Haweswater Aqueduct Resilience Programme - Proposed Bowland Section

Environmental Statement

Volume 4

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

June 2021

Water for the North West

Haweswater Aqueduct Resilience Programme - Proposed Bowland Section

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Capital Delivery

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

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Version 3	**January 2021**	**Figures amended to comply with security requirements.**	**J Whewell**	**T Berry**	**C Parks (Approver)**
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Contents

1 INTRODUCTION

1.1 Background to the Scheme

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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 preferred alignments for each tunnel. Option TR3_2 was selected as the preferred route option to replace T03. The horizontal and vertical alignments of option TR3_2 are presented as Figures 2 and 3 of this report, respectively.

The replacement tunnel section will be 15.8km long and of 3.65m internal diameter, formed of segmental lining and broadly follows the existing alignment of the HA. 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 the current preferred replacement tunnel option, TR3_2, 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 TR3-2 Horizontal Alignment;
- Figure 3 - Route Option TR3-2 Vertical Profile;
- Figure 4 - Historical Features (1 of 2);
- Figure 5 - Historical Features (2 of 2);
- Figure 6 - Environmental Setting (1 of 2);
- Figure 7 - Environmental Setting (2 of 2);
- Figure 8 - Superficial Deposits; and,
- Figure 9 - Bedrock and Linear Geology.

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 TR3-2 are presented in Appendix B.

The following tables are presented in Appendix C:

- Table C-1 - Landslide deposits according to BGS 1:10,000 scale mapping adjacent to the proposed route alignment;
- Table C-2 - Superficial deposits according to BGS 1:10,000 scale mapping along the proposed route alignment;
- Table C-3 – Bedrock geology according to BGS 1:10,000 scale mapping along the proposed route alignment;

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 north Lancashire, crossing the Forest of Bowland (Area of Outstanding Natural Beauty) between National Grid References SD636656 and SD689501. The study area is a linear route running approximately northwest to southeast, extending for approximately 16km between Wray to the north of the proposed tunnel, and Newton to the south east. The study area crosses areas of upland grazing in the northern and southern sections and high fells in the central section.

The majority of the central section is designated as a Site of Special Scientific Interest (SSSI) as the fells support the largest expanse of blanket bog and heather moorland in Lancashire. This provides a suitable habitat for breeding birds including three species (hen harrier, merlin and peregrine) under special protection (Natural England, 2020).

In the north of the study area the ground level generally rises from 175mAOD at Ch.0+000 to ~277mAOD at Ch.5+690 and the proposed tunnel alignment crosses several small peaks with a maximum elevation of ~308mAOD and three valleys associated with watercourses.

In the central section the proposed tunnel crosses a series of peaks between Ch.5+690 and Ch.14+160 including White Hill and Baxton Fell where the proposed tunnel reaches ~469mAOD and ~453mAOD respectively.

South of the peaks the ground level drops steeply to 195mAOD coincident with a watercourse before rising to ~225mAOD at Ch.14+760. The ground level then falls to 159mAOD at the end of the proposed tunnel.

Tunnel access will be accommodated by a shaft at the northern end and a portal at the southern end of the tunnel. The shaft, TR3/A, is located at Ch.0+173 with an invert level of 175.5mAOD. The portal is located at Ch.16+157 with an invert level 170.1mAOD. The shaft has a proposed internal diameter of 15m and a depth of around 13mbgl.

The whole replacement section together with the adjacent works, corresponds to a total length of 16.5km. The horizontal alignment of the proposed tunnel is shown on Figure 2.

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. Bedrock and Superficial.	59	Lancaster	1995
Geological Survey of England and Wales 1:63,360/1:50,000 geological map series, New Series. Bedrock	59	Lancaster	1989
Geological Survey of England and Wales 1:63,360/1:50,000 geological map series, New Series. Bedrock and Superficial	60	Settle	1991
Geological Survey of England and Wales 1:63,360/1:50,000 geological map series, New Series. Bedrock	60	Settle	1989
Geological Survey of England and Wales 1:63,360/1:50,000 geological map series, New Series. Bedrock and Superficial	68	Clitheroe	1990
Geological Survey of England and Wales 1:63,360/1:50,000 geological map series, New Series. Bedrock	68	Clitheroe	1971
British Geological Survey 1:10,000 Series.	SD66NW	Wray	1992
British Geological Survey 1:10,000 Series.	SD66SW	Goodber Common	1992
British Geological Survey 1:10,000 Series.	SD66SE	Cross of Greet	1992
British Geological Survey 1:10,000 Series.	SD65NE	White Hill	1992
British Geological Survey 1:10,000 Series.	SD65SE	Dunsop Bridge	1992

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 GeoIndex Onshore website (http://mapapps2.bgs.ac.uk/geoindex/home.html), 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 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 GeoIndex Onshore website were reviewed as part of this assessment:

Table 2.2: BGS historical borehole logs

BGS Borehole Reference	Easting, Northing	Date	Project	Type	Final Depth (mbgl)	Location
SD66NW8	363810, 465810	2000	-	Well	60.00	200m east of Ch.0+000
SD66NW3	363939, 465124	1981	-	Well	41.15	270m perpendicular east of Ch.0+640
SD66SE3	365115, 462412	1984	-	Well	51.82	680m perpendicular east of Ch.3+700
SD65SE37	365810, 453700	1964	-	Well	122.00	1780m perpendicular west of Ch.12+050
SD65SE10	365542, 453460	1963	-	Well	122.00	2115m perpendicular west of Ch.12+170
SD65SE12	369367, 451458	1965	-	Well	36.60	750m perpendicular east of Ch.15+410

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 1km of the proposed TR3-2 tunnel. These are summarised in Table 2.3 and extracts presented in Appendix B.

Table 2.3 Historical ground investigations

Report Title	Chainage / Offset	Contractor	Date	Exploratory Holes (Depth, mbgl)
Lunesdale South Well, Lancashire Haweswater Aqueduct VAS Entry Investigations Factual Report on Ground Investigation Report No. A3074-13/LS	Ch.0+085 – 0+095 / 85m E	ESG	November 2013	2 No. cable percussion boreholes, BHLS101 to BHLS102. Depths from 3.40 to 4.10mbgl. 3 No. machine excavated trial pits, TTLS101 to TPLS103. Depths from 2.85 to 3.00mbgl.
Hodder North Well, Lancashire Haweswater Aqueduct VAS Entry Investigations Factual Report on Ground Investigation Report No. A3074013/HN	Ch.16+360-16+462 / 15m S- 50m E	ESG	November 2013	8 No. machine excavated trial pits, TPHN101, TPHN101A, TPHN103-TPHN108. Depths from 1.5-3.0mbgl.
Ground Investigation Factual Report Hodder WwTW Site 2 Contract No. PR1315AZ	Ch.16+280-16+320 / 80-155m W	AEG	February 2007	2 No. cable percussive boreholes, BH-01 and BH-02. Depths from 2.6-3.4mbgl.
Report on a Ground Investigation for the Fober Barn Chlorine and Phosphate Dosing System	Ch.16+462 / 260-300m S	Norwest Holst	March 2013	6 No. cable percussive boreholes, BH01-03 and BH101A-103A. Depths from 1.1-3.3mbgl. 3 No. rotary boreholes, BH101R-103R. Depths of 8.0mbgl.
Lunesdale South Well, Lancashire Factual Report on Ground Investigation Report No. F8333	Ch.0+045-0+060 / 45-60m E	Soil Mechanics	November 2008	2 No. cable percussive boreholes. BH12 and BH13. Depths from 2.9-3.0mbgl.

2.3 Background Mapping

The following background mapping resources were used in the assessment:

- Open Street Maps under the Open Database License, accessed 16 December 2019; 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 – Reference HARP_131219_DS (Groundsure February 2020);
- Site sensitivity and environmental data (where available) – Order Number 4201046740 (Landmark December 2012);

- British Geological Survey website https://www.bgs.ac.uk/home.html, accessed August 2020;
- GOV.UK Flood map for planning website https://flood-map-for-planning.service.gov.uk/, accessed August 2020;
- HSE COMAH Public Information Search website https://www.hse.gov.uk/comah/comah-establishments.htm, accessed August 2020;
- MAGIC website https://magic.defra.gov.uk/, accessed August 2020; and
- Zetica UXO Unexploded Bomb Risk Map website https://zeticauxo.com/downloads-and-resources/risk-maps/, accessed August 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;
- T03 drawing references: 4510_1 to 4510_20;Proposed alignment details contained within document 80061155-01-UU-TR3-XX_M2_C_0017 (May 2020);
- Preene Report – hydrogeological desk study, assessment of groundwater pressures for tunnel sections T03, T05 and T06 (Preene, 2015);
- Atkinson Report - report into major water supply developments for Manchester 1945 to 1955 (Atkinson, 1955);
- Publication Paper: The Geology of the Bowland Forest Tunnel Lancashire, (Earp, 1955); and,
- Publication Paper: The construction of the Bowland Forest Tunnel, (Grundy, 1948).

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 below and shown in Figures 4 and 5. In addition, significant historical land uses outside of 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 Features (Date)
1	Ch.15+300 / 20m West	368622	451078	Limestone Quarry (disused) (1847)
2	Ch.16+200 / 100m East	368963	450469	Limestone Quarry (1847)
3	Ch.14+700 / 110m East	368540	451907	Limestone Quarry/ Unnamed Pit (1847)
4	Ch.14+900 / 150m West	368257	451634	Limestone Quarry (Disused) (1847)
5	Ch.6+000 / 100m East	365442	460180	Unspecified Mound (1891)
6	Ch.15+500 / On-site	368654	451120	Lime Kiln (1894)
7	Ch.3+100 / 40m East	364332	462725	Pit (1910)
8	Ch.0+330 / 90m East	363707	465382	Summer House Barn (1980)
9	Ch.15+200 / 150m East	368746	451356	Shake Holes (1981)
10	Ch.15+300 / 120m East	368738	451320	Shake Holes (1981)
11	Ch.16+350 / 70m East	368976	450297	Valve House (1981)
12	Ch.14+800 / On-site	368422	451802	Pits (Disused) (1981)

Table 3.2: Historical features located greater 250m of proposed tunnel

Distance and Orientation from Proposed Tunnel	Location		Historical Feature
	Easting	Northing	
1160m North	362781	466381	Abandoned coal mine
1200m West	362081	465541	Abandoned coal mine
7400m East	356622	462713	Abandoned coal mine

Distance and Orientation from Proposed Tunnel	Location		Historical Feature
	Easting	Northing	
7500m East	359463	454481	Abandoned coal mine
2580m East	364600	454500	Disused lead mine (Whitewell Mine SD65SW38)
5780m East	361760	452983	Abandoned coal mine
5300m East	362712	451779	Disused lead mine (Sykes Mine)
6170m Southeast	375003	449315	Unnamed disused lead mine (Harrop Fold area)
2530m South	369275	448066	Disused lead mine (Ashnott)
530m East	365633	460908	Quarry 1846 to 1891
470m East	365996	459661	Slate quarry 1846 to 1910
750m East	368964	452503	Limestone quarry 1847
380m East	368618	452345	Limestone quarry 1847
650m East	369049	451936	Limestone quarry 1847
580m West	368099	450968	Limestone quarry 1847
750m West	367955	450858	Limestone quarry 1847
320m West	368508	450575	Limestone quarry 1847
420m East	369371	450429	Limestone quarry 1847
335m East	369315	450342	Limestone quarry 1847
1350m East	368156	456382	Quarry 1892 to 1978 (disused)
1850m East	369049	452545	Quarry (disused) 1981
1650m East	369115	451957	Pits (disused) 1981
470m West	368205	451011	Quarry (disused) 1981
570m West	368254	451631	Quarry (disused) 1981
800m West	367914	450853	Quarry (disused) 1981
330m West	368231	451236	Shake holes 1981
370m West	368492	451225	Shake holes 1981
610m West	367991	451155	Shake holes 1981

Based on Table 3.2 the following should be noted:

- The recorded mines in the area are located away from the proposed tunnel suggesting that there is no potential interface hazard;
- Mine spoil could be a potential hazard along the northern part of the proposed tunnel (approach cuttings and shaft) from coal mines in the wider area;
- Lead mines are located in the south where limestone formations dominate; therefore, natural occurrences or mine spoil containing lead are potential hazards from Ch.13+500 to Ch.16+300; and,

- Within the same stretch (Ch.13+450 to Ch.16+300) numerous disused limestone quarries, pits and shake hole features have been identified, resulting in a potential hazard to surface works (approach cuttings and shafts) as well as tunnel stretches with a low overburden cover.

