Haweswater Aqueduct Resilience Programme - Proposed Marl Hill Section

Environmental Statement

Volume 4

Appendix 11.1 Geotechnical and Geo-environmental Site Briefing (Desk Study) Report

June 2021

United Utilities

Water for the North West

Haweswater Aqueduct Resilience Programme - Proposed Marl Hill Section

Project No:	B27070CT
Document Title:	Proposed Marl Hill Section Environmental Statement Volume 4 Appendix 11.1 Geotechnical and Geo-environmental Site Briefing (Desk Study) Report
Document Ref.:	RVBC-MH-TA-011-001
Revision:	0
Date:	June 2021
Client Name:	United Utilities Water Ltd

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United Utilities

Capital Delivery

Geotechnical and Geoenvironmental Site Briefing ('Desk Study') Report

Project Name: Haweswater Aqueduct Resilience Programme – Replacement Tunnel Section TR4

Report No: 80061155-01-UU-TR4-XX-RP-G-00001

Project No: 80061155

Date: June 2021

Version: No. 6

Client: United Utilities Water plc

Document Title: Geotechnical and Geoenvironmental Site Briefing Report

Document No: 80061155-01-UU-TR4-XX-RP-G-00001					
Version	**Date**	**Purpose**	**Prepared by (Author)**	**Checked by**	**Reviewed by**
Version 1	March 2020	HARP Site Briefing Report Initial Draft	K Clark A Skinner	T Berry A Wood	R Hunt C Parks (Approver)
Version 2	September 2020	Report updated with 1:10,000 scale geological mapping, Groundsure (2020) and archived UU ground investigation data.	A Skinner J Whewell	A Wood K Clark	N Thompson C Parks (Approver)
Version 3	January 2021	Figures amended to comply with security requirements.	J Whewell	T Berry	C Parks (Approver)
Version 4	March 2021	Minor amendments	A Skinner	R Hunt	C Parks
Version 5	March 2021	Minor drawing amendments	A Skinner	R Hunt	C Parks
Version 6	June 2021	EIA review amendments	A Skinner	R Hunt	C Parks

Hard Copy/External Distribution for this version only: None / As Below		
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1 INTRODUCTION

1.1 Background to the Scheme

‘*TEXT REDACTED*’

1.2 Proposed Scheme

Through an early-start programme, a significant portion of optioneering and risk assessment work has been undertaken, narrowing a large cohort of solutions into a smaller group of realistic options, including the identification of preferred alignments for each tunnel. Option TR4-1 was selected as the preferred route option to replace T04. The horizontal and vertical alignments of option TR4-1 are presented as Figures 2 and 3 to this report respectively.

The replacement tunnel section will be 4.1km long and of 2.85m internal diameter, formed of segmental lining. The invert of the proposed tunnel section falls at a gradient of approximately 1V:3000H. Approach cuttings will be used to accommodate the pipeline in the sections upstream and downstream of the tunnel, and these will be constructed as cut and cover.

1.3 Objectives of the Report

This report relates solely to current preferred replacement tunnel option TR4-1, at its stage of development in June 2020.

Selected information that could be used in the preparation of desk studies has been collected, digitised and collated into a geographic information system (GIS) based system. The information is available for viewing via a GIS browser named Project Mapper.

This report provides a high-level summary of the information held on Project Mapper and identifies potential ground related hazards and risks to the project to support the fieldwork team who do not have access to Project Mapper on site. The report will be provided for distribution to the project team and for information only for stakeholders who do not have access to Project Mapper.

This report is not intended to be a full desk study as defined in industry standards i.e. British Standards BS 5930:2015. Instead, it is a high-level synthesis of information summarised for the purposes of communicating the significant geotechnical, hydrogeological and geo-environmental geohazards and risks to the fieldwork team to support mitigation through ground investigations.

1.4 Report Layout

The report is set out as follows:

- Introduction to the project and aims of the report;
- Summary of information used in this assessment;
- Site history;
- Ground conditions;
- Environmental setting;
- Initial conceptual site model;
- Risk and opportunity register;

- Hazard mitigation; and,
- References.

The following figures are presented in Appendix A:

- Figure 1 – Schematic Drawing Showing the Relative Locations and Lengths of Existing Tunnel Sections on the Haweswater Aqueduct;
- Figure 2 - Route Option TR4-1 Horizontal Alignment;
- Figure 3 - Route Option TR4-1 Vertical Profile;
- Figure 6 – Historical Features and Environmental Setting;
- Figure 7 – Superficial Geology, and
- Figure 8 – Bedrock and Linear Geology.

NB Figures 4 and 5 are contained within the main body of the report.

The report makes reference to historical reports on ground investigations that were undertaken for other projects on behalf of UU and its predecessors. Extracts of historical reports that are relevant to proposed route alignment TR4-1 are presented in Appendix B.

1.5 Study Area

A study area extending up to 250m from the proposed tunnel has been used for the purpose of environmental assessment, other assessments extend beyond 250m to account for local and regional variations in topography, hydrology, geology, hydrogeology etc. as required.

The 250m study area is located in central Lancashire between National Grid References SD695490 and SD709446. The site is located west of the B6478 Slaidburn Road, north of the River Ribble, south of the River Hodder, north west of Waddington village and south west of Newton village.

The study area is located in the south of the Forest of Bowland Area of Outstanding Natural Beauty. The proposed tunnel alignment crosses several minor roads/tracks and minor watercourses. The majority of the study area comprises farmland with some wooded areas and open, upland areas.

The ground level in the north of the study area is around 175mAOD. The ground level starts to increase significantly from around Ch.0+750 to a peak of around 285mAOD between Ch.2+000 and 3+000, at Marl Hill. The ground levels then fall away to around 175mAOD in the south of the study area.

The tunnel will be accessed by two shafts, one at each end. It is anticipated that proposed shaft TR4/A, located in the north, will be of circa 15m diameter and approximately 10m deep. Proposed shaft TR4/B, located in the south, is anticipated to have a diameter of circa 15m and be approximately 9.5m deep. A 114m long open cut section is planned at the northern end and a 112m long section at the southern end of the proposed tunnel. The whole section to be replaced, together with the adjacent works, will be 4,358.9m in length.

2 EXISTING SOURCES OF INFORMATION

The following sources of information have been used in this assessment. Selected information is presented in Appendix A and in Project Mapper GIS browser.

2.1 British Geological Survey

The published geological maps available for the study area are presented in Table 2.1 below:

Table 2.1: Geological maps used in this report

Series	Sheet Ref.	Name	Edition
Geological Survey of England and Wales 1:63,360/1:50,000 geological map series, New Series. DRIFT.	68	Clitheroe	1990
Geological Survey of England and Wales 1:63,360/1:50,000 geological map series, New Series. SOLID.	68	Clitheroe	1971
British Geological Survey 1:10,000 Series.	SD64NE	Whitewell	1985
British Geological Survey 1:10,000 Series.	SD64SE	Bashall Eaves	1984
British Geological Survey 1:10,000 Series.	SD74NW	Clitheroe	1965
British Geological Survey 1:10,000 Series.	SD74SW	Clitheroe	1949-53

Other published geological information (i.e. memoirs, data sets etc.) available for the study area are presented below:

- BGS Maps Portal (https://www.bgs.ac.uk/data/maps/home.html), accessed June 2020;
- BGS Onshore Borehole Records (http://mapapps.bgs.ac.uk/geologyofbritain), accessed June 2020;
- BGS Lexicon of Named Rock Units (https://www.bgs.ac.uk/lexicon), accessed June 2020;
- 1:100,000 scale mineral resource map for Lancashire (BGS, 2006);
- BGS 1:50,000 digital mapping under the Open Government License, accessed June 2020;
- BGS Engineering Geology Viewer (http://mapapps.bgs.ac.uk/engineeringgeology/home.html), accessed January 2020);
- BGS WellMaster (https://www.bgs.ac.uk/products/hydrogeology/wellmaster.html), accessed June 2020; and
- The Institute of Geological Sciences Hydrogeological Map of England and Wales (The Institute of Geological Sciences, 1977).

The following historical borehole logs accessed via the BGS Onshore Borehole Records website were reviewed as part of this assessment:

Table 2.2: BGS historical borehole logs reviewed

BGS Borehole Reference	Easting, Northing	Date	Project	Type	Final Depth (mbgl)	Location
SD74NW12	370800, 446000	1992	Water well	Assumed to be rotary	36.00	~110m east of Ch.3+305

Note, confidential BGS boreholes have not been reviewed.

2.2 United Utilities Geotechnical Archives

United Utilities' Geotechnical Archive holds records of historical ground investigations that were undertaken for the purposes of other projects on behalf of UU and its predecessors. The archive includes details of the following ground investigations which have been identified within 250m of the proposed TR4-1 tunnel. These are summarised in Table 2.3.

Table 2.3 Historical ground investigations

Report Title	Chainage / Offset	Contractor	Date	Exploratory Holes (Depth mbgl)
Hodder South Well, Lancashire. Haweswater Aqueduct VAS Entry Investigations Factual Report on Ground Investigation	Ch. 0+060 / 60m S	ESG	November 2013	1no. cable percussion hole, BHHS101, to 5.50mbgl. 4no. machine dug trial pits, TPHS101-104, max. depth 4.60mbgl.
Ribblesdale North Well, Lancashire Haweswater Aqueduct VAS Entry Investigations Factual Report on Ground Investigation	Ch.4+410	ESG	September 2014	2no. cable percussion holes, BHRN101-102, max. depth 10.20mbgl. 3no. machine dug trial pits, TPRN101-103, max. depth 2.80mbgl. 16no. hand dug trial pits, HDPRN01-16 max. depth 1.70mbgl.
Hodder South Well, Lancashire. Factual Report on Ground Investigation.	Ch.0+050	Soil Mechanics	November 2008	3no. cable percussion holes, BH14, 14A and 15, max. depth 5.50mbgl.
Laundwood P.S. and Supply System Improvements. Factual Report on Site Investigation	Ch.4+675	Foundation and Exploration Services Ltd	March 1994	2no. cable percussion holes, BH1-2, max. depth 10.00mbgl. 2no. machine dug trial pits, TPA-B, max. depth 3.20mbgl.

Information extracted from these reports is presented as Appendix B to this report.

2.3 Background Mapping

- Open Street Maps under the Open Database License, accessed June 2020; and,

- Google Earth Pro, 2020.

2.4 Environmental Information

- 1:10,000 and 1:10,560 historical mapping (Groundsure 2018);

- Site sensitivity and environmental data – Order Number 4201046740 (Landmark, December 2012);

- Site sensitivity and environmental data – Reference HARP_131219_DS (Groundsure, February 2020);

- GOV.UK Flood map for planning website https://flood-map-for-planning.service.gov.uk/, accessed June 2020;

- HSE COMAH Public Information Search website https://www.hse.gov.uk/comah/comah-establishments.htm, accessed June 2020;

- MAGIC website https://magic.defra.gov.uk/, accessed June 2020; and,

- Zetica UXO Unexploded Bomb Risk Map website https://zeticauxo.com/downloads-and-resources/risk-maps, accessed June 2020.

2.5 Construction Records and Accounts

The following other information was used in the assessment:

- Drive records and construction drawings for the original Haweswater Aqueduct;

- T04 drawing references: 4530/1 to 4530/5;

- Proposed alignment details contained within document 80061155-01-UU-MISCE-ZZ-RP-C-00018;

- Atkinson Report - report into major water supply developments for Manchester 1945 to 1955 (Atkinson, 1955);

- Ashnott lead mine;

  - Northern mine research society web site https://www.nmrs.org.uk/mines-map/metal/mid-pennine-mines/fsouth/bowland/ashnott/, accessed 06 February 2020;

  - Historic England website https://historicengland.org.uk/listing/the-list/list-entry/1016550, accessed 06 February 2020;

  - Pastscape website https://www.pastscape.org.uk/hob.aspx?hob_id=1232229, accessed 06 February 2020.

3 SITE HISTORY

Historical mapping from Groundsure (November 2018, February 2020) and Coal Authority Data, both available on Project Mapper, have been reviewed. Also, a targeted review of aerial mapping from Google Earth has been undertaken.

The most significant historical land uses located within the study area are summarised in Table 3.1 and shown in Figure 6. In addition, significant historical land uses outside the study area are summarised in Table 3.2.

