



GLOBAL CENTRE OF RAIL EXCELLENCE - WASHERY

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Executive Summary

AtkinsRéalis has been commissioned by Walters Group as their designer to undertake the detailed design of proposed earthworks for the redevelopment of the Nant Helen wider site, near Onllwyn in South Wales. This includes the Onllwyn Washery area which will become a rolling stock and rail infrastructure testing facility as part of the Global Centre of Rail Excellence (GCRE).

An initial Ground Investigation (GI) (Stage 0 GI) was undertaken at the site between 15th November 2021 and 19th January 2022. A Ground Investigation Report (GIR) was then produced in June 2022 which discussed the findings of this investigation, proposed ground models for the development areas and derived site-wide geotechnical parameters. However, a number of risks and limitations, principally relating to ground modelling, ground characterisation, historical coal mining activity and contaminated land, were identified due to a lack of information provided by the Stage 0 GI.

Subsequently, an additional GI was proposed which aimed to mitigate the identified hazards and limitations. This investigation was split into two stages:

- Stage 1 – comprised works only within the Washery Phase 1A area of the site (to the north of the Onllwyn Washery area) and a small number of locations within the main site north eastern embankment. These areas were prioritised as the Washery Phase 1A earthworks are to be constructed first as part of the phased construction approach and the northern embankment was subject to critical design assumptions which needed to be addressed as early as possible.
- Stage 2 – comprised works across the whole site, outside of the Washery Phase 1A area.

The Stage 1 GI was undertaken on site between November 2022 and January 2023 and the Stage 2 GI was undertaken between March and June 2023 by Jackson Geo Services (GI contractor) with AtkinsRéalis acting as the investigation supervisor.

This report (Washery GIR) pertains only to the GI works undertaken within the Washery area of the site.

The Washery site initially comprised of two areas: the 'Phase 1A' area located to the north of the Washery site which comprised the proposed earthworks footprint (as shown within Figure 1-1) and the 'Phase 2' area located to the south of the Washery site which comprised buildings associated with GCRE (not included within the AtkinsRéalis geotechnical design scope of works). After the completion of the Stage 2 ground investigation, the design was amended, and the phased areas of the site merged into a single 'Washery' site which features an earthworks footprint further to the south than the original Phase 1A boundary.

As only the earthworks design was part of the AtkinsRéalis geotechnical scope of works, the Stage 1 and Stage 2 GI locations within the Washery Phase 2 area were solely investigated for contaminated land purposes (predominantly to assist with the discharge of planning consent). As a result, these locations were generally spaced as per the contaminated land requirements (targeted positions based on historical site processes, existing or demolished buildings, and potential sources of contamination), were relatively shallow, and no geotechnical testing was undertaken. This means that while the Stage 1 and Stage 2 GIs have improved the understanding of the northern Washery, limited additional geotechnical information is available for the southern Washery creating limitations with the ground modelling and geotechnical parameterisation of the geotechnical units encountered within this area, where any localised variation have not been identified.

Subsequently, a Stage 3 GI has been proposed with additional investigation within the southern Washery to mitigate the risks associated with the limited geotechnical information within this area. The recommended scope of this investigation was outlined within the Stage 3 GI specification [1], however, the works have not been undertaken at the time of this report (April 2024).

The Stage 1 and Stage 2 GIs enabled the ground model to be refined for the Washery site, with an increased understanding of the ground conditions particularly in the north of the site in relation to the thickness and distribution

of the made ground and Peat materials as well as the depth of the underlying South Wales Coal Measures Formation bedrock. The GI principally identified:

- Significant made ground deposits to the east of the site. The cause of these thicker deposits is unconfirmed, however, is likely to be either associated with a backfilled mining feature or a stockpile of spoil material placed within a topographical low point.
- Considerable Peat deposits underlying a significant proportion of the north of the site.
- A layer of relic topsoil underlying or interbedded within the made ground within a small portion of the east and south of the site.
- Artesian water in a number of exploratory holes to the west of the site.

In situ and laboratory information obtained from the Stage 1 and Stage 2 GIs allowed for the site-wide geotechnical parameters proposed within the Stage 0 GIR to be refined, providing geotechnical parameters specific to the Washery site. It was noted that these did not vary significantly from the site-wide parameters initially proposed. Additionally, sufficient information was also available to enable derivation of Peat material parameters (which was not previously possible within the Stage 0 GIR).

The geo-environmental and mining assessments for the Washery works are provided within separate reports [2, 3], which should be referenced in conjunction with this GIR.

1. Introduction

1.1 Background

AtkinsRéalis has been commissioned by Walters Group as their designer to undertake the detailed design of proposed earthworks for the redevelopment of the former Nant Helen opencast mining site, near Onllwyn in South Wales. This includes the Onllwyn Washery area (formerly associated with the Nant Helen opencast mine), which will become a rolling stock and rail infrastructure testing facility as part of the Global Centre of Rail Excellence (GCRE).

The site is comprised of two areas: the 'Land at Nant Helen' and the 'Washery'.

- The 'Land at Nant Helen' refers to the central body of the site located at the former Celtic Energy Nant Helen opencast site and contains the proposed rail test track. This area of the site is not the subject of this report.
- The 'Washery' refers to the extension of the site to the southeast incorporating the Onllwyn Washery, which comprises railway land, spoil heaps, stockpiles, lagoons, several buildings, conveyer belts and material sorting facilities. This area is the subject of this report.
 - The Washery site initially comprised two areas: the 'Phase 1A' area located to the north of the Washery site which comprised the proposed earthworks footprint (as shown within Figure 1-1) and the 'Phase 2' area located to the south of the Washery site which comprised buildings associated with GCRE (not included within the AtkinsRéalis geotechnical design scope of works). After the completion of the Stage 2 ground investigation (discussed below), the design was amended, and the phased areas of the site merged into a single 'Washery' site which features an earthworks footprint further to the south than the original Phase 1A boundary.

At the time of this report (April 2024), three Ground Investigations (GI) have been completed at the site.

Stage 0 GI (Nov 2021 – Jan 2022): Arup were previously commissioned by GCRE Ltd to scope and supervise an initial GI at the site (hereafter referred to as the Stage 0 GI) and to produce a GIR (hereafter referred to as the Arup GIR) [4] detailing interpretation of the ground and groundwater conditions at the site and to support the discharge of planning conditions.

On appointment to the project, AtkinsRéalis produced a site wide GIR (hereafter referred to as the Stage 0 GIR) [5] which outlined the Stage 0 GI works, derived a ground model and geotechnical parameters based on the information available at the time, identified geotechnical and geo-environmental risks and undertook an engineering assessment of the proposed works.

As part of that report, AtkinsRéalis identified a number of limitations with the existing Stage 0 GI and subsequently recommended that additional ground investigation be undertaken at the site. Resultantly, AtkinsRéalis were then instructed to produce an additional GI proposal which detailed the limitations of the existing GI (principally relating to ground modelling, ground characterisation, historical coal mining activity and contaminated land), the associated risks to the scheme, and proposed further GI works in order to mitigate these risks.

The Ground Investigation Proposal Technical Note [6] should be referenced for a full explanation of the identified limitations and proposals. Based on discussions with Walters Group and the Client (GCRE Ltd), the additional GI proposal was then split into two stages, based on priority:

Stage 1 (Nov 2022 – Feb 2023) (hereafter referred to as the Stage 1 GI) – comprised works only within the Washery Phase 1A area of the site (the north of Onllwyn Washery area) and a small number of locations within the main site north eastern embankment.

These areas were prioritised as the Washery Phase 1A earthworks are to be constructed first as part of the phased construction approach and the northern embankment was subject to critical design assumptions which needed to be addressed as early as possible.

Stage 2 (Mar 2023 – June 2023) (hereafter referred to as the Stage 2 GI) – comprised works across the whole site, outside of the Washery Phase 1A area.

As only the earthworks design was part of the AtkinsRéalis geotechnical scope of works, the GI locations within the Washery Phase 2 area were solely investigated for contaminated land purposes (predominantly to assist with the discharge of planning consent). As a result, these locations were generally spaced as per the contaminated land requirements (targeted positions based on historical site processes, existing or demolished buildings, and potential sources of contamination), were relatively shallow, and no geotechnical testing was undertaken.

Stage 3 (TBC) (hereafter referred to as the Stage 3 GI) – following the revised earthwork footprint of the Washery site, the ground conditions located outside the former Phase 1A area were identified as requiring additional investigation. The recommended scope of this investigation was outlined within the Stage 3 GI specification [1], however, the works have not been undertaken at the time of this report (April 2024).

This report (hereafter referred to as the Washery GIR) pertains only to the Washery area of the site.

1.2 Scope and objectives of the report

This GIR has been prepared in accordance with CD 622 ‘Managing Geotechnical Risk’ [7], the objectives of which are to:

- Outline the proposed Washery development works;
- Summarise existing information relating to the Washery site;
- Summarise the GI works undertaken within the Washery site;
- Establish a ground model and geotechnical parameters for the Washery site based on the available information;
- Identify geotechnical hazards at the Washery site and assess risks associated with the hazards; and
- Undertake an engineering assessment for the Washery proposed works.

Geo-environmental and mining assessments for the Washery are outside the scope of this report and are provided as separate reports [2, 3], which should be referenced in conjunction with this GIR.

1.3 Project description

1.3.1 Site description

The wider GCRE development site is located immediately to the south of Abercraf, approximately 20 km northwest of Swansea, south Wales. As discussed above, the site, as indicated in Figure 1-1, is comprised of two areas – the ‘Land at Nant Helen’ (not the subject of this GIR) and the ‘Washery’ site (the subject of this GIR).

The Washery site, as shown in Figure 1-1 comprises areas of vegetated colliery spoil and railway land to the north, two building structures and lagoons to the south and a raised area of coal stockpiles to the centre.

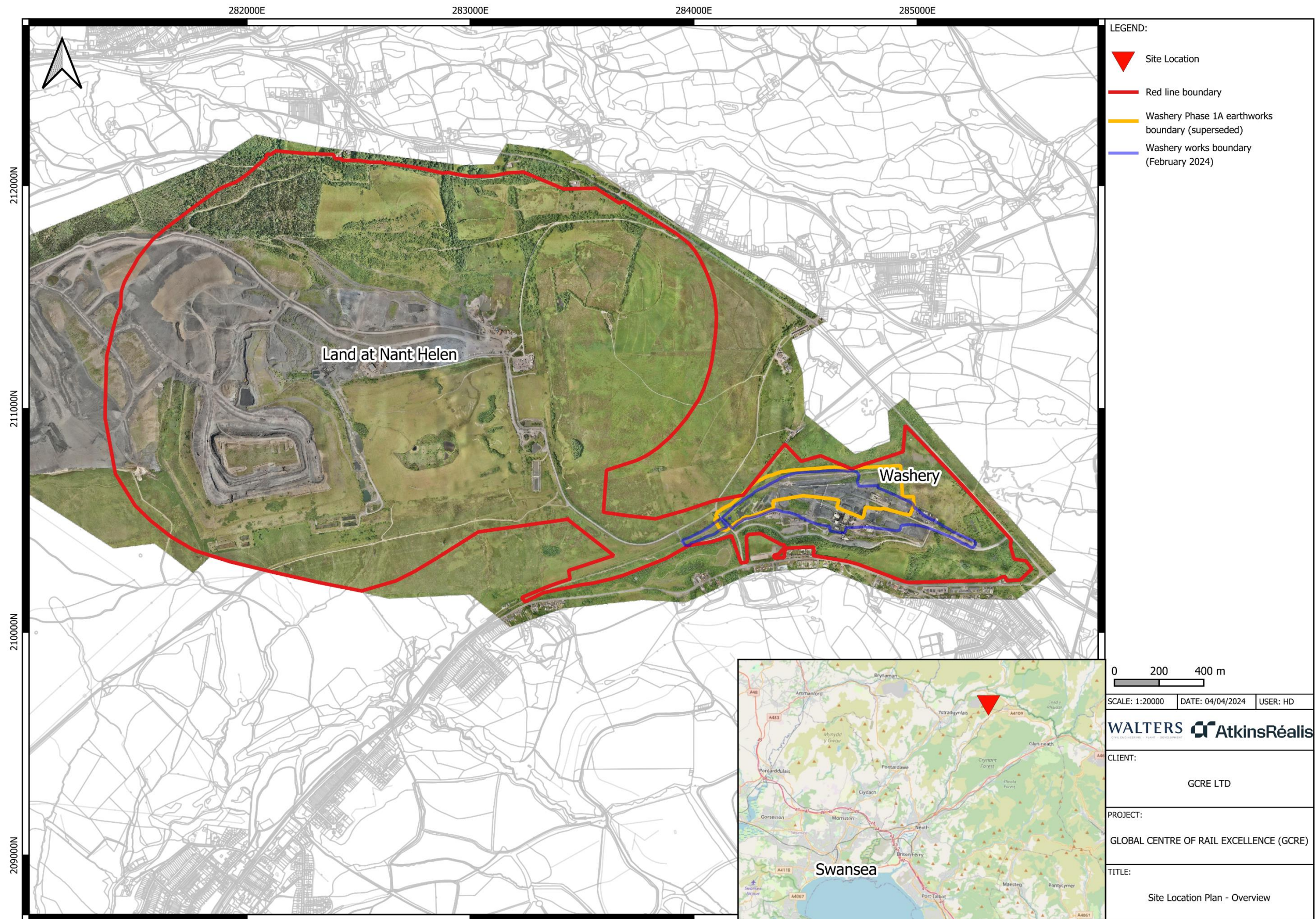


Figure 1-1: Site Plan – Overview (Imagery copyright AtkinsRéalis, [8])

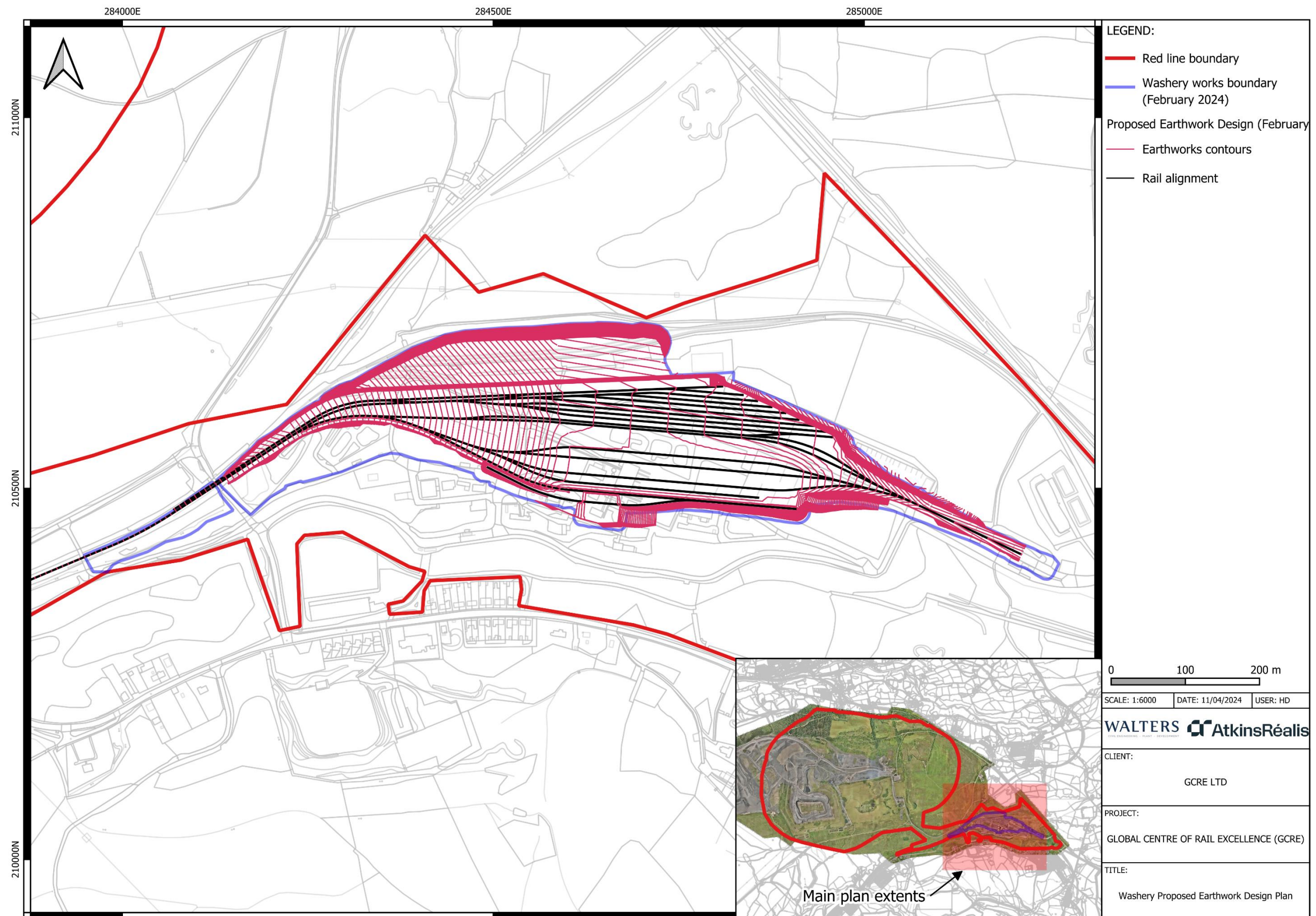


Figure 1-2: Washery Proposed Earthwork Design Plan (Imagery copyright AtkinsRéalis)

1.3.2 Proposed development

As shown within Figure 1-2, the proposed works within the Washery site comprise the installation of multiple sidings for rolling stock storage and decommissioning, as well associated buildings, and an electricity substation. The earthworks within this area comprise an embankment along the northern extent of up to approximately 7.5 m height, a cutting located along the eastern extent up to approximately 5.2 m depth and a cutting along the southern extent up to approximately 5.5 m depth.

1.3.3 Planning status

The current planning status and discharge of planning conditions is detailed within the separate geo-environmental interpretive report [3] for the Washery site, which should be referenced in conjunction with this GIR.

1.4 Geotechnical category

Based on the current scheme proposals and a review of the currently available information, it is determined that the works within the Washery site will fall within Geotechnical Category 2 as defined by Eurocode 7 [9] in accordance with the guidance given in Part 5 of CD 622 [7]. Where Geotechnical Category 2 includes conventional types of structures and foundations with no exceptional risk or difficult soil and/or loading conditions.

1.5 Limitations

Any geotechnical considerations based on GI data are subject to inherent limitations of any such study, whereby the nature of the work means that only a small proportion of the sub-surface conditions can be observed and sampled. Ground conditions can vary significantly between exploratory hole locations and groundwater conditions vary seasonally. Therefore, unexpected ground conditions could occur between the sampling points and groundwater conditions may differ from those encountered during the monitoring periods.

Opinions and recommendations presented in this report are based partly upon information provided by third party sources. AtkinsRéalis has not been able to independently verify all third-party information and for the purposes of this assessment it has been assumed that such information is accurate and complete. Therefore, whilst this report and the opinions contained herein are accurate to the best of AtkinsRéalis' knowledge and belief, AtkinsRéalis cannot guarantee the completeness nor accuracy of any descriptions or conclusions based on supplied third party information.

This report relates only to the geotechnical related aspects of the Washery site. The historical mining aspects and geo-environmental aspects are not considered as part of the scope of this report but are covered within the separate geo-environmental and mining reports [2, 3].

Geotechnical ground modelling and parameter derivation is based on the data available at the time of writing (March 2024). Limited information is currently available for the former Phase 2 area of the site; therefore, it is assumed to contain comparable material (both made ground and natural deposits) to that tested elsewhere within the Washery site. Should further site-specific information, including additional GI data, challenge this assumption, further assessment will be required.

This report has been based on the development proposals in place at the time of writing (April 2024) and should the scheme proposals change then further assessment may be required.

This report should be read considering the legislation, statutory requirements and/or industry best practice applicable at the time of writing (April 2024). Any subsequent changes in this legislation, guidance or design may require the findings to be reassessed.

2. Existing Information

2.1 General

A summary of the initial Arup and subsequent AtkinsRéalis work relating to the geotechnical investigation and characterisation of the site ground conditions, as well as the geotechnical risk management is provided below. The sources which predate the Stage 0 GIR are referenced and described in detail within that document.