The BGS mineral resources map for Lancashire (BGS, 2006), records the sandstone and limestone bedrock as viable resources.

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 T03 tunnel. The superficial geology is presented in Figure 8 and the solid and structural geology in Figure 9 (see Appendix A).

4.1 Made Ground

BGS 1:10,000 and 1:50,000 mapping records small areas of made ground (artificial ground) east of the study area along the T03 alignment from Ch.10+320 to Ch.10+800 and Ch.13+800 to Ch.14+030 (BGS,1971-1995) . A small area described as worked ground – void on the 1: 50,000 mapping and a disused quarry on the 1: 10,000 mapping is recorded approximately 1400m east of the proposed tunnel at Ch.10+350. Made ground is present east of Ch.0+050 and at Ch.16+300 associated with historical stockpile locations (see Section 5.3) (Groundsure,2020).

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 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 major outbreaks of Foot and Mouth Disease since construction of the existing HA.

4.2 Mass Movement

BGS mapping records numerous mass movement deposits in the area surrounding the proposed tunnel often coincident with river valleys. These are only significant to tunnel construction in areas with low overburden. Two historical landslides are coincident with low overburden conditions and represent a potential hazard to tunnelling; these are at Ch.3+094 and Ch.14+200 (BGS, 1971-1995).

Landslides within 1km of the proposed tunnel are summarised in Appendix C, Table C-1.

4.3 Superficial Geology

According to BGS 1:10,000 scale mapping, the proposed tunnel is overlain in places by superficial deposits (BGS, 1971-1995). Glacial Till partially covers the north and south lowland areas while peat and head are present at higher elevations along the central section of the proposed tunnel (approximately Ch.4+180 to Ch.13+830). Alluvium is identified adjacent to watercourses in the region. There are also large areas where there are no superficial deposits recorded, indicating that bedrock is at, or close to, ground level.

The superficial geology is presented as Figure 8 and the chainages summarised in Appendix C-Table C-2.

4.3.1 Peat

Peat is present across the majority of the high fells, Ch.6+430 to Ch.12+270, and in smaller areas over the northern end of the proposed tunnel (BGS, 1971-1995). There is no information available on the thickness or condition of the peat in this area.

4.3.2 Alluvium

BGS 1:10,000 scale mapping only identifies alluvium adjacent to the proposed tunnel at two locations, Ch.3+180 to Ch.3+230 and Ch.14+070 to Ch.14+120, associated with watercourses in the region (BGS, 1971-1995). There is no information available on the composition of the alluvium in the area, but it is anticipated to comprise a combination of clay, silt, sand and gravel components.

4.3.3 Head

Head is recorded by the BGS 1:10,000 scale mapping at several locations along the proposed tunnel generally associated with steep slopes and valleys (BGS, 1971-1995). There is no information on the thickness or composition of the head deposits in the area however they are expected to consist of poorly sorted and poorly stratified, angular rock debris and/or clayey hillwash and soil creep (BGS GeoIndex, 2020).

4.3.4 Glacial Till

The BGS 1:10,000 mapping records glacial till at the northern and southern extents of the proposed tunnel, where the ground level is lower, from Ch.0+000 to Ch.4+180 and Ch.13+080 to Ch.13+830 and Ch.16+460 (BGS, 1971-1995).

Glacial till is expected to be intersected by the open cut sections and shaft construction at the northern end of the proposed tunnel.

4.4 Solid Geology

Three geological groups were mapped by the BGS along the proposed tunnel. These are, from oldest to youngest, the:

- Bowland High Group (approximately equivalent to the Chatburn Limestone Group and the base of the Worston Shales Group);
- Craven Group (approximately equivalent to the Bowland Shales Group and the majority of the Worston Shales Group); and
- Millstone Grit Group.

The 1:50,000 scale solid and structural geology are depicted in Appendix A, Figure 9 and summarised in Appendix C, Table C-3.

The proposed tunnel is expected to encounter the same geological units as the existing T03 tunnel (although the alignments differ, particularly in the central section). Partial information was used from the T03 as-built records to determine the anticipated geology along the proposed TR3-2 tunnel. The recorded geology of the existing T03 tunnel (Earp,1955 and Preene, 2015) is summarised in Table 4.1.

Table 4.1: Geological conditions encountered during construction of the Bowland Forest Tunnel (T03) (source: Earp, 1955 and Preene, 2015)

Start (m)	End (m)	Formation	Description
0+000	0+840	Claughton Formation (Silsden Formation)	Tunnel driven through flat or very gently inclined deposits above the Caton Shale Formation. These are recorded as mainly mudstones and fine-grained sandstones.
0+840	3+065	Caton Shale Formation (Silsden Formation)	Between Millbeck and Wellbeck the shales were found to be much disturbed by faulting. They were also reported as much decomposed where the tunnel lies close to the base of the boulder clay on either side of the Wellbeck crossing.
3+065	4+741	Roeburndale Grit Formation (Silsden Formation)	Reported as shales and sandstones. This section includes the Hindburn Adit.
4+741	7+942	Warley Wise Grit Formation (Pendleton Formation)	Reported as ill-stratified material that is affected by faults. To the south of the fault the tunnel was driven at or near the base of the Warley Wise Grit for about 1.75 miles (2.8km). North of the fault the tunnel passed through a steadily dipping sequence of strata.
7+942	12+178	Pendle Grit Formation (Pendleton Formation)	These strata are disposed on a broad faulted syncline on the south side of the Croasdale shaft, followed by a faulted anticline to the north of the shaft. The belt of faulting is followed northwards by a steadily dipping section from somewhere near the base of the group up to the base of the Warley Wise Grit. The lower part of the Group is mainly grit, upper parts mainly shale.
12+178	13+001	Bowland Shale Group (Bowland Shale Formation)	The dip of the strata decreases northwards. The basal beds of the Pendle Grit Group (i.e. the top of the Bowland Shales) are intersected 2310yds (2110m) north of Ellerbeck shaft, dipping at 25 degrees.
13+001	13+032	Pendleside Limestone Formation	Three-quarters of a mile (1.2km) north of Ellerbeck shaft the steeply dipping Worston Shales are succeeded by a sequence of calcareous measures (cementstone) and limestone.
13+032	13+916	Hodder Mudstone Formation	The north drive from the Ellerbeck shaft intersected the base of this group 380yds (350m) north of the shaft. Strata dip at 60 degrees.
13+916 -T03 tunnel end		Clitheroe Limestone Formation	This section included the Ellerbeck shaft. The strata consisted of thickly bedded dark grey limestones with thin partings of calcareous shale.

The chainage in Table 5.4 refers to the local system for T03. It is also noted that in places, the drive records and the BGS mapping do not suggest the same geology, this may, in part, be due to updates to the nomenclature.

Based on the above information, the proposed tunnel TR3-2 is anticipated to be driven through the geological formations summarised in Table 4.2.

Table 4.2: Anticipated geology of the proposed tunnel TR3-2 at tunnel level

Anticipated Geology	**Approximate Chainage**
Glacial till	Ch.0+000-0+080
Claughton Member (Silsden Formation)	Ch.0+080-0+750 Ch.1+840-2+520
Caton Shales (Silsden Formation)	Ch.0+750-1+840 Ch.2+520-2+975
Ward's Stone Sandstone (Silsden Formation)	Ch.2+975-3+050
Roeburndale Member (Silsden Formation)	Ch.3+050-7+410
Brennand Grit (Pendleton Formation)	Ch.7+410-7+710
Surgill Shales (mudstone and sandstone) (Pendleton Formation)	Ch.7+710-7+820
Pendle Grit Member (Pendleton Formation)	Ch.7+820-12+920
Bowland Shales Formation	Ch.12+920-13+435
Pendleside Limestone Formation	Ch.13+435-13+475
Hodderense Limestone Formation	Ch.13+475-13+490
Hodder Mudstone Formation	Ch.13+490-13+720 Ch.13+920-14+170 Ch.16+380-16+460
Raingill Limestone Member (Hodder Mudstone Formation)	Ch.13+720-13+920
Thornton Limestone Member (Clitheroe Limestone Formation)	Ch.14+170-14+540
Chatburn Limestone Formation	Ch.14+540-16+230
Clitheroe Limestone Formation (Knoll-Reef)	Ch.16+230-16+380

4.5 Structural Geology

On a regional scale, the proposed tunnel TR3-2, lies in between two major faults, the Smeer Hall Fault located to the north and the Clitheroe/Abbeystead Fault located to the south.

The proposed tunnel is crossed by several faults generally northwest-southeast or northeast-southwest trending. These are summarised in Table 4.3. 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.

Table 4.3: Faults crossing the proposed tunnel at surface taken from 1:10,000 BGS mapping

Fault	Approximate Chainage
Stauvin Fault, downthrown to the south	1+930
Lordset Syke Fault, downthrown to the north-west by 7.5m at its midpoint.	4+780
Fault downthrown to the west.	5+370
Fault downthrown to the west	7+420
Fault downthrown to the west (splay off previous fault)	7+770
New Biggin Fault, downthrown to the north	14+620

A number of faults do not cross the proposed tunnel but may influence the ground conditions intersected. These are summarised in Table 4.4.

