A66 Northern Trans-Pennine Project
TR010062

3.4 Environmental Statement Appendix 14.6 Hydrogeological Impact Assessment

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3.4 ENVIRONEMENTAL STATEMENT APPENDIX 14.6 HYRDROGEOLOGICAL IMPACT ASSESSMENT

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14.6 Hydrogeological Impact Assessment

14.6.1 Introduction

14.6.1.1 The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017 (WFD Regulations) are described in Chapter 14: Road Drainage and the Water Environment of the Environmental Statement (ES) (Application Document 3.2).

14.6.1.2 The key objectives of the WFD Regulations, specifically in relation to groundwater, are to:

- Protect, enhance and restore all groundwater bodies.
- Achieve good chemical and quantitative status of groundwater.
- Prevent pollution and deterioration of groundwater.
- Ensure a balance between groundwater abstraction and recharge.

Purpose

14.6.1.3 The purpose of this report is to present the hydrogeological impact assessment (HIA) for the scheme, and to inform the conclusions of the ES regarding the water environment.

14.6.1.4 This HIA presents the baseline conditions of groundwater features and assesses potential impacts to groundwater flows, levels, and quality from the scheme.

14.6.1.5 The report is supported by a number of figures contained within Environmental Statement Volume 2 (Application Document Number 3.3). These include ES Figure 14.1: Surface Water Features to ES Figure 14.12: Potential Groundwater Dependent Terrestrial Ecosystems (GWDTE), ES Figure 14.6.1: Hydrogeological Conceptual Model Locations and ES Figure 14.6.2: Cutting Assessment Zone of Influence (Application Document 3.3).

14.6.2 Methodology

Overview

14.6.2.1 The Project crosses an area of valued geological and environmental interest and importance. To understand the environmental risks of the scheme in the context of groundwater, a desktop study and review of initial ground investigation data has been undertaken to understand the groundwater regime and to assess the potential impacts of the design.

14.6.2.2 The study area for the assessment includes groundwater features within a 1km radius of the Order Limits and is based on the 'source-pathway-receptor' pollutant linkage principle. The study area for each scheme is shown on all of the ES figures referenced above.

14.6.2.3 The assessment of the groundwater aspects of the project is being carried out in accordance with the *Design Manual for Roads and Bridges (DMRB) LA 113 Road Drainage and the Water Environment*

(Highways England, 2020)[1] and Environment Agency guidance for dewatering abstractions (SC040020/SR1) (Environment Agency, 2007a)[2] and groundwater abstractions (SC040020/SR2) (Environment Agency, 2007b)[3].

14.6.2.4 The geological setting and ground conditions along the route are presented in Chapter 9: Geology and Soils (Application Document 3.2) and Appendix 9.5 Ground Investigation Reports (GIR) (Application Document 3.4).

Ground investigation

14.6.2.5 Details of the completed ground investigations to date are presented in Appendix 9.5: Ground Investigation Reports (GIR) (Application Document 3.4). The following sections detail the hydrogeological aspects of these investigations.

14.6.2.6 The initial ground investigation phase was completed between February and May 2021. The ground investigation works were split into four packages (A, B, C and D) covering different sections along the proposed route.

14.6.2.7 Data from a total of 106 monitoring locations from the initial ground investigation are included in this HIA to support the ES.

14.6.2.8 A second phase of ground investigation is currently proposed which will include additional groundwater monitoring locations and a full year of groundwater monitoring to inform the detailed design. Due to limited winter monitoring data at the time of this assessment, conservative groundwater level parameters have been utilised which results in a reasonable worst case assessment to identify receptors potentially at risk.

M6 Junction 40 to Kemplay Bank and Penrith to Temple Sowerby

14.6.2.9 The scope of works for this area included sixteen monitoring installations. A summary of the monitoring installations is presented in Annex A of this document.

14.6.2.10 Groundwater monitoring of the boreholes was undertaken weekly between 27 May 2021 and 22 June 2021. Two subsequent follow up visits were undertaken in February/early March 2022.

14.6.2.11 To ascertain hydrogeological parameters, one soakaway test was undertaken in the M6 Junction 40 to Kemplay Bank Roundabout Order Limits and two soakaway tests were undertaken in the Penrith to Temple Sowerby Order Limits.

14.6.2.12 Groundwater quality was sampled, using low flow techniques, on 7th June 2021 from ten of the monitoring installations (four in the M6 Junction 40 to Kemplay Bank Order Limits and six in the Penrith to

[1] Highways England (2020) Design Manual for Roads and Bridges LA 113 Road Drainage and the Water Environment
[2] Environment Agency (2007a) Hydrogeological impact appraisal for dewatering abstractions
[3] Environment Agency (2007b) Hydrogeological impact appraisal for groundwater abstractions

Temple Sowerby Order Limits). Two surface water samples were also taken to assess water quality in the Penrith to Temple Sowerby Order Limits, from the Light Water and Unnamed Tributary of River Eamont 3.4.

Temple Sowerby to Appleby and Appleby to Brough

14.6.2.13 The scope of works for this area included forty monitoring installations within 37 boreholes (three boreholes had nested piezometers). A summary of the monitoring installations is presented in Annex A of this document.

14.6.2.14 Groundwater monitoring of the boreholes was undertaken weekly between 26 May 2021 and 23 June 2021. Two subsequent follow up visits were undertaken in February and March 2022.

14.6.2.15 To ascertain hydrogeological parameters, five soakaway tests were undertaken in the Temple Sowerby to Appleby Order Limits and ten soakaway tests were undertaken in the Appleby to Brough Order Limits.

14.6.2.16 Groundwater quality was sampled, using low flow techniques, between 8th and 10th June 2021 from 29 of the monitoring installation (nine in the Temple Sowerby to Appleby Order Limits and twenty in the Appleby to Brough Order Limits). Five surface water samples were also taken to assess water quality in the Appleby to Brough Order Limits, from Hayber Beck, Moor Beck (two samples), Eastfield Sike and Lowgill Beck.

Bowes Bypass and Cross Lanes to Rokeby

14.6.2.17 The scope of works for this area included 28 monitoring installations. A summary of the monitoring installations is presented in Annex A of this document.

14.6.2.18 Groundwater monitoring of the boreholes was undertaken weekly between 29 March 2021 and 6 May 2021, with a follow up reading on 27th August 2021. Two subsequent follow up visits were undertaken in February/early March 2022 for the boreholes in the Bowes Bypass Order Limits (the Cross Lanes to Rokeby monitoring sites were not revisited due to access constraints).

14.6.2.19 To ascertain hydrogeological parameters, variable head testing was carried out in 13 installations (nine in the Bowes Bypass Order Limits and four in the Cross Lanes to Rokeby Order Limits). Soakaway testing was also undertaken in selected Trial Pits (five in the Bowes Bypass Order Limits and four in the Cross Lanes to Rokeby Order Limits).

14.6.2.20 Groundwater quality was sampled, using low flow techniques, on the 30 March 2021 from three monitoring installations (two in the Bowes Bypass Order Limits and one in the Cross Lanes to Rokeby Order Limits). Four surface water samples were also taken to assess water quality (two in the Bowes Bypass Order Limits from the River Greta and two in the Cross Lanes to Rokeby Order Limits from Tutta Beck).

Stephen Bank to Carkin Moor and A1(M) Junction 53 Scotch Corner

14.6.2.21 The scope of works for this area included twenty-five monitoring installations; all located within the Stephen Bank to Carkin Moor area. Due to the limited construction works required in the A1(M) Junction 53 Scotch Corner area, ground investigation works were scoped out. A summary of the monitoring installations is presented in Annex A of this document.

14.6.2.22 Groundwater monitoring of the boreholes was undertaken weekly between 29 March 2021 and 5 May 2021, with a follow up reading on 26 August 2021. Two subsequent follow up visits were undertaken in February/early March 2022.

14.6.2.23 To ascertain hydrogeological parameters, variable head testing was carried out in fourteen installations in the Stephen Bank to Carkin Moor area. In addition, nine soakaway tests were also scheduled in the Stephen Bank to Carking Moor area. No ground investigation was scoped in the A1(M) Junction 53 section Order Limits, due to limited construction works.

14.6.2.24 Groundwater quality was sampled, using low flow techniques, on the 30 March 2021 from three monitoring installation in the Stephen Bank to Carking Moor Order Limits. Two surface water samples were also taken to assess water quality in the Order Limits, from Unnamed Tributary of Holme Beck 9.3 and Unnamed Tributary of Mains Gill 9.3.

Baseline conditions scope

14.6.2.25 The baseline describes the existing condition of groundwater related features within the Project study area; with the Project study area defined as within a 1km radius of the Order Limits.

14.6.2.26 The following data sources were used to compile the baseline conditions:

- Environment Agency Catchment Abstraction Management Strategies (Environment Agency, 2013a)[4] (Environment Agency, 2019)[5] (Environment Agency, 2013b)[6]
- Natural England, *Multi-Agency Geographic Information for the Countryside (MAGIC)* (Department for Environment, Food and Rural Affairs)[7]
- Environment Agency *Cycle 2 River Basin Management Plans* (Environment Agency, 2016)[8]

[4] Environment Agency (2013a) Eden and Esk Abstraction Management Strategy
[5] Environment Agency (2019) Tees Abstraction Management Strategy
[6] Environment Agency (2013b) Swale, Ure, Nidd and Upper Ouse Abstraction Management Strategy
[7] Department for Environment, Food and Rural Affairs (2019) MAGIC. Interactive mapping at your fingertips
[8] Environment Agency (2016) Cycle 2 River Basin Management Plans

- Environment Agency *Catchment Data Explorer* (Environment Agency, 2022)[9]
- Ordnance Survey (OS) mapping (including topography)
- British Geological Survey (BGS) mapping (British Geological Survey)[10]
- Environment Agency Data received following data request (Licensed Abstractions, Consented Discharges and Rainfall)
- Durham County Council Data received following data request (Unlicensed Abstractions)
- Site specific ground investigation reports (see Appendix 9.5: Ground Investigation Reports (GIR) (Application Document 3.4)
- Observations from site walkover surveys

14.6.2.27 The location of the groundwater monitoring installations used to inform the baseline conditions review are presented in ES Figure 14.10: Groundwater monitoring locations (Application Document 3.3). Groundwater monitoring data received until 1 March 2022 has been considered in this assessment. The factual data is presented in ES Appendix 9.5: Ground Investigation Reports (GIR) (Application Document 3.4).

14.6.2.28 Daily rainfall data has been acquired for the stations listed in Table 1: Rainfall Stations below from 1 January 2019 to 12 March 2022. The longer term rainfall record is provided to give context to the recent monitoring periods. The station locations are illustrated on ES Figure 14.10: Groundwater monitoring locations (Application Document 3.3).

Table 1: Rainfall Stations

Station name and number	Approximate elevation (mAOD)	Schemes applicable	Distance from scheme
Station 598691 - Appleby North	220	Appleby to Brough	5.0km
		Temple Sowerby to Appleby	5.6km
Station 028185 - Banard Castle	320	Bowes Bypass	4.5km
Station 52287 - Richmond	187	Cross Lanes to Rokeby	15.6km
		Stephen Bank to Carkin Moor	6.6km
Station 604742 - Penrith	170	M6 Junction	2.4km
		Kemplay Bank	3.1km
		Penrith to Temple Sowerby	5.0km

[9] Environment Agency (2022) Catchment Data Explorer
[10] British Geological Survey (2022) Geology of Britain viewer

14.6.3 Baseline

Designations and directives

Catchment Abstraction Management Strategy (CAMS)

14.6.3.1 The Project is located within three CAMS areas as designated by the Environment Agency. These are listed below and presented in ES Figure 14.5: Catchment Abstraction Management Strategy Areas (Application Document 3.3):

- Eden and Esk – M6 Junction 40 to Brough
- Tees – Bowes Bypass and Cross Lanes to Rokeby
- Swale, Ure, Nidd and Upper Ouse (SUNO) – Stephen Bank to Carkin Moor and Scotch Corner.

14.6.3.2 The Eden and Esk CAMS area covers the River Eden and its tributaries which rises in the eastern and northern Lake District fells and north-western Pennines and flow northwest to the Solway First.

14.6.3.3 In the location of the A66 within the Eden and Esk CAMS area, groundwater unit balance shows groundwater available for abstraction licensing.

14.6.3.4 The Tees CAMS area covers an area of approximately 1,092km^2, including the catchments of the River Tees and its associated tributaries.

14.6.3.5 In the location of the A66 within the Tees CAMS area, groundwater unit balance shows groundwater available for abstraction licensing.

14.6.3.6 The Swale, Ure, Nidd and Upper Ouse (SUNO) CAMS encompasses an area of circa 3,509km^2 of North Yorkshire, defined by the natural boundaries and catchment watersheds of the four noted rivers.

14.6.3.7 The groundwater resource availability in the location of the A66 within the SUNO CAMS area is not designated.

Environment Agency aquifer designations

14.6.3.8 Aquifers along the route that have been classified by the Environment Agency are listed in the following paragraphs and are presented in ES Figure 14.7: Aquifer Designations (Application Document 3.3).

14.6.3.9 The Alluvium, River Terrace Deposits and Glaciofluvial Deposits are designated by the Environment Agency as Secondary A aquifers. This designation indicates that the aquifers are 'permeable layers that can support local water supplies and may form an important source of base flow to rivers'.

14.6.3.10 Till is designated by the Environment Agency as a Secondary undifferentiated aquifer. This designation indicates that 'it is not possible to apply either a Secondary A or B definition because of the variable characteristics of the rock type. These have only a minor value.'

14.6.3.11 The Permian Eden Shale Formation is designated by the Environment Agency as a Secondary B aquifer. This designation indicates that 'aquifers are mainly lower permeability layers that may store and yield limited amounts of groundwater through characteristics like thin cracks (called fissures) and openings or eroded layers'.

14.6.3.12 The Penrith Sandstone Formation is designated by the Environment Agency as a Principal aquifer. Principal aquifers have high permeability, meaning they usually provide a high level of water storage and transmission; supporting water supply and river base flow on a strategic scale.

14.6.3.13 The Carboniferous Stainmore and Alston Formations are designated by the Environment Agency as Secondary A aquifers.

Water Framework Directive (WFD)

14.6.3.14 The Project is located over three river basin districts: the Solway Tweed river basin district, the Northumbria river basin district and the Humber river basin district.

14.6.3.15 Status and objectives of the features are based on those set out in the 2015 river basin management plan. The 2015 RBMP is the most up to date and will be updated in late 2022, following consultation.

14.6.3.16 The route of the Project crosses four WFD groundwater bodies; two are within the Solway Tweed river basin, one is within the Northumbria river basin and one is within the Humber river basin. A summary of the WFD groundwater bodies is presented in **Error! Reference source not found.** and ES Figure 14.4: WFD Groundwater Bodies (Application Document 3.3).

14.6.3.17 The superficial deposit aquifers are not specifically designated as WFD groundwater bodies. However, it is anticipated that they are hydraulically connected to the relevant underlying designated WFD groundwater bodies presented in Table 2: WFD Groundwater Bodies Summary.

Table 2: WFD Groundwater Bodies Summary

	Tees Carb Limestone & Millstone Grit	SUNO Millstone Grit and Carboniferous Limestone	Eden Valley and Carlisle Basin Permo-Triassic Sandstone Aquifers	Eden and Esk Lower Palaeozoic and Carboniferous Aquifers
Groundwater Body ID	GB40302G700300	GB40402G7019	GB40201G100400	GB40202G102300
River Basin District	Northumbria	Humber	Solway Tweed	Solway Tweed
Current Overall Status	Poor	Poor	Poor	Poor
Current Quantitative	Good	Good	Good	Good

	Tees Carb Limestone & Millstone Grit	SUNO Millstone Grit and Carboniferous Limestone	Eden Valley and Carlisle Basin Permo-Triassic Sandstone Aquifers	Eden and Esk Lower Palaeozoic and Carboniferous Aquifers
Current Chemical Status	Poor	Poor	Poor	Poor
Quantitative Objective	Good	Good	Good	Good
Chemical Objective	Poor	Good	Good	Good
Protected area	Drinking water protected area and nitrates directives	Drinking water protected area and nitrates directives	Drinking water protected area and nitrates directives	Drinking water protected area and nitrates directives

Regional geology

Superficial deposits

14.6.3.18 The superficial geology underlying the Project is presented in ES Figure 9.2: Published Geology - Superficial Geology (Application Document 3.3), with detailed descriptions of the superficial deposits presented in Chapter 9: Geology and Soils (Application Document 3.2) and associated appendices.

14.6.3.19 Superficial deposits are located along the route, and comprise of:

- Alluvium – Unconsolidated clays, silts, sands and gravels
- River Terrace Deposits – Stratified, well sorted sands and gravels
- Glaciofluvial Deposits – Stratified, well sorted sand and gravels
- Peat – Partially decomposed semi-carbonised vegetation which has grown under anaerobic conditions
- Glacial Till – Generally stiff silty sandy clay with areas of medium and fine-grained sands and gravels.

14.6.3.20 Alluvium and River Terrace Deposits are mapped along the route, in association with surface water bodies and flood zones and are crossed by the Project in several locations.

14.6.3.21 Glaciofluvial deposits are encountered in discrete areas along the route, generally adjacent to alluvial deposits and may potentially be encountered along the Project.

14.6.3.22 Peat beds are encountered in discrete areas within the study area; albeit not generally along the alignment. Significant peat deposits are located on the Moors to the west of Bowes (where no works are proposed).

14.6.3.23 Glacial Till is the most extensive unit along the route, with the majority of the A66 route anticipated to be located on a mixture of cohesive and granular Glacial Till deposits. The majority of cuttings are anticipated to be primarily located within Glacial Till deposits.

Bedrock geology

14.6.3.24 The bedrock geology underlying the Project is presented in ES Figure 9.3: Published Geology - Bedrock Geology (Application Document 3.3), with detailed descriptions of the bedrock groups presented in ES Chapter 9: Geology and Soils (Application Document 3.2) and associated appendices.

14.6.3.25 The Project is underlain by three main bedrock geological groups, from youngest to oldest:

- Cumbrian Coast Group – Permian shales and mudstones with local beds of gypsum and anhydrite
- Appleby Group – Permian interbedded red aeolian sandstones, fluviatile sandstones and breccias
- Yoredale Group – Carboniferous repeated upward-coarsening sedimentary cycles including the Alston Formation and Stainmore Formation.

14.6.3.26 The Eden Shale Formation (and associated gypsum and anhydrite beds) of the Cumbrian Coast Group conformably sit on top of the Penrith Sandstone and are generally located to the northeast of the A66 on the western half of the Project (M6 to Brough). The alignment of the Kirkby Thore Bypass will lie just south of the boundary between the Penrith Sandstone and Eden Shale Formation, with only auxiliary roads currently envisioned to extend over the Eden Shales.

14.6.3.27 The Penrith Sandstone of the Appleby Group will underlie the majority of the western half of the Project (M6 to Brough) beneath the superficial deposits.

14.6.3.28 The Stainmore Formation of the Yoredale Group, comprising interbedded Mudstone, Siltstone and Sandstone is anticipated to underlie the Project at the western extreme of the M6 Junction 40 to Kemplay Bank Roundabout scheme, the eastern edge of the Appleby to Brough scheme and the west of the Bowes Bypass scheme.

14.6.3.29 Further to the east, the Alston Formation comprising bioclastic limestones, sandstones, mudstones, siltstone and occasionally coal in regular cyclothemic cycles is anticipated to underlie the remainder of the A66 route.

Structural geology

14.6.3.30 The western study areas (M6 Junction 40 to Kemplay Bank, Penrith to Temple Sowerby, Temple Sowerby to Appleby and Appleby to Brough) are located within the Eden Valley which is aligned approximately northwest-southwest, is 56km long and varies in width from 5 to 15km (Butcher et al., 2006)[11].

[11] Butcher, A. & Lawrence, Adrian & Jackson, Chris & Cullis, Emma & Cunningham, Jennifer & Hasan, Kamrul & Ingram, John. (2006) Investigating rising nitrate concentrations in groundwater in the Permo-Triassic aquifer, Eden Valley, Cumbria, UK. Geological Society, London, Special Publications.

14.6.3.31 The Permo-Triassic rocks of the Eden valley lie in a fault-bounded basin located between two upland areas; the Pennines to the northeast and the Lake District to the southwest. The basin contains Permian and Triassic strata which gently dip to the north east (Lafare et al., 2014)[12].

14.6.3.32 The valley was formed by extension and rifting in the early Permian, with the Pennine Fault and associated North Pennine escarpment forming the eastern boundary in what is hypothesised to be a half-graben. To the west, the Permo-Triassic succession wedges out against Carboniferous strata (Allen et al., 1997)[13].

14.6.3.33 Moving eastwards along the route, past the Pennine Fault system, the Project overlies Carboniferous rocks of the Yoredale Group which were deposited in a series of troughs separated by higher areas, formed as extensional or transtensional features during a period of lithospheric stretching (from Late Devonian to late Visean). The east of the A66 route (i.e. Bowes Bypass to A1(M) Junction 53 Scotch Corner) sits within the Stainmore Trough; an embayment open to the east, bounded by the Alston Block to the north and Askrigg Block to the south (Stone et al., 2010)[14].

14.6.3.34 In more recent geological history, the quaternary glacial and interglacial processes have created the geomorphological setting of the region.

14.6.3.35 The majority of superficial deposits across the area are glacial in nature (i.e. Glacial Till and Glaciofluvial deposits), with more recent alluvial and river terrace deposits encountered in association with main water courses.

Regional hydrogeology

14.6.3.36 The hydrogeology along the Project is influenced by the complex relationships between aquifers, aquitards, glacial geomorphology and surface water - groundwater interactions.

Superficial deposits

14.6.3.37 Flow through the superficial deposit aquifers is dominated by intergranular flow where the permeability will support it. Groundwater

[12] Lafare, A E A, Hughes, A G, and Peach, D W. (2014) Eden Valley observation boreholes: hydrogeological framework and groundwater level time series analysis. British Geological Survey Internal Report, OR/14/041.
[13] Allen, D.J., Brewerton, L.M., Coleby, L.M., Gibbs, B.R., Lewis, M.A., MacDonald, A.M., Wagstaff, S. and Williams, A.T., (1997) The physical properties of major aquifers in England and Wales. British Geological Survey Technical Report, WD/97/34. Environment Agency R&D Publication 8.
[14] Stone, P, Millward, D, Young, B, Merritt, J W, Clarke, S M, McCormac, M and Lawrence, D J D. (2010) British regional geology: Northern England. Fifth edition. Keyworth, Nottingham: British Geological Survey

flow through the superficial deposits will be locally variable and limited to more permeable zones.

14.6.3.38 Superficial deposit aquifers are generally anticipated to be unconfined; however, heterogeneity of deposits means localised confinement of water bearing, coarse grained units is likely.

14.6.3.39 The stratigraphy of the Till deposits will be complex, with interdigitations of sand, gravel, silt and clays which may each develop their own piezometric level. Coarse grained units within the glacial deposits are likely to facilitate local zones of groundwater flow and will create zones of perched groundwater. These more permeable zones promote localised shallow groundwater flow which emerge as springs and seepages.

14.6.3.40 Glaciofluvial deposits are encountered in discrete areas along the route, but primarily at the western extreme of the Project and are likely to comprise highly permeable sand and gravel lenses which may be high yielding.

14.6.3.41 Alluvial and river terrace deposits are present across the Project, associated with main rivers, comprising a mixture of clays, silts, sands and gravels. Like Till, deposits can be complex with interdigitations of deposits which may develop separate piezometric levels. River Terrace Deposits generally comprise less fines than Alluvium and thus will be more permeable. Due to their general proximity to watercourses, the deposits may be in direct continuity with surface water features and contribute significant local baseflow.

14.6.3.42 Locally the superficial deposits are likely to confine the underlying bedrock aquifers leading to reduction in quantity of recharge that may occur.

Bedrock

14.6.3.43 The Permian strata comprises the Penrith Sandstone Formation and the Eden Shales Formation. Parts of the Eden Shale Formation have gypsum and anhydrite beds, which are designated as unproductive, although can be susceptible to dissolution.

14.6.3.44 The Penrith Sandstone Formation is highly permeable with high intergranular flow occurring except in areas where significant silica cementation has occurred. Silicified layers occur within the Penrith Sandstone Formation throughout the study area. These areas of silification planes are in the form of joint infillings or bedding-parallel horizons, which may act as barriers to flow. The Penrith Sandstone aquifer is regionally significant and is widely used for industry, public supply and small farms. Large quantities of groundwater for public supply are obtained from the aquifer.

14.6.3.45 The Penrith Sandstone Formation exhibits a dual permeability comprising of intergranular matrix flow as well as fracture flow.

Allen et al. (1997)[15] presents hydraulic conductivity of the Penrith Sandstone to be in the range of $3x10^{-4}$m/s to $4x10^{-10}$m/s, based on a compilation of laboratory testing of intergranular permeability and in-situ pumping and packer tests. Allen refers to the importance of both grain size and cementation in relation to the variation in intergranular permeability. Established large diameter boreholes within the Penrith Sandstone in the Vale of Eden typically yield up to 3,000m^3/d.

14.6.3.46 The Carboniferous strata comprises the Stainmore Formation (mudstone, siltstone and sandstone) and the Alston Formation (limestone, sandstone, siltstone and mudstone).

14.6.3.47 Locally, the limestone members include karst landforms and can include dissolution enhanced groundwater pathways, fracture flow, conduits and caves. Groundwater flow through the limestones is dominated by secondary (fracture) porosity pathways and tertiary (karstic) porosity features, so the aquifers may locally have a high permeability but overall have low storage capacity.

14.6.3.48 Limestones which are thicker and more fractured (e.g. Great Limestone Member) are expected to have higher hydraulic conductivity in comparison to thinner and less fractured units (e.g. Four Fathom Limestone Member). The density and size of fractures commonly decreases rapidly with depth, providing an effective aquifer thickness of only 50-80 m, although the actual thickness of the limestone formation may be considerably greater.

14.6.3.49 Borehole yields are highly variable within Carboniferous Limestones of the Northern Pennines. Well yields are generally in the range of 240m^3/d to 1,920m^3/d, although cases of dry boreholes with no yield are encountered and exceptionally high yields of almost 14,400m^3/d have been observed (Jones et al., 2000)[16]. As such, it is expected the hydraulic conductivity of the aquifers in the study area will also be highly variable.

14.6.3.50 Fracture flow through rock defects like joints and bedding planes is expected to be the main way groundwater will flow within carboniferous sandstone units. Compared to the limestone, sandstone is likely to have a lower hydraulic conductivity, but greater storage capacity. Siltstone and Mudstone units are generally anticipated to act as aquitards and aquicludes, although fracture flow may be observed in places.

14.6.3.51 Karst features can lead to significantly higher transmissivities in bedrocks susceptible to dissolution. See ES Appendix 14.8: Desk

[15] Allen, D.J., Brewerton, L.M., Coleby, L.M., Gibbs, B.R., Lewis, M.A., MacDonald, A.M., Wagstaff, S. and Williams, A.T., (1997) The physical properties of major aquifers in England and Wales. British Geological Survey Technical Report, WD/97/34. EA R&D Publication 8.

[16] Jones, H K, Morris, B L, Cheney, C S, Brewerton, L J, Merrin, P D, Lewis, M A, MacDonald, A M, Coleby, L M, Talbot, J C, McKenzie, A A, Bird, M J, Cunningham, J, and Robinson, V K (2000) The physical properties of minor aquifers in England and Wales. British Geological Survey Technical Report, WD/00/4. 234pp. Environment Agency R and D Publication 68.

Study Karst Risk Assessment (Application Document 3.4) for further details on the dissolution features along the scheme.

Recharge

14.6.3.52 The presence of superficial deposits over the majority of the region will limit the rate of infiltration into the bedrock. Vines (1984)[17] estimated that the recharge rate through till to Permo-Triassic sandstones was in the order of 50 mm/year.

14.6.3.53 Rainfall in the western half of the route is high; with the average annual rainfall approximately 1,000mm/yr in the Eden Valley and in excess of 1,500mm/yr on adjacent higher ground (Butcher et al., 2006)[18]. Moving eastwards average annual rainfall reduces.

14.6.3.54 Superficial deposit aquifers will be recharged by a variety of mechanisms including rainfall infiltration, run off from lower permeability units upgradient and groundwater draining from aquifers higher in the landscape.

Local geology and hydrogeology

14.6.3.55 This section details the local geology within each Project study area as determined by desk study and the site-specific ground investigation. In addition, this section details local receptors (abstractions, discharges and surface water features) determined through desk study and site walkovers.