- Geotechnical and Geo-environmental Desk Study, Arup, 2018 [10]
- Detailed Mine Workings Study, Arup, 2020 [11]
- Environmental Statement, Arup, 2020 [12]
- Ground Investigation Specification, Arup, 2021 [13]
- Ground Investigation Factual Report, Quantum Geotechnical Limited, 2022 [14]
- Ground Investigation Report, Arup, 2022 [4]
- Ground Investigation Report (GCRE001-AWJV-00-XX-RP-GE-00002), AtkinsRéalis, 2022 [5]
- Additional Ground Investigation Proposal (GCRE001-AWJV-EW-XX-DO-GE-00002), AtkinsRéalis, 2022 [6]
- Geo-environmental Interpretative Report, AtkinsRéalis, 2024 [3]
- Coal Mining Risk Review, AtkinsRéalis, 2024 [15]

The intention of this report is not to duplicate the findings of previous reports, but to supplement these studies with the findings of the recent ground investigations. Where additional information has been identified that allows assessments in previous reports to be further developed, this is discussed within this GIR and the supporting Appendices.

2.2 Topography

The wider Washery area is located at the base of a valley that rises to the north and south and which deepens to the west.

The Washery site rises from a minimum elevation of approximately 230 m Above Ordnance Datum (AOD) in the west to a maximum elevation of approximately 242 m AOD in the southeast. A topographic survey of the site undertaken in December 2023, as shown within Figure 2-1 below, shows that the site has very variable topography as a result of historical site activities including stockpiles and spoil heaps.

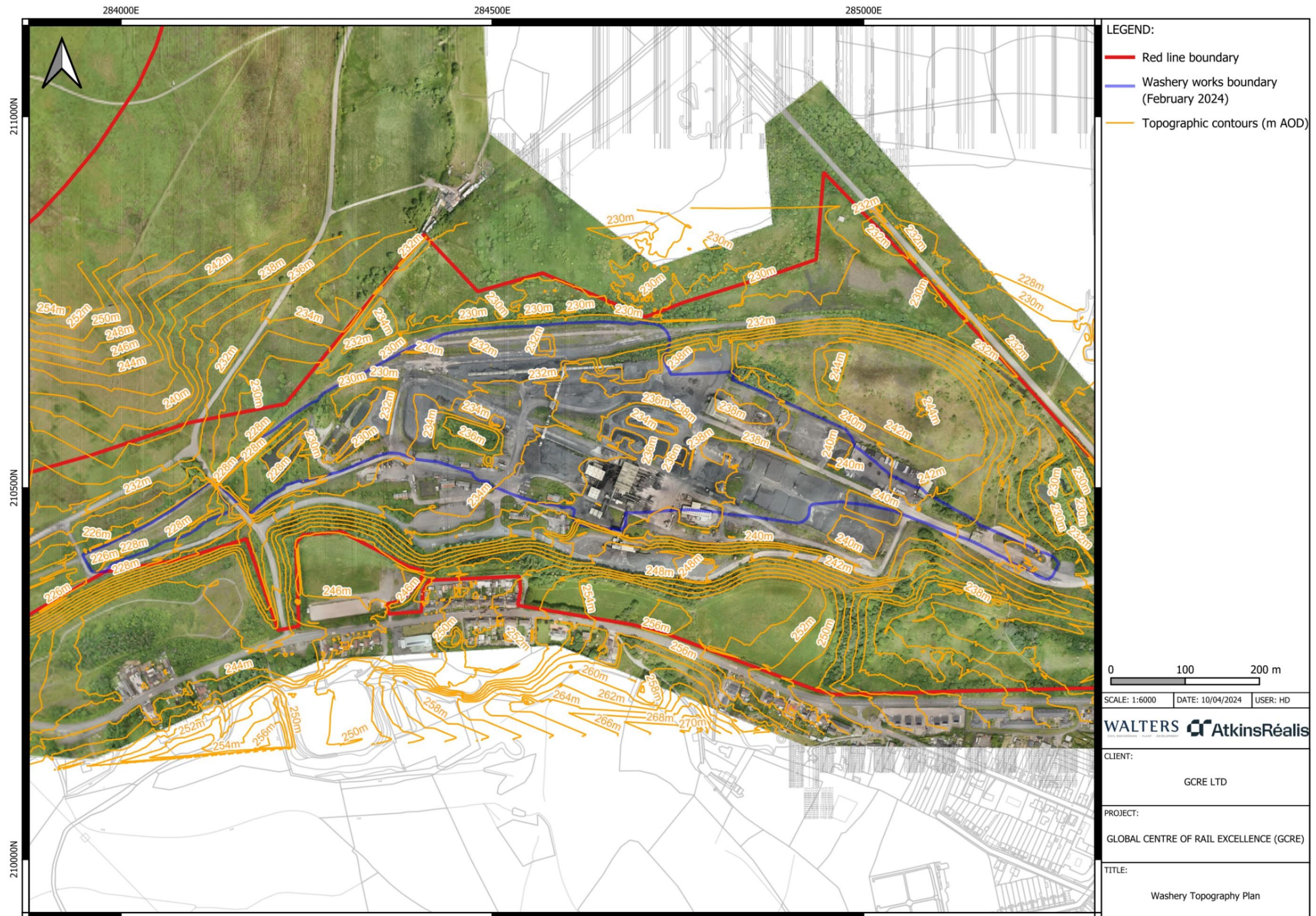


Figure 2-1: Washery Topography Plan (Imagery copyright AtkinsRéalis)

2.3 Site history & land use

2.3.1 Historical land use

The Washery site has an extensive history of industrial activities associated with the Onllwyn Coal Washery, including coal washery activities, railway land, works and mining activities.

A comprehensive discussion of the site historical land use is provided within the AtkinsRéalis Stage 0 GIR [5] which should be referenced.

2.3.2 Current land use

The Washery (as shown in Figure 1-1 above) currently consists of a core of industrial land concentrated around a network of site access roads and railway land (sidings and train heads) which connect to the Neath and Brecon line at the western end of the site. The industrial usage is surrounded to the east, and south by open land that comprises colliery spoil vegetated with rough grassland, areas of scrub and areas of deciduous woodland. The land use comprises:

- A network of railway sidings in the north that connect to the main line network to the east;
- Underground coal storage hoppers;
- Coal stockpiles covering a significant proportion of the site;
- Spoil heaps created by spoil from the washery;
- Extensive drainage network with adjacent settling lagoons before draining into the wider river system; and
- Series of buildings and overhead conveyor belts associated with the washery for the processing and washing of coal.

The site is currently undergoing demolition and reprofiling works, consisting of the removal of buildings associated with the washery and railway distribution, underground storage areas, railway sidings and concrete slabs. The majority of the buildings and stockpiles have been removed at the time of writing (April 2024).

2.4 Published geology

A detailed discussion of the published geology of the site based on geological mapping, memoirs, and relevant publications is presented in the AtkinsRéalis Stage 0 GIR [5], which should be referenced.

However, a summary of the bedrock and superficial stratigraphy relevant to the Washery site is provided in Table 2-1 below, with plans indicating the published mapped geology provided in Figure 2-2 and Figure 2-3.

Table 2-1: Washery summary of published geology

Lithology	Approximate Location	Description
Made ground	Entire site	Colliery spoil and slag generated by the Onllwyn and Dulais Collieries and coal washing from the opencast workings.
Superficial Deposits		
Peat	North and southwest	Partially decomposed mass of semi-carbonized vegetation which has grown under waterlogged, anaerobic conditions, usually in bogs or swamps.

Glacial Till	East	Heterogenous mixture of clay, sand, gravel, and boulders varying widely in size and shape.
Bedrock		
South Wales Lower Coal Measures*	East	Grey, (productive) coal-bearing mudstones/siltstones, with seatearths and minor sandstones.
South Wales Middle Coal Measures*	West	
Coal Seams		
New	Ordered from east to west	Additional description provided within the Mining Risk Review [2] included as an appendix within the AtkinsRéalis Stage 0 GIR [5].
Grey		
Rhyd		
Nine Feet		
Structural Geology - Faults		
Glyncorrwg	Centre	Glyncorrwg
*Due to the similarity of the Middle and Lower Coal Measure Formations and the difficulty of differentiating them in the field they have been treated as one unit within this and previous reports		

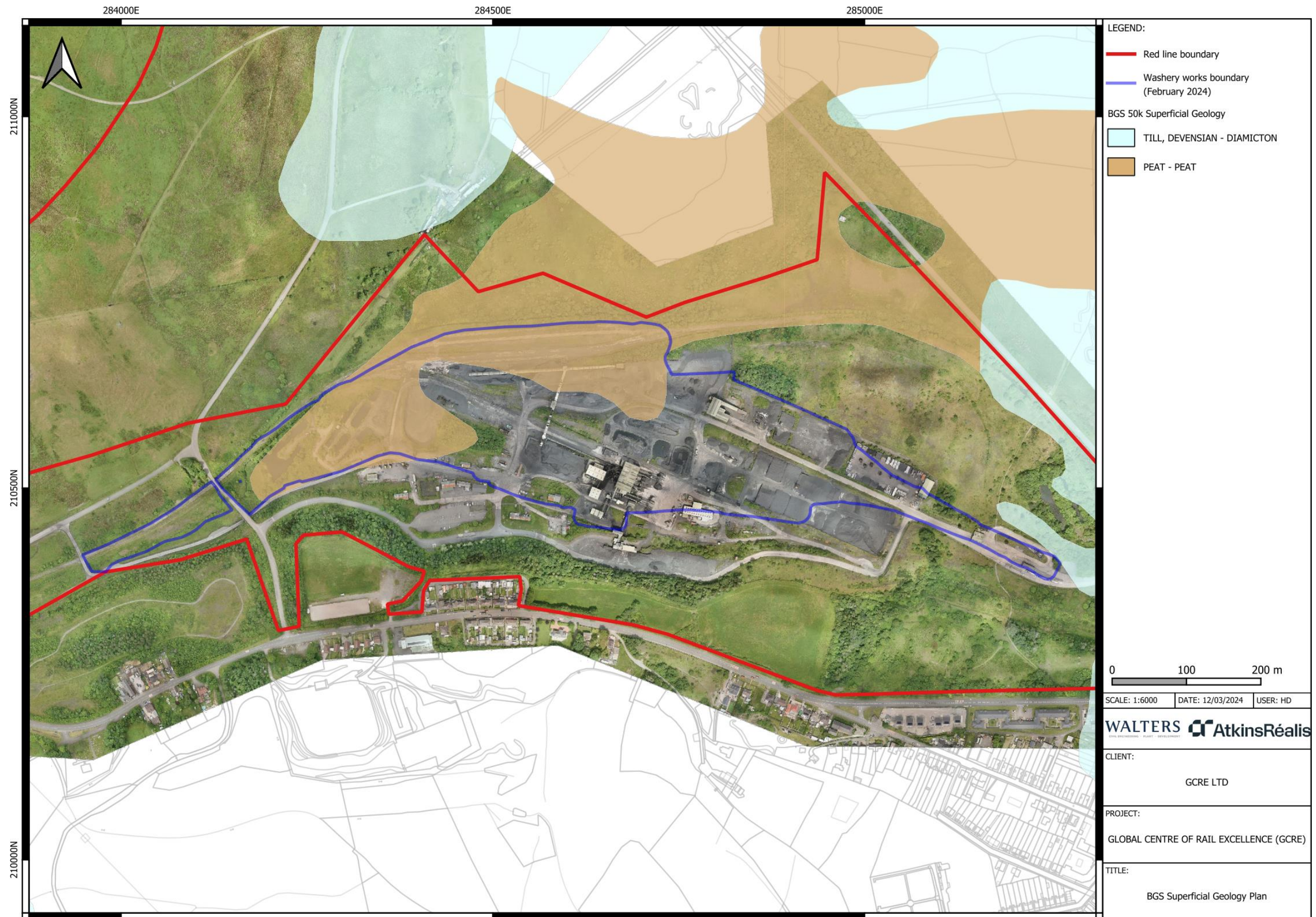


Figure 2-2: BGS Superficial Geology Plan (Imagery copyright AtkinsRéalis, [16])

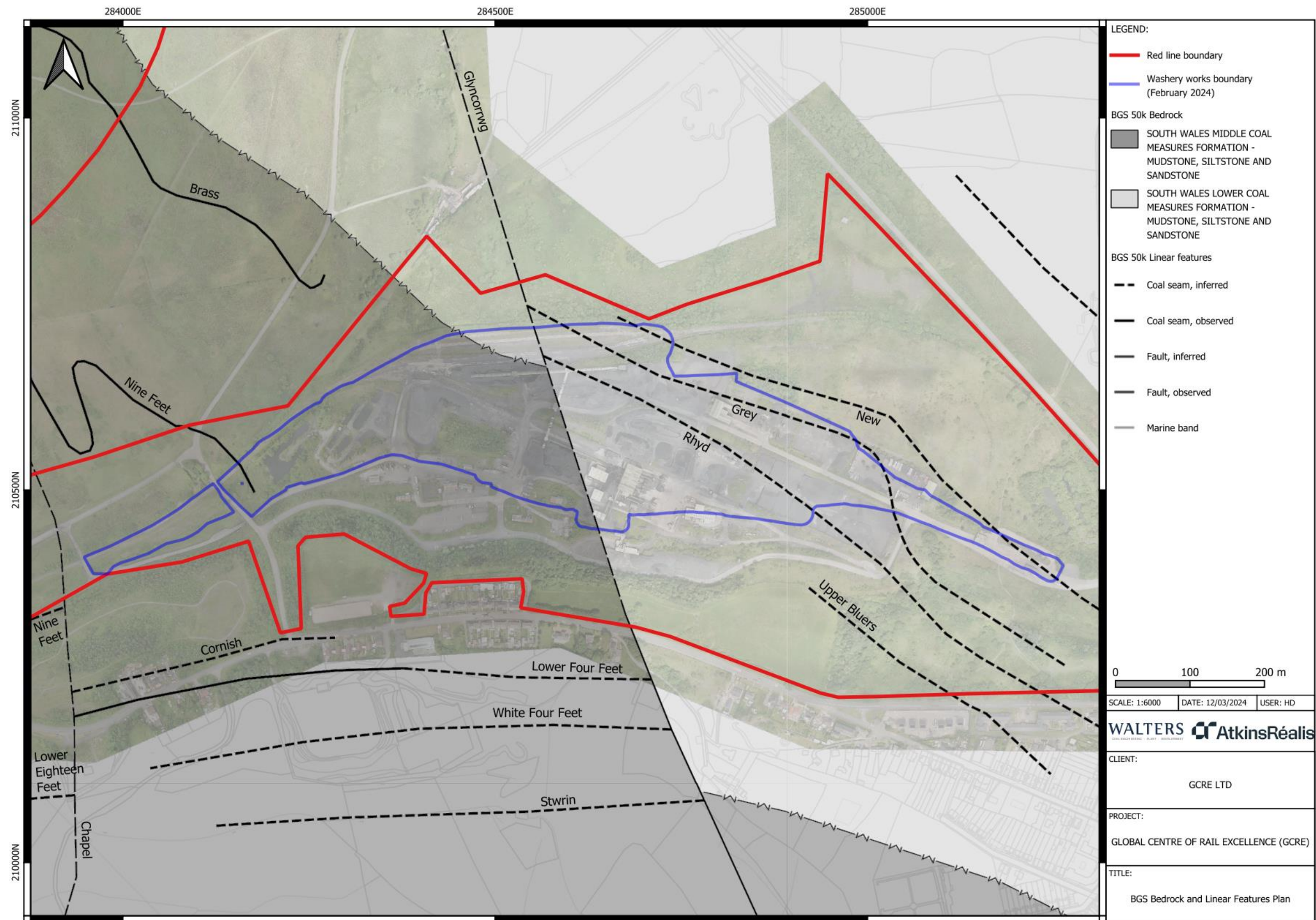


Figure 2-3: BGS Bedrock and Linear Features Plan (Imagery copyright AtkinsRéalis, [16])

2.5 Coal mining legacy

AtkinsRéalis has produced a separate Mining Risk Review for the Washery (Phase 1A/2A) [2], in support of detailed earthworks design for the Global Centre of Rail Excellence (GCRE) Project. This assessment has concluded that proposed earthworks in the Washery area are undermined by legacy underground workings, potential-opencast workings and mine entries.

A desk study review and subsequent investigations have identified workings within the Peacock, Bluers and Brass Coal Seams, with associated mine entries (shafts and adits). These recorded workings may pose a risk to the operation and safety of the proposed earthworks in the Washery. Additional, unrecorded mine workings have already been encountered beneath the site; with other unknown mine workings and mine entries potentially also present.

Refer to the AtkinsRéalis Washery Phase 1A/2A Mining Risk Review [2] for further details.

2.6 Hydrogeology

The strata underlying the Washery site is classified by the BGS [17] and Natural Resources Wales NRW [18] as the following:

- Peat – unproductive aquifer;
- Glacial Till – Secondary undifferentiated aquifer; and
- South Wales Coal Measures Formation – Secondary A aquifer.

A detailed discussion on the site hydrogeology is provided in the separate geo-environmental interpretive report for the Washery site [3], which should be referenced in conjunction with this GIR.

2.7 Hydrology

The River Dulais is shown to flow in a west-south-westerly direction through the western part of the Washery. The River Camnant is also shown approximately 35 m east of the Washery boundary, historically the Camnant was present within the Washery (outside of the earthworks design footprint) before its channel shifted to the east in 1979. The Washery is indicated to be at low risk of river or coastal flooding.

A detailed discussion on the site hydrology is provided in the separate geo-environmental interpretive report for the Washery site [3], which should be referenced in conjunction with this GIR.

3. Field and laboratory studies

3.1 Walkover survey & geomorphological mapping

Two walkover surveys have previously been undertaken across the Washery and the 'Land at Nant Helen'. The first was by Arup in November 2018, which comprised a broad overview of the site which mostly focused on the 'Land at Nant Helen' site. The survey provided minimal information with respect to the Washery site, apart from the observation of a large pond adjacent to the Washery. A more detailed discussion on the Arup walkover survey can be referenced within the AtkinsRéalis Stage 0 GIR [5].

The second walkover survey was undertaken by AtkinsRéalis in June 2022, which comprised a more comprehensive walkover and geomorphological mapping. The purpose of this survey was to provide more detailed site-based observations to inform the identification of areas of potential risks relating to contamination, mining, or other geotechnical factors and inform the specification of additional GI. A summary of the key features identified within the Washery area during this survey are as follows:

- Historical spoil heaps and stockpiles are distributed across the majority of the site with the largest of the spoil heaps located to the north-east;
- Rail infrastructure including sidings and loading platforms for the coal are located in the north and north-west of the site distributed across multiple levels, with the main rail access to the site located in the west;
- Surface drainage channels capture water from across the site, flowing from east to west into settling ponds before discharging into the River Dulais;
- The land to the north-east of the site is relatively flat and boggy with standing water at surface after periods of rainfall. The land to the north-west dips down towards the Washery Phase 1A area with surface and water flowing towards the site; and
- The majority of the site is covered in made ground due to the past industrial site uses.

A report detailing the full findings of the AtkinsRéalis survey is appended to the AtkinsRéalis Stage 0 GIR [5], which should be referenced.

3.2 Previous ground investigations

A summary of the ground investigations undertaken within the Washery prior to November 2022 (including the Stage 0 GI undertaken between November 2021 and January 2022) is provided in Table 3-1 and Table 3-2 below, with the locations shown within Figure 3-1. This information formed the basis of the initial AtkinsRéalis Stage 0 GIR [5], where more detail and discussion on the works can be referenced.

Geo-environmental testing is omitted from the summary below, as it is provided in the separate geo-environmental interpretive report for the Washery [3], which should be referenced in conjunction with this GIR.

A plan showing all of the ground investigation locations within the Washery (all stages of GI) is also provided within Figure 3-15.