Table 3.1: Historical features located within 250m of proposed tunnel

Map Ref.	Chainage / Distance from proposed tunnel (m)	Easting	Northing	Historical Feature (Date)
1	Ch.1+425 / 55m west	370101	447766	Limekiln (1847)
2	Ch.1+840 / 115m west	370128	447348	Possible old quarry (water filled depression today) named Browsholme Tarn (1893)
3	Ch.4+580 / 155m east	371178	444722	Reservoir (covered) (1971)

Table 3.2: Relevant historical features located beyond 250m of proposed tunnel

Chainage / Offset	Location		Historical Feature
	Easting	Northing	
Ch.1+000 / 770m west	369275	448066	Ashnott lead mine, lime kiln and quarries
Ch.1+320 / 5080m north east	375003	449315	Unnamed lead mine (Harrop Fold area)
Ch.1+700 / 1480m east	371649	447971	Waddington Fell quarry (Sandstone) - Active
Ch.0+740 / 575m east	370509	448616	Kiln

Some additional data is available for the Ashnott lead mine, a Scheduled Monument, which is located around 730m west of the proposed tunnel. The lead mine occupies the surface of a limestone knoll at the northern tip of a broad promontory below Crag Hill. The surface workings comprise a complex pattern of in-filled or roughly-capped shafts, open-cuts, adits, spoil heaps and dressing floors, extending over an area of about 0.03 km^2 (see Figure 4). The main entrance consists of a level on the western side of the limestone knoll approximately 160m south west of Ashnott Farm. Underground, the mine workings are on four major horizons, with the two upper levels served by shafts from the surface, whilst in the two lower levels underground shafts lead from the upper to the lower level (see Figure 5). The site also includes the upstanding remains of a lime kiln.

The date when lead mining first began at Ashnott is unknown. Documentary sources indicate that mining was taking place in the general area (the Honour of Clitheroe) around 1300, but the first specific reference to lead mining at Ashnott is contained in a lease dated 1538. Lead mining at Ashnott is thought to have ceased shortly after a major depression of lead prices in the 1830s.

Although it is situated around 730m west of the proposed alignment and west of the existing HA route it is considered as a potential geohazard only for surface related works due to the potential for unknown stock piling. For the proposed underground works it is not considered as a hazard due to the workings being confined to a reef-knoll deposit of the Clitheroe Limestone Formation, which the proposed tunnel does not intersect.

Figure 4: Ashnott Lead mine (source HistoricEngland.org).

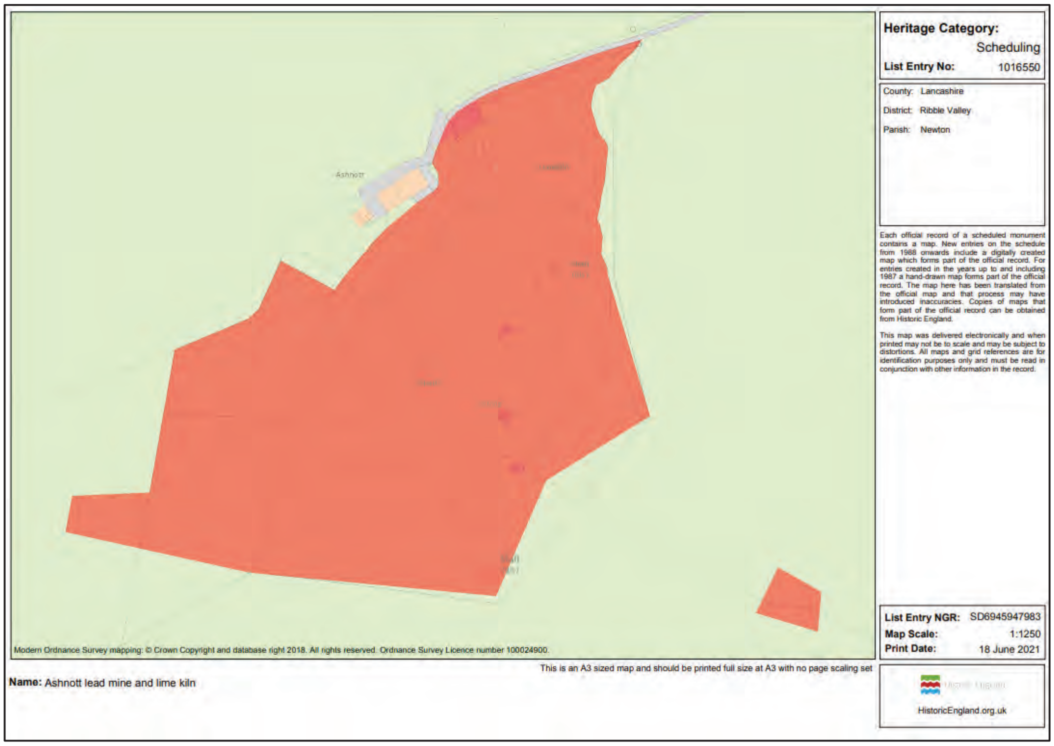

Figure 5: Ashnott Lead mine sketch plan (source https://www.nmrs.org.uk/mines-map/metal/mid-pennine-mines/fsouth/bowland/ashnott/)

4 GROUND CONDITIONS

The following section presents the regional geological setting, as well as the anticipated geology along the proposed tunnel based on available literature and information from the construction of the existing T04 tunnel. The superficial geology is presented in Figure 7 and the solid geology is presented in Figure 8 (see Appendix A).

Geological cross sections have been produced with varying updates during the project development. This includes updates from ongoing ground investigation undertaken during the production of the report. Drawing no. 80061155-01-UU-TR4-XX-DR-G-00008 presents the geological understanding of the tunnel route and also presents relevant geohazards.

4.1 Made Ground

BGS 1:10,000 mapping (BGS, 1953-1985) records made ground from Ch.0+260 to 0+370, offset 30m west of the proposed tunnel, associated with spoil from the original T04 tunnel.

BGS 1:50,000 mapping (BGS, 2020) does not record any made ground along the proposed tunnel.

Made ground is recorded in archived UU ground investigation data at Hodder South Well and Ribblesdale North Well.

Given the undeveloped landscape of the region, there may be other made ground deposits, likely localised and associated with the construction of the HA, minor access roads or agricultural development. It is also possible that unrecorded animal burial pits may be present, associated with mass culls of hooved farm animals during two outbreaks of Foot and Mouth Disease subsequent to construction of the existing HA.

4.2 Mass Movement

BGS 1:10,000 scale mapping records a landslide crossing the proposed tunnel alignment at Ch.0+650 to Ch.0+850 associated with Bonstone Brook. Earp, J.R. *et al*. (1961) note that landslips have been recorded in the region where thick glacial deposits are present on valley sides, particularly where these are over-steepened by erosion.

4.3 Superficial Geology

BGS 1:10,000 mapping (BGS, 1953-1985) and 1:50,000 mapping (BGS, 2020) record the superficial geology in the region as:

- Peat;
- Alluvial fan deposits; and
- Glacial till.

There is also a large area where there are no superficial deposits recorded, indicating that bedrock is at, or close to, ground level.

The superficial geology is presented as Figure 7 in Appendix A.

4.3.1 Peat

Hill peat is recorded on the northern side of Browsholme Moor between Ch.1+460 and 2+040. There is no information available on the thickness or condition of the peat in this area.

4.3.2 Alluvial Fan Deposits

Alluvial fan deposits are recorded between Ch.0+660 and 1+005 and are associated with Bonstone Brook, a tributary of the River Hodder. These are anticipated to comprise clay, silt, sand and gravel.

4.3.3 Alluvium

Although not recorded, isolated deposits of alluvium may be present associated with the watercourses in the study area; however, due to the size of the watercourses, these are anticipated to be minimal.

4.3.4 Glacial Till

Glacial till is anticipated from Ch.0+000 to 0+660 and from Ch.1+005 to Ch.1+380 and may underlie the alluvial fan deposits from Ch.0+660 to Ch.1+005. Glacial till is also recorded from Ch.2+785 to the end of the proposed tunnel. The memoir for the area (Earp, J.R. *et al*., 1961) notes that the glacial till in this region can be variable in thickness, even over small distances. BGS 1:10,000 mapping (BGS, 1965) notes a number of glacial till depths taken from boreholes along T04 (offset from TR4-1 ~100m west) including;

- 65ft depth (19.8m) at Ch.3+410;
- 129ft depth (39.3m) at Ch.3+560;
- 104ft depth (31.7m) at Ch.3+730;
- 105ft depth (32.0m) at Ch.4+010;
- 66ft depth (20.1m) at Ch.4+170.

To the south of the proposed tunnel the geological map notes that there is thick glacial till.

The historical holes all record glacial till except BHHS101 which is drilled entirely in made ground. SD74NW12 (BGS, 2020) describes the till as 'sand gravel/clay' and 'clay, gravel'. The Soil Mechanics (2008) boreholes generally describe the till as firm to stiff brown and grey slightly sandy gravelly clay with limestone cobbles. Boreholes YE019674_BH_1 and YE019674_BH_2 (Foundation and Exploration Services Ltd., 1994) describe the till as firm to very stiff brown and grey sandy silty clay with gravel. The till is described as soft to firm in the upper 2m. The ESG boreholes at Ribblesdale North Well describe the till as firm to stiff or soft to firm, grey, slightly sandy, slightly gravelly silty clay with low subangular to subrounded cobble content. Gravel is subangular to subrounded fine to coarse of predominantly sandstone.

4.4 Solid Geology

The bedrock along the proposed tunnel primarily comprises rocks of the Craven Group, with the addition of a member of the Millstone Grit Group, all of Carboniferous age. The Craven Group is approximately equivalent to the former Bowland Shale Group and part of the former Worston Shale Group.

The 1:50,000 scale solid geology and structural geology are depicted in Figure 8, Appendix A.

The 1:50,000 scale solid geology and structural geology are depicted in Figure 8, Appendix A.

Due to the structurally complex nature of the area, it is anticipated that the geology encountered along the proposed tunnel will differ to that mapped at the surface. BGS mapping and drive records available for the existing T04 tunnel have been reviewed to develop the following summary, see Table 4.1, of the anticipated geology at the approximate level of the proposed tunnel. This is also shown on drawing 80061155-01-UU-TR4-XX-DR-G-00008 (retained in ProjectWise – *Manchester Resilience* sub-folder).

Table 4.1: Summary of bedrock formations anticipated at tunnel level

Bedrock Formations at Tunnel Level	Approximate Chainages
Hodder Mudstone Formation (Craven Group) – mudstone with limestone, siltstone and sandstone	Ch.0+550 to 1+420
Hodderense Limestone Formation (Craven Group) - limestone	Ch.1+420 to 1+440
Bowland Shale Formation (Craven Group) - mudstone	Ch.1+440-1+580
Pendleside Sandstone Member of the Bowland Shale Formation (Craven Group) – sandstones with mudstones and siltstones	Ch.1+580-1+675
Bowland Shale Formation (Craven Group) - mudstone	Ch.1+675-2+400
Pendleside Sandstone Member of the Bowland Shale Formation (Craven Group) – sandstones with mudstones and siltstones	Ch.2+400-2+620
Bowland Shale Formation (Craven Group) - mudstone	Ch.2+620-2+700
Pendleside Limestone Formation (Craven Group) - limestone	Ch.2+700-2+825
Bowland Shale Formation (Craven Group) - mudstone	Ch.2+825-2+890
Pendleside Sandstone Member of the Bowland Shale Formation (Craven Group) – sandstones with mudstones and siltstones	Ch.2+890-3+080

Bedrock Formations at Tunnel Level	Approximate Chainages
Bowland Shale Formation (Craven Group) - mudstone	Ch.3+080-3+220
Pendleside Limestone Formation (Craven Group) - limestone	Ch.3+220-3+320
Hodderense Limestone Formation (Craven Group) - limestone	Ch.3+320-3+340
Hodder Mudstone Formation (Craven Group) – mudstone with limestone, siltstone and sandstone	Ch.3+340-3+530

The start and end of the tunnel drive are anticipated to be through glacial till.

4.5 Structural Geology

The BGS 1:10,000 mapping (BGS, 1953-1985) records three faults crossing the proposed tunnel. The first, an inferred fault known as the Crag Hill Fault, is at Ch.1+260 and trends east to west across the proposed tunnel but becomes north to south, west of the proposed tunnel. The fault is recorded as being downthrown to the south (becoming east). The second, an observed fault known as the Browsholme Moor Fault, crosses the proposed tunnel at Ch.2+405 and trends roughly east to west. The fault is recorded as being downthrown to the north, east of the proposed tunnel. The third fault, known as the Clitheroe Fault, is inferred and crosses the proposed tunnel at Ch.4+660. It is recorded as being downthrown to the south.