14.6.3.56 Impacts to Groundwater dependent terrestrial ecosystems (GWDTEs) are assessed separately in ES Appendix 14.7 Groundwater Dependent Terrestrial Ecosystem Assessment (Application Document 3.4).

14.6.3.57 More detailed discussion on the hydrogeological results from the ground investigation works (e.g. water levels, water quality and in-situ testing) is documented in sections 14.6.4, 14.6.5 and 14.6.6 of this report.

M6 Junction 40 to Kemplay Bank

14.6.3.58 The distribution of surface superficial deposits and bedrock at rockhead is shown in ES Figure 9.2 Published Geology - Superficials Geolgy and ES Figure 9.3: Published Geology - Bedrock Geology (Application Document 3.3) respectively.

14.6.3.59 Within the Eden Valley, the valley floor is underlain by Permo-Triassic Sandstone (Penrith Sandstone) which forms the major aquifer in the region. Approximately 20% of the sandstone outcrop is free of superficial deposits, with the remainder covered by various superficial

[17] Vines, K. J. (1984) Drift Recharge. North West Water Hydrogeological Report No. 145
[18] Butcher, A. & Lawrence, Adrian & Jackson, Chris & Cullis, Emma & Cunningham, Jennifer & Hasan, Kamrul & Ingram, John. (2006) Investigating rising nitrate concentrations in groundwater in the Permo-Triassic aquifer, Eden Valley, Cumbria, UK. Geological Society, London, Special Publications.

deposits including Till (dominant), glacial sands and gravels and river alluvium (Butcher et al., 2008)[19].

14.6.3.60 Geological mapping indicates that the study area is primarily underlain by till deposits, which are inherently variable in composition ranging from clays to gravels.

14.6.3.61 Alluvium and River Terrace deposits associated with the River Eamont and River Lowther area are mapped in the south of the study area, and in the east of the studay area associated with Thacka Beck.

14.6.3.62 Glaciofluvial deposits, comprising sand and gravel, are mapped in discrete areas mostly on the northern side of the River Eamont alluvium.

14.6.3.63 The west of the study area is primarily underlain by the Stainmore Formation, except the very western extreme of the study area which is potentially underlain by the Alston Formation. A fault striking north-west to south-east is located at this geological boundary. Mudstones and siltstones within the formations are likely to act as aquitards separating the more permeable limestone and sandstone formations.

14.6.3.64 The Permian aged, coarse grained Penrith Sandstone Formation underlies the study area in the east of the scheme.

14.6.3.65 Groundwater flow through the sandstone and limestone members is likely to be dominated by fracture flow along defects such as bedding planes and joints within the rock mass. The limestones may also include karst features, where fractures are enhanced by dissolution and provide wider flow paths for groundwater in the rock mass. Where mudstones and siltstones are absent at the geological contact between the formations, the formations will be hydraulically connected.

14.6.3.66 The 2021 site investigation documented the presence of Made Ground in the western end of the area (the M6 Junction 40). This was generally underlain by cohesive Glacial Till deposits.

14.6.3.67 Moving eastwards towards the Kemplay Bank Roundabout, more granular Glacial Till deposits were encountered, together with significant Glaciofluvial deposits identified at the location of the Kemplay Bank Roundabout underpass. Particle Size Distribution curves indicate very low fines in these glaciofluvial deposits (i.e. the deposits are likely to be highly permeable).

14.6.3.68 No Alluvium, River Terrace Deposits or bedrock were identified in the site investigation boreholes in the M6 Junction 40 to Kemplay Bank area.

14.6.3.69 The majority of cuttings in the Order limits are primarily related to widening of existing cuttings, with the main exception being the Kemplay Bank Underpass. All cuttings are anticipated to be fully

[19] Butcher, A. & Lawrence, A. & Mansour, Majdi & Burke, Sean & Ingram, J. & Merrin, P. (2008) Investigation of rising nitrate concentrations in groundwater in the Eden Valley, Cumbria. 2, unsaturated zone studies.

within the superficial deposits with bedrock not anticipated to be encountered in the scheme.

14.6.3.70 A summary of the hydrostratigraphy in the M6 Junction 40 to Kemplay Bank Roundabout study area is documented below in Table 3: Summary of hydrostratigraphy in the M6 Junction 40 to Kemplay Bank Roundabout Project study area.

Table 3: Summary of hydrostratigraphy in the M6 Junction 40 to Kemplay Bank Roundabout Project study area

Age	Group	Formation	Environment Agency designation	Description	Hydrogeological Properties
Quaternary	-	Alluvium	Secondary A aquifer	Unconsolidated clay, silt, sand and gravel.	Variable hydraulic conductivity. Groundwater flow though intergranular matrix.
		River terrace deposits	Secondary A aquifer	Stratified, well sorted sand and gravel deposits	Groundwater flow though intergranular matrix.
		Glaciofluvial deposits	Secondary A aquifer	Stratified, well sorted sand and gravel deposits.	Groundwater flow though intergranular matrix.
		Till	Secondary (undifferentiated) aquifer	Stiff, silty sandy clay to friable clayey sand, with pockets of medium and fine-grained sand and gravel.	Variable hydraulic conductivity. Groundwater flow though intergranular matrix.
Permian	Appley Group	Penrith Sandstone Formation	Principal aquifer	Red to red-brown in colour, consisting of well-sorted, medium to coarse grains. Less Well-sorted, fine to coarse grained sandstone beds with thin mudstone intercalation are common.	Major aquifer of the Eden valley, characterised by moderate-high permeability and porosity. Flow is dominated by intergranular flow, as fractures are not well connected. Horizontally and vertically heterogenous in cementation and grain size.
Carboniferous (Namurian)	Yoredale Group	Stainmore Formation	Secondary A aquifer	Cyclical repetition of sandstones, siltstones, mudstones, thin limestones and some coals	Moderately permeable. Generally, flow occurs as fracture flow. The interbedded nature of the formation leads to

Age	Group	Formation	Environment Agency designation	Description	Hydrogeological Properties
					groundwater occurring in limestone and sandstone units, but the siltstone and mudstones act as barrier. Limestone units have potential for solutional enlargement (karst) and may include conduits or caves.
Carboniferous (Visean, Namurian)		Alston Formation (Members include: Five Yard Limestone, Scar Limestone, Single Post Limestone, Tynebottom Limestone, Jew Limestone)	Secondary A aquifer	Bioclastic limestones, sandstones, mudstones, siltstones and rare coals typically in regular cyclothemic sequence	

14.6.3.71 Hydrogeological features within the study area are illustrated in ES Figure 14.6: Hydrogeological Study Areas and Features (Application Document 3.3) and discussed in further detail below.

14.6.3.72 There are two licensed abstraction wells in the M6 to Kemplay Bank study area:

- *Abstraction well 2776004056/R01 at Penrith Industrial Estate*
- *Abstraction well 277600644 at Penrith and District Farmers Auction Mart*

14.6.3.73 The above abstraction wells are both currently in use and are understood to abstract from the Penrith Sandstone bedrock at depth.

14.6.3.74 The Environment Agency protects groundwater sources used to supply drinking water from pollution by defining source protection zones, which show the level of risk to the source from contamination. The three main zones are Zone I (inner), Zone II (outer) and Zone III (total catchment).

14.6.3.75 The east of the study area is located within Source Protection Zone III; associated with large abstractions to the north of Penrith outside the study area. It is understood that these abstractions are Public Water Supply abstractions from the Penrith Sandstone aquifer.

14.6.3.76 There are potentially a number of smaller private domestic, commercial and agricultural unlicensed supplies within the scheme study area, which are assumed to abstract less than 20 m^3/d. Unlicensed abstraction data was requested from all local councils but only provided by Durham County Council at the time of this report. As such, it is assumed that each property has the potential to include a small private groundwater supply.

14.6.3.77 A consented discharge has been identified in Environment Agency data within the study area and order limits. As shown in Table 4: Consented discharges within the M6 Junction 40 to Kemplay Bank Project study area this discharge is associated with a United Utilities storm tank/combined sewage overflow (CSO). Additional discharges in the area were scoped out from further assessment due to lack of hydraulic continuity (see Table 5: Scoped out features within the M6 Junction 40 to Kemplay Bank Project study area).

Table 4: Consented discharges within the M6 Junction 40 to Kemplay Bank Project study area

Site Name	Licence Status	Description
Carleton Hall Templebank CSO (Ref. NPSWQD002845)	Active	Storm Tank/CSO on Sewerage Network (water company)

14.6.3.78 The River Eamont, a tributary to the River Eden, is located within the study area and flows parallel to the existing A66. The river is designated within the River Eden Special Area of Conservation (SAC) and River Eden and Tributaries Site of Special Scientific Interest (SSSI). A number of smaller watercourses also flow through the study area, eventually flowing into the River Eamont to the south west of the existing A66. See ES Chapter 14: Road Drainage and the

Water Environment (Application Document 3.2) for further details on the watercourses.

14.6.3.79 No groundwater-surface water interactions (e.g. springs or seepages) are mapped within the study area. Springs and seepages are likely to be present; particularly in the banks of the rivers and below the river level of the River Eamont and River Lowther. The River Eamont and River Lowther will receive groundwater baseflow from the superficial deposits and bedrock formations.

14.6.3.80 The features identified in Table 5: Scoped out features within the M6 Junction 40 to Kemplay Bank Project study area were scoped out from further assessment due to not being in hydraulic continuity with the scheme as documented below. Reasons for features being considered to not be in hydraulic continuity with the scheme include being in different geological strata to the scheme, in different surface water catchments, being upgradient or upstream of the scheme or being at significant distance from locations where new cuttings are to be constructed or where existing cuttings are to be modified.

Table 5: Scoped out features within the M6 Junction 40 to Kemplay Bank Project study area

Feature	Description	Reason for Descoping
Consented Discharge - 01EDE0036	Penrith Grammar School - Storm Tank/CSO on Sewerage Network (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 01EDE0035	Castle Hill Drive - Storm Tank/CSO on Sewerage Network (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 017680334	Brougham Pumping Station - Pumping Station on Sewerage Network (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 017680281	Penrith Outfall CSO - Storm Tank/CSO on Sewerage Network (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 017690501	Moor House - WwTW (not water co) (not STP at a private premises)	Not in hydraulic continuity with scheme
Consented Discharge - NPSWQD000013	Yanwath School - Education/Nursery Venue	Not in hydraulic continuity with scheme

Penrith to Temple Sowerby

14.6.3.81 The distribution of surface superficial deposits and bedrock at rockhead is shown in ES Figure 9.2: Published Geology - Superficial Geology and ES Figure 9.3: Published Geology - Bedrock Geology (Application Document 3.3) respectively.

14.6.3.82 Within the Eden Valley, the valley floor is underlain by Permo-Triassic Sandstone (Penrith Sandstone) which forms the major aquifer in the region. Approximately 20% of the sandstone outcrop is free of superficial deposits, with the remainder covered by various superficial deposits including Till (dominant), glacial sands and gravels and river alluvium.

14.6.3.83 Geological mapping indicates that the study area is primarily underlain by till deposits. The stratigraphy of the Till superficial deposits may be complex, with interdigitations of sand, gravel, silt and clay which may each develop their own piezometric level, resulting in perched water tables.

14.6.3.84 Alluvium and River Terrace Deposits related to water courses (e.g. Light Water, Swine Gill etc.) are also mapped which intersect the A66 alignment.

14.6.3.85 Peat deposits are mapped to the north of the study area, whilst Fluvioglacial deposits are mapped immediately north of the A66 road adjacent to Light Water.

14.6.3.86 The bedrock geology along the entire section is mapped as Penrith Sandstone. Literature indicates that in the study area the Penrith Sandstone Formation is in excess of 100m thick and underlain by Carboniferous limestone basement rock[20].

14.6.3.87 Extensional normal faults are present in the Vale of Eden, with sets trending west-north-west and north-north. Faults and their associated zones may either result in areas of enhanced flow, or locally can form barriers to flow.

14.6.3.88 The 2021 site investigation documents the presence of Glacial Till beneath the majority of the Penrith to Temple Sowerby area; a mixture of both granular and cohesive deposits.

14.6.3.89 Alluvium and Fluvioglacial deposits were both identified during the site investigation in discrete areas.

14.6.3.90 Alluvial deposits were primarily encountered as a relatively small bed at the location of Light Water and northwest of Whinfell Park (where anticipated from BGS mapping).

14.6.3.91 Fluvioglacial deposits were encountered more extensively at the western edge of the study area (east of the River Eamont), east of Light Water (where mapped previously by the BGS), along the northern edge of Whinfell Park and as a minor bed northeast of Whinfell House.

14.6.3.92 No River Terrace Deposits or Peat were identified in the site investigation boreholes in this area.

14.6.3.93 Bedrock belonging to the Penrith Sandstone Formation was identified beneath the Penrith to Temple Sowerby section as a reddish brown fine to coarse sandstone with bedding near horizontal.

14.6.3.94 Where bedrock was encountered by site investigation boreholes, it was at a relatively shallow depth (less than 10m deep, occasionally

[20] Bott, MHP (1974) The geological interpretation of a gravity survey of the English Lake District and the Vale of Eden Journal of the Geological Society (London) 130, 309-331

less than 5m deep). Commonly the bedrock was overlain by sand deposits (hypothesised to be weathered bedrock).

14.6.3.95 The majority of cuttings in the Order limits are extensions of existing cuttings and are anticipated to be fully within the superficial deposits. Bedrock may be encountered during the construction of the Whinfell Park Accommodation Underpass.

14.6.3.96 A summary of the hydrostratigraphy in the Penrith to Temple Sowerby scheme is documented below in Table 6: Summary of hydrostratigraphy in the Penrith to Temple Sowerby Project study area.

Table 6: Summary of hydrostratigraphy in the Penrith to Temple Sowerby Project study area

Age	Group	Formation	EA Designation	Description	Hydrogeological Properties
Quaternary	Till	-	Secondary (undifferentiated) Aquifer	Stiff, silty sandy clay to friable clayey sand, with pockets of medium and fine-grained sand and gravel.	Variable hydraulic conductivity. Groundwater flow though intergranular matrix.
	Glacio-Fluvial Deposits (Sand and Gravel)		Secondary A Aquifer	Stratified, well sorted sand and gravel deposits	Groundwater flow though intergranular matrix.
	Alluvium		Secondary A Aquifer	Unconsolidated clay, silt, sand and gravel.	Variable hydraulic conductivity. Groundwater flow though intergranular matrix.
	Peat		Unproductive	A partially decomposed mass of semi-carbonised vegetation which has grown under waterlogged, anaerobic conditions, usually in bogs or swamps.	-
Permian	Appleby	Penrith Sandstone	Principal Aquifer	Red to red-brown in colour, consisting of well-sorted, medium to coarse grains. Less Well-sorted, fine to coarse grained sandstone beds with thin mudstone intercalation are common.	Mostly highly permeable, but with local cemented zones where permeability is reduced. Productive highly yielding aquifer.

14.6.3.97 Hydrogeological features within the study area are illustrated in ES Figure 14.6: Hydrogeological Study Areas and Features (Application Document 3.3) and discussed in further detail below.

14.6.3.98 No licensed abstraction wells are located within the Penrith to Temple Sowerby study area. There are potentially a number of smaller private domestic, commercial and agricultural unlicensed supplies within the scheme study area, which are assumed to abstract less than 20 m^3/d. It is assumed that each property has the potential to include a small private groundwater supply.

14.6.3.99 The western edge of the study area is located within Source Protection Zone (SPZ) III; the same SPZ as identified in the M6 Junction 40 the Kemplay Bank area.

14.6.3.100 All consented discharges within the study area have been scoped out as they are considered to not be in hydraulic continuity with the scheme (see Table 7: Scoped out features within the Penrith to Temple Sowerby Project study area).

14.6.3.101 The River Eamont (a tributary of the River Eden) is within the study area and designated within the River Eden SAC and River Eden and Tributaries SSSI. The existing A66 crosses the River Eamont at Brougham Castle immediately west of the section; with the Eamont then flowing in a westerly direction towards the River Eden to the north of the A66.

14.6.3.102 A number of smaller watercourses also flow through the study area (including several which cross the A66 route), eventually flowing northwards into the River Eamont. See ES Chapter 14: Road Drainage and the Water Environment of the ES (Application Document 3.2) for further details on the watercourses.

14.6.3.103 A single groundwater-surface water interaction (e.g. springs or seepages) was identified during the desk study phase in this area (S29) which was subsequently scoped out following a site visit which identified land drainage confirming that the feature was not a groundwater-surface water interaction. Other springs and seepages are likely to be present in the area; particularly in the banks of the rivers and below the river level of the River Eamont. The River Eamont and its various tributaries are likely to receive groundwater baseflow from the superficial deposits and bedrock formations, as well as surface water runoff.

14.6.3.104 The features identified in Table 7: Scoped out features within the Penrith to Temple Sowerby Project study area were scoped out from further assessment due to not being in hydraulic continuity with the scheme as documented below:

Table 7: Scoped out features within the Penrith to Temple Sowerby Project study area

Feature	Description	Reason for Descoping
Spring - S29	Surveying indicated most likely to be land drainage, which ultimately feeds into river downstream.	Not in hydraulic continuity with scheme
Consented Discharge - 01523	Winderwath - Domestic property (single) (incl farmhouse)	Not in hydraulic continuity with scheme
Consented Discharge - 01524	Winderwath Cottages - Domestic property (multiple) (incl farmhouses)	Not in hydraulic continuity with scheme
Consented Discharge - 01522	1 – 4 Swinegill Cottages - Domestic property (multiple) (incl farmhouses)	Not in hydraulic continuity with scheme
Consented Discharge - 017670084	Penrith WwTW - WwTW/Sewerage Treatment Works (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 017690510	Sceugh Farm - WwTW (not water co) (not STP at a private premises)	Not in hydraulic continuity with scheme
Consented Discharge - 017680281	Penrith Outfall CSO - Storm Tank/CSO on Sewerage Network (water company)	Not in hydraulic continuity with scheme
Consented Discharge - NPSWQD002845	Carleton Hall Templebank CSO - Storm Tank/CSO on Sewerage Network (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 017680334	Brougham Pumping Station - Pumping Station on Sewerage Network (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 01360	Fremington - WwTW (not water co) (not STP at a private premises)	Not in hydraulic continuity with scheme

Temple Sowerby to Appleby

14.6.3.105 The distribution of surface superficial deposits and bedrock at rockhead is shown in ES Figure 9.2: Published Geology - Superficial Geology and ES Figure 9.3: Published Geology - Bedrock Geology (Application Document 3.3) respectively.

14.6.3.106 Within the Eden Valley, the valley floor is underlain by Permo-Triassic Sandstone (Penrith Sandstone) which forms the major aquifer in the region. Approximately 20% of the sandstone outcrop is free of superficial deposits, with the remainder covered by various superficial deposits including Till (dominant), glacial sands and gravels and river alluvium.

14.6.3.107 The superficial deposits in this section are predominantly glacial in origin, formed by the action of the ice sheets during the Ice Ages. The glaciation and deposits associated with it control the topography of the area where drumlins have been formed; notably between Kirkby Thore and Brough. The principal axes trend roughly north west to south east and the formed hills can be up to 30 or 40m in height.

14.6.3.108 Geological mapping indicates that the majority of the study area is underlain by till deposits. In the study area, the stratigraphy of the till superficial deposits may be complex, with interdigitations of sand, gravel, silt and clay which may each develop their own piezometric level, resulting in perched water tables.

14.6.3.109 Alluvium deposits associated with surface water features in the west of the study area and the River Eden are also mapped intersecting the study area. In these areas, it is likely that groundwater levels are linked to groundwater-surface water interactions with the associated surface watercourses.

14.6.3.110 Due to their variability, the superficial deposits are anticipated to exhibit heterogeneity and anisotropic behaviour; particularly in the till.

14.6.3.111 Mapping indicates Penrith Sandstone underlies the majority of the study area with the Eden Shales Formation underlying the northern part of the study area. The majority of the Project is anticipated to be constructed on the Penrith Sandstone Formation, with only some auxiliary roads (such as farm access roads off the main alignment) potentially constructed in the location of the Eden Shales Formation.

14.6.3.112 The Penrith Sandstone is a significant regional aquifer and is widely utilised for industry, public supply and agriculture. BGS boreholes in the study area indicate that the Penrith Sandstone is in excess of 50m thick and underlain by the Middle Coal Measures Carboniferous limestone basement rock[21].

14.6.3.113 Gypsum and anhydrite bearing strata are located within the Eden Shales Formation, with mining undertaken in the area for Alabaster/Gypsum since the 18th century. Gypsum and anhydrite are generally unproductive strata but have a tendency to form dissolution features when they are in contact with groundwater. See ES Appendix 14.8: Desk Study Karst Risk Assessment (Application Document 3.4) for further details on the dissolution features in this area.

14.6.3.114 Faults are mapped in the area, with sets primarily trending north-north-west; associated with extensional normal faulting in the Vale of Eden. These faults and their associated zones may result in an area of enhanced flow or locally act as barriers to flow.

14.6.3.115 Glacial deposits were identified during site investigation works along the route comprising a mixture of cohesive and granular deposits, with granular deposits most prevalent in the western extreme of the study area.

[21] British Geological Survey (2022) BH References: NY62NW490, NY62SW15, NY62NW606. Borehole Scan Viewer

14.6.3.116 No alluvium, river terrace deposits or glaciofluvial deposits were identified along the alignment; however, it should be noted that no site investigation has been undertaken at this stage in the valley where Trout Beck is located (between Chainage 33350 and 34550). As such, conservative assumptions have been utilised where site investigation data is limited.

14.6.3.117 Sand deposits were commonly identified above the bedrock; most likely weathered Penrith Sandstone bedrock.

14.6.3.118 Bedrock generally comprising the Penrith Sandstone was encountered at variable depths along the alignment, dependent on the topography. At its shallowest, bedrock was encountered within a couple of metres of the ground level (towards the west of the study area).

14.6.3.119 Bedrock of the Eden Shales Formation was identified in a number of boreholes north of the A66 alignment. At present, no cuttings are envisioned to encounter the Eden Shales.

14.6.3.120 Bedrock depth was not proven east of Powis House.

14.6.3.121 Significant sections of this scheme are offline, including the Kirkby Thore Bypass which involves the most significant cutting of the Project. Cuttings are anticipated to be primarily within glacial deposits, although bedrock is anticipated to be encountered at the base of some cuttings within the scheme.

14.6.3.122 A summary of the hydrostratigraphy in the Temple Sowerby to Appleby area is documented below in Table 8: Summary of hydrostratigraphy in the Temple Sowerby to Appleby Project study area.

Table 8: Summary of hydrostratigraphy in the Temple Sowerby to Appleby Project study area

Age	Group	Formation	EA Designation	Description	Hydrogeological Properties
Quaternary	Till	-	Secondary (undifferentiated) Aquifer	Stiff, silty sandy clay to friable clayey sand, with pockets of medium and fine-grained sand and gravel.	Variable hydraulic conductivity. Groundwater flow though intergranular matrix.
	Glacio-Fluvial Deposits (Sand and Gravel)		Secondary A Aquifer	Stratified, well sorted sand and gravel deposits	Groundwater flow though intergranular matrix.
	Alluvium		Secondary A Aquifer	Unconsolidated clay, silt, sand and gravel.	Variable hydraulic conductivity. Groundwater flow though intergranular matrix.
	Peat		Unproductive	A partially decomposed mass of semi-carbonised vegetation which has grown under waterlogged, anaerobic conditions, usually in bogs or swamps.	-
Permian	Cumbrian Coast	Eden Shale	Secondary B Aquifer	Red shales and mudstones with local beds of gypsum and anhydrite, rare dolomitic limestones.	Leaky aquitard, low permeability. Gypsum/anhydrite presence may impact water quality at edge of adjacent aquifers.

Age	Group	Formation	EA Designation	Description	Hydrogeological Properties
	Appleby	Penrith Sandstone	Principal Aquifer	Red to red-brown in colour, consisting of well-sorted, medium to coarse grains. Less Well-sorted, fine to coarse grained sandstone beds with thin mudstone intercalation are common.	Mostly highly permeable, but with local cemented zones. Productive highly yielding aquifer.

14.6.3.123 Hydrogeological features within the study area are illustrated in ES Figure 14.6: Hydrogeological Study Areas and Features (Application Document 3.3) and discussed in further detail below.

14.6.3.124 No source protection zones are located within the study area, however there are five licensed abstractions:

- *Agricultural abstraction well (*Licence number: *2776003013) at Spittals Farm -* Permo-triassic Sandstone
- *Agricultural abstraction well (*Licence number: *2776003012/R01) in Kirkby Thore -* Permo-Triassic Sandstone
- *Two Industrial abstraction wells (*Licence number: *277600311) in Kirkby Thore -* Permo-Triassic Sandstone
- *One industrial surface water abstraction (*Licence number: *2776003009) in Kirkby Thore.*

14.6.3.125 During consultation, an additional unlicensed private abstraction was identified in the study area utilised for residential and commercial water supply proximal to Sleastonhow Farm.

14.6.3.126 There are potentially a number of additional private domestic, commercial and agricultural unlicensed supplies within the scheme study area, which are assumed to abstract less than 20 m^3/d. It is assumed that each property has the potential to include a small private groundwater supply.

14.6.3.127 All consented discharges within the study area have been scoped out as they are considered to not be in hydraulic continuity with the scheme (see Table 9: Scoped out features within the Temple Sowerby to Appleby Project study area).

14.6.3.128 The River Eden and Trout Beck (a significant tributary to the River Eden) are located within the scheme study area. Both watercourses are designated within the River Eden SAC and River Eden and Tributaries SSSI. The new A66 diversion around Kirkby Thore will include a crossing of Trout Beck.

14.6.3.129 To the east of Temple Sowerby and 350m north of the existing A66, within the study area, is the Temple Sowerby Moss SSSI. This site is within a slight topographical depression in the glacial deposits over an area of Penrith Sandstone and is notable for the development of its fen communities.

14.6.3.130 A number of smaller watercourses also flow through the study area draining into the River Eden via a number of tributaries. See ES Chapter 14: Road Drainage and the Water Environment (Application Document 3.2) for further details on the watercourses.

14.6.3.131 All mapped groundwater-surface water interactions (e.g. springs or seepages) within the study area have been scoped out as they are considered to not be in hydraulic continuity with the scheme (see Table 9: Scoped out features within the Temple Sowerby to Appleby Project study area). Other springs and seepages are likely to be present; particularly in the banks of the rivers and below the river level of the River Eden and Trout Beck. The River Eden and its various tributaries are likely to receive groundwater baseflow from the superficial deposits and bedrock formations, as well as surface water runoff.

14.6.3.132 The features identified in Table 9: Scoped out features within the Temple Sowerby to Appleby Project study area were scoped out from further assessment due to not being in hydraulic continuity with the scheme as documented below.

Table 9: Scoped out features within the Temple Sowerby to Appleby Project study area

Feature	Description	Reason for Descoping
Spring - S24	Spring from bedrock which feeds into Unnamed Tributary of Trout Beck 4.3	Not in hydraulic continuity with scheme
Spring - S26	Boggy ground with iron oxide presence indicative of spring, but no flowing water observed	Not in hydraulic continuity with scheme
Spring - S27	No land access to potential groundwater-surface water interaction.	Not in hydraulic continuity with scheme
Spring - S28	No land access to potential groundwater-surface water interaction.	Not in hydraulic continuity with scheme
Abstraction License - 2776001134/R01	Agricultural abstraction well west of Appleby. Pumping from ‘Millstone Grit and Coal Measures’ aquifer (now known as Stainmore Formation)	Not in hydraulic continuity with scheme
Consented Discharge - 017670014	Kirkby Thore STW - WwTW/Sewerage Treatment Works (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 017680336	Kirkby Thore PS - Pumping Station on Sewerage Network (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 017690641	Bolton Mill Caravan Park - Holiday Accom/Camp Site/Caravan Site/Hotel/Hostel	Not in hydraulic continuity with scheme
Consented Discharge - 01417	Stamphill Mine - Mineral/Gravel/Extraction/Quarrying	Not in hydraulic continuity with scheme
Consented Discharge - 017690248	Stamphill Mine - Mining of Coal + Lignite	Not in hydraulic continuity with scheme
Consented Discharge - 017690390	The Stackyard - Food + Beverage Services/Café/Restaurant/Pub	Not in hydraulic continuity with scheme
Consented Discharge - 017690132	Hall Farmhouse - WwTW (not water company) (not STP at a private premises)	Not in hydraulic continuity with scheme
Consented Discharge - 017670016	Long Marton West STW - WwTW/Sewerage Treatment Works (water company)	Not in hydraulic continuity with scheme

Feature	Description	Reason for Descoping
Consented Discharge - 017670001	Appleby WwTW - WwTW/Sewerage Treatment Works (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 017680301	Appleby CSO - Storm Tank/CSO on Sewerage Network (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 017690453	Roman Road Campsite - Holiday Accom/Camp Site/Caravan Site/Hotel/Hostel	Not in hydraulic continuity with scheme
Consented Discharge - 01EDE0106	Butts Car Park - Storm Tank/CSO on Sewerage Network (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 017670042	Temple Sowerby STW - WwTW/Sewerage Treatment Works (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 01EDE0013	Chapel St (Temple Sowerby CSO) - Pumping Station on Sewerage Network (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 017670015	Long Marton East STW - WwTW/Sewerage Treatment Works (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 017670002	Bolton Penrith WwTW - WwTW/Sewerage Treatment Works (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 017670168	Hole St/Chapel St SSO - Storm Tank/CSO on Sewerage Network (water company)	Not in hydraulic continuity with scheme

Appleby to Brough

14.6.3.133 The distribution of surface superficial deposits and bedrock at rockhead is shown in ES Figure 9.2: Published Geology - Superficial Geology and ES Figure 9.3: Published Geology - Bedrock Geology (Application Document 3.3) respectively.

