THE FORMER SSI STEELWORKS, REDCAR: PRIORITY AREAS WITHIN SSI LANDHOLDINGS CONTRACT

Contracts 3: Geotechnical Risk Assessment Report

South Tees Site Company Limited

REPORT NO Redcar Steelworks-AUK-XX-XX-RP-GE-0001-P1-SSI3_GI_GRA

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Incorporating

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The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract

Contract 3: Geotechnical Risk Assessment Report

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This report dated November 2018 has been prepared for South Tees Site Company (the "Client") in accordance with the terms and conditions of appointment dated 14 September 2017(the "Appointment") between the Client and **Arcadis (UK) Limited** ("Arcadis") for the purposes specified in the Appointment. For avoidance of doubt, no other person(s) may use or rely upon this report or its contents, and Arcadis accepts no responsibility for any such use or reliance thereon by any other third party.

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1 INTRODUCTION

1.1 Project Background

The former SSI landholdings are made up of eleven discrete, sizeable land parcels situated in the Redcar, Lackenby, Grangetown and South Bank conurbations of the Borough of Redcar & Cleveland, within the industrial area generally known as ‘South Tees’.

Desk study work has been ongoing since November 2016, and in two of the SSI areas at Redcar (SSI1 and part of SSI2), this work has already been augmented by an advance programme of ground investigation works, comprising close to 300 trial pit excavations (SSI1) and 67 trial pit excavations (part of SSI2), together with laboratory analysis. The desk studies and advance programme of ground investigation works was undertaken by CH2M Hill (CH2M). A package of investigations was subsequently designed for the SSI land, namely SSI1, SSI2 and SSI3.

1.2 Contract Details

Arcadis (UK) Limited (Arcadis) were appointed by South Tees Site Company Limited (STSC) to oversee and manage a ground investigation undertaken by Allied Exploration and Geotechnics Limited (AEG) and to provide consultancy advice with respect to redevelopment of the site. The work was carried out in accordance with the “Ground investigation consultancy services former Iron and Steel Works Site, South Tees” contract (Ref: STSC-JN-0007) dated 14 September 2017.

The scope of works was defined by CH2M, on behalf of STSC, and presented in:

- South Tees Site Company Limited, Ground Investigation Consultancy Services, Former Iron and Steel Works Sites, South Tees, Invitation to Tender (STSC Reference Number: STSC-JN-0007, dated July 2017).

The scope of works being undertaken by AEG was developed by CH2M and is presented in:

- STSC - SS - 0030 - Ground Investigation – Contract 3 – Invitation to Tender – The Former SSI Steelworks, Redcar – Ground investigation: Priority Areas within SSI Landholdings Contract 3. CH2M., August 2017.

A site location plan is presented within Appendix C.

1.3 Project Aims and Objectives

The overarching aim of the works was to deliver a sustainable ground remediation strategy for the contract sites which is compliant with regulatory needs and has their approval in principle. As technical consultant, the specific objectives of this phase of works were to:

- Manage and technically supervise the site works, undertaken by AEG, on behalf of STSC;
- Direct the site works to ensure compliance by the ground investigation contractors with existing site management protocols and procedures;
- Specify the requirements for laboratory analysis;
- Analyse the results of ground investigations;
- Prepare interpretative technical reports, namely;
    - Site Condition Report
    - Environmental Risk Assessment Report
    - Geotechnical Risk Assessment Report
    - Remediation Options Appraisal
- Consult with regulators to ensure compliance with all relevant regulatory requirements;
- Develop cost-effective, value-engineered outline remediation strategies.

1.4 Report Aims

The aim of this geotechnical risk assessment is to use the available information to assess the significance of geotechnical development constraints identified by the site condition report within the conceptual site model (CSM) for the contract area.

1.5 Scope of Work

This geotechnical risk assessment relates to the physical ground investigation works relating to the SSI Landholding (external to buildings), Redcar (Contract 3, Areas A and B).

Figure 1 provides details of the facility location and the site investigation areas.

The scope for the risk assessment comprised:

- Review of ground conditions and development constraints identified within the site condition report;
- Review and update the CSM derived for the site.

1.6 Previous Information

The following reports have been prepared by CH2M, Enviros, AEG and Arcadis relating to SSI3:

- Enviros, Corus UK Ltd. – Soil and Groundwater Baseline Characterisation Study Teesside Works – Interpretative Report Volume 1, 2 and 3, June 2004
- CH2M, TS3 Grangetown Prairie – Phase 1 Geo-environmental Desk Study prepared for the Homes and Communities Agency (CH2M Reference Number 678079_TS3_001, dated August 2017), and;
- CH2M, SSI3 Redcar Works – Phase 1 Geo-environmental Desk Study prepared for the Homes and Communities Agency (CH2M Reference Number 678079_SSI3_001, dated August 2017).
- AEG, The Former SSI Steelworks, Redcar – Ground Investigation Contract – Priority Areas Within SSI Landholdings Contract 3, dated June 2018;
- Arcadis, The Former SSI Steelworks Redcar: Priority Areas Within SSI Landholdings Contract – Contract 3 Site Condition Report, Redcar Steelworks-AUK-XX-XX-RP-GE-0001-P1-SSI3_GI_SCR, dated May 2018; and,
- Arcadis, The Former SSI Steelworks Redcar: Priority Areas Within SSI Landholdings Contract – Contract 3 Environmental Risk Assessment, Redcar Steelworks-AUK-XX-XX-RP-GE-0001-P1-SSI3_GI_ERA, dated August 2018.

This geotechnical risk assessment report should be read in conjunction with the aforementioned reports.

1.7 Reliability / Limitations of Information

A complete list of Arcadis Study Limitations is presented in Appendix A.

It should be noted that ground conditions between exploratory holes may vary from those identified during this ground investigation; any design should take this into consideration. It should also be noted that groundwater levels may be subject to diurnal, tidal, seasonal, climatic variations and those recorded in this report are solely dependent on the time the ground investigation was carried out and the weather before and during the investigation.

2 Preliminary Conceptual Site Model

Contract 3 covers two distinct areas of land separated by Tees Dock Road. The area to the west is referred to as Area A and includes the former Torpedo Ladle Repair Shop (TLRS), the area to the east (Area B) includes the former Basic Oxygen Steel (BOS) plant and comcast water facility. Although disused, the TLRS and BOS plant remain in situ and in both areas A and B the site investigation was limited to the external site areas only.

Area A was developed as part of the Cleveland Ironworks by 1929, with much of the site covered by a building of similar layout to the current structure, with much of the external area occupied by rail sidings.

With the exception of a small plot of land in the northwest, Area B were recorded as largely open field until land raising took place in the 1950's/1960's. The areas were then subsequently developed with the above ground structures present today by 1971. The earliest development in Area B included a, transformer house and associated reservoirs located at the northernmost end of the site. The reservoirs appear to have been infilled as part of the 1950's/1960's land raising.

The desk study prepared by CH2M notes extensive basements, service tunnels and other below ground structures beneath the BOS plant.

Full details of the ground investigation are included in the factual Ground Investigation report (AEG) and Site condition report, however a brief summary is provided below.

2.1.1 Ground Conditions

2.1.1.1 Made Ground

The investigation has identified that within area A (former TLRS) the made ground is limited in thickness and generally included granular material with varying amounts of slag, brick demolition rubble and coal ash. Across the majority of Area A made ground was less than 1.5m thick, however this was noted to increase to 2.5 to 3m in the most easterly area of the site. Concrete obstructions, relict walls etc. were noted across Area A as were a limited number of areas of fused slag and slag boulders.

Made Ground within Area B was noted to be thicker, particularly in the area of the former reservoirs. The made ground was up to 4m thick and was predominantly found to comprise slag deposits with fragments of slag ranging from gravel to cobble and occasionally boulder size. Other made ground materials were also identified including refractory bricks, demolition wastes and cohesive made ground. 15 of the 27 trial pits excavated in this area terminated in made ground due to groundwater inflow, instability or encountering obstructions.

2.1.1.2 Superficial Deposits

The full thickness of superficial deposits was recorded in three boreholes in each of areas A and B. The investigation has identified that the site is underlain by a sequence of superficial deposits comprising:

- **Glaciolacustrine Deposits** Were noted to be present in one location in Area A and all three boreholes within Area B. These deposits were found to include a firm laminated clay, with silt along the laminations. Laboratory testing indicated the clay to be of medium or high plasticity.

  Glaciolacustrine deposits are normally consolidated and strength may decrease with depth. These soils are often sensitive and may also suffer significant loss of strength due to changes in loading.

- **Glacial Till** predominantly comprising firm becoming stiff slightly sandy slightly gravelly clay, with boulders recorded in two boreholes. One of the cable percussion boreholes in Area A was terminated due to refusal on a boulder within the glacial till.

  Glacial till can comprise a complex and variable sequence of soils which may also include sands and gravels, large boulders etc. Ground conditions may vary rapidly both laterally and vertically.

  Note at two locations within Area B, The Glaciolacustrine Deposits were found to be present between an upper and lower glacial till layer.

2.1.1.3 Bedrock

In Area A bedrock was encountered in only one borehole at 4.3mAOD and was described as an extremely weak distinctly weathered grey mudstone. This material is consistent with the Redcar Mudstone recorded on geological maps in this area of the site. Due to the drilling technique, only the uppermost surface of the bedrock was recorded in Area A.

Within Area B in boreholes S3-BHB02, S3-BHB03 and S3-BHB04, bedrock was encountered at – 0.4 to 1.4mAOD. This was recorded as an extremely weak distinctly weathered grey mudstone and is consistent with the Redcar Mudstone. Due to the drilling technique, the upper surface of the mudstone only was recorded.