In addition, there are faults running approximately parallel to the proposed tunnel, whose faulted zones may influence the works. A roughly north to south trending fault lies parallel to the proposed tunnel between Ch.0+000 and 1+265. At its closest this is 70m east of the proposed tunnel and is downthrown to the east. This fault is only recorded on the older SD74NW geological map and not on the SD64NE geological map. This may indicate that it is no longer thought to be present.

Another fault is recorded from Ch.2+430 to the end of the alignment, trending roughly north to south, immediately east of the proposed tunnel and crossing the proposed tunnel around Ch.4+100 and Ch.4+350. BGS 1:10,000 mapping records this as being downthrown to the west in the north and to the east in the south (BGS, 1953-1965). A further parallel fault is recorded approximately 600m west of the proposed tunnel, downthrown to the west and between similar chainages (BGS, 2020 and BGS, 1971). This fault only appears on older mapping.

Following discussions with the BGS, it is understood that more faults are likely to be present along the proposed tunnel than are recorded on the maps.

BGS mapping and the interpretation of the geological information, indicate that the strata generally dip in a south easterly direction in the north of the study area (dip on mapping 35°) and in a north westerly direction in the south of the study area (dip on mapping 35°) (BGS, 1971). The geological memoir records broad anticlines and synclines in the Pendleside Sandstone (Earp, J.R. et al., 1961). The exact location and extent of the anticlines and synclines is unknown. Parasitic folding may be present associated with larger scale folding recorded in the study area.

The geological memoir (Earp, J.R. *et al*., 1961) includes a geological section along the line of the existing Marl Hill Tunnel (T04). This records the 'Crag Hill Slide' at the interface between the Millstone Grit and underlying Craven Group rocks. A shear zone is associated with this interface which is anticipated to be an unconformable, erosional boundary.

4.6 Hydrogeology

The regional hydrogeological map (The Institute of Geological Sciences, 1977) records the Carboniferous limestones as aquifers with dominant flows through fissures and discontinuities. The yield is dependent on whether the limestone is well fissured and massive (potentially high yield) or rhythmic (alternating with sandstone and shales) (lower yields).

BGS borehole SD74NW12 was drilled as a water well and records water at rest at 23.6mbgl. Of the UU records, only YE019674_BH_2 records a water strike (others record none observed), at 2.55mbgl in the glacial till.

The geological memoir notes that during the construction of the Marl Hill Tunnel (T04) at the Pendleside Limestone horizon much water entered the tunnel and a nearby well dried up and that much water was encountered beneath the Warley Wise/ Pendle Grit (Earp, J.R. *et al*., 1961).

4.7 Chemical Testing

Historical chemical testing has been undertaken within the study area on three previous occasions at the two locations detailed below.

- Hodder South Well in 2008 and 2013 - Ch.0+050, approximately 50m south of the proposed tunnel;
- Ribblesdale North Well in 2013 - Ch.4+410, approximately 40m west of the proposed tunnel.

An initial assessment of this data is provided below.

4.7.1 Human Health Assessment – Soil Analysis

Hodder South Well

Soil concentrations analysed in made ground have been screened against current human health values (EA, Soil Guideline Values (SGVs), LQM/CIEH, Suitable 4 Use Levels (S4ULs) and Category 4 Screening Levels (C4SLs)) where available. The most conservative screening values were chosen for the site as Public Open Space Park (POS-Park @ 1% SOM), as the site is open and may be accessed by the public as well as operational workers. No determinands exceeded any of their screening values.

Asbestos was tested for in three out of five samples and no asbestos was recorded.

No visual or olfactory contamination was recorded in any of the exploratory holes.

Ribblesdale North Well

Soil concentrations analysed in made ground have been screened against current human health values (EA, SGVs, LQM/CIEH, S4ULs and C4SLs) where available. The most conservative screening values were chosen for the site as POS-Park @ 2.5% SOM, as the site is open and may be accessed by the public as well as operational workers. No determinands exceeded any of their screening values.

Visual and olfactory evidence of contamination identified during the 2013 ground investigation is present in Table 4.2 below.

Table 4.2 Summary of visual and olfactory observations

Exploratory Hole and Depth	Visual/ Olfactory Observation	Depth and PID* Result
TPRN103 at 0.70m	Hydrocarbon odour and sheen on water.	None recorded
HDPRN3 at 0.70m to 1.70m	Hydrocarbon odour.	0.60m – 3.20ppmv**
	Pieces of asbestos tile.	1.00m – 19.00ppmv
HDPRN9 at 0.90m	Volatile PID* detection.	0.90m – 10.00ppmv
HDPRN10 at 0.70m	Pieces of asbestos tile.	0.70m – 0.00ppmv
HDPRN11 at 0.80m	Volatile PID detection.	0.80m – 2.80ppmv
HDPRN15 at 0.70m	Volatile PID detection.	0.70m – 4.40ppmv

* photoionisation detector
** parts per million volume

All soil samples collected during the 2013 ground investigation were screened for asbestos. In two locations asbestos containing materials were identified as detailed in the table above and within the borehole logs. The laboratory screening results confirmed that asbestos was present within nine samples out of the 16 samples tested. The results of this testing are shown below in Table 4.3.

Table 4.3: Summary of asbestos results

Location and Depth	Asbestos Type	Sample Laboratory Description	Quantification Results
HDPRN3 at 1.00m	Chrysotile	MG – Free Fibres (Cement)	0.480%
HDPRN4 at 0.70m	Chrysotile	MG – Cement, Lagging	0.011%
HDPRN10 at 0.70m	Chrysotile	MG – Cement	>0.1%
HDPRN11 at 0.20	Chrysotile	MG – Free Fibres	<0.001%
HDPRN11 at 0.80	Chrysotile	MG – Free Fibres	<0.001%
HDPRN15 at 0.20	Chrysotile	MG – Free fibres (Lagging)	0.041%
HDPRN15 at 0.70	Crocidolite & Chrysotile	MG – Free fibres (Lagging)	0.001%
TPRN103 at 0.20	Chrysotile	MG – Free Fibres	<0.001%
TPRN103 at 1.00	Amosite	MG – Free Fibres (Cement, Lagging)	0.001%

4.7.2 Controlled Waters Assessment

Hodder South Well

No soil leachate or groundwater samples were collected or analysed as part of the 2013 ground investigation.

Ribblesdale North Well

Groundwater sampling was undertaken on two occasions during the 2013 ground investigation. The results from this analysis have been screened against appropriate Water Quality Standards (WQS). For this generic assessment the water quality standards have been chosen as the lowest of the freshwater Environmental Quality Standards (EQS) and Drinking Water Standards (DWS).

The following determinands were found to exceed the lowest and most conservative screening criteria:

Table 4.4: Groundwater analysis summary

Determinand (WQS Criteria)	Range of Concentrations > WQS	Location of Exceedances
Nickel (0.02mg/l)	0.021mg/l	HDPRN15
Chromium (0.0047mg/l)	0.005 – 0.007mg/l	HDPRN3 and HDPRN11
Cadmium (0.00025mg/l)	0.0003 – 0.0004mg/l	HDPRN3, BHRN101 and BHRN102
Lead (0.01mg/l)	0.062mg/l	HDPRN3
Arsenic (0.01mg/l)	0.011 – 0.022mg/l	HDPRN3, HDPRN11 and HDPRN15
Mercury (0.00007mg/l)	0.0042 – 0.0113mg/l	HDPRN11 and HDPRN15
Selenium (0.01mg/l)	0.03mg/l	BHRN101
Ammonical Nitrogen as N (0.2mg/l)	0.5 – 0.6mg/l	HDPRN11 and HDPRN15
Acenaphthene (0.1ug/l)	0.216ug/l	HDPRN3
Fluoranthene (0.0063ug/l)	0.019 – 0.338ug/l	BHRN101 and HDPRN3
Benzo[b]fluoranthene (0.00017ug/l)	0.109ug/l	HDPRN3
Benzo[k]fluoranthene (0.00017ug/l)	0.031ug/l	HDPRN3
Benzo[a]pyrene (0.00017ug/l)	0.064ug/l	HDPRN3
Benzo[g,h,i]perylene (0.00017ug/l)	0.048ug/l	HDPRN3
Aliphatics >C12 - C16 (0.3ug/l)	0.582ug/l	HDPRN3
Aromatics >C12 - C16 (0.09ug/l)	0.189ug/l	HDPRN3
Aromatics >C16 - C21 (0.09ug/l)	0.48ug/l	HDPRN3
Aliphatics >C21 - C35 (0.09ug/l)	0.027-0.572ug/l	BHRN101, BHRN102 and HDPRN3
Aromatics >C21 - C35 (0.09ug/l)	0.293ug/l	HDPRN3

4.7.3 Material Classification

Hodder South Well

The assessment of the likely classification of excavated soil identified that all the samples tested classified as not hazardous using guidance given in WM3.

No waste acceptance criteria (WAC) testing was undertaken as part of the 2008 and 2013 ground investigations.

Ribblesdale North Well

The assessment of the likely classification of excavated soil identified that all the samples tested classified as not hazardous using guidance given in WM3.

No waste acceptance criteria (WAC) testing was undertaken as part of the 2013 ground investigations.

4.7.4 Hazardous Ground Gas

Hodder South Well

No ground gas monitoring was undertaken as part of the historical ground investigations.

Ribblesdale North Well

No ground gas monitoring was undertaken as part of the historical ground investigation.

4.7.5 Phytotoxic Assessment

An assessment of risk to the establishment of flora upon the site following earthworks has been undertaken using phytotoxic screening values presented in DEFRA 2009 and the maximum permissible concentration of potentially toxic elements (PTE) in soil (mg/kg dry solids) for grasslands contained in Sewage sludge on farmland: code of practice for England, Wales and Northern Ireland 2017.

Hodder South Well

The results of the assessment identified that one, out of five samples tested, exceeded the screening criteria for lead. This sample was taken in made ground and had a maximum lead concentration of 357mg/kg.

Ribblesdale North Well

The results did not identify any phytotoxic exceedances.

5 ENVIRONMENTAL SETTING

5.1 Hydrogeology

Aquifer designation maps from the BGS website indicate the following designation and sensitivity of the geological aquifers:

- Peat – Unproductive Strata;
- Alluvial deposits – Secondary A Aquifer*;
- Glacial till – Unproductive Strata;
- Craven Group – Secondary (Undifferentiated)**;
- Millstone Grit Group – Secondary A Aquifer*.

* permeable layers, capable of local water supplies and can form important source of base flow to rivers (Environment Agency [EA], 2017);

** designated as Secondary A and Secondary B (lower permeability layers) in different places due to variability (EA, 2017).

There are no groundwater abstractions located within the study area.

There are three recorded private water supplies located within the study area. These locations have been recorded by United Utilities as a natural spring and two borehole supplies to private properties. Locations are described below and shown on Figure 6.

- Spring (numbered 31 on Figure 6) – Ch.1+520, 190m west (369997, 447640);
- Borehole (numbered 36 on Figure 6) – Ch.3+320, 165m east (370862, 445986);
- Borehole (numbered 28 on Figure 6) - Ch.3+530, 15m west (370741, 445755).

The MAGIC website (DEFRA, 2020) indicates that groundwater vulnerability of the aquifers underlying the proposed tunnel is medium to medium-low. Medium groundwater vulnerability is classified as areas that offer some groundwater protection. The definitions of these rankings are:

Low - areas that provide the greatest protection to groundwater from pollution. They are likely to be characterised by low-leaching soils and/or the presence of low-permeability superficial deposits;

Medium: areas that offer some groundwater protection. Intermediate between high and low vulnerability.

The study area is not located within a groundwater Source Protection Zone (SPZ), the closest being greater than 1km east of the site.

5.2 Hydrology

The table below indicates the surface water features the proposed tunnel alignment will cross. This is not a comprehensive list of water features and only includes larger tributaries to main rivers, and does not include drainage ditches, ponds and lakes for example.