14.6.3.134 Within the Eden Valley, the valley floor is underlain by Permo-Triassic Sandstone (Penrith Sandstone) which forms the major aquifer in the region. Approximately 20% of the sandstone outcrop is free of superficial deposits, with the remainder covered by various superficial deposits including Till (dominant), glacial sands and gravels and river alluvium.

14.6.3.135 In the region, the superficial cover is generally thin; comprising Till deposits, less than 2.0m thick over the majority of the area. However, the superficials can be significantly thicker; around Appleby and to the west of Brough a distinctive 'hummocky' topography with mounds in excess of 30m of relief can be identified (Wang and Burke, 2016)[22].

14.6.3.136 In the Project study area, the stratigraphy of the till superficial deposits may be complex, with interdigitations of sand, gravel, silt and clay which may each develop their own piezometric level, resulting in perched water tables. It is noted in the area that the till can be surprisingly sandy in composition (i.e. permeable) (Butcher, 2008)[23].

14.6.3.137 Alluvium deposits associated with surface water features are also mapped intersecting the study area and crossing the A66 in various locations. In these areas, it is likely that groundwater levels are linked to groundwater-surface water interactions with the associated surface watercourses.

14.6.3.138 An expansive area of River Terrace Deposits is mapped in the east of the study area, associated with the River Eden.

14.6.3.139 Peat and glaciofluvial deposits are also mapped within the study area, primarily to the southwest of the route in the west (e.g. around Sandford Mire). However, no peat or glaciofluvial deposits are mapped beneath the A66 alignment.

14.6.3.140 Due to their variability, the superficial deposits are anticipated to exhibit heterogeneity and anisotropic behaviour, particularly in the till.

14.6.3.141 As noted previously, the majority of the study area is underlain by the Penrith Sandstone formation; a significant regional aquifer widely utilised for industry, public supply and agriculture.

14.6.3.142 At the eastern end of the study area (around Brough) the scheme crosses the Pennine Fault, and is subsequently underlain by the Carboniferous Stainmore Formation, comprising cyclical repetition of sandstones, siltstone, mudstones, limestones and occasionally coal.

14.6.3.143 The 2021 site investigation documents the presence of Glacial Till beneath the majority of the Appleby to Brough area; a mixture of both granular and cohesive deposits.

14.6.3.144 Fluvioglacial deposits and sand deposits were encountered along the route at locations proximal to water courses including around Cringle Beck, Moor Beck and Low Gill.

14.6.3.145 Bedrock belonging to the Penrith Sandstone Formation (including the Brockram Conglomerate) was identified in discrete areas beneath the study area. Where bedrock was encountered by site investigation boreholes, it was at a relatively shallow depth (less than 10m deep, occasionally less than 5m deep). Commonly the bedrock was overlain by sand deposits (assumed to be weathered bedrock).

[22] Wang L, Burke S, (2016) A catchment-scale method to simulating the impact of historical nitrate loading from agricultural land on the nitrate-concentration trends in the sandstone aquifers in the Eden Valley, UK Science of the Total Environment

[23] Butcher A, Lawrence A, Jackson C, Cullis E, Cunningham J, Hasam K, Ingram J, (2008) Investigation of Rising Nitrate Concentrations in Groundwater in the Eden Valley, Cumbria, British Geological Survey Commissions Report No. OR/08/024

14.6.3.146 The majority of cuttings in this section of the Order Limits are anticipated to be fully within the superficial deposits (predominantly Glacial Till but occasionally Fluvioglacial Deposits). Bedrock may be encountered during a number of cuttings including cuttings at the eastern end of the Appleby to Brough Order Limits where bedrock is at its shallowest.

14.6.3.147 A summary of the hydrostratigraphy in the Appleby to Brough area is documented below in Table 10: Summary of hydrostratigraphy in the Appleby to Brough Project study area.

Table 10: Summary of hydrostratigraphy in the Appleby to Brough Project study area

Age	Group	Formation	EA Designation	Description	Hydrogeological Properties
Quaternary	Till	-	Secondary (undifferentiated) Aquifer	Stiff, silty sandy clay to friable clayey sand, with pockets of medium and fine grained sand and gravel.	Variable hydraulic conductivity. Groundwater flow though intergranular matrix.
	Glacio-Fluvial Deposits (Sand and Gravel)		Secondary A Aquifer	Stratified, well sorted sand and gravel deposits	Groundwater flow though intergranular matrix.
	Alluvium		Secondary A Aquifer	Unconsolidated clay, silt, sand and gravel.	Variable hydraulic conductivity. Groundwater flow though intergranular matrix.
	Peat		Unproductive	A partially decomposed mass of semi-carbonized vegetation which has grown under waterlogged, anaerobic conditions, usually in bogs or swamps.	-
Permian	Cumbrian Coast	Eden Shale	Secondary B Aquifer	Red shales and mudstones with local beds of gypsum and anhydrite, rare dolomitic limestones.	Leaky aquitard, low permeability. Gypsum/anhydrite presence may impact water quality at edge of adjacent aquifers.
	Appleby	Penrith Sandstone	Principal Aquifer	Red to red-brown in colour, consisting of well-sorted, medium to coarse grains. Less Well-sorted, fine to coarse grained sandstone beds with thin mudstone intercalation are common.	Mostly highly permeable, but with local cemented zones. Productive highly yielding aquifer.

Age	Group	Formation	EA Designation	Description	Hydrogeological Properties
Carboniferous (Namurian)	Stainmore Formation	Yoredale	Secondary A Aquifer	Cyclical repetition of sandstones, siltstones, mudstones, thin limestones and some coals	Moderately permeable. Generally flow occurs as fracture flow. The interbedded nature of the formation leads to groundwater occurring in limestone and sandstone units but the siltstone and mudstones act as barriers

14.6.3.148 Hydrogeological features within the Project study area are illustrated in ES Figure 14.6: Hydrogeological Study Areas and Features (Application Document 3.3) and discussed in further detail below.

14.6.3.149 No SPZs are located within the study area, however there are two licensed groundwater abstractions:

- Eastfield Farm (Licence Number: NW/076/0001/009) – Permo-Triassic Sandstone
- Borehole at West View Brough, Kirkby Stephen (Licence number: 2776001135/R01) – Permo-Triassic Sandstone.

14.6.3.150 There are potentially a number of smaller private domestic, commercial and agricultural unlicensed supplies within the scheme study area, which are assumed to abstract less than 20 m^3/d. It is assumed that each property has the potential to include a small private groundwater supply.

14.6.3.151 A consented discharge has been identified in Environment Agency data within the study area, as shown in Table 11: Consented discharges within the Appleby to Brough Project study area.

Table 11: Consented discharges within the Appleby to Brough Project study area

Site Name	Licence Status	Description
Warcop Camp STW (Ref. 017670162)	Active	WwTW/Sewerage Treatment Works (water company)

14.6.3.152 The study area is located on the southern boundary of the North Pennines Area of Outstanding Natural Beauty (AONB), with the following designations relating to the water environment falling into the eastern extent of the study area:

- The North Pennine Moors Special Protection Area (SPA)
- The North Pennine Moors SAC.

14.6.3.153 The River Eden and a number of its tributaries are within the Project study area, with the extent of the River Eden and a large number of its tributaries designated as the River Eden SAC and River Eden and Tributaries SSSI.

14.6.3.154 A number of smaller watercourses also flow through the study area draining into the River Eden via a number of tributaries. See Chapter 14: Road Drainage and the Water Environment (Application Document 3.2) for further details on the watercourses.

14.6.3.155 All mapped groundwater-surface water interactions originally identified (e.g. springs or seepages) within the study area have been scoped out as they are considered to not be in hydraulic continuity with the scheme or not groundwater-surface water (GWSW) interactions following surveying (see Table 12: Scoped out features within the Appleby to Brough Project study area).

14.6.3.156 During consultation additional potential groundwater-surface water interactions were noted by stakeholders within the study area which are scoped in for further assessment:

- Potential Springs/Seepages north-east of Sandford Junction.
- Flitholme 'Spring' - Northeast of Flitholme (used for supply).
- Wildboar Hill 'springs' - West of Wheat Sheaf Farm.

14.6.3.157 Additional springs and seepages are likely to be present; particularly in the banks of the rivers and below the river level of the River Eden and associated tributaries. The River Eden and it's various tributaries are likely to receive groundwater baseflow from the superficial deposits and bedrock formations, as well as surface water runoff.

14.6.3.158 The features identified in Table 12: Scoped out features within the Appleby to Brough Project study area were scoped out from further assessment due to the reasons documented below:

Table 12: Scoped out features within the Appleby to Brough Project study area

Feature	Description	Reason for Descoping
Spring - S23	Boggy ground, likely seepage	Not in hydraulic continuity with scheme
Spring - S50	Drainage feature	Not considered a GWSW interaction following surveying
Consented Discharge - 017690486	Coupland Hall - WwTW (not water co) (not STP at a private premises)	Not in hydraulic continuity with scheme
Consented Discharge - 017670004	Brough WWTW - WwTW/Sewerage Treatment Works (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 017680300	Sandford Village WWTW - WwTW/Sewerage Treatment Works (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 01EDE0070	Warcop Village Pumping Station - Pumping Station on Sewerage Network (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 01EDE0023	Crooks Beck Syphon CSO (172FU) - Storm Tank/CSO on Sewerage Network (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 017690370	Haybergill Centre – Sport, Amusement+Recreation/Golf Club/Gym/Theme Pk/Spa	Not in hydraulic continuity with scheme

Bowes Bypass

14.6.3.159 The distribution of surface superficial deposits and bedrock at rockhead is shown in ES Figure 9.2 Published Geology - Superficial Geology and ES Figure 9.3: Published Geology - Bedrock Geology (Application Document 3.3) respectively.

14.6.3.160 Glacial Till is mapped beneath the majority of the Bowes Bypass section, with discrete areas where no superficial deposits are mapped (e.g. east and west of the Order Limits, and east of Bowes).

14.6.3.161 Within the study area, peat deposits are mapped to the west associated with moor lands, whilst river terrace deposits, alluvial deposits and glaciofluvial deposits are mapped to the south associated with the River Greta.

14.6.3.162 BGS mapping illustrates that:

- The western region of the study area is underlain by bedrock of the Stainmore Formation (mudstone, siltstone and sandstone)
- The central region of the study area is underlain by bedrock of the Great Limestone Member (limestone member of the Alston Formation)
- The eastern region is underlain by bedrock of the Alston Formation (limestone, sandstone, siltstone and mudstone) and Four Fathom Limestone Member (limestone member of the Alston Formation).

14.6.3.163 The Alston and Stainmore Formations are formations of the Yoredale Group; characterised by repeated upward-coarsening sedimentary cycles on a wide range of scales.

14.6.3.164 There is a dip in the bedrock geology, approximately north at an angle between 5° and 15° (Hughes, 2003)[24] The Stainmore Formation (mudstone, siltstone and sandstone) in the western region of the study area, is stratigraphically highest (and youngest) as the northern most geological unit encountered. Heading eastward along the route, each bedrock unit encountered is stratigraphically lower than the previous.

14.6.3.165 Groundwater flow through the limestones is dominated by secondary (fracture) porosity pathways and tertiary (karstic) porosity features, so the aquifer may locally have a high permeability but overall have low storage capacity. Groundwater flow through the limestone matrix will not be appreciable, with a porosity average of 1% to 1.3% and permeability of 0.14 m/d. This will mean the Limestone units have a lower storage capacity in comparison to the Sandstone units (Holliday, 1986)[25].

14.6.3.166 Limestones which are thicker and more fractured (e.g. the Great Limestone Member) have been observed to have a higher hydraulic conductivity in comparison to thinner and less fractured units. The density and size of fractures commonly decreases rapidly with depth, providing an effective aquifer thickness of only 50-80 m, although the actual thickness of the limestone formation may be considerably greater.

14.6.3.167 Fracture flow through rock defects like joints and bedding planes is expected to be the main way groundwater will flow within sandstone

[24] Hughes, R A. (2003) Carboniferous rocks and Quaternary deposits of the Appleby district (part of Sheet 30, England and Wales). British Geological Survey Research Report, RR/01/09

[25] Holliday, D.W., (1986) Devonian and Carboniferous Basins. In: R.A. Downing and D.A. Gray (Editors), Geothermal Energy- The Potential in the United Kingdom. British Geological Survey, 84-109

units. Compared to the limestone, sandstone is likely to have a lower hydraulic conductivity, but greater storage capacity.

14.6.3.168 Siltstone and Mudstone units are generally anticipated to act as aquitards and aquicludes, although fracture flow may be observed in places.

14.6.3.169 The 2021 site investigation documents the ground conditions within the Bowes Bypass Order Limits generally comprise a sequence of thin Topsoil or Made Ground overlying variable thicknesses of predominantly cohesive glacial deposits, with Mudstone or Limestone bedrock at depth.

14.6.3.170 Glacial deposits were present in all exploratory holes, except those where ground levels have been reduced by previous developments. In these locations, Made Ground directly overlies Mudstone bedrock.

14.6.3.171 Bedrock was recorded within many of the site investigation trial pits and boreholes at depths ranging between 0.15m bgl and 17m bgl. Rockhead was shallowest in the area of the A67 underpass, which is anticipated to have been constructed directly onto bedrock.

14.6.3.172 The majority of cuttings in the Order Limits are in the west of the scheme, overlying the Stainmore Formation. The majority of cuttings are anticipated to be fully within the superficial deposits (predominantly cohesive Glacial Till) with Mudstone bedrock potentially encountered at the base of the cuttings in some areas.

14.6.3.173 A summary of the hydrostratigraphy in the Bowes Bypass area is documented below in Table 13: Summary of hydrostratigraphy in the Bowes Bypass Project study area.

Table 13: Summary of hydrostratigraphy in the Bowes Bypass Project study area

Age	Group	Formation	EA designation	Description	Hydrogeological properties
Devensian	-	Glacial Till	Secondary Undifferentiated Aquifer	Reflects the local geology, mainly rock fragments and boulders in a matrix of sandy-clay, silty-clay or clayey sands.	Variable hydraulic conductivity. Groundwater flow though intergranular matrix.
Carboniferous (Namurian)	Yoredale	Stainmore Formation	Secondary A Aquifer	Cyclical repetition of sandstones, siltstones, mudstones, thin limestones and some coals.	Moderately permeable. Generally, flow occurs as fracture flow. The interbedded nature of the formation leads to groundwater occurring in limestone and sandstone units, but the siltstone and mudstones act as barrier. Limestone units have potential for solutional enlargement (karst) and may include conduits or caves.
		Great Limestone Member		Limestone (bioclastic packstone), medium to dark blue-grey, thickly bedded with thin shaly mudstone partings along uneven or wavy bedding planes.	
		Four Fathom Limestone Member		Limestone, packstone, fine-grained, medium and dark grey, thick bedded and wavy-bedded, with few mudstone partings; somewhat	

Age	Group	Formation	EA designation	Description	Hydrogeological properties
				argillaceous, particularly at the top.	
Carboniferous (Visean, Namurian)		Alston Formation		Bioclastic limestones, sandstones, mudstones, siltstones and rare coals typically in regular cyclothemic sequence.	

14.6.3.174 Hydrogeological features within the study area are illustrated in ES Figure 14.6: Hydrogeological Study Areas and Features (Application Document 3.3) and discussed in further detail below.

14.6.3.175 No source protection zones or licensed groundwater abstractions are located within the study area.

14.6.3.176 Unlicensed abstractions data from Durham County Council identified a number of unlicensed abstractions across the region, including two abstractions to the south of the scheme; labelled as springs and assumed to be surface water abstractions. Due to their locations south of the River Greta, these springs have been determined to not be in hydraulic continuity with the scheme and scoped out from further assessment.

14.6.3.177 There are potentially a number of smaller private domestic, commercial and agricultural unlicensed supplies within the scheme study area, which are assumed to abstract less than 20 m^3/d. It is assumed that each property has the potential to include a small private groundwater supply.

14.6.3.178 All consented discharges within the study area have been scoped out as they are considered to not be in hydraulic continuity with the scheme (see Table 14: Scoped out features within the Bowes Bypass Project study area).

14.6.3.179 The study area is located on the eastern boundary of the North Pennines AONB. The following designations relating to the water environment fall within the study area:

- The North Pennine Moors SPA
- The North Pennine Moors SAC
- Bowes Moor SSSI
- Kilmond Scar SSSI.

14.6.3.180 The majority of watercourses within the study area drain into the River Greta to the south of Bowes, via a number of tributaries. See ES Chapter 14: Road Drainage of the Water Environment (Application Document 3.2) for further details on the watercourses.

14.6.3.181 All of the limestone formations within the study area have the potential to form karstic features, such as enclosed depressions, caves and springs. The Great Limestone Member includes a number of significant karst features in the area, including caves. The other limestone units have the potential for dissolution but those karst features in the area are generally small scale.

14.6.3.182 Bowes includes two known caves (K2 and K4) within 1km of the study area, and six karst landforms. See ES Appendix 14.8: Desk Study Karst Risk Assessment (Application Document 3.4) for further details.

14.6.3.183 The majority of mapped groundwater-surface water interactions in the scheme study area are south of the River Greta and have subsequently been scoped out from further assessment due to lack of hydraulic continuity (see Table 14: Scoped out features within the Bowes Bypass Project study area).

14.6.3.184 Spring 19 remains scoped in and is located to the south of the scheme and feeds into an adjacent ditch which runs from the eastern side of Bowes southeast towards the River Greta.

14.6.3.185 During consultation, additional springs were also identified at the western end of the scheme in the fields to the north of the existing A66 which are scoped in for further assessment.

14.6.3.186 Additional springs and seepages are likely to be present; particularly in the banks of tributaries and rivers and below the river level of the River Greta. The River Greta will receive groundwater baseflow from the superficial deposits and bedrock formations.

14.6.3.187 The features identified in Table 14: Scoped out features within the Bowes Bypass Project study area were scoped out from further assessment due to not being in hydraulic continuity with the scheme as documented below.

Table 14: Scoped out features within the Bowes Bypass Project study area

Feature	Description	Reason for Descoping
Springs - S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12, S13, S14, S15, S16, S17	Springs south of River Greta	Not in hydraulic continuity with scheme
Spring - S22	Outside catchment and several 100m's distance away. (Not able to survey as UXO area)	Not in hydraulic continuity with scheme
Spring - S20	No spring identified during field survey - stream that runs across centre of field into culvert that cuts under the A66.	Not in hydraulic continuity with scheme
Sink - 126	Water ponds, most likely mine water which discharges into a culvert below the mine access road and into Thorsgill beck.	Not in hydraulic continuity with scheme
DCC Unlicensed abstraction - Greta Spring	Unlicensed abstraction (assumed surface water) south of River Greta.	Not in hydraulic continuity with scheme
DCC Unlicensed abstraction - Plantation Spring	Unlicensed abstraction (assumed surface water) south of River Greta.	Not in hydraulic continuity with scheme
Consented Discharge - 25/02/1105	Bowes Sewage Treatment Works - WwTW/Sewerage Treatment Works (water company)	Not in hydraulic continuity with scheme
Consented Discharge - 252/1011	Hulands Quarry - Mineral/Gravel Extraction/Quarrying	Not in hydraulic continuity with scheme

Cross Lanes to Rokeby

14.6.3.188 The distribution of surface superficial deposits and bedrock at rockhead is shown in ES Figure 9.2 Published Geology - Superficial

Geology and ES Figure 9.3: Published Geology - Bedrock Geology (Application Document 3.3) respectively.

14.6.3.189 Glacial Till is mapped beneath the majority of the Cross Lanes to Rokeby section, with discrete areas where no superficial deposits are mapped to the west and southwest (within the study area but outside the Order Limits).

14.6.3.190 Alluvial deposits are mapped in small discrete areas associated with surface water courses (e.g. Tutta Beck to the south and Manyfold Beck to the north). At the east of the study area and to the north of the Order Limits, river terrace deposits, alluvium and glaciofluvial deposits are mapped in relation to the River Greta.

14.6.3.191 BGS mapping illustrates that:

- To the north of the scheme, within the Project study area but outside the Order Limits, lies the Stainmore Formation (mudstone, siltstone and sandstone)
- The majority of the A66 route in the Order Limits is underlain by the Great Limestone Member (of the Alston Formation)
- Moving south, the Project study area is underlain by Sandstone of the Alston Formation, followed by interbedded limestone, sandstone, siltstone and mudstone, the Four Fathom Limestone Member and then Sandstone of the Alston Formation again.

14.6.3.192 The Alston and Stainmore Formations are formations of the Yoredale Group; characterised by repeated upward-coarsening sedimentary cycles on a wide range of scales.

14.6.3.193 There is a dip in the bedrock geology, approximately north at an angle between 5° and 15°. The Stainmore Formation (mudstone, siltstone and sandstone) in the north of the study area, is stratigraphically highest (and youngest). Heading eastwards and southwards along the route, each bedrock unit encountered is stratigraphically lower than the previous.

14.6.3.194 Limestones which are thicker and more fractured (e.g. the Great Limestone Member) have been observed to have a higher hydraulic conductivity in comparison to thinner and less fractured units. The density and size of fractures commonly decreases rapidly with depth, providing an effective aquifer thickness of only 50-80 m, although the actual thickness of the limestone formation may be considerably greater (Jones, et al., 2000)[26].

14.6.3.195 Fracture flow through rock defects like joints and bedding planes is expected to be the main way groundwater will flow within sandstone units. Compared to the limestone, sandstone is likely to have a lower hydraulic conductivity, but greater storage capacity.

[26] Jones, H K, Morris, B L, Cheney, C S, Brewerton, L J, Merrin, P D, Lewis, M A, MacDonald, A M, Coleby, L M, Talbot, J C, McKenzie, A A, Bird, M J, Cunningham, J, and Robinson, V K (2000) The physical properties of minor aquifers in England and Wales. British Geological Survey Technical Report, WD/00/4. 234pp. Environment Agency R and D Publication 68.

14.6.3.196 Siltstone and Mudstone units are generally anticipated to act as aquitards and aquicludes, although fracture flow may be observed in places.

14.6.3.197 The 2021 site investigation documents the ground conditions within the Cross Lanes to Rokeby Order Limits generally comprise a sequence of thin Topsoil overlying predominantly cohesive glacial deposits with bedrock at depth.

14.6.3.198 Glacial deposits were present in all exploratory holes and typically comprised firm to stiff slightly sandy slightly gravelly clay with cobbles. The full thickness of the glacial deposits was proven within three boreholes in the west of the Order Limits only; where it was found to be 9.4m to 15.0m thick and up to at least 20m thick elsewhere.

14.6.3.199 Bedrock was encountered in three boreholes at depth and comprised weak mudstone (BH CLR003 and BH CLR003A) or interlaminated sandstone, siltstone and mudstone with a thin band of coal (CH BLR004A).

14.6.3.200 Due to the depth of the bedrock, all cuttings in the Order Limits are anticipated to be within the cohesive glacial deposits.

14.6.3.201 A summary of the hydrostratigraphy in the Cross Lanes to Rokeby area is documented below in Table 15: Summary of hydrostratigraphy in the Cross Lanes to Rokeby Project study area.

Table 15: Summary of hydrostratigraphy in the Cross Lanes to Rokeby Project study area

Age	Group	Formation	EA designation	Description	Hydrogeological properties
Quaternary (Holocene)	-	Alluvium	Secondary A Aquifer	Clay, silt, sand and gravel. Unconsolidated material deposited by a river, stream or other body of water.	Variable hydraulic conductivity. Groundwater flow though intergranular matrix.
Quaternary (Devensian)	-	Glacial Till	Secondary Undifferentiated Aquifer	Reflects the local geology, mainly rock fragments and boulders in a matrix of sandy-clay, silty-clay or clayey sands.	
Carboniferous (Namurian)	Yoredale (319 – 337Ma)	Great Limestone Member	Secondary A Aquifer	Limestone (bioclastic packstone), medium to dark blue-grey, thickly bedded with thin shaly mudstone partings along uneven or wavy bedding.	Moderately permeable. Generally, flow occurs as fracture flow. The interbedded nature of the formation leads to groundwater occurring in limestone and sandstone units, but the siltstone and mudstones act as barrier. Limestone units have potential for solutional enlargement (karst) and may include conduits or caves.
		Four Fathom Limestone Member		Limestone, packstone, fine-grained, medium and dark grey, thick bedded and wavy-bedded, with few mudstone partings; somewhat argillaceous, particularly at the top.	
Carboniferous (Visean, Namurian)		Alston Formation		Bioclastic limestones, sandstones, mudstones, siltstones and rare coals typically in regular cyclothemic sequence.	

14.6.3.202 Hydrogeological features within the study area are illustrated in ES Figure 14.6: Hydrogeological Study Areas and Features (Application Document 3.3) and discussed in further detail below.

14.6.3.203 No SPZs or licensed groundwater abstractions are located within the study area. No unlicensed abstractions (provided by Durham County Council) are recorded within the study area.

14.6.3.204 There are potentially a number of smaller private domestic, commercial and agricultural unlicensed supplies within the scheme study area, which are assumed to abstract less than 20 m^3/d. It is assumed that each property has the potential to include a small private groundwater supply.

14.6.3.205 Two consented discharges have been identified in Environment Agency data within the study area, as shown in Table 16: Consented discharges within the Cross Lanes to Rokeby study area. Additional discharges in the study area were scoped out (see Table 17: Scoped out features within the Cross Lanes to Rokeby Project study area).

Table 16: Consented discharges within the Cross Lanes to Rokeby study area

Site Name	Licence Status	Description
Sewage treatment plant serving the Morritt Arms Hotel (Ref. 252/1024)	Active	Food+Beverage Services/Cafe/Restaurant/Pub
Cross Lanes Organic Farm (Ref. EPRCB3393WJ)	Active	Food+Beverage Services/Cafe/Restaurant/Pub

14.6.3.206 There are no designated sites associated with the water environment within the study area.

14.6.3.207 Watercourses within the study area drain into the River Tees in the northeast, via a number of tributaries. Within the study area, the River Greta and River Tees are the only Environment Agency designated Main Rivers. See ES Chapter 14: Road Drainage of the Water Environment (Application Document 3.2) for further details on the watercourses.

14.6.3.208 All of the limestone formations within the study area have the potential to form karstic features, such as enclosed depressions, caves and springs. No enclosed depressions or caves were identified within 1km of the Order Limits. See ES Appendix 14.8: Desk Study Karst Risk Assessment (Application Document 3.4) for further details.

14.6.3.209 Spring S21 is located northwest of the western end of the Cross Lanes to Rokeby Order Limits in an area of limited to no superficial cover with the Great Limestone Member underlying. A pond is located at a topographical low within a field, which drains to an adjacent ditch. Surveying indicates the possibility that the pond may be groundwater fed.

14.6.3.210 Other springs and seepages are likely to be present; particularly in the banks of the rivers and below the river level of the River Tees, Tutta Beck and River Greta. The River Tees, River Greta and Tutta Beck will receive groundwater baseflow from the superficial deposits and bedrock formations.