Table 3-1: Summary of historical ground investigation

Fieldwork component		Description
Exploratory holes	Historical BGS	14No. cable percussion with rotary coring follow on boreholes progressed to depths of between 22.0 and 45.1 m bgl
	Stage 0 GI	6No. dynamic sampling with rotary coring follow on boreholes progressed to depths of between 5.0 and 10.8 m bgl
		3No. rotary coring boreholes progressed to depths of between 27.8 and 35.0 m bgl
		5No. rotary openhole boreholes progressed to depths of between 30.0 and 35.0 m bgl
		22No. mechanically excavated trial pits progressed to depths of between 2.0 and 4.5 m bgl
In-situ testing	Historical BGS	32No. Standard Penetration Tests (SPTs), including refusals
	Stage 0 GI	41No. SPTs, including refusals
		3No. soakaway infiltration tests
Installations	Stage 0 GI	6No. holes were installed with 50mm standpipes to allow for groundwater level and ground gas monitoring undertaken fortnightly for 12 weeks from the completion of the site works

Table 3-2: Summary historical laboratory testing

Fieldwork	Material	Category	Geotechnical test type	Quantity
Stage 0 GI	Soil	Classification testing	Moisture content of soil	61
			Atterberg Limits tests	10
			Particle size distribution (PSD) tests	24
		Strength testing	Unconsolidated undrained (UU) triaxial compression tests	4
		Consolidation testing	One-dimensional consolidation tests	4
		Earthworks testing	Compaction tests (dry density/moisture content relationship testing)	2
			Moisture condition value/moisture content relationship testing	2
		BRE SD-1	Chemistry testing	15
	Rock	Strength Testing	Point load Index (Rock)	7
			Uniaxial Compressive Strength (UCS – Rock)	1
		BRE SD-1	Chemistry testing	2



Figure 3-1: Historical BGS and Stage 0 GI Location Plan (Imagery copyright AtkinsRéalis, [16])

3.3 Stage 1 ground investigation

A summary of the Stage 1 GI undertaken within the Washery between November 2022 and February 2023 is provided below in Table 3-3, with plans indicating the exploratory hole locations provided in Figure 3-2, Figure 3-3, Figure 3-4, and Figure 3-5. The Stage 1 GI factual report [19] is provided within Appendix A.

A plan showing all of the ground investigation locations within the Washery (all stages of GI) is also provided within Figure 3-15.

Table 3-3: Summary of Stage 1 Washery GI

Fieldwork component	Description
Exploratory holes	17No. dynamic sampling boreholes with rotary coring follow on progressed to depths of between 8.0 and 30.8 m bgl
	1No. dynamic sampling borehole (terminated before encountering bedrock) progressed to 4.0 m bgl
	3No. mine entry probing locations comprising: - SOP001: 20No. rotary openholes progressed to depths of between 15.0 and 25.0 m bgl - SOP002: 25No. rotary openholes progressed to depths of between 11.5 and 20.0 m bgl - SOP003: 16No. rotary openholes progressed to depths of between 12.5 and 25.0 m bgl
	5No. mechanically excavated trial pits progressed to depths of between 0.7 and 4.0 m bgl
In situ testing	140No. SPTs, including refusals
	6No. hand shear vane tests
	1No. soakaway infiltration test
	954No. headspace tests
Installations	10No. holes were installed with 50mm standpipes to allow for groundwater level and ground gas monitoring. One consisted of a dule 55mm installation (S1-BH112) targeting shallow made ground and deeper stratigraphy.

A summary of the laboratory testing undertaken as part of the Stage 1 GI within the Washery is summarised within Table 3-4 below.

Table 3-4: Summary of the Washery Stage 1 GI laboratory testing

Material	Category	Geotechnical test type	Quantity
Soil	Classification testing	Moisture content of soil	155
		Atterberg Limits tests	41
		Particle size distribution (PSD) tests	60
		Organic Content test	19
	Strength testing	Unconsolidated undrained (UU) triaxial tests	1
		Shear box tests	9
	Consolidation testing	One-dimensional consolidation tests	4
	Earthworks testing	Compaction tests (dry density/moisture content relationship testing)	7
	BRE SD-1	Chemistry testing	43
Rock	Classification testing	Moisture content	28
	Strength Testing	Point load Index (Rock)	15
	BRE SD-1	Chemistry testing	2

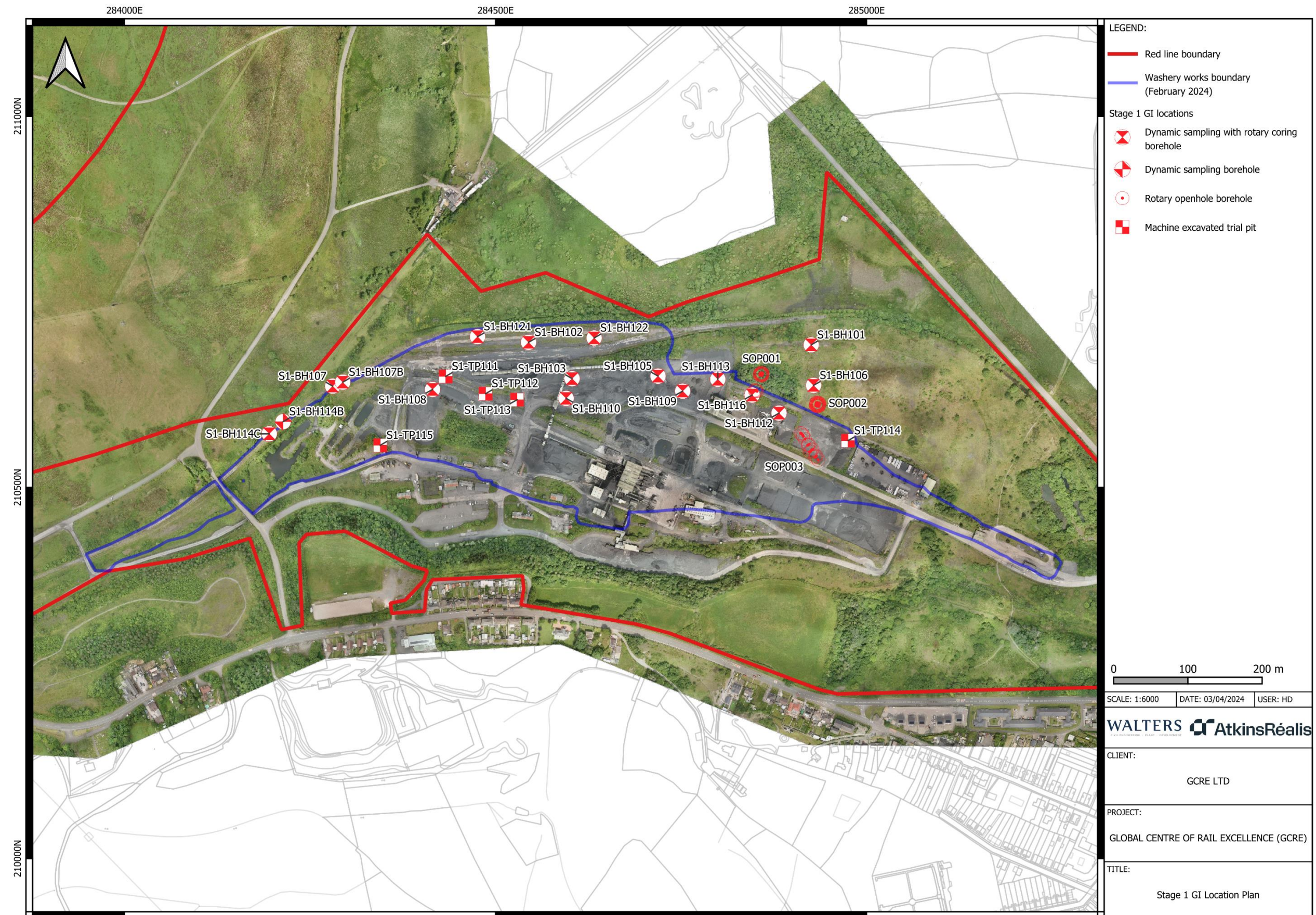


Figure 3-2: Stage 1 GI Location Plan (Imagery copyright AtkinsRéalis)

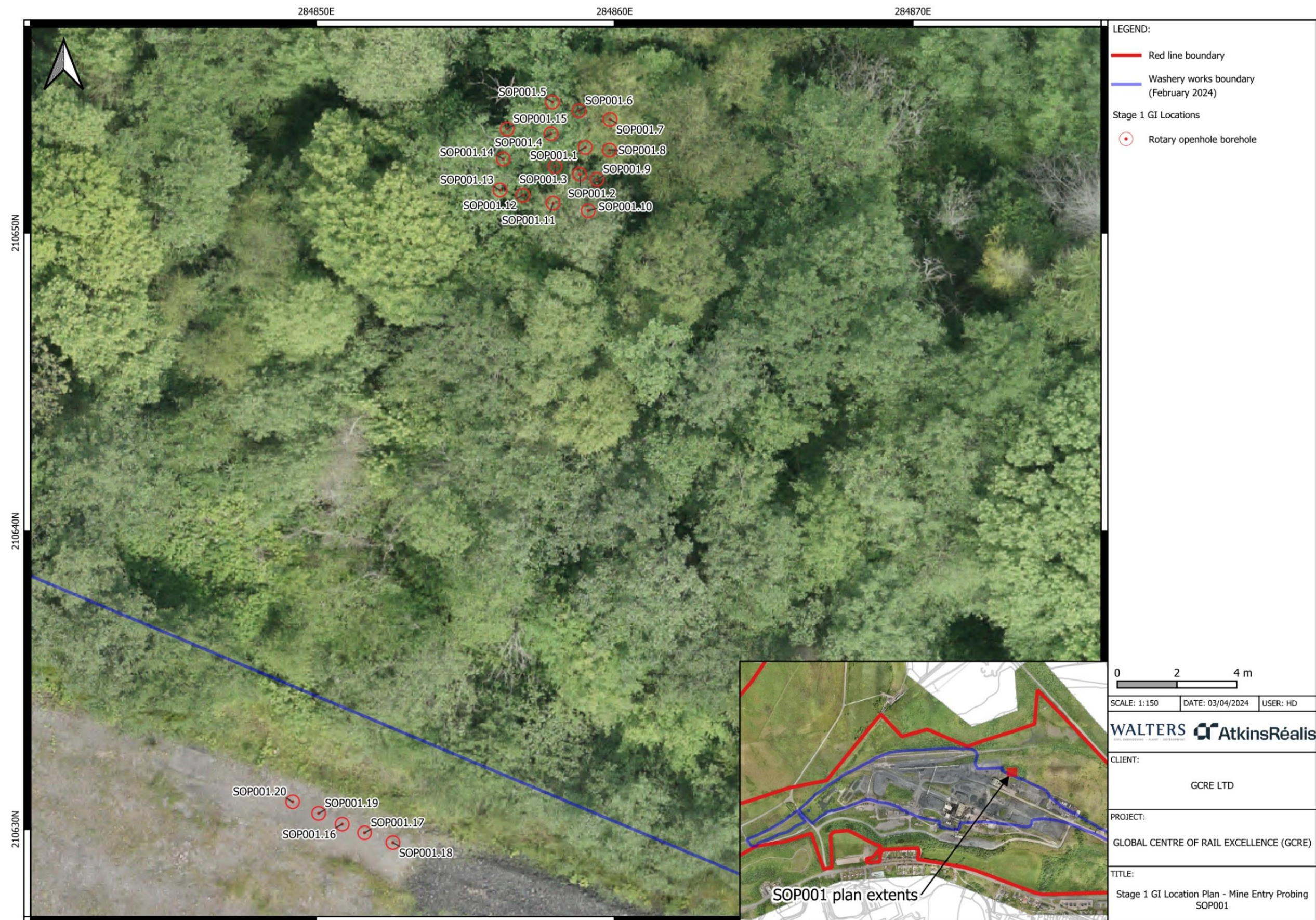


Figure 3-3: Stage 1 GI Location Plan – Mine Entry Probing SOP001 (Imagery copyright AtkinsRéalis)

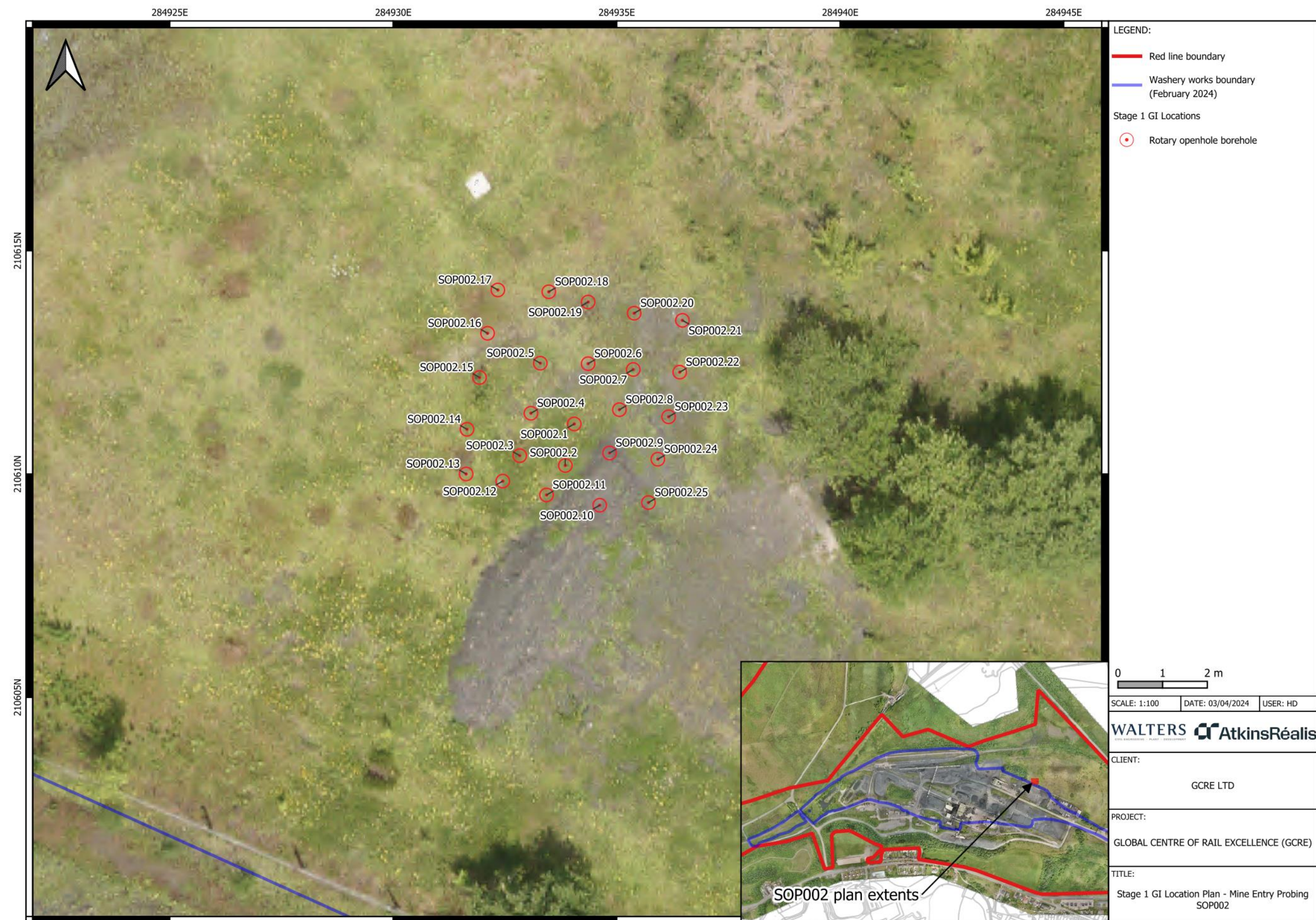


Figure 3-4: Stage 1 GI Location Plan – Mine Entry Probing SOP002 (Imagery copyright AtkinsRéalité)

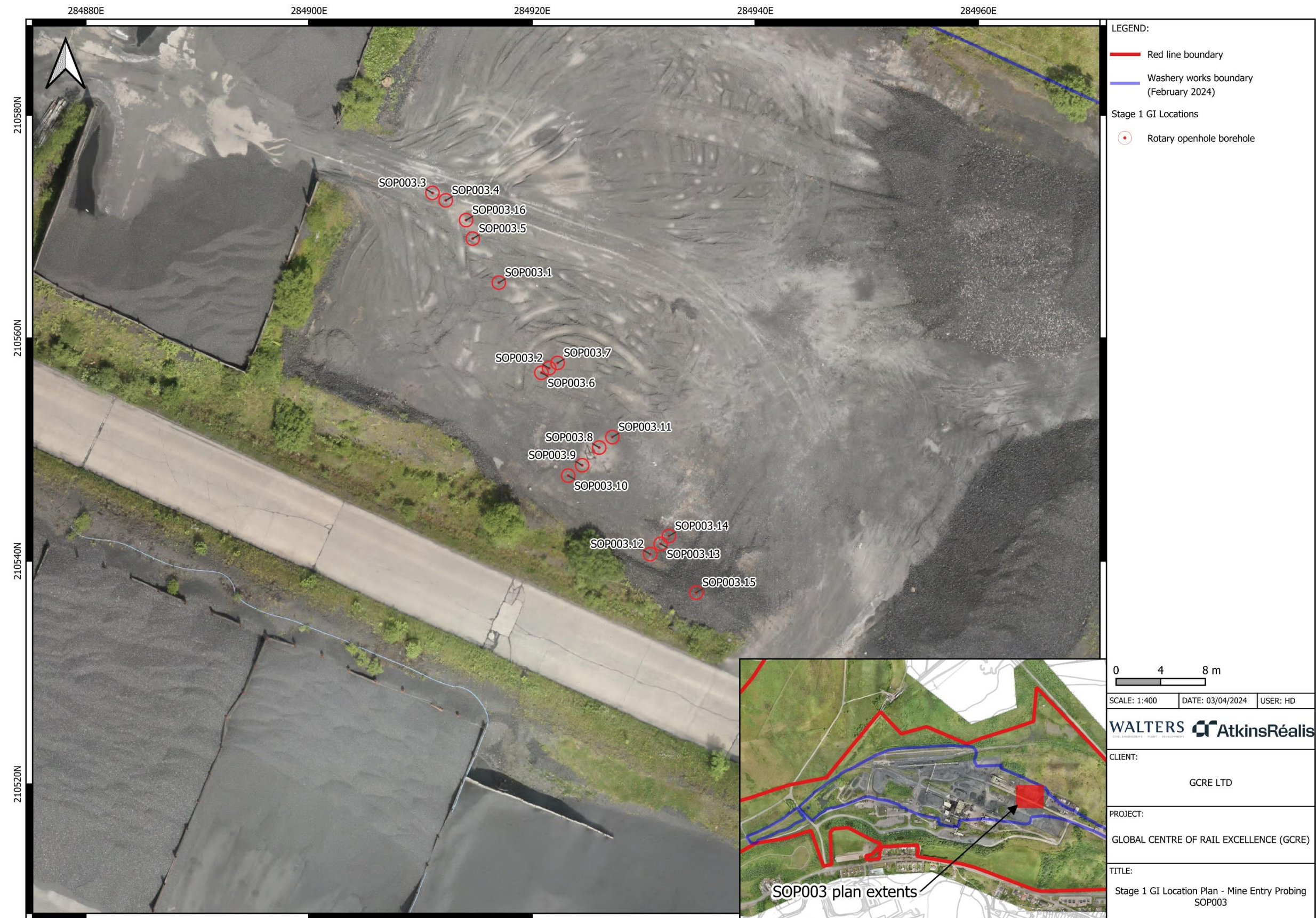


Figure 3-5: Stage 1 GI Location Plan – Mine Entry Probing SOP003 (Imagery copyright AtkinsRéalis)

3.4 Stage 2 ground investigation

A summary of the Stage 2 GI undertaken between March and June 2023 within the Washery is provided below in Table 3-5, with plans indicating the exploratory hole locations provided in Figure 3-6 to Figure 3-14. The Stage 2 GI factual report [19] is provided within Appendix A.

A plan showing all of the ground investigation locations within the Washery (all stages of GI) is also provided within Figure 3-15.

