting (UK) Ltd (Ref: February 2016 – 03)

A geoenvironmental Desk Study was undertaken by Arcadis prior to any intrusive site works. The pertinent Desk Study information obtained and described by Arcadis has been incorporated into this report and is not repeated here.

Arcadis Consulting (UK) Ltd (Ref: 001-UA008386-UP32R-01 – February 2018

- Two phases of intrusive work were undertaken in September 2016 and December 2017.
- The combined phases of works comprised windowless sampling to determine ground conditions and install ground gas monitoring wells, trial pits to allow infiltration testing, boreholes and dynamic probes to determine depth to rockhead within the former quarries and plate load testing.
- Dynamic probing in the Summer Paddock (Area B) indicated rockhead to be falling from around 5mbgl in the north, to around 12mbgl in the south;
- The landfill area (Area C) recorded depth to bedrock as between 6m to 7m and near surface waste including plastic bags, plastic and glass were identified.
- In Areas A and D, the exploratory holes typically terminate around 1-3mbgl on weathered bedrock.

Arcadis Consulting (UK) Ltd (Ref: 002-UA008386-UP32R-03 – July 2018)

- This report provide an interpretive compilation of the preceding Desk Study and Investigation Report.
- Wet ground conditions and waterlogging, limiting plant movements to some areas, were noted.
- The majority of the site is noted to be underlain by St Marys Well Bay member bedrock.
- Made Ground was identified in Area B and rock head proven at depths of between 5m and 12m.
- Landfill materials were recorded to depths of between 6m and 7m in Area C.
- Limited testing of soil and groundwater does identify some elevated levels of some contaminants. Significant ground gas (Methane >30%) is recorded as emanating from the historic landfill.
- In Areas A and D, soakaway testing indicated low permeability of the near surface, attributed to the clay weathering in the surficial zones of the rock. Shallow groundwater (1-2mbgl) is recorded at a number of positions.

- Area B noted relatively good infiltration likely, attributed to the poorly compacted infill materials.
- Arsenic and PAH contaminants were noted in samples tested by Arcadis;
- Chrysotile Asbestos was identified in one sample (TP06 at 1.0m to 1.9m) in Area B.

2.4 Hydrology

The site is bordered by the Vale of Glamorgan coastline and the Severn Estuary with the associated cliffs forming the east boundary of Area D. The main surface water feature is the Sully Brook which flows in a south-west direction and is located 40m to the west boundary of the site, on the opposite side of Lavernock Road. Approximately 200m to the west, is Cosmeston Lakes, which comprise former, flooded, quarries, approximately 15Ha in size.

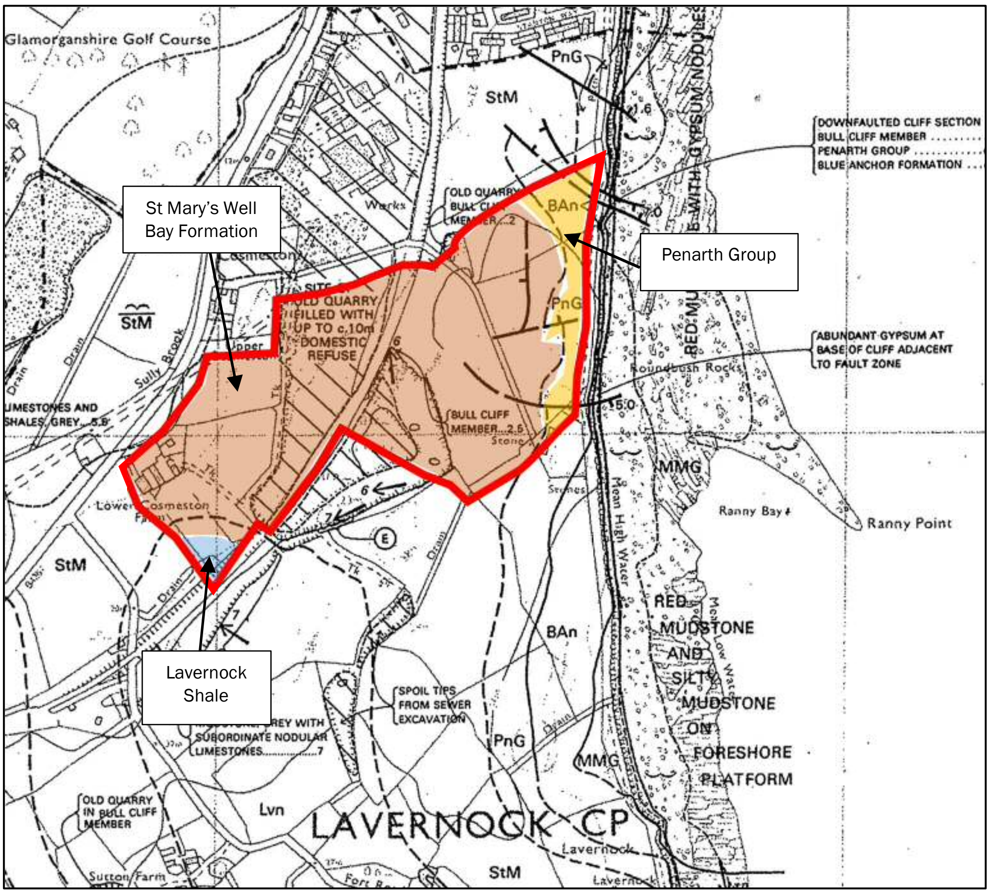
2.5 Geology

The published 1:10,560 scale geological map for the area of the site (Sheet ST16NE) indicates the majority of the site to be underlain by the Jurassic St Marys Well Bay Formation bedrock. A limited area of Lavernock Shales (Jurassic) are identified in the south west of the site (Area A) and in the east of the site (Area D) the bedrock is noted to become the Triassic Group bedrocks comprising the Penarth Group. These rocks typically comprise interbedded mudstones and limestones.

Limited superficial deposits are recorded, however, areas of Alluvium are noted at the western boundary (Area A) associated with the Sully Brook.

The published 1:50,000 scale geological map for the area of the site available on the website of the British Geological Survey, 2019) confirms this stratigraphy.

Based on site history and the use of Areas B and C as quarries and landfill, a potentially significant cover of Made Ground is anticipated, with the Made Ground in Area C, likely to comprise highly variable and potentially contaminating domestic type landfill materials. An extract from the geological sheet (ST18SW) is presented as Insert 2 below.



Insert 2: Extract from Geological Sheet ST16NE (1:10,560 Original - Ordnance Survey License No.: AL100015788).

2.6 Hydrogeology

The bedrock underlying the site are classified as potential aquifers. The St Marys Well Bay Formation and Penarth Group are classified as Secondary A Aquifers, whilst the Lavernock Shales are classified as a Secondary B Aquifer.

Secondary A Aquifers generally correspond with the previously classified minor aquifers, and comprise permeable layers capable of supporting water at a local, rather than strategic, scale and in some cases form an important base flow to rivers. Secondary A Aquifers are sensitive to pollution. Secondary B Aquifers generally correspond with the previously classified water bearing parts of non-aquifers and comprise strata of generally lower permeability, but which may store and yield limited amounts of groundwater due to localised features such as fissures, thin permeable horizons and weathering. In some circumstances, Secondary B Aquifers can be sensitive to pollution.

2.7 Environmental Setting

The site exists in a historically rural and currently rural/urban setting. A review of environmental information provided within the Arcadis Desk Study identifies, that the significant environmental risks stem from the use of Areas B and C as quarries and later infilled land and landfill respectively. A housing estate to the north is understood to have been constructed on historic landfill as identified on BGS borehole logs.

2.8 Preliminary Geotechnical Risk Register

2.8.1 Summary of Potential Geotechnical and Geomorphological Hazards

Based on the Desk Study information presented in the Arcadis Desk Study, a preliminary geotechnical risk register has been prepared. The "Potential" has been taken from the Arcadis obtained Envirocheck Report (see Appendix B) with further commentary provided by ESP.

Table 1: Preliminary Geotechnical Risk Register

Ground Stability Hazard	Potential[1]	ESP Comment
Coal Mining	-	No further information identified to contradict data report.
Mining (non-coal)	-	See Section 2.8.2
Shrinking or Swelling Clays	No Hazard to Very Low	See Section 2.8.3
Landslides	Very Low	No further information identified to contradict data report.
Ground Dissolution (Soluble Rocks)	Very Low	See Section 2.8.4
Compressible Ground	Very Low	See Section 2.8.5
Collapsible Ground	Very Low	No further information identified to contradict data report.
Running Sand	No Hazard to Very Low	No further information identified to contradict data report.
Sulphate/Pyritic Ground	Not reported.	See Section 2.8.6
Radon	Low	The property is in an area where less than 1% of homes are affected and no Radon protection is required.
Cliff Stability	-	See Section 2.8.7

Notes
1. Potential as reported in environmental data report (Appendix B)
2. Salient hazards discussed in following sections.
3. An updated Geotechnical Risk Register, following intrusive investigation of salient hazards, is presented as Table 8 in Section 8.2.1.

2.8.2 Mining (Non Coal)

The Envirocheck report provided as part of the Arcadis Desk Study indicates there are no hazards associated with mining (non coal), however, Areas B and C are both former quarries and therefore the hazard associated with this aspect should be advanced from that reported in the provided environmental data report (No Hazard) to **Moderate.**

2.8.3 Shrinkable and Swelling Soils

Any weathered bedrock that may be present at shallow depth beneath the site commonly have a moderate plasticity index and, hence, are often classified as of potential moderate volume change potential with changes in moisture content (shrinkage and swelling). Therefore, we consider that the potential for shrinkable/swelling soils at the site should be advanced from that reported in the provided environmental data report (No Hazard/Very Low) to **Moderate.**

2.8.4 Ground Dissolution

The anticipated bedrock beneath the site comprises the St Marys Well Bay Formation which is noted to contain bands of calcareous Mudstone and also Penarth Group/Blue Anchor Formation that can contain Limestone bands. These rock types can be prone to dissolution leading to the formation of cavities that have the potential to migrate to the surface. Therefore, we consider that the potential for ground dissolution at the site should be advanced from that reported in the environmental data report (Very Low) to **Moderate.**

2.8.5 Compressible Ground

The desk study assessment indicates the potential for both infilled land and landfill in Areas B and C of the site. These soils would be anticipated to be compressible, particularly where containing organic materials are present, which could lead to significant settlement at the surface. Therefore, we consider that the potential for compressible ground at the site should be advanced from that reported in the environmental data report (Very Low) to **Moderate/High.**

2.8.6 Pyritic Ground

The environmental data report does not consider the potential risk from sulphate rich or pyritic ground. The bedrock underlying the site are listed by the BRE (2005) as potentially containing elevated levels of pyrite, which may oxidise to sulphates and lead to aggressive attack on buried concrete. Depending on its origin, the Made Ground and/or landfill anticipated beneath Areas B and C of the site may also contain elevated levels of pyrite. Given the above, we consider that the potential for sulphate/pyrite attack on buried concrete would be **Moderate.**

2.8.7 Cliff Stability

The east boundary of the site is formed by cliffs associated with the Vale of Glamorgan Coastline which is recorded to fail periodically. A commonly observed and adopted rule for regression-rate of the Vale of Glamorgan coastline is approximately 1m per 30years. Whilst increases in sea level and storminess are forecast owing to global changes in climate, this rate is considered appropriate for reasoned decision making.

We understand that the site/land boundary is approximately 5m back from the cliff edge, to accommodate the Welsh Coast Path. Given the above, we consider that the potential for sulphate/pyrite attack on buried concrete would be **Moderate/High. .**

3 Preliminary Geo-Environmental Risk Assessment

3.1 Conceptual Site Model

3.1.1 Background

The Arcadis work and ESP review allows determination of the potential sources of geo-environmental risk, the receptors at risk and the pathways between the two. These are discussed in the following sections.

3.1.2 Potential Sources of Soil/Water Contamination

3.1.2.1 Potential Contamination Sources:

A review of the site history and existing investigation information indicates that the site has been occupied by farmland since at least the late 1800s. Parts of the site (Areas B and C) . From the available information, we consider that the following features on site could prove sources of diffuse and point source contamination that could impact on the development, environment or site users:

- Made Ground – general diffuse contamination (potential in all Areas);
- Made Ground – infilled quarry (Area B);
- Made Ground – landfill (Area C);
- Made Ground – historic railway that bisects Areas B and D.
- Made Ground – stockpiles of waste materials, fly tipping etc.
- Asbestos previously identified in work by Arcadis.
- Cattle Pyre in Area A.

3.1.2.2 Potential Contaminants Present:

The potential contaminants associated with the above potential sources have been identified from various guidelines published by DEFRA, the Environment Agency and others. The particular guidance referenced includes the Industry Profile for Railway Land (DoE, 1995). Based on this guidance and our experience, we consider that the following contaminants could be present on the site:

- heavy metals and semi-metals (arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, vanadium, zinc); plus other metals as indicated (e.g. barium, boron);
- cyanide, sulphate, sulphide;
- polyaromatic hydrocarbon (PAH) compounds;
- petroleum hydrocarbons;
- phenols;
- asbestos;
- Herbicides and Pesticides.

No evidence has been identified from the desk study to suggest that radioactive substances may be present on the site. The potential presence of radon in discussed in Section 3.1.4.

3.1.3 Potential Sources of Hazardous Ground Gas

Based on the available information, the following potential sources of hazardous ground gas have been identified on, or in close vicinity of, the site:

- General Made Ground – organic and other materials could generate combustible and noxious gases;
- Infilled land (Area B);
- Landfill (Area C);
- Infilled land (Area E – not investigated);
- Historically filled ground to the north (now housing);
- Remainder of landfill that occupies Area C, to the south.

Based on the guidelines presented by O'Riordan and Milloy (1995) and revised by Wilson et al (2009), the above potential gas sources would generally be classified as of generally low to moderate gas generation potential, however, the landfill would be classified as of high to very high gas generation potential

3.1.4 Potential Sources of Radon

As discussed in Section 2.10, the risk from radon as identified in the Arcadis Envirocheck report is low and no radon protection measures are required for development.

3.1.5 Potential Receptors

As discussed in Section 1.1, the proposed site development will comprise residential properties with private gardens, landscaping and vehicle parking areas. It is anticipated that at this outline stage, the landfill (Area C) will comprise Public Open Space.

Given the above, we consider that the most vulnerable receptors with regards to any contamination or hazardous ground gas present are likely to be as follows.

- Future residents, the critical receptors being young children playing in private garden areas.
- Future site visitors
- Construction and maintenance workers.
- Buried concrete (foundations, drainage etc.).
- The water quality in the Sully Brook;
- The groundwater within the bedrock beneath the site classified as Secondary A and B aquifers.

3.1.6 Potential Migration Pathways

Based on the Conceptual Site Model discussed in the previous sections, the following are considered the most likely migration pathways with regard to any contamination or hazardous ground gas present beneath the site.

3.1.6.1 Site Users:

- Ingestion of soils and inhalation of dust in garden areas.
- Ingestion of soils and inhalation of dust in landscaping areas.

- Ingestion of edible plants and dust associated with such plants.
- Dermal contact with contaminated soils.
- Exposure to asbestos containing materials within the shallow soils.
- Potential explosive risk from flammable ground gas/vapours from on-site sources.
- Potential risk from toxic ground gas/vapours from on-site sources.

3.1.6.2 Construction and Maintenance Workers:

- Exposure to asbestos containing materials within the existing buildings.
- Exposure to asbestos containing materials within the shallow soils.
- Ingestion of soils and inhalation of dust across site.
- Dermal contact with contaminated soils.
- Potential explosive risk from flammable or toxic ground gas/vapours from on-site sources.

3.1.6.3 Groundwater:

- Leaching of mobile contaminants into the water-bearing strata within the bedrock.
- Potential mobilisation of contaminants should SUDs be adopted;
- Downward movement of contaminants into water bearing strata during piling operations.

3.1.6.4 Sully Brook:

- Leaching of mobile contaminants to the groundwater beneath the site, and then on to the nearby surface water course.
- Surface run-off of contaminated leachate to adjacent stream/river.

3.1.6.5 Buildings:

- Sulphate attack on buried concrete (foundations, drainage etc.).
- Potential explosive risk from flammable ground gas/vapours from on-site sources.