14.6.3.211 The features identified in Table 17: Scoped out features within the Cross Lanes to Rokeby Project study area were scoped out from further assessment due to not being in hydraulic continuity with the scheme as documented below.

Table 17: Scoped out features within the Cross Lanes to Rokeby Project study area

Feature	Description	Reason for Descoping
Consented Discharge - 252/1026	Castle Farmhouse Egglestone Abbey Domestic property (single) (including farmhouse)	Not in hydraulic continuity with scheme
Consented Discharge - 25/02/1083	The Square WwTW (not water co) (not STP at a private premises)	Not in hydraulic continuity with scheme
Consented Discharge - 252/C/0304	Greta Bridge Farm WwTW (not water co) (not STP at a private premises)	Not in hydraulic continuity with scheme
Consented Discharge - 252/0073	Boldron STW Waste collection/treatment/ disposal/materials recovery	Not in hydraulic continuity with scheme
Consented Discharge - EPRKB3990NS	Thorpe Farm Holiday Accomodation/Camp Site/ Caravan Site/Hotel/Hostel	Not in hydraulic continuity with scheme
Spring - S18	Potential groundwater to surface water interaction – at a distance from the Order Limits and upgradient.	Not in hydraulic continuity with scheme

Stephen Bank to Carkin Moor

14.6.3.212 The distribution of surface superficial deposits and bedrock at rockhead is shown in ES Figure 9.2 Published Geology - Superficial Geology and ES Figure 9.3: Published Geology - Bedrock Geology (Application Document 3.3) respectively.

14.6.3.213 Glacial Till is mapped across the majority of the Stephen Bank to Carkin Moor route, with discrete areas (primarily to the south of the route) where no superficials are mapped.

14.6.3.214 Extensive alluvial and glaciofluvial deposits are mapped to the southwest of the Order Limits associated with the numerous becks (e.g. Dalton Beck and Holme Beck) that flow in a southeasterly direction.

14.6.3.215 The anticipated bedrock below the study area comprises of the Alston Formation (bioclastic limestone, sandstones, siltstone and mudstones with rare coals), Alston Formation (sandstone) and various limestone members of the Alston Formation (e.g. Three yard member, Five yard member, Four fathom member). Faulting is mapped crossing the scheme study area south of West Layton.

14.6.3.216 The 2021 site investigation documents the ground conditions within the Stephen Bank to Carkin Moor Order Limits generally comprise a sequence of thin Topsoil or Made Ground overlying various thicknesses of predominantly cohesive glacial deposits and sandstone and mudstone bedrock.

14.6.3.217 Glacial deposits were encountered in the majority of exploratory holes undertaken during the 2021 ground investigation and varied in thickness from 0.5m thick in the west to greater than 24m thick in the east of the site.

14.6.3.218 Bedrock was encountered in a number of the site investigation holes, at depths ranging from 0.8m bgl to 22.5m bgl. Rockhead was shallowest in the west of the site and significantly deeper in the central and eastern areas of the site. Bedrock generally comprised mudstone, with sandstone encountered at rockhead in the far west and central area of the site. Limestone was encountered at rockhead within one borehole in the central area of the site (BH SBC015).

14.6.3.219 Due to the depth of the bedrock at the cutting locations, all cuttings in the area are anticipated to be within the cohesive glacial deposits.

14.6.3.220 A summary of the hydrostratigraphy in the Stephen Bank to Carkin Moor area is documented below in Table 18: Summary of hydrostratigraphy in the Stephen Bank to Carkin Moor Project study area.

Table 18: Summary of hydrostratigraphy in the Stephen Bank to Carkin Moor Project study area

Age	Group	Formation	EA designation	Description	Hydrogeological properties
Quaternary (Holocene)	-	Alluvium	Secondary A Aquifer	Clay, silt, sand and gravel. Unconsolidated material deposited by a river, stream or other body of water.	Variable hydraulic conductivity. Groundwater flow though intergranular matrix.
Quaternary (Devensian)	-	Glacial Till	Secondary Undifferentiated Aquifer	Reflects the local geology, mainly rock fragments and boulders in a matrix of sandy-clay, silty-clay or clayey sands.	
Carboniferous	Yoredale	Four Fathom Limestone Member (Alston Formation)	Secondary A Aquifer	Limestone, packstone, fine-grained, medium and dark grey, thick bedded and wavy-bedded, with few mudstone partings; somewhat argillaceous, particularly at the top.	Moderately permeable. Generally, flow occurs as fracture flow. The interbedded nature of the formation leads to groundwater occurring in limestone and sandstone units, but the siltstone and mudstones act as barrier. Limestone units have potential for solutional enlargement (karst) and may include conduits or caves.
		Three Yard Limestone Member (Alston Formation)		Limestone, packstone, fine-grained, medium and dark grey, thick bedded.	
		Five Yard Limestone Member (Alston Formation)		Limestone, dark grey, argillaceous, becoming grey compact towards base.	
		Alston Formation		Bioclastic limestones, sandstones, mudstones, siltstones and rare coals typically in regular cyclothemic sequence.	

14.6.3.221 Hydrogeological features within the study area are illustrated in ES Figure 14.6: Hydrogeological Study Areas and Features (Application Document 3.3) and discussed in further detail below.

14.6.3.222 There are two licensed groundwater abstractions within the study area:

- Pond Dale abstraction well (license number: 2/27/23/661/R01)
- Blackhill Farm abstraction well (no licence number).

14.6.3.223 There are two designated groundwater SPZ I (inner zones) within the study area. These SPZ are associated with the Environment Agency licensed abstractions (above).

14.6.3.224 There are potentially a number of smaller private domestic, commercial and agricultural unlicensed supplies within the scheme study area, which are assumed to abstract less than 20 m^3/d. It is assumed that each property has the potential to include a small private groundwater supply.

14.6.3.225 All consented discharges within the study area have been scoped out as they are considered to not be in hydraulic continuity with the scheme (see Table 19: Scoped out features within the Stephen Bank to Carkin Moor Project study area).

14.6.3.226 There are no designated sites associated with the water environment within the study area.

14.6.3.227 Watercourses within the study area drain into the River Swale via a number of tributaries. None of the watercourses are designated by the Environment Agency as a Main River. See ES Chapter 14: Road Drainage for the Water Environment of the ES (Document Number 3.2) for further details on the watercourses.

14.6.3.228 All of the limestone formations within the Project study area have the potential to form karstic features, such as enclosed depressions, caves and springs. The Great Limestone Member includes a number of significant karst features in the area, including caves. The other limestone units has the potential for dissolution but those karst features in the area are generally small scale. See ES Appendix 14.8: Desk Study Karst Risk Assessment (Application Document 3.4) for further details.

14.6.3.229 Spring S1 is a suspected groundwater-surface water interaction comprising an ornamental pond fed by a pipe at the base of a brick wall on sloping ground. The area is overgrown, but water quality parameters indicate that the pond is likely to be groundwater fed.

14.6.3.230 Additional springs and seepages are likely to be present; particularly in the banks of water courses and below the river level of the courses. The water courses will receive groundwater baseflow from the superficial deposits and bedrock formations.

14.6.3.231 The features identified in Table 19: Scoped out features within the Stephen Bank to Carkin Moor Project study area were scoped out from further assessment due to not being in hydraulic continuity with the scheme as documented below.

Table 19: Scoped out features within the Stephen Bank to Carkin Moor Project study area

Feature	Description	Reason for Descoping
Consented Discharge Ref. S/P/997	Monks Rest Farm - WwTW (not water co) (not STP at a private premises)	Not in hydraulic continuity with scheme
Consented Discharge Ref. S/P/1233	Foxwell Farm - WwTW (not water co) (not STP at a private premises)	Not in hydraulic continuity with scheme
Consented Discharge Ref. E807 (SS)	Newsham (Richmond) STW WwTW/Sewage Treatment Works (water company)	Not in hydraulic continuity with scheme
Consented Discharge Ref. 25/02/1096	A66 Motel - WwTW (not water co) (not STP at a private premises)	Not in hydraulic continuity with scheme
Consented Discharge Ref. 27/23/0205	Ravensworth Sewage Pumping Station Pumping Station on Sewerage Network (water company)	Not in hydraulic continuity with scheme
Consented Discharge Ref. COPA/1403	Ravensworth WPC Works WwTW/Sewage Treatment Works (water company)	Not in hydraulic continuity with scheme
Groundwater-Surface Water Interaction 51	Surveying determined not a relevant interaction	Not in hydraulic continuity with scheme

A1(M) Junction 53 Scotch Corner

14.6.3.232 The ground conditions at Scotch Corner are anticipated to comprise Made Ground, underlain by natural superficial deposits comprising predominantly Glacial Till. No superficial deposits are mapped in an area just south of the junction, indicating bedrock at shallow depth in this area. The anticipated bedrock below the study area comprises the Four Fathom Limestone Member (of the Alston Formation).

14.6.3.233 A summary of the hydrostratigraphy in the A1(M) Junction 53 area is documented below in Table 20: Summary of hydrostratigraphy in the A1(M) Junction 53 Scotch Corner Project study area.

Table 20: Summary of hydrostratigraphy in the A1(M) Junction 53 Scotch Corner Project study area

Age	Group	Formation	EA designation	Description	Hydrogeological properties
Quaternary	-	Glacial Till	Secondary Undifferentiated Aquifer	Reflects the local geology, mainly rock fragments and boulders in a matrix of sandy-clay, silty-clay or clayey sands.	Variable hydraulic conductivity. Groundwater flow though intergranular matrix.
Carboniferous	Yoredale	Four Fathom Limestone Member	Secondary A Aquifer	Limestone, packstone, fine-grained, medium and dark grey, thick bedded and wavy-bedded, with few mudstone partings; somewhat argillaceous, particularly at the top.	Moderately permeable. Generally, flow occurs as fracture flow. Limestone units have potential for solutional enlargement (karst) and may include conduits or caves.

14.6.3.234 Hydrogeological features within the study area are illustrated in ES Figure 14.6: Hydrogeological Study Areas and Features (Application Document 3.3) and discussed in further detail below.

14.6.3.235 There are no designated groundwater SPZ within the study area.

14.6.3.236 There is one Environment Agency licensed abstraction within the study area which abstracts from the Carboniferous Limestone:

- Abstraction well (licence reference 2/27/23/702/R01) in Middleton Tyas.

14.6.3.237 There are potentially a number of smaller private domestic, commercial and agricultural unlicensed supplies within the Project study area, which are assumed to abstract less than 20 m^3/d. It is assumed that each property has the potential to include a small private groundwater supply.

14.6.3.238 There are no consented discharges within the study area recorded in the Environment Agency data.

14.6.3.239 The study area surrounds the Scotch Corner junction, west of Middleton Tyas. There are no designated sites associated with the water environment within the study area.

14.6.3.240 No main river watercourses are present within the study area. Smaller watercourses in the area drain south towards the River Swale.

14.6.3.241 No groundwater-surface water interactions are mapped within the area. Springs and seepages are likely to be present; particularly in the banks of water courses. Watercourses in the area will receive groundwater baseflow from the superficial deposits and bedrock formations.

14.6.3.242 Due to the limited number of features identified in this area, no features have been scoped out. With works limited in the scheme area, groundwater level and flow impacts are anticipated to be negligible with potential impacts primarily in relation to water quality (such as pollution).

14.6.4 Groundwater level monitoring

14.6.4.1 Groundwater monitoring was undertaken as part of the first phase of ground investigations, with monitoring data available for dates between March 2021 and March 2022. The geological setting and ground conditions along the route are presented in Chapter 9: Geology and Soils (Application Document 3.2) and associated appendices.

14.6.4.2 In summary:

- 106 monitoring locations were installed during the site investigation.
- Groundwater monitoring of the boreholes was undertaken weekly following installation for 4/5 weeks (Spring/Summer 2021)

- A follow up visit was undertaken in August 2021 for schemes in the east (Bowes Bypass to A1(M) Junction 53 Scotch Corner)
- A further follow up visit was undertaken in early February 2022 (excluding Cross Lanes to Rokeby due to access constraints).

14.6.4.3 The groundwater monitoring installations were installed at locations where specific design elements are proposed or where water receptors have been identified. Together, these locations provide a spatial network of groundwater monitoring across the study area so that hydraulic gradients and directions of flow can be identified.

14.6.4.4 The locations of the monitoring wells are presented in ES Figure 14.10: Groundwater monitoring locations (Application Document 3.3)

14.6.4.5 In-situ testing to ascertain hydrogeological parameters was undertaken in a number of areas and is discussed in further detail in Section 14.6.5. Water quality testing was also completed and is discussed in further detail in section 14.6.6.

Superficial Deposits

M6 Junction 40 to Kemplay Bank Roundabout

14.6.4.6 Eight groundwater monitoring installations were installed in the M6 Junction 40 to Kemplay Bank Roundabout Order Limits.

14.6.4.7 Table 21: Groundwater Monitoring Results for Superficial Deposits in the M6 Junction 40 to Kemplay Bank Roundabout Order Limits provides a summary of the groundwater levels recorded in Superficial Deposits in the M6 Junction 40 to Kemplay Bank Roundabout Order Limits. Plate 1: Hydrograph for M6 J40 and Kempley Bank Project study area - Groundwater Monitoring in Superficial Deposits with Rainfall Data from Station 604742 - Penrith in Annex B: Rainfall Hydrographs illustrates the groundwater monitoring data to date, together with rainfall data for the area.

Table 21: Groundwater Monitoring Results for Superficial Deposits in the M6 Junction 40 to Kemplay Bank Roundabout Order Limits

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
BH M6J40.001	138.93	0.8 - 5 m bgl (138.13 to 133.93m OD)	Glacial Till (Cohesive)	0.95 to 3.72m bgl (137.98 to 135.21m OD)
SD M6J40.005a	138.07	8 - 17 m bgl (130.07 to 121.07m OD)	Glacial Till (Cohesive + Granular Fluvioglacial Deposits)	Dry
BH KBR003	134.87	1 – 14.2 m bgl (133.87 to 120.67m OD)	Glacial Till + Fluvioglacial Deposits	8.65 to 12.4m bgl (126.22 to 122.47m OD)

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
SD KBR005	135.78	2 to 24.5 m bgl (133.78 to 111.28m OD)	Glacial Till + Fluvioglacial Deposits	18.02 to 18.73m bgl (117.76 to 117.18m OD)
BH KBR006	135.2	1 – 8.2 m bgl (134.2 to 127m OD)	Glacial Till + Fluvioglacial Deposits	5.62m bgl to Dry (129.58m OD)
SD KBR007	135.83	4.5 – 15.5 m bgl (131.33 to 120.33m OD)	Glacial Till + Fluvioglacial Deposits	15.27m bgl to Dry (120.56m OD)
BH KBR011	133.99	1 – 6 m bgl (132.99 to 127.99m OD)	Glacial Till + Fluvioglacial Deposits	5.82m bgl to Dry (128.17m OD)
BH KBR012	121.43	3 – 15.5 mbgl (118.43 to 105.93m OD)	Fluvioglacial Deposits	5.82 to 7.44m bgl (115.61 to 113.99m OD)

14.6.4.8 Groundwater levels within the superficial deposits in this scheme are variable, as anticipated due to the heterogenous nature of the ground. Groundwater levels within the fluvioglacial deposits in this scheme are generally at greater depth than the groundwater levels monitored in other superficial deposits in the area.

Penrith to Temple Sowerby

14.6.4.9 Five groundwater monitoring installations were installed in the Penrith to Temple Sowerby Order Limits, within the Superficial Deposits.

14.6.4.10 Table 22: Groundwater Monitoring Results for Superficial Deposits in the Penrith to Temple Sowerby Order Limits provides a summary of the groundwater levels recorded in Superficial Deposits in the Penrith to Temple Sowerby Order Limits. Plate 2: Hydrograph for Penrith to Temple Sowerby Project study area - Groundwater Monitoring in Superficial Deposits with Rainfall Data from Station 604742 - Penrith in Annex B: Rainfall Hydrographs illustrates the groundwater monitoring data to date, together with rainfall data for the area.

Table 22: Groundwater Monitoring Results for Superficial Deposits in the Penrith to Temple Sowerby Order Limits

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
BH PTS003	116.26	3 – 9 mbgl (113.26 to 107.26m OD)	Glacial Till	7.04 to 7.49m bgl (109.22 to 108.77m OD)
BH PTS005	107.22	1.5 – 4 mbgl (105.72 to 103.22m OD)	Glacial Till	0.17 to 0.41m bgl (107.05 to 106.81m OD)

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
BH PTS011	119.17	1 – 3.5 mbgl (118.17 to 115.67m OD)	Glacial Till	1.55 to 3.65m bgl (117.62 to 115.52m OD)
BH PTS012	128.66	1 – 6 mbgl (127.66 to 122.66m OD)	Glacial Till	Dry
BH PTS020	132.55	1 – 9.7 mbgl (131.55 to 122.85m OD)	Glacial Till	7.64 to 7.98m bgl (122.76 to 122.5m OD)

14.6.4.11 Groundwater levels within the superficial deposits in this scheme are highly variable, as anticipated due to the heterogenous nature of the ground.

Temple Sowerby to Appleby

14.6.4.12 Nine groundwater monitoring installations were installed in the Temple Sowerby to Appleby Order Limits, within the Superficial Deposits.

14.6.4.13 Table 23: Groundwater Monitoring Results for Superficial Deposits in the Temple Sowerby to Appleby Order Limits provides a summary of the groundwater levels recorded in Superficial Deposits in the Temple Sowerby to Appleby Order Limits. Plate 4: Hydrograph for Temple Sowerby to Appleby Project study area - Groundwater Monitoring in Superficial Deposits with Rainfall Data from Station 598691 - Appleby N in Annex B: Rainfall Hydrographs illustrates the groundwater monitoring data to date, together with rainfall data for the area.

Table 23: Groundwater Monitoring Results for Superficial Deposits in the Temple Sowerby to Appleby Order Limits

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
BH KTA015	170.24	5 – 8 mbgl (165.24 to 162.24m OD)	Glacial Till	0.31 to 1.23m bgl (169.93 to 169.01m OD)
BH KTA018	166.35	9 – 16 mbgl (157.35 to 150.35m OD)	Glacial Till	7.05 to 9.15m bgl (159.30 to 157.2m OD)
BH KTA021	148.64	1 – 3.6 mbgl (147.64 to 145.04m OD)	Glacial Till	2.08 to 3.36m bgl (146.56 to 145.28m OD)
BH KTA022	155.8	2 – 7 mbgl (153.8 to 148.8m OD)	Glacial Till	2.01 to 2.75m bgl (153.79 to 153.05m OD)

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
BH KTB003	121.78	1 – 3.7 mbgl (120.78 to 118.08m OD)	Glacial Till + Sand (Possible weathered bedrock)	3.57m bgl to Dry (118.21m OD)
BH KTB005	117.13	4 – 5.5 mbgl (113.13 to 111.63m OD)	Sand (Possible weathered bedrock)	Dry
BH KTB013	126.11	1.5 – 9.5 mbgl (124.61 to 116.61m OD)	Glacial Till	1.99 to 2.4m bgl (124.12 to 123.71m OD)
BH KTB018	127.68	1 – 5 mbgl (126.68 to 122.68m OD)	Glacial Till (Sandy) + Sand (Possible Weathered Sandstone)	1.2 to 4.84m bgl (126.48 to 122.84m OD)
BH KTB024	131.26	1 – 7.5 mbgl (130.26 to 123.76m OD)	Glacial Till + Fluvioglacial Deposits	2.18 to 4.44m bgl (129.08 to 126.82m OD)
BH KTB025	134.79	1 – 11.5 mbgl (133.79 to 123.29m OD)	Till	1.57 to 2.07m bgl (133.22 to 132.72m OD)

14.6.4.14 Groundwater levels within the superficial deposits in this scheme are variable, as anticipated due to the heterogenous nature of the ground. Groundwater levels were generally monitored within a couple of metres of ground level.

Appleby to Brough

14.6.4.15 Seventeen groundwater monitoring installations were installed in the Appleby to Brough Order Limits, within the Superficial Deposits.

14.6.4.16 Table 24: Groundwater Monitoring Results for Superficial Deposits in the Appleby to Brough Order Limits provides a summary of the groundwater levels recorded in Superficial Deposits in the Appleby to Brough Order Limits. Plate 6: Hydrograph for Appleby to Brough Project study area - Groundwater Monitoring in superficial Deposits with Rainfall Data from Station 598691 - Appleby N in Annex B: Rainfall Hydrographs illustrates the groundwater monitoring data to date, together with rainfall data for the area.

Table 24: Groundwater Monitoring Results for Superficial Deposits in the Appleby to Brough Order Limits

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
BH AB008 S	150.78	3 – 4 mbgl (147.78 to 146.78m OD)	Glacial Till	0.51 to 1.46m bgl (150.27 to 149.32m OD)

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
BH AB009 S	156.07	2 – 10 mbgl (154.07 to 146.07m OD)	Glacial Till	3 to 3.47m bgl (153.07 to 152.6m OD)
BH AB010 S	154.21	1 – 8.5 mbgl (153.21 – 145.71m OD)	Sand + Glacial Till	0.45 to 2m bgl (153.76 to 152.21m OD)
BH AB011	152.66	1 – 10 mbgl (151.66 to 142.66m OD)	Glacial Till	1.21 to 1.93m bgl (151.45 to 150.73m OD)
BH AB020	151.71	2 – 7 mbgl (149.71 to 144.71m OD)	Glacial Till	1.81m bgl to Dry (149.9m OD)
BH AB021	156.72	3 – 5 mbgl (153.72 to 151.72m OD)	Glacial Till	2.65 to 4.62m bgl (154.07 to 152.1m OD)
BH AB025	143.81	1.7 – 3.2 mbgl (142.11 to 140.61m OD)	Fluvioglacial Deposits + Glacial Till	0.65 to 1.2m bgl (143.16 to 142.61m OD)
BH AB026	142.89	1.5 – 4.5 mbgl (141.39 to 138.39m OD)	Glacial Till + Fluvioglacial Deposits	0.21 to 0.56m bgl (142.68 to 142.33m OD)
BH AB028	144.59	2 – 9 mbgl (142.59 to 135.59 m OD)	Sand + Glacial Till	2.39 to 2.78m bgl (142.2 to 141.81m OD)
BH AB030	158.06	0.75 – 5.5 mbgl (157.31 to 152.26m OD)	Glacial Till	4.45 to 5.55m bgl (153.61 to 152.51m OD)
BH AB031	169.62	1 – 4 mbgl (168.62 to 165.62m OD)	Glacial Till	0.56 to 3.59m bgl (169.06 to 166.03m OD)
BH AB032	172.25	1 – 6 mbgl (171.25 to 166.25m OD)	Glacial Till	2.24 to 3.12m bgl (170.01 to 169.13m OD)
BH AB033	173.89	1 – 8 mbgl (172.89 to 165.89m OD)	Glacial Till	3.5 to 4.62m bgl (170.39 to 169.27m OD)
BH AB034	172.24	3 – 4 mbgl (169.24 to 168.24m OD)	Glacial Till	0.95 to 3.91m bgl (171.29 to 168.33m OD)
BH AB042	174.1	10.5 – 15 mbgl (163.6 to 159.1m OD)	Glacial Till	5.93 to 7.32m bgl (168.17 to 166.78m OD)

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
BH AB044	175.26	1 – 7.5 mbgl (174.26 to 167.76m OD)	Glacial Till	0.44 to 1.31m bgl (174.82 to 173.95m OD)
BH AB045	178.3	1 – 5 mbgl (177.3 to 173.3m OD)	Glacial Till	0.5 to 2.06m bgl (177.8 to 176.24m OD)

14.6.4.17 Groundwater levels within the superficial deposits in this scheme are variable, as anticipated due to the heterogenous nature of the ground. Groundwater levels were generally monitored within a couple of metres of ground level, with several monitoring locations recording groundwater levels less than 1.0m below ground level.

Bowes Bypass

14.6.4.18 13 groundwater monitoring installations were installed in the Bowes Bypass Order Limits, within the Superficial Deposits.

14.6.4.19 Table 25: Groundwater Monitoring Results for Superficial Deposits in the Bowes Bypass Order Limits provides a summary of the groundwater levels recorded in Superficial Deposits in the Bowes Bypass Order Limits. Plate 8: Hydrograph for Bowes Bypass Project study area - Groundwater Monitoring in superficial deposits with Rainfall Data from Station 028185 - Barnard Castle in Annex B: Rainfall Hydrographs illustrates the groundwater monitoring data to date, together with rainfall data for the area.

Table 25: Groundwater Monitoring Results for Superficial Deposits in the Bowes Bypass Order Limits

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
BH BB002	296.211	3.5 – 4.5 mbgl (292.711 to 291.711m OD)	Glacial Deposits	2.16 to 7.28m bgl (294.051 to 288.931m OD)
BH BB004	288.734	1 – 5 mbgl (287.734 to 283.734m OD)	Glacial Deposits	1.33 to 1.76m bgl (287.404 to 286.974m OD)
BH BB005	292.732	4.5 – 5.5 mbgl (288.232 to 287.232m OD)	Glacial Deposits	3.57 to 4.09m bgl (289.162 to 288.642m OD)
BH BB008	291.185	2 – 3 mbgl (289.185 to 288.185m OD)	Glacial Deposits	0.47 to 1.81m bgl (290.715 to 289.375m OD)
BH BB013	290.791	1.5 – 4 mbgl (289.291 to 286.791m OD)	Glacial Deposits	0.82 to 2.85m bgl (289.971 to 287.941m OD)

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
BH BB014	284.564	1.5 – 3.5 mbgl (283.064 to 281.064m OD)	Glacial Deposits	0.61 to 2.24m bgl (283.954 to 282.324m OD)
BH BB015	287.201	1 – 3 mbgl (286.201 to 284.201m OD)	Glacial Deposits	1.47m bgl to Dry (285.731m OD)
BH BB016	285.634	1.5 – 2.4 mbgl (284.134 to 283.234m OD)	Glacial Deposits	Dry
BH BB022	262.349	1.5 – 3 mbgl (260.849 to 259.349m OD)	Glacial Deposits	0.36 to 0.78m bgl (261.989 to 261.569m OD)
BH BB023	265.463	5 – 7 mbgl (260.463 to 258.463m OD)	Glacial Deposits	0.53 to 2.83m bgl (264.933 to 262.633m OD)
BH BB024	264.105	1 – 3 mbgl (263.105 to 261.105m OD)	Glacial Deposits	0.6 to 1.78m bgl (263.505 to 252.325m OD)
BH BB025	262.943	1.5 – 2.3 mbgl (261.443 to 260.643m OD)	Glacial Deposits	0.2 to 0.3m bgl (262.743 to 262.643m OD)
WS BB002	284.986	0.5 – 3 mbgl (284.486 to 281.986m OD)	Glacial Deposits	Damp to Dry

14.6.4.20 Groundwater levels within the superficial deposits in this scheme are variable, as anticipated due to the heterogenous nature of the ground. Groundwater levels were generally monitored within a couple of metres of ground level, with several monitoring locations recording groundwater levels less than 1.0m below ground level.

Cross Lanes to Rokeby

14.6.4.21 Seven groundwater monitoring installations were installed in the Cross Lanes to Rokeby Order Limits, within the Superficial Deposits.

14.6.4.22 Table 26: Groundwater Monitoring Results for Superficial Deposits in the Cross Lanes to Rokeby Order Limits provides a summary of the groundwater levels recorded in Superficial Deposits in the Cross Lanes to Rokeby area. Plate 10: Hydrograph for Cross Lane to Rokeby Project study area - Groundwater Monitoring in superficial deposits with Rainfall Data from Station 52287 - Richmond in Annex B: Rainfall Hydrographs illustrates the groundwater monitoring data to date, together with rainfall data for the area.

Table 26: Groundwater Monitoring Results for Superficial Deposits in the Cross Lanes to Rokeby Order Limits

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
BH CLR001A	206.247	15 – 16 mbgl (191.247 to 190.247m OD)	Glacial Deposits	6.37 to 9.57m bgl (199.877 to 196.677m OD)
BH CLR003A	200.24	5 – 7 mbgl (195.24 to 193.24m OD)	Glacial Deposits	-0.32 to -0.2m bgl (artesian) (200.56 to 200.44m OD)
BH CLR004A	198.392	3 – 5 mbgl (195.392 to 193.392m OD)	Glacial Deposits	-0.16 (artesian) to 0.9m bgl (198.552 to 197.492m OD)
BH CLR010	171.362	1 – 3 mbgl (170.362 to 168.362m OD)	Glacial Deposits	-
BH CLR011	156.989	1 – 3 mbgl (155.909 to 153.909m OD)	Glacial Deposits	-
WS CLR001	166.917	1.5 – 2.5 mbgl (165.417 to 164.417m OD)	Glacial Deposits	0.8m bgl (166.117m OD)
WS CLR003	201.282	1 – 3 mbgl (200.282 to 198.282m OD)	Glacial Deposits	0.8 to 1.2m bgl (200.482 to 200.082m OD)

14.6.4.23 Groundwater levels within the superficial deposits in this scheme are variable, as anticipated due to the heterogenous nature of the ground. Flowing artesian groundwater levels were recorded in two of the boreholes in this scheme during monitoring visits. Flowing artesian groundwater conditions have not been recorded to date in any other schemes.