Table 3-5: Summary of Stage 2 Washery GI

Fieldwork component	Description
Exploratory holes	12No. dynamic sampling boreholes with rotary coring follow on progressed to depths of between 6.5 and 10.0 m bgl
	5No. window sample boreholes progressed to depths of between 1.0 and 5.45 m bgl.
	4No. rotary open hole rotary coring boreholes progressed to depths of between 7.0 and 25.0 m bgl.
	8No. mine entry probing locations comprising: - S2-BH256: 18No. rotary openholes progressed to depths of 20.0 m bgl - S2-BH257: 17No. rotary openholes progressed to depths of between 20.3 and 22.2 m bgl - S2-BH258: 25No. rotary openholes progressed to depths of between 18.0 and 21.0 m bgl - S2-BH259: 28No. rotary openholes progressed to depths 20.0 m bgl - S2-BH262: 12No. rotary openholes progressed to depths of between 11.0 and 21.0 m bgl - S2-BH263: 11No. rotary openholes progressed to depths of between 13.5 and 21.0 m bgl - S2-BH264: 12No. rotary openholes progressed to depths of between 2.0 and 25.0 m bgl - S2-BH265: 6No. rotary openholes progressed to depths of 25.0 m bgl
	48No. mechanically excavated trial pits progressed to depths of between 0.5 and 4.0 m bgl
In-situ testing	23No. SPTs, including refusals
	97No. hand shear vane tests
	45No. dynamic probes undertaken within the north of the Washery to assist with determining the extent of the Peat previously identified within this area.
	1No. soakaway infiltration test
	183No. headspace tests

Installations	23No. holes were installed with 50mm standpipes, and 1No. holes (S2-BH249) was installed with a 19mm standpipe to allow for groundwater level and ground gas monitoring.
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A summary of the laboratory testing undertaken as part of the Stage 2 GI within the Washery is summarised within Table 3-6 below.

As discussed above, as only the earthworks design was part of the AtkinsRéalis geotechnical scope of works, the GI locations within the Washery Phase 2 area were solely investigated for contaminated land purposes (predominantly to assist with the discharge of planning consent). As a result, limited additional geotechnical testing was undertaken.

Table 3-6: Summary of the Washery Stage 2 GI laboratory testing

Material	Category	Geotechnical test type	Quantity
Soil	Classification testing	Moisture content of soil	221
		Atterberg Limits tests	22
		Particle size distribution (PSD) tests	24
		Organic Content test	12
	BRE SD-1	Chemistry testing	9
Rock	Strength Testing	Point load Index (Rock)	4
	BRE SD-1	Chemistry testing	2



Figure 3-6: Stage 2 GI Location Plan (Imagery copyright AtkinsRéalis)



Figure 3-7: Stage 2 GI Location Plan – Mine Entry Probing S2-BH256 (Imagery copyright AtkinsRéalis)

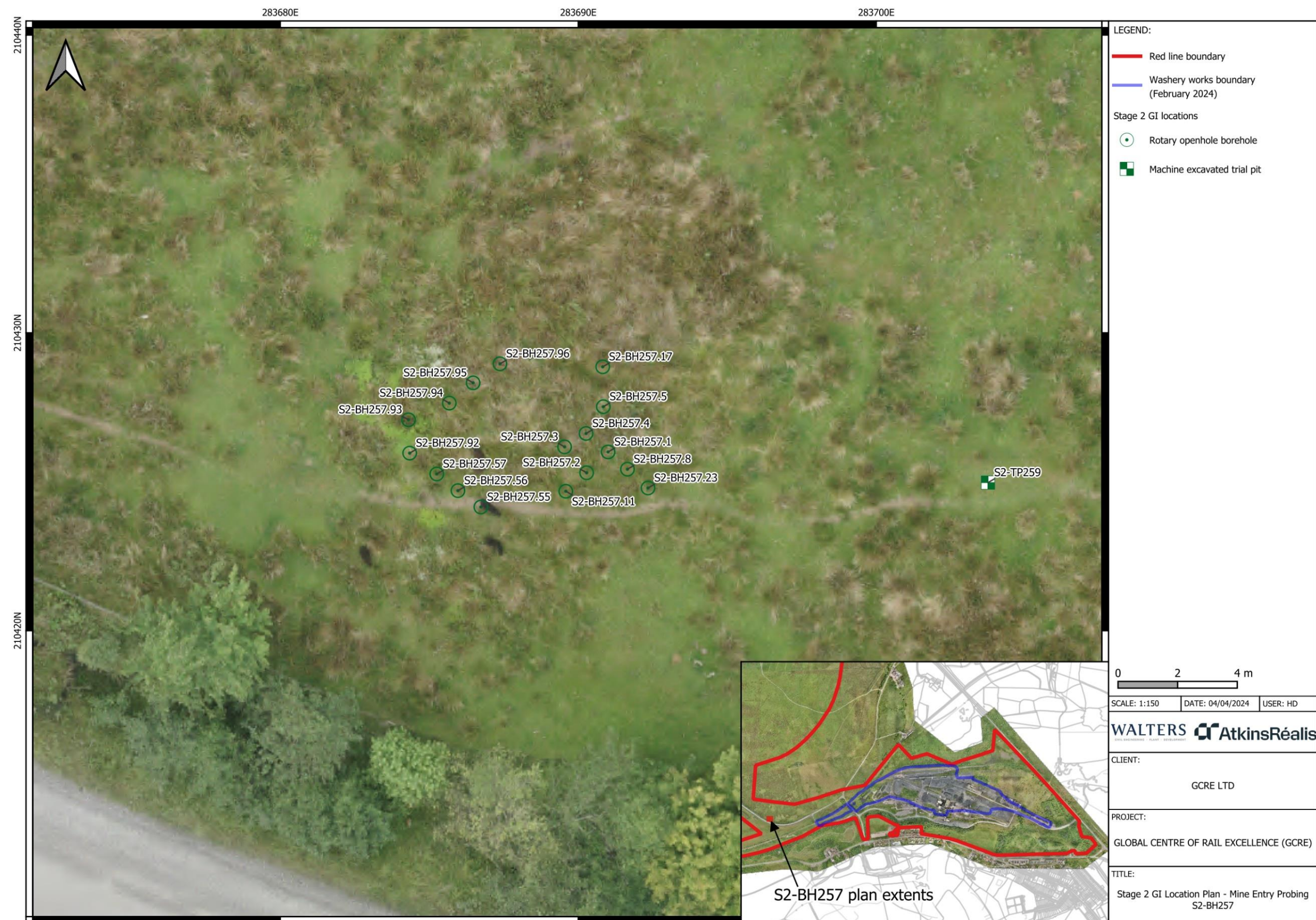


Figure 3-8: Stage 2 GI Location Plan – Mine Entry Probing S2-BH257 (Imagery copyright AtkinsRéalis)

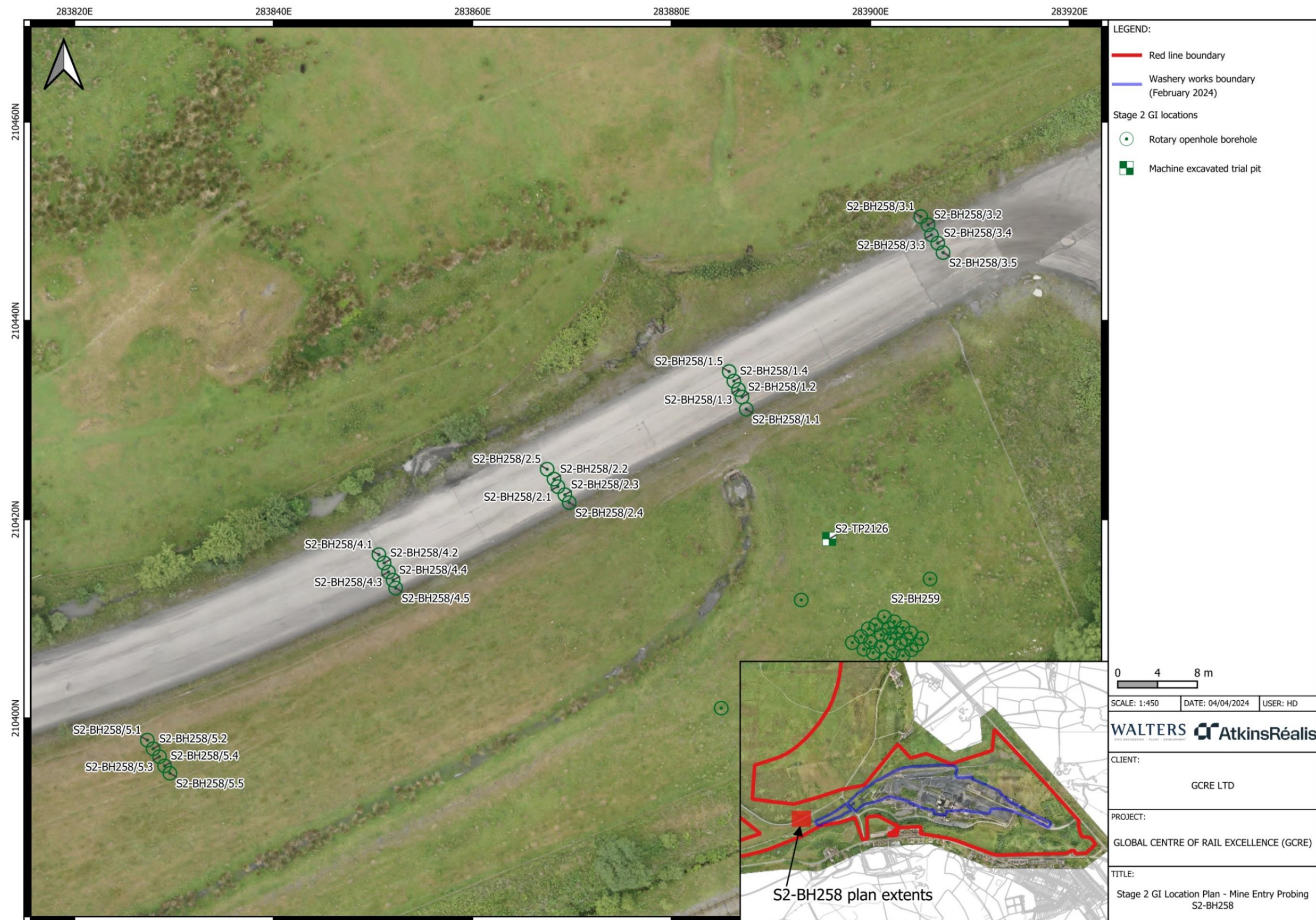


Figure 3-9: Stage 2 GI Location Plan – Mine Entry Probing S2-BH258 (Imagery copyright AtkinsRéal

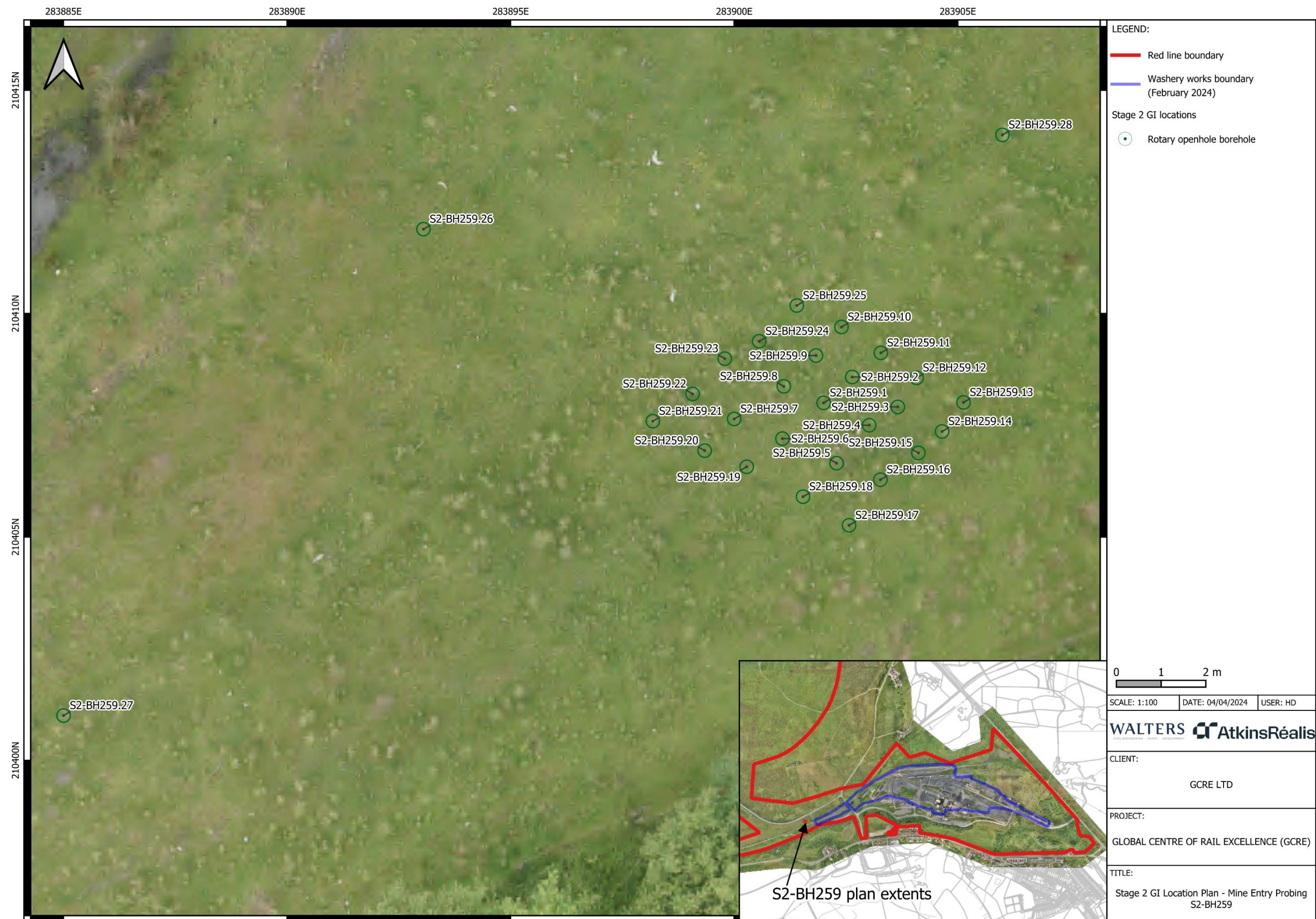


Figure 3-10: Stage 2 GI Location Plan – Mine Entry Probing S2-BH259 (Imagery copyright AtkinsRéalisis)



Figure 3-11: Stage 2 GI Location Plan – Mine Entry Probing S2-BH262 (Imagery copyright AtkinsRéalis)



Figure 3-12: Stage 2 GI Location Plan – Mine Entry Probing S2-BH263 (Imagery copyright AtkinsRéalis)

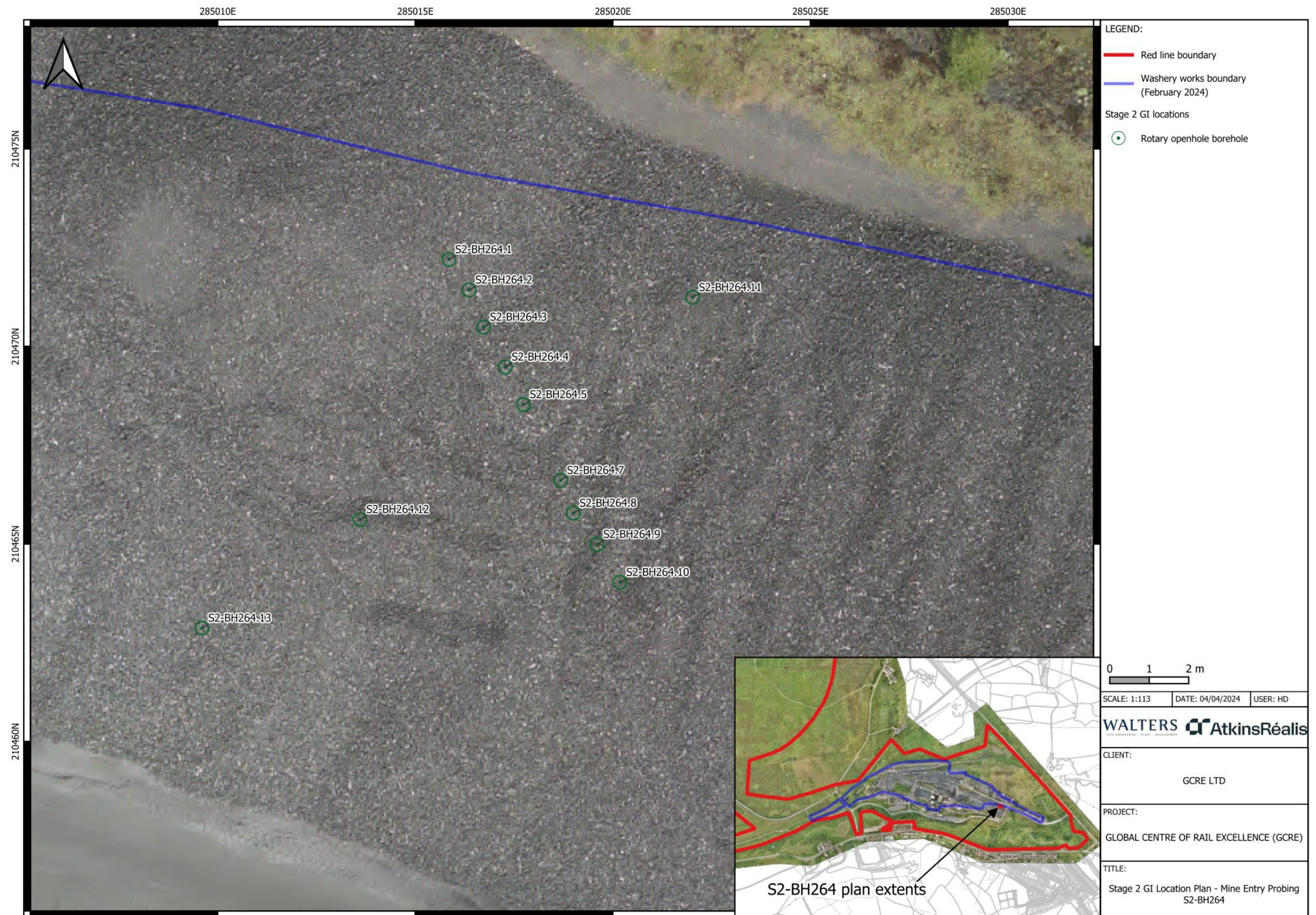


Figure 3-13: Stage 2 GI Location Plan – Mine Entry Probing S2-BH264 (Imagery copyright AtkinsRéalis)

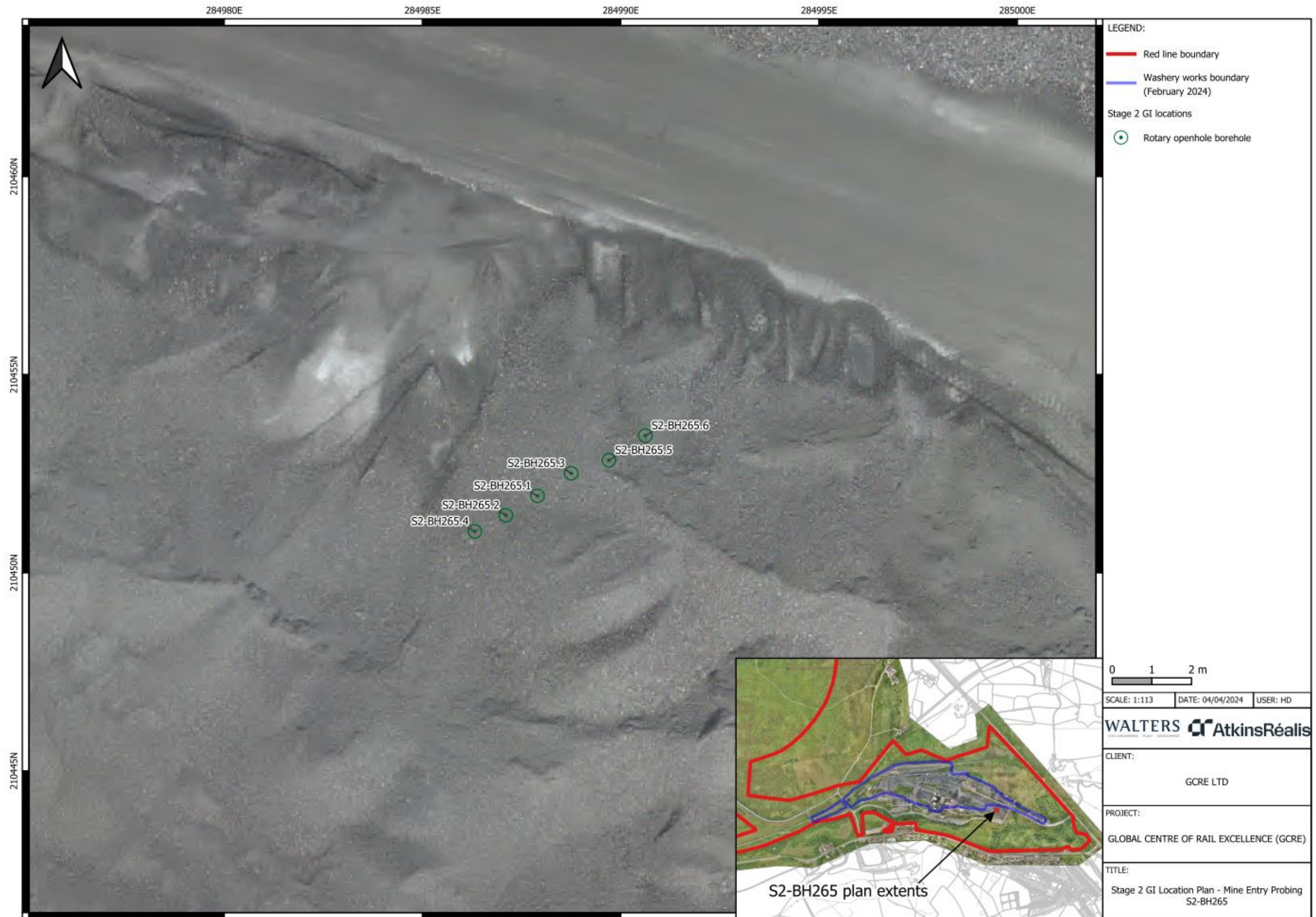


Figure 3-14: Stage 2 GI Location Plan – Mine Entry Probing S2-BH265 (Imagery copyright AtkinsRéal