3.2 Preliminary Risk Evaluation & Plausible Pollutant Linkages

The land use history of the site and surrounding area, as established from the desk study and walkover, has identified a number of potential contamination linkages due to ground conditions or former operations either on, adjacent to, or in the vicinity of the site. Note that these potential linkages will need to be later assessed and re-established using actual site data obtained during the exploratory investigation as discussed in later sections.

3.2.1 Introduction to Risk Evaluation Methodology

The methodology set out in CIRIA C552 *Contaminated Land Risk Assessment – A Guide to Good Practice* (Rudland et al, 2001), has been used to assess whether or not risks are acceptable, and to determine the need for collating further information or remedial action.

Whilst at a later stage, this methodology may be informed by quantitative data (such as laboratory test results) the assessment is a qualitative method of interpreting findings to date and evaluating risk. The methodology requires the classification of:

- The magnitude of the potential consequence (severity) of risk occurring (Table A1 in Appendix A):
- The magnitude of the probability (likelihood) of risk occurring (Table A2 in Appendix A).

The classifications defined above are then compared to indicate the risk presented by each pollutant linkage, allowing evaluation of a risk category (Tables A3 and A4 in Appendix A). These tables have been revised slightly from those presented in CIRIA C552, to allow for the circumstances where no plausible linkage has been identified and, therefore, no risk would exist.

The methodology described above has been used to establish Plausible Pollutant Linkages (PPL) based on the Conceptual Site Model generated for the site and proposed development, and to evaluate the risks posed by those linkages, using information known about the site, at this desk study stage. This is presented as Tables 2 and 3 in Section 3.2.2 below.

Table 2: Plausible Risk Evaluation & Relevant Pollutant Linkages (RPL) – Areas A and D

Source	Pathway	Receptor	Classification of Consequence	Classification of Probability	Risk Category	Further Investigation/ Remedial Action
Potential contaminants in shallow soils (see Section 3.1.2)	Direct contact/ inhalation/ ingestion of contaminated soil or dust	Site Users (residents)	Medium – potential for chronic levels.	Likely[2]	Moderate	Sampling and testing required (and addressed as part of this scope of works).
	Direct contact/ inhalation/ ingestion of contaminated soil or dust	Construction/ Maintenance Workers	Minor/Medium – standard PPE likely to be sufficient	Likely[2]	Moderate/Low Risk	
	Leaching of soil contaminants	Impact on Groundwater	Medium – site lies on Secondary A and B Aquifer	Likely[2]	Moderate	Sampling and testing required with initial assessment of risk to Controlled Waters.
	Leaching of soil contaminants	Impact on Sully Brook	Medium – site lies adjacent to water course	Likely[2]	Moderate	
Asbestos in shallow soils	Ingestion of fibres	Construction/ Maintenance Workers	Medium – potential for chronic levels	Low Likelihood[3]	Moderate/Low Risk	Sampling and testing required.
Soil sulphate/ pyrite	Aggressive groundwater	Buried Concrete	Mild – damage to structures	High likelihood[4]	Moderate Risk	Sampling and testing required.
Hazardous ground gas/vapours, from gas migration from infilled land and landfill (see Section 3.1.3).	Asphyxiation/poisoning. Injury due to explosion.	Site Users/Visitors.	Severe – acute risk.	Likely[5]	High Risk	Ground gas monitoring and assessment to be implemented.
	Damage through explosion.	Building/Property	Severe – acute risk.		High Risk	
	Asphyxiation/poisoning. Injury due to explosion.	Construction and Maintenance Workers.	Severe – acute risk.		High Risk	
Radon gas (see Section 3.1.4)	Migration into Buildings	Site Users (residents)	Medium – potential for chronic levels	Low Likelihood	Low Risk	Nc protection required as reported by Arcadis Desk Study

Notes:
1. This table represents ESP assumptions and recommendations based on a review of previously undertaken Arcadis works
2. Limited Made Ground identified and further confidence required.
3. Due to age of buildings on site, potential for buried asbestos on farmland.
4. Preliminary assessment of soil sulphate to be undertaken.
5. Ground gas potential as a result of migration from adjoining infilled land (Area B) and landfill (Area C).

Table 3: Plausible Risk Evaluation & Relevant Pollutant Linkages (RPL) – Areas B and C

Source	Pathway	Receptor	Classification of Consequence	Classification of Probability	Risk Category	Further Investigation/ Remedial Action
Potential contaminants in shallow soils (see Section 3.1.2)	Direct contact/ inhalation/ ingestion of contaminated soil or dust	Site Users (residents)	Medium – potential for chronic levels.	High Likelihood[2]	High Risk	Sampling and testing required (and addressed as part of this scope of works).
	Direct contact/ inhalation/ ingestion of contaminated soil or dust	Construction/ Maintenance Workers	Minor/Medium – standard PPE likely to be sufficient	High Likelihood[2]	High Risk	
	Leaching of soil contaminants	Impact on Groundwater	Medium – site lies on Secondary A and B Aquifer	High Likelihood[2]	High Risk	Sampling and testing required with initial assessment of risk to Controlled Waters.
	Leaching of soil contaminants	Impact on Sully Brook	Medium – site lies adjacent to water course	High Likelihood[2]	High Risk	
Asbestos in shallow soils	Ingestion of fibres	Construction/ Maintenance Workers	Medium – potential for chronic levels	Likely[3]	Moderate/ High Risk	Sampling and testing required.
Soil sulphate/ pyrite	Aggressive groundwater	Buried Concrete	Mild – damage to structures	High likelihood[4]	Moderate Risk	Sampling and testing required.
Hazardous ground gas/vapours, from gas migration from infilled land and landfill (see Section 3.1.3)	Asphyxiation/poisoning. Injury due to explosion.	Site Users/Visitors.	Severe – acute risk.	High Likelihood [5]	Very High Risk	Ground gas monitoring and assessment to be implemented.
	Damage through explosion.	Building/Property	Severe – acute risk.			
	Asphyxiation/poisoning. Injury due to explosion.	Construction and Maintenance Workers.	Severe – acute risk.			
Radon gas (see Section 3.1.4)	Migration into Buildings	Site Users (residents)	Medium – potential for chronic levels	Low Likelihood	Low Risk	Nc protection required as reported by Arcadis Desk Study

Notes:
1. This table represents ESP assumptions and recommendations based on a review of previously undertaken Arcadis works
2. Potential for significant Made Ground in Area B and Landfill materials in Area C - further confidence required.
3. Due to age of buildings on site, potential for buried asbestos on farmland and identification of asbestos in Area B by Arcadis.
4. Preliminary assessment of soil sulphate to be undertaken.
5. Ground gas potential as a result of generation from infilled land (Area B) and landfill (Area C). Arcadis reports note >30% Methane.

4 Exploratory Investigation (Areas A – D)

4.1 Investigation Points

4.1.1 Introduction

The intrusive investigation was undertaken between 28th January and 21st February 2019 in accordance with BS5930:2015 and BS10175:2013, and was designed to investigate both geo-environmental and geotechnical hazards that may impact on the proposed Masterplan.

It comprised trial pitting, rotary openhole and rotary cored boreholes, cable percussion commencement boreholes, soakaway and falling head infiltration testing, geoenvironmental and geotechnical laboratory testing, gas and groundwater monitoring, monitoring and sampling of groundwater. An inspection of the cliff line that forms the east boundary of the site has also been undertaken. The primary purpose of the intrusive investigation was to provide additional supplementary information to the intrusive investigation undertaken by Arcadis in 2018 and comprised investigation in areas where previous works had not been undertaken or to supplement pre-existing information.

4.1.2 Investigation Strategy and Restrictions

As the site has been split into four investigated Areas (A – D), the exploratory holes have been addressed on an Area by Area basis as outlined in Table 4 below and shown on Figure 2. In order to differentiate exploratory holes from previous third party works, all ESP positions undertaken in 2019 are preceded with the notation "E" i.e. E-TP01.

Table 4: Placement Rationale for Investigation Points (see Figure 2)

Area	Trial Pits	Boreholes
A	E-TP1 to E-T03	E-BH01 to E-BH04
B	E-TP4 to E-TP9	E-BH05 to E-BH7
C	E-TP17 to E-TP19	E-BH08 to E-BH10
D	E-TP10 to E-TP13, E-TP15 and E-TP20 to E-TP26	E-BH11 to E-BH13
E	Not investigated at this time due to ecological constraints.	
Notes: 1. E-TP14, E-TP16 and E-TP21 omitted due to archaeology constraints. 2. E-TP27 and E-TP28 omitted in area D due to ecology.		

During the investigation a number of restrictions prevented full and unhindered access across the site. These restrictions are summarised below and pertinent features identified on Figure 3:

- Archaeology – prevented investigation works in some discrete locations in Area A and D;
- Ecology- prevented any access in to Area E and set an exclusion zone of 5m around all hedgerows/tree lines etc. This is of particular importance in the

central portion of the site where anticipated Made Ground associated a former railway was likely present, but could not be investigated and also between Areas C and D where high wall trenching was proposed;

- The existing farm and show jumping field in Area A was not accessible;
- South portion of Area B (former funeral pyre) which was fully occupied by stockpiled/fly tipped materials.;
- Project team direction to reduce the number of trial pits, resulted in some trial pit being removed from the scope or substituted for shallow hand excavated pits;
- Planned skip tests in Area C have not yet been able to be set up due to access concerns raised by the tenant over rutting and soft ground.

4.2 Trial Pits

23no. trial pits (E-TP1 to E-TP26, excluding TP14, TP16 and TP21) were excavated across the site using a wheeled, backacting/ tracked hydraulic excavator. The trial pits were excavated to a maximum depth of 3.5m. Disturbed samples were collected from the trial pits for laboratory testing.

In situ measurements of the undrained shear strength of fine-grained soils at shallow depth were taken using a calibrated hand vane. The results of hand vane measurements are presented on the trial pit records in Appendix C.

On completion, the trial pits were backfilled with arisings in layers compacted with the excavator bucket, and the Topsoil reinstated on the surface, where possible. The arisings were left slightly proud of the adjacent surface to allow for future settlement.

4.3 Pre-Commencement Cable Percussion Boreholes

Due to the identification of landfill materials, 3no. 200mm diameter cable percussion boreholes (E-BH08 to E-BH10) were constructed through the landfill material to the top of bedrock, prior to construction of aquifer protection measures and follow on rotary cored drilling (see Section 4.4). At the commencement of each borehole, a square of the grass landscaping was cut and a service inspection pit excavated by hand to a depth of 1.2m.

Standard Penetration Tests (SPT) were carried out using a split spoon/solid cone in the boreholes in accordance with BS EN ISO 22476-3 (2005) and BS5930 (2015) to assess the relative density of the coarse-grained soils encountered in the borehole and to provide an correlated assessment of the likely undrained shear strength of fine-grained soils using relationships published by Stroud (1975). As required in BS5930:2015, the SPT N-values shown on the borehole records are the direct, uncorrected results obtained in the field. The pre-commencement borehole sections are presented as part of the boreholes records in Appendix D.

4.4 Rotary Cored/Dynamic Samples Drillholes

13no. rotary cored/dynamic sampled drillholes (E-BH01 to E-BH13were constructed) utilising the ODEX 115 system of simultaneous drilling and casing was used in the superficial deposits and the drillhole records are presented as Appendix D.

At the commencement of each borehole, a square of the grass landscaping was cut and a service inspection pit excavated by hand to a depth of 1.2m. In the case of E-BH08 to E-BH10, the rotary borehole was constructed through the light cable percussion section and associated aquifer protection measures. Compressed air/circulated water was used as a flushing medium to keep the drill bits cool.

Initially the boreholes were dynamically sample to bedrock, or refusal of the dynamic sampler, before the switching to rotary cored drilling to allow recovery of rock cores.

Cores of nominal 76mm diameter were recovered in plastic liners using a triple tube barrel system, over runs of nominal 1.5m length. Where recovery was poor, the core length was reduced for the next run to maximise the chances of good recovery. The recovered cores were sealed in the plastic liners and placed in solid core boxes to prevent disturbance and swelling before logging. The plastic liners were only cut immediately prior to logging and sampling. In addition to the nature of the rock material, the identified fractures within the rock mass were also logged in accordance with BS5930:2015. The Rock Quality Designation (RQD) recorded was for rock core 100mm or greater in length. The fracture state of the recovered cores is presented on the drillhole records. On completion, instrumentation was installed in boreholes as detailed in Section 4.7.

4.5 Soakaway Infiltration Testing

Soakaway infiltration tests were undertaken in general accordance with BRE Digest 365 (2007) in 7no. selected trial pits in Areas A, B and D . The results of the infiltration testing, and the calculated infiltration rates, are presented in Appendix E.

The infiltration rate was calculated from the time taken for the water to fall between the 75% and 25% full level. Where insufficient time was available for the water level to fall to the 25% full level, but a significant drop in water level was recorded, the infiltration rate can be estimated by extrapolating the test results. However, where the water level only dropped marginally during the available test period (e.g. not as far as the 75% full level), we consider that there is insufficient data to allow a valid extrapolation with any confidence and no infiltration rate can be estimated.

Herras fencing was erected around the test pits during the testing to protect site workers and livestock. On completion of the testing in each pit, any remaining water was removed from the test pit and it was backfilled with the excavated arisings.

4.6 In-situ Permeability Tests

Falling head permeability testing was undertaken within rotary drillholes at 8no. locations to determine the hydraulic conductivity of the soils/bedrock at that depth. The testing was undertaken in accordance with BS5930 (2015) and BS EN ISO 22282-2 (2012).

At each test zone, the drilling casing was withdrawn to expose a section of the test stratum within the sides of the borehole. In general terms for falling head tests, the prepared test section borehole was filled with clean water from a water bowser and the level to which the resulting water level falls is measured over time. The permeability is calculated using the methodology presented in BS EN ISO 22282-2 (2012). The test results and permeability calculations are presented in Appendix F.

4.7 Instrumentation

4.7.1 Ground Gas and Groundwater Well Installations

50mm diameter monitoring well was installed in selected boreholes in accordance with BS8576:2013 in order to allow monitoring of hazardous ground gases. The wells, comprising slotted plastic pipe with a gravel surround (the response zone), bentonite seals above and below the response zone, and a lockable vandal proof cover, were installed as detailed on the borehole records and summarised in Table 5 below.

Table 5: Monitoring Well Installations

Well ID	Date of Installation	Response Zone depth	Response Zone Stratum
Area A			
E-BH1	14.02.19	0.5 – 7.1	St Marys Well Bay Formation
E-BH2	06.02.19	0.5 – 7.5	St Marys Well Bay Formation
E-BH3	06.02.19	0.5 – 7.5	St Marys Well Bay Formation
E-BH4	14.02.19	0.5 – 6.5	St Marys Well Bay Formation
Area B			
E-BH5(s)	30.01.19	1.0 – 6.0	Made Ground
E-BH5(d)	30.01.19	10.1 – 13.0	St Marys Well Bay Formation
E-BH6(s)	01..02.19	0.9 – 4.0	Made Ground
E-BH6(d)	01.02.19	6.0- 14.7	St Marys Well Bay Formation
E-BH7(s)	04.02.19	0.8 – 5.45	Made Ground
E-BH7(d)	04.02.19	7.5 – 13.7	St Marys Well Bay Formation
Area C			
E-BH8(s)	05.02.19	1.0 – 6.0	Made Ground
E-BH8(d)	05.02.19	8.0 – 11.7	St Marys Well Bay Formation
E-BH9(s)	18.02.19	1.0 – 6.5	Made Ground
E-BH9(d)	18.02.19	8.5 – 12.5	St Marys Well Bay Formation
E-BH10(s)	19.02.19	1.0 – 6.0	Made Ground
E-BH10(d)	19.02.19	8.2 – 12.0	St Marys Well Bay Formation
Area D			
E-BH11	13.02.19	0.6 – 6.5	St Marys Well Bay Formation
E-BH12	07.02.19	1.0 – 6.5	St Marys Well Bay Formation
E-BH13	12.02.19	1.0 – 10.2	St Marys Well Bay Formation
Notes 1. Details of each monitoring well are presented on the individual borehole records (Appendix D).			