Stephen Bank to Carkin Moor

14.6.4.24 21 groundwater monitoring installations were installed in the Stephen Bank to Carkin Moor Order Limits, within the Superficial Deposits.

14.6.4.25 Table 27: Groundwater Monitoring Results for Superficial Deposits in the Stephen Bank to Carkin Moor Order Limits provides a summary of the groundwater levels recorded in Superficial Deposits in the Stephen Bank to Carkin Moor Order Limits. Plate 11: Hydrograph for Stephen Bank to Carkin Moor Project study area - Groundwater Monitoring in superficial deposits with Rainfall Data from Station 52287 - Richmond in Annex B Rainfall Hydrographs illustrates the groundwater monitoring data to date, together with rainfall data for the area.

Table 27: Groundwater Monitoring Results for Superficial Deposits in the Stephen Bank to Carkin Moor Order Limits

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
BH SBC002	166.931	3.5 – 4.5 mbgl (163.431 to 162.431m OD)	Glacial Deposits	1.62m bgl to Dry (165.311m OD)
BH SBC005	178.737	2 – 3.5 mbgl (176.737 to 175.237m OD)	Glacial Deposits	0.96m bgl to Dry (177.777m OD)
BH SBC011	169.334	1 – 3 mbgl (168.334 to 166.334m OD)	Glacial Deposits	0.75 to 0.98m bgl (168.584 to 168.354m OD)
BH SBC013	163.634	7 – 9 mbgl (156.634 to 154.634m OD)	Glacial Deposits	5.13 to 5.66m bgl (158.504 to 157.974m OD)
BH SBC014A	158.931	13 – 15 mbgl (145.931 to 143.931m OD)	Glacial Deposits	6.47m bgl to Dry (152.461m OD)
BH SBC016	158.127	4 – 6 mbgl (154.127 to 152.127m OD)	Glacial Deposits	0.49 to 1.26m bgl (157.637 to 156.867m OD)
BH SBC017	151.483	2 – 4 mbgl (149.483 to 147.483m OD)	Glacial Deposits	0.85 to 1.4m bgl (150.633 to 150.083m OD)
BH SBC018	153.639	2 – 3.5 mbgl (151.639 to 150.139m OD)	Glacial Deposits	0.72 to 1.48m bgl (152.919 to 152.159m OD)
BH SBC019	141.622	3 – 4 mbgl (138.622 to 137.622m OD)	Glacial Deposits	0.57 to 1.33m bgl (141.052 to 140.292m OD)
BH SBC020	148.393	5 – 6 mbgl (143.393 to 142.393m OD)	Glacial Deposits	1.41 to 2.25m bgl (146.983 to 146.143m OD)
BH SBC021	148.438	2 – 3 mbgl (146.438 to 145.438m OD)	Glacial Deposits	0.49 to 1.04m bgl (147.948 to 147.398m OD)
BH SBC022	146.029	1 – 2 mbgl (145.029 to 144.029m OD)	Glacial Deposits	0.49 to 0.81m bgl (145.539 to 145.219m OD)
BH SBC023A	145.359	7.5 – 9 mbgl (137.859 to 136.359m OD)	Glacial Deposits	1.62 to 6.39m bgl (143.739 to 138.969m OD)
BH SBC024	145.897	14 – 16 mbgl (131.897 to 129.897m OD)	Glacial Deposits	1.76 to 5.93m bgl (144.137 to 139.967m OD)

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
BH SBC025	142.968	3 – 5 mbgl (139.968 to 137.968m OD)	Glacial Deposits	1.67 to 2.07m bgl (141.298 to 140.898m OD)
BH SBC026	143.638	4 – 5 mbgl (139.638 to 138.638m OD)	Glacial Deposits	1.05 to 1.25m bgl (142.588 to 142.388m OD)
BH SBC027	141.958	2 – 3 mbgl (139.958 to 138.958m OD)	Glacial Deposits	0.82 to 1.12m bgl (141.138 to 140.838m OD)
BH SBC029	150.166	3 – 5 mbgl (147.166 to 145.166m OD)	Glacial Deposits	1.00 to 1.36m bgl (149.166 to 148.806m OD)
BH SBC030	150.261	2 – 4 mbgl (148.261 to 146.261m OD)	Glacial Deposits	0.33 to 0.94m bgl (149.931 to 149.321m OD)
BH SBC031	155.627	5 – 8 mbgl (150.627 to 147.627m OD)	Glacial Deposits	5.87 to 6.05m bgl (149.757 to 149.577m OD)
BH SBC032A	147.467	4 – 7 mbgl (143.467 to 140.467m OD)	Glacial Deposits	1.34 to 6.09m bgl (146.127 to 141.377m OD)

14.6.4.26 Groundwater levels within the superficial deposits in this scheme are variable, as anticipated due to the heterogenous nature of the ground. Groundwater levels were generally monitored within a couple of metres of ground level, with several monitoring locations recording groundwater levels less than 1.0m below ground level.

A1(M) Junction 53 Scotch Corner

14.6.4.27 No groundwater monitoring installations were installed in the Scotch Corner Order Limits, due to limited construction works in the scheme area.

Bedrock

M6 Junction 40 to Kemplay Bank

14.6.4.28 No groundwater monitoring installations were installed into the bedrock in the M6 Junction 40 to Kemplay Bank Order Limits, as the bedrock was at significant depth relative to the works. The bedrock was not encountered within site investigation boreholes in the scheme area.

Penrith to Temple Sowerby

14.6.4.29 Three groundwater monitoring installations were installed in the Penrith to Temple Sowerby Order Limits., within the Penrith Sandstone bedrock.

14.6.4.30 Table 28: Groundwater Monitoring Results for Bedrock in the Penrith to Temple Sowerby Order Limits provides a summary of the groundwater levels recorded in the bedrock in the Penrith to Temple Sowerby Order Limits. Plate 3: Hydrograph for Penrith to Temple Sowerby Project study area - Groundwater Monitoring in Bedrock Deposits with Rainfall Data from Station 604742 - Penrith in Annex B: Rainfall Hydrographs illustrates the groundwater monitoring data to date, together with rainfall data for the area.

Table 28: Groundwater Monitoring Results for Bedrock in the Penrith to Temple Sowerby Order Limits

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
BH PTS010	118.69	3 – 10m bgl (115.69 to 108.69m OD)	Penrith Sandstone	9.5m bgl to Dry (109.19m OD)
BH PTS017	132.91	5.5 – 15m bgl (127.41 to 117.91m OD)	Penrith Sandstone	9.25 to 12.47m bgl (123.66 to 120.44m OD)
BH PTS018	130.09	6.5 – 12.5m bgl (123.59 to 117.59m OD)	Penrith Sandstone	7.14 to 10.12m bgl (122.95 to 119.97m OD)

14.6.4.31 The groundwater levels noted during the monitoring are all below the bedrock-superficial deposits interface.

Temple Sowerby to Appleby

14.6.4.32 Seven groundwater monitoring installations were installed in the Temple Sowerby to Appleby Order Limits, within the bedrock (five within the Penrith Sandstone and two within the Eden Shale Formation).

14.6.4.33 Table 29: Groundwater Monitoring Results for Bedrock in the Temple Sowerby to Appleby Order Limits provides a summary of the groundwater levels recorded in the bedrock in the Temple Sowerby to Appleby area. Plate 5: Hydrograph for Temple Sowerby to Appleby Project study area - Groundwater Monitoring in bedrock Deposits with Rainfall Data from Station 598691 - Appleby N in Annex B: Rainfall Hydrographs illustrates the groundwater monitoring data to date, together with rainfall data for the area.

Table 29: Groundwater Monitoring Results for Bedrock in the Temple Sowerby to Appleby Order Limits

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
BH KTA004	121.87	6.3 – 8.8 mbgl (115.57 to 113.07m OD)	Glacial Till + Penrith Sandstone	4.91m bgl to Dry (116.96m OD)
BH KTB007A	110.88	1 – 5 mbgl (109.88 to 105.88m OD)	Glacial Till + Eden Shale	2.97 to 3.34m bgl (107.91 to 107.54m OD)
BH KTB010	111.32	5 – 8 mbgl (106.32 to 103.32m OD)	Penrith Sandstone	0.18 to 1.39m bgl (111.14 to 109.93m OD)
BH KTB016A	125.79	3.2 – 7.2 mbgl (122.59 to 118.59m OD)	Sand (Possible Weathered Bedrock) + Penrith Sandstone	5.22m bgl to Dry (120.57m OD)
BH KTB019	132.32	12 – 15 mbgl (120.32 to 117.32m OD)	Penrith Sandstone	14.35m bgl to Dry (117.97m OD)
BH KTB023 Mining	131	13 – 35 mbgl (118 to 96m OD)	Glacial Till + Eden Shales Formation	15.04 to 34.14m bgl (115.96 to 96.86m OD)
BH KTB028	128.18	5.5 – 9.5 mbgl (122.68 to 118.68m OD)	Penrith Sandstone	8.7m bgl to Dry (119.48m OD)

14.6.4.34 Groundwater monitoring in the Penrith Sandstone measured groundwater levels in the range of 109.93m OD to 120.57m OD. The groundwater levels recorded during the monitoring visits were variable, and are likely to be influenced by local hydrogeological features such as abstractions.

Appleby to Brough

14.6.4.35 Six groundwater monitoring installations were installed in the Appleby to Brough Order Limits, within the bedrock.

14.6.4.36 Table 30: Groundwater Monitoring Results for Bedrock in the Appleby to Brough Order Limits provides a summary of the groundwater levels recorded in the bedrock in the Appleby to Brough area. Plate 7: Hydrograph for Appleby to Brough Project study area - Groundwater Monitoring in bedrock deposits with Rainfall Data from Station 598691 - Appleby N in Annex B: Rainfall Hydrographs illustrates the groundwater monitoring data to date, together with rainfall data for the area.

Table 30: Groundwater Monitoring Results for Bedrock in the Appleby to Brough Order Limits

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
BH AB001	151.29	9.5 – 13 mbgl (141.79 to 138.29m OD)	Penrith Sandstone	5.2 to 5.76m bgl (146.09 to 145.53m OD)
BH AB008 D	150.78	9 – 12 mbgl (141.78 to 138.78m OD)	Penrith Sandstone	4.56 to 11.03m bgl (146.22 to 139.75m OD)
BH AB009 D	156.07	12.5 – 25 mbgl (143.57 to 131.07m OD)	Glacial Till + Penrith Sandstone	8.49 to 8.63m bgl (147.58 to 147.44m OD)
BH AB010 D	154.21	10 – 25 mbgl (144.21 to 129.21m OD)	Glacial Till + Penrith Sandstone (Brockram)	11.42 to 11.77m bgl (142.79 to 142.44m OD)
BH AB027	143.13	14 – 20 mbgl (129.13 to 123.13m OD)	Penrith Sandstone	1.39 to 1.79m bgl (141.74 to 141.34m OD)
BH AB043	164.85	7.5 – 18.5 mbgl (157.35 to 146.35m OD)	Penrith Sandstone	11.5 to 11.84m bgl (153.35 to 153.01m OD)

14.6.4.37 Groundwater monitoring in the Penrith Sandstone in this area measured groundwater levels in the range of 153.35m OD to 139.75m OD.

Bowes Bypass

14.6.4.38 Eight groundwater monitoring installations were installed in the Bowes Bypass Order Limits, within the bedrock.

14.6.4.39 Table 31: Groundwater Monitoring Results for Bedrock in the Bowes Bypass Order Limits provides a summary of the groundwater levels recorded in the bedrock in the Bowes Bypass area. Plate 9: Hydrograph for Bowes Bypass Project study area - Groundwater Monitoring in bedrock deposits with Rainfall Data from Station 028185 - Barnard Castle in Annex B: Rainfall Hydrographs illustrates the groundwater monitoring data to date, together with rainfall data for the area.

Table 31: Groundwater Monitoring Results for Bedrock in the Bowes Bypass Order Limits

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
BH BB003	287.563	10 – 12 mbgl (277.563 to 275.563m OD)	Mudstone	7.5 to 7.65m bgl (280.063 to 279.913m OD)
BH BB006	291.887	4.5 – 5.5 mbgl (287.387 to 286.387m OD)	Glacial Deposits + Mudstone	3.85m bgl to Dry (288.037m OD)

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
BH BB007	291.669	10 – 12 mbgl (281.669 to 279.669m OD)	Mudstone/Limestone	4.3 to 4.5m bgl (287.369 to 287.169m OD)
BH BB009	289.926	6 – 7 mbgl (283.926 to 282.926m OD)	Mudstone	3.3 to 3.95m bgl (286.626 to 285.976m OD)
BH BB010	283.005	1 – 3 mbgl (282.005 to 280.005m OD)	Mudstone	Dry
BH BB011	283.418	3.5 – 4.5 mbgl (279.918 to 278.918m OD)	Mudstone	0.9 to 1.43m bgl (282.518 to 281.988m OD)
BH BB012	282.526	7 – 9 mbgl (275.526 to 273.526m OD)	Limestone	2.07m bgl to Dry (280.456m OD)
BH BB018	271.411	3.5 – 5 mbgl (267.911 to 266.411m OD)	Limestone	3.86 to 4.09m bgl (267.551 to 267.321m OD)

14.6.4.40 Groundwater levels recorded in this scheme during the monitoring visits were variable but generally within less than 5.0 metres of ground level (with the exception of BB003 and BB010).

Cross Lanes to Rokeby

14.6.4.41 No groundwater monitoring installations were installed into the bedrock in the Cross Lanes to Rokeby Order Limits, as the bedrock was at significant depth relative to the works.

Stephen Bank to Carkin Moor

14.6.4.42 Four groundwater monitoring installations were installed in the Stephen Bank to Carkin Moor Order Limits, within the bedrock.

14.6.4.43 Table 32: Groundwater Monitoring Results for Bedrock in the Stephen Bank to Carkin Moor Order Limits provides a summary of the groundwater levels recorded in the bedrock in the Stephen Bank to Carkin Moor area. Plate 12: Hydrograph for Stephen Bank to Carkin Moor Project study area - Groundwater Monitoring in bedrock deposits with Rainfall Data from Station 52287 - Richmond in Annex B illustrates the groundwater monitoring data to date, together with rainfall data for the area.

Table 32: Groundwater Monitoring Results for Bedrock in the Stephen Bank to Carkin Moor Order Limits

Location	Top of Hole (mOD)	Response Zone	Strata	GWL Range
BH SBC001	158.629	1 – 3 mbgl (157.629 to 155.629m OD)	Sandstone and Mudstone	None recorded
BH SBC006	179.718	5 – 7 mbgl (174.718 to 172.718m OD)	Mudstone	2.82 to 4.67m bgl (176.898 to 175.048m OD)
BH SBC008	172.437	2 – 4 mbgl (170.437 to 168.437m OD)	Glacial Deposits and Mudstone	0.78 to 1.7m bgl (171.657 to 170.737m OD)
BH SBC009	173.519	4 – 6 mbgl (169.519 to 167.519m OD)	Mudstone	1.2 to 2.26m bgl (172.319 to 171.259m OD)

14.6.4.44 Groundwater levels recorded in this scheme during the monitoring visits were shallow and recorded within a couple of metres of ground level.

A1(M) Junction 53 Scotch Corner

14.6.4.45 No groundwater monitoring installations were installed in the Scotch Corner area, due to limited construction works in the scheme area.

Hydraulic gradient and groundwater flow

14.6.4.46 The stratigraphy of the superficial deposits is complex, with interdigitations of sand, gravel, silt and clays which may each develop their own piezometric level. Coarse grained units within the deposits are likely to facilitate local zones of groundwater flow and will create zones of perched groundwater. These more permeable zones promote localised shallow groundwater flow which emerge as springs and seepages.

14.6.4.47 In general, groundwater levels within the superficials will typically follow the topography and flow towards surface watercourses.

14.6.4.48 Groundwater flow in the Penrith Sandstone will regionally be towards the River Eden, although localised variations may exist due to groundwater abstractions, localised infiltration and the topography.

14.6.4.49 Flows and gradient are more complex in the Carboniferous strata due to the interbedded nature of the deposits, steeper topography and more extensive faulting. Groundwater flows and gradient are anticipated to be towards the main rivers in the scheme areas (e.g. River Greta and River Tees).

14.6.5 Groundwater transmissivity

Literature values

Superficial Deposits

14.6.5.1 The permeability of the superficial deposits is widely variable, especially within Till, which is anticipated to include both lenses and laterally extensive units of sand and gravel that are bound above and below by more clay dominated material. Alluvium and in particular river terrace deposits are likely to be more consistent in their hydraulic properties owing to their greater homogeneity.

14.6.5.2 Table 33: Permeabilities of typical soils (Preene, 2016) summarises the permeabilities of typical superficial soils.

Table 33: Permeabilities of typical soils (Preene, 2016)[27]

Indicative Soil Type	Permeability (m/s)
Clean gravels	>1 x 10^{-3}
Sand and gravel mixtures	1 x 10^{-3} to 1 x 10^{-5}
Very fine sands, silty sands	1 x 10^{-4} to 1 x 10^{-7}
Silt and interlaminated silt/sand/clays	1 x 10^{-6} to 1 x 10^{-9}
Intact clays	<1 x 10^{-9}

Bedrock Units

14.6.5.3 The Penrith Sandstone exhibits a dual permeability comprising of intergranular matrix flow as well as fracture flow. Allen et al (1997) presents hydraulic conductivity of the Penrith Sandstone to the range from $3x10^{-4}$m/s to $4x10^{-10}$m/s, based on a compilation of laboratory testing of intergranular permeability and in-situ pumping and packer tests. Allen refers to the importance of both grain size and cementation in relation to the variation in intergranular permeability. Established large diameter boreholes within the Penrith Sandstone in the Vale of Eden typically yield up to 3,000m^3/d (Allen et al., 1997)[28].

14.6.5.4 Groundwater flow through the limestones is dominated by secondary (fracture) porosity pathways and tertiary (karstic) porosity features, so the aquifer may locally have a high permeability but overall have low storage capacity. Fracture flow through rock defects like joints and bedding planes is expected to be the main way groundwater will flow within sandstone units. Compared to the limestone, sandstone is likely to have a lower hydraulic conductivity, but greater storage capacity.

[27] Preene, M, Roberts, T O L and Powrie, W (2016) Groundwater Control – Design and Practice, 2nd edition. Construction Industry Research and Information Association, CIRIA Report C750, London.
[28] Allen, D.J., Brewerton, L.M., Coleby, L.M., Gibbs, B.R., Lewis, M.A., MacDonald, A.M., Wagstaff, S. and Williams, A.T., (1997) The physical properties of major aquifers in England and Wales. British Geological Survey Technical Report, WD/97/34. Environment Agency R&D Publication 8.

14.6.5.5 Limestones which are thicker and more fractured have been observed to have a higher hydraulic conductivity in comparison to thinner and less fractured units. The density and size of fractures commonly decreases rapidly with depth, providing an effective aquifer thickness of only 50-80 m, although the actual thickness of the limestone formation may be considerably greater (Jones et al., 2000)[29].

14.6.5.6 Groundwater flow through the limestone matrix will not be appreciable, with a porosity average of 1% to 1.3% and permeability of 0.14 m/d. This will mean the Limestone units have a lower storage capacity in comparison to the Sandstone units (Holliday, 1986)[30].

14.6.5.7 Borehole yields are highly variable, within Carboniferous Limestones in the Northern Pennines, a range from 240m^3/d to 1,920m^3/d have been observed. There are also cases of dry boreholes with no yield. It is expected the hydraulic conductivity of the aquifer in the study area is also highly variable.

14.6.5.8 The multilayered Stainmore Formation and Alston Formation are expected to have similar properties to the Limestone units in the corresponding Limestone layers, and similar in the sandstone layers. The mudstone layers will have a very low hydraulic conductivity, they will act as aquitards and it can be assumed little to no significant water will flow across these layers, other than by means of a fault.

14.6.5.9 The interbedded nature of the Alston Formation will create formation scale anisotropy in the hydraulic conductivity, where the value will be higher parallel to the bedding dip and lower normal to the bedding dip.

Site investigation data

14.6.5.10 In-situ testing to ascertain hydraulic conductivity parameters was undertaken in a number of ground investigation boreholes as part of the first phase of ground investigations. See ES Appendix 9.5: Ground Investigation Reports (GIR) (Application Document 3.4).

14.6.5.11 In summary:

- Seven falling head and 20 rising head permeability tests were undertaken during the phase one ground investigation; Nine tests in the Bowes Bypass section, four tests in the Cross Lanes to Rokeby section and 14 tests in the Stephen Bank to Carkin Moor section

[29] Jones, H K, Morris, B L, Cheney, C S, Brewerton, L J, Merrin, P D, Lewis, M A, MacDonald, A M, Coleby, L M, Talbot, J C, McKenzie, A A, Bird, M J, Cunningham, J, and Robinson, V K (2000) The physical properties of minor aquifers in England and Wales. British Geological Survey Technical Report, WD/00/4. 234pp. Environment Agency R and D Publication 68.

[30] Holliday, D.W., (1986) Devonian and Carboniferous Basins. In: R.A. Downing and D.A. Gray (Editors), Geothermal Energy- The Potential in the United Kingdom. British Geological Survey, 84-109

- 36 soakaway infiltration tests were undertaken during the phase one ground investigation works; one test in the M6 Junction 40 to Kemplay Bank section, two tests in the Penrith to Temple Sowerby section, five in the Temple Sowerby to Appleby section, 10 in the Appleby to Brough section, five in the Bowes Bypass section, four in the Cross Lanes to Rokeby section, nine in the Stephen Bank to Carkin Moor section and zero in the A1(M) J53 Scotch Corner section.

14.6.5.12 Borehole locations are illustrated in ES Figure 14.11: Site Investigation Locations (Application Document 3.3).

M6 Junction 40 to Kemplay Bank

14.6.5.13 No in-situ permeability testing was scoped in the M6 Junction 40 to Kemplay Bank Roundabout Order Limits.

14.6.5.14 An infiltration test was undertaken in TP KBR009 which provided no infiltration rate (no infiltration occurred during the test).

Penrith to Temple Sowerby

14.6.5.15 No in-situ permeability testing was scoped in the Penrith to Temple Sowerby Order Limits.

14.6.5.16 Two infiltration tests were undertaken in TP PTS013 and TP PTS023 which provided no infiltration rate (insufficient infiltration to obtain infiltration rate).

Temple Sowerby to Appleby

14.6.5.17 No in-situ permeability testing was scoped in the Temple Sowerby to Appleby Order Limits.

14.6.5.18 Five infiltration tests were undertaken in the Temple Sowerby to Appleby area as summarised in Table 34: Infiltration tests in Temple Sowerby to Appleby Order Limits below.

Table 34: Infiltration tests in Temple Sowerby to Appleby Order Limits

Location	Infiltration Rate (m/s)	Comments
TP KTB008	3.76×10^{-6}	
TP KTB016	N/A	No infiltration occurred
TP KTA006	N/A	No infiltration occurred
TP KTA012	N/A	Insufficient infiltration to obtain infiltration rate
TP KTA018	N/A	No infiltration occurred

Appleby to Brough

14.6.5.19 No in-situ permeability testing was scoped in the Appleby to Brough Order Limits.

14.6.5.20 10 infiltration tests were undertaken in the Appleby to Brough area as summarised in Table 35: Infiltration tests in Appleby to Brough Order Limits below.

Table 35: Infiltration tests in Appleby to Brough Order Limits

Location	Infiltration Rate (m/s)	Comments
TP AB004	N/A	Insufficient infiltration to obtain infiltration rate
TP AB007	N/A	No infiltration occurred
TP AB019	N/A	No infiltration occurred
TP AB022	N/A	No infiltration occurred
TP AB027	N/A	No infiltration occurred
TP AB029	N/A	Insufficient infiltration to obtain infiltration rate
TP AB038	N/A	Insufficient infiltration to obtain infiltration rate
TP AB039	3.45×10^{-6}	
TP AB045	N/A	Insufficient infiltration to obtain infiltration rate
TP AB057	N/A	Insufficient infiltration to obtain infiltration rate

Bowes Bypass

14.6.5.21 Nine in-situ permeability tests were undertaken in the Bowes Bypass Order Limits as summarised in Table 36: Insitu permeability tests in Bowes Bypass Order Limits below.

Table 36: Insitu permeability tests in Bowes Bypass Order Limits

Location	Test Type	Response Zone	Permeability (m/s)
BH BB002	Falling Head	3.5 – 4.5m bgl Granular Glacial Deposits	2.39×10^{-4}
BH BB004	Falling Head	1.0 – 5.0m bgl Cohesive Glacial Deposits	1.43×10^{-5}
BH BB005	Falling Head	4.5 – 5.5m bgl Granular Glacial Deposits	4.66×10^{-5}
BH BB011	Rising Head	3.5 – 4.5m bgl Mudstone	1.43×10^{-4}
BH BB012	Rising Head	7.0 – 9.0m bgl Limestone	1.13×10^{-5}
BH BB013	Falling Head	1.5 – 4.0m bgl Cohesive Glacial Deposits	9.18×10^{-5}
BH BB018	Rising Head	3.5 – 5.0m bgl Limestone	1.69×10^{-4}
BH BB022	Rising Head	1.5 – 3.0m bgl Cohesive Glacial Deposits	2.09×10^{-7}
BH BB024	Rising Head	1.0 – 3.0m bgl Cohesive Glacial Deposits	3.83×10^{-6}

14.6.5.22 The recorded permeabilities for the glacial deposits are towards the higher end of what would usually be anticipated for glacial deposits, which generally have a reasonably low permeability (due to their high fines content and over-consolidation). The bedrock permeabilities are also towards the higher end of what would usually be anticipated, potentially indicating a high degree of fracturing and weathering in the test locations.

14.6.5.23 Five infiltration tests were undertaken in the Bowes Bypass area as summarised in Table 37: Infiltration tests in Bowes Bypass Order Limits below.

Table 37: Infiltration tests in Bowes Bypass Order Limits

Location	Infiltration Rate (m/s)	Comments
TP BB005	N/A	Insufficient infiltration to obtain infiltration rate
TP BB011	4.24×10^{-5}	Average of three tests: 4.88×10^{-5} m/s
TP BB011	7.06×10^{-5}	
TP BB011	3.32×10^{-5}	
TP BB014	N/A	Water level rose during test

Cross Lanes to Rokeby

14.6.5.24 Four in-situ permeability tests were undertaken in the Cross Lanes to Rokeby area as summarised in Table 38: Insitu permeability tests in Cross Lanes to Rokeby Order Limits below.

Table 38: Insitu permeability tests in Cross Lanes to Rokeby Order Limits

Location	Test Type	Response Zone	Permeability (m/s)
BH CLR001A	Rising Head	15.0 – 16.0m bgl Cohesive Glacial Deposits	3.14×10^{-7}
BH CLR001A	Rising Head	5.0 – 7.0m bgl Cohesive Glacial Deposits	5.40×10^{-6}
BH CLR001A	Rising Head	3.0 – 5.0m bgl Cohesive Glacial Deposits + Limestone Boulder	4.09×10^{-7}
WS CLR003	Rising Head	1.0 – 3.0m bgl Cohesive Glacial Deposits	1.29×10^{-6}

14.6.5.25 The recorded permeabilities for the cohesive glacial deposits are in the mid to high end of what would usually be anticipated for glacial deposits, which generally have a reasonably low permeability (due to their high fines content and over-consolidation).

14.6.5.26 Four infiltration tests were undertaken in the Cross Lanes to Rokeby area as summarised in Table 39: Infiltration tests in Cross Lanes to Rokeby Order Limits below.