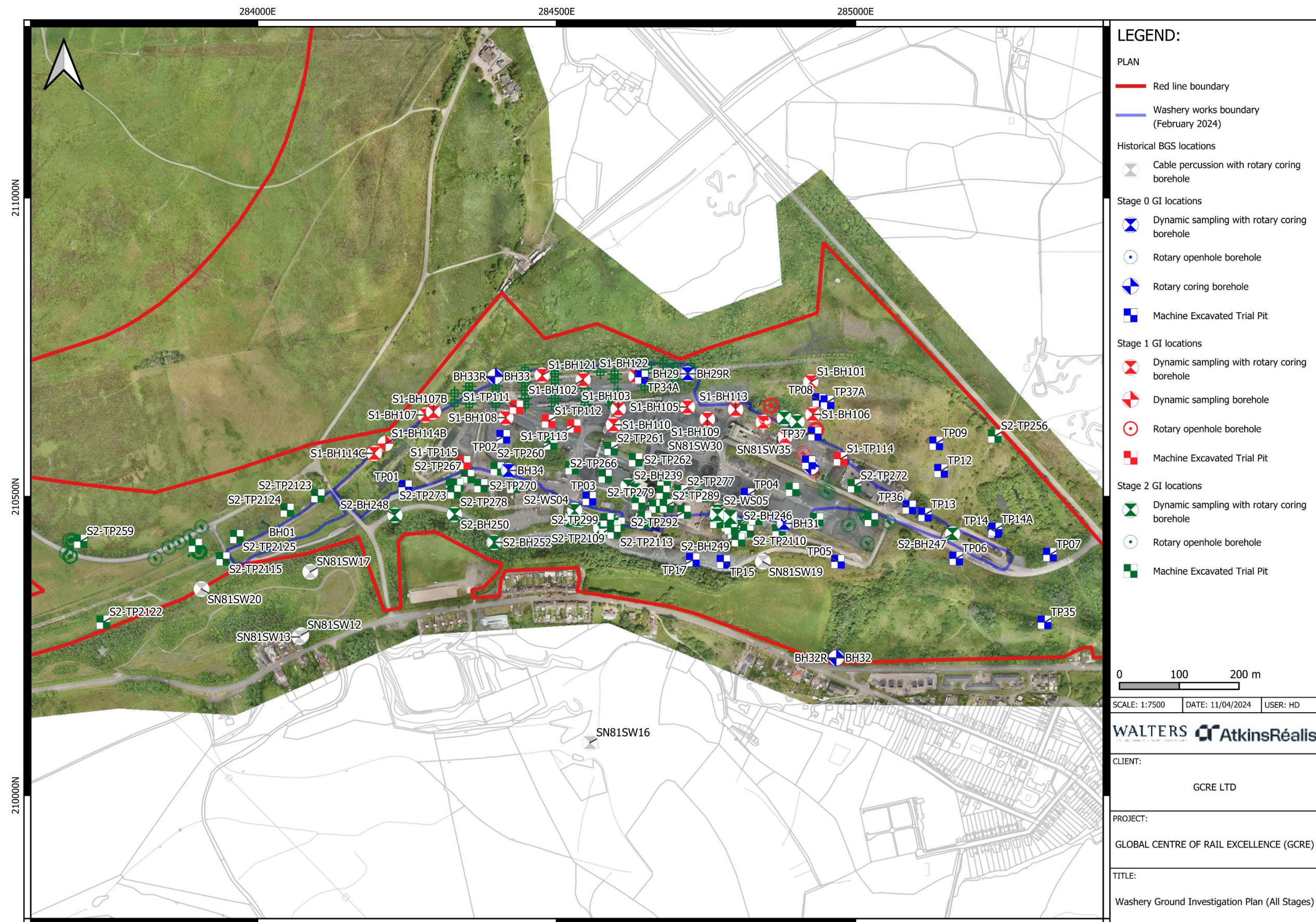


Figure 3-15: Washery Ground Investigation Plan (All Stages) (Imagery copyright AtkinsRéalis)

4. Ground summary

4.1 General

A 2D ground model was proposed within the Stage 0 GIR for the Washery Phase 1A site [20], however, due to the limited information available at the time the ground model had significant associated uncertainty. Similarly, it was not possible to derive location specific parameters and site wide geotechnical parameters (i.e., not specific to the Washery) were instead proposed.

The Stage 0 GIR proposed that additional GI be undertaken in order to refine the ground modelling and geotechnical parameters within the Washery Phase 1A site.

The Stage 1 and Stage 2 GIs have enabled the ground model to be refined as presented below in Section 4.2, and site-specific parameters have been derived, as detailed within Section 4.3 below. As noted previously however, some uncertainty still remains particularly within the south of the Washery which was investigated predominantly for contaminated land purposes with the majority of exploratory holes within this area closely spaced and terminated at shallow depths,

4.2 Ground model

The ground conditions were found to generally comprise of made ground overlying intermittent superficial materials of Peat and Glacial Till underlain by bedrock of South Wales Coal Measures Formation.

A ground model for the Washery has been developed based on the available information including GI data (comprising a total of 332No. exploratory holes across the Washery site, as summarised in Section 3 above), geomorphological mapping, historical mapping, published geological mapping, and topographic surveys.

The ground model is described within the following sections. Due to the variable conditions encountered across the site it is recommended that designs consider the ground model on a location specific basis.

The developed ground model was utilised by the AtkinsRéalis design team to inform the detailed design of earthworks within the Washery (as discussed within Section 6).

4.2.1 Made ground

Made ground was encountered by 327No. of the 332No. exploratory hole (including probe holes) locations across the Washery. The material was generally encountered from the ground surface (221.1 to 262.2 m AOD) with variable thicknesses.

The material was predominantly encountered as gravel described as “*black to dark grey, slightly sandy, silty, clayey, fine to coarse, angular to sub-angular gravel of mudstone, siltstone and sandstone with coal and ash*” interbedded with occasional “*medium dense, black, silty, gravelly, fine to coarse sand derived from coal*” and rare “*soft to firm, dark grey to black, silty, sandy, gravelly clay*”. Based on the available descriptions and the historical mining and coal washery usage of the site, the made ground is interpreted to be colliery spoil material.

The made ground was identified as being predominantly granular, however, layers of interbedded cohesive material were also identified in the exploratory hole log descriptions and by a small number of particle size distribution laboratory testing (discussed in more detail within Section 4.4.2 below). The cohesive made ground was not encountered at a consistent elevation or thickness meaning that a defined layer was not able to be modelled

separately. The locations where cohesive material has been identified, as shown within Figure 4-3, should be considered on a location specific basis, as this material is likely to be more compressible and lower strength than the broader granular material.

Two boreholes, one to the east of the Washery (S1-BH101) and one to the southeast (SN81SW19), encountered the thickest accumulation of made ground at 21.6 m and 26.2 m respectively. The cause of these thicker accumulations is unconfirmed but is likely to be either associated with a backfilled mining feature or a stockpile of spoil material placed within a topographical depression. Across the remainder of the site, the made ground was found to vary in thickness from 0.1 m to 11.3 m.

Due to the number and distribution of locations which encountered the made ground (undifferentiated granular and cohesive material), it was possible to interpolate surfaces for the base and thickness of the material using the Delaunay triangulation algorithm. The algorithm utilises a nearest neighbour methodology to triangulate between the recorded locations. The interpolated surfaces are shown within Figure 4-1 and Figure 4-2 below. Areas with a large density of points are anticipated to be more accurate, with areas with large spacing between points likely to be less accurate where any unrecorded localised variations will not be captured.

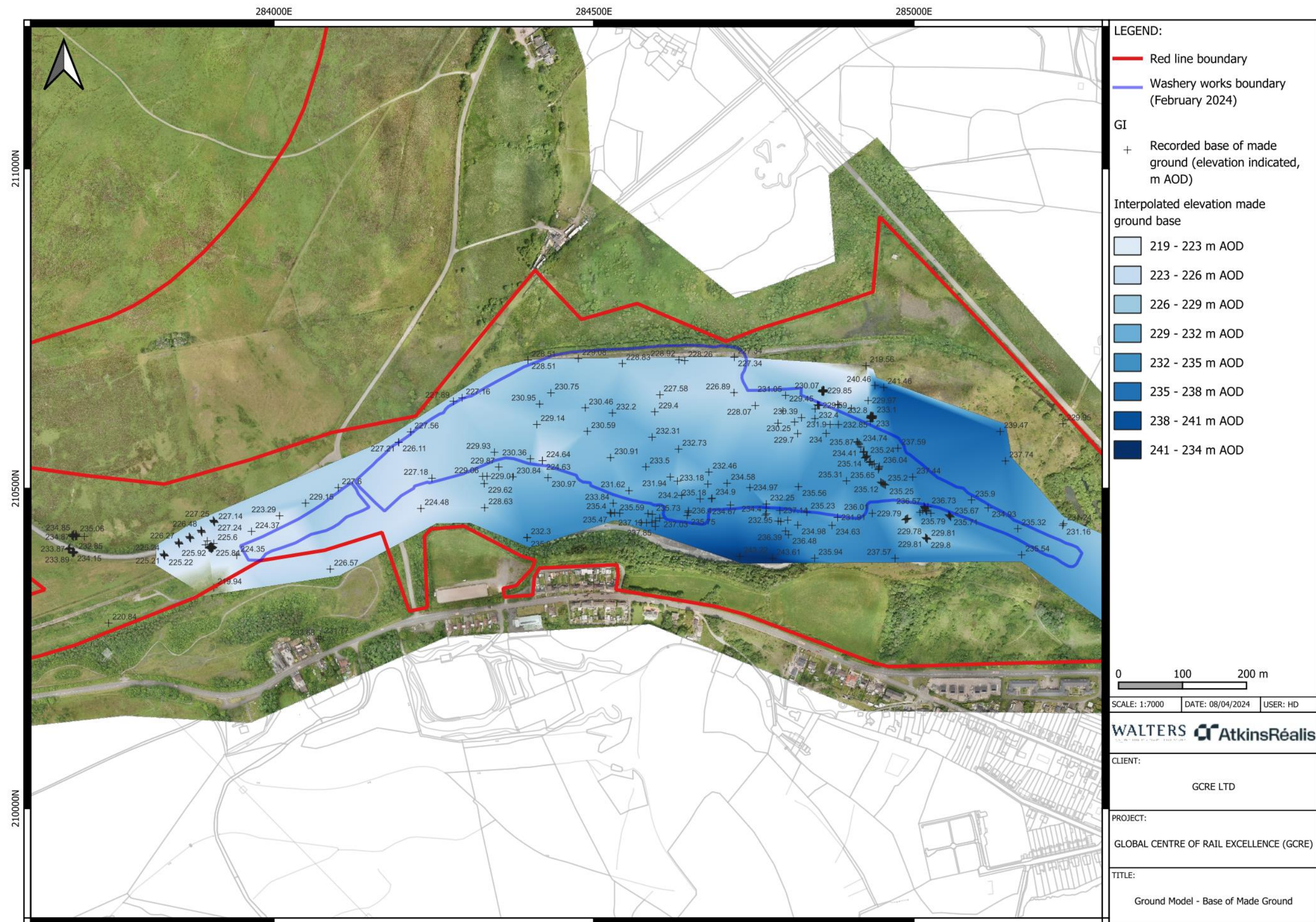


Figure 4-1: Ground Model – Base of Made Ground (Imagery copyright AtkinsRéalis)

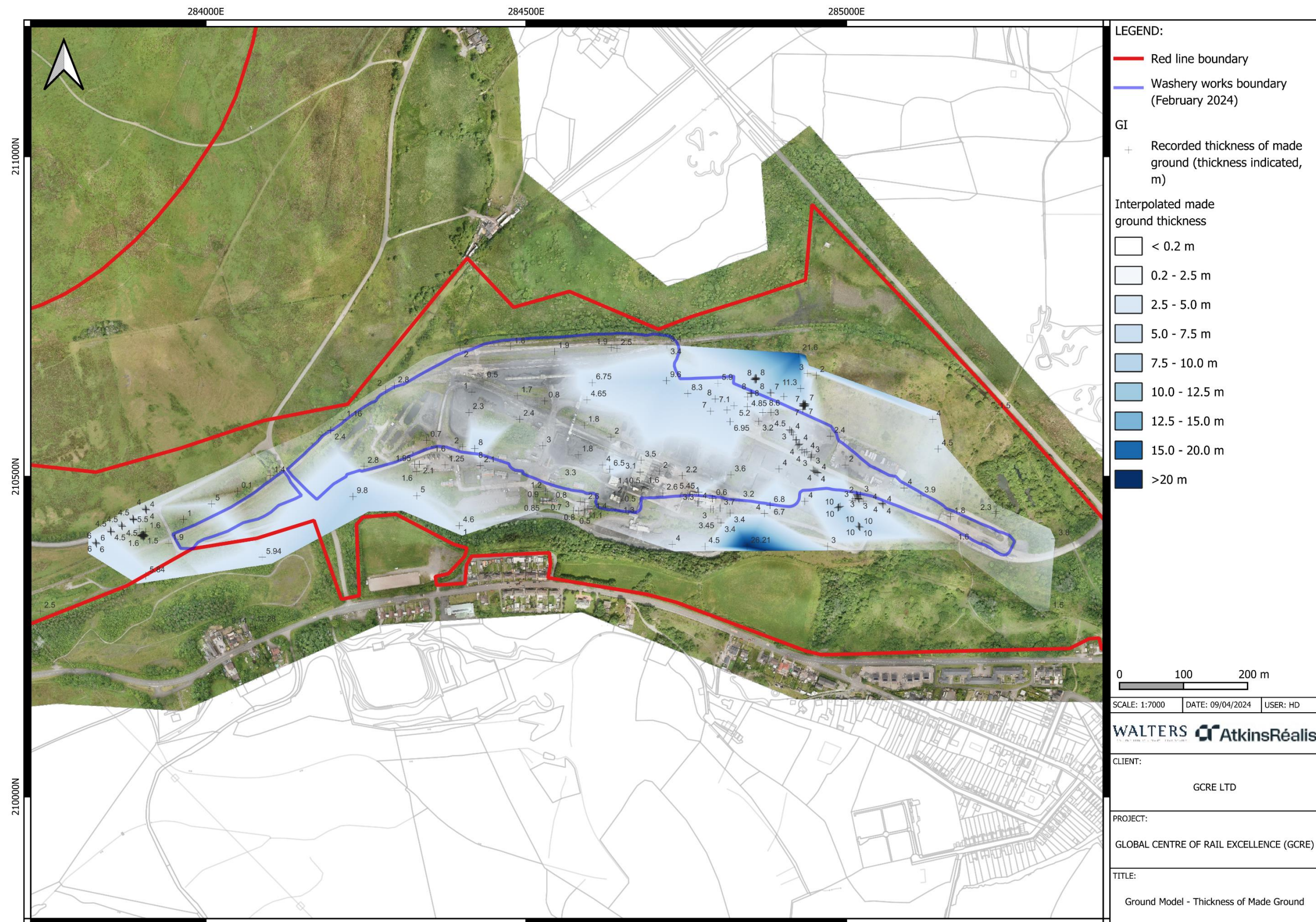


Figure 4-2: Ground Model – Made Ground Thickness (Imagery copyright AtkinsRéalis)

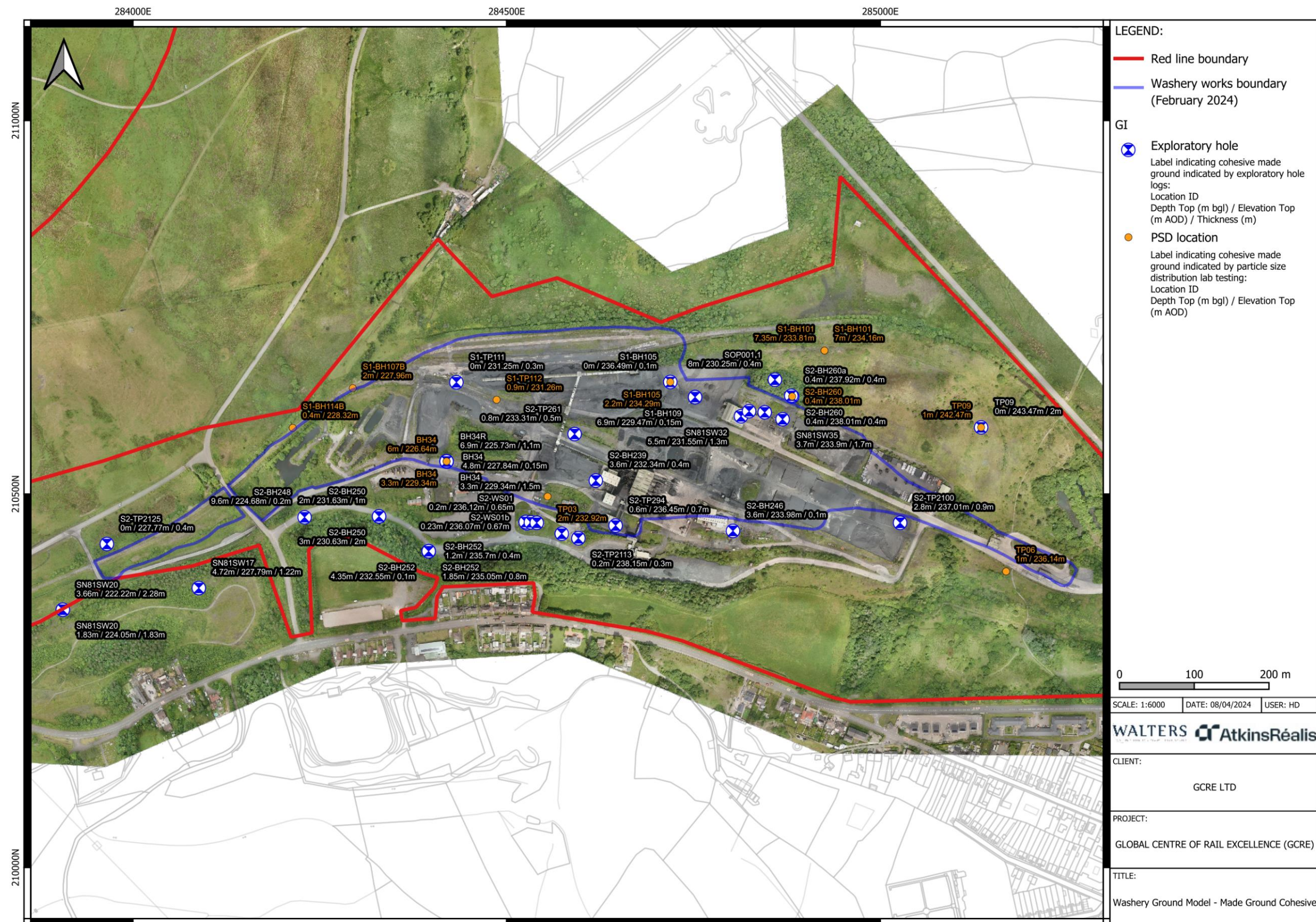


Figure 4-3: Ground Model – Locations where Cohesive Made Ground was Encountered (Imagery copyright AtkinsRéalis)

4.2.2 Glacial Till

Glacial Till was encountered by 56No. of the 332No. exploratory hole (including probe holes) locations across the Washery. It was encountered predominantly to the east and south of the Washery, as shown in Figure 4-4, outside of areas indicated by the BGS to be underlain by Glacial Till.