4.7.2 Gas Monitoring

Monitoring of the installed gas wells has been undertaken on a 'spot' monitoring basis (periodic visits to monitor gas levels at the time of the visit). CIRIA C665 (Wilson et al, 2007) provides guidance on the number and frequency of monitoring visits required for installed gas wells. These depend on the gas generation potential of the source and the sensitivity of the development to gas risk and are designed as a typical minimum only. At present a regime comprising a total of 12no. visits has been implemented.

During each visit, Gas Data LMSxi G3.18e portable monitoring equipment was used to measures levels of the following ground gases within the airspace in the wells and the flow rates from the wells:

- Methane - total and percentage of Lower Explosive limit (LEL);
- Carbon dioxide;
- Oxygen; and
- Hydrogen sulphide.

The monitoring results undertaken are presented in Appendix I and an assessment of the risks posed by ground gases presented in Section 7.3.

4.8 Skip Testing

Two skip tests were set up at ground level in Area C, the former landfill. The empty skips were placed at the desired location and levelled using survey equipment to provide an initial base reading. Once the levelling was complete, a well graded sandy gravel was quickly placed into each skip and once the material was flush with the top of the skip, a second levelling exercise was done to measure any initial settlement.

The skips tests were commenced on 16th July 2019 and have been monitored on two subsequent, monthly occurrences, on the 14th August and 17th September 2019.

Both skips were '4 yard' skips with the following dimensions:

- Height 1.07m
- Total Length 2.3m
- Width 1.48m
- Base length 1.55m

Using a bulk density of 1900 kg/m^3 of the material within the skip and the skips volume, the calculate mass if each skip is approximately 55 kN. Assuming the base of the skip is rigid, the pressure imposed on the ground surface is in the region of 24kN/m^2.

4.9 Sampling Strategy

4.9.1 Soil Sampling

Soil samples were collected from the exploratory holes as discussed in the previous sections. The sampling procedures were selected on the basis of the suitability for the laboratory testing proposed (see Sections 4.10 and 4.11).

A non-targeted, random sampling strategy was used to obtain representative information on soil contamination across the site as a whole. Environmental samples (denoted as E on the exploratory holes records) were collected for possible geo-environmental laboratory testing and generally comprised a plastic tub, an amber glass jar and an amber glass vial. The sample containers provided clean by the testing laboratory appropriate for the proposed testing to be scheduled. Immediately after collection the samples were placed in sealed cool boxes with ice packs where they remained during storage and transport to the laboratory.

Samples for logging and geotechnical laboratory testing purposes were collected at regular intervals within the exploratory holes.

4.9.2 Soil Sample Quality

Samples of soil recovered from investigations are classified as Classes 1 to 5 in terms of quality and depend on the investigation and sampling method, the particle size of the strata sampled, and the presence of groundwater. Class 1 and 2 samples are those in which there has been no or only slight disturbance of the soil structure, with moisture contents and void ratios being similar to the in-situ soil. Class 3 and 4 samples contain all the constituents of the in-situ soil in their original proportions, and the soil has retained its original moisture content, but the structure of the soil has been disturbed. In Class 5 samples, the soil structure and original layering cannot be identified and the water content may have changed from that in-situ. The category and class of samples are discussed further in BS EN ISO 22476:2006, EN 1997-2:2007 and BS5930:2015.

In general terms, disturbed samples recovered from trial pits (bulk bags and small tubs) are classed as Class 3 (if dry), Class 4 (fine soil below the water table), or Class 5 (coarse soils from beneath the water table). Cutting relatively undisturbed block samples from trial pit walls provides Class 1 or 2 samples, provided that they are collected, preserved and transported in an appropriate manner.

During cable percussion drilling, the split spoon sample from a Standard Penetration Test (SPT) is usually considered a Class 5 sample however, it can be deemed Class 4 in homogeneous fine-grained soils. Disturbed sampling (bulk bags and small tubs) from boreholes is considered Class 3 (if dry), Class 4 (fine soil below the water table) or Class 5 (coarse soils from beneath the water table).

Provided recovery is good, rock cores collected using rotary techniques are classified as Class 2 samples, provided that the plastic liners are sealed and only opened immediately prior to logging. The chippings recovered during open-holes drilling are considered Class 5 samples.

The quality class of each sample collected as part of the investigation is shown on the exploratory hole records.

4.9.3 Groundwater Sampling

In order to assess the groundwater quality beneath the site, samples of groundwater are being collected as part of the monitoring regime in general accordance with BS ISO 5667-11 (2009). Prior to sampling, the wells were purged by the removal of three well volumes where practical, to obtain a water sample representative of the groundwater in the vicinity.

All groundwater samples taken for possible laboratory chemical analysis were collected in suitable clean containers provided by the testing laboratory for (e.g. clean polyethylene jars/bottles with fitted lids for routine soil testing, clear or amber glass bottles with screw on air-tight caps for organic contaminants, glass vials for volatile contaminants, etc.). Immediately after collection the samples were placed in sealed cool boxes with an ice pack where they remained during storage and transport to the laboratory.

4.10 Evidence of Site Hazards Found During Site Works

With regard to potential hazards identified in the desk study and Preliminary Risk Assessment, the following observations were made.

4.10.1 Site Stability

During the undertaking of exploratory holes in Area B, the presence of deep infilled land was identified in Area B and deep domestic/commercial landfill materials was identified in Area C. The landfill arisings were recorded to comprise variable man made materials.

4.10.2 Site Evidence of Contamination

During the undertaking of exploratory holes in Area C the presence of deep landfill materials was identified. The landfill material was recorded to comprise variable man made materials. In Area B, reworked soils and general Made Ground was encountered and in Areas A and D no obvious evidence of contamination was recorded.

In the south of the Area B (not investigated) we understand from anecdotal evidence that during the 2001 Foot and Mouth Outbreak, the area was used as a pyre for cattle. This presents a potential contamination risk including for biological contamination.

4.11 Geotechnical Laboratory Testing

Geotechnical laboratory testing was undertaken on samples from the suitable quality classes recovered from the exploratory holes in order to obtain information on the geotechnical properties on the soils beneath the site.

The following tests were undertaken by a UKAS accredited laboratory on samples selected by ESP in accordance with the methodologies presented in BS1377:1990. The results are presented in Appendix H.

- Natural moisture content.
- Atterberg limits.
- Particle size analysis.

Selected samples were also analysed for soil sulphate and pH value in accordance with the analytical methods specified in BRE Special Digest SD1 (BRE, 2005).

The results of the sulphate testing are included with the geo-environmental test results in Appendix G.

4.12 Geo-environmental Laboratory Testing

Laboratory testing has been undertaken to identify the levels of selected contaminants within samples of soil, leachate generated from shallow soils, groundwater, surface water on/in the vicinity of the site. The geo-environmental analyses were carried out by a UKAS accredited testing laboratory with detection limits being generally compatible with the relevant guideline values adopted in the assessment (see Section 4.1.1).

4.12.1 Soil Samples

To allow an assessment of the potential chronic risks posed to human health, a selection of the near surface soils have been analysed for the contaminants identified in Section 3.1.2, plus other determinands typically present on brownfield sites in the UK.

The general suite of geo-environmental laboratory testing undertaken comprised:

- Arsenic, barium, beryllium, boron, cadmium, total chromium, chromium VI, copper, lead, mercury, nickel, selenium, vanadium, zinc;
- US EPA 16 polyaromatic hydrocarbon (PAH) compounds;
- Total monohydric phenols;
- Total cyanide, asbestos qualitative screen (presence or absence);
- Soil organic content, pH value;
- Speciated TPH inc. BTEX.

The geo-environmental soil test results are presented in Appendix G.

4.12.2 Groundwater Samples

In order to allow a preliminary assessment of the potential pollution risks to controlled waters, samples of groundwater are to recovered from all groundwater wells as part of the ongoing monitoring regime and are to be analysed for the following determinands:

- Arsenic, barium, beryllium, boron, cadmium, total chromium, copper, iron, lead, mercury, nickel, selenium, vanadium, zinc;
- US EPA 16 polyaromatic hydrocarbon (PAH) compounds;
- Total monohydric phenols;
- Cyanide, soluble sulphate, pH value;
- Speciated TPH inc. BTEX.

The results of groundwater testing will be presented alongside the monitoring regime data as part of the monitoring addendum report.

5 Development Of The Revised Conceptual Model

5.1 Geology (Areas A – D)

The exploratory holes undertaken across the site, have identified a variable ground model within the different areas, as anticipated.

During works, in Areas A and D the investigation has generally identified a cover of topsoil over weathered rock.

General Made Ground has been encountered in Area B to a depth of 5.5m to 9m comprising a generally gravelly, cobbly clay with cobbles consisting of Mudstone and Limestone. Some fragments of clinker, ash, coal and slag were noted.

In Area C, markedly different ground conditions were encountered and comprised a highly variable landfill/refuse deposit. The material was primarily noted to comprise domestic and/or commercial refuse type materials and obviously "landfill".

The ground conditions and typical depths encountered are summarised in Table 6 below.

Table 6: Ground Conditions Encountered

Strata	Area A (Fields)	Area B (Infilled Quarry)	Area C (Landfill)	Area D (Fields)
Topsoil	0.2 – 0.3m	(Placed Topsoil) 0.25m	(Placed Topsoil) 0.2m	0.2 – 0.45m
Made Ground	n/a	5.5 – 9m	0.5m	n/a
Landfill	n/a	n/a	7m	n/a
Bedrock (St Marys Well Bay)	From 0.3m	From 5.5 to 9m	From around 7m	From 0.5m
Bedrock (Probable Penarth Group)	n/a	n/a	n/a	From 0.5m

Laboratory testing within the fine-grained weathered bedrock has indicated liquid limits between 44% and 77%, plasticity indices between 21% and 43%, and natural moisture contents between 15% and 50%. The modified plasticity indices (after the coarse-grained particles have been removed) suggest that the soils are generally of intermediate to very high plasticity. The summary of plasticity results on an area by area basis are presented on Table 7 below. Particle size analyses taken from samples of weathered rock in Areas A and D have indicated a predominantly cobbly (32-57%) silt and clay (31-63%).

Table 7: Summary of Plasticity Testing

Area	Moisture Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
A	15 - 27	44 - 61	21 - 26	21 - 35
B	32 - 34	80	30	50
C	17 - 24	32 - 56	18 - 28	14 – 35
D	21 - 31	52 - 74	23 - 34	27 - 48

5.2 Hydrogeology

5.2.1 Groundwater Bodies

The majority of exploratory holes were completed within one working day and due to the soils low permeability, it is possible that groundwater may be present within the depth of investigation, but there was insufficient time for it to be recorded. No obvious groundwater strikes were recorded during the construction of boreholes. The levels of groundwater encountered during the monitoring programme are recorded in Table 8 below.

Table 8: Summary of Groundwater Levels From Monitoring Data (Visits 1 to 12)

Area	Well	No visits	Groundwater Level (mbgl)
A	E-BH1	12	1.5 – 3.0
	E-BH2	12	0.1 – 2.6
	E-BH3	12	1.2 – 3.0
	E-BH4	12	3.4 – 6.7
B	E-BH5(s)	12	Dry
	E-BH5(d)	12	Dry – 12.1
	E-BH6(s)	12	Dry – 4.24
	E-BH6(d)	12	9.5 – 10.4
	E-BH7(s)	12	Dry – 5.5
	E-BH7(d)	12	8.7 – 8.96
C	E-BH8(s)	12	4.1 – 6.0
	E-BH8(d)	12	5.4 – 6.35
	E-BH9(s)	12	6.1 – 6.7
	E-BH9(d)	12	8.1 -8.7
	E-BH10(s)	12	5.1 – 5.65
	E-BH10(d)	12	4.6 – 5.6
D	E-BH11	12	2.6 – 6.8
	E-BH12	12	0.2 – 5.2
	E-BH13	12	2.7 – 10.1

Groundwater level monitoring has indicated the presence of a consistent groundwater body within the bedrock. Shallow groundwater bodies are also recorded in the Made Ground in Area B and within the landfill in Area C. It should be noted that in most areas of the site, the surface was soft and waterlogged.

5.2.2 Hydraulic Gradient

Hydraulic gradients are discussed in detailed in our Controlled Waters Risk Assessment and full reference should be made to Appendix N.

5.3 Site Instability

5.3.1 Global Site Stability

No evidence was identified of potential landslips or unstable ground in the Preliminary Geotechnical Risk Register (Table 3) and we identified no evidence of any global instability issues on the site, however potential and site specific stability hazards are recorded below. As part of the investigation scope, a preliminary assessment of cliff stability along the eastern boundary of Area D has been undertaken and is discussed further in Section 8.10.

5.3.2 Excavation Stability

No significant side wall instability was experienced during the excavation of the trial pits to a maximum depth of 3.5m, however, the majority of trial pits encountered weathered rock at shallow depth. In areas of Made Ground (Area B), there remains a potential for instability/spalling in open excavation.

5.3.3 Landfill Materials

Significant variable and loose landfill deposits have been identified in Area C. These materials will be highly variable and likely to spall during open excavation. No significant works are anticipated in this Area due to the human health concerns, however, any subsequently planned excavation will require suitable shuttering/bracing on top of appropriate health protection measures.

5.4 Limestone Solution

No obvious evidence of limestone solution was identified in the investigation, however, the bedrock present beneath the site can be susceptible to Limestone Solution and this is discussed further in Section 8.0..

5.5 Chronic Risks to Human Health – Generic Assessment (Areas A – D)

5.5.1 Assessment Methodology

The long term risks to health have been assessed using methodologies and frameworks determined by the Environment Agency within documents SR2, SR3, SR4 and the CLEA Technical Review published to support the Contaminated Land Exposure Assessment Model (CLEA). Where applicable, reference has been made to the supporting toxicological reports (TOX Series) and the Soil Guideline Value reports (SGV Series). It is assumed that the reader is familiar with the above documents and it is not intended to repeat these described methodologies in detail, for further information, please refer directly to the specific documents.

In order to provide an initial 'screen' to identify elevated levels of contaminants, a Generic Quantitative Risk Assessment (GQRA) has been undertaken using the most appropriate Generic Assessment Criteria (GAC) determined by assessment of exposure frequency/duration relevant to the critical receptor.

5.5.2 Assessment Criteria

In 2014, DEFRA published the Category 4 Screening Levels (C4SL) for use in Part 2A determinations. The C4SL are designed to be more pragmatic, but still strongly precautionary, assessment criteria compared to the previous assessment criteria (SGV – see below) used to assess chronic human health risks. They are designed for use in deciding whether land is suitable for use and definitely not contaminated, and DEFRA and the Welsh Government have recommended that they be used in assessing human health risks during the planning regime (i.e. as part of standard development investigations). However, the C4SL have been calculated for a limited number of contaminants at this stage, and range of land uses including residential, commercial and public open space, but are based on a 'low level' of risk rather than the 'minimal level' of risk adopted by the Environment Agency in preparing their Soil Guideline Values (SGV). At the time of writing, the use of the C4SL in planning has not yet been accepted by many parties, including some regulators. The C4SL have also only been published for a limited number of contaminants. The C4SL have not been generally adopted in this assessment.

In this assessment, where available, the Soil Guideline Values (SGV) published by the Environment Agency have been adopted as the Generic Assessment Criteria (GAC) in the first instance. However, the SGV are only available for a limited number of contaminants for three proposed land uses (residential, commercial and allotments - not public open space). Where no SGV is available, the Suitable For Use Levels (S4ULs) published in January 2015 by the Chartered Institute of Environmental Health (CIEH) and Land Quality Management (LQM) have been adopted (Nathanail et al, 2015). These assessment criteria adopt updated toxicological data and exposure models, but the same 'minimal level' of risk as the SGV (i.e. unlike the C4SL). The S4ULs have been published for a large number of contaminants typically found on brownfield sites in the UK, and for the same range of land uses as the C4SL, i.e. including public open space scenarios.

For more exotic, predominantly organic, compounds no SGV, S4UL or C4SL assessment criteria have been published. In this instance, GAC published by CL:AIRE and the Environmental Industries Commission (CL:AIRE/EIC, 2010) have been adopted. These GAC have also been developed using the CLEA UK software based on a 'minimal level' of risk and for the same land use scenarios as the SGVs (i.e. not public open space).