Table 39: Infiltration tests in Cross Lanes to Rokeby Order Limits

Location	Infiltration Rate (m/s)	Comments
TP CLR005	N/A	Insufficient infiltration to obtain infiltration rate
TP CLR006	N/A	Water level rose during test
TP CLR009	N/A	Water level rose during test
TP CLR020	N/A	Insufficient infiltration to obtain infiltration rate

Stephen Bank to Carkin Moor

14.6.5.27 14 in-situ permeability tests were undertaken in the Stephen Bank to Carkin Moor area as summarised in Table 40: Insitu permeability tests in Stephen Bank to Carkin Moor Order Limits below.

Table 40: Insitu permeability tests in Stephen Bank to Carkin Moor Order Limits

Location	Test Type	Response Zone	Permeability (m/s)
BH SBC001	Falling Head	1.0 – 3.0m bgl Interbedded Mudstone/Sandstone	1.76×10^{-4}
BH SBC005	Rising Head	2.0 – 3.5m bgl Cohesive Glacial Deposits	5.47×10^{-6}
BH SBC006	Rising Head	5.0 – 7.0m bgl Mudstone	2.62×10^{-6}
BH SBC009	Rising Head	4.0 – 6.0m bgl Mudstone	1.04×10^{-8}
BH SBC013	Rising Head	7.0 – 9.0m bgl Cohesive Glacial Deposits	4.88×10^{-6}
BH SBC016	Rising Head	4.0 – 6.0m bgl Cohesive Glacial Deposits	7.4×10^{-6}
BH SBC016	Falling Head	4.0 – 6.0m bgl Cohesive Glacial Deposits	1.64×10^{-6}
BH SBC018	Rising Head	2.0 – 3.5m bgl Cohesive Glacial Deposits	9.32×10^{-6}
BH SBC020	Rising Head	5.0 – 6.0m bgl Cohesive Glacial Deposits	2.72×10^{-6}
BH SBC0021	Falling Head	2.0 – 3.0m bgl Cohesive Glacial Deposits	1.01×10^{-5}
BH SBC0022	Rising Head	1.0 – 2.0m bgl Cohesive Glacial Deposits	6.19×10^{-6}
BH SBC023A	Rising Head	7.5 – 9.0m bgl Cohesive and Granular Glacial Deposits	2.86×10^{-8}
BH SBC030	Rising Head	2.0 – 4.0m bgl Cohesive Glacial Deposits	1.59×10^{-5}
BH SBC032A	Rising Head	4.0 – 7.0m bgl Cohesive Glacial Deposits	2.54×10^{-5}

14.6.5.28 The recorded permeabilities for the cohesive glacial deposits are towards the high end of what would usually be anticipated for glacial deposits, which generally have a reasonably low permeability (due to their high fines content and over-consolidation). The bedrock permeabilities are also towards the higher end of what would usually be anticipated, potentially indicating a high degree of fracturing and weathering in the test locations.

14.6.5.29 Nine infiltration tests were undertaken in the Stephen Bank to Carkin Moor area as summarised in Table 41: Infiltration tests in Stephen Bank to Carkin Moor Order Limits below.

Table 41: Infiltration tests in Stephen Bank to Carkin Moor Order Limits

Location	Infiltration Rate (m/s)	Comments
TP SBC001	4.92×10^{-5}	Average of three tests: 6.52×10^{-5} m/s
TP SBC001	1.10×10^{-4}	
TP SBC001	3.65×10^{-5}	
TP SBC008	N/A	Insufficient infiltration to obtain infiltration rate
TP SBC018	N/A	Insufficient infiltration to obtain infiltration rate
TP SBC022	N/A	Insufficient infiltration to obtain infiltration rate
TP SBC026	N/A	No infiltration occurred
TP SBC030	N/A	No infiltration occurred
TP SBC040	N/A	No infiltration occurred

A1(M) Junction 53 Scotch Corner

14.6.5.30 No in-situ permeability testing or infiltration testing was scoped in for the A1(M) Junction 53 Scotch Corner Order Limits, as construction works are limited in this scheme.

Hydraulic parameters for assessment

14.6.5.31 The proposed hydraulic parameters of the geology are based on a combination of the field tests and published data summarised above and are presented in Table 42: Summary of Ground Permeabilities below.

14.6.5.32 Note that the below ranges are representative of intergranular and fracture flow. Where there is potential for higher permeabilities as a result of karst ground conditions, this is noted in section 14.6.8.

Table 42: Summary of Ground Permeabilities

Geology	Min K (m/s)	Max K (m/s)	Values used for impact assessment (m/s)
Alluvium	1×10^{-7}	1×10^{-3}	N/A (no cuttings anticipated within alluvium deposits)
River Terrace Deposits	1×10^{-5}	$>1 \times 10^{-3}$	N/A (no cuttings anticipated within river terrace deposits)
Glaciofluvial Deposits	1×10^{-5}	$>1 \times 10^{-3}$	1×10^{-3}
Peat	Highly Variable		N/A (no cuttings anticipated within peat deposits)
Glacial Till (Cohesive)	$<1 \times 10^{-9}$	1×10^{-5}	1×10^{-5}
Glacial Till (Granular)	$<1 \times 10^{-9}$	1×10^{-4}	1×10^{-4}

Geology	Min K (m/s)	Max K (m/s)	Values used for impact assessment (m/s)
Penrith Sandstone	<1 x 10^{-9}	3 x 10^{-4}	1 x 10^{-4}
Eden Shale	<1 x 10^{-9}	1 x 10^{-7}	N/A (no cuttings anticipated within Eden Shale)
Stainmore/Alston Formation - Limestone	<1 x 10^{-9}	1 x 10^{-3}	1 x 10^{-4}
Stainmore/Alston Formation - Sandstone	<1 x 10^{-9}	1 x 10^{-4}	1 x 10^{-4}
Stainmore/Alston Formation - Mudstone	<1 x 10^{-9}	1 x 10^{-4}	1 x 10^{-5}

14.6.6 Groundwater quality

14.6.6.1 During the site investigation, groundwater samples were taken in boreholes along the route from both the superficial deposits and bedrock, as summarised in Table 43: Summary of groundwater samples.

Table 43: Summary of groundwater samples

Scheme	Groundwater Sample Locations
M6 Junction 40 to Kemplay Bank Roundabout	M6J40.001, KBR003, KBR012, SD KBR005
Penrith to Temple Sowerby	PTS003, PTS005, PTS011, PTS017, PTS018, PTS020
Kirkby Thore to Appleby	KTB007A, KTB010, KTB013, KTB024, KTB025, KTA015, KTA018, KTA021, KTA022
Appleby to Brough	AB001, AB008S, AB008D, AB009S, AB009D, AB010S, AB010D, AB011, AB020, AB025, AB026, AB027, AB028, AB031, AB032, AB033, AB042, AB043, AB044, AB045
Bowes Bypass	BB007, BB013
Cross Lanes to Rokeby	CLR003A
Stephen Bank to Carkin Moor	SBC006, SBC008. SBC032A
A1(M) Junction 53 Scotch Corner	N/A

14.6.6.2 Screening of the groundwater samples for quality exceedances (against Environmental Quality Standards (EQS)) associated with the WFD, has been undertaken as part of the geo-environmental assessment and is summarised within the Appendix 9.5: Ground Investigation Reports (GIR) (Application Document 3.4).

14.6.6.3 Groundwater quality within superficial deposits is anticipated to be highly variable along the route and is more likely to contain exceedances of anthropogenic contaminants due to proximity to potential contaminant sources.

14.6.6.4 Literature indicates that the quality of groundwater in the Vale of Eden (i.e. the Penrith Sandstone) is generally good, and conforms to Ca–HCO_3 facies. Local trends towards Ca–SO_4 facies are found adjacent to the Eden Shales, but salinities are not generally excessive (Younger and Milne, 1997)[31].

14.6.6.5 Groundwater sampling from various strata (superficial and bedrock) within the area of the Kirkby Thore bypass is illustrated in Plate 13: Piper Plot of groundwater chemistry in Kirkby Thore Bypass area in Annex C: Piper Plots and identifies that the groundwater conforms to Ca-HCO3 facies.

14.6.6.6 Groundwaters associated with the Carboniferous Limestone Aquifers in the east are anticipated to be predominantly Ca-HCO_3 type waters based on previous studies (Brandon et al., 1998)[32] (Abesser et al., 2005)[33], whereas groundwater quality in other stratum is anticipated to be more heterogenous as supported by the data gathered to date.

14.6.7 Groundwater conceptual model

Routewide

14.6.7.1 The groundwater conditions are bespoke to each scheme and therefore are considered on a scheme-by-scheme basis, as documented below.

14.6.7.2 The local groundwater regimes for each study area of the Project are presented in the scheme sections below. These tables are a collation of the data documented in Sections 14.6.3 to 14.6.6 of this report.

M6 Junction 40 to Kemplay Bank Roundabout

14.6.7.3 A summary of the groundwater conceptual model elements within the M6 Junction 40 to Kemplay Bank Roundabout Project study area are presented in Table 44: M6 Junction 40 to Kemplay Bank Roundabout conceptual model elements.

14.6.7.4 Representative cross sections have been developed and are presented in Annex D: Hydrogeological Conceptual Models, Plate 14: Hydrogeological Conceptual Model in M6 Junction 40 to Kemplay Bank Roundabout Project study area (M6 Junction 40 area) and Plate 15: Hydrogeological Conceptual Model in M6 Junction 40 to Kemplay

[31] Younger, Paul & Milne, CA. (1997) Hydrostratigraphy and hydrogeochemistry of the Vale of Eden, Cumbria, UK. Proceedings of The Yorkshire Geological Society - Proc. Yorkshire Geological Society. 51. 349-366.
[32] Brandon, A., Aitkenhead, N., Crofts, R.G., Ellison, R.A., Evans, D.J. and Riley, N.J., (1998) Geology of the country around Lancaster. Memoirs of the British Geological Survey. Her Majesty's Stationary Office, London.
[33] Abesser, C, Shand, P. & Ingram, J, (2005) Baseline Report Series: 22. The Carboniferous Limestone of Northern England. British Geological Survey Commissioned Report No. CR/05/076N

Bank Roundabout Project study area (Kemplay Bank Roundabout area). The location of the cross section is shown on ES Figure 14.6.1: Hydrogeological Conceptual Model Locations (Application Document 3.3).

Table 44: M6 Junction 40 to Kemplay Bank Roundabout conceptual model elements

Model element	Description
Surface topography	Within the Order Limits, ground level along the route gradually slopes down to the east - approximate elevation 138-131mAOD. There is a gradual slope downwards from north to south across the scheme study area from Penrith (approximately 150mAOD) towards the River Eamont (approximately 120mAOD).
WFD groundwater catchment	Chainage 9100 to 10650 – Eden and Esk Lower Palaezoic Carboniferous Aquifers Chainage 10650 to 11610 – Eden Valley and Carlisle Basin Permo-Triassic Sandstone Aquifers
Main groundwater bodies	Superficial: Route overlies glacial till with likely intergranular flow paths towards the alluvium associated with the River Eamont. Route overlies alluvium associated with Thacka Beck. Bedrock: Beneath superficial deposits, Chainage 9100 to 9270 is atop Alston formation, Chainage 9270 to 10700 is atop Stainmore Formation, Chainage 107000 to 11610 is atop Penrith Sandstone.
Groundwater flow direction	Localised: Flow through Superficial deposits is to the east/south east controlled by the River Eamont and Thacka Beck. Regional: Flow in the area is likely from west to east towards the River Eden.
Approximate groundwater level in scheme study area	No data available for bedrock. Superficial winter max around 135mAOD towards the M6, and 120mAOD in the east of the scheme study area.
Regional faults	Two faults running north west/south east in western edge of scheme separating Alston and Stainmore Formation
Surface water bodies	Carlsike Beck Myers Beck Dog Beck Thacka Beck Unnamed Tributary of River Eamont 3.2 Unnamed Tributary of Light Water 3.1 River Eamont River Lowther
Groundwater Abstractions Licenses (within 1km)	Abstraction at Penrith & District Farmers Market used for washing and process washing – Penrith Sandstone Abstraction at A W Jenkinson Forest Products used as a truck wash for forestry trucks – Penrith Sandstone

Model element	Description
	Data was not provided by local councils for unlicenced abstractions for this region
Source Protection Zones	The eastern edge of the scheme study area is located within SPZ III associated with abstractions a minimum of 1.5km to the north of the scheme study area
Springs	No springs or seepages are mapped within the scheme study area
Recharge	Variable thickness of clayey glacial till will limit recharge, whilst alluvium deposits and glaciofluvial deposits around surface water flow areas will allow for recharge to Penrith Sandstone.

Penrith to Temple Sowerby

14.6.7.5 A summary of the groundwater conceptual model elements within the Penrith to Temple Sowerby scheme are presented in Table 45: Penrith to Temple Sowerby conceptual model elements.

14.6.7.6 A representative cross section has been developed and is presented in Annex D: Hydrogeological Conceptual Model, Plate 16: Hydrogeological Conceptual Model in Penrith to Temple Sowerby Project study area. The location of the cross section is shown on ES Figure 14.6.1: Hydrogeological Conceptual Model Locations (Application Document 3.3).

Table 45: Penrith to Temple Sowerby conceptual model elements

Model element	Description
Surface topography	Approximately 115mAOD at either end of the Order Limits, rising to 137mAOD in the centre. Southern side of scheme study area gradually slopes upwards towards Whinfell Forest, whilst northern side slopes downwards towards River Eamont and Lowther.
WFD groundwater catchment	Eden Valley and Carlisle Basin Permo-Triassic Sandstone Aquifers
Main groundwater bodies	Superficial: Route overlies glacial till with likely intergranular flow paths towards the alluvium associated with the River Eamont. Route overlies alluvium associated with Unnamed Tributary of River Eamont 3.3, Swine Gill and Light Water. Bedrock: Penrith Sandstone aquifer beneath superficial deposits
Groundwater flow direction	Localised: Flow through glacial till is likely localised and there may be some perched water in lower permeability sections of the till. The groundwater flow direction will be towards localised water courses and tributaries across the scheme study area. Regional: Regional flow through the Penrith Sandstone is from west to east.
Approximate groundwater level in scheme study area	Bedrock groundwater levels in the scheme study area is approximately 114m AOD. Superficial groundwater levels range between 124mAOD and 102m AOD.

Model element	Description
Regional faults	Fault running north/south in Penrith Sandstone
Surface water bodies	River Eamont River Lowther Unnamed Tributary of River Eamont 3.2 Unnamed Tributary of Light Water 3.1 Light Water Unnamed Tributary of River Eamont 3.3 Unnamed Tributary of River Eamont 3.5 Swine Gill Unnamed tributary of River Eden 4.5
Groundwater Abstractions Licenses (within 1km)	There are no licenced groundwater abstractions in the scheme study area. Data was not provided by local councils for unlicenced abstractions for this region.
Source Protection Zones	The western edge of the study area is located within a SPZ III (the same SPZ as identified in the M6 Junction 40 to Kemplay Bank Roundabout study area).
Springs	No springs or seepages are mapped within the study area
Recharge	Variable thickness of clayey glacial till will limit recharge, whilst alluvium deposits and glaciofluvial deposits around surface water flow areas will allow for recharge to Penrith Sandstone.

Temple Sowerby to Appleby

14.6.7.7 A summary of the groundwater conceptual model elements within the Temple Sowerby to Appleby scheme are presented in Table 46: Temple Sowerby to Appleby conceptual model elements.

14.6.7.8 Representative cross sections have been developed and are presented in Annex D: Hydrogeological Conceptual Model, Plate 17: Hydrogeological Conceptual Model in Temple Sowerby to Appleby Project study area (Kirby Thore Bypass area) and Plate 18: Hydrogeological Conceptual Model in Temple Sowerby to Appleby Project study area (southeast area). The location of the cross section is shown on ES Figure 14.6.1: Hydrogeological Conceptual Model Locations (Application Document 3.3).

Table 46: Temple Sowerby to Appleby conceptual model elements

Model element	Description
Surface topography	From the north west, the route within Order Limits cuts across rolling hills from approximately 110mAOD to 120mAOD to the north of Kirkby Thore. The Order Limit topography then increases in height to 160mAOD close to Appleby. East of the scheme study area slopes downwards towards River Eden, west of the scheme study area slopes upwards.
WFD groundwater catchment	Eden Valley and Carlisle Basin Permo-Triassic Sandstone Aquifers

Model element	Description
Main groundwater bodies	Superficial: Route overlies glacial till with likely intergranular flow paths towards the alluvium associated with the River Eden and Trout Beck. Route overlies alluvium associated with Trout Beck and Order Limits overlays Birk Sike. Bedrock: Route mostly overlies Penrith Sandstone beneath superficial deposits. To the north east of the scheme study area is the Eden Shales formation and associated gypsum beds. Eden Shales generally unproductive, However, dissolution of gypsum beds and faulting in the area may play important local impact on groundwater behaviour.
Groundwater flow direction	Localised: Flow through glacial till is likely localised and there may be some perched water in lower permeability sections of the till. The groundwater flow direction will be towards the River Sike, Trout Beck localised water courses and tributaries across the scheme study area Regional: Flow through the Penrith Sandstone is from east to west (towards the River Eden). However, at depth groundwater may preferentially flow along gypsum karst features within the Eden Shale. Faulting and gypsum beds within the Eden Shale should not be overlooked in this area.
Approximate groundwater level in scheme study area	Bedrock: Between 98mAOD and 118mAOD Superficials: Variable, between 105mAOD and 169mAOD
Regional faults	Multiple faults running north west/south east through Penrith Sandstone and Eden Shales
Surface water bodies	Birk Sike River Eden River Lyvennet Unnamed Tributary of Birk Sike 4.2 Unnamed Tributary of Birk Sike 4.3 Unnamed Tributary of Trout Beck 4.1 Trout Beck Unnamed Tributary of Keld Sike 4.1 Keld Sike (1) Unnamed Tributary of Trout Beck 4.2 Unnamed Tributary of Trout Beck 4.3 Unnamed Tributary of Trout Beck 4.6 Keld Sike (2) Unnamed Tributary of River Eden 4.2 Unnamed Tributary of River Eden 4.3
Groundwater Abstractions Licenses (within 1km)	Abstraction at Spittals Farm – General farming and domestic – Penrith Sandstone (Licence number: 2776003013) Abstraction at Crossfell House Farm – General farming and domestic – Penrith Sandstone (Licence number: 2776003012/R01)

Model element	Description
	2 x abstractions at British Gypsum – Industrial – Penrith Sandstone (Licence number: 277600311) Unlicensed private abstraction identified in consultation utilised for residential and commercial water supply proximal to Chainage 34000. Data was not provided by local councils for unlicenced abstractions for this region.
Source Protection Zones	There are no source protection zones mapped in the scheme study area
Springs	No springs or seepages are mapped within the scheme study area
Recharge	Variable thickness of clayey glacial till will limit recharge, whilst alluvium deposits and glaciofluvial deposits around surface water flow areas will allow for recharge to Penrith Sandstone. Penrith Sandstone is at surface at high topographic points to the north and south of the scheme study area.

Appleby to Brough

14.6.7.9 A summary of the groundwater conceptual model elements within the Appleby to Brough scheme are presented in Table 47: Appleby to Brough conceptual model elements.

14.6.7.10 A representative cross section has been developed and is presented in Annex D, Plate 19: Hydrogeological Conceptual Model in Appleby to Brough Project study area. The location of the cross section is shown on ES Figure 14.6.1: Hydrogeological Conceptual Model Locations (Application Document 3.3).

Table 47: Appleby to Brough conceptual model elements

Model element	Description
Surface topography	Order Limit topography gradually increases in height from approximately 148mAOD at Coupland to 174mAOD at Brough. South east of scheme study area slopes down towards River Eden, north west of scheme study area slopes upwards.
WFD groundwater catchment	Rest of route - Eden Valley and Carlisle Basin Permo-Triassic Sandstone Aquifers Northern edge of redline boundary from Chainage 47300 to 48000 - Eden and Esk Lower Palaeozoic Carboniferous Aquifers
Main groundwater bodies	Superficial: Route overlies glacial till with likely intergranular flow paths towards the alluvium associated with Mire Sike and associated tributaries, and Crooks Beck. Route overlies alluvium associated with Cringle Beck, Eastfield Sike, Moor Beck, Unnamed Tributary of Lowgill Beck 6.1, Lowgill Beck and Unnamed Tributary of Lowgill Beck 6.7. Bedrock: Beneath superficial deposits, route mostly overlies Penrith Sandstone aquifer. Northern section of Chainage 47500 to 48000 is on Stainmore Formation

Model element	Description
Groundwater flow direction	Localised: On a localised scale the route crosses alluvium associated with numerous water courses. Localised flow is likely to be towards the alluvium and surface water features. Regional: Groundwater flow is regionally from east to west in the Penrith sandstone.
Approximate groundwater level in scheme study area	Bedrock: Approximately 140mAOD across scheme study area Superficials: 176mAOD in the east of the scheme to 145mAOD in the west of the scheme study area.
Regional faults	Single fault running north/south at Chainage 46800
Surface water bodies	Hilton Beck George Gill Coupland Beck Lycum Beck River Eden Unnamed Tributary of Mire Sike 6.1 Unnamed Tributary of Mire Sike 6.4 Unnamed Tributary of Mire Sike 6.8 Unnamed Tributary of Mire Sike 6.12 Mire Sike Unnamed Tributary of Cringle Beck 6.1 Cringle Beck Hayber Beck Moor Beck Eastfield Sike Crooks Beck Lowgill Beck Unnamed Tributary of Lowgill Beck 6.1 Woodend Sike Yosgill Sike Unnamed Tributary of Lowgill Beck 6.7 Unnamed Tributary of Lowgill Beck 6.3 Swindale Beck Augill Beck
Groundwater Abstractions Licenses (within 1km)	Eastfield Farm (Licence Number: NW/076/0001/009) – Permo-Triassic Sandstone Borehole at West View Brough, Kirkby Stephen (Licence number: 2776001135/R01) – Permo-Triassic Sandstone. Data was not provided by local councils for unlicenced abstractions for this region.

Model element	Description
Source Protection Zones	There are no source protection zones mapped in the scheme study area
Springs	Flitholme 'Spring' - South of Chainage 45650 (used for supply). Wildboar Hill springs - Southwest of Chainage 42900. Potential spring/seepage north-east of Sandford Junction.
Recharge	Variable thickness of clayey glacial till will limit recharge, whilst alluvium deposits and glaciofluvial deposits around surface water flow areas will allow for recharge to Penrith Sandstone.

Bowes Bypass

14.6.7.11 A summary of the groundwater conceptual model elements within the Bowes Bypass scheme are presented in Table 48: Bowes Bypass conceptual model elements

14.6.7.12 A representative cross section has been developed and is presented in Annex D: Hydrogeological Conceptual Model, Plate 20: Hydrogeological Conceptual Model in Bowes Bypass Project study area. The location of the cross section is shown on ES Figure 14.6.1: Hydrogeological Conceptual Model Locations (Application Document 3.3).

Table 48: Bowes Bypass conceptual model elements

Model element	Description
Surface topography	Order Limit topography descends from 288mAOD west of Bowes to 260mAOD east of Bowes. South of the scheme study area is steeply sloped towards River Greta.
WFD groundwater catchment	Tees Carboniferous Limestone & Millstone Grit
Main groundwater bodies	Superficial: Route overlies glacial till with likely intergranular flow paths towards the river terrace deposits and alluvium associated with River Greta. Route overlies Unnamed Tributary of River Greta 7.3, which sits on Glacial Till Bedrock: Beneath superficial deposits, Chainage 50000 to 51150 sits atop the Stainmore formation, Chainage 51150 to 51800 sits atop the Great Limestone, and 51800 to 52941 is atop the Alston formation. The southern section of the order limits of Chainage 52300 to 52941 is atop sandstone of the Alston formation.
Groundwater flow direction	There is a steep slope to the south of the Order Limits towards the River Greta. This is likely to impact both the superficial aquifer and the bedrock aquifer, thus the regional and localised flow. The hydraulic gradient from the scheme study area is towards the south towards the River Greta.
Approximate groundwater level	Bedrock: 287mAOD to 280mAOD in west of scheme study area and between 267mAOD to 262mAOD in the east of the scheme study area.

Model element	Description
in scheme study area	Superficial deposits are between 290mAOD to 282mAOD in the west of the scheme study area, and 264mAOD to 262mAOD in the east of the scheme study area.
Regional faults	No mapped faults present in region
Surface water bodies	Bessy Sike Unnamed Tributary of River Greta 7.7 Unnamed Tributary of River Greta 7.1 Unnamed Tributary of River Greta 7.3 Chert Gill How Low Gill Unnamed Tributary of River Greta 7.5 Unnamed Tributary of River Greta 7.6 River Greta Thorsgill Beck
Groundwater Abstractions Licenses (within 1km)	There are no groundwater abstractions within the scheme study area.
Source Protection Zones	There are no source protection zones mapped in the scheme study area
Springs	Spring S19 – Spring to side of surface water stream During consultation, additional springs were also identified at the western end of the Order Limits in the fields to the north of the existing A66.
Recharge	Variable thickness of clayey glacial till will limit recharge to bedrock aquifers, whilst alluvium deposits and glaciofluvial deposits around surface water flow areas will allow for recharge to the fractured limestones of the Alston and Stainmore Formation. Recharge likely to be higher in areas where no superficial cover is present such as to the north of the east of the scheme, and along the route of the River Greta to the south.

Cross Lanes to Rokeby

14.6.7.13 A summary of the groundwater conceptual model elements within the Cross Lanes to Rokeby scheme are presented in Table 49: Cross Lanes to Rokeby conceptual model elements.

14.6.7.14 A representative cross section has been developed and is presented in Annex D: Hydrogeological Conceptual Model, Plate 21: Hydrogeological Conceptual Model in Cross Lanes to Rokeby Project study area. The location of the cross section is shown on ES Figure 14.6.1: Hydrogeological Conceptual Model Locations (Application Document 3.3).

Table 49: Cross Lanes to Rokeby conceptual model elements

Model element	Description
Surface topography	Order Limit topography descends from approximately 237mAOD east of Boldron to 140mAOD near Greta Bridge. There is a gradual slope across the scheme study area downwards towards the River Greta to the south.
WFD groundwater catchment	Tees Carboniferous Limestone & Millstone Grit
Main groundwater bodies	Superficial: Route overlies glacial till with likely intergranular flow paths towards alluvium associated with Tutta Beck and Manyfold Beck, and glaciofluvial deposits, alluvium and river terrace deposits associated with the River Tees. Bedrock: Beneath superficial deposits, the scheme mostly overlies the Great Limestone. Chainage 62150 to 62000 and Chainage 63400 to 63700 the route overlies sandstone of the Alston Formation. The order limits of the rest of the route also overlie sandstones of the Alston Formation.
Groundwater flow direction	Both localised and regional flow direction is likely to be towards the east, towards the River Greta and River Tees.
Approximate groundwater level in scheme study area	Only superficial groundwater level recorded during summer months – approximate level at 200mAOD.
Regional faults	No mapped faults present in region
Surface water bodies	Thorsgill Beck Punder Gill Unnamed Tributary of Punder Gill 8.1 Unnamed Tributary of Tutta Beck 8.1 Tutta Beck New Cut Unnamed Tributary of Tutta Beck 8.2 Unnamed Tributary of Tutta Beck 8.3 Partridge Gill Wellfield Strand Manyfold Beck Unnamed Tributary of Manyfold Beck 8.3 Unnamed Tributary of Manyfold Beck 8.1 River Greta River Tees
Groundwater Abstractions Licenses (within 1km)	There are no groundwater abstractions within the scheme study area
Source Protection Zones	There are no source protection zones mapped in the scheme study area
Springs	Spring S21 – Boggy ground and possible groundwater fed pond which discharges to adjacent ditch

Model element	Description
Recharge	Variable thickness of clayey glacial till will limit recharge to bedrock aquifers, whilst alluvium deposits and glaciofluvial deposits around surface water flow areas will allow for recharge to the fractured limestones Alston and Stainmore Formation.

Stephen Bank to Carkin Moor

14.6.7.15 A summary of the groundwater conceptual model elements within the Stephen Bank to Carkin Moor scheme are presented in Table 50: Stephen Bank to Carkin Moor conceptual model elements.

14.6.7.16 A representative cross section has been developed and is presented in Annex D: Hydrogeological Conceptual Model, Plate 22: Hydrogeological Conceptual Model in Stephen Bank to Carkin Moor Project study area. The location of the cross section is shown on ES Figure 14.6.1: Hydrogeological Conceptual Model Locations (Application Document 3.3).