Table 4.4: Parallel or nearby faults at surface taken from 1:10,000 BGS mapping

Fault	Approximate Chainage
Fault downthrown to the north, terminates 30m east of the proposed tunnel	0+750
Parallel fault downthrown to the west by 18m at Ch.4+080	3+410-5+120

Fault	Approximate Chainage
Roeburn Fault downthrown to the south offset by 8m west	8+970
Burn Fell Fault, downthrown to the north, oblique of the proposed tunnel and offset by minimum 57m west	13+270 (closest chainage)

Based on the available information, the strata are anticipated to dip gently to the north-northwest between Ch.0+000 and ~9+980 and dip gently south from approximately Ch.15+200 to 16+200. Through the central part of the proposed tunnel, a steep dip towards the southeast and northwest is anticipated due to the presence of the Sykes Anticline (~Ch.9+980), Beatrix Fell Syncline (Ch.12+020) and a further anticline (Ch.15+200). Parasitic folding may be present associated with the larger scale folding recorded. Based on the T03 tunnel drive records, the dip is also expected to be steep near to faulted areas.

4.6 Hydrogeology

The regional hydrogeological map (The Institute of Geological Sciences, 1977) shows that the Millstone Grit Series and the Carboniferous limestone and basal conglomerate strata underlying the study area are classed as locally important aquifers.

Based on information from the Preene hydrological report (Preene, 2015), it is anticipated that the TR3-2 tunnel will be driven through a sequence of sedimentary rocks of lower hydraulic conductivity (shales and mudstones), higher hydraulic conductivity (grits and sandstones) and variable hydraulic conductivity (limestones and coals). The predominant means of groundwater flow is expected to be along fractures and fissures, although interstitial flow may be significant in the grits and sandstones. The following points are noted:

- The bedrock has been folded and generally has a gentle dip, mostly to the north. It is intersected by faults, which are typically of high hydraulic conductivity;
- The tunnel passes under relatively hilly terrain, and the primary sources of groundwater recharge are from surface infiltration of precipitation, and possibly from hydraulic connection with watercourses in the valleys;
- The recharge will occur preferentially where grits and sandstones outcrop, with less infiltration where shales and mudstones outcrop, or where there is significant cover of low hydraulic conductivity superficial deposits; and,
- Faults may also play a role in transmitting water from the surface to depth.

The above agree with the observed water inflow data gathered during the construction of T03 and presented by Earp et al. (1955). Little water flow was recorded within the Claughton Member, Caton Shales or the Roeburndale Member (all Silsden Formation) between Ch.0+000 and Ch.4+741 except for south of the Hindburn Adit. Significant water inflows were recorded between Ch.4+741 and Ch.12+178 (local T03 chainages) where the tunnel was driven through grit formations under the hilly terrain of White Hill, with a significant overburden thickness. The recorded inflow was interstitial water from the rock mass, but major feeders were generally associated with faults and fissures.

Based on the above it is anticipated that during construction of TR3-2 significant water inflow could be expected along the section between Ch.7+410 and Ch.12+920, where sandstones and grits are anticipated.

4.7 Chemical Testing

Historical chemical testing has been undertaken within the study area on one previous occasion, in 2013 by Environmental Scientifics Group (ESG). The limited chemical testing was conducted on samples from Lunesdale South Well, approximately 120m east of Ch.0+000.

An initial assessment of this data is provided below.

4.7.1 Human Health Assessment – Soils Analysis

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 Residential (POS-Res @ 1% SOM), as the site is open and may be accessed by the public as well as operational workers. No determinands from either of the two samples exceeded any of their screening values.

No asbestos was recorded in the two samples tested.

No visual or olfactory contamination was recorded in any of the trial pits or boreholes.

4.7.2 Controlled Waters Assessment

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

4.7.3 Material Classification

An assessment of the likely classification of excavated soil identified that the two samples tested are not hazardous.

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

4.7.4 Hazardous Ground Gas

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

5 ENVIRONMENTAL SETTING

5.1 Hydrogeology

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

- Glacial till – Unproductive Strata;
- Peat – Unproductive Strata;
- Head - Secondary (undifferentiated)*;
- Alluvium - Secondary A Aquifer**;
- Chatburn Limestone Group – Secondary A Aquifer**;
- Worston Shale Group – Secondary A Aquifer**;
- Bowland Shale Group – Secondary (undifferentiated)*;
- Millstone Grit Group - Secondary A Aquifer**;

* designated as Secondary A and Secondary B (lower permeability layers) in different places due to variability (Environment Agency [EA], 2017);

** permeable layers, capable of local water supplies and can form important source of base flow to rivers (EA, 2017).

Information provided by the Environment Agency and Groundsure indicates five historical groundwater abstractions recorded within the study area. Information regarding these is provided in Table 5.1 and shown on Figures 6 and 7. Figures 6 and 7 also show groundwater abstractions beyond the study area.

Table 5.1: Summary of groundwater abstractions

Name	Type / Reference	Location		Status
		Easting, Northing	TR3_2 Chainage/ Distance from Tunnel	
Lower House, Wray	Groundwater 2672521014	363810, 465810	Ch. 0+000 200m North East	Unknown
Botton Hall Farm Spring	Groundwater spring 88008914	363810, 465570	Ch.0+140 225m East	Closed
Botton Hall Farm Land Drain	Groundwater spring 88008931	363810, 465560	Ch.0+140 225m East	Closed
Overhouses Borehole	Groundwater borehole 88008916	363940, 465130	Ch.0+600 250m East	Closed
Burn House (The Hay)	Groundwater borehole 88021540	368200, 452800	Ch.13+700 140m East	Closed

As part of this project, private supply information will be collected by UU but is not presented within this report.

The MAGIC website indicates that groundwater vulnerability of the aquifers underlying the study area is Low which is defined as:

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.

Groundsure data indicates there are two groundwater source protection zones (SPZ) located within the study area and crossed by the TR3-2 proposed tunnel.

SPZ 3 - Total Catchment, between Ch.8+000 and Ch.13+100; and,

SPZ 2 - Outer Catchment, located approximately 50m west of the proposed tunnel between Ch.11+450 and Ch.13+000.

5.2 Hydrology

There are no EA designated Main Rivers that cross the proposed tunnel or are within 250m of it. However, a number of smaller surface water features cross the proposed tunnel. Due to the number of smaller water features located across the study area, Table 5.2 only provides information on the larger tributaries to Main Rivers, and does not include drainage ditches, ponds and lakes for example.

Table 5.2: Summary of surface water features that cross the proposed tunnel

Surface Water Feature	Flow Direction	Location of Crossing Point		Surface Water Feature Type
		Easting, Northing	TR3-2 Chainage and Distance	
Tributary to the River Hyndburn	North East	364319, 462633	Ch.3+180 On-site	Inland River/ Tributary
Lordset Syke	East	364834, 461188	Ch. 4+745 On-site	Inland River/ Tributary
Ridge Clough	North East	365209, 460290	Ch.5+690 On-site	Inland River/ Tributary to the River Hyndburn
Brim Clough	West	366296, 457424	Ch.8+750 On-site	Inland River/ Tributary to the Whitendale River
Middle Grain Clough	West	366931, 455340	Ch.10+850 135m West	Inland River/ Tributary to the Whitendale River
Rough Syke	West	368085, 452260	Ch.14+150 170m West	Inland River/ Tributary to the River Hodder

Information provided by Groundsure indicates three historical surface water abstractions recorded within the study area. Information regarding these is provided in Table 5.2 and shown on Figure 7.

Table 5.3: Summary of surface water abstractions

Name	Type / Reference	Location		Status
		Easting, Northing	TR3_2 Chainage/ Distance from proposed tunnel	
Spring Fed Storage Tank, Slaidburn	Surface, Non-Tidal	368100, 453200	Ch. 13+350 185m East	Unknown
Spring east of Newton-in-Bowland	Surface, Non-Tidal	368700, 450400	Ch. 16+120 200m South West	Unknown
Spring fed tank Newton-in-Bowland	Surface, Non-Tidal	368900, 450300	Ch. 16+120 225m South	Unknown

Surface water drainage plans have not been reviewed as part of this study.

5.2.1 Flooding

Groundsure data indicates there are no EA flood zones recorded within the study area.

The watercourses crossing the proposed tunnel have surface water flood extents of between 0.1% and 3.33% Annual Expected Probability.

5.2.2 Discharge Consents

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

5.2.3 Pollution Incidents

Groundsure information indicates no recorded pollution incidents have been identified within the study area.

5.3 Waste

There are four recorded historical landfills located within study area. Table 5.3 below provides a summary of the landfills and Figures 6 and 7 show their locations.

Table 5.4: Summary of historical landfills

Location		Site Name / Licence No. Ref.	Received Wastes	Further Information
Easting Northing	TR3-2 Chainage			
368550, 451900	Ch.14+700 / 130m East	Newton Tip / EAHLD32079	Commercial	First input 1947
368400, 451800	Ch.14+750 / On-site	Newton / EAHLD07497	Inert, Industrial, Household	First input 1947 Last input 1976
368250, 451630	Ch.14+900 / 210m West	Newton / EAHLD07497	Inert, Industrial, Household	First input 1947 Last input 1976

Location		Site Name / Licence No. Ref.	Received Wastes	Further Information
Easting Northing	TR3-2 Chainage			
368717, 451554	Ch.15+100 / 170m East	Newton / EAHLD07497	Inert, Industrial, Household	First input 1947 Last input 1976

BGS also record a non-operational landfill site at Ch.14+650, 100m East (368500, 451900). The Newton Tip site is recorded as being a risk to the Secondary A Aquifer of the Chatburn Limestone Formation.

No authorised landfills or active mines or quarries are located within the study area.

No BGS recorded mineral sites are located within the study area.

During construction of the HA, excavated materials were placed at various locations along the route corridor. Sites located within 250m of the proposed tunnel and their areas are listed in Table 5.4 and locations are shown on Figures 4 and 5. Stockpile locations beyond the study area are also shown on the figures.

Table 5.5: Summary of historic stockpile locations

Stockpile Ref.	Easting/ Northing	TR3-2 Chainage	Area (m^2)
A	363868, 465494	Ch.0+050	13,351
B	368912, 450253	Ch.16+300	10,183

5.4 Environmental Permits

There are no recorded environmental permits located within the study area.

5.5 Designated Environmentally Sensitive Sites

Groundsure information indicates there are two designated environmentally sensitive sites located within the study area:

Site of Special Scientific Interest (SSSI) and Special Protection Area (SPA) – named the Bowland Fells and located between Ch.5+200 and Ch.12+500; and,

Area of Outstanding Natural Beauty – This encompasses the entire proposed alignment for TR3-2.

5.6 Radon

The proposed tunnel is within an area affected by radon. Table 5.5 gives details regarding radon and its classification along the proposed tunnel as described by the BGS and Public Health England.

Table 5.6: Summary of radon classifications

Radon Potential Class	Property Exceeding Radon Action Levels	Chainage
1	0 to 1%	Ch.0+000 to Ch.2+100 Ch.2+300 to Ch.3+050 Ch.3+250 to Ch.4+450 Ch.4+900 to Ch.5+050 Ch.5+850 to Ch.6+500 Ch.6+650 to Ch.7+400 Ch.7+800 to Ch.8+000 Ch.8+350 to Ch.12+250 Ch.12+750 to Ch.13+200 Ch.14+300 to Ch.14+450 Ch.14+850 to Ch.16+100
2	1 to 3%	Ch.2+100 to Ch.2+300 Ch.3+050 to Ch.3+250 Ch.4+450 to Ch.4+900 Ch.5+050 to Ch.5+850 Ch.6+500 to Ch.6+650 Ch.7+400 to Ch.7+800 Ch.8+000 to Ch.8+350 Ch.12+250 to Ch.12+750 Ch.2+550 to Ch.10+000 Ch.10+650 to Ch.12+150
3	3 to 5%	Ch.14+300 to Ch.14+450 Ch.14+450 to Ch.14+850
4	5 to 10%	-
5	10 to 30%	Ch.13+200 to Ch.14+300 Ch.16+100 to Ch.16+500

5.7 Fuel Station Entries

There are no recorded fuel station entries identified within the study area.