At the time of writing there is no published SGV, S4UL or CL:AIRE/EIC assessment criteria for lead. For the purposes of this assessment, and in the absence of any other current authoritative guidance, the Category 4 Screening Level (C4SL) value published by DEFRA has been adopted.

Details of the source of the GAC adopted for each contaminant are presented on the assessment table below.

The proposed Masterplan is to allow for a development that comprises residential properties with private gardens. Therefore, the GAC appropriate for the residential land use with plant uptake have been adopted in this assessment in the first instance.

5.5.3 Generic Quantitative Risk Assessment

The results of the Generic Quantitative Risk Assessment are presented in Tables 9 – 12 below. The assessment has been conducted on the individual areas within the site and has also been expanded to include contamination assessment data from the previously undertaken by Arcadis.

Review of the Arcadis contamination assessment data has indicated that generally the limited testing undertaken satisfied the comparative guidelines available at the time within Areas A, C and D. Some exceedances of metals and PAH compounds was noted within samples collected and tested in Area B and these have been summarised in the data for Area B below (see Table 10).

Table 9: Summary of Geo-environmental Soil Results (Area A – Generally Comprising Naural Soils)

Determinand	Range Recorded ESP 2019*	GAC	Source of GAC	Exceedances (Of 4no. Samples)
Metals and Semi-metals				
Arsenic	16-21mg/kg	32mg/kg	SGV[2]	None
Barium[6]	140-170mg/kg	1,300mg/kg	CL:AIRE[4]	None
Beryllium	1.1-1.4mg/kg	1.7mg/kg	S4UL[3]	None
Cadmium	0.8-1.4mg/kg	10mg/kg	SGV[2]	None
Chromium (total)[7]	29-37mg/kg	910mg/kg	S4UL[3]	None
Chromium (hexavalent)	<0.5mg/kg	6.0mg/kg	S4UL[3]	None
Copper	45-52mg/kg	2,400mg/kg	S4UL[3]	None
Lead	38-58mg/kg	200mg/kg	C4SL[5]	None
Mercury[8]	<0.1-0.1mg/kg	170mg/kg	SGV[2]	None
Nickel	43-76mg/kg	130mg/kg	SGV[2]	None
Selenium	0.71-0.1.4mg/kg	350mg/kg	SGV[2]	None
Vanadium	34-44mg/kg	410mg/kg	S4UL[3]	None
Zinc	100-160mg/kg	3,700mg/kg	S4UL[3]	None
Polyaromatic Hydrocarbons (PAH)				
Acenaphthene	<0.01 – 3.1mg/kg	210mg/kg	S4UL[3,9]	None
Acenaphthylene	<0.01 – 1.6mg/kg	170mg/kg		None
Anthracene	<0.01 -0.45 mg/kg	2,400mg/kg		None
Benzo(a)anthracene	<0.01mg/kg	7.2mg/kg		None
Benzo(a)pyrene	<0.01mg/kg	2.2mg/kg		None
Benzo(b)fluoranthene	<0.01mg/kg	2.6mg/kg		None
Benzo(ghi)perylene	<0.01mg/kg	320mg/kg		None
Benzo(k)fluoranthene	<0.01mg/kg	77mg/kg		None
Chrysene	<0.01mg/kg	15mg/kg		None
Dibenzo(a,h)anthracene	<0.01mg/kg	0.24mg/kg		None
Fluoranthene	<0.01 – 1.1mg/kg	280mg/kg		None
Fluorene	<0.01 – 1.9mg/kg	170mg/kg		None
Indeno(123-cd)pyrene	<0.01 - mg/kg	27mg/kg		None
Naphthalene	<0.01 – 4.6mg/kg	2.3mg/kg		1 of 4
Phenanthrene	<0.01 – 2.5mg/kg	95mg/kg		None
Pyrene	<0.01 – 1.2mg/kg	620mg/kg		None
Aliphatic Petroleum Hydrocarbons (Equivalent Carbon Number)				
Ali EC 5-6	<1.0mg/kg	42mg/kg	S4UL[3,9]	None
Ali EC 6-8	<1.0mg/kg	100mg/kg		None
Ali EC 8-10	<1.0mg/kg	27mg/kg		None
Ali EC 10-12	<1.0mg/kg	130mg/kg*		None
Ali EC 12-16	<1.0mg/kg	1,100mg/kg*		None
Ali EC 16-35	<2.0mg/kg	65,000mg/kg*		None
Ali EC 35-44	<1.0mg/kg	65,000mg/kg*		None
Aromatic Petroleum Hydrocarbons (Equivalent Carbon Number)				
Aro EC 5-7	<1.0mg/kg	70mg/kg	S4UL[3,9]	None
Aro EC 7-8	<1.0mg/kg	130mg/kg		None
Aro EC 8-10	<1.0mg/kg	34mg/kg		None
Aro EC 10-12	<1.0mg/kg	74mg/kg		None
Aro EC 12-16	<1.0mg/kg	140mg/kg		None
Aro EC 16-21	<1.0mg/kg	260mg/kg		None
Aro EC 21-35	<1.0mg/kg	1,100mg/kg		None
Aro EC 35-44	<1.0mg/kg	1,100mg/kg		None
Asbestos	None detected in laboratory samples			

Notes

1. Assessment for residential land use with home-grown produce (apart from barium – see Note 4 below).
2. CLR SGV: Soil Guideline Value published by Environment Agency.
3. S4ULs Suitable 4 Use Levels. Copyright Land Quality Management Limited, reproduced with permission; Publication No. S4UL3156. All Rights Reserved.
4. CL:AIRE/EIC GAC published by CL:AIRE and Environment Industries Commission.
5. C4SL: Category 4 Screening Level. No current SGV, S4UL or CLAIRE/EIC assessment criteria for lead. Category 4 Screening Level adopted in assessment.
6. GAC for barium for residential use without plant uptake. No GAC published for plant uptake risk drivers.
7. In the absence of Chromium VI, all chromium present likely to be Chromium III. GAC for Chromium III adopted.
8. GAC for inorganic mercury adopted.
9. GAC for organic compounds based on 1% soil organic content.
10. GAC for xylene based on p-xylene (lowest S4UL).
11. ESP - Generic Assessment Criteria generated by ESP using CLEA software.
12. Exceedances highlighted in red and bold.
13. Laboratory results presented in Appendix G.
14. Arcadis results not discussed for Area A as below guideline values.

Table 10: Summary of Geo-environmental Soil Results (Area B – Generally comprising infilled land)

Determinand	Exceedances Recorded By Arcadis 2018*	Range Recorded ESP 2019	GAC	Source of GAC	Exceedances (Of 10no. samples)
Metals and Semi-metals					
Arsenic	37-110mg/kg	13-47mg/kg	32mg/kg	SGV[2]	2 of 10
Barium[6]	-	50-190mg/kg	1,300mg/kg	CL:AIRE[4]	None
Beryllium	-	<1.0-1.7mg/kg	1.7mg/kg	S4UL[3]	None
Cadmium	-	0.11-1.2mg/kg	10mg/kg	SGV[2]	None
Chromium (total)[7]	-	16-34mg/kg	910mg/kg	S4UL[3]	None
Chromium (hexavalent)	-	<0.5mg/kg	6.0mg/kg	S4UL[3]	None
Copper	-	18-86mg/kg	2,400mg/kg	S4UL[3]	None
Lead	-	14-290mg/kg	200mg/kg	C4SL[5]	None
Mercury[8]	-	<0.1-0.18mg/kg	170mg/kg	SGV[2]	None
Nickel	-	16-66mg/kg	130mg/kg	SGV[2]	None
Selenium	-	0.33-1.3mg/kg	350mg/kg	SGV[2]	None
Vanadium	-	14-27mg/kg	410mg/kg	S4UL[3]	None
Zinc	-	40-140mg/kg	3,700mg/kg	S4UL[3]	None
Polyaromatic Hydrocarbons (PAH)					
Acenaphthene	-	<0.01 - mg/kg	210mg/kg		None
Acenaphthylene	-	<0.01 – 1.4mg/kg	170mg/kg		None
Anthracene	-	<0.01 – 7.8mg/kg	2,400mg/kg		None
Benzo(a)anthracene	-	<0.01 – 9.8mg/kg	7.2mg/kg		None
Benzo(a)pyrene	<0.1 – 3.1mg/kg	<0.01 – 9.6mg/kg	2.2mg/kg		3 of 10
Benzo(b)fluoranthene	<0.1 – 5.7mg/kg	<0.01 - 12mg/kg	2.6mg/kg		3 of 10
Benzo(ghi)perylene	-	<0.01 - mg/kg	320mg/kg		None
Benzo(k)fluoranthene	-	<0.01 – 3.9mg/kg	77mg/kg	S4UL[3,9]	None
Chrysene	-	<0.01 - 10mg/kg	15mg/kg		None
Dibenzo(a,h)anthracene	<0.1 – 0.59mg/kg	<0.01 – 1.0mg/kg	0.24mg/kg		3 of 10
Fluoranthene	-	<0.01 - 27mg/kg	280mg/kg		None
Fluorene	-	<0.01 – 5.9mg/kg	170mg/kg		None
Indeno(123-cd)pyrene	-	<0.01 – 6.2mg/kg	27mg/kg		None
Naphthalene	-	<0.01 – 7.0mg/kg	2.3mg/kg		1 of 10
Phenanthrene	-	<0.01 - 34mg/kg	95mg/kg		None
Pyrene	-	<0.01 - 29mg/kg	620mg/kg		None
Aliphatic Petroleum Hydrocarbons (Equivalent Carbon Number)					
Ali EC 5-6	-	<1.0mg/kg	42mg/kg		None
Ali EC 6-8	-	<1.0mg/kg	100mg/kg		None
Ali EC 8-10	-	<1.0mg/kg	27mg/kg		None
Ali EC 10-12	-	<1.0mg/kg	130mg/kg*	S4UL[3,9]	None
Ali EC 12-16	-	<1.0-8.3mg/kg	1,100mg/kg*		None
Ali EC 16-35	-	<2.0-58mg/kg	65,000mg/kg*		None
Ali EC 35-44	-	<1.0mg/kg	65,000mg/kg*		None
Aromatic Petroleum Hydrocarbons (Equivalent Carbon Number)					
Aro EC 5-7	-	<1.0mg/kg	70mg/kg		None
Aro EC 7-8	-	<1.0mg/kg	130mg/kg		None
Aro EC 8-10	-	<1.0mg/kg	34mg/kg		None
Aro EC 10-12	-	<1.0mg/kg	74mg/kg	S4UL[3,9]	None
Aro EC 12-16	-	<1.0mg/kg	140mg/kg		None
Aro EC 16-21	-	<1.0-13mg/kg	260mg/kg		None
Aro EC 21-35	-	<1.0-76mg/kg	1,100mg/kg		None
Aro EC 35-44	-	<1.0mg/kg	1,100mg/kg		None

Asbestos	None detected in laboratory samples

Notes

1. Assessment for residential land use with home-grown produce (apart from barium – see Note 4 below).
2. CLR SGV: Soil Guideline Value published by Environment Agency.
3. S4ULs Suitable 4 Use Levels. Copyright Land Quality Management Limited, reproduced with permission; Publication No. S4UL3156. All Rights Reserved.
4. CL:AIRE/EIC GAC published by CL:AIRE and Environment Industries Commission.
5. C4SL: Category 4 Screening Level. No current SGV, S4UL or CLAIRE/EIC assessment criteria for lead. Category 4 Screening Level adopted in assessment.
6. GAC for barium for residential use without plant uptake. No GAC published for plant uptake risk drivers.
7. In the absence of Chromium VI, all chromium present likely to be Chromium III. GAC for Chromium III adopted.
8. GAC for inorganic mercury adopted.
9. GAC for organic compounds based on 1% soil organic content.
10. GAC for xylene based on p-xylene (lowest S4UL).
11. ESP - Generic Assessment Criteria generated by ESP using CLEA software.
12. Exceedances highlighted in red and bold.
13. Laboratory results presented in Appendix G.
14. Exceedances of guideline values as identified in Arcadis report.

Table 11: Summary of Geo-environmental Soil Results (Area C – Generally comprising landfill materials)

Determinand	Range Recorded ESP 2019*	GAC	Source of GAC	Exceedances (Of 9no. samples)
Metals and Semi-metals				
Arsenic	13-33mg/kg	32mg/kg	SGV[2]	1 of 9
Barium[6]	51-240mg/kg	1,300mg/kg	CL:AIRE[4]	None
Beryllium	<1.0mg/kg	1.7mg/kg	S4UL[3]	None
Cadmium	0.15-0.61mg/kg	10mg/kg	SGV[2]	None
Chromium (total)[7]	11-31mg/kg	910mg/kg	S4UL[3]	None
Chromium (hexavalent)	<0.5mg/kg	6.0mg/kg	S4UL[3]	None
Copper	13-240mg/kg	2,400mg/kg	S4UL[3]	None
Lead	19-100mg/kg	200mg/kg	C4SL[5]	None
Mercury[8]	<0.1-0.42mg/kg	170mg/kg	SGV[2]	None
Nickel	21-59mg/kg	130mg/kg	SGV[2]	None
Selenium	0.36-0.98mg/kg	350mg/kg	SGV[2]	None
Vanadium	18-34mg/kg	410mg/kg	S4UL[3]	None
Zinc	24-270mg/kg	3,700mg/kg	S4UL[3]	None
Polyaromatic Hydrocarbons (PAH)				
Acenaphthene	<0.01 – 2.6mg/kg	210mg/kg	S4UL[3,9]	None
Acenaphthylene	<0.01 – 1.0mg/kg	170mg/kg		None
Anthracene	<0.01 – 2.7mg/kg	2,400mg/kg		None
Benzo(a)anthracene	<0.01 – 4.7mg/kg	7.2mg/kg		None
Benzo(a)pyrene	<0.01 – 3.2mg/kg	2.2mg/kg		2 of 9
Benzo(b)fluoranthene	<0.01 – 6.5mg/kg	2.6mg/kg		None
Benzo(ghi)perylene	<0.01 – 2.3mg/kg	320mg/kg		None
Benzo(k)fluoranthene	<0.01 – 2.8mg/kg	77mg/kg		None
Chrysene	<0.01 – 6.4mg/kg	15mg/kg		None
Dibenzo(a,h)anthracene	<0.01 – 0.98mg/kg	0.24mg/kg		2 of 9
Fluoranthene	<0.01 - 12mg/kg	280mg/kg		None
Fluorene	<0.01 – 2.9mg/kg	170mg/kg		None
Indeno(123-cd)pyrene	<0.01 – 2.6mg/kg	27mg/kg		None
Naphthalene	<0.01 – 1.8mg/kg	2.3mg/kg		None
Phenanthrene	<0.01 - 11mg/kg	95mg/kg		None
Pyrene	<0.01 - 10mg/kg	620mg/kg		None
Aliphatic Petroleum Hydrocarbons (Equivalent Carbon Number)				
Ali EC 5-6	<1.0mg/kg	42mg/kg	S4UL[3,9]	None
Ali EC 6-8	<1.0mg/kg	100mg/kg		None
Ali EC 8-10	<1.0-7.2mg/kg	27mg/kg		None
Ali EC 10-12	<1.0-21mg/kg	130mg/kg*		None
Ali EC 12-16	<1.0-67mg/kg	1,100mg/kg*		None
Ali EC 16-35	<2.0346mg/kg	65,000mg/kg*		None
Ali EC 35-44	<1.0-41mg/kg	65,000mg/kg*		None
Aromatic Petroleum Hydrocarbons (Equivalent Carbon Number)				
Aro EC 5-7	<1.0mg/kg	70mg/kg	S4UL[3,9]	None
Aro EC 7-8	<1.0mg/kg	130mg/kg		None
Aro EC 8-10	<1.0mg/kg	34mg/kg		None
Aro EC 10-12	<1.0-13mg/kg	74mg/kg		None
Aro EC 12-16	<1.0-240mg/kg	140mg/kg		1 of 9
Aro EC 16-21	4.7-590mg/kg	260mg/kg		1 of 9
Aro EC 21-35	180-1600mg/kg	1,100mg/kg		1 of 9
Aro EC 35-44	<1.0-130mg/kg	1,100mg/kg		None
Asbestos	None detected in laboratory samples			

Notes
1. Assessment for residential land use with home-grown produce (apart from barium – see Note 4 below).
2. CLR SGV: Soil Guideline Value published by Environment Agency.
3. S4ULs Suitable 4 Use Levels. Copyright Land Quality Management Limited, reproduced with permission; Publication No. S4UL3156. All Rights Reserved.
4. CL:AIRE/EIC GAC published by CL:AIRE and Environment Industries Commission.
5. C4SL: Category 4 Screening Level. No current SGV, S4UL or CLAIRE/EIC assessment criteria for lead. Category 4 Screening Level adopted in assessment.
6. GAC for barium for residential use without plant uptake. No GAC published for plant uptake risk drivers.