S3-BH01 included the use of rotary coring techniques, which allowed samples of the rock to be recovered for detailed logging. At S3-BH01 at the north end of the area, bedrock was found to be different to that recorded within the cable percussion boreholes. In S3-BH01 bedrock was found to comprise a weak or extremely weak red green marl with numerous veins and inclusions of gypsum from -1.24 to at least -27mAOD. This material is consistent with the Mercia Mudstone recorded on geological maps for the area. In certain circumstances, Mercia Mudstone may suffer from solution of gypsum leading to the formation of voids, however the recovered core samples did not indicate any evidence of solution features being present.

The area has been extensively affected by processes associated with the most recent ice age. This may have resulted in weathering and degradation of the upper layers of bedrock by solifluction, cryoturbation and weathering in both areas, and variation in depth to rock due to glacial erosion processes.

2.1.2 Hydrogeology

Groundwater elevation data collected between November 2017 and May 2018. Within Area A groundwater was noted to be standing at depths between 1.4 and 4.0m bgl, and in Area B between 1.00 and 2.00m bgl. Groundwater elevation and flow direction are anticipated to be significantly affected by local factors such as preferential pathways within made ground.

2.2 Proposed Redevelopment

Precise redevelopment proposals were not available at the time of writing this report. However, it is anticipated that the site is likely to have a number of different types of development ranging from relatively lightly loaded commercial structures to larger industrial uses potentially with high structural loads. It is also anticipated that the development could include large span warehouses potentially including ground bearing floors where differential settlements will need to be minimised.

2.3 Site Conceptualisation

The site condition report developed a geo-environmental CSM for the Area A and Area B of the site, these are presented as Figure 2_SSI3_Area A and Figure 2_SSI3_Area B below and in Appendix A

Potential Human Health SPR Linkages
A = Dust inhalation from Made Ground from site and adjacent land
D = Accumulation of ground gas in confined spaces
SPR linkages for construction workers during redevelopment not shown

Potential Water Resource SPR Linkages
E = Leaching of contaminants from Made Ground and point sources to groundwater in superficial deposits
F = Migration of contaminated groundwater to (Secondary (Undifferentiated) Aquifer) in bedrock
G = Migration of contaminated groundwater onto site in Made Ground and Superficial Deposits
H = Migration of contaminated groundwater off site in Made Ground and Superficial Deposits

Other SRP Linkages
J = Attack by contaminants of concern on foundations

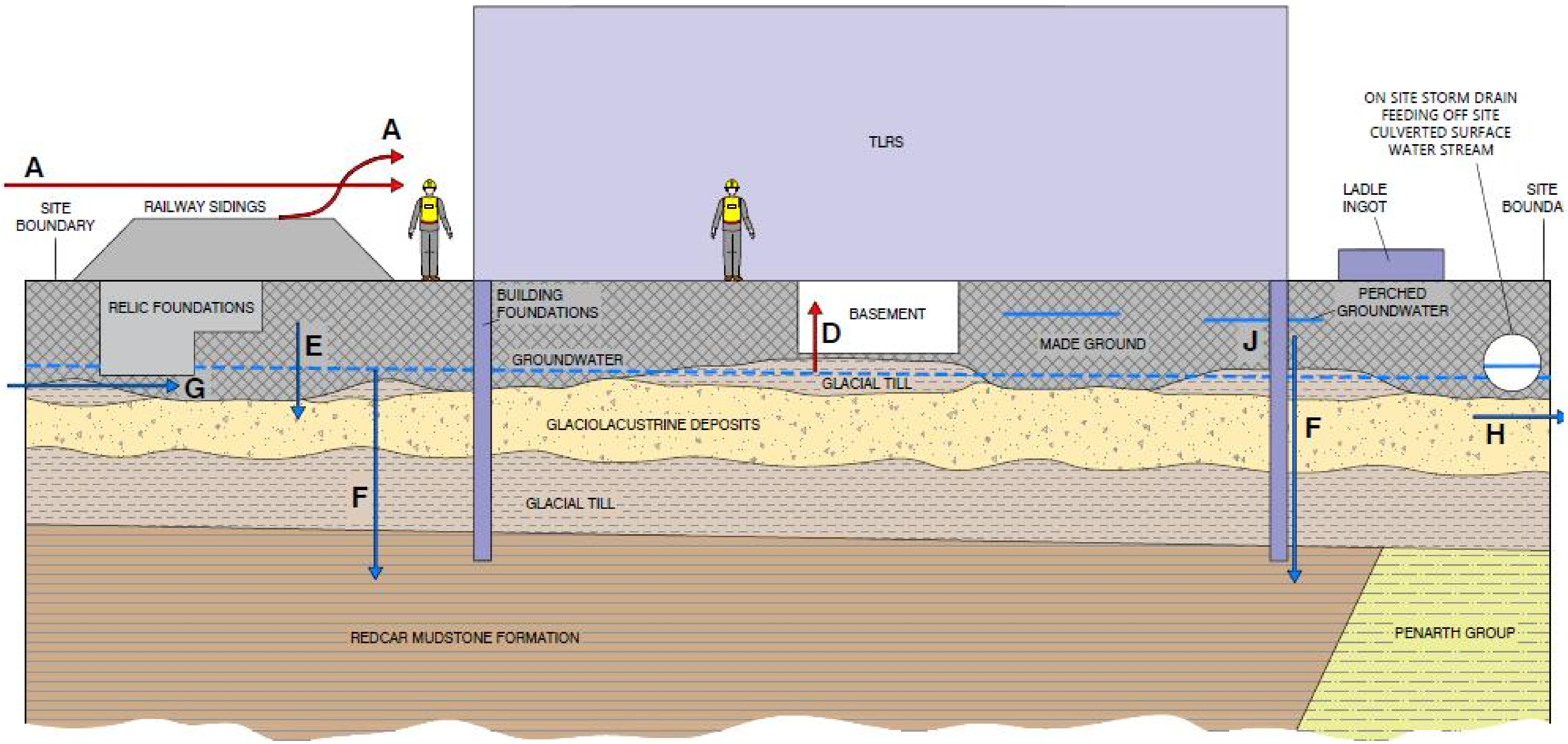


Figure 2: Updated Conceptual Site Model Area A

Potential Human Health SPR Linkages

A = Dust inhalation from Made Ground from site and adjacent land
D = Accumulation of ground gas in confined spaces
SPR linkages for construction workers during redevelopment not shown

Potential Water Resource SPR Linkages

E = Leaching of contaminants from Made Ground and point sources to groundwater in superficial deposits
F = Migration of contaminated groundwater to Secondary Aquifers in bedrock
G = Migration of contaminated groundwater onto site in Made Ground and Superficial Deposits
H = Migration of contaminated groundwater off site in Made Ground and Superficial Deposits
I = Migration of contaminated groundwater into culverted surface water streams (Kinkerdale Beck, Boundary Beck), and off site pond

Other SRP Linkages

J = Attack by contaminants of concern on foundations

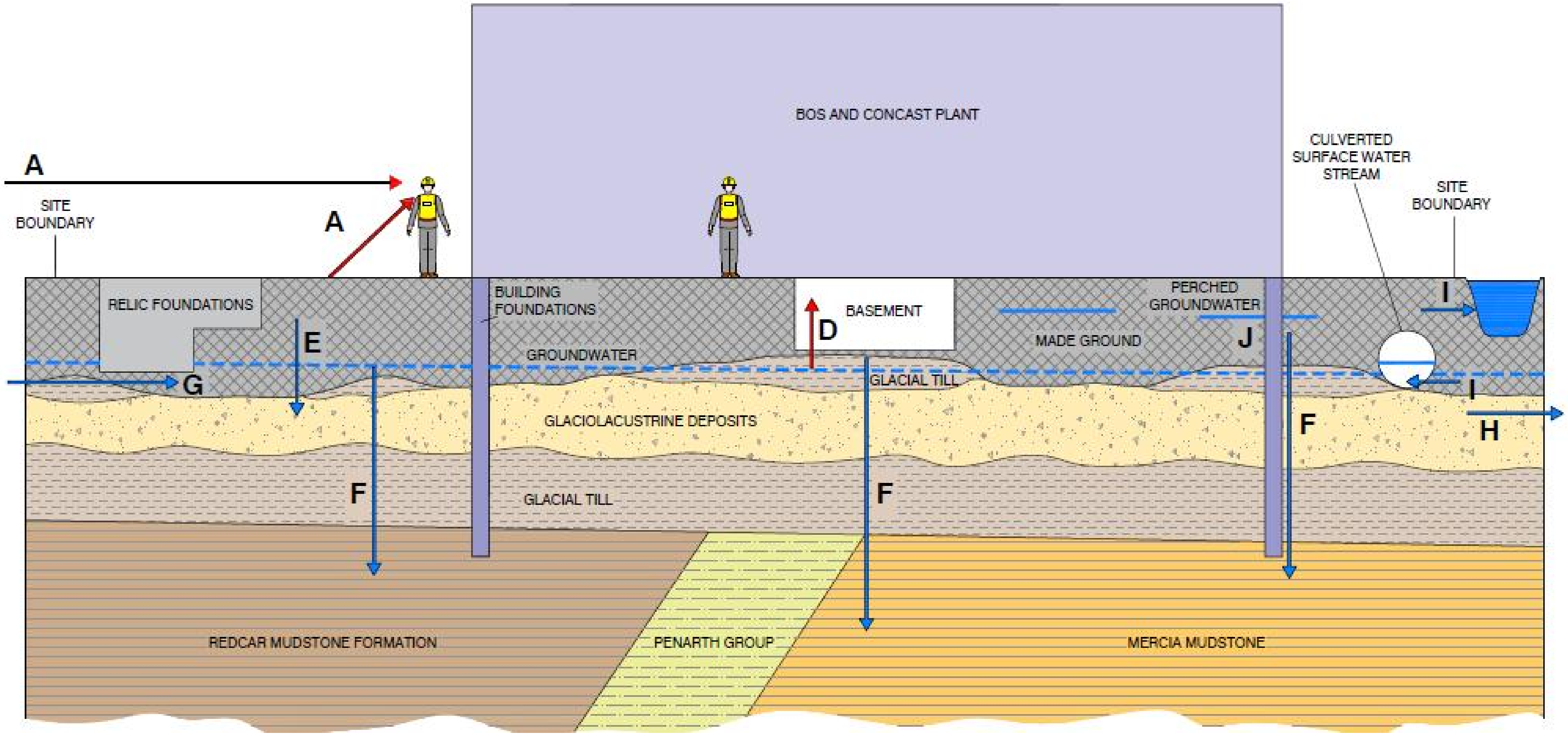


Figure 3: Updated Conceptual Site Model Area B

2.4 Identified Geotechnical Constraints

The following geotechnical risk drivers have been identified that will be discussed in detail in Section 3:

- Inadequate bearing capacity of made ground to support proposed structures;
- Variations in depth/thickness of made ground due to former structures (e.g. former lagoons, basements within existing structures).
- Anticipated total and differential settlement/heave in excess of the tolerable limits;
- Potential collapse compression as a result of surface water infiltration and groundwater movement;
- Potential heave as a result of chemical changes causing expansion of the ferrous slag;
- Sulphate attack of concrete (from made ground and Mercia Mudstone); and
- Obstructions within the made ground (boulder size fragments of slag and buried underground structures) and natural ground (boulders in glacial till).

3 Geotechnical Constraints

The following subsections provide a commentary on the different identified geotechnical constraints in light the identified ground conditions and proposed redevelopment plans. At this stage the proposed redevelopment is not finalised and therefore generalised recommendations only have been made, however it is assumed that the development will include a mix of commercial and industrial uses.

Potential remedial solutions are presented here but are discussed in greater detail in the Remediation Options Appraisal Report as part of the overall strategy for the site.

3.1 Made Ground

There are no records available as to how the made ground was placed at the site and desk study information (including aerial photographs) suggest that the made ground may have been end tipped from a railway to reclaim the land from the sea. This would tie in with site observations which suggest that groundwater is resting within the lower part of the made ground. While the majority of the made ground predominantly comprised slag there were layers of very loose silt/sand (often present beneath the water table) that suggest that the made ground had not been compacted.

Area A has an industrial history, including buildings similar to the current site layout associated with the Cleveland Ironworks. Additionally, former residential properties were present along the southern boundary, relics of these structures are anticipated onsite within the made ground.

Area B remained as predominantly open fields until the late 1950's after which it was developed into the South Teesside Works, Lackenby. However, it should also be noted that a large substation and reservoirs were present in the northern area of the site, with the reservoirs being infilled in the 1950's/1960's. This area was further developed around the mid 1970's, including the construction of the BOS plant and ancillary structures, generally into its present-day arrangement.

Note, no intrusive works have been carried out within the buildings in either areas A or B. in both areas, extensive floor slabs foundations to structures, chimneys etc are expected. The CH2M desk study indicates that subsurface basements, service conduits etc. are present in Area B.

Made ground which has not been compacted during placement can be subject to ground movements as a result of:

- Self-weight of the made ground;
- Future loading due to imposed structural loads or addition of further fill material;
- Changes in groundwater level or moisture content;
- Decomposition of biodegradable made ground;
- Chemical reactions.

3.1.1 Self-Weight

The majority of the made ground (and underlying natural soils) at the site are predominantly granular in nature and therefore settlement due to self-weight will predominantly occur during the placement of the fill. As the made ground has been in place for several decades the risk of further settlement due to self-weight of the fill is considered to be negligible and has not been considered further.

3.1.2 Future Loading

During the redevelopment new loads are likely to be imposed as a result of the new buildings and in some cases due to raising site levels/ filling of basements etc. If site levels are to be raised to be consistent with remainder of the site this would result in an additional applied load in the order of 30 to 80kPa (assuming materials with a normal density are used and not higher density slag). Therefore, settlement due to increasing loadings is considered likely.

3.1.3 Collapse Compression

As poorly compacted, partially saturated fills become inundated or submerged for the first time there is the potential for a reduction in volume to occur due to a phenomenon known as collapse compression. Collapse compression can occur in both man made materials and natural soils (e.g. wind blown deposits) without the application of addition load. Essentially the addition of water reduces the interparticle bonds resulting in the movement of particles to a more closely packed configuration. The potential for collapse compression remains within a soil until it has become inundated. Inundation can occur due to a number of different mechanisms such as rising groundwater levels, increased rainwater infiltration or leaking water/drainage pipes. It is therefore important that the potential for collapse compression to occur at some point in the future is removed from the soils. This can be done by ensuring that the materials above the water table are sufficiently compacted.

The majority of the made ground encountered during the intrusive works was found to comprise granular slag deposits which was locally difficult to excavate and penetrate. While it would appear that this is indicative of a well-compacted fill material there are several indications to suggest that this may not be the case. The first is the desk study information suggests that the material was end tipped, a method of uncontrolled fill placement. The second is the number of large boulder size fragments, which not only act as obstructions that are difficult to bore or excavate through but also increase the risk of voids or poorly compacted soils immediately adjacent to the large fragments. The presence of boulders within the made ground only increases the potential for, and magnitude of, the collapse compression.

3.1.4 Decomposition

Observations made during the site investigation did not indicate that the made ground was highly biodegradable and as such the risk of ground movement due to decomposition is considered to be low.

3.1.5 Chemical Reactions

Particular types of fill material are prone to chemical reactions that result in volume changes (normally expansion) of the soil. Certain types of slag deposit are particularly prone to increases in volume leading to heave at ground surface. This phenomenon is described and assessed in detail in Section 3.3.

3.1.6 Remediation

In order to reduce the potential for future collapse compression it is important to treat all of the made ground that is located above the water table (i.e. materials that have not been inundated). There are different methods for achieving this but the most suitable are considered to comprise:

- Excavation and replacement of made ground to an engineering specification;
- Ground improvement utilising techniques such as dynamic compaction or pre-loading; or
- Provision of an engineering control that is tolerant to future settlement.

Treatment of the material above the water table will also help to reduce future settlement cased by imposing additional loads. However, there is still the potential for materials below the water table to settle due to additional loadings. It should also be noted that while ground improvement will help to minimise future settlement it will not treat materials that are potentially expansive. It is therefore considered that excavation and replacement is likely to form the most appropriate remediation strategy for the site. However, the extent of the excavation (both laterally and vertically) will need to be determined on a case by case basis depending upon the ground conditions encountered and the proposed structures/end use at that location.

3.2 Removal of Obstructions

The investigation has identified that there are numerous obstructions within the made ground and that in several locations the exploratory holes had to be terminated. The obstructions included buried concrete structures associated with the previous development and large fragments or compacted layers of slag. Slag fragments in the order of 1m diameter were found at some locations. Additionally, the desk study indicates significant basements and service conduits are present in Area B, thick floor slabs and redundant foundations can be expected in both areas A and B. These obstructions can cause two types of problem:

- they prevent the easy installation of piles and other sub-surface structures associated with the new development; and/or
- they act as hard zones within the ground enhancing the potential for differential ground movement.

It is therefore important that obstructions that pose a problem to the future development are removed. There are different solutions available depending upon the type of foundations required and the strategy for dealing with the other identified geotechnical constraints. However, in general the following options are available:

- If excavation of the made ground is identified as the most suitable option, then segregation and crushing of oversize material prior to replacement is likely to be the most economical solution;
- If the other geotechnical constraints can be dealt without excavation of made ground, then pre-probing and selective removal of obstructions within selected zones (dictated by proposed development) would offer a suitable alternative.

3.3 Ferrous Slag

3.3.1 Potential Ferrous Slag Issues

As discussed in Sections 3.1 and 3.2 slag deposits, as well as other made ground deposits, are prone to ground settlement caused by self-weight, applied loads or infiltration of groundwater and, in addition, can contain large boulder size fragments of slag that would obstruct installation of future piles and other underground infrastructure (e.g. services). However, ferrous slags also have the following potential geotechnical issues:

- Differential expansion of the different types of slag, possibly decades after placement, which can cause damage to buildings, roads and other structures. The mixture of the different types of slag material means will only increase the magnitude of the differential movements;
- Presence of other chemically active materials (those containing sulphates) potentially triggering expansive reactions when mixed with blast furnace or steel slag; and
- Presence of sulphates and sulphides within the blast furnace and steel slag that could potentially attack buried concrete.

Vertical movements are likely to be reduced in slag materials that have been excavated, blended and replaced in compacted layers. However, according to BRE document BR481 'Regeneration of brownfield sites containing ferrous slags' there are reported cases where differential movement in the order of 60mm in four years (with a maximum heave in the order of 100mm) at a reclaimed steel works site.

The following sections, providing background information on the different types of slag material and expansion mechanisms has been based on information provided in BR481.

3.3.2 Types and Composition of Ferrous Slags

3.3.2.1 Blast Furnace Slag

Blast Furnace Slag essentially comprises silicate and alumino silicates of calcium and magnesium (lime) and other bases resulting from the fusion of limestone, coke ash and the silica/aluminium based residues formed by separating the iron from its ore. Blast furnace slag also contain other compounds of sulphur, iron, manganese and trace elements. An important function of the slag is to remove sulphur from the melt. Sulphides therefore may be present in fresh blast furnace slag which can oxidise to form sulphates.

There are two types of blast furnace slag that are distinguished by how the slag was cooled. Air-cooled blast furnace slag (as was predominately produced at SSI) is often used for construction aggregate. The other type of slag was cooled by using high pressure water jets which produces granulated blast furnace slag (ggbs) which is then used as cement replacement in concrete.