Table 50: Stephen Bank to Carkin Moor conceptual model elements

Model element	Description
Surface topography	From the north west, the Order Limit topography rises from approximately 150mAOD to 170mAOD, before falling to approximately 150mAOD towards the south east. There is a gradual slope across the scheme study area to the east and west .
WFD groundwater catchment	Western section of Order Limits, and northern section of Chainage 70600 to 70900 - Tees Carboniferous Limestone & Milstone Grit Rest of route – SUNO Milstone Grit and Carboniferous Limestone
Main groundwater bodies	Superficial: Route overlies glacial till with likely intergranular flow paths towards glaciofluvial deposits associated with alluvium of Cottonmill Beck and Holme Beck. Bedrock: Beneath the superficial deposits, the route overlies sandstones, siltstones, mudstones and limestones of the Alston Formation.
Groundwater flow direction	Regional: Groundwater flow is towards the south east in the direction of the flow direction of Holme Beck. Localised: Flow is likely south towards Holme Beck and associated tributaries
Approximate groundwater level in scheme study area	The groundwater levels within the superficials range from 177mAOD in the west of the scheme study area to 141mAOD in the east of the scheme study area. Bedrock is only recorded in the west of the scheme study area and is recorded between 158mAOD and 176mAOD
Regional faults	Two faults running north east/south west through the Alston Formation
Surface water bodies	Dyson Beck Smallways Beck

Model element	Description
	Unnamed Tributary of Smallways Beck 9.1 Unnamed Tributary of Smallways Beck 9.4 Cottonmill Beck Unnamed Tributary of Cottonmill Beck 9.3 Browson Beck Stalwath Beck Holme Beck Unnamed Tributary of Dalton Beck 9.1 Unnamed Tributary of Holme Beck 9.3 Unnamed Tributary of Holme Beck 9.4 Unnamed Tributary of Mains Gill 9.1 Unnamed Tributary of Mains Gill 9.3 Mains Gill Unnamed Tributary of Holme Beck 9.1 Unnamed Tributary of Holme Beck 9.2 Hartforth Beck
Groundwater Abstractions Licenses (within 1km)	Abstraction at Pondale Farm – General Farming and Domestic (license number: 2/27/23/661/R01) Abstraction at Blackhill Farm - Agriculture (No Licence number available). Data was not provided by local councils for unlicenced abstractions for this region
Source Protection Zones	Two source protection zones are identified within the scheme study area associated with the two licensed abstractions noted above.
Springs	Spring S1 – Spring feeding man made pond
Recharge	Variable thickness of clayey glacial till will limit recharge to bedrock aquifers, whilst alluvium deposits and glaciofluvial deposits around surface water flow areas will allow for recharge to the fractured limestones and the sandstones of Alston and Stainmore Formation.

A1(M) Junction 53 Scotch Corner

14.6.7.17 A summary of the groundwater conceptual model elements within the A1(M) Junction 53 scheme are presented in Table 51: A1(M) Junction 53 conceptual model elements.

Table 51: A1(M) Junction 53 conceptual model elements

Model element	Description
Surface topography	Ground level at this part of the Order Limits and scheme study area is approximately 140mAOD.
WFD groundwater catchment	SUNO Milstone Grit and Carboniferous Limestone
Main groundwater bodies	Superficial: Route overlies Glacial Till.

Model element	Description
	Bedrock: Beneath superficial deposits, the route overlies the Four Fathom Limestone of the Alston Formation
Groundwater flow direction	There is no available groundwater data for this scheme study area
Approximate groundwater level at scheme	There is no available groundwater data for this scheme study area
Regional faults	No mapped faults present in region
Surface water bodies	There are no main watercourses within the study area. The ordinary watercourses in the study area drain south towards the River Swale. Ludburn Beck
Groundwater Abstractions Licenses (within 1km)	Abstraction at Landteam Farms Ltd Abstraction – Agriculture (Licence Number 2/27/23/702/R01) Data was not provided by local councils for unlicenced abstractions for this region.
Source Protection Zones	There are no source protection zones mapped in the scheme study area.
Springs	No springs observed in this scheme study area
Recharge	Variable thickness of clayey glacial till will limit recharge to bedrock aquifers, whilst alluvium deposits and glaciofluvial deposits around surface water flow areas will allow for recharge to the fractured limestones of the Alston and Stainmore Formation.

14.6.8 Potential impacts to groundwater related features

Overview

14.6.8.1 This section assesses potential impacts to groundwater features as a result of interaction with design elements of the scheme. This section particularly focuses on cuttings and embankments and their potential impacts on both flow and drawdown. Water quality impacts from the works are also discussed qualitatively in the individual scheme sections

Methodology

14.6.8.2 Groundwater flow impacts have been assessed qualitatively. The assessment has considered both below ground works such as structures or cuttings which may intercept groundwater or act as a barrier to flow, and above ground works which may impact local surface water-groundwater interactions.

14.6.8.3 Quantitative dewatering calculations have been completed for below ground works likely to intercept groundwater to determine the extent and magnitude of drawdown effects on local receptors and predict potential flow rates either during construction or operational phases of the scheme.

14.6.8.4 The radius of influence from each of the cuttings has been assessed using the Sichardt equation (Preene et al., 2016)[34] (below), which assumes the aquifer is unconfined, infinite horizontal extent, constant thickness, homogenous and isotropic with respect to hydrogeological parameters.

$$R_0 = C(H - h)\sqrt{K}$$

Where:

R_0 = Radius of influence (m)

C = Empirical Correlation factor (taken as 2000 as design elements are linear)

H = Piezometric level in the aquifer (mAOD)

h = Target drawdown level (mAOD)

K = Hydraulic conductivity (m/s)

14.6.8.5 It should be noted that the Sichardt equation is a useful tool for ascertaining indicative flow rates and ascertaining receptors at the most risk of impact. However, the actual hydrogeological zone of influence from any works will be more complex and dependent on specific local conditions (e.g. boundary conditions, leakage, infiltration and time).

14.6.8.6 The inflow rates have been calculated using the Mansur and Kaufman formulae (Mansur and Kaufman, 1962)[35] for one-sided and two-sided trenches depending on the cut geometry and groundwater flow direction.

$$Q = ((0.73 + 0.27\frac{(H-h_w)}{H})\frac{KL}{2R_0}(H^2 - h_w^2)] \text{ One-sided trench inflow}$$

$$Q = ((0.73 + 0.27\frac{(H-h_w)}{H})\frac{KL}{R_0}(H^2 - h_w^2)] \text{ Two-sided trench inflow}$$

Where

Q = Flow rate (m^3/day)

H = Height of water table above base of aquifer

h_w = Height of drawdown level above base of aquifer

L = length of the element (m); such as the length of the cutting.

14.6.8.7 The equations represent steady-state conditions and are indicative of the groundwater conditions at a point where the groundwater level has stabilised due to passive dewatering at the cutting location. During construction, initial flow rates may be higher.

[34] Preene, M, Roberts, T O L and Powrie, W (2016) Groundwater Control – Design and Practice, 2nd edition. Construction Industry Research and Information Association, CIRIA Report C750, London.

[35] Mansur CI and Kaufman RI (1962) Dewatering In: Foundation Engineering (G A Leonards, ed), McGraw-Hill, New York, pp 241-350

14.6.8.8 To determine a reasonable worst case, a conservative approach has been taken to the drawdown assessment where the drawdown has been calculated using the following assumptions and criteria:

- Cutting depth taken as the maximum cutting height along the design element
- Groundwater table assumed at ground surface (unless otherwise noted), due to limited monitoring data available from the winter period
- Target water level taken as 1.0m below the road level
- Cuttings are assumed to be open excavations (i.e. no retaining structures considered)
- Hydraulic conductivity values selected to provide a conservative estimate of the zone of influence
- Aquifer base taken as 1.5 times the maximum cutting depth.

14.6.8.9 It is acknowledged that the conservative approach utilised to undertake the cuttings assessment will lead to a likely overestimation of the zone of influence and particularly ingress rates in several of the schemes. This is discussed following the detailed assessment in each scheme, the methodology for which is described below.

14.6.8.10 Karstic features within the Eden Shales Formation and Limestone units of the Stainmore and Alston Formations may be present along the route. These features can lead to significantly higher permeabilities of the bedrock and as such significantly higher inflows. See Appendix 14.8: Desk Study Karst Risk Assessment (Application Document 3.4) for further details. Care should be taken when any cuttings encounter the Eden Shales Formation or significant limestone beds during construction, with additional mitigation measures implemented, as required (e.g. voids treatment protocol as detailed in Annex B7: Ground and surface water management plan of the EMP (Application Document 2.7)).

Detailed assessment

Overview

14.6.8.11 A detailed assessment has been undertaken to assess the potential quantitative impacts from cuttings greater than 1.0m deep along the A66 route in accordance with the methodology presented above. It is considered that the impacts from cuttings shallower than 1.0m deep would be minimal, and as such detailed assessment is unnecessary.

14.6.8.12 The cuttings assessment has been undertaken based on the Project design for DCO submission. Due to the selection of conservative parameters in the assessment, it is considered that no additional impacts will occur as a result of the Project moving within the Limits of Deviation (LoD) outlined within Chapter 2: The Project (Application Document 3.2). This is on the basis that project design principles are implemented, together with the mitigation measures detailed in Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7). As also detailed in the EMP, the cuttings assessments will be reviewed at detailed design when further ground investigation data is available to review the need for mitigation in areas across the Project.

14.6.8.13 Hydraulic conductivity values have been selected to provide a conservative estimate of the drawdown radius of influence. The radius of influence represents a 'reasonable worst-case' and is based on conservative inputs derived from available field or desk study data and published research literature relevant to the study area.

14.6.8.14 Receptors located within the zone of influence of cuttings are susceptible to potential impacts, which need to be individually considered. The zone of influences are illustrated in ES Figure 14.6.2: Cutting Assessment ZOI (Application Document 3.3).

14.6.8.15 The conservative maximum inflows calculated are the potential groundwater abstraction rates that could be encountered during steady state conditions, under the parameters assessed. To mitigate the impacts of net abstractions from the aquifer, as detailed in the EMP (Application Document Number 2.7) all intercepted groundwater will be carried from drainage to surface water discharge points, where feasible within the same receiving water that groundwater would naturally have discharged to. The drainage design will need to account for a realistic groundwater ingress rate into the system, although surface water runoff flow rates usually dominate.

14.6.8.16 For all abstractions (such as dewatering) and discharges, appropriate licenses and permits will be obtained from the Environment Agency prior to construction.

M6 Junction 40 to Kemplay Bank Roundabout

Assessment

14.6.8.17 The M6 Junction 40 improvement is the most westerly of the carriageway improvements on the A66 scheme. Widening will be required on the following M6 Junction 40 approach arms to provide additional lanes and a dedicated left turn facility, each controlled under its own signal phase: M6 North, M6 South, A66 East, A66 West, and A592 Ullswater Road. All existing local and depot accesses will be accommodated, and it is proposed to relocate the existing A66 access to Skirsgill Depot by approximately 95m east.

14.6.8.18 A number of the approach arms will require widening into the existing cuts. An assessment of the potential zone of influence of the new widened cuttings and conservative inflows are detailed in Table 52: M6 Junction 40 to Kemplay Bank Roundabout Inflow Assessment and illustrated in ES Figure 14.6.2 Cutting Assessment ZOI (Application Document 3.3).

14.6.8.19 At the Kemplay Bank Roundabout, the scheme will provide a new underpass beneath the existing roundabout, allowing free-flowing traffic east-west and improving access to Penrith and the A6. This scheme includes new on-slip and off-slip roads with the A6 and A686.

14.6.8.20 The new underpass will require a relatively significant cutting approaching and beneath the existing Kemplay Bank roundabout. An assessment of the potential zone of influence of the new cutting and inflows are detailed in Table 52: M6 Junction 40 to Kemplay Bank Roundabout Inflow Assessment (Chainage 10+750m to 10+900m) and illustrated in ES Figure 14.6.2: Cutting Assessment ZOI (Application Document 3.3).

14.6.8.21 In the west of the M6 Junction 40 to Kemplay Bank Roundabout Order Limits, the geology is anticipated to consist of Made Ground overlying Glacial Till (both cohesive and granular deposits).

14.6.8.22 To the east, in the area of the Kemplay Bank Roundabout, the geology is anticipated to consist of Made Ground overlying Glacial Till (both cohesive and granular deposits) and Glaciofluvial gravels.

14.6.8.23 No cuttings are anticipated into the bedrock within the M6 Junction 40 to Kemplay Bank Roundabout Order Limits.

14.6.8.24 In the area of the Kemplay Bank Roundabout underpass, groundwater monitoring has indicated the groundwater table in the Glaciofluvial deposits is at greater depth; several metres below ground level. As such, a conservative groundwater table of 5.0m bgl has been selected for the assessment in this area only.

Table 52: M6 Junction 40 to Kemplay Bank Roundabout Inflow Assessment

Cutting	Anticipated Ground Conditions	Length of Cutting (m)	Drawdown Required (m)	Hydraulic Conductivity (m/s)	Zone of Influence (m)	Maximum Inflow (m^3/d)	
						One-sided	Two-sided
Eastbound: Ch 09+100m to Ch 09+200m	Glacial Till	100	2.1	1×10^{-4}	42.0	82.6	-
Eastbound: Ch 09+300m to Ch 09+450m	Glacial Till	150	2.2	1×10^{-4}	44.0	129.7	-
Eastbound: Ch 10+050m to Ch 10+100m	Glacial Till	50	2.2	1×10^{-4}	44.0	43.2	-
Eastbound: Ch 10+750m to Ch 10+900m	Glacial Till + Fluvioglacial Deposits	150	5.0	1×10^{-3}	316.2	1329.4	-
Westbound: Ch 10+750m to Ch 10+900m	Glacial Till + Fluvioglacial Deposits	150	5.0	1×10^{-3}	316.2	1329.4	-
M6 NB Diverge Slip Road to M6J40: Ch 520m to 750m	Glacial Till	230	6.8	1×10^{-4}	136.0	614.8	-
M6 NB Merge Slip Road from M6J40: Ch 500m to 600m	Glacial Till	100	2.3	1×10^{-4}	45.6	89.6	-
M6 SB Diverge Slip Road to M6J40: Ch 560m to 590m	Glacial Till	30	2.2	1×10^{-4}	44.5	26.3	-
M6 SB Diverge Slip Road to M6J40: Ch 460m to 520m	Glacial Till	60	2.3	1×10^{-4}	46.4	54.7	-
-A592 NB: Ch 200m to 340m	Glacial Till	140	2.7	1×10^{-4}	53.3	146.7	-
A592 SB: Ch 140m to 220m	Glacial Till	80	2.9	1×10^{-4}	58.0	91.2	-
New access to CCC buildings (Skirsgill Depot etc.) NB: Ch 10m to 135m	Glacial Till	125	4.6	1×10^{-4}	91.5	224.9	-

Assessment Interpretation

14.6.8.25 The works in the area of the M6 Junction 40 are primarily related to the widening of existing cuttings and embankments. These works are anticipated to result in minor alterations/impacts to the groundwater regime with groundwater levels likely to be encountered closer to the road levels than conservatively assumed, due to the existing roads and drainage. As such, the flows documented in the assessments above are considered to be very conservative and unlikely. In practice, flows are likely to be at least an order of magnitude lower during normal flow conditions.

14.6.8.26 Should the groundwater table be intercepted during wetter conditions in the area of the Kemplay Bank Roundabout underpass, groundwater inflows could be high due to the anticipated high permeability of the glaciofluvial deposits.

14.6.8.27 Identified receptors in the area (documented in the Section 14.6.3) are unlikely to be impacted due to their distance from the works, the majority of the cuttings being within glacial deposits and the likelihood of the groundwater level being lower than conservatively assumed.

14.6.8.28 Abstractions in the area are understood to be screened within the Penrith Sandstone bedrock and abstract at significant depth relative to the scheme which would result in no impact.

14.6.8.29 The value of receptors in the scheme area are documented in ES Appendix 14.10 Assessment of Value (Application Document 3.4), with non-significant effects documented in ES Appendix 14.11 Non-significant Effects (Application Document 3.4).

Potential Impacts Requiring Mitigation

14.6.8.30 As detailed in the EMP (Application Document Number 2.7), a principle of mitigation that needs to be adhered to, to avoid impacts, is that all intercepted groundwater would be carried from the cuttings to a surface water discharge point; generally, within the same receiving water that the groundwater would naturally have discharged to. As all groundwater will still be received by the natural receiving water there will be no net change in the total water quantities in the catchment. Where groundwater interception occurs, then the top of the groundwater table may be intercepted and seasonally decant into drainage inverts and cuttings. This has the potential to shorten the pathway from ground to watercourses, which may allow a component of groundwater to enter the watercourses more rapidly if not appropriately attenuated.

14.6.8.31 Unmapped receptors, such as groundwater-surface water interactions (springs) and unlicensed abstractions, could be located within the vicinity of cuttings, embankments or structures. The presence of these is to be considered when developing the detailed design with mitigation measures implemented as outlined in Annex B7: Ground and surface water management plan of the EMP (Application Document 2.7).

14.6.8.32 Land drainage plays an important role in preventing localised flooding and feeding local surface water features. Any cuttings, embankments or structures may intercept localised land drainage which will need to be appropriately maintained, reinstated or compensated.

14.6.8.33 To prevent degradation of groundwater quality (i.e. runoff and spillages), best practice mitigation measures and temporary construction drainage would be implemented including comprehensive runoff control installed at the start of construction, as outlined in Annex B7: Ground and surface water management plan of the EMP (Application Document 2.7).

Penrith to Temple Sowerby

Assessment

14.6.8.34 The Penrith to Temple Sowerby section will provide full dualling of the current A66 single carriageway section between Penrith and Temple Sowerby; predominantly through online widening. The existing carriageway will be utilised as one side of the new dual carriageway, with the second carriageway constructed to the north. Access to existing side roads will be improved through new junction layouts and construction of overbridges and underpasses. New side roads shall run parallel to the new A66 carriageway providing local access.

14.6.8.35 The geology is anticipated to consist of Made Ground overlying Glacial Till (both cohesive and granular deposits) and occasionally Glaciofluvial gravels. The Whinfell Park Underpass may require cutting into the underlying Penrith Sandstone, however groundwater monitoring indicates that the water table in the bedrock is likely to be below the excavation formation. All other cuttings along the scheme are anticipated to be within the superficial deposits only. An assessment of the potential zone of influence of the new cuttings and potential inflows are detailed in Table 53: Penrith to Temple Sowerby Inflow Assessment below and illustrated in ES Figure 14.6.2: Cutting Assessment ZOI (Application Document 3.3).

Table 53: Penrith to Temple Sowerby Inflow Assessment

Cutting	Anticipated Ground Conditions	Length of Cutting (m)	Drawdown Required (m)	Hydraulic Conductivity (m/s)	Zone of Influence (m)	Maximum Inflow (m^3/d)	
						One-sided	Two-sided
Eastbound: 20+200m to 20+365m	Glacial Till	165	7.6	1 x 10-4	152.00	493.0	-
Eastbound: 20+400m to 20+440m	Glacial Till	40	9.4	1 x 10-4	188.00	147.8	-
Eastbound: 20+440m to 20+540m	Glacial Till	100	2	1 x 10-4	40.00	78.6	-
Eastbound: 20+540m to 20+600m	Glacial Till	60	5	1 x 10-4	100.00	117.9	-
Eastbound: 21+070m to 21+300m	Glacial Till + Fluvioglacial Deposits	230	4.5	1 x 10-3	284.60	1286.7	-
Eastbound: 21+300m to 21+500m	Glacial Till + Fluvioglacial Deposits	200	2.8	1 x 10-3	177.09	696.2	-
Eastbound: 22+000m to 22+250m	Glacial Till	250	3.6	1 x 10-4	72.00	353.8	-
Eastbound: 23+700m to 24+100m	Glacial Till	400	5	1 x 10-4	100.00	786.2	-
Eastbound: 24+650m to 24+850m	Glacial Till	200	2	1 x 10-4	40.00	157.2	-
Westbound: 20+200m to 20+370m	Glacial Till	170	2.5	1 x 10-4	50.00	167.1	-
Westbound: 20+400m to 20+620m	Glacial Till	220	7.6	1 x 10-4	152.00	657.3	-

Cutting	Anticipated Ground Conditions	Length of Cutting (m)	Drawdown Required (m)	Hydraulic Conductivity (m/s)	Zone of Influence (m)	Maximum Inflow (m^3/d)	
						One-sided	Two-sided
Westbound: 21+000m to 21+500m	Glacial Till + Fluvioglacial Deposits	500	2	1 x 10-3	126.49	1243.2	-
Westbound: 22+000m to 22+300m	Glacial Till	300	3.5	1 x 10-4	70.00	412.8	-
Westbound: 22+450m to 22+690m	Glacial Till	240	2.1	1 x 10-4	42.00	198.1	-
Westbound: 23+450m to 24+175m	Glacial Till	725	4.8	1 x 10-4	96.00	1368.1	-
Westbound: 24+200m to 24+975m	Glacial Till	775	4.8	1 x 10-4	96.00	1462.4	-
New realigned access between Ch. 20+900m and 21+000 NB: Ch. 0m to 95m	Glacial Till	95	4.3	1 x 10-4	86.00	160.6	-
New realigned access between Ch. 20+900m and 21+000 SB: Ch. 0m to 95m	Glacial Till	95	2.2	1 x 10-4	44.00	82.2	-
New realigned access for Whinfell Park SB: Ch. 0m to 100m	Glacial Till + Fluvioglacial Deposits	100	2	1 x 10-3	126.49	248.6	-
New realigned access for Whinfell Park NB: Ch. 0m to 100m	Glacial Till + Fluvioglacial Deposits	100	2	1 x 10-3	126.49	248.6	-
Whinfell Park Underpass NB: Ch. 80m to 200m	Glacial Till + Penrith Sandstone	120	6	1 x 10-4	120.00	283.0	-

Cutting	Anticipated Ground Conditions	Length of Cutting (m)	Drawdown Required (m)	Hydraulic Conductivity (m/s)	Zone of Influence (m)	Maximum Inflow (m^3/d)	
						One-sided	Two-sided
Whinfell Park Underpass NB: Ch. 240m to 290m	Glacial Till + Penrith Sandstone	50	3.8	1 x 10-4	76.00	74.7	-
Whinfell Park Underpass SB: Ch. 80m to 200m	Glacial Till + Penrith Sandstone	120	7.7	1 x 10-4	154.00	363.2	-
Whinfell Park Underpass SB: Ch. 270m to 290m	Glacial Till + Penrith Sandstone	20	5.7	1 x 10-4	114.00	44.8	-
Realigned access to Centerparcs: Ch. 150 to 340m	Glacial Till	190	5.5	1 x 10^{-4}	110.00	410.8	-

Assessment Interpretation

14.6.8.36 Penrith to Temple Sowerby primarily involves online widening of the existing carriageway, and as such calculated inflows for the cuttings are likely to be overestimated as the existing water table is likely to be at or below the road level. Furthermore, the more granular glacial deposits are likely to be laterally finite resulting in reduced inflows after initial draining.

14.6.8.37 Whinfell Park Underpass is the only cutting which is anticipated to potentially intercept the underlying Penrith Sandstone (designated a Principal Aquifer, and as such of higher importance as a receptor). Monitoring in the bedrock indicates that the groundwater table is likely to be lower than the road level, and as such any groundwater ingress is likely to be within the overlying Superficial Deposits.

14.6.8.38 The identified receptors in the area (documented in section 14.6.3) are unlikely to be impacted due to their distance from the works, the majority of the cuttings being within glacial deposits and the likelihood of the groundwater level being lower than conservatively assumed.

14.6.8.39 The value of receptors in the scheme area are documented in ES Appendix 14.10: Assessment of Value (Application Document 3.4), with non-significant effects documented in ES Appendix 14.11: Non-significant Effects (Application Document 3.4).

Potential Impacts Requiring Mitigation

14.6.8.40 A principle of mitigation that needs to be adhered to, to avoid impacts, is that all intercepted groundwater would be carried from the cuttings to a surface water discharge point; generally, within the same receiving water that the groundwater would naturally have discharged to. As all groundwater will still be received by the natural receiving water there will be no net change in the total water quantities in the catchment. Where groundwater interception occurs, then the top of the groundwater table may be intercepted and seasonally decant into drainage inverts and cuttings. This has the potential to shorten the pathway from ground to water courses, which may allow a component of groundwater to enter the water courses more rapidly if not appropriately attenuated.

14.6.8.41 Unmapped receptors, such as groundwater-surface water interactions (springs) and unlicensed abstractions, could be located within the vicinity of cuttings, embankments or structures. The presence of these is to be considered when developing the detailed design with mitigation measures implemented as outlined in Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7).

14.6.8.42 Land drainage plays an important role in preventing localised flooding and feeding local surface water features. Any cuttings, embankments or structures may intercept localised land drainage which will need to be appropriately maintained, reinstated or compensated.

14.6.8.43 To prevent degradation of groundwater quality (i.e. runoff and spillages), best practice mitigation measures and temporary construction drainage would be implemented including comprehensive runoff control installed at the start of construction, as outlined in Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7).

Temple Sowerby to Appleby

Assessment

14.6.8.44 The route diverges north and east from the eastern end of the Temple Sowerby Bypass and is constructed entirely offline joining with the western end of Appleby Bypass. The Kirkby Thore Bypass in the west of the section includes a significant cutting, where the alignment transects a series of drumlins.

14.6.8.45 The geology encountered during construction is anticipated to consist primarily of Glacial Till (both cohesive and granular, but primarily cohesive). Alluvial deposits may be encountered around Trout Beck, however site investigation data in this area is limited at this time. Bedrock comprising the Penrith Sandstone is likely to be intercepted in discrete areas during construction of the main cuttings for the Kirkby Thore Bypass. This is regularly overlain by a sand bed considered to most likely be weathered bedrock. The Eden Shale Formation is not anticipated to be encountered during construction. An assessment of the potential zone of influence of the new cuttings and potential inflows are detailed in

14.6.8.46 Table 54: Temple Sowerby to Appleby Inflow Assessment below and illustrated in ES Figure 14.6.2 Cutting Assessment ZOI (Document Number 3.3).

Table 54: Temple Sowerby to Appleby Inflow Assessment

Cutting	Anticipated Ground Conditions	Length of Cutting (m)	Drawdown Required (m)	Hydraulic Conductivity (m/s)	Zone of Influence (m)	Maximum Inflow (m^3/d)	
						One-sided	Two-sided
Eastbound: 29+950m to 30+170m	Glacial Till	220	3.29	1×10^{-4}	65.80	284.5	-
Eastbound: 31+095m to 31+541m	Glacial Till	446	2.59	1×10^{-4}	51.80	454.1	-
Eastbound: 31+595m to 33+884m	Glacial Till + Penrith Sandstone	2289	12.33	4×10^{-5}	155.96	7017.2	-
Eastbound: 35+744m to 36+448m	Glacial Till	704	5.08	1×10^{-5}	32.13	444.6	-
Eastbound: 36+784m to 37+192m	Glacial Till	408	8.19	1×10^{-5}	51.80	415.4	-
Eastbound: 37+423m to 38+387m	Glacial Till	964	9.92	1×10^{-5}	62.74	1188.8	-
Westbound: 30+498m to 33+744m	Glacial Till + Penrith Sandstone	3246	10.5	4×10^{-5}	132.82	8474.1	-
Westbound: 34+595m to 34+877m	Glacial Till	282	2.29	1×10^{-5}	14.48	80.3	-
Westbound: 35+811m to 36+498m	Glacial Till	687	6.83	1×10^{-5}	43.20	583.3	-
Westbound: 36+942m to 37+222m	Glacial Till	280	4.8	1×10^{-5}	30.36	167.1	-
Westbound: 37+368m to 37+948m	Glacial Till	580	10.55	1×10^{-5}	66.72	760.7	-
Westbound: 38+259m to 38+445m	Glacial Till	186	6.12	1×10^{-5}	38.71	141.5	-
Spital Farm NB 00+270m to 00+369m	Glacial Till	99	3.46	1×10^{-4}	69.2	-	269.3
B6542 EB 00+050m to 00+566m	Glacial Till	516	3.8	1×10^{-5}	24.03	243.8	-
B6542 EB 00+759m to 00+915m	Glacial Till	156	5.59	1×10^{-5}	35.35	108.4	-
B6542 EB 00+978m to 01+087m	Glacial Till	109	7.64	1×10^{-5}	48.32	103.5	-
Long Martan EB 00+368m to 00+698m	Glacial Till	330	7.12	1×10^{-5}	45.03	292.1	-
Long Martan EB 00+885m to 01+061	Glacial Till	176	4.86	1×10^{-5}	30.74	106.3	-
Long Martan WB 00+185m to 00+742m	Glacial Till	557	11.83	1×10^{-5}	74.82	819.2	-

Cutting	Anticipated Ground Conditions	Length of Cutting (m)	Drawdown Required (m)	Hydraulic Conductivity (m/s)	Zone of Influence (m)	Maximum Inflow (m^3/d)	
						One-sided	Two-sided
Long Martan WB 00+885m to 01+065m	Glacial Till	180	6.49	1×10^{-5}	41.05	145.2	-
Long Marton East Sideroad 2 00+107 to 00+285m	Glacial Till	178	2.24	1×10^{-5}	14.17	49.6	-
Long Marton West Sideroad 1 00+072m to 00+177m	Glacial Till	105	2.41	1×10^{-5}	15.24	31.5	-
Sideroad 1 00+048m to 00+166m	Glacial Till + Penrith Sandstone	118	7.84	4×10^{-5}	99.17	230.0	-
Sideroad 1 00+037m to 00+164m	Glacial Till + Penrith Sandstone	127	3.44	4×10^{-5}	43.51	108.6	-

Assessment Interpretation

14.6.8.47 The Kirkby Thore to Appleby section is primarily off-line and comprises the longest new cuttings of the Project. The majority of cuttings are anticipated to be predominantly within cohesive Glacial Till deposits which will be heterogenous and anisotropic in nature; likely resulting in smaller zones of influence and lower flows than conservatively calculated.