The exploratory holes indicate that Glacial Till may have been deposited across the Washery, more extensively than mapped by the BGS. This material may have also been excavated within the Washery due to the historical activity at the site. Additionally, gaps in the ground investigation mean that the full extent of any deposits has not been characterised and may be encountered within other areas of the Washery.

The material was encountered at varying depths from the ground surface to 9.9 m bgl (224.4 to 244.7 m AOD) and ranged in thickness from 0.4 m (S1-BH114B) to 5.7 m (S2-BH242).

The stratum was generally described as “*soft to stiff, brownish grey mottled orangish brown, slightly sandy, very gravelly, silty clay with cobbles and boulders where gravel is angular to sub-rounded mudstone, siltstone and sandstone*”, “*brownish grey, clayey, gravelly, fine to coarse sand where gravel is angular to subrounded*” and “*brownish grey, clayey, sandy, very angular to rounded, fine to coarse gravel*”.

A plan showing the locations, thickness, and elevation of Glacial Till across the Washery is shown below in Figure 4-4.

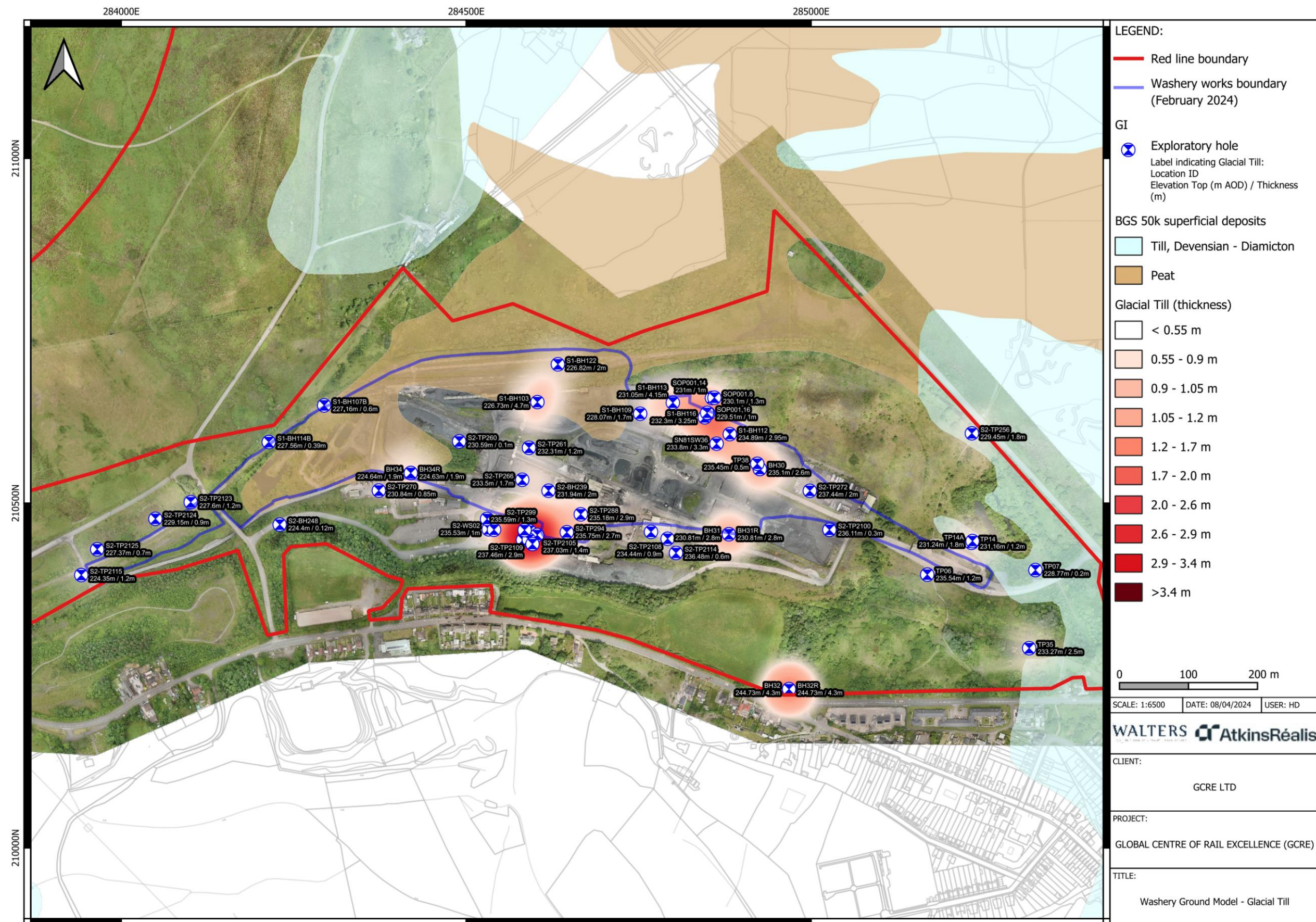


Figure 4-4: Ground Model – Glacial Till (Imagery copyright AtkinsRéalis, [16])

4.2.3 Peat

A consistent layer of Peat described as “*soft to firm (some spongy) brown to dark brown fibrous to pseudo-fibrous Peat with occasional plant remains*” was encountered by the GIs within areas to the north of the Washery site. This coincides with the areas shown on the available BGS 1:50:000 superficial mapping [21] as being underlain by Peat deposits. These areas were also indicated to be marshland by available historical mapping, as shown in Figure 4-5.

Peat was encountered predominantly by exploratory holes located within the north of the Washery at depths of between 1.3 and 9.8 m bgl (223.5 to 235.7 m AOD) with thicknesses ranging from 0.35 m (S1-BH114) to 2.1 m (S1-BH102/S1-BH122), as shown in Figure 4-6. Based on this information, it is anticipated that a significant layer of Peat material up to 2 m thickness encountered at approximately 2 m bgl is located along the northern extent of the Washery (BH33, BH33R, S1-BH121, S1-BH102, S1-BH122, BH29 and BH29R) which extends to the centre of the site (S1-BH103 & S1-BH110) and decreases in thickness to the south.

The dynamic probing was undertaken as part of the Stage 2 GI to assist with determining the extent of the Peat identified within this area. 45No. probes were undertaken across the area in an approximate grid formation with a 10 m (north/south) by 50 m (east/west) spacing. As shown in Figure 4-6, the probing indicated regions of soft material (characterised by low (0-2) blow count increments) across the north of the site. The depths and thicknesses of the interpreted soft material generally correspond well to the Peat identified by the GIs within the area. Based on the available information, it is likely that the Peat deposits extend across the northern Washery, as indicated by the BGS. However, additional intrusive investigation would be required to confirm that the soft deposits are classified as Peat, rather than another low strength material.

Additionally, S1-BH114B encountered a layer described as “*soft dark brown peaty clay with occasional rootlets and rare plant remains*” of 1.25 m thickness. Due to the proximal location, it is anticipated that this material is associated with the more significant peat material encountered to the north of the site.

S2-TP2115 to the east, S2-TP256 to the west, BH31 / BH31R to the southeast, and BH34 / BH34R to the southwest also recorded thicknesses of Peat material. No other exploratory holes confirmed the present of Peat within these areas. However, this may be due to the limited spacing and depth of the GI within these areas. S2-TP2115, BH31 / BH31R, and BH34 / BH34R are all also within areas indicated to be marshland by available historical mapping. Further instructive investigation would be required to confirm the extent of Peat within these areas.

Outside of this area, thin (thicknesses generally ranging from 0.05 – 0.2 m) layers of organic/peaty material were also recorded within additional locations, as indicated in . A number of these were recorded by the BGS historical exploratory holes (SN81SW32, SN81SW33, SN81SW34, SN81SW35 & SN81SW36), as well as within five of the Stage 1 and Stage 2 GI locations (S1-BH112, S1-BH116, S2-BH242, S2-BH248 & S2-TP2126) and one of the Stage 0 GI locations (TP38). The material was generally encountered interbedded within, or at the base of, the made ground within these areas, and considering the relatively small thickness, this material has been interpreted as relic topsoil and is not anticipated to form part of the more significant Peat deposits.

Figure 4-5 below provides an interpreted extent indicating where Peat may be encountered across the Washery.



Figure 4-5: Washery Ground Model – Peat (Imagery copyright AtkinsRéalis, [16])

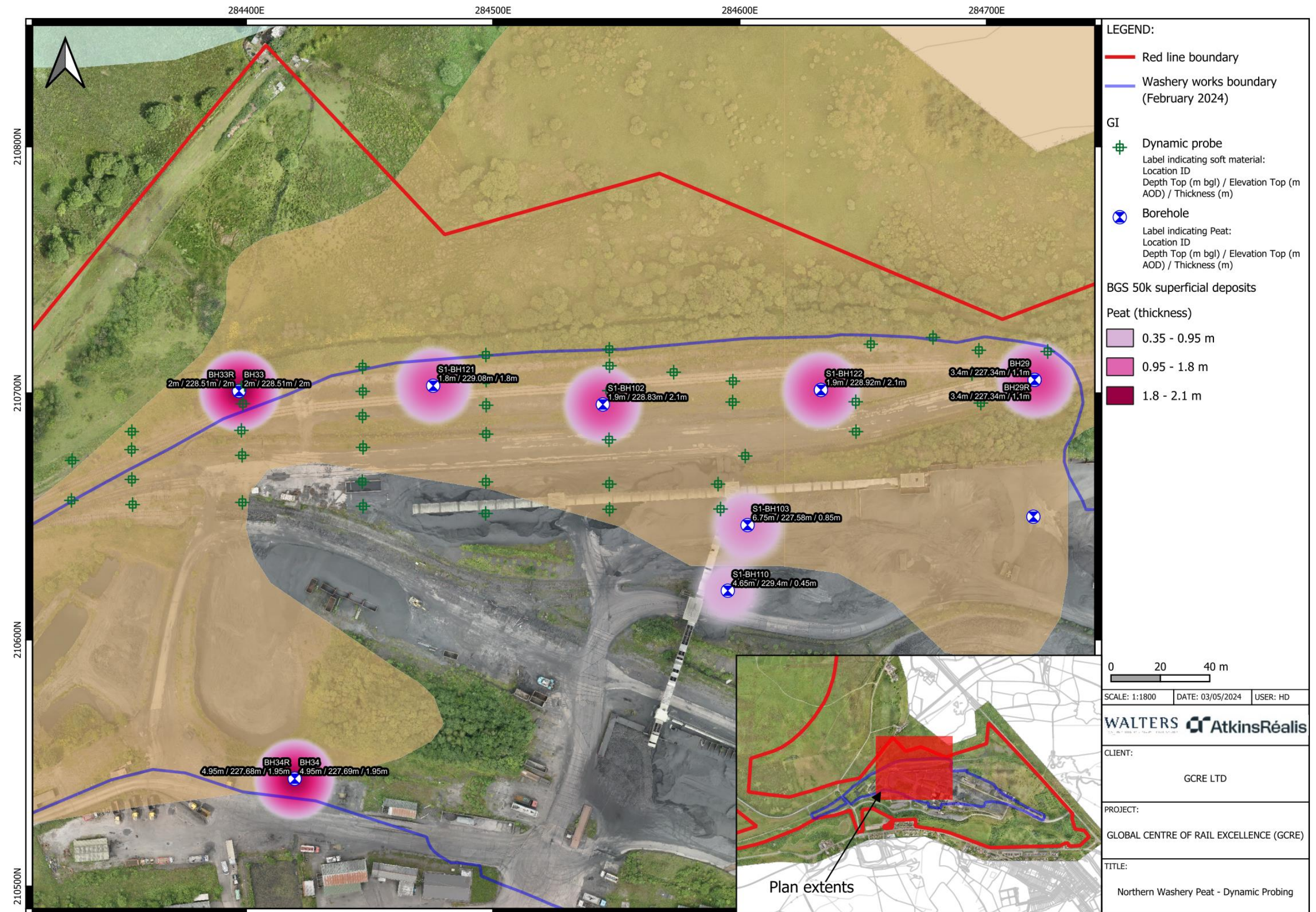


Figure 4-6: Northern Washery Peat – Dynamic Probing (Imagery copyright AtkinsRéalis, [16])

4.2.4 South Wales Coal Measures Formation

Undifferentiated South Wales Middle and Lower Coal Measures Formation (SWCM) was encountered underlying the Washery site within 257No. of the 332No. exploratory hole (including probe holes) locations, with the remaining locations terminated before encountering bedrock.

This stratum was encountered at varying depths from the ground surface to 26.2 m bgl (219.6 to 277.5 m AOD) and was generally described as a weathered rock and further described as a “*soft to very stiff, slightly sandy (fine to coarse), slightly gravelly (mudstone and siltstone), slightly silty grey clay*” (thicknesses ranging 0.2 to 4.5 m) overlying a more competent “*weak to moderately strong, thickly laminated to thinly bedded, grey to dark grey mudstone with closely spaced sub-horizontal to randomly spaced discontinuities*” with interbedded “*weak to strong, thinly bedded, grey to dark grey Siltstone, with sub-horizontal to 20° closely spaced fractures infilled with silt*” and “*medium strong to strong, medium bedded, grey, fine sandstone, with sub-horizontal to 30° locally medium spaced fractures infilled with fine sand*”.

Coal and voiding were also encountered within the bedrock, related to the site history of shallow coal mining. A discussion on these workings is provided within the separate Mining Risk Review [2], which should be referenced in conjunction with this GIR.

Due to the number and distribution of locations which encountered the bedrock, it was possible to interpolate a surface for the top of the material using the Delaunay triangulation algorithm. The algorithm utilises a nearest neighbour methodology to triangulate between the recorded locations. Areas with a large density of points are anticipated to be more accurate, with areas with large spacing between points likely to be less accurate where any unrecorded localised variations will not be captured. A plan showing the interpolated surface is shown within Figure 4-7.



Figure 4-7: Washery Ground Model – South Wales Coal Measures Formation (Imagery copyright AtkinsRéalis)

4.3 Groundwater

4.3.1 Groundwater strikes and monitoring

Groundwater strikes were recorded across the Washery within a total of 115No. exploratory holes (11No. BGS historical, 29No. Stage 0, 30No. Stage 1, and 45No. Stage 2). A summary of the strikes is provided within Table 4-1 below.

Table 4-1: Groundwater strikes within the Washery

GI	Stage 0 & Stage 1				Stage 2			
Strata	Min of Water Level (m bgl)	Max of Water Level (m bgl)	Min of Water Level (m AOD)	Max of Water Level (m AOD)	Min of Water Level (m bgl)	Max of Water Level (m bgl)	Min of Water Level (m AOD)	Max of Water Level (m AOD)
Made ground	0	11.3	228.0	247.2	0.2	6.0	221.3	237.6
Glacial Till	2.0	2.3	231.2	232.8	1.4	4.0	230.1	237.0
Peat	6.8		231.8		None recorded within this strata			
South Wales Coal Measures Formation	4.0	19.8	208.7	240.2	3.0	15.0	224.1	234.4

Artesian groundwater was also encountered to the southeast of the Washery within 4No. exploratory holes with water levels ranging from 1 m to 3 m above ground level. Artesian groundwater is discussed further within Section 4.3.2 below.

As summarised within Section 3, groundwater monitoring was also undertaken following the Stage 0, Stage 1, and Stage 2 GIs. Table 4-2 and Figure 4-8 below summarises minimum and maximum groundwater levels recorded on-site during three post-ground investigation monitoring periods.

The first AtkinsRéalis monitoring was undertaken during winter and early spring months, from November 2022 to April 2023 (following the Stage 1 GI), where groundwater levels would be expected to be higher relative to the rest of the year, and the second AtkinsRéalis monitoring was completed during spring and summer, from April to August 2023 (following the Stage 2 GI), where groundwater levels would be anticipated to be reduced.

Table 4-2: Groundwater levels within the Washery

GI	Stage 0 & Stage 1				Stage 2			
Strata	Min of Water Level (m AOD)	Max of Water Level (m AOD)	Min of Water Level (m bgl)	Max of Water Level (m bgl)	Min of Water Level (m AOD)	Max of Water Level (m AOD)	Min of Water Level (m bgl)	Max of Water Level (m bgl)
Made ground	229.73	236.30	0.15	10.66	231.84	235.84	1.28	7.21
Peat	230.12	230.45	0.43	0.76	236.15	236.45	1.88	2.18
South Wales Coal Measures Formation	226.43	241.82	0.10	12.35	227.47	234.20	1.74	11.58

Generally, water levels tended to be shallowest in the centre and north of the site and to fall slightly in monitoring wells to the west and east with depth to water increasing with the rising topography in the north of the site relative to the lower lying areas in the south. These changes correspond to the sites changing topography. Typically, water levels varied within individual installations by less than 1 m over the course of the monitoring period.

A further detailed assessment of the site groundwater and hydrogeological conditions is provided within the separate geo-environmental interpretive report [3], which should be referenced in conjunction with this GIR.

4.3.2 Artesian water

Artesian water was encountered within a number of exploratory holes (S1-BH107, S1-BH114, S1-BH114B and S1-BH114C) to the west of the Washery.

Two distinct water levels relating to artesian water were identified. The first, situated at the interface between the superficial and weathered South Wales Coal Measures (between 4 m and 9 m bgl), was found to be at a lower pressure with the water rising to a maximum head of 1.5 m above ground level (average head approximately 1 m above ground level). The second, situated at a depth of 19.8 m bgl within a fractured sandstone bed, was only encountered in S1-BH114C (due to other holes in the area being abandoned) and produced a head of water of 3 m above ground level.

The artesian water was able to be controlled in S1-BH107, S1-BH114 and S1-BH114B by conventional means and backfilling of the holes, while S1-BH107B and S1-BH114C were installed with packers above the water strikes to prevent further water egress from the boreholes, as detailed in Table 4-3 below.

Table 4-3: Artesian water strikes and installation summary

BH ID	Depth of water strike below ground level (m)	Artesian water	Maximum head of water above ground level (m)	Maximum head of water above ground level (m AOD)	Installation
S1-BH107	7.0	Yes	~1.0	230.9	Backfilled with grout
S1-BH107B	First strike: 4.0 Second strike 15.5	No	N/A	N/A	Installed with a packer and grouted above
S1-BH114	9.0	Yes	1.5	230.0	Backfilled with grout
S1-BH114B	4.0	Yes	~1.0	229.7	Backfilled with grout
S1-BH114C	First strike: 6.8 Second strike: 19.8	Yes	3.0	231.5	Installed with a packer and grouted above

The factors leading to the two artesian water strikes in this area are multi multifaceted. Exploratory holes in this area are topographically lower than the surrounding land to the north, east, and south resulting in any surface or groundwater flowing downwards into this low point. Regional and localised faulting in the area may also produce pathways for pressurised water to travel though, with evidence of faulting found in the recovered core samples through the presence quartz veining.

Additionally, the second higher pressure water strike (encountered within S1-BH114C only) is likely to be associated with the presence of underground mine workings beneath the Washery.

Historical mine abandonment plans indicate that the area where S1-BH114C was located is underlain by underground mine workings within the Peacock coal seam, and also that the 1972-82 Onllwyn opencast workings crosscut the underground workings, thus providing a pathway for groundwater through the backfilled opencast fill into the underground workings. Evidence of the underground workings was also indicated within S1-BH107B with the presence of a void, recovery of timbers, and a significant increase in water at 18.0 m bgl (211.96 m AOD).

It is understood that the coal seams in the area generally dip to the south, therefore resulting in the coal seams and subsequently mine workings shallowing to the north, with the exploratory holes which recorded artesian water interacting with the lowest point of the workings where water pressure would be highest due to the significant head of water upslope.

Therefore, it has been interpreted from the available information that the water pressure increases at depth in the areas in close proximity to historical mine workings (approximately 18.0 m to 19.0 m bgl). The water pressure also appears to increase from east to west across the workings.

The full extent of the artesian water is unconfirmed, but it is likely to continue to the west of S1-BH114 towards the western extent of the underground workings. Further ground investigation would be required to fully define the extent of the artesian water, but its presence should be considered within the detailed design.