Only a small proportion of blast furnace slag is currently disposed of to landfill and this is normally the materials that fails the chemical criteria for stability. However, according to BR481, prior to the 1980s due to insufficient construction requirements and a greater proportion of chemically unstable blast furnace slag far more slag was disposed to landfill.

Prior to the 1930s blast furnace slag was not produced to controlled standards and as such is likely to be more variable. The blast furnace slag was often mixed with other wastes such as those associated with coking plants, steel slags or unstable refractory slags. These deposits are known as old bank or old banked slags.

3.3.2.2 Steel Slag

Steel slag originates from the refining of iron by melting under oxidising conditions using a flux of limestone or dolomite. Unwanted elements in iron such as carbon silicon and sulphur are either oxidised to gases or pass into the slag. Chemically, steel slags are complex and variable, but commonly contain impurities such as silicon, manganese and phosphorous. It is also likely to contain some free lime (CaO) and free magnesia (MgO) which can hydrate in the presence of water resulting in a volume expansion of up to 30%. Steel slag must therefore be properly weathered to hydrate these components before it can be used as a construction material.

3.3.3 Expansive Properties

3.3.3.1 Blast Furnace Slag

Expansive properties of blast furnace slags include:

1. **Periclase (magnesium oxide) hydration** to form brucite (Mg(OH)2) which results in a large volume increase in the order of 130%. Periclase is only occasionally present in blast furnace slags.
2. **Iron unsoundness** comprising hydrolysis of iron sulphide, metal or low oxidation state oxide. These reactions commonly require acidic conditions. Iron unsoundness is rare in modern blast furnace slags but can occur in older slags. However, the process is rapid and, once started, continues to completion. It is therefore unlikely that iron unsound slag will remain intact on an open site under moist conditions for many years.
3. **Lime unsoundness** comprises a change from a high temperature beta form of dicalcium silicate to a normal temperature gamma form which results in a 10% volume increase. The reaction, occurs during the cooling of the slag immediately post production and therefore should not be present a problem in the long term.
4. **Sulphoaluminate hydrate (ettringite)** formation is the commonest form of volumetric instability in air-cooled blast furnace slags. It occurs in old slags that have been exposed to the atmosphere long enough for a significant proportion of the sulphides to oxidise to sulphates. Sulphates in the form of gypsum, under alkaline conditions, can react to form ettringite with a resultant volume expansion in the order of 130% relative to the glass phase of the slag. For this mechanism to have any significance, the slag needs to have residual potential for this reaction.
5. **Thaumasite formation** is a relatively rare form of expansion.

Blast furnace slag is known to contain high concentrations of sulphate and sulphides (which can oxidise to form sulphates). It is therefore important that sulphate resistant concrete is used for all below ground concrete. Historically issues have been associated with concrete floor slabs that are placed over sulphate-bearing blast furnace slag without the use of a separating damp-proof membrane. Without the damp-proof membrane sulphate-rich groundwater can be drawn into the concrete slab which then reacts with tricalcium aluminate found in Portland cement to form ettringite, or with calcium silicate and carbonate, to form thaumasite. This type of sulphate attack results in the upward doming of the floor slab caused by the expansion of the concrete and is separate from the expansion of the slag itself.

3.3.3.2 Steel Slags

Expansive properties of steel slags include:

1. **Free lime hydration** whereby calcium carbonate reacts with water to form calcium hydroxide resulting in a large volume increase in the order of 100%. Calcium carbonate can also react with sulphates to form calcium sulphate (gypsum) and then calcium sulphoaluminate. Specific sources of free lime include undigested lime and free CaO from the breakdown of alite (tricalcium silicate). In practical terms, it is impossible to forecast when hydration will take place, but it can be decades after the material was cooled or placed.

2. **Periclase (magnesium oxide) hydration** from magnesium limestone or dolomite to form brucite resulting in a large volume increase in the order of 130%. The reaction time is very slow, with a timescale of decades.
3. **Rusting of the free metal** due to one of the hydrolysis reactions covered by iron unsoundness.

3.3.4 Assessment Methodology

For the slag to cause a problem at the site there needs to be a hazard (e.g. presence of potentially expansive slag), an event (e.g. ground disturbance and/or ingress of water) and a consequence (e.g. damage to a building or structure).

The normal recommended procedure for investigation, assessment of sites that potentially contain expansive slag deposits comprises:

1. Desk study to determine if ferrous slag deposits are likely to be present;
2. Site reconnaissance for visual clues for presence of ferrous slags;
3. Formation of conceptual site model and preliminary risk assessment;
4. Initial site investigation to determine the following:
    a. Basic on-site diagnostic examination;
    b. Laboratory diagnostic testing for slag identification;
    c. Slag-specific expansion tests to determine whether the identified slag deposits are potentially expansive and likely magnitude of expansion; and
    d. Examination of samples for any chemically reactive materials that may react with blast furnace or steel slags.
5. Review of conceptual site model and risk assessment;
6. Main investigation to determine type, concentration and distribution (laterally and vertically) of slags and any materials which may react with the slag. This will include further testing to determine the percentage expansion of the material.
7. Final review of conceptual site model and risk assessment to determine the potential for future expansion in light of proposed redevelopment together with estimates of the amount of ground movement that may arise from slag expansion.
8. Design of mitigation measures to account for likely movement.

The methodology outlined above provides several opportunities to refine the conceptual site model and to undertake investigation to delineate where the expansive slag may be located. The discussion below outlines the results of the desk study, site reconnaissance, initial site investigation (undertaken by CH2M), refinement of the conceptual site model and recommendations for mitigation methods. Due to the quantity of the slag material present at the site it is considered that it is likely to be cost prohibitive to undertake a detailed investigation to delineate the potentially expansive slag *in situ*.

3.3.5 Desk Study and Site Reconnaissance

The desk study has indicated that a large quantity of ferrous slag (including blast furnace, basic oxygen steel (BOS) slag as well as basic refractory slag has been produced at the site and has been used to raise ground levels and reclaim land from former marshes. Historical photographs suggest that slag material may have been placed from railway sidings by end tipping. It is therefore considered that the slag materials are likely to have been placed in an uncontrolled manner and that it is feasible that the different types of slag material would have been co-disposed and that there was no consideration of blending or mixing. Given the dates of development of the two areas, it is anticipated that Area A may include predominantly blast furnace slag, while Area B may include both blast furnace and steel slag.

3.3.6 Petrographic Analysis and Expansion Testing

Area A

The site condition report indicated that a large quantity of slag is present within the made ground at the site, based on petrographic analysis the slags contain mixed deposits of blast furnace slags and basic steel slags, blast furnace slags predominated however notable amounts of steel slag were present in most samples. The analysis indicated the following:

- Very small amounts of lime phase material were noted in three of the six slag samples, this material may be identified by the white crystallisation noted on some of the slag materials. These deposits are considered to be at risk of free lime hydration.
- Very small quantities of basic refractories were noted in one sample. These materials contain periclase (magnesium oxide) and hence can be subject to hydration. Of note basic refractory materials were widely observed during the site works.
- The free calcium oxide and periclase (magnesium oxide) levels within the steel slag dominant sample was higher than the corresponding hydroxides $Ca(OH)_2$ and brucite $Mg(OH)_2$ indicating the slag retains a significant capacity for future expansion as demonstrated by the expansion testing results

Slag Sample	Free CaO (%)	Free MgO (%)	$Ca(OH)_2$ (%)	$Mg(OH)_2$ (%)	28 Day Expansion (%)
S3-TPA03	1.3	0.1	0	0	1.16

- Expansion results showed 28 day expansion volumes of between 0.04 and 1.16% (3 no samples).
- Based on the petrology and expansion testing a minority of the slag deposits at the site are considered to contain quantities of basic steel slag containing minerals with higher future expansion potential.

Area B

The site condition report indicated that a large quantity of slag is present within the made ground at the site, based on petrographic analysis the slags contain mixed deposits of blast furnace slags and basic steel slags, blast furnace slags predominated however notable amounts of steel slag were present in most samples. The analysis indicated the following:

- Small or very small amounts of lime phase material were noted in nine of the 15 slag samples, this material may be identified by the white crystallisation noted on some of the slag materials. These deposits are considered to be at risk to free lime hydration.
- Very small of basic refractories were noted in eight samples. These materials contain periclase (magnesium oxide) and hence can be subject to hydration.
- The free calcium oxide and periclase (magnesium oxide) levels within the steel slag dominant samples was higher than the corresponding hydroxides $Ca(OH)_2$ and brucite $Mg(OH)_2$ indicating the slag retains a significant capacity for future expansion as demonstrated by the expansion testing results

Slag Sample	Free CaO (%)	Free MgO (%)	$Ca(OH)_2$ (%)	$Mg(OH)_2$ (%)	28 Day Expansion (%)
S3-TPB08	0.8	0.2	0	0	0.09
S3-TPB31	3.6	1.3	0.8	0.5	3.19
S3-TPB36	4.4	0.4	0.6	Trace	0.98

Slag Sample	Free CaO (%)	Free MgO (%)	$Ca(OH)_2$ (%)	$Mg(OH)_2$ (%)	28 Day Expansion (%)
S3-TPB52	0.6	0.2	0	0	0.29

- Expansion results showed 28 day expansion volumes of between 0.05 and 3.19% (15 no. samples).
- Based on the petrology and expansion testing a minority of the slag deposits at the site are considered contain quantities of basic steel slag containing minerals with higher future expansion potential.

3.3.7 Conceptual Site Model

Due to the nature of the slag material and the type of development proposed the slag material would require some form of processing (e.g. removal of large obstructions prior to piling or installation of services). It is therefore possible that the act of development would result in an event that could potentially trigger future expansion. In addition, the potential for groundwater regime changes in the future (e.g. due to rising sea levels or future leaking water pipes and/or drainage) could result in an event occurring post development that could trigger further expansion at some point in the future. It is therefore important that the potential for further expansion to occur at some point in the future is limited as far as is reasonably practicable.