7. In the absence of Chromium VI, all chromium present likely to be Chromium III. GAC for Chromium III adopted.
8. GAC for inorganic mercury adopted.
9. GAC for organic compounds based on 1% soil organic content.
10. GAC for xylene based on p-xylene (lowest S4UL).
11. ESP - Generic Assessment Criteria generated by ESP using CLEA software.
12. Exceedances highlighted in red and bold.
13. Laboratory results presented in Appendix G.
14. Arcadis results not discussed for Area A as below guideline values.

Table 12: Summary of Geo-environmental Soil Results (Area D – Generally natural soils)

Determinand	Range Recorded ESP 2019*	GAC	Source of GAC	Exceedances (Of 12no. samples)
Metals and Semi-metals				
Arsenic	13-21mg/kg	32mg/kg	SGV[2]	None
Barium[6]	110-200mg/kg	1,300mg/kg	CL:AIRE[4]	None
Beryllium	1.0-1.4mg/kg	1.7mg/kg	S4UL[3]	None
Cadmium	0.70-1.9mg/kg	10mg/kg	SGV[2]	None
Chromium (total)[7]	26-36mg/kg	910mg/kg	S4UL[3]	None
Chromium (hexavalent)	<0.5mg/kg	6.0mg/kg	S4UL[3]	None
Copper	36-50mg/kg	2,400mg/kg	S4UL[3]	None
Lead	37-50mg/kg	200mg/kg	C4SL[5]	None
Mercury[8]	<0.1-0.27mg/kg	170mg/kg	SGV[2]	None
Nickel	32-69mg/kg	130mg/kg	SGV[2]	None
Selenium	0.23-0.80mg/kg	350mg/kg	SGV[2]	None
Vanadium	34-44mg/kg	410mg/kg	S4UL[3]	None
Zinc	79-130mg/kg	3,700mg/kg	S4UL[3]	None
Polyaromatic Hydrocarbons (PAH)				
Acenaphthene	<0.1	210mg/kg		None
Acenaphthylene	<0.1 – 0.18	170mg/kg		None
Anthracene	<0.1	2,400mg/kg		None
Benzo(a)anthracene	<0.1 – 0.41	7.2mg/kg		None
Benzo(a)pyrene	<0.1 – 0.2	2.2mg/kg		2 of 12
Benzo(b)fluoranthene	<0.1 – 0.21	2.6mg/kg		None
Benzo(ghi)perylene	<0.1 – 0.33	320mg/kg		None
Benzo(k)fluoranthene	<0.1	77mg/kg	S4UL[3,9]	None
Chrysene	<0.1 – 0.41	15mg/kg		None
Dibenzo(a,h)anthracene	<0.1-0.16	0.24mg/kg		2 of 12
Fluoranthene	0.26-0.41	280mg/kg		None
Fluorene	<0.1	170mg/kg		None
Indeno(123-cd)pyrene	<0.1-0.17	27mg/kg		None
Naphthalene	<0.1-0.26	2.3mg/kg		None
Phenanthrene	<0.1-0.45	95mg/kg		None
Pyrene	<0.1-0.52	620mg/kg		None
Aliphatic Petroleum Hydrocarbons (Equivalent Carbon Number)				
Ali EC 5-6	<1.0mg/kg	42mg/kg		None
Ali EC 6-8	<1.0mg/kg	100mg/kg		None
Ali EC 8-10	<1.0-2.8mg/kg	27mg/kg		None
Ali EC 10-12	<1.0-50mg/kg	130mg/kg*	S4UL[3,9]	None
Ali EC 12-16	<1.0-270mg/kg	1,100mg/kg*		None
Ali EC 16-35	<2.0-690mg/kg	65,000mg/kg*		None
Ali EC 35-44	<1.0-7.6mg/kg	65,000mg/kg*		None
Aromatic Petroleum Hydrocarbons (Equivalent Carbon Number)				
Aro EC 5-7	<1.0mg/kg	70mg/kg		None
Aro EC 7-8	<1.0mg/kg	130mg/kg		None
Aro EC 8-10	<1.0-28mg/kg	34mg/kg		None
Aro EC 10-12	<1.0-77mg/kg	74mg/kg		1 of 5
Aro EC 12-16	<1.0-480mg/kg	140mg/kg	S4UL[3,9]	1 of 5
Aro EC 16-21	<1.0-530mg/kg	260mg/kg		1 of 5
Aro EC 21-35	180-770mg/kg	1,100mg/kg		None
Aro EC 35-44	<1.0-28mg/kg	1,100mg/kg		None
Asbestos	None detected in laboratory samples			

Notes

1. Assessment for residential land use with home-grown produce (apart from barium – see Note 4 below).
2. CLR SGV: Soil Guideline Value published by Environment Agency.
3. S4ULs Suitable 4 Use Levels. Copyright Land Quality Management Limited, reproduced with permission; Publication No. S4UL3156. All Rights Reserved.
4. CL:AIRE/EIC GAC published by CL:AIRE and Environment Industries Commission.
5. C4SL: Category 4 Screening Level. No current SGV, S4UL or CLAIRE/EIC assessment criteria for lead. Category 4 Screening Level adopted in assessment.

6. GAC for barium for residential use without plant uptake. No GAC published for plant uptake risk drivers.
7. In the absence of Chromium VI, all chromium present likely to be Chromium III. GAC for Chromium III adopted.
8. GAC for inorganic mercury adopted.
9. GAC for organic compounds based on 1% soil organic content.
10. GAC for xylene based on p-xylene (lowest S4UL).
11. ESP - Generic Assessment Criteria generated by ESP using CLEA software.
12. Exceedances highlighted in red and bold.
13. Laboratory results presented in Appendix G.
14. Arcadis results not discussed for Area A as below guideline values.

5.6 Statistical Analysis

The results of the testing for determinands which have been identified at levels in excess of the Generic Assessment Criteria (GAC) in at least one sample in each area, have been assessed statistically in accordance with CIEH/CL:AIRE (2008).

Whilst a much large sample population will be required on an area by area basis, a summary of the preliminary statistical analysis is presented in Table 13 below and the results provide in Appendix M.

Table 13: Summary of Preliminary Statistical Analysis

Area	Exceedances Recorded For	Outcome of Preliminary Statistical Analysis
A	PAH	Outlier present and more information required.
B	Arsenic, PAH	Outliers present and more information required.
C	Arsenic, PAH, TPH	Outliers present and more information required.
D	PAH, TPH	Outlier present and more information required.

5.7 New Planting

Soil contamination can have a deleterious impact on the health of new plants. Such ‘phytotoxic’ effects can include inhibited growth, nutrient deficiencies and discolouration of vegetation. However, the potential impact on planting is difficult to quantify partly due to differing abilities of various plants to tolerate different soil conditions.

Contaminants are taken up by plants in a number of ways, the principal mechanism being via root uptake, but also including adsorption to roots. The impact on contaminants on plant growth depends on a number of factors, including the plant species, the soil type, the soil pH, the availability of the contaminant, and the impact of other external stresses on the plant such as drought.

The British Standard for the provision of Topsoil (BS3882:2007) provides guidance on acceptable levels of copper, nickel and zinc within a growing medium, which vary with soil pH value. ICRCL 70/90 (1990) discussing the restoration of metalliferous mining sites also provides ‘threshold trigger levels’ for a number of metals and fluoride, below which there should be no impact on plant growth. Finally MAFF (1998) provides assessment criteria for the assessment of the impact of a number of metals on the growth of plants. For the purposes of this assessment, we have adopted the BS3882 guidance values in the first instance, followed by the MAFF published guidelines, and finally the ICRCL ‘trigger values’.

The assessment along with the assessment criteria adopted are presented in Tables 14 to 17 below:

Table 14: Summary of Assessment Criteria for Planting – Area A

Determinand	Range Recorded ESP & Arcadis	GAC	Source of GAC	Exceedances
Metals and Semi-metals				
Arsenic	16-21mg/kg	250mg/kg	MAFF[1]	None
Cadmium	0.8-1.4mg/kg	3mg/kg	ICRCL[2]	None
Chromium (total)[6]	29-37mg/kg	400mg/kg	MAFF[1]	None
Copper	45-52mg/kg	200mg/kg (pH>7)	BS3882[3]	None
Lead	38-58mg/kg	300mg/kg	MAFF[1]	None
Mercury	<0.1-0.1mg/kg	1mg/kg	MAFF[1]	None
Nickel	43-76mg/kg	110mg/kg (pH>7)	BS3882[3]	None
Zinc	100-160mg/kg	300mg/kg (pH>7)	BS3882[3]	None

Notes
1. MAFF: Ministry of Agriculture, Fisheries and Food guideline for maximum permissible concentrations in agricultural soils.
2. ICRCL: ICRCL 70/90.
3. BS3882:2007 – values dependent on soil pH values.

From Table 14, it can be seen that the levels of the potentially phytotoxic contaminants recorded in Area A were all below the respective assessment criteria.

Table 15: Summary of Assessment Criteria for Planting – Area B

Determinand	Range Recorded ESP & Arcadis	GAC	Source of GAC	Exceedances
Metals and Semi-metals				
Arsenic	13-47mg/kg	250mg/kg	MAFF[1]	None
Cadmium	0.1-1.2mg/kg	3mg/kg	ICRCL[2]	None
Chromium (total)[6]	16-34mg/kg	400mg/kg	MAFF[1]	None
Copper	18-86mg/kg	200mg/kg (pH>7)	BS3882[3]	None
Lead	14-290mg/kg	300mg/kg	MAFF[1]	None
Mercury	<0.1-0.18mg/kg	1mg/kg	MAFF[1]	None
Nickel	16-66mg/kg	110mg/kg (pH>7)	BS3882[3]	None
Zinc	40-140mg/kg	300mg/kg (pH>7)	BS3882[3]	None

Notes
1. MAFF: Ministry of Agriculture, Fisheries and Food guideline for maximum permissible concentrations in agricultural soils.
2. ICRCL: ICRCL 70/90.
3. BS3882:2007 – values dependent on soil pH values.

From Table 15, it can be seen that the levels of the potentially phytotoxic contaminants recorded in Area B were all below the respective assessment criteria.

Table 16: Summary of Assessment Criteria for Planting – Area C

Determinand	Range Recorded ESP & Arcadis	GAC	Source of GAC	Exceedances
Metals and Semi-metals				
Arsenic	13-33mg/kg	250mg/kg	MAFF[1]	None
Cadmium	0.15-0.61mg/kg	3mg/kg	ICRCL[2]	None
Chromium (total)[6]	11-31mg/kg	400mg/kg	MAFF[1]	None
Copper	13-240mg/kg	200mg/kg (pH>7)	BS3882[3]	1 of 9
Lead	19-100mg/kg	300mg/kg	MAFF[1]	None
Mercury	<0.1-0.42mg/kg	1mg/kg	MAFF[1]	None
Nickel	21-59mg/kg	110mg/kg (pH>7)	BS3882[3]	None
Zinc	24-270mg/kg	300mg/kg (pH>7)	BS3882[3]	None

Notes
1. MAFF: Ministry of Agriculture, Fisheries and Food guideline for maximum permissible concentrations in agricultural soils.
2. ICRCL: ICRCL 70/90.
3. BS3882:2007 – values dependent on soil pH values.

As identified in Table 16, the testing has indicated that in Area C, levels of copper to be present at concentrations which could be potentially phytotoxic to new planting. This should be considered in designing the planting regime for the development.

Table 17: Summary of Assessment Criteria for Planting – Area D

Determinand	Range Recorded ESP & Arcadis	GAC	Source of GAC	Exceedances
Metals and Semi-metals				
Arsenic	13-21mg/kg	250mg/kg	MAFF[1]	None
Cadmium	0.7 – 1.9mg/kg	3mg/kg	ICRCL[2]	None
Chromium (total)[6]	26-36mg/kg	400mg/kg	MAFF[1]	None
Copper	35-50mg/kg	200mg/kg (pH>7)	BS3882[3]	None
Lead	37-50mg/kg	300mg/kg	MAFF[1]	None
Mercury	<0.1-0.27mg/kg	1mg/kg	MAFF[1]	None
Nickel	32-69mg/kg	110mg/kg (pH>7)	BS3882[3]	None
Zinc	79-130mg/kg	300mg/kg (pH>7)	BS3882[3]	None

Notes
1. MAFF: Ministry of Agriculture, Fisheries and Food guideline for maximum permissible concentrations in agricultural soils.
2. ICRCL: ICRCL 70/90.
3. BS3882:2007 – values dependent on soil pH values.
4. Laboratory test results presented in Appendix ??.

From Table 17, it can be seen that the levels of the potentially phytotoxic contaminants recorded in Area D were all below the respective assessment criteria.

5.8 Risks to Controlled Waters (Areas A – D)

Collection of groundwater samples was undertaken as part of the ongoing monitoring regime and reported separately by ESP as a preliminary Controlled Waters Risk Assessment (CWRA) in August 2019 (Ref; 7061d.3215). At the request of the Client, the CWRA has been included as an appendix to this report revision (see Appendix N) and is discussed further in Section 7.2.

5.9 Ground Gas (Areas A – D)

5.9.1 Degradation of Organic Materials

The likelihood and severity of a gassing event is considered as part of the risk assessment process in accordance with C665 (Wilson et al, 2007).

The Preliminary Risk Assessment (Section 3.1.3) has identified the following potential sources of hazardous ground gas which could impact on the proposed development:

1. General Made Ground (whole site),
2. Historic Filling of Former Quarry (Area B);
3. Historic Landfill (Area C) extending beyond boundary to the south;
4. Area E (infilled quarry); and
5. Former landfill (now housing) to the north.

Works undertaken by Arcadis have indicated maximum levels of methane in the area of landfill of 37% and carbon dioxide, 21%. Outside the landfill, concentrations were generally noted to be lower.

Ground gas wells installed by ESP have been monitored on 12no. occasions with the results of the monitoring presented in Table 18 below and discussed further in Section 7.3.

Table 18: Summary of Gas Monitoring Data (Visits 1 to 12)

Area	Well	No visits	Methane (%)	Carbon dioxide (%)	Oxygen (%)	Gas Flow (L/hr)	Atmospheric pressure
A	E-BH1	12	Nd – 0.5	Nd – 5.4	8.5 - 21.8	0.0	992 – 1030 including low, high, falling, rising and steady pressure states.
	E-BH2	12	Nd – 1.7	Nd – 5.1	14.7 – 21.9	0.0 – 0.1	
	E-BH3	12	Nd	Nd – 8.3	6.2 – 21.8	0.0 – 0.6	
	E-BH4	12	Nd	Nd – 4.9	3.3 – 22.1	0.0 – 7.4	
B	E-BH5(s)	12	Nd	Nd – 1.9	20.6 - 21.8	0.0 -0.5	
	E-BH5(d)	12	Nd	Nd – 1.7	20.0 – 21.7	0.0 – 0.5	
	E-BH6(s)	12	Nd	Nd – 2.4	19.5 – 21.7	0.0 - .0.6	
	E-BH6(d)	12	Nd – 1.6	Nd – 2.8	19.4 – 21.6	0.0 – 0.4	
	E-BH7(s)	12	Nd	Nd – 3.5	18.3 – 21.6	0.0 – 0.8	
	E-BH7(d)	12	Nd	Nd – 5.0	17.5 – 21.4	0.0 – 0.4	
C	E-BH8(s)	12	Nd – 20.5	Nd – 32.0	0.3 – 21.4	0.0 – 2.4	
	E-BH8(d)	12	Nd –1.2	Nd – 8.0	14.5 – 21.4	0.0 – 0.7	
	E-BH9(s)	12	Nd –33.5	Nd – 26.0	0.4 – 21.5	0.0 – 1.4	
	E-BH9(d)	12	Nd –5.1	Nd – 8.4	11.7 – 21.4	0.0 – 0.3	
	E-BH10(s)	12	Nd – 42.0	Nd – 28.0	0.5 – 21.2	0.0 – 3.7	
	E-BH10(d)	12	Nd – 8.8	Nd –9.5	12.3 – 21.5	0.0 – 1.7	
D	E-BH11	12	Nd	Nd – 4.8	8.4 – 21.2	0.0 – 0.2	
	E-BH12	12	ND – 3.6	Nd – 4.0	12.7 – 21.6	0.0 – 2.5	
	E-BH13	12	Nd	Nd – 4.1	18.6 – 22.0	0.0 – 1.9	

Notes:
1. Wells were installed with response zones in targeted strata, see Section 4.7.1 and Table 5 for details.
2. Nd – none detected with instrument (<0.2% for methane, <0.1% for carbon dioxide).