Figure 4-8: Washery Groundwater Monitoring (Imagery copyright AtkinsRéalis)

4.4 Geotechnical parameters

4.4.1 Rationale for geotechnical parameter deviation

Wherever possible, direct testing results from the Stage 0, Stage 1, and Stage 2 GIs have been used to provide characteristic geotechnical parameters. However, where direct testing was not available or the number of available direct tests was insufficient, published empirical correlations have been used to inform the derivation of the required characteristic parameters.

The parameter derivation methodology is outlined within the AtkinsRéalis Stage 0 GIR [20]. However, as Peat parameters were not derived as part of that report, the derivation rationale for this material is detailed in Section 4.4.3 below.

Where several derivation methods have been proposed, the results of each will be considered to establish characteristic values to be used for design purposes.

4.4.2 Made ground

Made ground was encountered across the Washery, the majority of which is assessed to be colliery spoil and coal washing material as a result of the site historical usage.

330No. of the exploratory holes recorded made ground, with the available information provided by these investigations summarised below:

- 581No. field based geological descriptions, 245 (or approximately 42%) of which were drillers descriptions;
- 124No. SPTs, 2 (or approximately 2%) of which refused at 50 blows most likely on cobbles or boulders;
- 7No. in situ hand shear vanes;
- 309No. moisture content tests;
- 5No. Atterberg tests;
- 62No. PSD tests;
- 2No. MCV tests;
- 10No compaction tests;
- 9No. shear box tests; and
- 49No. BRE SD-1 tests.

Characterisation

As shown in Figure B.1, the material was shown to be predominantly coarse grained with 12No. of the PSD tests yielding fines content above 35%, defined by BS 6031:2009 [22] as likely to behave as a cohesive soil. Based on exploratory hole log descriptions and other PSD data, these appear to be fine grained layers within a predominantly coarse-grained strata.

Additionally, analysis of the available field geological descriptions, as shown in Figure B.2, indicates that 51% of the entries were classified as predominantly gravel, with an overall total of 68% of entries classified as coarse grained and 10% of entries classified as fine grained (22% of entries were not classified as comprised of materials such as concrete and tarmac which were typically cored from the ground surface).

3No. Atterberg tests undertaken on cohesive samples yielded Plasticity Index (PI) values between 12 and 29% (average 21%) ranging from a low to high plasticity clay, as shown in Figure B.3.

On the basis of this discussion, the stratum is classified as predominantly coarse grained. There was insufficient information to derive reliable material parameters for the cohesive material separately - available data for the cohesive material: 62No. field based geological descriptions, 7No. in situ hand shear vanes, 5No. Atterberg tests, and 1No. SPT. As such, granular geotechnical parameters have been derived for the material as an undivided unit, as summarised within Table 4-4 below.

Table 4-4: Summary of made ground (granular) parameters

Parameter		Range	Proposed value	characteristic	Figure
Unit Weight, γ' (kN/m ³)		Shear box testing: 12.8 to 18.6 Description: 16 to 21	18		-
Effective stress parameters	Cohesion, c' (kPa)	Shear box testing: 3 to 13	0		-
	Angle of shearing resistance, ϕ' (°)	Shear box testing: 23 to 33 BS8004: 29 to 40 BS8002: 32	32		-
Young's Modulus	Drained, E' (MPa)	C143: 2 to 48	<4.0 m bgl: 12 3.0 to 10.0 m bgl: 3.8z-3.3 >10.0 m bgl: 35		Figure B.4
Poisson's Ratio	Drained, ν'	0.1 to 0.3	0.2		-
Moisture Condition Value (%)		3.9 to 15.7			-
Optimum Moisture Content (%)		15 to 18	16		-
Maximum Dry Density (Mg/m ³)		1.2 to 1.4			-
BRE Classification	Total potential sulphate (% SO ₄)	2.7	Design sulphate class: DS-5		-
	pH	7.5	Aggressive chemical environment for concrete class: AC-4s		-

4.4.3 Peat

4.4.3.1 Peat derivation rationale

Unit Weight

Unit weight values were obtained by converting density (ρ) values ($\gamma = 9.81\rho$) recorded during direct laboratory testing (triaxial and consolidation). In addition, values have been estimated from moisture content using correlations proposed by Hobbs [23].

Effective Strength

No direct laboratory testing was undertaken on samples of Peat. Additionally, available literature did not provide any relevant correlations to enable the derivation of values, therefore, published literature values have been used to provide values.

Mesri and Ajlouni [24] summarised numerous published literature laboratory testing undertaken on fibrous peat published between 1961 and 2000. Undrained triaxial testing generally provided results ranging between 40° and 60°, while drained direct shear testing reported by Landva and La Rochelle [25] generally provided results

between 32° and 40° whilst noting that shear strength of peat in ring shear tests was found to be virtually unaffected by fibre reinforcement with friction angles reported to be between 27° and 32° with a cohesion of 2.4kPa.

Based on this, and as the Peat within the Washery is anticipated to be pseudo-fibrous to fibrous, a conservative angle of shearing resistance (ϕ') of 22° is proposed with a cohesion (c') of 0 kPa.

Undrained Shear Strength

Undrained shear strength values (c_u) have been obtained from direct laboratory triaxial testing, with 4No. unconsolidated-undrained (UU) triaxial tests available for the Peat material.

Undrained shear strength values have been correlated from moisture content and humification (H1 to H6 Van Post humification classification assumed for pseudo-fibrous to fibrous peat as reproduced in The International Levee Handbook [26]) using correlations proposed by Helenlund [27] as reproduced by Boylan et al [28].

Additionally, values have also been correlated from undrained strength ratios (c_u / σ'_{v0}) stated within literature sources to range between 0.3 and 0.8 for Peat material. Mesri and Ajlouni [24] summarised ratios of between 0.47 and 0.78 for fibrous peat. Based on this, and as the Peat within the Washery is anticipated to be pseudo-fibrous to fibrous, a ratio of 0.5 is proposed as summarised below:

$$\frac{c_u}{\sigma'_{v0}} = 0.5$$

Coefficient of Volume Compressibility

Coefficient of Volume Compressibility values have been estimated from 6No. oedometer tests undertaken on samples of Peat from within the Washery.

Compression and Recompression Index

Compression (C_c) and Recompression (C_r) indexes have been estimated from 6No. oedometer tests undertaken on samples of Peat from within the Washery.

Additionally, compression index has been estimated from moisture content based on correlations proposed by Long and Boylan [29].

Coefficient of Secondary Consolidation

The coefficient of secondary consolidation (C_α) has been estimated from a ratio with the proposed compression index (C_α/C_c).

Mesri et al [30] summarised that for amorphous and fibrous peats the ratio varies between 0.035 – 0.091. Additionally, Long and Boylan [29] provide correlations allowing the ratio to be estimated from moisture content. Based on these, and as the Peat within the Washery is anticipated to be pseudo-fibrous to fibrous, a ratio of 0.07 is proposed as summarised below:

$$\frac{C_\alpha}{C_c} = 0.07$$

Coefficient of Consolidation

It is widely known that oedometer testing is an unreliable method of estimating Coefficient of Consolidation (c_v) values of soils. Therefore, results from the 6No. available oedometer results have been considered, but greater consideration has been given to typical coefficient of consolidation values from available literature.

A literature review undertaken by Long and Boylan [29] indicated that the c_v values for peats can range between 2 and 13m²/year for a Van Post humification classification of between 5.5 and 6.5 with greater c_v values for lower humification.

4.4.3.2 Peat geotechnical parameters

Peat was encountered predominantly to the north of the Washery, within areas indicated to be marshy by historical maps, with other areas to the southeast of the Washery also encountering a thin layer (maximum thickness of 200 mm) of peaty organic material interpreted to be relic topsoil.

24No. of the exploratory holes recorded Peat, with the available information provided by these investigations is summarised below:

- 24No. field based geological descriptions;
- 7No. SPTs;
- 24No. moisture content tests;
- 9No. Atterberg tests (6No. of which returned non plastic results);
- 11No. organic matter tests;
- 6No. PSD tests;
- 6No. consolidation tests; and
- 4No. UU triaxial tests.

Characterisation

Peat is a highly compressible organic soil, formed from “*partially decomposed semi-carbonised vegetation that has grown under waterlogged, anaerobic conditions*” [31]. The material encountered within the Washery was generally described as “*soft to firm (some spongy) brown to dark brown fibrous to pseudo-fibrous Peat with occasional plant remains*”.

While not provided as part of the field geological descriptions, pseudo-fibrous peat is specified as H3 to H6, and fibrous peat is specified as H1 to H2 on the Von Post scale of humification [26].

Organic content testing reported an average organic content of 48.5% (range: 12.0% - 66%) from lab testing on samples of Peat.

Based on the currently available information, geotechnical parameters proposed for the Peat are summarised in Table 4-5 below.

Table 4-5: Summary of Peat parameters

Parameter		Range	Proposed characteristic value	Figure
Moisture content (%)		Lab testing: 15 to 738	350	Figure B.5
Unit Weight, γ' (kN/m ³)		Lab testing: 10.4 to 21.7 MC correlation: 10.6	11.2	Figure B.6
Effective stress parameters	Cohesion, c' (kPa)	-	0	-
	Angle of shearing resistance, ϕ' (°)	-	22	-
Undrained shear strength, c_u (kPa)		UU triaxial testing: 25 to 100 MC correlation: 26	20 to 25	Figure B.7

	σ'_{v0} correlation: 6.6 to 34.3		
Coefficient of volume compressibility, m_v (m^2/MN)	Oedometer testing: 0.01 to 8.4	0 to 50 kPa: 4.8 50 to 225 kPa: $6 - 0.024\sigma$ >225 kPa: 0.6	Figure B.8
Compression Index, C_c	Oedometer testing: 1.5 to 14.0 MC correlation: 3.5	5	Figure B.9
Recompression Index, C_r	0.9 – 1.2	1	
Coefficient of secondary consolidation, C_{α}	-	0.35	-
Coefficient of consolidation, c_v ($m^2/year$)	Oedometer testing: 0.03 to 26 Literature: 2 to 13	5 - 10	-

4.4.4 Glacial Till

Glacial Till was encountered intermittently across the Washery, with the majority encountered to the east and south of the site.

Glacial Till was encountered in 56No. of the exploratory holes. A summary of the available information provided by these investigations is included below:

- 103No. field based geological descriptions, 6 (or approximately 6%) of which are drillers descriptions;
- 29No. SPTs, 3 (or approximately 10%) of which refused at 50 blows most likely on cobbles or boulders;
- 86No. moisture content tests;
- 40No. Atterberg tests;
- 25No. PSD tests; and
- 13No. BRE SD-1 tests.

4.4.4.1 Characterisation

As shown in Figure B.10, the material was shown to be predominantly fine grained with 16No. of the PSD tests yielding fines content above 35%, defined by BS 6031:2009 [22] as likely to behave as a cohesive soil. Of the remaining 9No. tests which returned fines content less than 35%, 4No. of these returned relatively high fines content of 29 to 32%, 4No. of these were undertaken on samples described as being predominantly clay and 1No. was undertaken on a sample described as predominantly gravel but that was overlain by layers of Glacial Till described as predominantly clay.

Additionally, analysis of the available field geological descriptions indicates that 85% of the entries were classified as predominantly clay, with 1% of entries classified a predominantly silt, 9% of entries classified predominantly gravel and 5% of entries classified as predominantly sand.

19No. Atterberg tests undertaken on cohesive samples yielded Plasticity Index (PI) values between 10 and 54% (average 26%) ranging from a low to high plasticity clay, as shown in Figure B.11.

Approximately 10% of the SPTs refused at 50 blows which may still indicate a more significant granular element within the material which is not represented within the exploratory hole logs and laboratory testing. However, based on the available information, the Glacial Till is conservatively assumed to behave as a cohesive material. The presence of granular layers within the Glacial Till material should be considered as a risk during detailed

design, as they may contain perched water or create permeable pathways for groundwater leading to softening of the surrounding material.

Geotechnical parameters proposed for the cohesive Glacial Till are summarised in Table 4-6.

Table 4-6: Summary of Glacial Till (cohesive) parameters

Parameter		Range	Proposed characteristic value	Figure
Unit Weight, γ' (kN/m ³)		Description: 16 to 22	19	-
Effective stress parameters	Cohesion, c' (kPa)	-	0	-
	Angle of shearing resistance, ϕ' (°)	PI BS8002: 25 PI C504: 22 to 35	25	-
Undrained shear strength, c_u (kPa)		PI C143: 60 to 320 Description: 20 to 150	<3.0 m bgl: 50 3.0 to 8.0 m bgl: 16z+2 >8.0 m bgl: 130	Figure B.12
Young's Modulus	Drained, E' (MPa)	C143: 12 - 64 Muir Wood: 10 to 53.3 Cu: 12 to 64	<3 m bgl: 10 3 to 8 m bgl: 5z - 5 >8 m bgl: 35	Figure B.13
	Undrained, E_u (MPa)	C143: 12 to 64	<3 m bgl: 12 3 to 8 m bgl: 6z - 6 >8 m bgl: 42	Figure B.14
Poisson's Ratio	Drained, ν'	0.1 to 0.3	0.25	-
	Undrained, ν_u	-	0.5	-
Coefficient of volume compressibility, m_v (m ² /MN)		C143: 0.003 to 0.02 ICE: 0.02 to 0.08	<3 m bgl: 0.04 3 to 8 m bgl: -0.006z+0.058 >8 m bgl: 0.01	Figure B.15
BRE Classification	Design Sulphate Class	DS-1		-
	ACEC Class	AC-1s		-

4.4.5 South Wales Coal Measures

Undifferentiated South Wales Coal Measures Formation bedrock was encountered across the site, with the base of this stratum not proven by any of the investigations which were progressed to a maximum depth of 45.1 m bgl.

The material was generally encountered as a layer of weathered material, encountered as predominantly clay, which then became competent rock with depth predominantly comprised of Mudstone, with some interbedded Siltstone and Sandstone.

The bedrock has been divided into the encountered lithologies and discussed in the following sections.

4.4.5.1 Weathered South Wales Coal Measures

159No. of the 243No. exploratory holes which recorded encountering SWCM bedrock also documented a weathered layer of strata described predominantly as a clay derived soil.

A summary of the available information provided by these investigations is included below:

- 193No. field based geological descriptions, 129No. (or approximately 67%) of which are drillers descriptions partially a result of drilling method;
- 27No. SPTs, 7 (or approximately 26%) of which refused at 50 blows most likely due to intersecting with more competent bedrock;
- 6No. hand shear vanes;
- 39No. moisture content tests;
- 20No. Atterberg tests;
- 14No. PSD tests; and
- 4No. BRE SD-1 tests.

Characterisation

As shown in Figure B.16, 5No. of the PSD tests yielding fines content above 35%, being defined by BS 6031:2009 [22] as likely to behave as a cohesive soil. Of the remaining 9No. tests which returned fines content less than 35%, 2No. of these returned relatively high fines content of 33 to 34%, 5No. of these were undertaken using samples described as predominantly gravel at the base of the material described as weathered, therefore, likely to be less weathered and degraded.

Additionally, analysis of the available field geological descriptions indicates that 85% of the entries were classified as predominantly clay, with 13.5% of entries classified predominantly gravel and 1.5% of entries classified as predominantly silt.

20No. Atterberg tests undertaken on cohesive samples yielded Plasticity Index (PI) values between 11 and 57% (average 23%, or 21% with two significantly higher values omitted from the dataset) ranging from an low to extremely high plasticity clay, as shown in Figure B.17.

On the basis of this discussion, the strata is classified as predominantly fine grained with cohesive geotechnical soil parameters derived for the material. Geotechnical parameters proposed for the cohesive weathered SWCM are summarised in Table 4-7.

Table 4-7: Summary of Weathered SWCM (cohesive soil) parameters

Parameter		Range	Proposed characteristic value	Figure
Unit Weight, γ' (kN/m ³)		Description: 15 - 24	20	-
Effective stress parameters	Cohesion, c' (kPa)	-	0 - 2	-
	Angle of shearing resistance, ϕ' (°)	PI BS8002: 25	25	-
Undrained shear strength, c_u (kPa)		PI C143: 64.4 to 359 Description: 20 to 300	<3.0 m bgl: 70 3.0 to 8.0 m bgl: 21z+7 >8.0 m bgl: 175	Figure B.18

Young's Modulus	Drained, E' (MPa)	C143: 14 to 78 Muir Wood: 11.7 to 65 Cu: 12.9 to 71.7	<3 m bgl: 15 3 to 8 m bgl: 4.4z+1.8 >8 m bgl: 37	Figure B.19
	Undrained, E _u (MPa)	C143: 14 to 53.3	<2.5 m bgl: 17 3 to 8 m bgl: 4.18z+6.55 >8 m bgl: 40	Figure B.20
Poisson's Ratio	Drained, ν'	0.1 to 0.3	0.25	-
	Undrained, ν _u	-	0.5	-
Coefficient of volume compressibility, m _v (m ² /MN)		C143: 0.003 to 0.02 ICE: 0.01 to 0.07	<2 m bgl: 0.025 3 to 8 m bgl: -0.003z+0.031 >7 m bgl: 0.01	Figure B.21
BRE Classification *	Design Sulphate Class	DS-3		-
	ACEC Class	AC-3		-
* Due to limited available testing within the Washery, testing across the whole site has been considered				

4.4.5.2 South Wales Coal Measures Bedrock

243No. of the exploratory holes recorded encountering competent SWCM strata. The material was encountered predominately as mudstone (56% of field geological descriptions) with bands of sandstone (5% of field geological descriptions) and siltstone (12% of field geological descriptions), with coal (15% of field geological descriptions), voids (3% of field geological descriptions) and areas of no recovery (9% of field geological descriptions) also noted.

A summary of the available information provided by these investigations is included below:

- 785No. field based geological descriptions, 451 (or approximately 57%) of which are drillers descriptions;
- 2679No. Rock Quality Designations;
- 1No. Uniaxial Compressive Strength (UCS) tests;
- 26No. Point Load Tests (PLT); and
- 2No. BRE SD-1 tests.

Hoek Brown parameters have been derived for the mudstone, siltstone and sandstone lithologies, as summarised in the Table 4-8, Table 4-9 and

Parameter	Range	Proposed characteristics value	Figure
Unit Weight, γ' (kN/m ³)	-	22	-
Uniaxial Compressive Strength, UCS (MPa)	2 - 56	5	Figure B.23
Geological Strength Index, GSI	25 - 35	35	-
mi	7±2	7	-
Disturbance factor, D	0 – 0.7		-
Rock Quality Designation, RQD (%)	0 - 94	30	

BRE Classification *	Design Sulphate Class	DS-3
	ACEC Class	AC-3
* Due to limited available testing within the Washery, testing across the whole site has been considered		

Table 4-10

below. However, based on the available information, Mudstone is assessed to be the dominant component of the bedrock.

Table 4-8: Summary of SWCM Mudstone parameters

Parameter	Range	Proposed characteristics value	Figure
Unit Weight, γ' (kN/m ³)	-	22	-
Uniaxial Compressive Strength, UCS (MPa)	UCS: 6.1 PLT: 4 - 84	5	Figure B.22
Geological Strength Index, GSI	20 - 40	30	-
mi	6 $\pm$ 2	6	-
Disturbance factor, D	0 – 0.7		-
Rock Quality Designation, RQD (%)	0 – 94	10	
BRE Classification *	Design Sulphate Class	DS-3	
	ACEC Class	AC-3	
* Due to limited available testing, BRE testing across the whole site has been considered when specifying a BRE classification.			

Table 4-9: Summary of SWCM Siltstone parameters

Parameter	Range	Proposed characteristics value	Figure
Unit Weight, γ' (kN/m ³)	-	22	-
Uniaxial Compressive Strength, UCS (MPa)	2 - 56	5	Figure B.23
Geological Strength Index, GSI	25 - 35	35	-
mi	7 $\pm$ 2	7	-
Disturbance factor, D	0 – 0.7		-
Rock Quality Designation, RQD (%)	0 - 94	30	
BRE Classification *	Design Sulphate Class	DS-3	
	ACEC Class	AC-3	
* Due to limited available testing within the Washery, testing across the whole site has been considered			

Table 4-10: Summary of SWCM Sandstone parameters

Parameter	Range	Proposed characteristics value	Figure
Unit Weight, γ' (kN/m ³)	-	24	-
Uniaxial Compressive Strength, UCS (MPa) *	54	50	-
Geological Strength Index, GSI	35 - 45	40	-

mi		17±4	17	-
Disturbance factor, D		0 – 0.7		-
Rock Quality Designation, RQD (%)		0 – 100	40	-
BRE Classification *	Design Sulphate Class	DS-3		
	ACEC Class	AC-3		
* Due to limited available testing within the Washery, testing across the whole site has been considered				

4.4.6 Parameter comparison

A comparison of the proposed characteristic geotechnical parameters between the site wide Stage 0 GIR and the Washery (as detailed above) are presented below in Table 4-11 and Table 4-12. Where parameters were not proposed within the Stage 0 GIR due to limited available information, Peat and weathered SWCM, the materials have been omitted from the comparison table and the individual sections above should be referenced.