5.8 Unexploded Ordnance (UXO)

The Zetica Unexploded Bomb Map (Zetica, 2019) 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.

5.9 Control of Major Accident Hazards (COMAH)

The Health & Safety Executive website (HSE, 2020) indicates that no COMAH sites are located within three miles of the proposed tunnel.

5.10 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 TR3-2 is the existing HA. T03 is located east of the proposed TR3-2 tunnel, and ranges from immediately adjacent to the proposed works at connection points to up to approximately 2km from TR3-2.

6 INITIAL CONCEPTUAL SITE MODEL (ICSM)

6.1 General

In accordance with Environment Agency land contamination: risk management (LCRM), CLR11, BS EN ISO 21365:2020 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 historical features located within the study area including landfills and quarries. Made ground may exist in localised areas associated with construction of the current HA, 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.

Areas of higher levels of radon have also been reported in the southernmost sections of the proposed tunnel.

Given the current and historical use of the site there are very limited areas for potential contamination risks. 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 can be 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 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.	Metals, inorganic compounds, hydrocarbon fuels/ oils and asbestos. Ground gas generation: methane, carbon dioxide, hydrogen sulphide & carbon monoxide.
Agricultural land use/ grazed land.	Pathogens
Geological Hazard	Radon (southern section Ch. 13+000 to Ch. 16+500) Ground gas generation: methane, carbon dioxide, hydrogen sulphide & carbon monoxide.
Shaft and Portal	
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.
Geological Hazard (Shaft T03/C)	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 or confined space working. Future site operatives and maintenance workers post development. Potable water supply.
Controlled waters	Surface water features; unnamed watercourse, two tributaries of Park Beck and tributary of Flooder Beck. Groundwater in the solid geology. Potable water supply – proposed pipeline/ aqueduct. Source Protection Zone.
Property receptors	Proposed below and above ground infrastructure and services.
Ecological Receptors	SSSI

6.5 Pathways

There are a number of potential pathways that may allow the transport of contaminants to impact upon potential human and controlled water 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 foundations/ services; • 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**	**Gases / Radon**
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	Gases / Radon
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	X	P	-
Dermal contact with contaminated soil	P	P	P	X	P	-
Inhalation of volatile compounds in soil or groundwater	-	X	-	-	-	-
Inhalation of ground gases within confined spaces or ambient air	-	-	-	-	-	P
Fire/ explosion risk	-	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 within confined spaces or ambient air	X	X	X	-	X	P
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/ SPZ)	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/ SPZ)	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			
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/ SPZ)	X	X	X

Potential Pollution Linkages	Metals	Organics	Inorganics
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

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 presented in Section 8.

7 GEOTECHNICAL AND GEOENVIRONMENTAL 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 structural geology	TBM launch cuttings or open-cut sections	Superficial glacial till formations including periglacial and glacial features and processes overlying a variety of bedrock formations (mudstone, siltstone, sandstone, limestone).	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. Undertake Phase 2, targeted ground investigation to understand potential risks so these can be mitigated for during design. Mitigation may include further ground investigation and appropriate excavation and foundation design.	Low
			Information gaps between exploratory holes.	Almost Certain		High	High		Medium

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
2a	Poor ground conditions for surface excavations	TBM launch cuttings or open-cut sections	Low strength superficial formations (glacial till) and / or weathered rock formations (mudstone, siltstone, sandstone, limestone).	Almost Certain	Adverse excavation conditions - potential slope instability, surface settlement.	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 optioning, grouting and piling.	Low
3a	Potential for karst dissolution	TBM launch cuttings or open-cut sections	Excavation situated in natural dissolution features giving an uneven rockhead excavation.	Probable	Adverse excavation and support conditions due to the potential for instability issues in the surrounding area, leading to subsidence or collapse of the cut.	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 techniques to identify subsurface karstic	Low

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
			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 cut and the 'chimney' effect leading to subsidence or collapse of the cut.	Medium	Medium	features so that mitigation can be incorporated into design. Mitigation for cuttings may include appropriate excavation and support design, grouting, piling, dewatering, drainage holes.	Low
			Superficial deposits overlying dissolution features.	Probable	Differential settlement. Adverse excavation and support conditions due to the potential for loose soil to flow into the cut and the 'chimney' effect leading to subsidence or collapse of the cut.	Medium	Medium		Low
			Preferential seepage flow paths.	Probable	Adverse excavation and support conditions due to the potential for high water inflow.	Medium	Medium		Low

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
4a	Rock mineralogy	TBM launch cuttings or open-cut sections	Naturally occurring asbestos and lead or mine spoil.	Probable	Adverse health effects from contact with hazardous materials	High	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 health and safety measures.	Low
5a	Historical quarrying/mining	TBM launch cuttings or open-cut sections	Infilled quarries/mines, quarry and mine workings and quarry and mine spoil.	Probable	Unstable and variable ground conditions leading to settlement, subsidence or collapse of infrastructure.	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 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

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
6a	Water features	TBM launch cuttings or open-cut sections	Flooding from watercourses.	Highly Unlikely	Flooding, erosion and deposition of sediment in or around 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
7a	High groundwater levels	TBM launch cuttings or open-cut sections	High groundwater levels and perched water tables. Surface water seepage flow paths.	Probable	Adverse excavation conditions - potential for high water pressures around the excavation, leading to infiltration (high water inflow), uplift and flooding/instability of temporary cut, settlements, 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

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
8a	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
9a	Existing infrastructure	TBM launch cuttings or open-cut sections	Interference with existing infrastructure e.g. utilities, structures, watercourses, quarries, existing HA (T03).	Probable	Settlement, differential movements, structural damage and obstructions to works.	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 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

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
10a	Potential for compressible soils and shrink swell issues	TBM launch cuttings or open-cut sections	Alluvial clays and peat may be susceptible to compression and shrinking / swelling during wetting and drying cycles.	Highly Unlikely	Compression and shrink/swell may result in settlement/ heave and desiccation of soils leading to damage of shallow 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 laboratory testing to understand the compressibility and shrink/swell characteristics of the soils so the risk can be mitigated during design. Mitigation could include dig out and replacement of small volumes of peat and alluvial clays or ground improvement techniques or deep foundation design.	Low
11a	Potential for Hazardous Waste Materials	TBM launch cuttings or open-cut sections	Potential for localised hazardous waste materials associated with historical land use and/ or made ground.	Probable	Elevated disposal costs associated with landfill taxes.	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.	Low

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
12a	Potential for Ground Contamination	TBM launch cuttings or open-cut sections	Potential for ground contamination within localised Made ground.	Probable	Risks to Human Health, the Environment and potable water.	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
1b	Poor ground conditions for shaft excavation	Shafts	Low strength superficial formations (glacial till, and probably peat) and / or weathered rock formations (mudstone, siltstone, sandstone, shale, limestone).	Almost Certain	Adverse excavation conditions - potential shaft wall instabilities, surface settlement.	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 optioning, grouting and piling.	Medium

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
2b	Complex structural geology	Shafts	Low strength superficial formations (glacial till, and probably peat) and / or weathered rock formations (mudstone, siltstone, sandstone, shale, limestone).	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	Potential for karst dissolution	Shafts	Excavation situated in natural dissolution features giving an uneven rockhead excavation	Probable	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	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 techniques to	Low

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
4b			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 shaft and the 'chimney' effect leading to subsidence or collapse of the shaft.	High	Medium	identify 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
5b			Superficial deposits overlying dissolution features.	Probable	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	Medium		Low
6b			Preferential seepage flow paths.	Probable	Adverse excavation and support conditions due to the potential for high water inflow.	Medium	Medium		Low

<table>
<tr><th>No.</th><th>Geohazard</th><th>Structure</th><th>Hazard</th><th>Likelihood</th><th>Consequence</th><th>Impact</th><th>Initial Risk</th><th>Mitigation</th><th>Residual Risk</th></tr>
<tr><td>7b</td><td rowspan="2">Geological faults crossing/running parallel to the proposed tunnel</td><td rowspan="2">Shafts</td><td>Weak, fractured rock and high stresses around faulted areas</td><td>Probable</td><td>Adverse excavation conditions - potential shaft wall instability, surface settlement.</td><td>High</td><td>Medium</td><td rowspan="2">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 optioning, grouting and piling.
Mitigation could include grouting, dewatering wells, drainage holes.</td><td>Low</td></tr>
<tr><td>8b</td><td>Preferential seepage flow paths around faulted areas</td><td>Probable</td><td>High water pressures around shaft, leading to infiltration (high water inflow), flooding/instability of shaft excavation.</td><td>Medium</td><td>Medium</td><td>Low</td></tr>
</table>

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
9b	High groundwater levels	Shafts	High groundwater levels and perched water tables.	Probable	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 wells, drainage, diaphragm walls	Low
10b	Water features	Shafts	Flooding from watercourses.	Highly unlikely	Flooding, erosion and deposition of sediment in or around 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

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
11b	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
12b	Ground gases	Shafts	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.	High	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

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
13b	Rock mineralogy	Shafts	Naturally occurring asbestos, lead or mine spoil	Probable	Adverse health effects from contact with hazardous materials.	High	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 health and safety measures.	Low
14b	Historical quarrying and mining	Shafts	Infilled quarries/mines, quarry and mine workings and quarry and mine spoil.	Probable	Unstable and variable ground conditions leading to settlement, subsidence or collapse of infrastructure.	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 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

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
15b	Potential for Hazardous Waste Materials	Shafts	Potential for localised hazardous waste materials associated with historical land use and/ or made ground.	Probable	Elevated disposal costs associated with landfill taxes.	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.	Low
16b	Potential for Ground Contamination	Shafts	Potential for ground contamination within localised Made ground.	Probable	Risks to Human Health, the Environment and potable water.	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

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
1c	Poor ground conditions for shallow tunnelling	Tunnel	Low overburden thickness. Low strength superficial formations (glacial till) and / or weathered rock formations (mudstone, siltstone, sandstone, shale, limestone).	Almost Certain	Adverse tunnelling conditions and tunnel advance difficulty - excessive ground settlement, surface instability / landslides, 'chimney' effect, tunnel 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 grouting, pre support techniques, conventional excavation option (SCL), appropriate TBM and lining design.	Medium
2c	Poor ground conditions in deep tunnelling	Tunnel	Weak rock, high stresses and squeezing conditions. Tunnel convergence.	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

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
3c	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 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. 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 drainage, selection of an appropriate tunnel driving direction, appropriate TBM and lining design.	Medium
4c	Geological faults crossing/running parallel to the proposed tunnel	Tunnel	Weak, fractured rock and high stresses around faulted areas	Almost Certain	Adverse tunnelling conditions and tunnel advance difficult 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	Medium