The results were then assessed in general accordance with the CIRIA document C665, Assessing Risks Posed by Hazardous Ground Gases to buildings. The results are shown in Table 19 below.

Table 19 - Maximum Gas/Flow Levels and Calculated GSV

Hazardous Gas	Maximum Recorded Level (%)	Maximum Gas Flow Rate (L/hr)	GSV (L/hr)	Characteristic Situation
Area A				
Methane	1.7	7.4	0.1258	CS-2
Carbon dioxide	8.3	7.4	0.6142	CS-2
Area B				
Methane	1.6	0.8	0.0128	CS-1 *increase to CS-2
Carbon dioxide	5.0	0.8	0.04	CS-1 *increase to CS-2
Area C				
Methane	42.0	3.7	1.554	CS-3
Carbon dioxide	32.0	3.7	1.184	CS-3
Area D				
Methane	3.6	2.5	0.09	CS-2
Carbon dioxide	4.8	2.5	0.12	CS-2

Based on the available results, Areas A and D are classified as CS-2 and Area C classified as CS-3. Area B, based on GSV, is classified as CS-1, however in line with CIRIA C665 and BS8485 +A1:2019, as methane is noted to exceed 1% and Carbon Dioxide 5%, the classification should be increased to CS-2. The implications of the Characteristic Situation are discussed further in Section 7.3.

5.9.2 Radon

As discussed in the Arcadis Desk Study, no radon protection is required for the development.

5.10 Sulphate Attack

The assessment of the concrete protection against sulphate attack has been undertaken in accordance with BRE SD1 (2005).

5.10.1 Classification of Site:

Due to the presence of Made Ground and areas of previous development at the site, we consider that it should be considered as 'brownfield' in terms of concrete classification.

5.10.2 Groundwater Setting:

Groundwater level monitoring has indicated the presence of a consistent groundwater body within the bedrock. Shallow groundwater bodies are also recorded in the Made Ground in Area B and within the landfill in Area C. It should be noted that in most areas of the site, the surface was soft and waterlogged.

5.10.3 Sulphate Levels (Area A)

Laboratory test results indicate the levels of water soluble sulphate (as SO_4) in the Made Ground soils to be between 10 and 30mg/l. As levels of water soluble sulphate are less than 3,000mg/l, there is no need to consider the levels of magnesium present in the soils. Levels of acid soluble sulphate varied between 0.03 and 0.1% and total sulphur between 0.06 and 0.23%. From these results, the calculated levels of total potential sulphate are between 0.18 and 69%, and oxidisable sulphides are between 0.08 and 0.62%. As the level of oxidisable sulphides exceeds 0.3%, pyrite is likely to be present.

pH values varied between 7.5 and 8.4, indicating near neutral slightly alkaline soil conditions to exist. As the pH levels all exceed 5.5, there is no need to further assess the soils for the types of acids present (e.g. hydrochloric and nitric acids).

5.10.4 Sulphate Levels (Area B)

Laboratory test results indicate the levels of water soluble sulphate (as SO_4) in the Made Ground soils to be between 20 and 30mg/l. As levels of water soluble sulphate are less than 3,000mg/l, there is no need to consider the levels of magnesium present in the soils. Levels of acid soluble sulphate varied between 0.16 and 0.23% and total sulphur between 0.02 and 0.1%. From these results, the calculated levels of total potential sulphate are between 0.24 and 0.3%, and oxidisable sulphides are between 0.06 and 0.08%. As the levels of oxidisable sulphide are well below 0.3%, pyrite is unlikely to be present.

pH values varied between 7.2 and 7.8, indicating near neutral/slightly alkaline soil conditions to exist. As the pH levels all exceed 5.5, there is no need to further assess the soils for the types of acids present (e.g. hydrochloric and nitric acids).

5.10.5 Sulphate Levels (Area C)

As Area C is anticipated to comprise Public Open Space, a classification of sulphate attack has not been undertaken at present. Should this requirement change a detailed assessment of the potential for sulphate attack will be required through the landfill material for pile design (see Section 8.0), however, it is anticipated an advanced concrete class would be required in Area C.

5.10.6 Sulphate Levels (Area D)

Laboratory test results indicate the levels of water soluble sulphate (as SO_4) in the Made Ground soils to be between 10 and 40mg/l. As levels of water soluble sulphate are less than 3,000mg/l, there is no need to consider the levels of magnesium present in the soils. Levels of acid soluble sulphate varied between 0.05 and 0.25% and total sulphur between 0.02 and 0.11%. From these results, the calculated levels of total potential sulphate are between 0.04 and 0.16%, and oxidisable sulphides are between 0.01 and 0.08%. As the levels of oxidisable sulphide are well below 0.3%, pyrite is unlikely to be present.

pH values varied between 7.4 and 8.5, indicating near neutral /slightly alkaline soil conditions to exist. As the pH levels all exceed 5.5, there is no need to further assess the soils for the types of acids present (e.g. hydrochloric and nitric acids).

5.10.7 Foundation Concrete Design:

Using the above results, we consider that the following characteristic values are applicable for the shallow soils at the site (all as SO_4), as presented in Table 20 below.

Table 20: Summary of Sulphate Classification Data (Areas A, B and D)

Determinand	Area A	Area B	Area D
Water Soluble Sulphate (mg/l)	30	30	40
Total Potential Sulphate (%)	0.69	0.3	0.33
pH Value	7.5	7.2	7.4

This assessment of soil sulphate and pH levels has been used to provide a concrete classification on an area by area basis, as presented in Section 7.4.2.

6 Phase Two Geo-Environmental Risk Assessment

6.1 Discussion on Occurrence of Contamination and Distribution (Areas A – D)

The site is located within the existing Cosmeston Farm and as described throughout this report, has been split into a number of Areas for concise description and assessment for a proposed site Masterplan. It is anticipated that supplementary investigation and assessment will be required on an Area by Area basis, undertaken by individual developers. The areas discussed by ESP comprise:

- Area A – Comprising the West fields that make up the winter paddocks and fields associated with the livery;
- Area B – The historic former quarry/infilled land now used as summer paddocks;
- Area C – The historic former quarry and part of a former landfill;
- Area D – The North/North East fields that are currently used for crop growth.

In Area A and D, a general ground model comprising Topsoil over weathered bedrock has been identified, with limited Made Ground and/or contamination sources identified.

In Area B, a thick cover of general Made Ground has been identified that generally comprises reworked bedrock materials, with occasional man made fragment such as brick, concrete, ash and slag etc.

In Area C, extensive and highly variable landfill materials have been identified The landfill materials generally comprise domestic and commercial type refuse.

Preliminary laboratory testing has indicated the presence of Arsenic, PAH and TPH in Areas, B and C and the presence of PAH and TPH compounds in Area D. A single elevated occurrence of Naphthalene was noted in Area A.

6.2 Revised Risk Evaluation & Relevant Pollutant Linkages

As discussed in detail within Section 3.2.1, the methodology set out in CIRIA C552 (2001) has been used to assess whether or not risks are acceptable, and to determine the need for collating further information or remedial action.

The risks evaluated at the desk study stage of this report (Table 6, Section 3.2.2) have been updated and revised in Tables 21 and 22 following information learned from the exploratory works and results of monitoring and laboratory testing.

Table 21: Plausible Risk Evaluation & Relevant Pollutant Linkages (RPL) – Areas A and D

Source	Pathway	Receptor	Classification of Consequence	Classification of Probability	Risk Category	Further Investigation/ Remedial Action
Potential contaminants in shallow soils	Direct contact/ inhalation/ ingestion of contaminated soil or dust	Site Users (residents)	Medium – potential for chronic levels.	Likely	Moderate	Arsenic and PAH compounds identified close to or just above guideline values, with further assessment required.
	Direct contact/ inhalation/ ingestion of contaminated soil or dust	Construction/ Maintenance Workers	Minor/Medium – standard PPE likely to be sufficient	Likely	Moderate/Low Risk	Arsenic and PAH compounds identified close to or just above guideline values, but likely to be managed by good site practice.
	Leaching of soil contaminants	Impact on Groundwater	Medium – site lies on Secondary A and B Aquifer	Likely[1]	Moderate	Ongoing monitoring and sampling of groundwaters with initial assessment of risk to Controlled Waters.
	Leaching of soil contaminants	Impact on Sully Brook	Medium – site lies adjacent to water course	Likely[1]	Moderate	
Asbestos in shallow soils	Ingestion of fibres	Construction/ Maintenance Workers	Medium – potential for chronic levels	Low Likelihood	Moderate/Low Risk	Not detected in samples submitted to laboratory.
Soil sulphate/ pyrite	Aggressive groundwater	Buried Concrete	Mild – damage to structures	High likelihood	Moderate Risk	Sulphate classification indicates an advanced concrete classification may be required. .
Hazardous ground gas/vapours, from gas migration from infilled land and landfill.	Asphyxiation/poisoning. Injury due to explosion.	Site Users/Visitors.	Severe – acute risk.	Likely[2]	High Risk	Ground gas protection measures are required – see Section 7.3.
	Damage through explosion.	Building/Property	Severe – acute risk.		High Risk	
	Asphyxiation/poisoning. Injury due to explosion.	Construction and Maintenance Workers.	Severe – acute risk.		High Risk	
Radon gas	Migration into Buildings	Site Users (residents)	Medium – potential for chronic levels	Low Likelihood	Low Risk	Nc protection required as reported by Arcadis Desk Study

Notes:
1. Groundwater monitoring is ongoing and a preliminary assessment of risk to Controlled Waters is to be provided.
2. Ground gas monitoring is ongoing.

Table 22: Plausible Risk Evaluation & Relevant Pollutant Linkages (RPL) – Areas B and C

Source	Pathway	Receptor	Classification of Consequence	Classification of Probability	Risk Category	Further Investigation/ Remedial Action
Potential contaminants in shallow soils including biological contaminants in landfill materials in Area C.	Direct contact/ inhalation/ ingestion of contaminated soil or dust	Site Users (residents)	Medium – potential for chronic levels.	High Liklihood[2]	High Risk	Arsenic, PAH and TPH compounds identified above guideline values, with further assessment required.
	Direct contact/ inhalation/ ingestion of contaminated soil or dust	Construction/ Maintenance Workers	Minor/Medium – standard PPE likely to be sufficient	High Liklihood[2]	High Risk	Protection of workers will need to be considered in detail, particularly in Area C.
	Leaching of soil contaminants	Impact on Groundwater	Medium – site lies on Secondary A and B Aquifer	High Liklihood[2]	High Risk	Ongoing monitoring and sampling of groundwaters with initial assessment of risk to Controlled Waters.
	Leaching of soil contaminants	Impact on Sully Brook	Medium – site lies adjacent to water course	High Liklihood[2]	High Risk	
Potential contaminants including biological within anecdotally recorded area of cattle pyre	Direct contact/ inhalation/ ingestion of contaminated soil or dust	Site Users (residents)	Medium – potential for chronic levels.	Likely	Moderate	Evidence is anecdotal, however, area not investigated during this phase of works and will require future consideration.
	Direct contact/ inhalation/ ingestion of contaminated soil or dust	Construction/ Maintenance Workers	Medium – standard PPE likely to be sufficient	Likely	Moderate Risk	
Asbestos in shallow soils	Ingestion of fibres	Construction/ Maintenance Workers	Medium – potential for chronic levels	Likely[3]	Moderate/ High Risk	Not detected in samples submitted to laboratory by ESP but identified in Area B by Arcadis.
Soil sulphate/ pyrite	Aggressive groundwater	Buried Concrete	Mild – damage to structures	High likelihood[4]	Moderate Risk	Sulphate classification indicates an advanced concrete classification may be required. .
Hazardous ground gas/vapours, from gas migration from infilled land and landfill.	Asphyxiation/poisoning. Injury due to explosion.	Site Users/Visitors.	Severe – acute risk.	High Likelihood [5]	Very High Risk	Ground gas protection measures are required – see Section 7.3.
	Damage through explosion.	Building/Property	Severe – acute risk.			
	Asphyxiation/poisoning. Injury due to explosion.	Construction and Maintenance Workers.	Severe – acute risk.			
Radon gas	Migration into Buildings	Site Users (residents)	Medium – potential for chronic levels	Low Likelihood	Low Risk	Nc protection required as reported by Arcadis Desk Study

Notes:

1. Groundwater monitoring is ongoing and a preliminary assessment of risk to Controlled Waters is to be provided.
2. Ground gas monitoring is ongoing.

7 Remedial Strategy For Contamination Risks (Areas A – D)

The following recommendations are based on interpretations made from the relatively limited site investigation data obtained to-date, and do not form the full Options Appraisal stage of CLR11.

It is understood that this investigation is required to inform a Masterplan and provide recommendations for further investigation and assessment in areas of the site as necessary. The scoping, sourcing and implementation of this phase of works, has been undertaken with multi-party input and has been impacted by a prescriptive scope of works provided by the Client and subsequently reviewed and amended by the project team.

It should be noted that to date no investigation works have been carried out in Area E (small quarry) or along the historical railway line that bisects the site due to ecological constraints. The recommendations below relate to the works undertaken to date in Areas A to D only and assume the non-investigated areas will be assessed under a separate investigation. Consideration will also have to be given for the potential for biological hazards within the landfill materials in Area C and the anecdotal evidence for a cattle pyre in Area B.

7.1 Risks to Health

7.1.1 Asbestos

No evidence of asbestos was detected in the any of the samples submitted to the laboratory by ESP. The Arcadis works, report the occurrence at one location at a depth of between 1.0m to 1.9m in Area B.

As parts of the site are occupied by landfill and other areas, previously developed with farm buildings, which commonly contained asbestos containing materials (ACM), the presence of asbestos in the landfill and/or Made Ground cannot be discounted.

Although no evidence has been identified in the investigation, on any historic farmland such as the site, it cannot be discounted that former hollows in the site surface may have been infilled in the past, and asbestos containing materials (ACM) may have been included in the backfill materials.

If any suspected asbestos containing materials (ACM) are identified during development, the advice of a suitably qualified specialist should be sought immediately. Any identified ACM would need to be removed from site by a licensed specialist contractor.

There is no clear UK guidance on what would constitute an acceptable concentration of asbestos in soil. Therefore, we recommend that all asbestos contaminated soils be removed from site prior to development. Working with asbestos (even within soils) is governed by the Control of Asbestos Regulations (2012). This requires that the excavation and removal of the asbestos contaminated soils musty be undertaken by a licensed contractor. Alternatively, an asbestos specialist may be employed to undertake further assessment of the risk from the asbestos present in the soils beneath the site with a view to investigating whether there would be an alternative risk mitigation method to prevent the expensive and non-sustainable removal and disposal of soils, such as use of capping layers. .

7.1.2 Site End Users

As discussed in Section 5.8.1, the levels of arsenic and some PAH compounds are elevated above the generic assessment criteria in Areas B, C and D and close to the guideline value for Area A. In addition to this, the presence of TPH compounds has been identified in Areas B, C and D.

At present the limited investigation has been aimed at informing the design master plan and as part of detailed design, further testing and assessment (including statistical) should be undertaken in all Areas to determine the likely resultant risk to site end users.

Additional testing and assessment can likely be used to reduce the risk in Areas A and D, where shallow, weathered rock has been identified below the topsoil or at least zone these Areas, so that mitigating measures can be reduced/removed in some or all parts of theses areas.