The limited testing undertaken to date has revealed that there is evidence that the blast furnace slag has been subject to past expansion and that there is some potential for future expansion, in particular in Area B. Further testing is required to understand the likely magnitude of the expansion. There is also evidence that the steel slag has been subject to past expansion and that there is still the potential for future expansion. The limited testing indicates that the steel slag still has the greater potential for future expansion, although it should be noted that this is based on limited analysis.

The substantial thicknesses of made ground across parts of Area B SSI3 which predominantly contain slag material means that meaningful testing of slag material *in situ* in order to zone the different types of slag material will not be feasible. As detailed in Section 2.1.2.1 the slag-dominant material extended to depths of up to 4m bgl with an average thickness in the order of 2 to 3m. In addition, the slag is likely to have been end tipped with the different types of slag being co-disposed. In Area A, the slag is of limited thickness and is older than that observed in Area B.

3.3.8 Mitigation Measures

The main mitigation methods that are generally employed to mitigate the risks presented by expansive ferrous slags include:

1. Adjustment of the proposed development layout and levels to ensure that vulnerable buildings, structures and infrastructure are located on areas free of expansive slag;
2. Removal of potentially expansive slag from footprints of proposed buildings, structures and infrastructure and replaced with stable fill if necessary; or
3. Engineering of the potentially unstable ground to improve the site.

Given the large quantity of the ferrous slag containing discrete random pockets of expansive BOS and refractory slags at the site it is considered that *in situ* delineation of the expansive BOS and refractory slags will be cost prohibitive. It is therefore considered that options 1 and 2 presented above will not be viable solutions.

Beneath Area A and much of Area B, the thickness of made ground is limited (typically <1.5m in Area A and <2.5m in Area B) and an engineering/earthworks solution may be possible. An engineering solution would involve the excavation of the slag material followed by either:

1. Crushing, blending and replacement to improve character of the slag by dispersion/mixing with non-reactive materials (dilution) and/or removal of hotspots; or

2. Acceleration of expansive reactions caused by exposure to water. However it should be noted that made ground beneath Area B may include a greater proportion of steel slag, and so may require additional segregation/processing.

Excavation and treatment would have three other advantages that would help in solving other geotechnical ground related issues including:

- Removal of obstructions within the made ground;
- Removal of poorly compacted made ground that could potentially be prone to settlement;
- Removal of material that would prevent the use of cone penetration testing to clear future pile locations for potential UXO.

If excavation and replacement is deemed to be the appropriate solution for the site it will not be necessary to fully delineate where the potentially expansive slag is prior to excavation. However, a robust screening method will need to be employed during the excavation works to ensure that potentially expansive materials are quickly and effectively identified and segregated for treatment. The segregation procedures must be robust enough to ensure that all potentially expansive materials are identified and, in order to control costs, materials that do not warrant treatment are not included.

3.4 Building Foundations

While an outline redevelopment strategy has been provided, comprising large commercial/warehouse structures, the final development is not known and is likely to change and include some industrial development that may have higher structural loads. Structural loads were not known at the time of writing this report and therefore, at this stage, only preliminary recommendations can be made. Further investigation and detailed design will be required for each building once redevelopment plans have been finalised.

The site is underlain by a variable thickness of uncontrolled made ground (that has the potential to result in heave and settlement), as well as soft/firm Glaciolacustrine Deposits and at greater depth Glacial Till Deposits. All of these material types are likely to be prone to differential movement without remediation or engineering controls. Viable solutions include:

- Piling of buildings (likely to be required in certain areas of the site and for heavily loaded structures); or
- Ground improvement to reduce risk of settlement and heave with strip/pad/raft foundations (only likely to be suitable in some areas of the site and for lightly loaded structures).

The following provides some commentary on the two options provided above and when each could be considered suitable. It may be that a combination of ground improvement (to support floors and external pavements/hardstanding) as well as piling of the superstructure will be required for some structures.

It is also noted that Mercia Mudstone may be subject to karst type formation due to the dissolution of water soluble minerals (in particular gypsum). The site is not recorded to be in an area at high risk of dissolution, and the single cored borehole in Area B which encountered Mercia Mudstone did not record any evidence of dissolution, however further testing should be carried out once development plans are finalised.

3.4.1 Piled Foundations

If a piled foundation solution is adopted, then either driven or continuous flight auger (CFA) piles could be utilised. Driven piles have the advantage of improving the density of the ground whereas CFA piles could potentially loosen the granular deposits and thus result in a reduced safe working load. The main disadvantage of driven piles is that they can cause unacceptable amounts of vibration that could potentially damage nearby above and underground structures. If driven piles are used then assurances will need to be sought from the piling contractor that damage will not be caused to nearby structures, including buried infrastructure on the site.

The superficial deposits beneath the site were found to be extremely variable both laterally and vertically to the extent that it is likely that piles will need to be designed to end bear within the underlying bedrock deposits.

There are several reasons why designing piles to end bear within the superficial deposits are likely to be problematic including:

- The glaciolacustrine deposits were found to be soft and of included high plasticity clays. These deposits may suffer from excessive settlement and may add additional load to piles (negative skin friction).
- The Glacial Till was generally found to have a stiff to very stiff consistency that in many situations would provide a suitable stratum into which to end bear piles. However, at this site not only was the depth to the Glacial Till found to vary considerably (or was even absent) but the Glacial Till at several locations was found to be interbedded with Glaciolacustrine Deposits which comprised soft or firm laminated clays. The soft consistency of the Glaciolacustrine Deposits could be problematic for piles end bearing within or immediately above one of these layers.

For these reasons it is considered prudent to design piles to transfer loads to the bedrock deposits located beneath the full sequence of superficial deposits. Shallower piles may be suitable for some proposed buildings but further detailed investigation will be required to ensure that there are none of the problematic features beneath the proposed building.

If it is assumed that most piles will extend a short distance into the bedrock, the anticipated pile lengths will be dictated by the bedrock profile across the site which has been discussed in detail in Section 2.1.2.3. This drawing will provide an indication of the likely required pile length. However, it should be noted that as the model generally smooths out changes in topography where this could mean that bedrock elevation changes occur over shorter distances that depicted by the model. It is therefore important that this is only used as a preliminary guide and that building-specific investigation to prove bedrock is undertaken prior to any detailed design.

Installation of piles at the site will be complicated by two further factors: the presence of obstructions (including large boulders of slag) within the made ground and the potential for UXO to be present within the superficial deposits. This is discussed in further details in Sections 3.2 and 3.6 respectively.

3.4.2 Ground Improvement

There are a wide variety of ground improvement techniques available including vibro-compaction, vibro-replacement, dynamic compaction, high energy impact compaction, preloading or earthworks.

Several of the techniques such as vibro-compaction or vibro-replacement will not be suitable at the site due to the nature of the made ground and the large number of boulder size fragments that would be present. Other techniques, such as dynamic compaction and high energy impact compaction may help to solve some of the likely settlement issues associated with the made ground but will not solve other problems such as the presence of obstructions (for future piling and UXO clearance) or the presence of expansive slag. It is therefore, likely that an earthworks programme would most effectively solve the identified problems at the site.

Excavation of the made ground to the depth of the groundwater will be relatively easy and straight forward (with the right machinery specification to remove large slag boulders and other underground structures) but is likely to be problematic beneath the groundwater table. Given the large site area, the coastal setting (reclaimed land) and the predominantly granular nature of the made ground and underlying natural Tidal Flat Deposits keeping the excavation dry will be difficult. The investigation has shown that there are in some cases there are several metres of slag deposits present beneath the groundwater table.

While slag deposits placed beneath the groundwater table are more likely to have already undergone expansion, it is known that some chemical reactions associated with expansive slag, known to be present at the site, are likely to take several decades. Further assessment will be required to determine whether the slag material present beneath the water table has reached its full expansive potential, particularly where water may not have fully infiltrated the large boulders of slag. It should also be noted that made ground beneath the water table is also less likely to cause future settlement as the collapse compression should have already occurred. Therefore, leaving slag deposits *in situ* beneath the groundwater table will not present the same level of risk as those present in the unsaturated zone. However, there will still be the potential problems associated with obstructions to future piling and UXO clearance and also settlement caused by implying future loads.

It is likely that there will not be a 'one size fits all' solution for the site and that the site will need to be zoned to enable different solutions to be implemented. Potential solutions include:

- Local excavation of materials beneath the groundwater table, with associated groundwater control to allow for crushing and reuse. The main aim of this will be to remove obstructions and therefore may be required beneath proposed buildings;
- Probing at future pile locations to clear for future obstruction and UXO clearance prior to backfilling of excavation crushed slag deposits. NB. This solution could potentially cause disturbance of the made ground and therefore some form of ground improvement (dynamic compaction or high energy impaction compaction) may be required prior to backfilling;
- Preloading to reduce likely settlement below the groundwater table in areas where poor ground conditions are identified and future loading suggests there could be unacceptable amounts of settlement.

3.5 Earthworks

3.5.1 Geotechnical Suitability

The geotechnical testing has demonstrated that the made ground in its current condition is unlikely to meet the requirements of an earthworks specification (such as the Highways Agency Manual of Contract for Highways Work, Volume 1: Specification for Highway Works, Series 600, Earthworks (SHW)). This is mainly due to the presence of a large number of cobbles and boulders within the made ground. It will therefore be necessary to crush the larger fragments within the made ground in order to confirm to a suitable particle size grading prior to placement and compaction.

The investigation has demonstrated that there are a variety of different material types present at the site that could be potentially reused in accordance with an earthworks specification. It is important that each material type is assessed, and that material specific specification is developed. Initial earthworks testing has been undertaken in order to assist with this process. However, once more detailed earthworks requirements are developed and the source material is known then further earthworks testing is likely to be required.