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
5c			Preferential seepage flow paths around faulted areas	Almost Certain	Adverse tunnelling conditions and tunnel advance difficulty due to the potential for high water pressures around tunnel and possible high water inflow	High	High	these can be mitigated for during design. Mitigation could include grouting, pre support, dewatering, relief tunnel drainage holes, appropriate TBM and lining design.	Medium
			Unrecorded faults	Almost Certain	Adverse tunnelling conditions and tunnel advance difficulties due to tunnel face instability, convergence, tunnel closure and collapse.	High	High		Medium
6c	Complex structural geology	Tunnel	Tunnel face mixed conditions (weak rock/soil alternations with competent rock, i.e. glacial till / weathered rock / 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	Medium
7c			Information gaps between exploratory holes	Almost Certain		High	High		Medium

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
8c			Lithological alternations (mudstone, siltstone, sandstone, shale, limestone).	Almost Certain		Medium	Medium	these can be mitigated for during design. Mitigation may include selection of an appropriate tunnel driving direction, appropriate TBM and lining design.	Low
9c			Intense folding/ Parasitic folding.	Almost Certain		Medium	Medium		Low
10c			Intense fracturing.	Almost Certain		Medium	Medium		Low
11c			Tunnel drive against strata dip.	Almost Certain		Medium	Medium		Low
12c	Historical landslides and slope instability	Tunnel	Slide, creep associated with low overburden thickness and head deposits	Almost Certain	Adverse tunnelling conditions and tunnel advance difficulty due to the potential for instability issues in the surrounding area, tunnel closure and collapse.	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 may include an appropriate stabilization design, piling	Low

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
13c	Potential for karst dissolution	Tunnel	Excavation situated in natural dissolution features giving an uneven rockhead excavation	Probable	Adverse excavation and support conditions due to the potential for instability issues in the surrounding area, leading to subsidence or collapse of the tunnel.	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
14c			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 shaft and the 'chimney' effect leading to subsidence or collapse.	High	Medium		Low

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
15c			Superficial deposits overlying dissolution features.	Probable	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 tunnel.	High	Medium		Low
16c			Preferential seepage flow paths.	Probable	Adverse excavation and support conditions due to the potential for high water inflow.	High	Medium		Low
			Hydraulic conductivity with surface.	Probable	Adverse excavation and support conditions due to the potential for high water inflow.	High	Medium		Low
17c	Water features	Tunnel	Scour along banks of watercourses.	Probable	Scour leading to erosion of overburden.	Medium	Medium	Where watercourses are identified close to the preferred option, design to include mitigation to prevent erosion of overburden. This may include bed scour protection e.g. geotextiles or rock armour or concrete slab.	Low

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
18c	Potential for high sulphate and chloride levels	Tunnel	Aggressive ground conditions.	Probable	Degradation of concrete structures and metals.	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
19c	Rock mineralogy	Tunnel	High abrasiveness lithology (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

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
20c			Naturally occurring asbestos and lead	Probable	Adverse health effects from contact with hazardous materials.	High	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 health and safety measures.	Low
21c	Historical quarrying and mining	Tunnel	Infilled quarries/mines, quarry and mine workings and quarry and mine spoil.	Probable	Unstable and variable ground conditions leading to settlement, subsidence or collapse of Tunnel.	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 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

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
22c	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.	High	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
23c	Water, gas and oil wells	Tunnel	High water inflow and gas release.	Highly Unlikely	High water inflow. Build up of dangerous gases within confined spaces during construction. High concentrations of gases may lead to adverse health effects, asphyxiation and explosive atmospheres.	Medium	Low	Review likelihood of hazard following Phase 1 ground investigation and avoid hazard where possible during option selection. Mitigation in design and construction could include installation of continuous gas monitoring devices and appropriate ventilation. Mitigation for water wells could include grouting.	Low

No.	Geohazard	Structure	Hazard	Likelihood	Consequence	Impact	Initial Risk	Mitigation	Residual Risk
	Igneous dykes	Tunnel	Lithological bedrock alternations, highly abrasive lithology.	Probable	Adverse tunnelling conditions and tunnel advance difficulty. 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

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 thus 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

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 alignments that might pose a risk to tunnel boring operations;
- Identify and map the extent of geotechnical variability to 30m below ground surface;
- Identify potential slope stability failure surfaces;
- Identify anomalous groundwater conditions including contamination;
- Map the spatial extent of shallow mine workings and other cavities;
- Map the spatial extent of landfill deposits; 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 **Error! Reference source not found.** and **Error! Reference source not found.** below.

The following geophysical techniques are proposed:

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

Deep geophysical investigation

Several deep seismic investigation profiles ("DS" lines) shall be carried out along the preferred route alignment 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, mine-workings 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 **Error! Reference source not found.** and **Error! Reference source not found.** 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 for 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, landslide stabilization design); and,

- 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

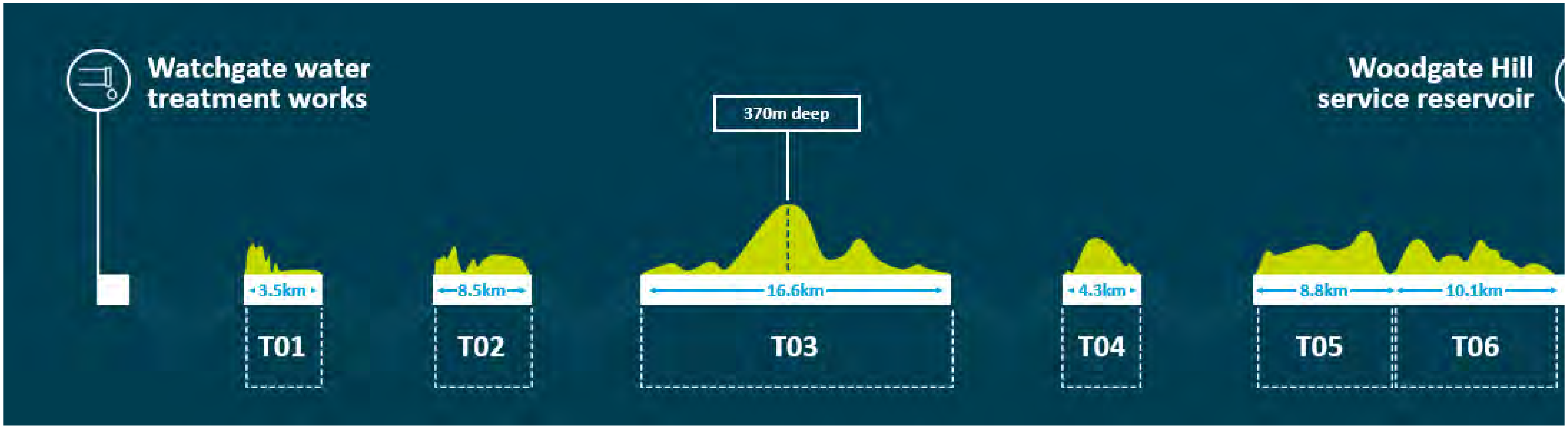


Figure 1 – TR3 Desk Study
Schematic Drawing Showing the Relative Locations and Lengths of Existing Tunnel Sections on the Haweswater Aqueduct'

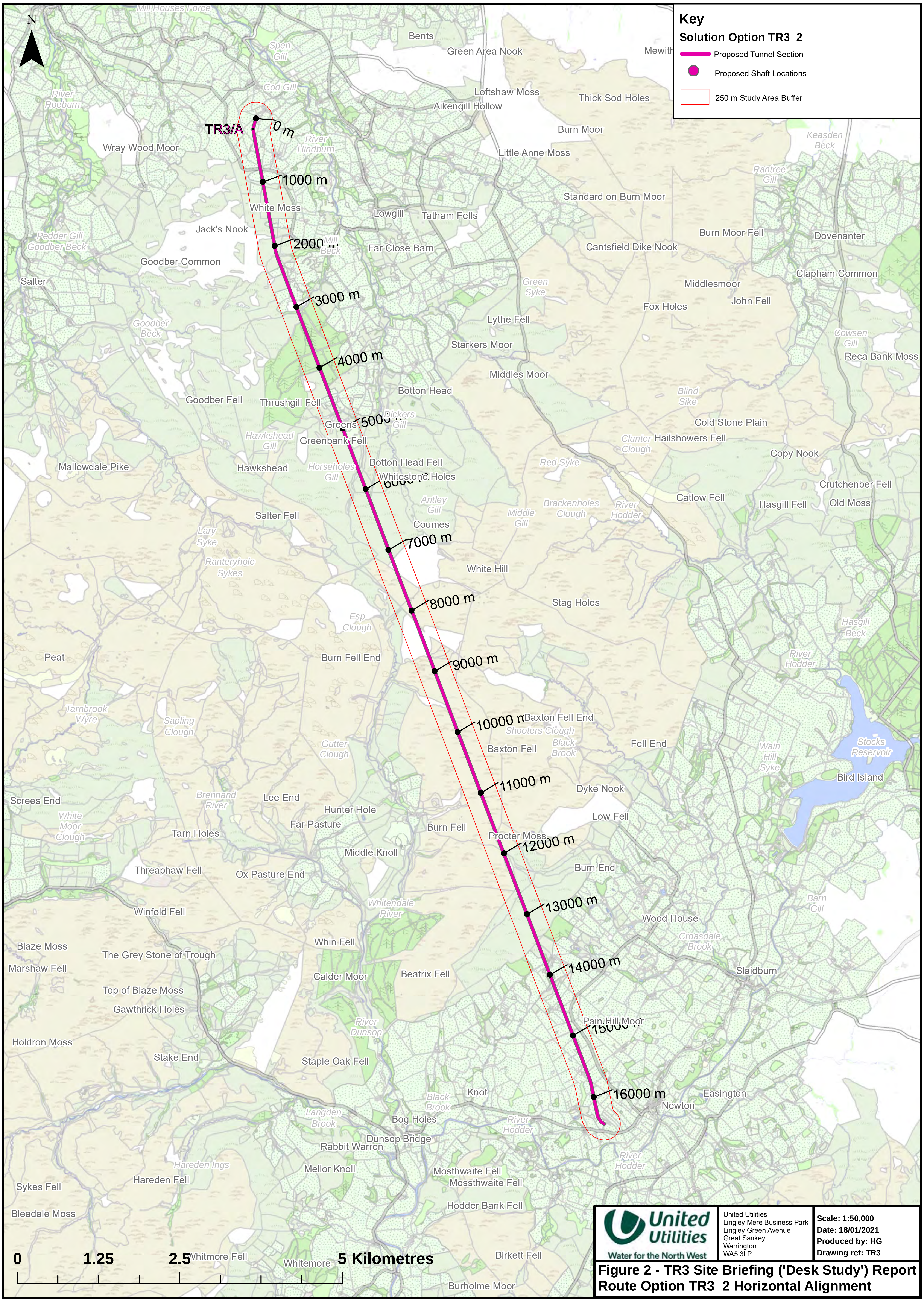


Figure 2 - TR3 Site Briefing ('Desk Study') Report Route Option TR3_2 Horizontal Alignment