Table 5.1: Summary of surface water features crossed by the proposed tunnel alignment

Surface Water Feature	Flow Direction	Location of Crossing Point		Surface Water Feature Type
		Easting, Northing	Chainage	
Bonstone Brook	North west	369997, 448320	Ch.0+850	Tributary of the River Hodder
Braddup Clough	West	370795, 445616	Ch.3+680	Tributary of the River Ribble

5.2.1 Flooding

One area of flooding has been identified associated with Bonstone Brook, intersecting the proposed tunnel at Ch.0+825.

5.3 Discharge Consents

Groundsure information indicates there are no consented discharges within the study area.

5.4 Pollution Incidents

Groundsure information indicates there are no recorded pollution incidents identified within the study area.

5.5 Waste

There are no active or historical landfill sites located within the study area.

There are no active quarries or mines located within the study area.

During the construction of the existing HA, excavated materials were placed at various locations along the route corridor. The sites located within the study area are listed in the table below and locations shown on Figure 6.

Table 5.2: Summary of historic stockpile locations

Stockpile Ref.	Easting/ Northing	Chainage and Location	Area (m^2)
A	369661, 448778	Ch.0+280 35m west	12,350
B	370803, 444674	Ch.4+530 170m west	10,140

5.6 Environmental Permits

There are no recorded environmental permits within the study area.

5.7 Designated Environmentally Sensitive Sites

The proposed tunnel is located within an Area of Outstanding Natural Beauty (AONB).

5.8 Radon

The proposed tunnel passes through a number of different radon classes as described by the BGS and PHE (Public Health England). The table below gives details regarding radon and its classification along the proposed tunnel route. Higher radon classifications are associated with the underlying geology.

Table 5.3: Summary of radon classifications

Radon Potential Class	Property Exceeding Radon Action Levels	Chainage
1	0 to 1%	Ch.4+320 to Ch.4+680
2	1 to 3%	Ch.3+280 to Ch.4+320
3	3 to 5%	Ch.2+230 to Ch.3+280
5	10 to 30%	Ch.0+000 to Ch.2+230

5.9 Unexploded Ordnance (UXO)

The Zetica Unexploded Bomb Map (Zetica, 2020) indicates that the site is at low risk, which is defined as having 15 bombs per 1000 acre or less.

Zetica have not been commissioned to carry out a full risk assessment.

5.10 Control of Major Accident Hazards (COMAH)

The Health & Safety Executive website (HSE, 2020) indicates one COMAH site located within 3 miles (4.8km) of the proposed tunnel. This is associated with Pimlico Industrial Area located approximately 4km south east of the site and is for the manufacturing of chemicals.

5.11 Utilities

A utility search was not carried out as part of this report as this was considered by the UU engineering team. The presence of utilities was assessed by the engineering team when considering proposed routes and has been captured in the Hazard And Risk Management System (HARMS).

The major utility relevant to the proposed works for TR4 is the existing HA. T04 is located west of the proposed TR4-1 tunnel, and ranges from immediately adjacent to the proposed works at connection points to up to approximately 165m from TR4-1. In summary, both the alignment and elevation of the proposed TR04 tunnel is broadly similar to the existing HA.

6 INITIAL CONCEPTUAL SITE MODEL (ICSM)

6.1 General

In accordance with Environment Agency (EA) land contamination: risk management (LCRM), CLR11, BS EN ISO 21365:2020 (Soil quality. Conceptual site models for potentially contaminated sites) and Guiding Principles for Land Contamination (GPLC) and the requirements set out in the National Planning Policy Framework (NPPF) implications of potential contamination are assessed through the development of a conceptual site model (CSM) which uses source-pathway-receptor methodology.

Historical plans indicate that the site has remained free from development since the earliest mapping available. There are a number of small historical features located within the study area but none are located in close proximity to the site. Made ground may exist in localised locations associated with construction of the current Haweswater Aqueduct, minor roads and small agricultural developments.

The land surrounding the site has been used for agricultural purposes and remains largely undeveloped with the exception of small agricultural properties and minor roads.

Given the current and historical use of the site there is very limited potential for contamination risk. For a risk of pollution or environmental harm to occur as a result of ground contamination, all of the following elements must be present:

a) Source, i.e. a substance that is capable of causing pollution or harm;

b) Receptor, i.e. something which could be adversely affected by the contaminant; and

c) Pathway, i.e. a route by which the contaminant can reach the receptor.

If one of these elements is missing, there is no significant risk. If all are present a pollutant linkage exists and the magnitude of the risk is a function of the magnitude and mobility of the source, the sensitivity of the receptor and the nature of the migration pathway.

6.2 Preliminary Contamination Assessment

The information presented below has been collated and evaluated qualitatively to develop an initial CSM for the site. The aim of the CSM is to present any plausible contaminant-pathway-receptor linkages (potential pollutant linkages) under the future development scenario.

The model will also identify environmental liabilities or constraints on the development, associated with possible ground contamination.

6.3 Source of Contamination

Table 6.1 details historic site uses that have been identified as providing potential sources of contamination. The potential sources of contamination have been split into the three distinct tunnel construction elements: approach cuttings, shafts and tunnels.

Table 6.1: Potential sources of contamination

On-site Land use	Potential Contaminants of Concern (PCoC)
Approach Cuttings	
Historical made ground associated with the construction of the HA, in particular well houses.	Metals, inorganic compounds, hydrocarbon fuels/ oils and asbestos. Ground gas generation: methane, carbon dioxide, hydrogen sulphide, carbon monoxide and radon.
Agricultural land use/ grazed land.	Pathogens and fuels.
Geological Hazard	Radon Ground gas generation: methane, carbon dioxide, hydrogen sulphide & carbon monoxide
Shafts	
Historical made ground associated with the construction of the HA.	Metals, inorganic compounds, hydrocarbon fuels/ oils and asbestos. Ground gas generation: methane, carbon dioxide, hydrogen sulphide, carbon monoxide and radon.
Agricultural land use/ grazed land.	Pathogens
Geological Hazard	Radon Ground gas generation: methane, carbon dioxide, hydrogen sulphide & carbon monoxide
Tunnel	
Geological Hazard	Radon Ground gas generation: methane, carbon dioxide, hydrogen sulphide & carbon monoxide

6.4 Receptors

A receptor is defined as “either controlled waters, humans, ecological systems or property”.

For the purpose of the initial CSM and also future quantitative risk assessments (QRA) works, it is intended that any works will prepare the land to a standard suitable for the proposed end use scenario of the site.

Based on the data previously discussed and the proposed development use, the following potential receptors to contamination have been identified.

Table 6.2: Potential receptors

Potential Receptors	
Human health	Construction workers involved in excavations, material handling, water management and confined space working. Future site operatives and maintenance workers post development. Potable water supply.
Controlled waters	Surface water features. Groundwater in the solid geology.
Property receptors	Proposed below and above ground infrastructure and services.

6.5 Pathways

There are a number of potential pathways that may allow the transport of contaminants to impact upon potential receptors as detailed below in Table 6.3.

Table 6.3: Potential pathways

Potential Pathways	
Human health	• Dermal contact with soil and indoor dusts backtracked to construction offices; • Ingestion of soil and indoor dust; • Inhalation of outdoor and indoor dust; • Inhalation of fibres; and, • Inhalation of outdoor and indoor gases and vapours.
Controlled waters	• Surface water run-off to nearby surface water features; • Vertical / lateral migration via the unsaturated zone; • Lateral migration of groundwater to surface water features; • Vertical migration to underlying groundwater in the solid geology; and, • Preferential migration of dissolved phase contaminants along drains, cable ducts, pipes and/or associated bedding materials.
Property receptors	• Direct contact with construction materials (shafts / tunnel); and, • Accumulation of flammable/ asphyxiate contaminant vapours and gases in confined spaces and resultant fire / explosion risk.

6.6 Potential Pollutant Linkages

Potential pollutant linkages have been identified which are considered to warrant further assessment, in particular those associated with ground gas, contaminant migration to groundwater and assessment of direct contact and inhalation pathways. The table below represents the likelihood ((in terms of 'likely', 'possible' or 'unlikely') of the various pathways linking the identified sources to the receptors.

Table 6.4: Potential pollutant linkages (human health receptors)

Potential Pollution Linkages	Metals	Organics	Inorganic	Pathogens	Asbestos	Ground Gases
Approach Cuttings (Future Occupiers and Construction Workers)						
Ingestion/ inhalation of contaminated soils/dust	P	P	P	X	P	-
Dermal contact with contaminated soil	P	P	P	X	P	-
Inhalation of volatile compounds in soil or groundwater	-	X	-	-	-	-

Potential Pollution Linkages	Metals	Organics	Inorganic	Pathogens	Asbestos	Ground Gases
Inhalation of ground gases within confined spaces or ambient air	-	-	-	-	-	P
Fire/ explosion risk	-	X	-	-	-	P
Potable water supply	X	X	X	X	-	-
Shafts (Future Occupiers and Construction Workers)						
Ingestion/ inhalation of contaminated soils/dust	P	P	P	-	P	-
Dermal contact with contaminated soil	P	P	P	-	P	-
Inhalation of volatile compounds in soil or groundwater	-	X	-	-	-	-
Inhalation of ground gases (including radon) within confined spaces or ambient air	-	-	-	-	-	P
Fire/ explosion risk	-	X	-	X	-	P
Tunnels (Future Occupiers and Construction Workers)						
Ingestion/ inhalation of contaminated soils/dust	X	X	X	-	X	X
Dermal contact with contaminated soil	X	X	X	-	X	X
Inhalation of volatile compounds in soil or groundwater	X	X	X	-	X	X
Inhalation of ground gases (including radon) within confined spaces or ambient air	X	X	X	-	X	X

Potential Pollution Linkages	Metals	Organics	Inorganic	Pathogens	Asbestos	Ground Gases
Fire/ explosion risk	X	X	X	-	X	P

X = pollutant linkage unlikely

√ = pollutant linkage likely

P = pollutant linkage possible

Table 6.5: Potential Pollutant Linkages (Controlled Waters Receptors)

Potential Pollution Linkages	Metals	Organics	Inorganics
Approach Cuttings			
Contamination from site drainage / runoff	P	P	P
Leaching of soluble contaminants from soil to groundwater within the unsaturated and saturated zone.	P	P	P
Lateral and vertical migration of soluble contaminants within groundwater to surface water bodies	P	P	P
Vertical migration to underlying groundwater in the solid geology (Secondary A aquifer)	P	P	P
Preferential migration of dissolved phase contaminants along drains, cable ducts, pipes and/or associated bedding materials	P	P	P
Lateral and vertical migration via flood waters	X	X	X
Shafts			
Contamination from site drainage / runoff	P	P	P
Leaching of soluble contaminants from soil to groundwater within the unsaturated and saturated zone.	P	P	P
Lateral and vertical migration of soluble contaminants within groundwater to surface water bodies	P	P	P
Vertical migration to underlying groundwater in the solid geology (Secondary A aquifer)	P	P	P
Preferential migration of dissolved phase contaminants along drains, cable ducts, pipes and/or associated bedding materials	P	P	P
Lateral and vertical migration via flood waters	X	X	X
Tunnels			

Potential Pollution Linkages	Metals	Organics	Inorganics
Contamination from site drainage / runoff	X	X	X
Leaching of soluble contaminants from soil to groundwater within the unsaturated and saturated zone.	X	X	X
Lateral and vertical migration of soluble contaminants within groundwater to surface water bodies	X	X	X
Vertical migration to underlying groundwater in the solid geology (Secondary A aquifer)	X	X	X
Preferential migration of dissolved phase contaminants along drains, cable ducts, pipes and/or associated bedding materials	X	X	X
Lateral and vertical migration via flood waters	X	X	X

X = pollutant linkage unlikely

√ = pollutant linkage likely

P = pollutant linkage possible

Table 6.6: Potential Pollutant Linkages (Property Receptors)

Potential Pollution Linkages	Sulphate, Ammonia, pH	Organics	Ground Gases
Shafts			
Direct contact with construction materials (shafts / tunnel)	P	P	P
Fire or explosion of ground gases or flammable contaminant vapours	-	-	P
Tunnel			
Direct contact with construction materials (shafts / tunnel)	P	X	X
Fire or explosion of ground gases or flammable contaminant vapours	-	-	P

X = pollutant linkage unlikely

√ = pollutant linkage likely

P = pollutant linkage possible

Table 6.7: Potential Pollutant Linkages (Phytotoxic)

Potential Pollution Linkages	Metals and Inorganics	Organics	Asbestos
Shafts			
Potential adverse impact on landscape plants	X	X	-

Tunnel			
Potential adverse impact on landscape plants	X	X	-

X = pollutant linkage unlikely

√ = pollutant linkage likely

P = pollutant linkage possible

6.7 Potential Pollutant Linkage Summary

The initial conceptual site model of the site demonstrates that there are potential pollutant linkages that may pose a risk to human health and the environment. In order to gain a better understanding of these potential risks an intrusive ground investigation will be undertaken. Further details regarding this are discussed in Section 8.