In Areas B and C, we would advise that whilst additional, detailed testing is required, it is very likely that a suitable geotextile separator and clean cover system will be required in all external parts of these Areas.

We understand that consideration is being given to the use of allotment gardens in Area C. If this design element is to be progressed, it will be necessary to utilise a suitable cover system (minimum 1.0m clean cap) separated from the underlying soils by a proprietary no dig membrane.

7.1.3 New Service Connections

The current water industry guidance for the suitability of pipe materials on potentially contaminated sites (Blackmore et al, 2010) has onerous requirements and it is likely/possible, based on this guidance, that the levels of contaminants on site may prevent the use of plastic pipework. We recommend that enquiries are made to the local water authority to confirm their requirements for underground service materials for this development.

7.1.4 Risk to Construction and Maintenance Workers

<u>General Site (Areas A and D)</u>

Short term (acute) risks to construction and maintenance workers are generally poorly understood within the industry, certainly when compared to the volume of research undertaken on long term risks. However, we anticipate that the levels of contamination at the site are not likely to pose a severe acute risk to construction workers or future maintenance workers.

Ground workers would need to undertake their own assessment of the risks to their workers, particularly in relation to works to be undertaken in the historic landfill and the appropriate protection and decontamination measures put in place to ensure protection of construction and maintenance workers.

Notwithstanding the above, we recommend that construction workers adopt careful handling of the potential contaminants and good standards of personal hygiene should be adopted to reduce the risk of possible ingestion and skin contact should any hotspots be encountered. The contractor should comply with the appropriate current Health and Safety at work legislation.

Landfill Areas (Areas B and C)

In addition to the above the recommendations contained within the Health and Safety Executive Document: *Protection of Workers and the General Public During the Development of Contaminated Land* (HSE, 1991) should be implemented.

The above precautions would be required for both construction workers during development and maintenance workers following development. A copy of this report and these recommendations should be included in the Health and Safety File for the development and provided to all future ground workers, including utility companies so that they may undertake their own assessment of risks to their operatives.

7.1.5 General Public/Neighbouring Properties

We do not anticipate any significant risks to the general public from the development of the majority of the site. However, careful dust control measures should be adopted during construction to minimise the risk (and nuisance) to the general public and neighbouring residents, this will be of particular importance in the area of the historic landfill.

7.2 Risks to Controlled Waters (CWRA)

Collection of groundwater samples was undertaken as part of the ongoing monitoring regime and reported separately by ESP as a preliminary Controlled Waters Risk Assessment (CWRA) in August 2019 (Ref; 7061d.3215). At the request of the Client, the CWRA has been included as an appendix to this report revision (see Appendix N for full content and context). The report concluded that the investigation and monitoring programme enabled the development of a confident ground model such that the risks posed to receptors is well understood, and essentially quantifiable.

Although the groundwater testing has shown slightly elevated levels of contaminants at the site, these have generally been observed to decrease down gradient such that risks to receptors are generally considered to be low. The concentrations of contaminants anticipated to be leaving site are at such a low levels, no current technology exists that could provide significant or meaningful betterment or treatment. The removal of the source, thought to be Area C and the wider landfill (off site) is unlikely to be economically viable for the development.

If further confidence on the above is required, then further monitoring could be carried out in due course, which could coincide with investigation of nearby land, including the landfill and the quarry (Area E). Due care in construction and site clearance activities should be maintained throughout the development of the site and as more detailed investigations are carried out for separate parcels of land, this risk assessment should be reviewed and updated as necessary.

7.3 Risks from Ground Gas

Works undertaken by Arcadis have indicated maximum levels of methane in the area of landfill of 37% and carbon dioxide, 21%. Outside the landfill, concentrations were generally noted to be lower.

To supplement the ground gas monitoring undertaken by Arcadis, ESP have installed and monitored contemporary ground gas wells on 12no. occasions (see Table 17). Based on the available results and subsequent classification, Areas A and D are classified as CS-2 and Area C classified as CS-3. Area B, based on GSV, is classified as CS-1, however in line with CIRIA C665 and BS8485 +A1:2019, as methane has been noted to exceed 1% and Carbon Dioxide 5%, and due to the presence of adjacent sources (landfill) the classification should be increased to CS-2.

In areas A, B and D, the proposed development comprises residential housing, therefore, we consider this to be classified as a Type A building of BS8485:2015. We understand that at present, no development is proposed in Area C and this area is to be used as attenuation and allotments.

The requirements for ground gas protection are assessed in accordance with BS 8485+A1:2019, which considers gas protection in terms of a ranking 'score' for various property types. The proposed development in areas A, B and D comprises private residential dwellings with small room sizes, and there is unlikely to be any building management control on alterations to the internal structure or ventilation (Table 3 of BS 8485+A1:2019), which requires a minimum gas protection score of 3.5 (Table 4 of BS 8485+A1:2019).

To achieve the minimum gas protection score of '3.5' a combination of two or more of the following three types of protection measures should be used:

1. Structural barrier i.e. floor slab or basement slab and wall if present;
2. Ventilation measures; and
3. Gas resistant membrane.

In accordance with Tables 5, 6 and 7 of BS8485+A1:2019 a combination of the following protection measures would satisfy the requirement for 3.5 points:

1. Cast in situ monolithic well reinforced ground bearing raft or well reinforced cast in situ or suspended floor slab with minimal penetrations (1.0 point or 1.5 point - conservative, as no option for precast slab);
2. Good performance passive subfloor dispersal layer in accordance with Annex B (1.5 points) with the criteria for void formers presented in Table 6 adhered to – a pressure relief pathway could also be incorporated into the design for a further 0.5 point.
3. Taped and sealed membrane gas resistant membrane meeting all criteria outlined in Table 7 of BS8485:2019 (2 points). Note – If the membrane installed does not meet all criteria outlined in Table 7 (BS8485:2019), then the score is zero.

Should any permanent structures be subsequently proposed in Area C, the implications of ground gas protection measures will need to be carefully considered. Dependant on proposed end use "Type", the above gas protection measures would be required, however, the level of protection would also need to be increased. Type A buildings (residential) require a total of 4.5 protection points whilst Type B buildings (small to medium room private or commercial) require 4 protection points. If development of Area C is proposed, the ground gas levels encountered should be reviewed alongside BS8485 +A1:2019 to determine the most appropriate protection measures.

Due to the potential for ground gas generation from the former landfill within Area C, should allotments be considered for Area C, it may be necessary to implement control on some practises common associated with allotments. The use of heaters/burners within cabins or greenhouses etc. is unlikely to be acceptable. In addition to this, we understand adjacent attenuation ponds are to be lined which will modify the ground gas escape pathways and could increase ground gas levels below allotment structures, with venting and other control measures required to address this. Aspects such as this, in relation to the use of Area C as allotments, will need detailed consideration.

7.3.1 Risk to the Development – Radon

As discussed in Section 3.1.4, the Preliminary Risk Assessment has indicated that no radon protection is required.

7.3.2 Risk to Construction and Maintenance Workers

Works undertaken by Arcadis have indicated maximum levels of methane in the area of landfill of 37% and carbon dioxide, 21%. Outside the landfill, concentrations were generally noted to be lower. Monitoring undertaken by ESP has identified the presence of methane and carbon dioxide across all areas of the site, with concentration dependant on location. The displacement of oxygen in areas of ground gas is cause for concern and all excavations should be considered confined spaces with regard to the protection of workers and the appropriate mitigating measures taken.

7.4 Risks to Property

7.4.1 Spontaneous Combustion

No evidence of combustible materials has been identified in the shallow soils. Therefore, the risk from spontaneous combustion is considered to be low.

7.4.2 Sulphate Attack on Buried Concrete

From Section 5.0, the following characteristic values are applicable for the shallow soils at the site (all as SO_4):

Table 23: Summary of Assessment Criteria for Planting

Determinand	Area A	Area B	Area D
Water Soluble Sulphate (mg/l)	30	30	40
Total Potential Sulphate (%)	0.69	0.3	0.33
pH Value	7.5	7.2	7.4

Based on these characteristic values, we consider that the areas of the site would be classified as the following:

- Area A – Available information for Area A, suggest the site is classified between Sulphate Class DS-2 and Aggressive Chemical Environment for Concrete Class AC-2 and DS-3/AC3.
- Area B – – Available information for Area B, suggest the site is classified between Sulphate Class DS-2 and Aggressive Chemical Environment for Concrete Class AC-2.
- Area D - – Available information for Area D, suggest the site is classified between Sulphate Class DS-2 and Aggressive Chemical Environment for Concrete Class AC-2.

Further detailed testing and assessment would be required on a Area by Area basis to further refine the sulphate risk and concrete classification particularly in Area A. however, at this stage an allowance should be made for an advanced concrete class. As Area C is anticipated to comprise Public Open Space, a classification of sulphate attack has not been undertaken at present. Should this requirement change a detailed assessment of the potential for sulphate attack will be required through the landfill material for pile design (see Section 8.0), however, it is anticipated an advanced concrete class would be required in Area C.

7.5 Risks to New Planting

As discussed in Section 5.7, analysis of the shallow soils has indicated no levels of contaminants above the respective assessment criteria for general new planting in Areas A, B and D, however, levels of Copper are present in Area C that will require further consideration in regard to planting. It should be noted that some species of plant have particular requirements and limitations and a landscaping specialist should be consulted with regards to future planting. In addition to the above, the material quality of arisings in all Areas. In Areas A and D, the near surface weathered rock may not constitute a suitable planting matrix. In Areas B and C the respective Made Ground and Landfill will not be suitable for planting.

7.6 Re-Use of Materials/Disposal of Excess Arisings

7.6.1 General Comments on Re-use and Disposal of Soils During Development

All soils or other materials excavated from development sites are generally classified as waste under the Waste Framework Directive (European Union, 2008) and their re-use is controlled by this legislation. If the soils are to be re-used on site, provided that they are 'uncontaminated' or other naturally occurring deposits and they are certain to be used for the purposes of construction in their natural state on the site from which they are excavated, they may be excluded from waste regulation (Duckworth, 2011). A Materials Management Plan (MMP) may be required – further guidance can be provided by this office once proposals have been finalised. However, if they are man-made or contaminated materials, their use on the site may be limited.

If the soils are to be removed from site, they are automatically classified as waste, and they may only be:

- Disposed at a licensed landfill;

- Disposed at a licensed, permitted soil treatment centre; or
- Removed to a Receiver Site for beneficial re-use.

In Scenarios 1 and 2, the materials must be transferred by a licensed waste carrier and the waste producer (the developer) must ensure that the destination landfill or treatment centre is a legitimate operation (e.g. by requesting a copy of the Environmental Permit before releasing the soils). Prior to removal from site, the excavated arisings would need to be classified as either 'hazardous' or 'non-hazardous' waste based on the hazard that they pose– a WM3 assessment (note that this is a different assessment to the risk assessments reported on in earlier sections of this report). This can commonly be undertaken on the results of soils testing undertaken during the investigation, although further sampling and testing may be required.

Only once the soils have been classified under the WM3 assessment, would Waste Acceptability Criteria (WAC) testing then be required to determine the type of landfill in which the arisings could be disposed in Scenario 1. Further testing and assessment may also be required by the soil treatment centre in Scenario 2.

In Scenario 3, management of soils could be undertaken via an Environmental Permit or Exemption. However, these can take time and are costly to arrange. Therefore, in certain circumstances, it is permissible to use the protocols laid down in the CL:AIRE Definition of Waste, Development Industry Code of Practice (DoWCoP, Duckworth, 2011) to classify the arisings and put a management plan in place to control the use. This involves approval of the proposals by a Qualified Person and is generally more efficient (in terms of time and cost) to implement.

The stockpiles of demolition rubble/soil present on site would be initially classified as waste and cannot be managed under the DoWCoP protocols. If it can be demonstrated (by further testing and assessment) that the materials are compliant with the WRAP protocols, they may be de-classified as waste. Exemptions from the waste legislation may also be applicable.

For information, a material re-use flowchart in included as Appendix J of this report.

Further guidance on the legislative requirements of the re-use/disposal of materials generated by the development can be provided by this office once the development proposals have been finalised. Based on the materials encountered at the site, it is likely excavation arisings will predominantly comprise natural arisings in Areas A and D, reworked materials in Area B, that will require further testing and assessment, and landfill materials in Area C that will likely be classified as Hazardous Waste.

It should be noted that dependant on the arising conditions, more detailed testing would be required to aid in disposal options and allow the undertaking of a WAC Testing and a formal WM3 assessment, however a preliminary assessment of the likely disposal options are presented in Table 24 below.

Table 24: Summary of Assessment Criteria for Planting

Likely Classification	Area A	Area B	Area C	Area D
	Inert	Non Hazardous	Hazardous	Inert

8 Geotechnical Comments (Areas A – D)

8.1 Site Preparation and Earthworks

8.1.1 Invasive Plants

No evidence of invasive plants such as Japanese Knotweed/Himalayan Balsam etc. was identified on the site during the site works, however, as the works were undertaken during the winter months, this should be confirmed as part of detailed ecological design works by others.

8.1.2 Existing Foundations and Services

No evidence of old foundations and underground structures have been identified in the investigation and are not anticipated beneath the general site. However in specific areas such as the location of the existing farm buildings/livery (Area A), foundations are likely to be present and should be grubbed up as part of the site preparation works.

8.1.3 New Services

For new services, flexible pipework and connections should be provided as a safeguard against potential settlements.

In Areas A and D, consideration could be given to increasing the gradients on sewage connections to mitigate against possible settlements that are anticipated to be within the normal range of development tolerances.

In Areas B and C, particularly C, careful consideration will have to be given to the potential for settlement and disruption to new services. Settlement within the landfill will likely be extensive and lead to a loss of integrity along service runs.

Where services transition between Areas, careful design will be required to mitigate against differential settlement.

8.1.4 Earthworks

We understand that earthworks are proposed at the site, particularly where the dismantled historic railway bisects Areas B and D and understand that these earthworks will likely be for the main carriageway. As outline guidance and subject to detailed design, slopes of 1 in 3 are likely to be suitable. The re-use of site won materials will need to be considered in line with the appropriate engineering guidance and also in line with the recommendations contained in Section 7.6.

Any permanent cuttings or embankment surcharges associated with earthworks or landscaping within the site should be kept to a minimum to avoid any possible adverse effects on the existing stability of the site. Any proposed changes to the topography should reviewed in full by a geotechnical engineer as part of detailed design.

As outlined in Table 7 and repeated in Table 25 below, the natural soils at the site are predominantly fine in composition. Based on the information available it is likely that excavated materials would be determined as Class 2 in line with the Series 600 specification. Sub-classification would need to be determined as part of a detailed earthworks specification.

Table 25: Summary of Plasticity Testing

Area	Moisture Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
A	15 - 27	44 - 61	21 - 26	21 - 35
B	32 - 34	80	30	50
C	17 - 24	32 - 56	18 - 28	14 – 35
D	21 - 31	52 - 74	23 - 34	27 - 48

8.2 Sulphate Attack

As discussed in Section 8.5, an advanced concrete class will be required for preliminary design purposes, with additional testing and assessment recommended to further define concrete class.

8.3 Foundation Design and Construction (Areas A – D)

We understand that the site Masterplan is to consider the a potential development for residential purposes and the comments and recommendations in this report assume that the development will involve the construction of residential houses, apartment type buildings and public buildings of conventional load-bearing brickwork construction.

8.3.1 Area A

On the basis of the available investigation information, we consider that mass concrete spread foundations could be used within Area A, constructed in the more competent St Marys Well Bay Formation encountered from depths of 0.95m beneath ground level, allowing for plasticity. We consider that for foundations placed in this stratum, a presumed bearing value of around 100kPa should maintain total and differential settlements to less than 25mm.

Dependant on the plasticity in individual areas, the depth of foundation may need to be deepened in line with NHBC guidance. High plasticity soils identified at the site, can require a minimum of 0.95m up to 3.5m foundation depth in areas of planting, established trees, foundations, however, foundation recommendations are for construction within the competent bedrock and therefore through the weathered plastic soils, where deeper foundations would not be feasible/required.

For all spread foundation options, the formations should be cleaned, and subsequently inspected by a suitably qualified engineer prior to placing concrete. The foundations should be placed within the competent unweathered bedrock. Should any soft, compressible or otherwise unsuitable materials be encountered they should be removed and replaced.