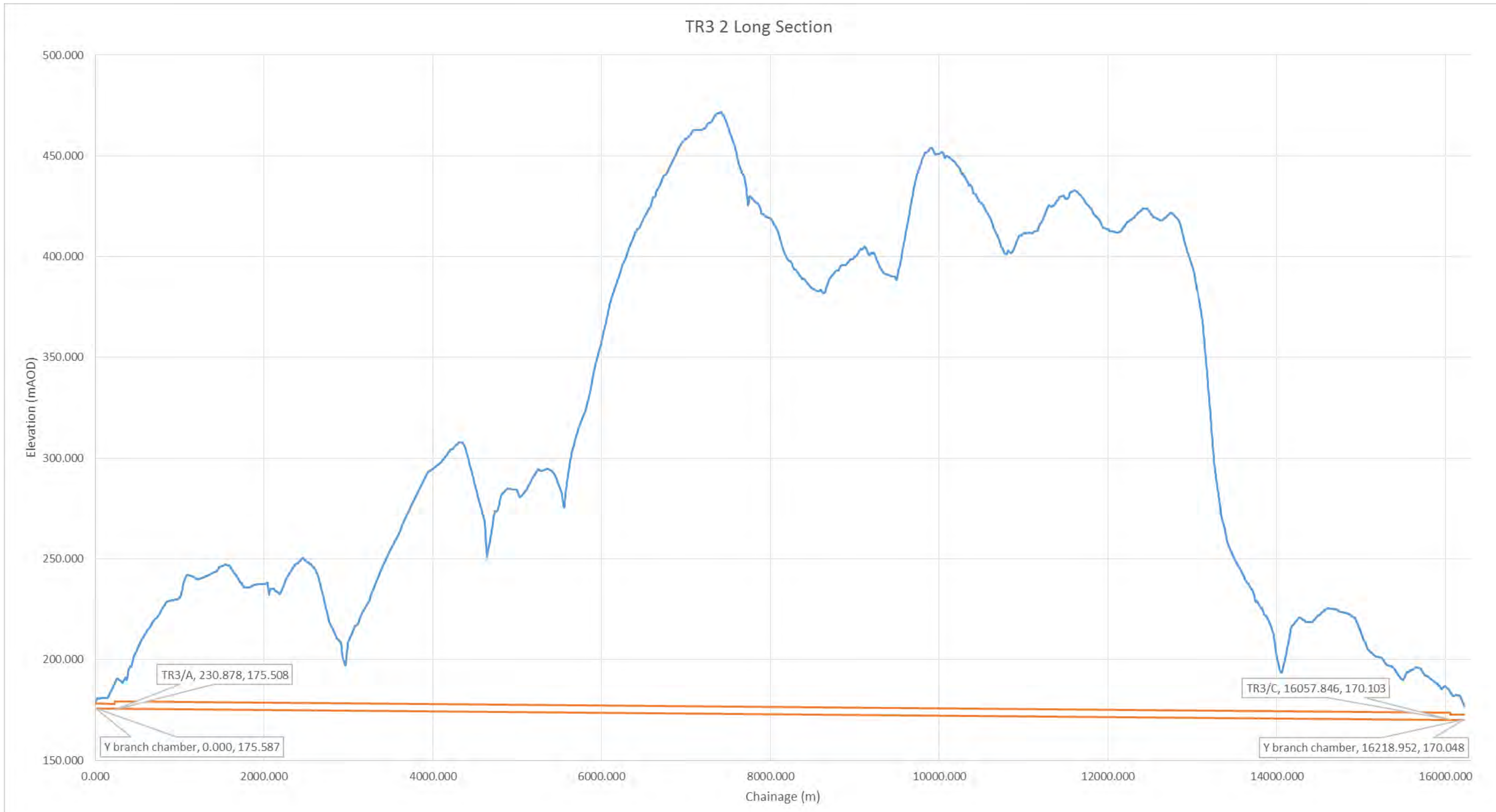


Figure 3 – TR3 Desk Study
Route Option TR3-2 longitudinal section (extract from 80061155-01-UU-TR2-XX-SP-C-00001)

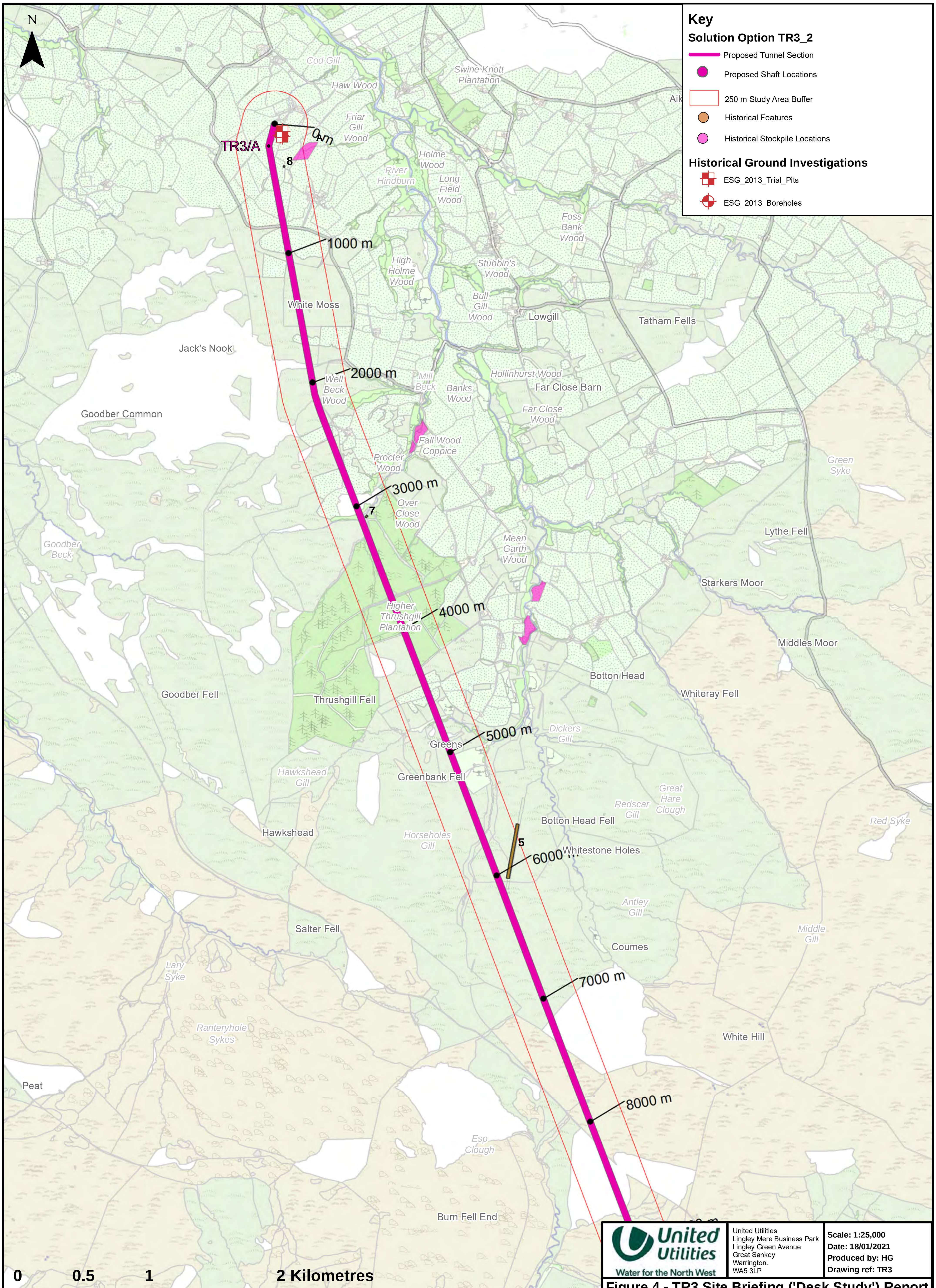


Figure 4 - TR3 Site Briefing ('Desk Study') Report
Historical Features (1 of 2)