7 GEOTECHNICAL RISK AND OPPORTUNITIES REGISTER

The Geotechnical and Geoenvironmental Risk Register has been based on the following risk matrices:

Table 7.1: Likelihood criteria

Likelihood	Description
Highly Unlikely	Highly unlikely to occur on this project
Probable	Has occurred on similar projects
Almost Certain	Incident is very likely to occur on this project, possibly several times

Table 7.2: Impact criteria

Impact	Description
High	Hazard could have significant impacts on the scheme in terms of cost and/or programme
Medium	Hazard could have notable impacts on the scheme in terms of cost and/or programme
Low	Hazard is unlikely to have any impact on the scheme in terms of cost and/or programme

Table 7.3: Risk matrix

Initial/Residual Risk Matrix		Impact		
		Low	Medium	High
Likelihood	Highly Unlikely	Low	Low	Low
	Probable	Low	Medium	Medium
	Almost Certain	Low	Medium	High

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
1a	Complex geology	TBM launch cuttings or open-cut sections	Superficial glacial till formations including periglacial and glacial features and processes overlying bedrock	Almost certain	Adverse excavation and foundation conditions due to variable and unpredictable ground conditions.	Medium	Medium	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard where possible during option selection.	Low
2a	Complex geology	TBM launch cuttings or open-cut sections	Information gaps between exploratory holes.	Almost certain	Adverse excavation and foundation conditions due to variable and unpredictable ground conditions.	High	High	Undertake Phase 2, targeted ground investigation to understand and reduce potential risks so these can be mitigated for during design. Mitigation may include further ground investigation and appropriate excavation and foundation design.	Medium

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
3a	Poor ground conditions for surface excavations	TBM launch cuttings or open-cut sections	Low strength superficial formations (possible and glacial till) and/or weathered rock formations	Almost certain	Adverse excavation conditions – potential slope instabilities, surface settlements.	Medium	Medium	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard where possible during option selection. Undertake Phase 2, targeted ground investigation to understand potential risks so these can be mitigated for during design. Mitigation could include appropriate excavation and foundation design including support optioneering, grouting and piling.	Low

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
4a	High groundwater levels	TBM launch cuttings or open-cut sections	High groundwater levels and perched water tables. Surface water seepage flow paths.	Almost certain	Adverse excavation conditions; potential for high water pressures around the excavation, leading to infiltration (high water inflow), uplift and flooding/instability of temporary cut, settlement, scouring and erosion.	Medium	Medium	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard where possible during option selection. Phase 2 ground investigation to include appropriate groundwater monitoring to understand risks so that mitigation can be included in design. Mitigation may include grouting, dewatering works, drainage and infrastructure constructed to counteract uplift.	Low

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
5a	Potential for high sulphate and chloride levels	TBM launch cuttings or open-cut sections	Aggressive ground conditions.	Probable	Degradation of concrete and metal structures.	Medium	Medium	Review likelihood of hazard following Phase 1 ground investigation and avoid hazard where possible during option selection. Phase 2 ground investigation to include appropriate laboratory testing to characterise ground conditions so that concrete mix design can be appropriately specified to avoid degradation.	Low
6a	Rock mineralogy	TBM launch cuttings or open-cut sections	Naturally or mine spoil occurring asbestos and lead.	Highly Unlikely	Adverse health effects from contact with hazardous materials.	High	Low	Review likelihood of hazard following Phase 1 ground investigation and avoid hazard where possible during option selection. Undertake Phase 2, targeted ground investigation to understand potential risks so these can be mitigated for during design. Mitigation could include appropriate health and safety measures.	Low

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
7a	Existing infrastructure	TBM launch cuttings or open-cut sections	Interference with existing infrastructure e.g. utilities, structures, watercourses, quarries.	Highly unlikely	Settlement, differential movements, structural damage and obstructions to works.	Low	Low	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard where possible during option selection. Undertake Phase 2, targeted ground investigation to understand ground conditions around existing infrastructure to understand potential risks so these can be mitigated for during design. Mitigation could include support design, diversion of existing utilities and ground improvements.	Low

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
8a	Historical quarrying and mining	TBM launch cuttings or open-cut sections	Infilled quarries/mines, quarry and mine workings and quarry and mine spoil.	Highly unlikely	Unstable and variable ground conditions leading to settlement, subsidence or collapse of infrastructure.	High	Low	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard where possible during option selection. Phase 2 ground investigation to include appropriate techniques to identify quarrying and mining features so that mitigation can be incorporated into design. Mitigation may include backfilling of voids, grouting and pumping.	Low
9a	Water features	TBM launch cuttings or open-cut sections	Flooding from watercourses.	Highly unlikely	Flooding, erosion and deposition of sediment in or around infrastructure.	Low	Low	Where watercourses are identified close to the preferred option, design to include mitigation to prevent degradation of infrastructure. This may include raising flood banks to reduce flood risk, temporary pumping, drainage or installing scour protection e.g. geotextiles or rock armour.	Low

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
10a	Landslides and slope instability	TBM launch cuttings or open-cut sections	Landslides, creep	Highly unlikely	Adverse conditions due to the potential for instability issues in the surrounding area, infrastructure damage	Low	Low	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard where possible during option selection. Undertake Phase 2, targeted ground investigation to understand potential risks so these can be mitigated for during design. Mitigation may include an appropriate stabilization design, piling	Low
11a	Ground Contamination	TBM launch cuttings or open-cut sections	Potential for ground contamination within localised made ground.	Probable	Risks to Human Health and the Environment	High	Medium	Review likelihood of hazard following Phase 1 ground investigation. Undertake Phase 2, targeted ground investigation to understand potential risks so these can be mitigated for during design. Mitigation could include appropriate health and safety measures during construction.	Low

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
1b	Poor ground conditions for shaft excavation	Shafts	Low strength superficial formations (alluvium and glacial till) and/or weathered rock formations	Almost certain	Adverse excavation conditions – potential shaft wall instabilities, surface settlements.	High	High	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard where possible during option selection. Undertake Phase 2, targeted ground investigation to understand potential risks so these can be mitigated for during design. Mitigation could include appropriate excavation and foundation design including support optioneering, grouting and piling.	Medium

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
2b	Complex geology	Shafts	Superficial glacial till formations including periglacial and glacial features and processes overlying a variety of bedrock formations	Almost certain	Adverse excavation conditions due to variable and unpredictable ground conditions.	Medium	Medium	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard where possible during option selection. Undertake Phase 2, targeted ground investigation to understand potential risks so these can be mitigated for during design. Mitigation for shaft excavation may include appropriate excavation and foundation design.	Low
3b	Geological faults crossing/running adjacent to the shaft	Shafts	Weak, fractured rock and high stresses around faulted areas.	Almost certain	Adverse excavation conditions – potential shaft wall instabilities, surface settlements.	Medium	Medium	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard	Medium

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
4b			Preferential seepage flow paths around faulted areas.	Probable	High water pressures around shaft, leading to infiltration (high water inflow), flooding/instability of shaft excavation.	Medium	Medium	where possible during option selection. Undertake Phase 2, targeted ground investigation to understand potential risks so these can be mitigated for during design. Mitigation could include appropriate excavation and foundation design, including support optioneering, grouting and piling. Mitigation for high water pressures could include grouting, pre support, dewatering and drainage holes.	Low

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
5b	High groundwater levels	Shafts	High groundwater levels and perched water tables. Surface water seepage flow paths.	Almost certain	High water pressures around shaft, leading to infiltration (high water inflow), flooding/instability of shaft excavation.	Medium	Medium	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard where possible during option selection. Phase 2 ground investigation to include appropriate groundwater monitoring to understand risks so that mitigation can be included in design. Mitigation may include grouting, dewatering works, drainage and infrastructure constructed to counteract uplift.	Low

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
6b	Potential for high sulphate and chloride levels	Shafts	Aggressive ground conditions.	Probable	Degradation of concrete and metal structures.	Medium	Medium	Review likelihood of hazard following Phase 1 ground investigation and avoid hazard where possible during option selection. Phase 2 ground investigation to include appropriate laboratory testing to characterise ground conditions so that concrete mix design can be appropriately specified to avoid degradation.	Low
7b	Rock mineralogy	Shafts	Naturally or mine spoil occurring asbestos and lead	Highly unlikely	Adverse health effects from contact with hazardous materials.	High	Low	Review likelihood of hazard following Phase 1 ground investigation and avoid hazard where possible during option selection. Undertake Phase 2, targeted ground investigation to understand potential risks so these can be mitigated for during design. Mitigation could include appropriate health and safety measures.	Low

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
8b	Ground gases	Shafts	Potential for dangerous gas release (Methane, Carbon Monoxide, Carbon Dioxide, Radon etc.).	Highly unlikely	Build-up of dangerous gases within confined spaces during construction and permanent works. High concentrations of gases may lead to adverse health effects, asphyxiation and explosive atmospheres.	Medium	Medium	Review likelihood of hazard following Phase 1 ground investigation and avoid hazard where possible during option selection. Phase 2 ground investigation to include appropriate regime of gas monitoring to understand potential risks to they can be mitigated during design and construction. Mitigation in design and construction could include installation of continuous gas monitoring devices and appropriate ventilation.	Low

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
9b	Historical quarrying and mining	Shafts	Infilled quarries/mines, quarry and mine workings and quarry and mine spoil.	Highly unlikely	Unstable and variable ground conditions leading to settlement, subsidence or collapse of infrastructure.	High	Low	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard where possible during option selection. Phase 2 ground investigation to include appropriate techniques to identify quarrying and mining features so that mitigation can be incorporated into design. Mitigation may include backfilling of voids, grouting and pumping.	Low
10b	Water features	Shafts	Flooding from watercourses.	Highly unlikely	Flooding, erosion and deposition of sediment in or around shaft infrastructure.	Medium	Low	Where watercourses are identified close to the preferred option, design to include mitigation to prevent degradation of infrastructure. This may include raising flood banks to reduce flood risk, temporary pumping, drainage or installing scour protection e.g. geotextiles or rock armour.	Low

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
11b	Landslides and slope instability	Shafts	Landslides, creep	Highly unlikely	Adverse conditions due to the potential for instability issues in the surrounding area, infrastructure damage	Low	Low	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard where possible during option selection. Undertake Phase 2, targeted ground investigation to understand potential risks so these can be mitigated for during design. Mitigation may include an appropriate stabilization design, piling.	Low
12b	Potential for karst dissolution	Shafts	Excavation intersecting natural dissolution features giving an uneven rockhead excavation	Highly unlikely	Adverse excavation and support conditions due to the potential for instability issues in the surrounding area, leading to subsidence or collapse of the shaft.	High	Low	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard where possible during option selection. Phase 2 ground investigation to include appropriate techniques to identify	Low

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
13b			Presence of loose soil infill within natural dissolution features.	Highly unlikely	Differential settlement. Adverse excavation and support conditions due to the potential for loose soil to flow into the shaft and the 'chimney' effect leading to subsidence or collapse of the shaft.	High	Low	subsurface karstic features so that mitigation can be incorporated into design. Mitigation for Shafts may include appropriate excavation and support design, grouting, piling, dewatering, drainage holes.	Low
14b			Superficial deposits overlying dissolution features.	Highly unlikely	Differential settlement. Adverse excavation and support conditions due to the potential for loose soil to flow into the shaft and the 'chimney' effect leading to subsidence or collapse of the shaft.	Medium	Low		Low