3.5.2 Environmental Suitability

The Environmental Risk Assessment report includes full details of the environmental condition of the soils encountered beneath the site and provides discussion on which materials will require treatment prior to reuse. It is therefore important that during excavation works all materials with olfactory or visual evidence of contamination are segregated and assessed by a geo-environmental engineer prior to ensure that they are suitable for reuse.

It should also be noted that the environmental testing revealed that some of the made ground contained fibres of asbestos. While the identified asbestos is unlikely to present a risk to end users of the site, if the material is placed below a suitable capping layer it is possible that the asbestos could present a risk to groundworkers during the earthworks. It is therefore important that the presence of asbestos fibres is taken into consideration during the design of the earthworks and appropriate mitigation measures and/or precautionary measures taken to minimise the risk.

The geotechnical and environmental testing has indicated that some of the materials have a high organic content and/or exhibit high loss on ignition results. While the majority of materials are likely to be suitable for reuse it is considered that there may be some materials that will not be suitable as a structural fill due to its organic content. Depending upon the finial development proposals it may be possible to reuse materials with high organic contents and/or exhibiting high loss on ignition results in specific areas of the scheme.

3.5.3 Achieving Non-Waste Status

It is important that materials that moved around the site are not classified as a waste (as defined by Waste Framework Directive) on completion of the works. All materials that are excavated (with the exception of clean natural soils used for the purposes of construction on the site of origin) are deemed to be a waste unless the following four factors can be demonstrated (via appropriate permitting etc.):

- Factor 1: Protection of human health and protection of the environment;

- Factor 2: Suitability for use, without further treatment;
- Factor 3: Certainty of use; and
- Factor 4: Quantity of material.

There are several different waste regulatory options available, the suitability of which is dependent upon the complexity of the site and the quantity/composition of the material to be reused. These include:

- **Waste Exemption** – suitable for small volumes of non-hazardous waste;
- **Standard Rules Environmental Permit** – Suitable for non-hazardous waste with limits on the quantity. Can take several months to obtain from the Environment Agency;
- **Bespoke Environmental Permit** – Suitable for greater volumes of waste and includes hazardous waste. Can take several months to obtain from the Environment Agency;
- **WRAP Aggregates Quality Protocol** – Allows for inert aggregate waste to be recovered and used subject to meeting set conditions.
- Application in accordance with **CL:AIRE guidance 'Definition of Waste: Development Industry Code of Practice' (DoWCoP)**.

The complexity of the site and the volume of material to be moved will mean that the site will not be exempt from the need to hold an Environmental Permit. In addition, the large volume of material it is unlikely that a Standard Rules Environmental Permit will be suitable. Bespoke Environmental Permits can be slow to obtain and therefore it is considered that the DoWCoP route is likely to be the most suitable

If materials are dealt within in accordance with the DoWCoP then the materials are unlikely to be waste. This is either due to the fact that the materials were never discarded in the first place or because they have been submitted to a recovery operation and have been completely recovered so that they have ceased to be waste.

In order to demonstrate that the four factors have been fulfilled will require preparation of various reports including:

- Site investigation report (Site Condition Report).
- Quantitative Risk Assessment (QRA);
- Remediation Strategy or Design Statement;
- Materials Management Plan (MMP); and
- Verification Report (on completion of the works).

In addition to the risk assessment, a materials management plan will be required detailing where soils will be moved to and how they will be tracked. Approvals will also need to be sought from the Local Authority and the Environment Agency (groundwater team) with respect to the remediation strategy. Planning permission may also be required.

Once this documentation is in place a Qualified Person will review the overall strategy and ensure that everything is in place prior to submitting a formal declaration to the Environment Agency (waste team), via CL:AIRE (the scheme administrators). On completion of the work a verification report will need to be completed.

This is comparable to the information that will need to be supplied to the Environment Agency as part of the Standard Rules Environmental Permit application but as the declaration can be made by Arcadis costs would be lower.

3.6 Future UXO Clearance

Magnetic anomalies have been identified at two locations elsewhere within the wider SSSI site. It has not been possible to confirm whether these were in fact UXO, or other features. In Area B in particular (which was not developed during World War 2), it should be assumed that UXO present a potential risk.

The redevelopment strategy for the site needs to take account of the identified anomaly and in addition the presence of further anomalies that could be indicative of UXO.

Given that UXO are potentially present beneath the site, any piles will need to be pre-cleared prior to piling. The easiest way to do this is to utilise a CPT (Cone Penetrometer Testing) with a magnetometer cone. However, on this site the presence of the slag material will mean that each CPT position would need to be pre-drilled as the probe would not be able to penetrate through the slag. Potential options for UXO clearance will therefore depend upon the strategy for dealing with the other geotechnical issues at the site and the time of the remediation compared with the design of the foundations for the proposed building/structure. Potential options include:

- If made ground is to be excavated as part of the remediation strategy, then the most cost effective method of undertaking the UXO clearance would be once the made ground had been excavated. However, this is reliant upon having an understanding of where the proposed buildings would be located and preferably the pile layout design. Two options are available:
    - The magnetometers used to clear for UXO typically will detect anomalies within a 1.5m radius which in the right ground conditions could potentially be extended to 2m. Therefore, if the pile layout is not known, in order to successfully clear beneath the proposed building then the CPT probes would need to be undertaken on a grid of 3m spacings in order to ensure that a potential anomaly is detected. For large size buildings this requires a large number of probe locations;
    - If the precise pile layout is known, then it would be necessary to reduce the number of CPT probe holes to ensure that each individual pile/pile group is cleared. This will reduce the number of probe holes required compared with grid clearance.

If the building location is not known at the time of undertaking the remediation there is one further, albeit more costly option available:

- Clearance once the processed slag material has been replaced and compacted. However, given the nature of the slag material and the condition it is likely to be in after placement, it is considered unlikely that the CPT probe would be able to penetrate through the made ground. Therefore, pre-clearance at each location will be required. As this will result in ‘damage’ to the placed engineered fill it is important that this is only undertaken at the proposed pile locations where the subsequent installation of the pile would essentially ‘mend’ the engineered fill platform.

It should be noted that clearance of the whole site would be uneconomical (hundreds of millions of pounds) and as such is not considered to be a viable option.

It should be noted that due to the presence of groundwater within the basal part of the made ground it is considered likely that it may not be feasible to economically excavate the basal part of the made ground (it also may not be technically necessary either). If this is the case, then some form of pre-probing may still be required prior to UXO clearance via CPT probing. The design will need to take into account potential weakening/damage to the made ground remaining in situ.

3.7 Floors

Beneath Area A if made ground is removed and replaced with a compacted fill placed to an engineering specification, ground bearing slabs may be appropriate. Consolidation settlement of the glaciolacustrine deposits may occur depending on loading, slab dimensions etc. and detailed settlement analysis will be required. Depending on the sensitivity of the structure, the use of pre-consolidation with wick drains may reduce the settlement to acceptable levels. If particularly sensitive structures are proposed (e.g. high bay warehouses) then settlement reducing piles or lime columns may be appropriate.

Similar conditions may be encountered beneath Area B, however there are also additional areas of deep made ground, former basements service conduits etc. The proposed layout should be designed to avoid rapid changes in ground conditions (e.g. straddling former basements, infilled reservoirs etc.). Where this cannot be avoided, the slab will need to be thickened, or piled. In Area B, the presence of more expansive slag will also suggest that suspended flor slabs will be more appropriate.

3.8 Ground Gas

Preliminary gas investigation recorded no elevated concentrations of carbon dioxide and a maximum methane concentration of 0.2% (v/v). While the number of sampling locations is limited, this suggests that gas protection measures are unlikely to be required.

3.9 Groundwater Control

Groundwater was not recorded during the investigation in Area A, however post fieldwork monitoring recorded standing water levels at between 1.0 and1.5m bgl. In Area B, groundwater inflow was recorded in several locations within the made ground. Post fieldwork monitoring recorded standing water levels at 1.5 to 2.0m bgl. Shallow groundwater may therefore be expected in both areas. Allowance should therefore be made for groundwater control for even shallow excavations.

3.10 Buried Concrete

Laboratory analysis has identified elevated concentrations of water soluble sulphate in a range of materials across site. Desk study information, backed up by laboratory data indicate that sulphides are also present at the site and therefore an assessment of the total potential oxidisable sulphate has been undertaken as outlined in BRE Special Digest 1.

The results to date indicate that the very high concentrations of sulphates and sulphides present within the made ground that would place the site into Design Sulphate Class DS-5. The corresponding ACEC Class, which takes into consideration the pH and mobility of groundwater is AC-5.

Precautionary measures will therefore need to be taken to protect buried concrete against sulphate attack. This will not only require the use of sulphate resistant cement but will also require Additional Protective Measures (APMs) to be used. This can include the provision of surface protection, sacrificial layers and/or enhanced concrete quality. However, it will also depend upon other design factors such as the intended working life.

4 Data Gaps

Following completion of the site investigation and geotechnical assessment the following data gaps have been identified that will warrant further investigation to formulate an outline remediation strategy for the site:

1. Further deep boreholes in both Areas A and B in order to provide a better indication of likely depth to rockhead, and the variation in geology across the site;
2. Further investigation of ground conditions beneath the existing buildings which cover much of the site footprint;
3. Further investigation and assessment of the existing subsurface structures, in particular in Area B.

In addition, once specific details of the proposed development is known then detailed investigation will be required to aid in the detailed design of foundations, floors, and external pavements. This will include an assessment of likely settlement due to future loadings.