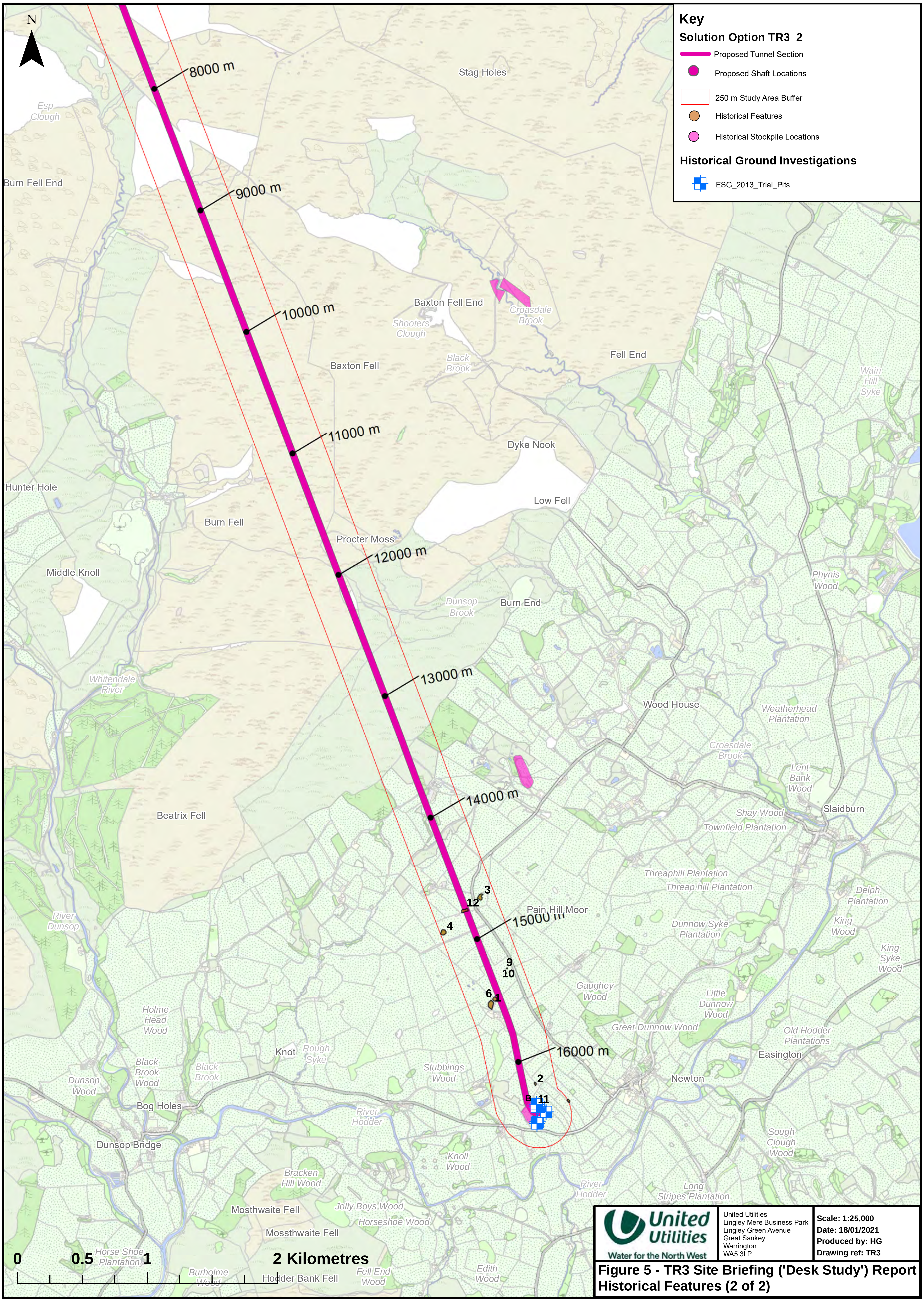
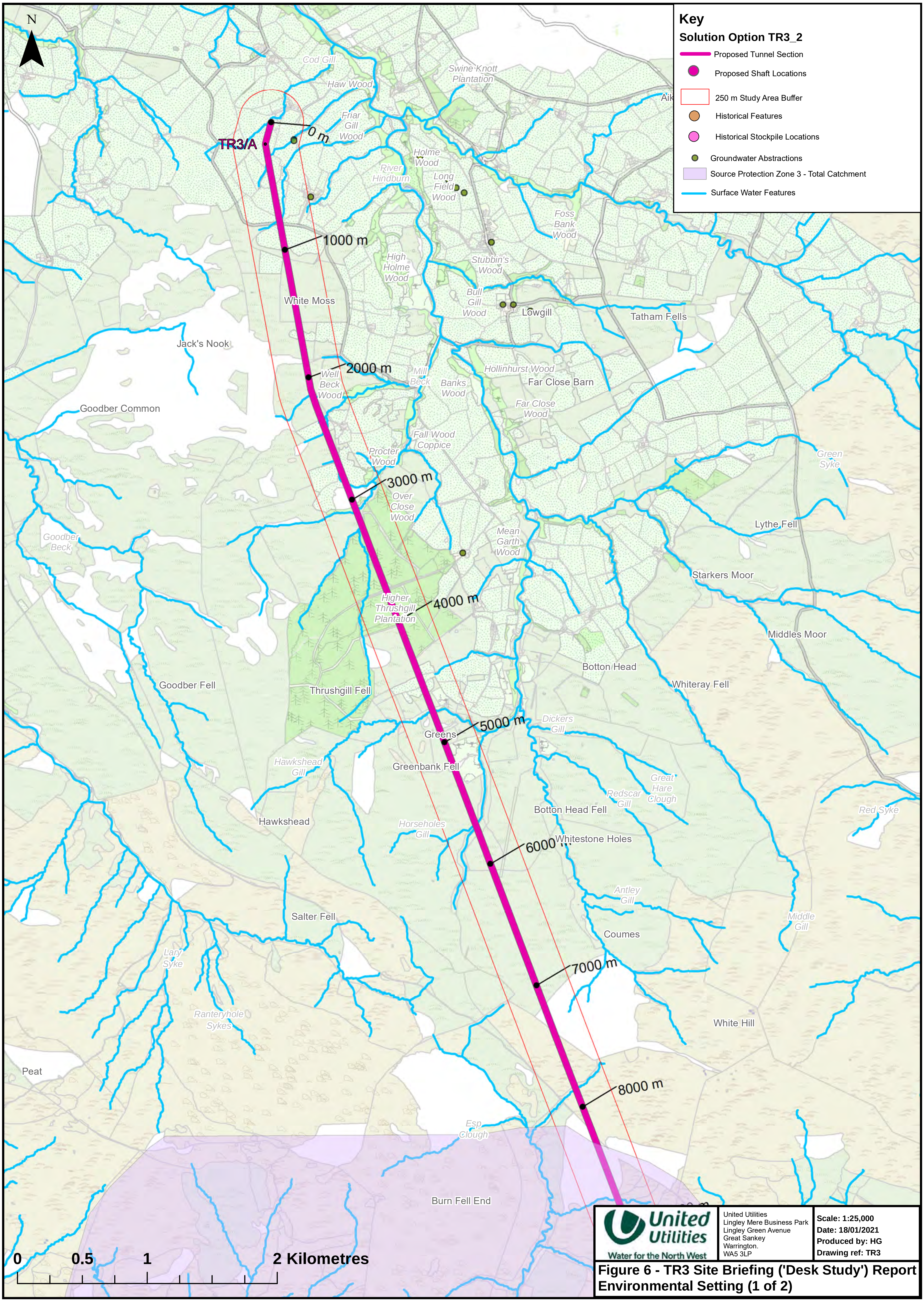


Figure 5 - TR3 Site Briefing ('Desk Study') Report Historical Features (2 of 2)



United Utilities
Water for the North West

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

Scale: 1:25,000
Date: 18/01/2021
Produced by: HG
Drawing ref: TR3

Figure 6 - TR3 Site Briefing ('Desk Study') Report Environmental Setting (1 of 2)

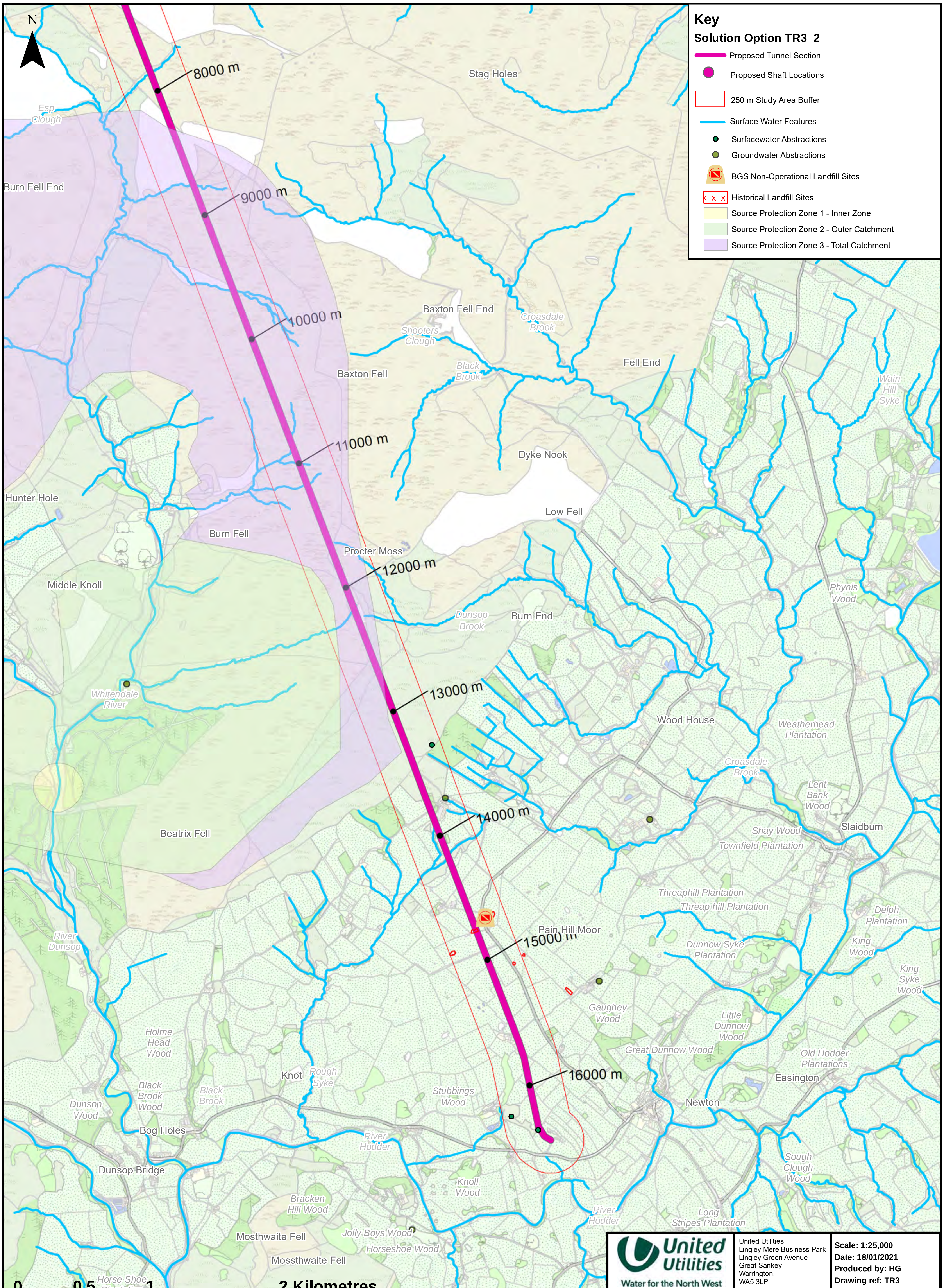


Figure 7 - TR3 Site Briefing ('Desk Study') Report Environmental Setting (2 of 2)