Table 4-11: Comparison of Soil Geotechnical Parameters

Strata	Unit Weight, γ' (kN/m ³)	Effective Strength		Undrained shear strength, c_u (kPa)	Stiffness		Coefficient of volume compressibility, m_v (m ² /MN)	Poisson's Ratio		BRE Classification	
		Angle of shearing resistance, ϕ'_{cv} (°)	Apparent cohesion, c'_{cv} (kPa)		Drained Young's Modulus, E' (MPa)	Undrained Young's Modulus, E_u (MPa)		Drained, v'	Undrained v_u	Design Sulphate Class	ACEC Class
Site Wide Parameters (Stage 0 GIR) Made ground (granular)	20	34	0	-	23	-	-	0.2	-	DS-5	AC-4s
Washery GIR Made ground (granular)	18	32	0	-	23	-	-	0.2	-	DS-5	AC-4s
Site Wide Parameters (Stage 0 GIR) Glacial Till	19	25	0	<2.5 m bgl: 40 2.5 to 8.0 m bgl: 20z-10 >8.0 m bgl: 150	<2 m bgl: 12 2 to 8 m bgl: 7.16z-2.32 >8 m bgl: 55	<2 m bgl: 10 2 to 8 m bgl: 5.97z-1.94 >8 m bgl: 45.8	0.01 to 0.3	0.25	0.5	DS-1	AC-1s
Washery GIR Glacial Till	19	25	0	<3.0 m bgl: 50 3.0 to 8.0 m bgl: 16z+2 >8.0m bgl: 130	<3.0 m bgl: 10 3.0 to 8.0 m bgl: 5z-5 >8.0m bgl: 35	<3.0 m bgl: 12 3.0 to 8.0 m bgl: 6z-6 >8.0m bgl: 42	<3.0 m bgl: 0.04 3.0 to 8.0 m bgl: -0.006z+0.058 >8.0m bgl: 0.01	0.25	0.5	DS-1	AC-1s

(1) where z is metres below ground level

Table 4-12: Comparison of Rock Parameters

Strata	Unit Weight, γ' (kN/m ³)	Hoek Brown					BRE Classification	
		Uniaxial Compressive Strength, UCS (MPa)	Geological Strength Index, GSI	m_i	Disturbance factor, D	Rock Quality Designation, RQD (%)	Design Sulphate Class	ACEC Class
Site Wide Parameters (Stage 0 GIR) SWCM (Mudstone)	22	5	30	6	0	20	DS-3	AC-3
Washery GIR SWCM (Mudstone)	22	5	30	6	0 – 0.7	10	DS-3	AC-3
Site Wide Parameters (Stage 0 GIR) SWCM (Siltstone)	22	5	40	8	0	30	DS-3	AC-3
Washery GIR SWCM (Siltstone)	22	5	35	7	0 – 0.7	30	DS-3	AC-3
Site Wide Parameters (Stage 0 GIR) SWCM (Sandstone)	24	50	50	17	0.7	30	DS-3	AC-3
Washery GIR SWCM (Sandstone)	24	50	40	17	0 – 0.7	40	DS-3	AC-3

4.5 Material reuse

An assessment of the material reuse is provided within the separate geo-environmental interpretive report [3], which should be referenced in conjunction with this GIR.

4.6 Ground gas

An assessment of the ground gas is provided within the separate geo-environmental Interpretive report [3], which should be referenced in conjunction with this GIR.

4.7 Mining

A summary of the mining considerations is provided within Section 2.5 above. A detailed assessment of the mining risk is provided within the separate Mining Risk Review [2], which should be referenced in conjunction with this GIR.

5. Geotechnical risk register

Only risks applicable to the Washery have been discussed within the following sections of this report. For a comprehensive list of risks applicable to the site as a whole, the AtkinsRéalis Stage 0 GIR should be referenced.

Additionally, mining and geo-environmental related risks are also omitted as they form part of the separate geo-environmental interpretive [3] and mining risk [15] reports, which should be referenced in conjunction with this GIR.

5.1 Geotechnical risk matrix

Geotechnical risk is defined as the possibility of an adverse consequence arising from a ground hazard or circumstance [32]. The Geotechnical risk register considers the identified geotechnical constraints, along with additional project details to ensure that all significant geotechnical risks are identified, recorded, analysed, and controlled. The geotechnical risks are discussed in terms of likelihood, severity, and risk, as defined below:

- **Likelihood (L):** The perceived likelihood of the identified geotechnical hazard occurring.
- **Severity (S):** The perceived severity, in terms of safety, financial, temporal, legal, or operational consequence, of the occurrence of the identified geotechnical hazard on the identified receptor(s)
- **Risk (R):** The perceived level of concern which should be assigned to the identified hazard, based on the likelihood of occurrence, and taking into due account the perceived severity of the impact.

The risk uses the following equation:

$$\text{Degree of Risk (R)} = \text{Likelihood (L)} \times \text{Severity (S)}$$

The likelihood and severity values are detailed in Table 5-1, with the risk matrix and perceived degree of risk summarised in Table 5-2 and Table 5-3 respectively.

Table 5-1: Likelihood and severity rating

Likelihood		Severity			
		Health and safety		Operational	
5	Very likely	5	Fatality	5	Fatality
4	Likely	4	Major injury	4	Irreversible damage
3	Possible	3	Reportable injury	3	Major damage
2	Unlikely	2	Lost time injury	2	Minor damage
1	Remote	1	Minor injury	1	No effect

Table 5-2: Geotechnical risk assessment matrix

Likelihood	5	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5
		1	2	3	4	5
	Severity					

Table 5-3: Perceived degree of risk

Risk Number	Risk Ranking	Comments
20 - 25	Unacceptable	Which cannot be justified except in extraordinary circumstances, where resources and finance are provided to control the risk irrespective of cost.
15 - 19	Substantial	Tolerable only if risk reduction is impracticable or if its cost is disproportionate to improvement.
7 - 12	Moderate risk	Tolerable if cost of reduction would exceed the improvement gained in reducing the risk further.
0 – 6	Low	Tolerable

5.2 Geotechnical risk register

The geotechnical risk register, provided below in Table 5-4, comprises an initial assessment of the geotechnical risks identified, prior to the application of risk mitigation measures, and shows how the risks can be reduced by the application of certain measures. For an assessment of the geo-environmental risks the separate geo-environmental report should be referenced.

Table 5-4: Geotechnical risk register

Risk No.	Hazard	Impact	Initial Risk Rating			Mitigation Measures	Risk After Mitigation Measures			Description of Residual Hazard
			P	S	R		P	S	R	
1	Limited number, generally shallow depths, and limited spacing of GI locations within the south of the Washery. Very limited geotechnical laboratory testing undertaken for locations within the south of the Washery.	Uncertainty associated with the ground model and geotechnical parameters within the south of the Washery, where any localised variations will not be captured. Resulting in inaccurate ground modelling and/or designs and potentially more onerous ground conditions than anticipated causing in delays to construction, redesign, or failure / serviceability issues with earthworks during operation.	4	4	16	Additional GI (not undertaken at the time of this report, Stage 3 GI has been proposed) within the southern Washery to identify any localised variations. Design to account for any remaining uncertainty. Contractor to notify designer if unexpected ground conditions encountered during construction.	2	4	8	Unanticipated ground conditions encountered.
2	Variable ground conditions	Variable ground conditions identified across the site, potentially resulting in over or under designed elements. Which may result in excessive material usage (cost and environmental implications), redesign, increased costs and program delay, or ultimately failure / serviceability issues of geotechnical assets.	4	4	16	GI (Stage 0 – 2 GIs, detailed within this report) undertaken identifying varying ground conditions which have been considered within the ground modelling. Design to account for location specific and variable ground conditions. Contractor to notify designer if unexpected ground conditions encountered during construction.	2	4	8	Ground conditions not identified by the GI encountered.
3	Significant thickness and extent of Peat identified within the northern Washery, as well as within other areas of the site.	Highly compressible and low strength material resulting in bearing failure, excess settlement, or preferential slip surfaces. Which may result in redesign, increased costs and program delay, or ultimately failure / serviceability issues of geotechnical assets.	4	5	20	GI (Stage 0 – 2 GIs, detailed within this report) undertaken to identify extent and characterise Peat material which has been considered within the ground modelling. Design to account for the Peat material, with settlement and bearing assessments undertaken. Monitoring may be undertaken during and post construction to ensure that behaviour is as anticipated within the design. Contractor to notify designer if variations are encountered during construction.	2	10	10	More significant Peat encountered than anticipated.
4	Relic 'peaty topsoil' identified by the GI within areas of the site.	Relic topsoil resulting in preferential slip surfaces which may result in redesign, increased costs and program delay, or ultimately failure of geotechnical assets.	4	4	16	GI (Stage 0 – 2 GIs, detailed within this report) undertaken identifying areas of relic topsoil which have been considered within the ground modelling. Design to be undertaken on a location specific basis, which considers the localised areas of relic material. Contractor to notify designer if unexpected ground conditions encountered during construction.	2	4	8	More significant relic topsoil encountered than anticipated.
5	Areas of cohesive made ground recorded within the Washery.	Localised cohesive made ground resulting in reduced geotechnical parameters potentially resulting in under designed elements, increased settlement/heave, or a preferential slip surfaces.	4	4	16	GI (Stage 0 – 2 GIs, detailed within this report) undertaken identifying varying ground conditions which have been considered within the ground modelling.	2	4	8	More significant cohesive material encountered than anticipated.

Risk No.	Hazard	Impact	Initial Risk Rating			Mitigation Measures	Risk After Mitigation Measures			Description of Residual Hazard
			P	S	R		P	S	R	
		Which may result in redesign, increased costs and program delay, or ultimately failure / serviceability issues of geotechnical assets.				Design to be undertaken on a location specific basis, which considers the localised areas of cohesive material. Contractor to notify designer if unexpected ground conditions encountered during construction.				
6	Artesian water	Artesian groundwater may cause excess pressures (including uplift forces), flooding of excavations, or disruption to construction activities. Which may result in redesign, increased costs and programme delay or ultimately failure / serviceability issues of geotechnical assets.	4	4	16	Designs to consider artesian groundwater. Contractor to ensure suitable arrangements for artesian ground conditions are made during construction where required.	2	4	8	More significant artesian groundwater encountered than anticipated.
7	Groundwater	Shallow groundwater may cause excess porewater pressures and instability within geotechnical elements. Shallow groundwater during construction resulting in water ingress into excavations. Which may result in redesign, increased costs and programme delay or ultimately failure / serviceability issues of geotechnical assets.	4	5	20	Groundwater monitoring has been undertaken as part of the GI (Stage 0 – 2 GIs, detailed within this report). Designs to account for a suitably conservative groundwater level, and appropriate drainage measures to be incorporated. Contractor should notify the designer if groundwater levels encountered on site are in excess of those assumed during the design. Contractor to ensure suitable de-watering arrangements during construction where required.	2	5	10	External source (e.g. failed drainage causing) raised groundwater levels resulting in possible failure. Groundwater encountered at shallower depths than anticipated.
8	Soft / compressible ground	Soft or compressible ground resulting in excessive settlement or differential settlement resulting in instability or excessive deformation of geotechnical elements. Particularly within the field to the south of the railway line. Which may result in redesign, increased costs and programme delay or ultimately failure of geotechnical assets.	4	3	12	GI (Stage 0 – 2 GIs, detailed within this report) has identified areas of soft ground, parameters derived to make assessment of the anticipated settlement. Settlement assessment to be made for geotechnical assets to ensure that they meet the limit criteria. Variation in settlement along the length of geotechnical assets to be considered to ensure that they meet limit criteria. Inspection of foundation formation to be undertaken by suitably qualified Geotechnical Engineer during construction to ensure design requirements are met. Monitoring may be undertaken during and post construction to ensure that behaviour is as anticipated within the design.	2	3	6	Softer than expected material encountered or unencountered soft areas cause excessive settlements.
9	Limited in-situ and laboratory data available for the derivation of Peat geotechnical parameters. Subsequently, published	Soft or compressible ground resulting in excessive settlement or differential settlement resulting in instability or excessive deformation of geotechnical elements. Particularly within the field to the south of the railway line.	4	4	16	Conservative parameters proposed based on the limited available information and the published literature.	2	4	8	N/A

Risk No.	Hazard	Impact	Initial Risk Rating			Mitigation Measures	Risk After Mitigation Measures			Description of Residual Hazard
			P	S	R		P	S	R	
	literature guidance and values have been used.	Which may result in redesign, increased costs, and programme delay or ultimately failure of geotechnical assets				Settlement assessment to be made for geotechnical assets to ensure that they meet the limit criteria. Variation in settlement along the length of geotechnical assets to be considered to ensure that they meet limit criteria. Designs undertaken using these parameters to be verified with suitable monitoring and observation of actual settlement behaviour during and post construction of earthworks.				
10	Aggressive ground	Potentially high sulphates in the ground/groundwater leading to thaumasite sulphate attack (TSA) of buried concrete. Which may result in the degradation of the structural integrity of assets over time, leading to maintenance issues or asset not reaching the required design life leading to replacement or redesign with associated cost implications. Earthworks design does not include any buried concrete.	2	4	8	GI (Stage 0 – 2 GIs, detailed within this report) included BRE SD1 testing to identify aggressive ground conditions. Buried concrete to be specified in accordance with characteristic BRE Classification. Excavated material which is identified to pose a risk to be stored away from any concrete structures. Earthworks design does not include any buried concrete.	1	4	4	N/A
11	Historic mining risk	Please refer to “Washery Phase 1A/2A Mining Risk Review,” AtkinsRéalis, 2024 [15]								
12	Ground contamination and ground gas risk	Please refer to “Geo-Environmental Interpretive Report,” AtkinsRéalis, 2024 [3]								

6. Engineering assessment

The current earthworks designs (dated February 2024) have been considered as part of the engineering assessment, which is discussed in the following sections.

Figure 6-1 to Figure 6-6 below present geological sections through the Washery which indicate existing topography (dated December 2023) and the proposed earthworks designs (dated February 2024).

Additionally, Figure 6-7 presents the interpreted strata located at earthworks formation level, based on the current ground modelling, which has been used to inform the geotechnical designs.

6.1 Overview of the main risks identified by the GIR

6.1.1 Southern Washery

At the time that the GIs were undertaken (before June 2023) the earthworks design scope encompassed only the northern Washery. Consequently, GI locations within the south of the Washery were solely investigated for contaminated land purposes (predominantly to assist with the discharge of planning consent). As a result, these locations were generally spaced as per the contaminated land requirements (targeted positions based on historical site processes, existing or demolished buildings, and potential sources of contamination), relatively shallow, and no geotechnical testing was undertaken.

This limited GI creates uncertainty with the ground modelling and geotechnical parameters within this area, where any localised variations will not have been identified.

An additional (Stage 3) GI was specified in order to address the revised earthworks design and reduce the uncertainty within the south of the site. The recommended scope of this investigation was outlined within the Stage 3 GI specification [1], however, the works have not been undertaken at the time of this report (April 2024).

6.1.2 Peat

Peat was encountered across the Washery by the GIs. These deposits have been interpreted into two types:

- A significant layer of Peat material, up to approximately 2 m thickness encountered at approximately 2 m bgl, mainly located along the northern extent of the Washery, as shown within Figure 6-1; and
- A thin, approximately 0.05 – 0.2 m thick, layer of '*organic/peaty*' relic topsoil material located to mainly the east of the Washery.

The engineering considerations associated with each of these types is discussed below.

Significant peat

Due to the thickness, depth, and extent of the Peat deposits to the north of the Washery, it is assessed that excavation and replacement of this material is unfavourable.

The earthwork design indicates an embankment (approximately 7.5 m maximum height) within the area anticipated to be underlain by the significant Peat deposits. Consequently, settlement of the Peat is anticipated to be a significant concern for this embankment. Additionally, as the Peat reduces in thickness to the south, differential settlement of the embankment is also a concern. Settlement parameters have been calculated as part of this report, and a settlement assessment should be undertaken as part of the earthworks design.

Additionally, due to the relatively low strength of the Peat material a bearing capacity and global stability assessment should be undertaken as part of the earthworks design.

Relic topsoil

Relic topsoil identified to the east and south of the Washery, was generally encountered within or at the base of made ground material.

The earthwork design indicates a cutting (approximately 3.7 m maximum height) at the east of the site where the largest amount of relic material was encountered by 10No. of the exploratory hole locations, and a cutting (approximately 1.4 m maximum height) at the south of the site where the relic material was encountered by one of the exploratory holes.

The ground modelling indicates that the toe of the cuttings within these areas in close proximity (within 0.5 m) to the relic material, which has the potential to create a preferential slip surface that could potentially lead to slope instability. The presence of this material should be considered in the design of these earthworks, with Peat parameters applied to a thin layer of material, and global slope stability analysis undertaken for critical sections where the toe of the cutting intersects with the material.

6.1.3 Significant thicknesses of made ground

Made ground was encountered within S1-BH101 and SW81SW19 (21.6 m and 26.2 m respectively) to the northeast and south of the Washery. The cause of these thicker accumulations is not known but is likely to be either associated with the backfilling of a mining feature or a stockpile of spoil material.

The earthwork design indicates a cutting (approximately 2.5 m maximum height) within the area of S1-BH101, the design of which should consider the thickness of the made ground as well as the variability of the material. SW81SW19 is located approximately 70 m to the south of the Washery boundary, and it not anticipated to have an impact on the proposed earthworks design.

6.1.4 Cohesive made ground

The made ground within the Washery was identified to be predominantly granular, however, layers of interbedded cohesive material were also identified in the exploratory hole log descriptions and in a small number of particle size distribution laboratory tests.

There were not sufficient amounts of the cohesive material to characterise as a separate unit or to derive separate geotechnical parameters separately (available data for the cohesive material: 62No. field based geological descriptions, 7No. in situ hand shear vanes, 5No. Atterberg tests, and 1No. SPT), therefore, the made ground parameters and ground modelling has been undertaken as a single granular unit. Therefore, the areas identified as having cohesive layers, as shown in Figure 4-3, should be considered on a location specific basis by the geotechnical design.

6.1.5 Groundwater

Groundwater monitoring has been undertaken across the Washery following the Stage 0, Stage 1, and Stage 2 GIs. Generally, water levels tended to be shallowest in the centre and north of the site and to fall slightly in monitoring wells to the west and east with depth to water increasing with the rising topography in the north of the site relative to the lower lying areas in the south.

Figure 4-8, indicates the maximum and minimum groundwater levels recorded by the monitoring at each location. Generally, the monitoring indicates groundwater levels below the proposed earthworks design surface, however, perched water within the made ground has been identified at some locations. Additionally, BH30, to the southeast of the Washery, and S1-BH112, to the northeast of the Washery recorded groundwater levels which intersect with the proposed earthworks design surfaces, as shown within Figure 6-6.

The geotechnical design should consider all of the available groundwater monitoring information on a location specific basis.

Groundwater considerations have also been addressed by the separate geo-environmental interpretive report [3], which should be referenced in conjunction with this GIR.

6.1.6 Artesian water

During the Stage 1 GI, artesian groundwater was encountered within a number of exploratory holes (S1-BH107, S1-BH114, S1-BH114B and S1-BH114C) to the west of the Washery.

Embankments are proposed within this area within the current earthworks design. However, if excavations are required the artesian water should be considered both within the designs and during the construction.

6.1.7 Contaminated ground

Contaminated ground considerations have been addressed by the separate geo-environmental interpretive report [3], which should be referenced in conjunction with this GIR.

6.1.8 Material reuse

Material reuse considerations have been addressed by the separate Earthworks Specification [33] and the geo-environmental interpretive report [3], which should be referenced in conjunction with this GIR.

6.1.9 Mining

An engineering assessment of the mining risk is provided within the separate Mining Risk Review [2], which should be referenced in conjunction with this GIR.