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
15b			Preferential seepage flow paths.	Highly unlikely	Adverse excavation and support conditions due to the potential for high water inflow.	Medium	Low		Low
16b	Ground Contamination	Shafts	Potential for ground contamination within localised made ground.	Probable	Risks to Human Health and the Environment	High	Medium	Review likelihood of hazard following Phase 1 ground investigation. Undertake Phase 2, targeted ground investigation to understand potential risks so these can be mitigated for during design. Mitigation could include appropriate health and safety measures during construction.	Low
1c	Poor ground conditions for shallow tunnelling	Tunnel	Low overburden thickness. Low strength superficial formations (possible alluvium and glacial till) and/or weathered rock formations	Almost certain	Adverse tunnelling conditions and tunnel advance difficulty – excessive ground settlements, surface instabilities/landslides, ‘chimney’	High	High	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard where possible during option selection. Undertake Phase 2, targeted ground investigation to understand potential risks so	Medium

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
					effect, tunnel collapse.			these can be mitigated for during design. Mitigation may include grouting, pre support techniques, conventional excavation option (SCL), appropriate TBM and lining design.	
2c	Complex structural geology	Tunnel	Tunnel face mixed conditions (weak rock/soil alternations with competent rock).	Almost certain	Adverse tunnelling conditions and tunnel advance difficulty due to potential tunnel face instability.	High	High	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard where possible during option selection. Undertake Phase 2, targeted ground investigation to understand potential risks so these can be mitigated for during design. Mitigation may include selection of an appropriate tunnel driving direction, appropriate TBM and lining design.	Medium
3c			Information gaps between exploratory holes.	Almost certain		High	High		Medium
4c			Lithological alternations (mudstone, siltstone and sandstone).	Almost certain		Medium	Medium		Low
5c			Intense folding/ parasitic folding.	Almost certain		Medium	Medium		Low
6c			Intense fracturing.	Almost certain		Medium	Medium		Low
7c			Tunnel drive against strata dip.	Almost certain		Medium	Medium		Low

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
8c	Geological faults crossing/running parallel to the alignment	Tunnel	Weak, fractured rock and high stresses around faulted areas.	Almost certain	Adverse tunnelling conditions and tunnel advance difficulties due to tunnel face instability, convergence, tunnel closure and collapse.	High	High	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard where possible during option selection. Undertake Phase 2, targeted ground investigation to understand potential risks so these can be mitigated for during design. Mitigation could include grouting, pre support, dewatering, relief tunnel drainage holes, appropriate TBM and lining design.	Medium
9c			Preferential seepage flow paths around faulted areas.	Probable	Adverse tunnelling conditions and tunnel advance difficulty due to the potential for high water pressures around tunnel and possible high water inflow.	High	Medium		Low
10c			Unrecorded faults.	Probable	Adverse tunnelling conditions and tunnel advance difficulties due to tunnel face instability, convergence, tunnel closure and collapse.	High	High		Medium

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
11c	Potential for karst dissolution	Tunnel	Excavation situated into natural dissolution features giving an uneven rockhead excavation.	Probable	Differential settlement. Adverse excavation and support conditions due to the potential for loose soil to flow into the tunnel and the 'chimney' effect leading to subsidence or collapse.	High	Medium	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard where possible during option selection. Undertake Phase 2, targeted ground investigation to understand potential risks so these can be mitigated for during design. Mitigation for tunnelling may include grouting, pre-support, dewatering, appropriate TBM and lining design.	Low
12c			Presence of loose soil infill within natural dissolution features.	Probable	Differential settlement. Adverse excavation and support conditions due to the potential for loose soil to flow into the tunnel and the 'chimney' effect leading to subsidence or collapse of the shaft.	High	Medium		Low
13c			Superficial deposits overlying dissolution features.	Probable	Adverse excavation and support conditions due to the potential for high water inflow.	High	Medium		Low

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
14c			Preferential seepage flow paths.	Probable	Adverse excavation and support conditions due to the potential for high water inflow.	High	Medium		Low
15c			Hydraulic conductivity with surface.	Probable	Adverse excavation and support conditions due to the potential for high water inflow.	High	Medium		Low
16c	High groundwater levels	Tunnel	High groundwater levels and perched water tables.	Almost certain	High water pressures around tunnel, leading to infiltration (high water inflow) and potential instabilities.	High	High	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard where possible during option selection. Phase 2 ground investigation to include appropriate groundwater monitoring to understand risks so that mitigation can be included in design. Mitigation may include grouting, dewatering wells, relief tunnel holes, selection of an appropriate tunnel driving direction, appropriate TBM and lining design.	Medium

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
17c	Potential for high sulphate and chloride levels	Tunnel	Aggressive ground conditions.	Probable	Degradation of concrete and metal structures.	Medium	Medium	Review likelihood of hazard following Phase 1 ground investigation and avoid hazard where possible during option selection. Phase 2 ground investigation to include appropriate laboratory testing to characterise ground conditions so that concrete mix design can be appropriately specified to avoid degradation.	Low
18c	Poor ground conditions in deep tunnelling	Tunnel	Weak rock, high stresses and squeezing conditions.	Almost certain	Adverse tunnelling conditions and tunnel advance difficulty due to potential convergence, tunnel closure and collapse.	High	High	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard where possible during option selection. Undertake Phase 2, targeted ground investigation to understand potential risks so these can be mitigated for during design. Mitigation may include appropriate TBM and lining design.	Medium

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
19c	Ground gases	Tunnel	Potential for dangerous gas release (Methane, Carbon Monoxide, Carbon Dioxide, Radon etc.).	Probable	Build-up of dangerous gases within confined spaces during construction and permanent works. High concentrations of gases may lead to adverse health effects, asphyxiation and explosive atmospheres.	Medium	Medium	Review likelihood of hazard following Phase 1 ground investigation and avoid hazard where possible during option selection. Phase 2 ground investigation to include appropriate regime of gas monitoring to understand potential risks so they can be mitigated during design and construction. Mitigation in design and construction could include installation of continuous gas monitoring devices and appropriate ventilation.	Low
20c	Rock mineralogy	Tunnel	High abrasive lithologies (silica, quartz, chert etc.).	Probable	High rate of TBM cutting disc wear.	Medium	Medium	Review likelihood of hazard following Phase 1 ground investigation and avoid hazard where possible during option selection. Undertake Phase 2, targeted ground investigation to understand potential risks so these can be mitigated for during design. Mitigation could include appropriate design of TBM.	Low

Table 7.4: Geotechnical Risk Register

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
21c	Historical quarrying and mining	Tunnel	Infilled quarries/mines, quarry and mine workings and quarry and mine spoil.	Highly unlikely	Unstable and variable ground conditions leading to collapse of infrastructure.	High	Low	Review likelihood of hazard following Phase 1 ground investigation and development of BGS ground model and avoid hazard where possible during option selection. Phase 2 ground investigation to include appropriate techniques to identify quarrying and mining features so that mitigation can be incorporated into design. Mitigation may include backfilling of voids, grouting and pumping.	Low

8 MITIGATION OF GROUND RELATED RISKS

The project is committed to further describing the nature and possible impact of the above hazards and through additional work mitigating the risks as detailed in the following sections.

8.1 BGS Ground Model

A number of geohazards have been identified as part of this report. Ground investigation alone will not be sufficient to investigate the whole proposed tunnel alignment or understand the implications of the geohazards. As such, some assessment of the likely geology and ground conditions between the exploratory hole points will be necessary to understand the geology and geohazards in three dimensions (3D).

The BGS is a globally recognised institution with expertise in ground modelling. UU have commissioned the BGS to use their expertise to generate a 3D ground model of the proposed tunnel alignment which can be used to better understand the implications of geohazards on the proposed construction.

The BGS will interpret their existing information; including, geological and hydrogeological maps and relevant geological memoirs, the geological records from the existing HA construction, archival UU records relevant to the site and UU bespoke ground investigations undertaken for HARP, as described in the following sections.

8.2 Geophysics

8.2.1 Shallow geophysical investigation

A number of shallow screening geophysical profiles (“SS” lines) shall be carried out along the preferred route alignment option to investigate the nature and consistency of the ground to a depth of circa 30m.

The objectives of the shallow screening exercise are to better understand the shallow subsurface and associated ground risks that might pose a risk to tunnel construction and future asset operation namely:

- To provide relevant data that will help to confirm and characterise the stratigraphy to a depth of 30m below ground surface;
- Identify significant fault structures/zones and geo-hazards along the tunnel alignment that might pose a risk to tunnel boring operations;
- Identify and map the extent of geotechnical variability to 30m below the ground surface;
- Identify potential slope stability failure surfaces;
- Identify anomalous groundwater conditions including contamination;
- Map the spatial extents of any subsurface cavities, and
- Map potential obstructions.

Information obtained from the shallow screening investigation will be used to supplement and improve the current ground model that will be used for tunnel alignment selection and design. The data will also help to inform subsequent intrusive investigation locations as part of the overall route alignment ground investigation, see Sections 8.3 and 8.4 below.

The following geophysical techniques are proposed:

- Combined Seismic Profiling – simultaneous seismic refraction and surface wave data acquisition;
- Electrical Resistivity Tomography (ERT);
- Microgravity;
- Frequency Domain Electromagnetic Profiling (FDEM).

8.2.2 Deep geophysical investigation

Several deep seismic investigation profiles ("DS" lines) shall be carried out along the preferred route alignment option to investigate the nature and consistency of the ground below approximately 30mbgl.

The objectives of the deep seismic reflection scope are to better understand the subsurface and associated ground risks that might pose a risk to tunnel construction and future asset operation namely:

- Confirm and characterise stratigraphy within the depth range ~30m to 500m; and,
- Identify significant fault structures/zones, voids, and any other subsurface geohazards along the tunnel alignments that might pose a risk to tunnel boring operations.

Information obtained from the deep seismic investigation will be used to supplement and improve the current ground model that will be used for tunnel alignment selection and design. The data will also help to inform intrusive investigation locations as part of the overall route alignment ground investigation, see Sections 8.3 and 8.4 below.

8.3 Phase 1 Intrusive Ground Investigation

To establish the geological/hydrogeological regime along the proposed tunnel alignment intrusive ground investigation is required, to be undertaken in two phases.

The objectives of the Phase 1 intrusive ground investigation are to better understand the geology and hydrogeology and any associated hazards that might pose risks to tunnel construction and future asset operation, namely:

- characterise the general geological and hydrogeological conditions;
- investigate, at a high level, the feasibility of the preferred alignment; and
- identify geohazards so these can be further investigated during the Phase 2 ground investigation.

Information obtained from the Phase 1 intrusive ground investigation will be used to supplement and improve the current ground model that will be used for tunnel alignment selection and design. The data will also help to inform the Phase 2 intrusive ground investigation.

The proposed Phase 1 intrusive ground investigation comprises the following:

- exploratory hole construction (cable percussion boring, rotary open hole drilling and rotary coring);

- core logging (photo documented, geotechnical logging, discontinuity logging);

- sampling (groundwater, soil and rock samples for laboratory geotechnical and geoenvironmental testing);

- in-situ testing (field groundwater quality testing, packer permeability tests, standard penetration tests, dilatometer tests, downhole geophysics);

- monitoring (groundwater level with vibrating wire and standpipe piezometers, Multi-Parameter Groundwater Monitoring including pH, EC, Eh, DO and temperature, ground gas).

8.4 Phase 2 Intrusive Ground Investigation

Following review of the findings of the Phase 1 intrusive GI, geophysical surveys and the site briefing report, a more comprehensive and targeted phase of ground investigation will be proposed.

The objectives of the Phase 2 intrusive ground investigation are to refine the ground model and better understand the risks posed by geohazards identified previously, namely:

- understand in detail the ground conditions and variability along the preferred tunnel alignment;

- identify in detail potential geotechnical, hydrogeological and geoenvironmental risks so these can be mitigated during design;

- verify the feasibility of the preferred alignment; and

- minimise the uncertainties and manage the risks for the contract documents.

The proposed Phase 2 intrusive ground investigation shall comprise of the following:

- exploratory hole construction (cable percussion boring, rotary open hole drilling and rotary coring);

- core logging (photo documented, geotechnical logging, discontinuity logging);

- sampling (groundwater, soil and rock samples for laboratory geotechnical and geoenvironmental testing);

- in-situ testing (field groundwater quality testing, pumping tests, packer permeability tests, standard penetration tests, dilatometer tests, hydraulic stimulation tests, downhole geophysics); and

- monitoring (groundwater level with vibrating wire and standpipe piezometers, Multi-Parameter Groundwater Monitoring including pH, EC, Eh, DO and temperature, ground gas).