5 Conclusions and Recommendations

Detailed redevelopment proposals are not available for either Area A or Area B, however it is assumed that both areas will continue to be used for commercial/industrial purposes. It is likely that enabling works will be required to remove obstructions and recompact the shallower material across both Areas A and B.

Within Area A, the investigation has revealed ground conditions to include typically granular made ground overlying tidal flat deposits and glacial till, with mudstone of the Redcar Mudstone formation proved within one borehole. The made ground was typically thinner than elsewhere within the former SSI Steelworks site and was typically less than 3m in thickness (however locally greater thicknesses were encountered). Slag within the made ground was noted to have limited expansion potential, with a maximum 28 day expansion of 1.16%. Water was encountered within the made ground at several locations as were concrete and other obstructions.

Within Area B, ground conditions were found to include a thicker layer of made ground (typically 4m thick or greater), which was again dominated by cobble and boulder sized fragments of slag. Expansion testing of the slag in Area B typically recorded 28 day expansion values of <1%, however one sample encountered up to 3.19% this sample was noted to contain a large proportion of basic steel slag. Approximately half of the trial excavations within Area B were terminated due to obstructions, groundwater inflow or instability in the made ground. Natural deposits were found to include glacial till, glaciolacustrine deposits (sandwiched between layers of till), overlying bedrock of the Redcar Mudstone and Mercia Mudstone formations, with the latter containing a significant proportion of gypsum. It is understood that extensive basements, service conduits and other structures exist beneath the buildings in Area B.

It is understood that Area A is likely to be fully redeveloped, while Area B may either be fully redeveloped, or involve partial retention of existing structures. Identified geotechnical constraints for each are summarised below:

Expansion of steel slag beneath the site is not yet complete, future expansion may lead to disruption and damage of new of proposed structures. Bulk screening, crushing and processing the made ground to reduce expansion potential may be feasible, particularly in Area A where the total thickness of made ground is limited. Bulk excavation will also assist in removal of obstructions within the made ground. Care will however be needed to ensure materials which are to be reused do not include potentially expansive materials (e.g. basic steel slag, refractories etc.). In Area B where the thickness of made ground is more extensive, this option may not be feasible.

Additionally, the natural soils beneath the made ground may suffer from long term creep settlement if loadings are changed where glaciolacustrine soils are present.

Subject to proposed loadings, slab dimensions etc. ground bearing slabs may be suitable for new structures within Area A, provided the made ground is excavated, processed and recompacted to an engineering specification. For higher loadings or particularly sensitive structures, piling may be required.

For new structures within Area B, piling is likely to prove the most cost effective solution. Piles would need to be predrilled to overcome obstructions and UXO clearance carried out at each location. Piles would also need to be designed to resist lateral and vertical pressures which might be exerted by expansion of the made ground. Ground beams and floor slabs would need to be suspended.

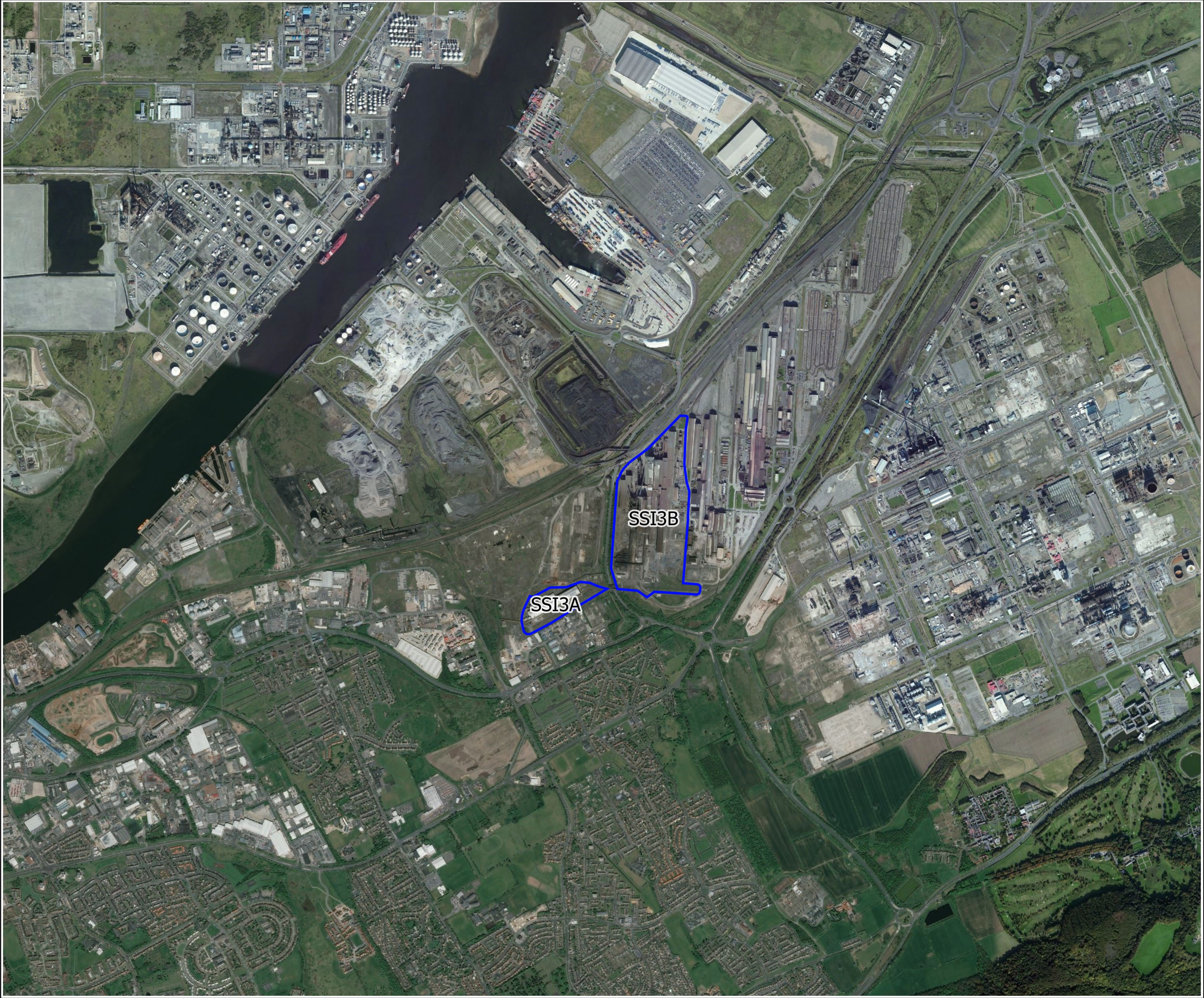
Within Area B infilled lagoons are known to be present to the north-west of the existing structure. It may prove beneficial to limit development in these areas.

Additionally, if buildings in Area B are to be retained, the existing foundations should be examined to confirm that sulphate attack has not resulted in deterioration of the current foundations.

In both areas, once detailed development proposals are available, further investigation will be required to confirm depth to rockhead, ground gas regime, settlement of made ground and natural soils under proposed loading etc.

APPENDIX A

Figures



Legend

Contract 3

Notes:

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Title:
SSI3 Site Location Plan

Site:
Redcar Steelworks

Client:
South Tees Site Company

Project: **37774100**	**Figure 1**

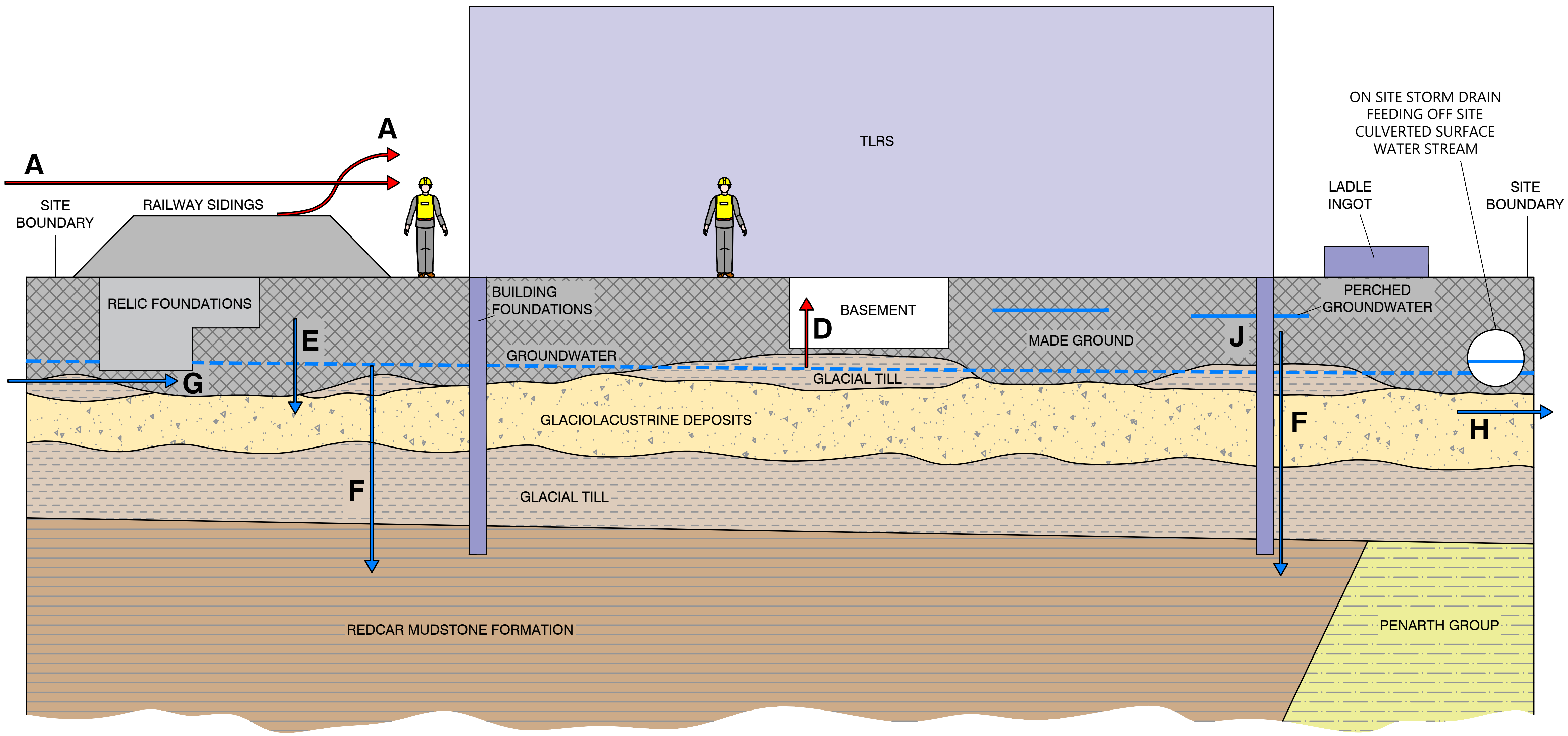
Date: 24/04/2018
Drawn By: JALM
DRG No: 37774100_01_SSI2b_Figure_1