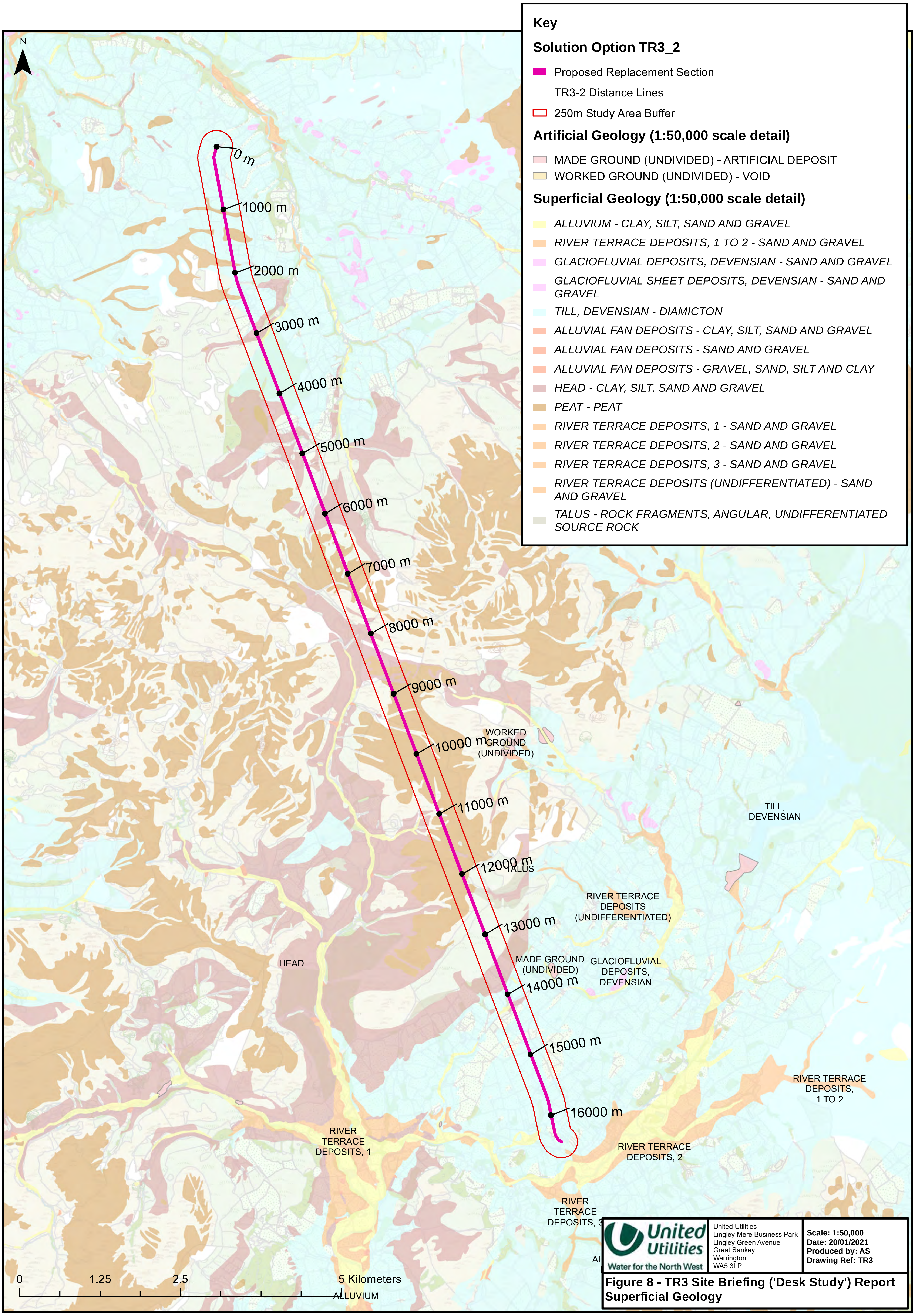


Figure 8 - TR3 Site Briefing ('Desk Study') Report Superficial Geology

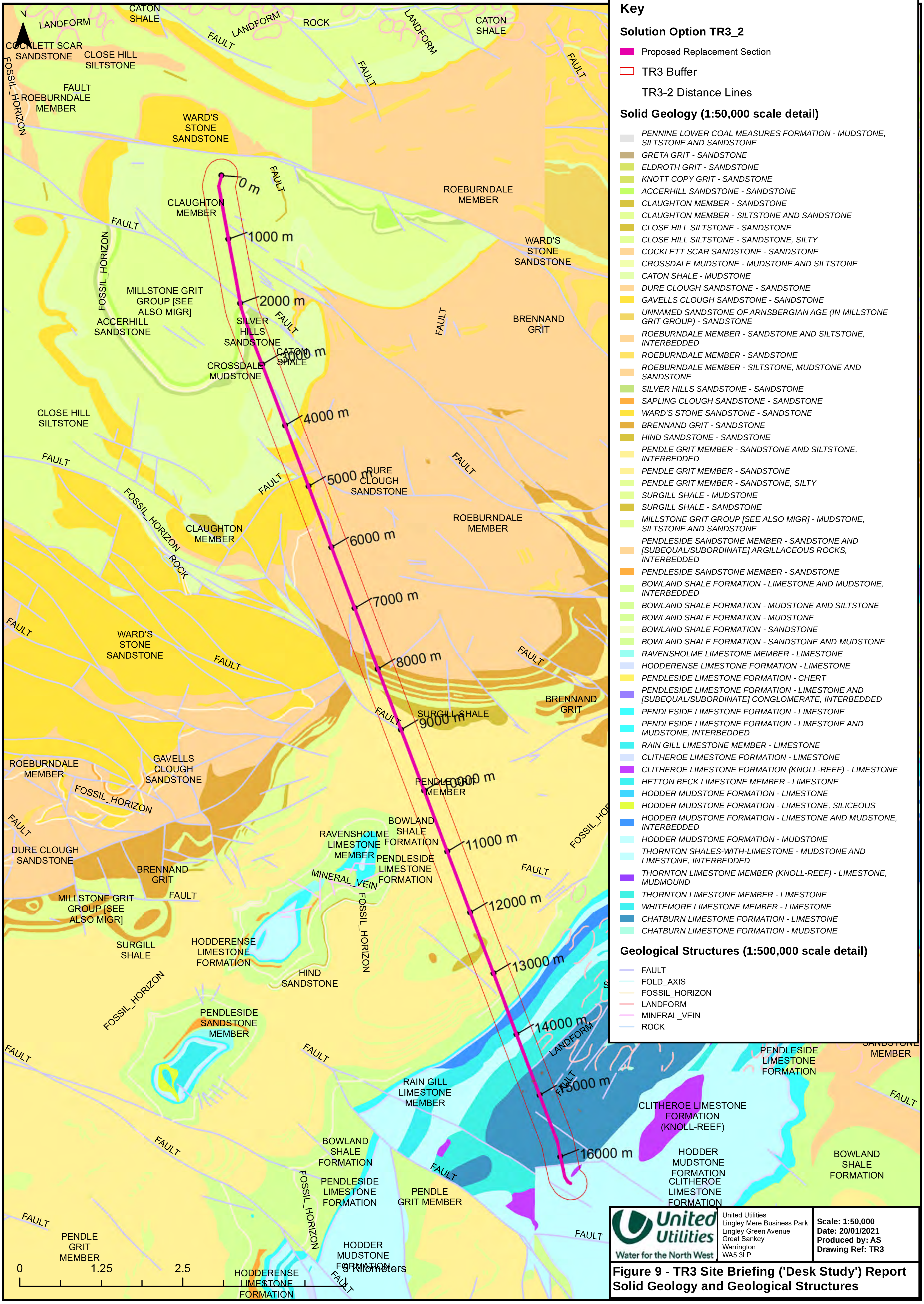


Figure 9 - TR3 Site Briefing ('Desk Study') Report Solid Geology and Geological Structures

APPENDIX B. HISTORICAL GROUND INVESTIGATIONS

'*INFORMATION REDACTED*'

APPENDIX C. GEOLOGY SUMMARY TABLES

Table C-1: Landslide deposits according to BGS 1:10,000 scale mapping within 1km of the proposed route alignment

Chainage	Offset
0+690-1+820	700m east
2+070-2+310	200m east
2+690-2+850	350m east
2+940-3+050	65m east
2+980-3+160	0m west
3+200-3+420	110m west
3+480-3+610	480m west
4+320-4+360	620m west
4+670-4+830	0m east
4+780-4+860	165m east
5+050-5+120	330m east
5+340-5+550	590m east
5+620-5+820	40m west
6+510-7+190	560m east
7+070-7+140	450m east
8+210-8+310	480m west
8+620-9+190	135m west
10+740-11+070	535m west
14+200-14+280	85m west
14+490-14+660	860m west
15+960-16+220	920m west

Table C-2: Superficial deposits according to BGS 1:10,000 scale mapping along the proposed route alignment

Superficial Deposits	Approximate Chainage
Glacial till	Ch. 0+000-1+000 Ch. 1+070-1+280 Ch.1+450-1+820 Ch.1+870-2+135 Ch. 2+150-2+830 Ch. 3+230-4+180 Ch. 13+830-14+070 Ch. 14+340-14+680 Ch. 14+780-15+380 Ch. 15+710-16+080 Ch. 16+400-16+460
Peat	Ch. 1+000-1+070 Ch. 1+280-1+450 Ch. 1+820-1+870 Ch. 6+430-6+440 Ch.6+480-6+700 Ch. 6+770-6+860 Ch. 6+890-7+390 Ch. 8+480-8+650 Ch. 8+680-8+740 Ch. 8+770-9+280 Ch. 9+300-9+590 Ch. 9+620-10+810 Ch. 10+900-10+920 Ch.10+950-10+990 Ch. 11+010-11+150 Ch. 11+170-11+570 Ch. 11+640-12+270

Superficial Deposits	Approximate Chainage
Head (clay, silt, sand and gravel)	Ch. 2+830-3+080 Ch. 4+180-4+310 Ch. 4+590-4+710 Ch. 4+750-4+790 Ch.5+195-5+215 Ch. 5+720-6+160 Ch. 7+710-7+760 Ch. 7+840-8+050 Ch. 8+100-8+130 Ch. 8+150-8+170 Ch.8+250-8+480 Ch. 8+650-8+680 Ch. 8+740-8+770 Ch. 11+570-11+640 Ch. 13+340-13+830 Ch. 14+120-14+200
Alluvium	Ch. 3+180-3+230 Ch. 14+070-14+120
River Terrace deposits	Ch. 4+710-4+750

Table C-2: Bedrock geology according to BGS 1:10,000 scale mapping along the proposed route alignment

Surface Bedrock Formations	**Approximate Chainages**
Claughton Member (sandy shaly siltstone and sandstone) [Silsden Formation]	Ch. 0+000-1+940 Ch. 2+520-2+890
Millstone Grit Group (formerly Kirkbeck Formation) (Sandstone)	Ch. 1+940-1+990
Accerhill Sandstone (Sandstone with sandstone seatearths and thin coals) [Samlesbury Formation]	Ch. 1+990-2+070
Crossdale Mudstone (laminated Mudstone and Siltstone) [Millstone Grit Group]	Ch. 2+070-2+270
Silver Hills Sandstone (Sandstone) [Silsden Formation]	Ch. 2+270-2+520
Caton Shale (shaly Mudstone-Claystone) [Silsden Formation]	Ch. 2+890-4+260
Ward's Stone Sandstone (Sandstone) [Silsden Formation]	Ch. 4+260-4+520 Ch. 4+790-5+140
Roeburndale Member (sandy, shaly Siltstone interbedded with Sandstone) [Silsden Formation]	Ch.4+520-4+790 Ch. 5+140-7+740
Brennand Grit (pebbly Sandstone with minor interbedded Siltstone) [Pendleton Formation]	Ch. 7+740-8+240
Surgill Shale (sandstone) [Pendleton Formation]	Ch. 8+240-8+380 Ch. 12+300-12+620
Pendle Grit Member (Sandstone with Siltstone and Mudstone interbeds) [Pendleton Formation]	Ch. 8+380-12+300 Ch. 12+620-13+280
Bowland Shales Formation (blocky Mudstone with subordinate sequences of interbedded Limestone and Sandstone)	Ch. 13+280-13+540
Pendleside Limestone Formation (Limestone with some mudstone)	Ch. 13+540-13+575

Surface Bedrock Formations	Approximate Chainages
Hodderense Limestone Formation (Limestone with mudstone)	Ch. 13+575-13+585
Hodder Mudstone Formation (Mudstone, with subordinate and variable detrital limestone, siltstone and sandstone)	Ch. 13+585-13+770 Ch. 13+970-14+190 Ch. 16+400-16+642
Rain Gill Limestone Member (Limestone interbedded with mudstones)	Ch. 13+770-13+970
Thornton Limestone Member (Limestone interbedded with variable amounts of calcareous Mudstone and siltstone)	Ch. 14+190-14+610
Chatburn Limestone Formation (Limestone with chert lenses and subordinate partings or thin beds of shaly calcareous mudstone and siltstone)	Ch. 14+610-16+240
Clitheroe Limestone Formation (Knoll Reef) (Limestone)	Ch. 16+240-16+400