8.5 Recommendations for Design – Construction Mitigation Measures

Potential geohazards are presented in detail in Section 7, which includes indicative recommendations for mitigation measures during the design and construction phases. Those mitigation measures are briefly presented below and may include but not be limited to:

- Appropriate approach cutting and shaft excavation and foundation design (including support optioneering, ground improvements, soil replacement, grouting and piling, diaphragm walls, dewatering works, drainage holes, infrastructure constructed to counteract uplift, flood protection, diversion of existing utilities).

- Appropriate tunnel excavation and support design (including appropriate TBM and lining design, tunnel driving direction optioneering, tunnel support optioneering, pre support techniques, conventional excavation options (sprayed concrete lining), ground improvements, grouting, relief tunnel drainage holes, dewatering works).

- Appropriate design and construction mitigation measures (including concrete mix design, health and safety measures, continuous gas monitoring devices and appropriate ventilation).

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APPENDIX A. FIGURES AND DRAWINGS

Figure 1 – Schematic Drawing Showing the Relative Locations and Lengths of Existing Tunnel Sections on the Haweswater Aqueduct;

Figure 2 - Route Option TR4-1 Horizontal Alignment;

Figure 3 - Route Option TR4-1 Vertical Profile;

Figure 6 – Historical Features and Environmental Setting;

Figure 7 – Superficial Geology, and

Figure 8 – Bedrock and Linear Geology.

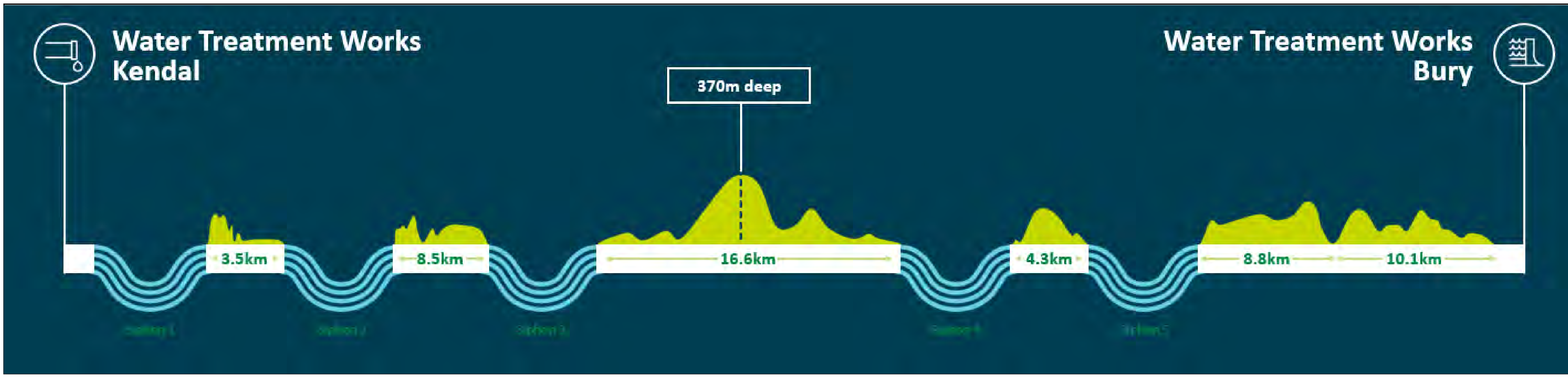
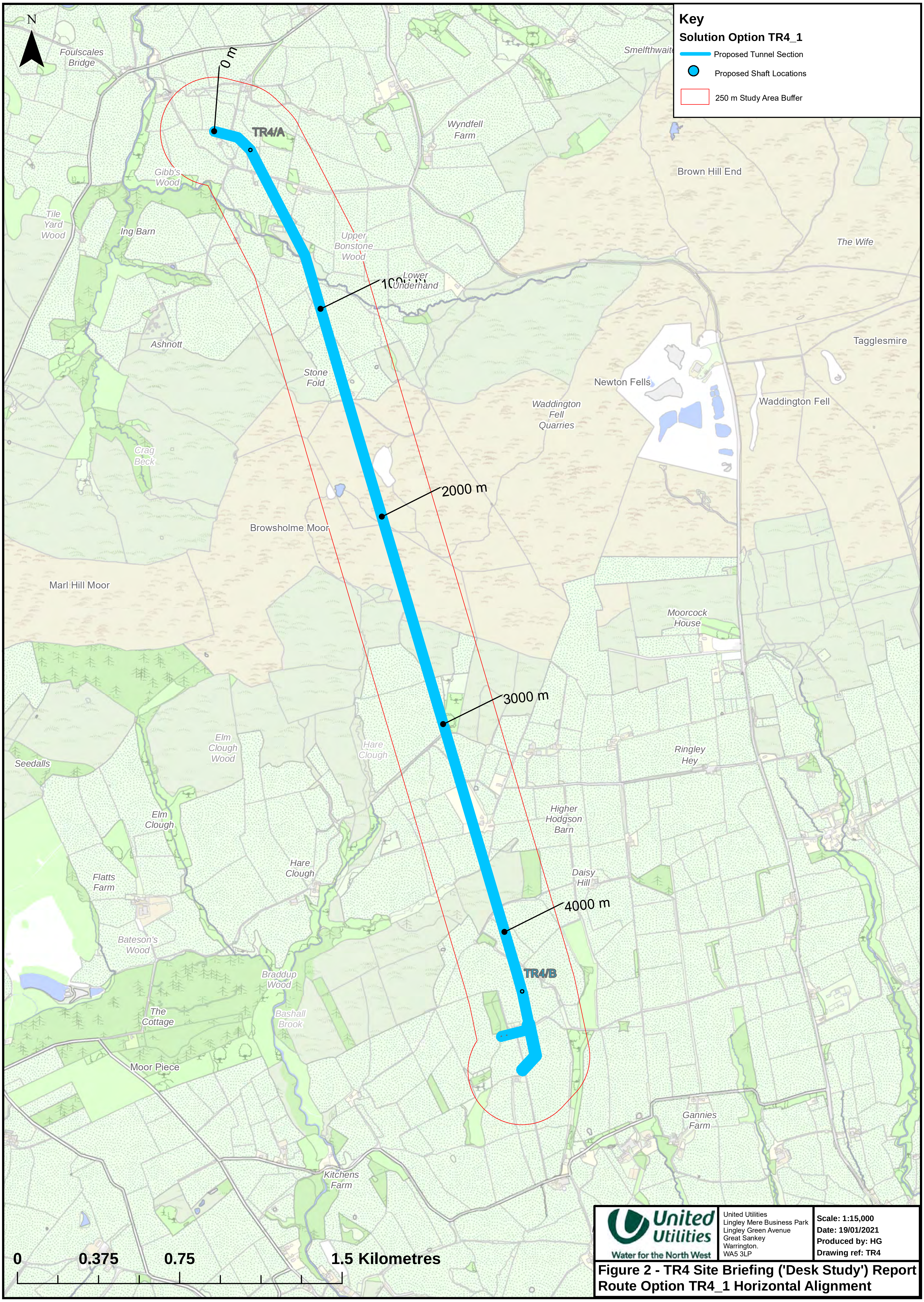


Figure 1 - Schematic Drawing Showing the Relative Locations and Lengths of Existing Tunnel Sections on the Haweswater Aqueduct'



Key

Solution Option TR4_1

Proposed Tunnel Section

Proposed Shaft Locations

250 m Study Area Buffer

United Utilities
Water for the North West

United Utilities
Lingley Mere Business Park
Lingley Green Avenue
Great Sankey
Warrington.
WA5 3LP

Scale: 1:15,000
Date: 19/01/2021
Produced by: HG
Drawing ref: TR4

Figure 2 - TR4 Site Briefing ('Desk Study') Report Route Option TR4_1 Horizontal Alignment

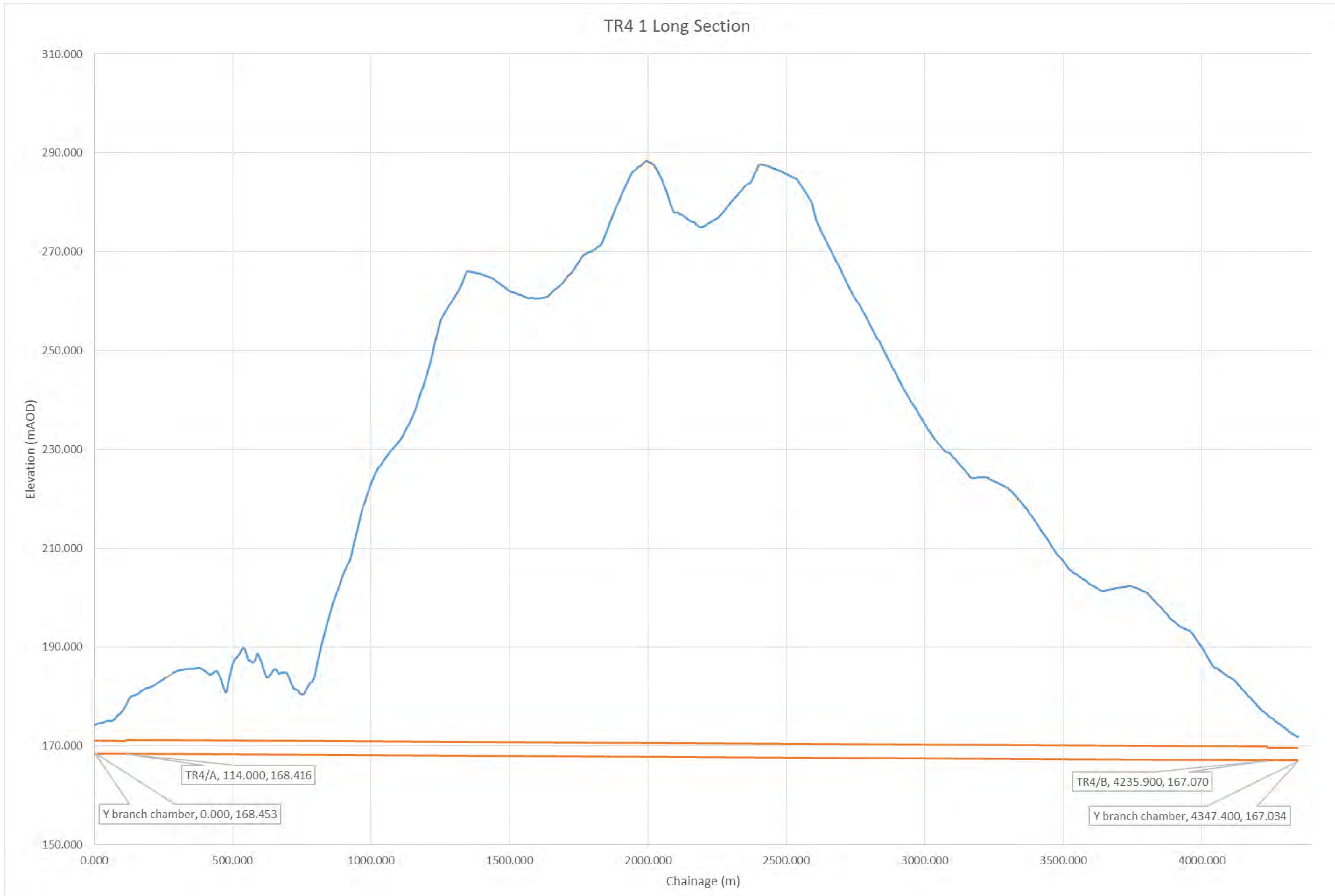


Figure 3 – TR4 Desk Study
Route Option TR4-1 longitudinal section (extract from draft document 80061155-01-UU-MISCE-ZZ-RP-C-00018)