ARCADIS Design & Consultancy for natural and built assets

Potential Human Health SPR Linkages
A = Dust inhalation from Made Ground from site and adjacent land
D = Accumulation of ground gas in confined spaces
SPR linkages for construction workers during redevelopment not shown

Potential Water Resource SPR Linkages
E = Leaching of contaminants from Made Ground and point sources to groundwater in superficial deposits
F = Migration of contaminated groundwater to (Secondary (Undifferentiated) Aquifer) in bedrock
G = Migration of contaminated groundwater onto site in Made Ground and Superficial Deposits
H = Migration of contaminated groundwater off site in Made Ground and Superficial Deposits

Other SRP Linkages
J = Attack by contaminants of concern on foundations



KEY

NOTES

SCHEMATIC DRAWING ONLY - NOT TO SCALE

REV	DATE	COMMENT	CAD

TITLE: UPDATED CONCEPTUAL SITE MODEL - SSI3 AREA A TLRS

SITE: REDCAR

CLIENT: STSC

PROJECT: 10013655 | FIGURE 2a

DATE: 02/07/18 | DRAWN: BNB | REV: -

DRG.No.: 10013655_CSM_1 | PRINT: A3

ARCADIS Design & Consultancy for natural and built assets

Potential Human Health SPR Linkages
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SPR linkages for construction workers during redevelopment not shown

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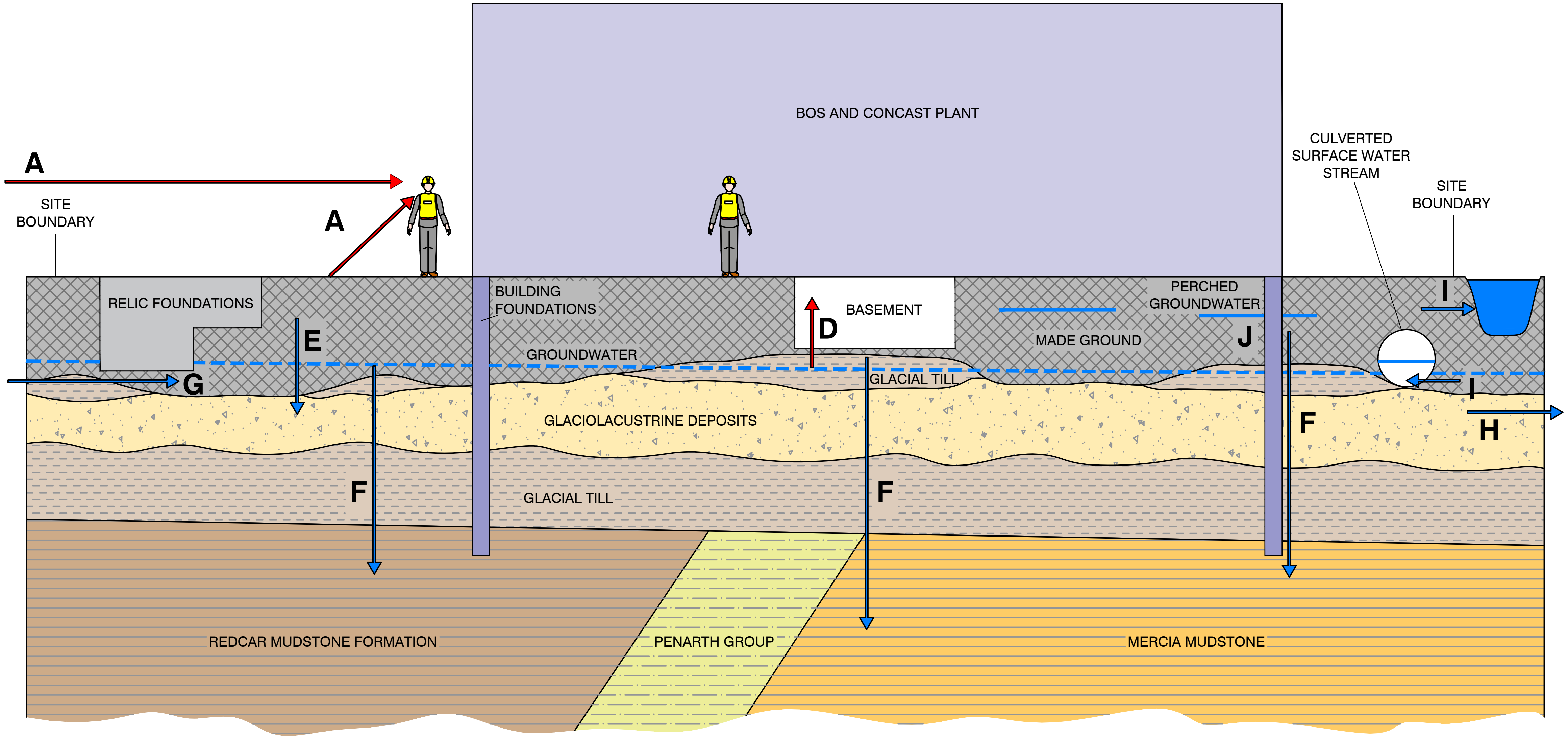
G = Migration of contaminated groundwater onto site in Made Ground and Superficial Deposits
H = Migration of contaminated groundwater off site in Made Ground and Superficial Deposits
I = Migration of contaminated groundwater into culverted surface water streams (Kinkerdale Beck, Boundary Beck), and off site pond

Other SRP Linkages
J = Attack by contaminants of concern on foundations



KEY

NOTES

SCHEMATIC DRAWING ONLY - NOT TO SCALE

REV	DATE	COMMENT	CAD

TITLE: UPDATED CONCEPTUAL SITE MODEL - SSI3 AREA B BOS AND CONCAST PLANT

SITE: REDCAR

CLIENT: STSC

PROJECT: 10013655 FIGURE 2b

DATE: 02/07/18 DRAWN: BNB REV: -

DRG.No.: 10013655_CSM_2 PRINT: A3

ARCADIS Design & Consultancy for natural and built assets

APPENDIX B

Study Limitations

IMPORTANT: This section should be read before reliance is placed on any of the information, opinions, advice, recommendations or conclusions contained in this report.

1. This report has been prepared by Arcadis UK Ltd (Arcadis), with all reasonable skill, care and diligence within the terms of the Appointment and with the resources and manpower agreed with **STSC** (the 'Client'). Arcadis does not accept responsibility for any matters outside the agreed scope.

2. This report has been prepared for the sole benefit of the Client unless agreed otherwise in writing.

3. Unless stated otherwise, no consultations with authorities or funders or other interested third parties have been carried out. Arcadis are unable to give categorical assurance that the findings will be accepted by these third parties as such bodies may have unpublished, more stringent objectives. Further work may be required by these parties.

4. All work carried out in preparing this report has used, and is based on, Arcadis' professional knowledge and understanding of current relevant legislation. Changes in legislation or regulatory guidance may cause the opinion or advice contained in this report to become inappropriate or incorrect. In giving opinions and advice, pending changes in legislation, of which Arcadis is aware, have been considered. Following delivery of the report, Arcadis have no obligation to advise the Client or any other party of such changes or their repercussions.

5. This report is only valid when used in its entirety. Any information or advice included in the report should not be relied upon until considered in the context of the whole report.

6. Whilst this report and the opinions made are correct to the best of Arcadis' belief, Arcadis cannot guarantee the accuracy or completeness of any information provided by third parties.

7. This report has been prepared based on the information reasonably available during the project programme. All information relevant to the scope may not have been received.

8. This report refers, within the limitations stated, to the condition of the Site at the time of the inspections. No warranty is given as to the possibility of changes in the condition of the Site since the time of the investigation.

9. The content of this report represents the professional opinion of experienced environmental consultants. Arcadis does not provide specialist legal or other professional advice. The advice of other professionals may be required.

10. Where intrusive investigation techniques have been employed they have been designed to provide a reasonable level of assurance on the conditions. Given the discrete nature of sampling, no investigation technique is capable of identifying all conditions present in all areas. In some cases, the investigation is further limited by site operations, underground obstructions and above ground structures. Unless otherwise stated, areas beyond the boundary of the site have not been investigated.

11. If below ground intrusive investigations have been conducted as part of the scope, service tracing for safe location of exploratory holes has been carried out. The location of underground services shown on any drawing in this report has been determined by visual observations and electromagnetic techniques. No guarantee can be given that all services have been identified. Additional services, structures or other below ground obstructions, not indicated on the drawing, may be present on Site.

12. Unless otherwise stated the report provides no comment on the nature of building materials,

operational integrity of the facility or on any regulatory compliance issues

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