8.3.2 Area B

The presence of extensive compressible Made Ground possessing very low bearing and high consolidation properties could lead to significant and unacceptable settlements for developments constructed on shallow footings of any form. Therefore, we consider that piled foundations would be required for the development.

Within Area B we consider that the piled foundations should be taken down to the bedrock at depths between 9 and 12m below ground level. SPT-N values through the Made Ground ranged from 4 to 14 and generally increased with depth, however weaker horizons were recorded. SPT-N values of 20+ were recorded once boreholes entered the weathered St Marys Well Bay Formation.

In both areas, the following criteria should be considered for pile design:-

- The magnitude and resulting effect of different structural loadings, including any machine vibration effects;
- Possible impacts on neighbouring structures and underground services;
- Pile/soil/structure interaction effects;
- The design philosophy for pile bearing capacity - the estimation of pile bearing capacity in the bedrock requires careful consideration of the skin friction developed over the penetration depth into the rock and the end bearing resistance beneath the pile toe.
- The probable presence of obstructions and buckling of piles;
- Negative skin friction forces.

The final safe working load on the pile will be dependent on the pile type, diameter and length of the piles, the penetration into the bearing stratum, and the settlement tolerances required.

Based on the available information, and given the site constraints, it is likely that the most appropriate system is likely to be a driven, displacement pile system, which may prove most efficient for the particular ground conditions. Pile foundations will create a potential pollution pathway between the near-surface Made Ground and the underlying coarse-grained glacial soils, which are classed as a Secondary A aquifer. It will be necessary to appropriately assess the risk through a piling risk assessment and further guidance is provided by Westcott et al (2001).

Discussions should be held with specialist piling contractors to obtain specific piling proposals based on their particular proprietary system and to evaluate costs. The piling contractor should be asked to provide a performance specification and in particular the magnitude of total and differential settlements which could be guaranteed. Test loading will be required on a proportion of the piles to confirm that they are adequate to carry the design working loads, and the contractor should monitor closely the pile installations to satisfy himself that the ground conditions encountered are as good as, or better than, those assumed in his design. Care should be taken to ensure that piles are not stopped short on obstructions and that all are taken down into the coarse-grained glacial soils.

Should alternative foundations be preferred in this area, the use of reinforced raft foundations on a 1-2m layer of suitable engineered fill. Consideration would need to be given to settlement tolerances, development zoning and transition zones and further guidance on design criteria can be given by this office when structural loadings and layouts are available.

8.3.3 Area C

Within Area C, only public open space is anticipated, however, should any subsequent development be proposed, we consider that the piled foundations should be taken down to the bedrock at depths of around 7m below ground level. Should development be proposed in this area (subject to ground gas conditions) and the use of piles implemented, it is likely the piling risk assessment will need to enhanced to account for the highly variable materials in the landfill, including risks to construction workers.

8.3.4 Area D

On the basis of the available investigation information, we consider that mass concrete spread foundations could be used at the site, constructed in the probable St Marys Well Bay Formation and/or Penarth Group, encountered from depths of 0.95m beneath ground level, allowing for plasticity. We consider that for foundations placed in this stratum, a presumed bearing value of around 100kPa should maintain total and differential settlements to less than 25mm.

Dependant on the plasticity in individual areas, the depth of foundation may need to be deepened in line with NHBC guidance. High plasticity soils identified at the site, can require a minimum of 0.95m up to 3.5m foundation depth in areas of planting, established trees, foundations, however, foundation recommendations are for construction within the competent bedrock and therefore through the weathered plastic soils, where deeper foundations would not be feasible/required.

For all spread foundation options, the formations should be cleaned, and subsequently inspected by a suitably qualified engineer prior to placing concrete. The foundations should be placed within the competent unweathered bedrock. Should any soft, compressible or otherwise unsuitable materials be encountered they should be removed and replaced..

8.4 Skip Load Testing

We understand that the historic landfill (Area C) is to be used for allotment gardens and drainage attenuation, with a number of aspects of the drainage infrastructure terminating storage swales and cascading attenuation ponds. Due to highly variable nature of landfill materials, significant settlement could be realised within this area.

Skip load testing has been undertaken at the site. The results are presented in full in Appendix O and summarised in Table 26 below.

Table 26: Summary of Skip Test Data

Point	Empty 16/7/19	Full 16/7/19	Level 14/8/19	Level 17/9/19
C1	30.321	30.297	30.292	30.288
C2	30.204	30.193	30.183	30.178
C3	30.196	30.183	30.174	30.173
C4	30.321	30.294	30.289	30.287
C5	34.472	34.457	34.450	34.444
C6	34.501	34.465	34.460	34.454
C7	34.471	34.456	34.449	34.445
C8	34.454	34.440	34.431	34.428

Notes:
1. The C1 to C8 references are for the individual corners of each skip.
2. Points C1 to C4 are for skip 1 and points C5 to C8 are for skip 2.
3. All units in meters.

Skip testing showed some initial settlement to occur, in the region of 11 to 27mm for skip 1 and 14 to 36mm. Once the initial settlement has occurred, ongoing settlement was in the region of 7 to 15mm in skip 1 and 11 to 13mm in skip 2. Adding both movements suggests total settlement for skip 1 in in the region of 23 to 34mm and 26 to 47mm for skip 2.

We understand that the historic landfill (Area C) is to be used for allotment gardens and drainage attenuation, with a number of aspects of the drainage infrastructure terminating storage swales and cascading attenuation ponds. Due to highly variable nature of landfill materials, significant settlement could be realised within this area.

The BRE have published a document *"Building on fill: Geotechnical Aspects"* which provides a useful indication as to the processes affecting old-landfills and some informative case histories.

Domestic refuse landfill is subject to large reductions in volume due to biodegradation, and is highly compressible under applied load. Measurements at case study sites suggest that large downwards movements may continue for many years.

Settlements of biodegradable fills are affected by a number of factors:

- Age of waste mass;
- Composition of the waste;
- Initial bulk density;
- Initial moisture content;
- Level of leachate/groundwater; and
- Time over which the fill was placed.

Movement can be attributed to the following causes:

- Immediate physical compression due to the weight of fill causing crushing, distortion, bending and re-orientation of the materials;
- Long-term movements as biodegradation causes a reduction in volume; and
- Long-term movements by physical creep-compression as the particles become more closely packed.

Owing to the inherently variable nature of refuse materials, performance under loading is highly variable and movements of up to 5-10% of the waste thickness are not uncommon. This could mean 0.3-0.7m in Area C (based on available borehole data), however, it cannot be discounted that landfill materials are thicker in areas that have not been investigated.

As the design Proposals in this area (Area C) predominantly comprise attenuation ponds, these should be robustly lined, and gradients on drainage falls steepened to ensure plausible changes in surface level are accommodated. Also design should be prepared so that if later in the lifetime of the development, remedial/repair works are required, then this can be accommodated.

8.5 Limestone Solution Features

As discussed in Section 5.5, the site lies in an area susceptible to limestone solution. Therefore, following excavation, the formation should be very carefully inspected and any anomalous feature investigated further. In particular, areas of broken rock or clay infill alongside otherwise competent limestone should be excavated further to check the underlying materials. If in doubt, further geotechnical advice should be sought.

Should any solution features or faults be encountered in foundation excavations within the bedrock, the following treatment may be appropriate.

- Where faults cross a trench they can be treated by removing the soft clay and fragmented rock infill to a depth of 500mm below formation level and then backfilling with concrete or designing the foundation to span such areas.
- Solution features such as cavities, pipes or channels should be treated by lining with a geotextile fabric and filling with free draining compacted suitable material.
- Ponds should be treated by excavating any unsuitable material and replacing with free draining compacted suitable material.

These recommendations should be approved by a geotechnical engineer before the foundations are constructed. The above measures would only be practicable provided the size of the features does not exceed a nominal 3m^2. If an individual feature does exceed 3m^2 in size, then the most economical option may be to reposition the structure.

8.6 Floor Slab Foundations

High plasticity soils have been encountered in Areas A and D and extensive Made Ground in Areas B and C. Based on this, the use of ground bearing floor slabs cannot be recommended and floor slabs should be suspended or combined into a raft foundation if used in Area B. Should shallow competent (fresh) rock be encountered, it may be feasible to utilise ground bearing floor slabs and this should be reviewed as part of detailed design on an area by area basis.

Ground gas monitoring is ongoing and will be reported as an addendum, however, based on available information, we would anticipate ground gas protection measures having to be incorporated into floor slabs.

8.7 Pavement Design

8.7.1 Areas A and D

We understand that vehicle access roads/hardstanding are proposed at the site. California Bearing Ratio (CBR) tests have not been carried out at the site, but based on experience and published guidelines, a CBR value of 2-5% is considered appropriate for preliminary design purposes, for the near surface soils, with the value likely to increase below topsoil, within the weathered bedrock. Actual design values should be determined for designated areas as required.

8.7.2 Areas B and C

Based on experience and published guidelines, a CBR value of <2% is considered appropriate for preliminary design purposes, for the near surface Made Ground.

In Area B where general compacted Made Ground has been encountered CBR values are likely to increase with depth, with localised treatment of soft spots likely. In Area C, poor values are likely throughout the Made Ground profile with a significant potential for settlement to occur.

If any access roads and/or hardstanding are proposed in these areas, that at least 1m of engineered fill materials and the use of geogrids will be required. Where highways/access roads transition between Areas, careful design will be required to mitigate against differential settlement. Notwithstanding the above, residual settlement is likely, particularly in Area C. Consideration could be given to pre-treatment and surcharging of all land areas.

8.8 Susceptibility to Frost Action

Given their plasticity, the near surface fine grained soils are considered to be frost susceptible. A total thickness of 450mm non-frost susceptible pavement construction will be required to avoid frost heave. In coastal areas such as this, this thickness may be reduced subject to the Mean Annual Frost Index (MAFI) and the agreement of any parties who will adopt the highway.

8.9 Excavation and Dewatering

It is anticipated that excavation of superficial soils throughout most of the site will be within the capabilities of conventional mechanical excavators, however, in Areas A and D, the excavation of rock will require high capacity machines and/or ripping.

For shallow excavations where there is no danger to life, support of excavation sides is unlikely to be necessary in Areas A and D. Should any indication of excavation instability be noted at any depth, support should be provided as appropriate. In Areas B and C, side support is anticipated to be required.

Groundwater level monitoring has indicated the presence of a consistent groundwater body within the bedrock. Shallow groundwater bodies are also recorded in the Made Ground in Area B and within the landfill in Area C. It should be noted that in most areas of the site, the surface was soft and waterlogged.

Where water ingress occurs it is likely that pumping from screened sumps within shallow excavations will be adequate. In Area C, it is likely that any groundwater will require appropriate disposal due to the presence of contamination.

8.10 Soakaway Drainage

8.10.1 Soakaway Design

A series of soakaway infiltration and falling head testing has been undertaken at the site in Areas A and D in order to provide preliminary design information for sustainable drainage. Due to the extensive Made Ground and Landfill materials encountered in Areas B and C, no shallow testing has been carried out, in order to avoid the mobilisation of contaminants, however, 2no. falling head tests have been undertaken in rotary boreholes within the bedrock, below the aquifer protection measures. The range of calculated results are summarised in Table 27 below. For tests determined as “Failed” no suitable drop in head of water was noted and therefore calculation of infiltration rates was not possible.

Table 27: Summary of Infiltration Results

	Area A	Area B	Area C	Area D
Number of tests (soakaway and falling head)	3no. soakaways & 3no. falling heads undertaken in bedrock.	No soakaways No falling heads	No soakaways & 2no. falling heads undertaken in bedrock.	4no. soakaways & 3no. falling heads undertaken in bedrock.
Permeability Range (m/s)	All soakaways failed. $3.8x10^{-8}$ to $5.5x10^{-9}$ in falling head tests	N/A	$5x10^{-7}$ and $1.2x10^{-8}$	$3.8x10^{-5}$ to $5.8x10^{-9}$ (*1)

1) *Infiltration rates to the order of 10^{-5}m/s were recorded in one location only (TP26) and not repeated across the site.
2) SUDs utilisation not anticipated in Area B and so no infiltration testing carried out.
3) SUDs testing was undertaken within the bedrock in Area C as we understand attenuation ponds may be constructed in this area.

Generally poor infiltration rates have been recorded. The fine weathered bedrock is likely to retard the permeability of the shallow soils and due to the shallow bedrock encountered beneath Areas A and D, fracture flow is likely to dictate permeabilities, which may vary significantly across the site.

At the request of the client, interpolated data has been compiled for the soakaways undertaken in TP1 and TP23. Interpolated data indicates that infiltration rates of 10^{-6}m/s may be achievable in these areas, subject to extended supplementary testing. We would note that as outlined above, infiltration in these areas will be heavily influenced by fractures in the bedrock.

8.10.2 Soakaway Location

Care should be taken in the siting of the soakaways, with in particular, soakaways should be constructed a minimum of 10m away from the crest of slopes.

Given the site lies in an area susceptible to limestone solution, soakaways should be sited a minimum of 5m away from structures and pavements.

8.10.3 Soakaway Discharge

The Environment Agency has a general policy that no direct discharge of surface run-off would be accepted in vulnerable groundwater aquifers. Given the shallow depth of the bedrock at the site, any soakaways would result in the direct discharge of surface water run-off into the aquifer. We recommend that enquiries are made to Natural Resources Wales (who have taken over the role of the Environment Agency) to identify whether they would allow such discharge at the site and their requirements for further testing and assessment and also requirement for risk mitigation. As a minimum, risk mitigation measures such as oil interceptors are likely to be required.

8.11 Cliff Inspection

As part of the works, a cliff inspection was undertaken (see Appendix L). The inspection confirms the published geological sequence of near horizontally bedded Jurassic and Triassic mudstones and marls. Occasional near vertical joints were noted, trending NE-SW, and whilst localised fault zones were observed there were no obvious areas of structural distress that were significantly different to other stretches of the Penarth-Lavernock coast.

The coast path meets a gate as it adjoins the north corner of the site, and then continues within a 1-1.5m corridor between the hedge of the site-boundary on the west, and a densely vegetated zone atop the cliff to the east.

Access was restricted, so using visual estimation the cliff line is typically 5-8m east of the footpath, and where inspection permitted there were no clear indications for instability in this zone, where some relatively mature trees were occasionally present - also indicating the zone to be historically relatively stable.

At the southern point adjoining the site, the coastpath moves much closer (<1m) to the cliff edge; however, at this point the development site comprises part of a copse/vegetated area so the actual development line in this area should be checked once the masterplan is available.

A commonly observed and adopted rule for regression-rate of the Vale of Glamorgan coastline is approximately 1m per 30years. Whilst increases in sea level and storminess are forecast owing to global changes in climate, this rate is considered appropriate for reasoned decision making.

We understand that the site/land boundary is approximately 5m back from the cliff edge, to accommodate the Welsh Coast Path. Based on the above rule the boundary of the site is likely to be on the margins of the area which could be affected by the regressing coastline over the presumed development lifetime (100yrs).

We recommend that any critical infrastructure be kept a minimum of 10m from the cliff edge, and consideration be given to adopting the same building-line as used in developments to the north, whereby private properties are stepped back further from the cliff by positioning the access roads on the seaward side.

9 Recommendations

It is understood that this investigation is required to inform a Masterplan and provide recommendations for further investigation and assessment in areas of the site as necessary. The recommended further investigation required as part of the Masterplan works or future Area specific works are outlined below:

- Review of all ground gas monitoring data and assessment should proposals change;
- Consideration of the ground gas protection measures required in allotment areas;
- Investigation of Area E, if development of this area is proposed;
- Additional sampling in all Areas and appropriate detailed statistical assessment;
- Investigation and testing in areas not accessible due to ecology (railway line);
- Supplementary groundwater testing if further confidence is required in the outcome of the preliminary Controlled Waters Risk Assessment;
- Supplementary concrete class assessment;
- Formulation of H&S documentation for workers across all Areas notably for works in Area C;
- Consideration of ecological and archaeological constraints; and
- Review of all available information (Arcadis and ESP) once the Masterplan has been finalised to ensure suitability and to determine refinement of supplementary works.

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