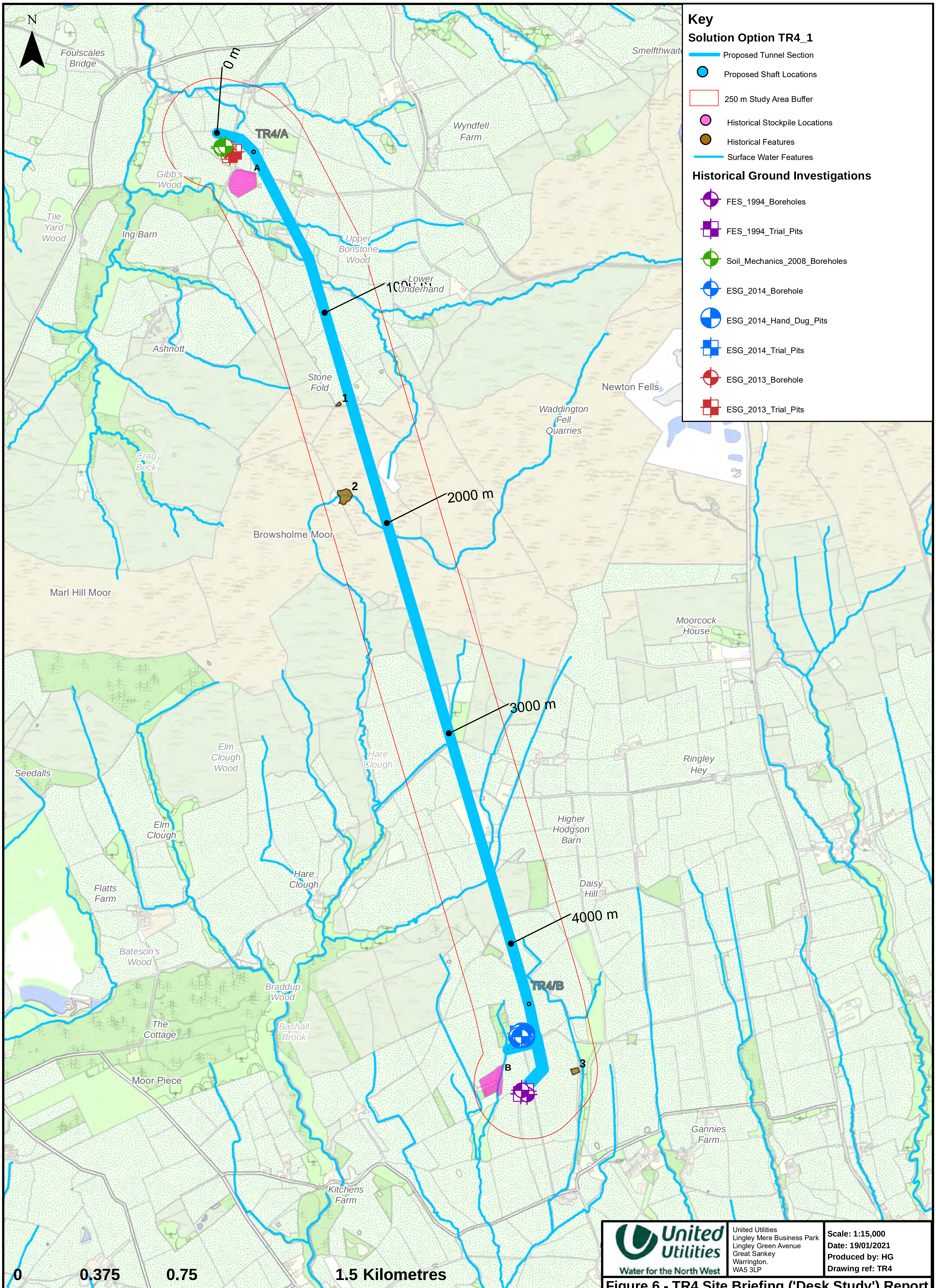
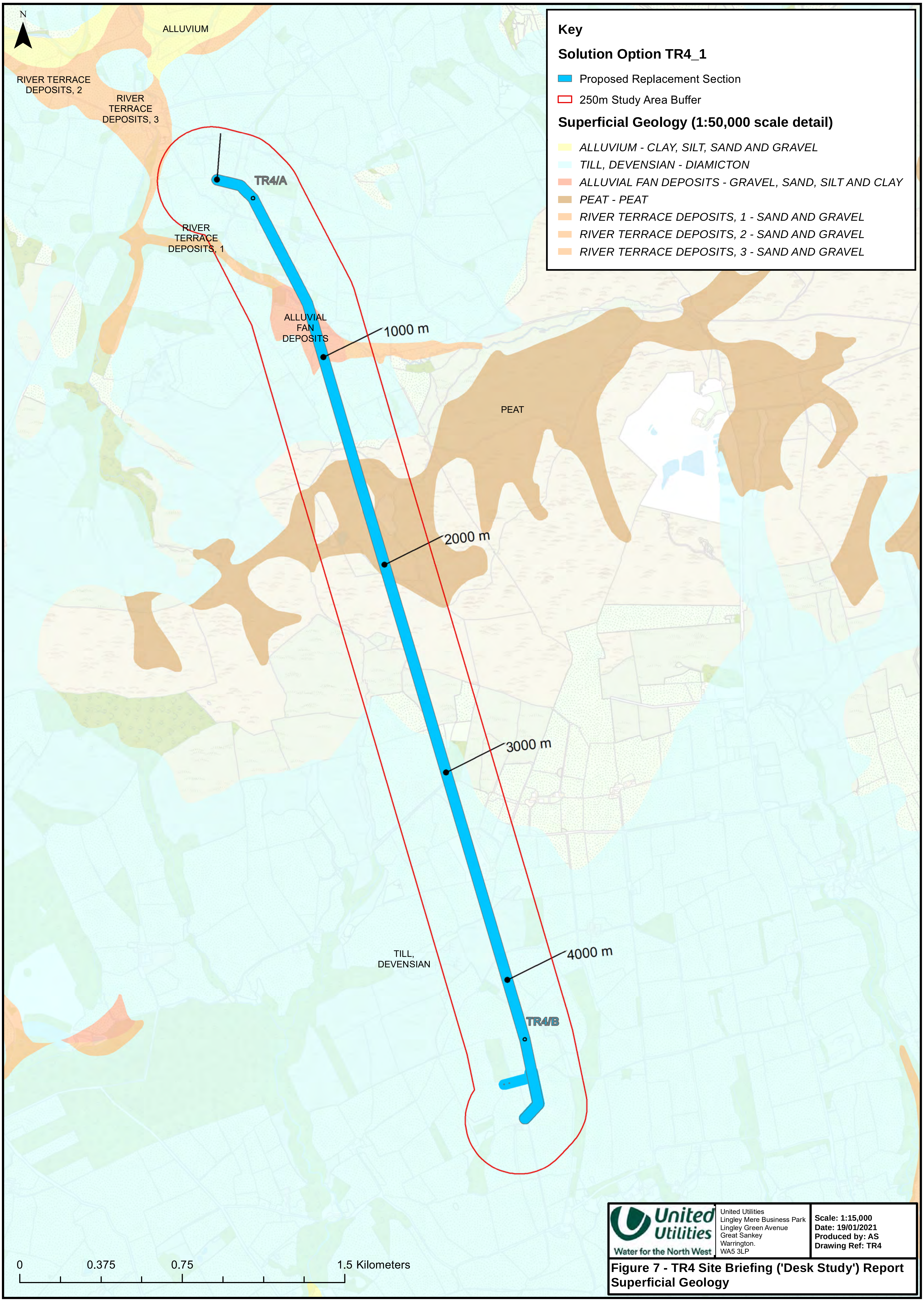


Figure 6 - TR4 Site Briefing ('Desk Study') Report Historical Features & Environmental Setting


N
ALLUVIUM
RIVER TERRACE DEPOSITS, 2
RIVER TERRACE DEPOSITS, 3
RIVER TERRACE DEPOSITS, 1
TR4/A
ALLUVIAL FAN DEPOSITS
1000 m
PEAT
2000 m
3000 m
TILL, DEVENSIAN
4000 m
TR4/B
0
0.375
0.75
1.5 Kilometers
Key
Solution Option TR4_1
Proposed Replacement Section
250m Study Area Buffer
Superficial Geology (1:50,000 scale detail)
ALLUVIUM - CLAY, SILT, SAND AND GRAVEL
TILL, DEVENSIAN - DIAMICTON
ALLUVIAL FAN DEPOSITS - GRAVEL, SAND, SILT AND CLAY
PEAT - PEAT
RIVER TERRACE DEPOSITS, 1 - SAND AND GRAVEL
RIVER TERRACE DEPOSITS, 2 - SAND AND GRAVEL
RIVER TERRACE DEPOSITS, 3 - SAND AND GRAVEL
United Utilities
Water for the North West
United Utilities
Lingley Mere Business Park
Lingley Green Avenue
Great Sankey
Warrington.
WA5 3LP
Scale: 1:15,000
Date: 19/01/2021
Produced by: AS
Drawing Ref: TR4
Figure 7 - TR4 Site Briefing ('Desk Study') Report
Superficial Geology

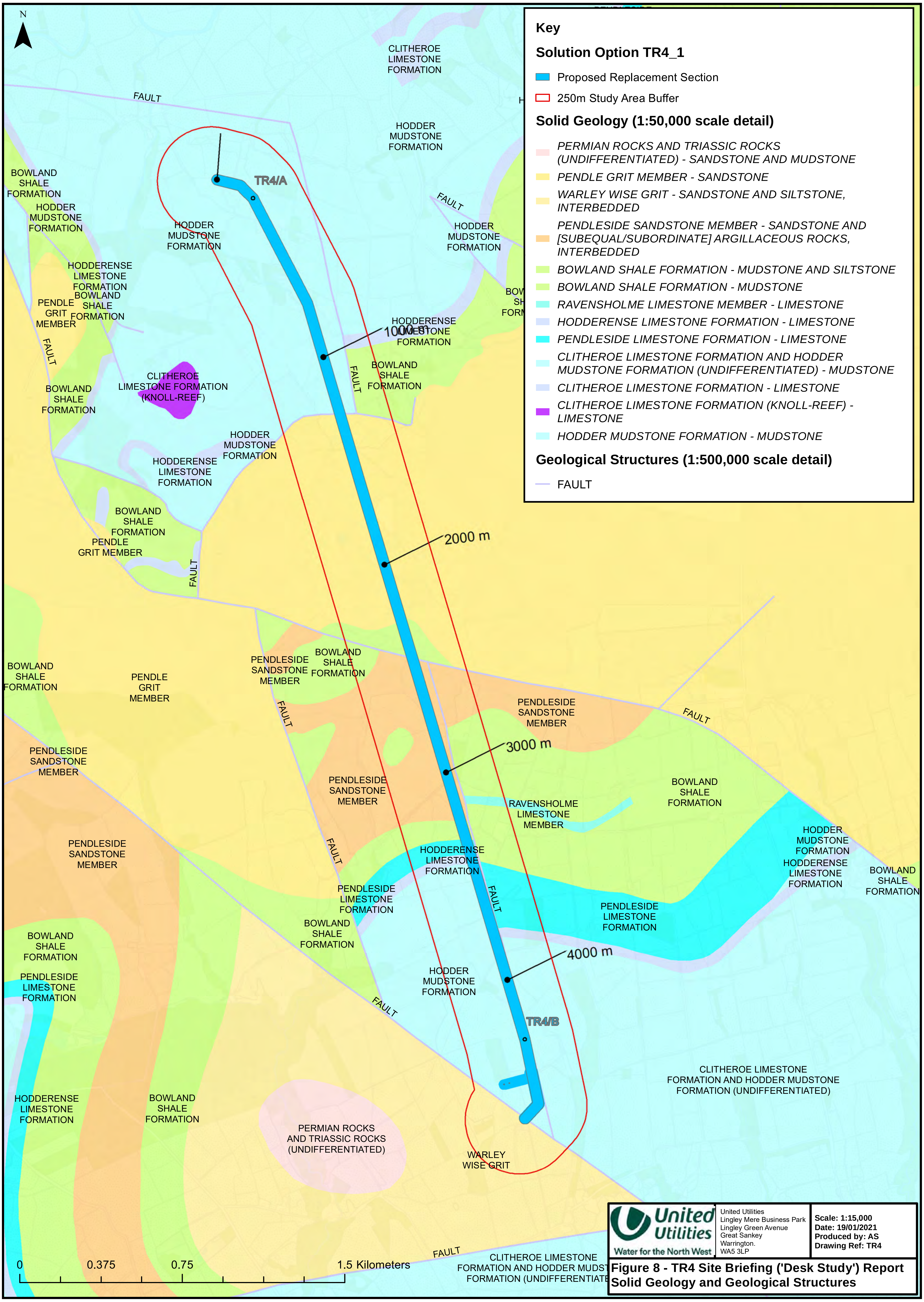


Figure 8 - TR4 Site Briefing ('Desk Study') Report Solid Geology and Geological Structures

APPENDIX B. HISTORICAL GROUND INVESTIGATIONS

'*INFORMATION REDACTED'*