14.6.8.48 The deepest cuttings may occasionally cross through sand (weathered bedrock) and Penrith Sandstone units, which may be water bearing during wetter periods. The groundwater table in the bedrock (both Penrith Sandstone and Eden Shales) is anticipated to be primarily beneath the road excavation level from groundwater monitoring assessed to date.

14.6.8.49 The majority of identified receptors in the area (documented in section 14.6.3) are unlikely to be impacted due to their distance from the works, the majority of the cuttings being within glacial deposits and the likelihood of the groundwater level being lower than conservatively assumed. Where receptors will be potentially impacted, these are documented below.

14.6.8.50 Abstractions in the area are understood to be screened within the Penrith Sandstone or Eden Shales bedrock, and abstract at significant depth relative to the scheme. As such, drawdown impacts are likely to be negligible.

14.6.8.51 The value of receptors in the scheme area are documented in ES Appendix 14.10 Assessment of Value (Application Document 3.4), with non-significant effects documented in ES Appendix 14.11: Non-significant Effects (Application Document 3.4).

Potential Impacts Requiring Mitigation

14.6.8.52 A number of receptors are in close proximity to the route within the Order Limits and need further consideration and mitigation:

- The two industrial abstractions along Norman Lane
- The private abstraction proximal to Sleastonhow Farm.

14.6.8.53 The two industrial groundwater abstractions alongside Norman Lane are within the construction footprint and are likely to be directly impacted by the construction of the Kirkby Thore bypass. An alternative abstraction arrangement will need to be supplied (e.g. replacement boreholes) in agreement with relevant stakeholders. To prevent potential contamination risks during construction works, the boreholes will need to be appropriately decommissioned.

14.6.8.54 The private abstraction in the vicinity of Sleastonhow Farm is in proximity of the Trout Beck crossing and has the potential to be impacted by the construction works. Adherence to Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7) and the document mitigations is to be undertaken to minimise the risks to the source of supply once the design of the crossing is finalised (e.g. foundation works risk assessment, pollution prevention measures etc.)

14.6.8.55 A principle of mitigation that needs to be adhered to, to avoid impacts, is that all intercepted groundwater would be carried from the cuttings to a surface water discharge point; generally, within the same receiving water that the groundwater would naturally have discharged to. As all groundwater will still be received by the natural receiving water there will be no net change in the total water quantities in the catchment. Where groundwater interception occurs, then the top of the groundwater table may be intercepted and seasonally decant into drainage inverts and cuttings. This has the potential to shorten the pathway from ground to water courses, which may allow a component of groundwater to enter the water courses more rapidly if not appropriately attenuated.

14.6.8.56 Unmapped receptors, such as groundwater-surface water interactions (springs) and unlicensed abstractions, could be located within the vicinity of cuttings, embankments or structures. The presence of these is to be considered when developing the detailed design with mitigation measures implemented as outlined in Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7).

14.6.8.57 Land drainage plays an important role in preventing localised flooding and feeding local surface water features. Any cuttings, embankments or structures may intercept localised land drainage which will need to be appropriately maintained, reinstated or compensated.

14.6.8.58 To prevent degradation of groundwater quality (i.e. runoff and spillages), best practice mitigation measures and temporary construction drainage would be implemented including comprehensive runoff control installed at the start of construction, as outlined in Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7).

Appleby to Brough

Assessment

14.6.8.59 The Appleby to Brough scheme is summarised in ES Chapter 2: The Project (Application Document 3.2). The scheme has sections in cutting and on embankment, with junctions provided using both bridges and underpasses.

14.6.8.60 The geology encountered during construction is anticipated to consist primarily of Glacial Till (both cohesive and granular). Fluvioglacial deposits are anticipated to be encountered when in proximity to local water courses. Bedrock comprising the Penrith Sandstone is likely to be intercepted in discrete areas in the west of the scheme during construction. This is regularly overlain by a sand bed considered to most likely be weathered bedrock. The Stainmore Formation at the eastern extreme of the scheme is not anticipated to be encountered during construction works.

14.6.8.61 An assessment of the potential zone of influence of the new cuttings and potential inflows are detailed in

14.6.8.62 Table 55: Appleby to Brough Inflow Assessment below and illustrated in ES Figure 14.6.2: Cutting Assessment ZOI (Application Document 3.3).

Table 55: Appleby to Brough Inflow Assessment

Cutting	Anticipated Ground Conditions	Length of Cutting (m)	Drawdown Required (m)	Hydraulic Conductivity (m/s)	Zone of Influence (m)	Maximum Inflow (m^3/d)	
						One-sided	Two-sided
Eastbound: Ch 39+880m to Ch 40+000m	Glacial Till	120	2.57	1×10^{-4}	51.40	121.2	-
Eastbound: Ch 40+000m to Ch 40+150m	Glacial Till	150	4.75	1×10^{-4}	95.00	280.1	-
Eastbound: Ch 40+150m to Ch 40+420m	Glacial Till + Penrith Sandstone	270	10.76	1×10^{-4}	215.20	1142.1	-
Eastbound: Ch 41+320m to Ch 42+000m	Glacial Till	680	3.79	1×10^{-4}	75.80	1013.1	-
Eastbound: Ch 42+320m to Ch 42+740m	Glacial Till	420	7.01	1×10^{-4}	140.20	1157.4	-
Eastbound: Ch 43+000m to Ch 43+060m	Glacial Till	60	3.05	1×10^{-4}	61.00	71.9	-
Eastbound: Ch 43+770 to Ch 44+220m	Glacial Till + Fluvioglacial Deposits	450	7.19	1×10^{-3}	454.74	4022.2	-
Eastbound: Ch 45+240m to Ch 45+640m	Glacial Till	400	5.05	1×10^{-4}	101.00	794.1	-
Eastbound: Ch 45+800m to Ch 46+350m	Glacial Till + Fluvioglacial Deposits	550	6.02	1×10^{-3}	380.74	4116.1	-
Eastbound: Ch 46+560m to Ch 47+450m	Glacial Till	890	2.93	1×10^{-4}	58.60	1025.1	-
Westbound: Ch 42+800m to 43+080m	Glacial Till	280	5.22	1×10^{-4}	104.40	574.6	-
Westbound: Ch 43+570m to 43+710m	Glacial Till	140	2.37	1×10^{-4}	47.40	130.4	-

Cutting	Anticipated Ground Conditions	Length of Cutting (m)	Drawdown Required (m)	Hydraulic Conductivity (m/s)	Zone of Influence (m)	Maximum Inflow (m^3/d)	
						One-sided	Two-sided
Westbound: Ch 45+160m to 45+550m	Glacial Till	390	4.92	1×10^{-4}	98.40	754.3	-
Westbound: Ch 46+040m to 46+200m	Glacial Till + Fluvioglacial Deposits	160	3.23	1×10^{-3}	204.28	642.5	-
Westbound: Ch 46+270m to 46+340m	Glacial Till + Fluvioglacial Deposits	70	2.43	1×10^{-3}	153.69	211.5	-
Westbound: Ch 46+740 to 47+850m	Glacial Till	1110	5.49	1×10^{-4}	109.80	2395.6	-
Café 66 Access (Ch 39890 to 40190)	Glacial Till	300	4.585	1×10^{-4}	91.70	540.7	-
Underpass (Ch 40190 to 40520)	Glacial Till + Penrith Sandstone	474	10.922	1×10^{-4}	218.44	-	4070.4
Farm Access south of A66 (Ch 40270 to 40370)	Glacial Till + Penrith Sandstone	100	5.863	1×10^{-4}	117.26	-	461.0
Farm access track to underpass (Northern) (Ch 40430 to 40740)	Glacial Till	310	6.956	1×10^{-4}	139.12	-	1695.4
Farm access track to Eastbound A66 and underpass (Ch 40530 to 40530)	Glacial Till	170	2.458	1×10^{-4}	49.16	-	328.5
Sanford Underpass (Ch 41930 to 42090)	Glacial Till	558	8.664	1×10^{-4}	173.28	-	3801.1
Eastbound verge (of local road behind old MOD compound, flat between A66 and new local road) (Ch 43780 to 44190)	Glacial Till + Fluvioglacial Deposits	410	7.192	1×10^{-3}	454.86	3665.7	-
Warcop Underpass (Ch 44240 to 44400)	Glacial Till + Fluvioglacial Deposits	120	8.121	1×10^{-3}	513.62	-	2423.0

Cutting	Anticipated Ground Conditions	Length of Cutting (m)	Drawdown Required (m)	Hydraulic Conductivity (m/s)	Zone of Influence (m)	Maximum Inflow (m^3/d)	
						One-sided	Two-sided
New local Road used to merge with existing A66 (Ch 45230 to 46040)	Glacial Till	810	2.703	1×10^{-4}	54.06	860.7	-
Flitholme local road connecting to underpass (Ch 45490 to 45740)	Glacial Till	440	4.353	1×10^{-4}	87.06	753.0	-
Broomrigg to Flitholme local road (Ch 45740 to 46230)	Glacial Till	560	4.065	1×10^{-4}	81.30	894.9	-
Farm Access Underpass (Ch 47080 to 47240)	Glacial Till	356	11.12	1×10^{-5}	70.33		984.3
Brough access road leading to underpass (Ch 47630 to 48120)	Glacial Till	490	6.019	1×10^{-4}	120.38	1159.4	-
Side road connecting to Brough Underpass (Ch 47700 to 47880)	Glacial Till	190	5.482	1×10^{-4}	109.64	-	818.9

Assessment Interpretation

14.6.8.63 The Appleby to Brough section primarily utilises the existing alignment for one of the carriages, with a new carriageway constructed adjacent. As such, the majority of earthworks are extensions of existing cuttings/embankments.

14.6.8.64 The majority of cuttings are anticipated to be predominantly within cohesive Glacial Till deposits which will be heterogenous and anisotropic in nature; resulting in smaller zones of influence and lower flows than conservatively calculated.

14.6.8.65 The deepest cuttings may occasionally cross through sand (weathered bedrock) and Penrith Sandstone units, which may be water bearing during wetter periods. Based on available groundwater monitoring in the east of the Order Limits, the groundwater table in the bedrock is anticipated to be primarily beneath the road excavation level.

14.6.8.66 The majority of identified receptors in the area (documented in section 14.6.3) are unlikely to be impacted due to their distance from the works, the majority of the cuttings being within glacial deposits and the likelihood of the groundwater level being lower than conservatively assumed. Where receptors will be potentially impacted, these are documented below.

14.6.8.67 Abstractions in the area are understood to be screened within the Penrith Sandstone and abstract at significant depth relative to the scheme. As such, drawdown impacts on existing abstractions is considered to be negligible.

14.6.8.68 The value of receptors in the scheme area are documented in ES Appendix 14.10 Assessment of Value (Application Document 3.4), with non-significant effects documented in ES Appendix 14.11: Non-significant Effects (Application Document 3.4).

Potential Impacts Requiring Mitigation

14.6.8.69 A number of receptors are in close proximity to the route and need further consideration and mitigation:

- Potential groundwater-surface water interaction north-east of the Sandford Junction which may feed a local GWDTE.
- Flitholme 'Spring 'which is utilised for supply will likely require mitigation/compensation measures, as a result of its proximity to the route and likelihood of direct construction impacts at their locations
- Springs in the vicinity of Wildboar Hill are understood to feed local ditches which livestock drink from. The exact location of springs around Wildboar Hill are unknown. Mitigation of impacts, such as an alternative source of supply, may be required should the A66 impact local groundwater-surface water interactions in the area.

14.6.8.70 The hydrogeological impact assessment indicates that the potential groundwater-surface water interaction north-east of the Sandford

Junction is within the zone of influence of the junction and may be impacted by the works. Further surveying and assessment is to be undertaken during detailed design, to assess if the junction will impact the potential groundwater-surface water interaction, requiring additional mitigation. Mitigation could comprise lining of the cutting to prevent groundwater ingress into the cutting with appropriate drainage beneath/surrounding to enable continued groundwater flow, or alternatively redesigning the junction within the LoD to reduce any potential impact. This mitigation is secured in the Project Design Principles (Application Document 5.11) which is certified as part of the DCO.

14.6.8.71 Flitholme spring is located south of the A66 route north-east of Flitholme Farm. The 'spring' is utilised for supply of fields and buildings but lies within the construction footprint, so will likely be directly impacted (i.e. loss of supply) by the roadworks that will connect the Flitholme local road to the underpass. To prevent a significant effect on the water supply, appropriate mitigation and/or compensation measures are to be implemented to ensure continued supply (e.g. replacement mains supply), in consultation with the stakeholder.

14.6.8.72 Springs in the area surrounding Wildboar Hill feed local ditches that are used by livestock. Cuttings in the area have the potential to reduce baseflow to springs, resulting in a reduction in spring flow rates or alteration of flow paths. Embankments in the area could act as a barrier to flow and alter flow paths. Due to uncertainty in the exact location of the springs, there is the potential for a significant impact without appropriate mitigation measures. Surveying of areas at risk prior to commencement of construction will assist in the identification of spring locations and enable a further assessment of risk to be undertaken. If required following further assessment, appropriate mitigation and/or compensation measures will need to be implemented to ensure continued supply (e.g. lining of cuttings or replacement mains supply), in consultation with the stakeholder.

14.6.8.73 A principle of mitigation that needs to be adhered to, to avoid impacts, is that all intercepted groundwater would be carried from the cuttings to a surface water discharge point; generally, within the same receiving water that the groundwater would naturally have discharged to. As all groundwater will still be received by the natural receiving water there will be no net change in the total water quantities in the catchment. Where groundwater interception occurs, then the top of the groundwater table may be intercepted and seasonally decant into drainage inverts and cuttings. This has the potential to shorten the pathway from ground to water courses, which may allow a component of groundwater to enter the water courses more rapidly if not appropriately attenuated.

14.6.8.74 Unmapped receptors, such as groundwater-surface water interactions (springs) and unlicensed abstractions, could be located within the vicinity of cuttings, embankments or structures. The presence of these is to be considered when developing the detailed design with mitigation measures implemented as outlined in Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7).

14.6.8.75 Land drainage plays an important role in preventing localised flooding and feeding local surface water features. Any cuttings, embankments or structures may intercept localised land drainage which will need to be appropriately maintained, reinstated or compensated.

14.6.8.76 To prevent degradation of groundwater quality (i.e. runoff and spillages), best practice mitigation measures and temporary construction drainage would be implemented including comprehensive runoff control installed at the start of construction, as outlined in Annex B7: Ground and surface water management plan of the EMP (Application Document 2.7).

Bowes Bypass

Assessment

14.6.8.77 The Bowes Bypass scheme is summarised in ES Chapter 2: The Project (Application Document 3.2). Bowes Bypass is located to the east of the North Pennines AONB and will closely follow the existing A66 north of the village of Bowes, with a new adjacent eastbound carriageway constructed to the north. New underbridges, slip roads and overpasses will accommodate traffic to ensure continued access and provide an all movement grade separated junction to the north of the village.

14.6.8.78 The geology encountered during construction is anticipated to consist primarily of cohesive Glacial Till deposits with Mudstone bedrock (of the Stainmore Formation) occasionally encountered towards the base of cuttings.

14.6.8.79 An assessment of the potential zone of influence of the new cuttings and potential inflows are detailed in

14.6.8.80 Table 56: Bowes Bypass Inflow Assessment below and illustrated in ES Figure 14.6.2: Cutting Assessment ZOI (Application Document 3.3).

Table 56: Bowes Bypass Inflow Assessment

Cutting	Anticipated Ground Conditions	Length of Cutting (m)	Drawdown Required (m)	Hydraulic Conductivity (m/s)	Zone of Influence (m)	Maximum Inflow (m^3/d)	
						One-sided	Two-sided
Eastbound: Ch 50+090m to Ch 50+220m	Glacial Deposits	130	3.2	1×10^{-4}	64.00	163.5	-
Eastbound: Ch 50+220m to Ch 50+415m	Glacial Deposits	195	9.1	1×10^{-4}	182.00	697.6	-
Eastbound: Ch 50+415m to Ch 50+670m	Glacial Deposits + Possibly Mudstone	255	7.7	1×10^{-4}	154.00	771.9	-
Eastbound Slip Road Ch 50+670m to Ch 50+739m	Glacial Deposits + Possibly Mudstone	69	10	1×10^{-4}	200.00	271.3	-
Eastbound Slip Road Ch 50+769m to Ch 50+975m	Glacial Deposits + Mudstone	206	6.3	1×10^{-4}	126.00	-	1020.4
Eastbound Slip Road Ch 51+025m to Ch 51+215m	Glacial Deposits	190	11.8	1×10^{-4}	236.00	881.4	-
Westbound to Diverge Slip Road Ch 51+181m to Ch 51+630m	Glacial Deposits + Mudstone	449	5.2	1×10^{-4}	104.00	917.9	-
Lyndale Farm Underpass Extension (Ch 50+753 to 50+828m)	Glacial Deposits + Possibly Mudstone	109	5.7	1×10^{-4}	114.00	244.2	-
Blacklodge Farm Underpass Extension (Ch 51+527 to 51+702)	Glacial Deposits + Possibly Limestone	214	4.9	1×10^{-4}	98.00	412.2	-

Assessment Interpretation

14.6.8.81 The Bowes Bypass scheme primarily utilises the existing alignment for one of the carriageways, with a new carriageway constructed adjacent to the north.

14.6.8.82 The majority of cuttings are anticipated to be predominantly within cohesive Glacial Till deposits which will be heterogenous and anisotropic in nature; resulting in smaller zones of influence and lower flows than conservatively calculated. Low permeability Mudstone bedrock may be encountered in a number of the cuttings.

14.6.8.83 The majority of identified receptors in the area (documented in section 14.6.3) are unlikely to be impacted due to their distance from the works, the majority of the cuttings being within glacial deposits and the likelihood of the groundwater level being lower than conservatively assumed. Where receptors will be potentially impacted, these are documented below.

14.6.8.84 The value of receptors in the scheme area are documented in ES Appendix 14.10: Assessment of Value (Application Document 3.4), with non-significant effects documented in ES Appendix 14.11: Non-significant Effects (Application Document 3.4).

Potential Impacts Requiring Mitigation

14.6.8.85 Springs on the western end of the Bowes Bypass scheme are used for local agricultural water supply. Cuttings in the area have the potential to reduce baseflow to springs, resulting in a reduction in spring flow rates or alteration of flow paths. Due to uncertainty in the exact location and nature of the springs, there is the potential for a significant impact without appropriate mitigation measures. Surveying of areas at risk in the area prior to commencement of construction will assist in the identification of spring locations and enable a further assessment of risk to be undertaken. If required following further assessment, appropriate mitigation and/or compensation measures (e.g. lining of cuttings or replacement mains supply etc) will need to be implemented to ensure continued supply, in consultation with the stakeholder.

14.6.8.86 A principle of mitigation that needs to be adhered to, to avoid impacts, is that all intercepted groundwater would be carried from the cuttings to a surface water discharge point; generally, within the same receiving water that the groundwater would naturally have discharged to. As all groundwater will still be received by the natural receiving water there will be no net change in the total water quantities in the catchment. Where groundwater interception occurs, then the top of the groundwater table may be intercepted and seasonally decant into drainage inverts and cuttings. This has the potential to shorten the pathway from ground to water courses, which may allow a component of groundwater to enter the water courses more rapidly if not appropriately attenuated.

14.6.8.87 Unmapped receptors, such as groundwater-surface water interactions (springs) and unlicensed abstractions, could be located within the vicinity of cuttings, embankments or structures. The presence of these is to be considered when developing the detailed design with mitigation measures implemented as outlined in Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7).

14.6.8.88 Land drainage plays an important role in preventing localised flooding and feeding local surface water features. Any cuttings, embankments or structures may intercept localised land drainage which will need to be appropriately maintained, reinstated or compensated.

14.6.8.89 To prevent degradation of groundwater quality (i.e. runoff and spillages), best practice mitigation measures and temporary construction drainage would be implemented including comprehensive runoff control installed at the start of construction, as outlined in Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7).

Cross Lanes to Rokeby

Assessment

14.6.8.90 The Cross Lanes to Rokeby scheme is summarised in ES Chapter 2: The Project (Application Document 3.2). A link road will be constructed linking Rutherford Lane and the B6277 Moorhouse Lane with the existing junction at Cross Lanes upgraded where the new link road crosses over the A66. A new adjacent westbound carriageway will be constructed to the south between the B6277 junction at Cross Lanes and the existing Tutta Beck Cottage access and both carriageways will then be diverted to the south of The Old Rectory and St Mary’s Church, re-joining the existing A66 at Rokeby.

14.6.8.91 The geology encountered during construction is anticipated to consist primarily of cohesive Glacial Till deposits with no bedrock anticipated to be encountered.

14.6.8.92 An assessment of the potential zone of influence of the new cuttings and potential inflows are detailed in

14.6.8.93 Table 57: Cross Lanes to Rokeby Inflow Assessment below and illustrated in ES Figure 14.6.2: Cutting Assessment ZOI (Application Document 3.3).

Table 57: Cross Lanes to Rokeby Inflow Assessment

Cutting	Anticipated Ground Conditions	Length of Cutting (m)	Drawdown Required (m)	Hydraulic Conductivity (m/s)	Zone of Influence (m)	Maximum Inflow (m^3/d)	
						One-sided	Two-sided
Eastbound Ch 60+800m to Ch 61+200m	Glacial Deposits	400	2.1	1×10^{-5}	13.28	104.4	-
Eastbound Ch 61+500m to Ch 61+750m	Glacial Deposits	250	2.5	1×10^{-5}	15.81	77.7	-
Eastbound Ch 62+870m to Ch 62+970m	Glacial Deposits	100	2.7	1×10^{-5}	17.08	33.6	-
Westbound Ch 62+650m to Ch 62+825m	Glacial Deposits	175	3.5	1×10^{-5}	22.14	76.1	-
Westbound Ch 62+875m to Ch 63+050m	Glacial Deposits	175	3.2	1×10^{-5}	20.24	69.6	-
Rokeby Junction, Compact connector road (starting from mainline westbound junction). Left hand side of carriageway. (00+135 to 00+260)	Glacial Deposits (Limited GI)	125	5.7	1×10^{-5}	36.05	88.6	-
Rokeby Junction. North of mainline. Left hand side of carriageway. (00+315 to 00+470)	Glacial Deposits (Limited GI)	155	5.3	1×10^{-5}	33.52	102.1	-
Rokeby Junction, Compact connector road (starting from mainline westbound junction). Right hand side of carriageway. (00+070 to 00+260)	Glacial Deposits (Limited GI)	190	5.4	1×10^{-5}	34.15	127.5	-
Rokeby Junction. North of mainline. Right hand side of carriageway. (00+315 to 00+440)	Glacial Deposits (Limited GI)	125	4.5	1×10^{-5}	28.46	69.9	-

Assessment Interpretation

14.6.8.94 The Cross Lanes to Rokeby scheme primarily utilises the existing alignment for one of the carriageways, with a new carriageway constructed adjacent.

14.6.8.95 The majority of cuttings are anticipated to be predominantly within cohesive Glacial Till deposits which will be heterogenous and anisotropic in nature; resulting in smaller zones of influence and lower flows than conservatively calculated. Bedrock is not anticipated to be encountered during construction.

14.6.8.96 The majority of identified receptors in the area (documented in section 14.6.3) are unlikely to be impacted due to their distance from the works, the majority of the cuttings being within glacial deposits and the likelihood of the groundwater level being lower than conservatively assumed. Where receptors will be potentially impacted, these are documented below.

14.6.8.97 The value of receptors in the scheme area are documented in ES Appendix 14.10: Assessment of Value (Application Document 3.4), with non-significant effects documented in ES Appendix 14.11: Non-significant Effects (Application Document 3.4).

Potential Impacts Requiring Mitigation

14.6.8.98 A principle of mitigation that needs to be adhered to, to avoid impacts, is that all intercepted groundwater would be carried from the cuttings to a surface water discharge point; generally, within the same receiving water that the groundwater would naturally have discharged to. As all groundwater will still be received by the natural receiving water there will be no net change in the total water quantities in the catchment. Where groundwater interception occurs, then the top of the groundwater table may be intercepted and seasonally decant into drainage inverts and cuttings. This has the potential to shorten the pathway from ground to water courses, which may allow a component of groundwater to enter the water courses more rapidly if not appropriately attenuated.

14.6.8.99 Unmapped receptors, such as groundwater-surface water interactions (springs) and unlicensed abstractions, could be located within the vicinity of cuttings, embankments or structures. The presence of these is to be considered when developing the detailed design with mitigation measures implemented as outlined in Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7).

14.6.8.100 Land drainage plays an important role in preventing localised flooding and feeding local surface water features. Any cuttings, embankments or structures may intercept localised land drainage which will need to be appropriately maintained, reinstated or compensated.

14.6.8.101 To prevent degradation of groundwater quality (i.e. runoff and spillages), best practice mitigation measures and temporary construction drainage would be implemented including comprehensive runoff control installed at the start of construction, as outlined in Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7).

Stephen Bank to Carkin Moor

Assessment

14.6.8.102 Stephen Bank to Carkin Moor is summarised in Chapter 2: The Project (ES Volume 1, Application Document Number 3.2). The scheme will comprise a new dual carriageway section between Stephen Bank and Carkin Moor Farm. The new dual carriageway will be to the north of the existing A66, re-joining the existing A66 alignment after Mainsgill Farm. A new accommodation underpass will be provided to the north of Dick Scot Lane to allow access to land to the north of the new A66 alignment. The existing A66 will be de-trunked and used as a collector road for local access. An overbridge is to link Collier Lane and West Layton to the de-trunked A66. A new grade-separated junction to the western boundary of the existing alignment of Moor Lane will also provide connectivity between the de-trunked A66 and the mainline of the new A66. The southern section of Moor Lane will be realigned and placed into a cutting beneath the mainline. Along the Carkin Moor Scheduled Monument the road will be widened within the existing cutting using retaining structures. The existing right turn to Warrener Lane will be removed with traffic joining the A66 via the link road at Moor Lane and a new bridleway underpass will be provided to the north of Warrener Lane.

14.6.8.103 The geology is anticipated to consist of predominantly cohesive Glacial Deposits. No cutting into the underlying bedrock is anticipated in this area.

14.6.8.104 An assessment of the potential zone of influence of the new cuttings and potential inflows are detailed in

14.6.8.105 Table 58: Stephen Bank to Carkin Moor Inflow Assessment below and illustrated in ES Figure 14.6.2: Cutting Assessment ZOI (Application Document 3.3).

Table 58: Stephen Bank to Carkin Moor Inflow Assessment

Cutting	Anticipated Ground Conditions	Length of Cutting (m)	Drawdown Required (m)	Hydraulic Conductivity (m/s)	Zone of Influence (m)	Maximum Inflow (m^3/d)	
						One-sided	Two-sided
Eastbound Ch. 70+660m to 70+900m	Glacial Deposits	240	3.484	1×10^{-5}	22.03	103.9	-
Eastbound Ch. 71+255m to 72+230m	Glacial Deposits	975	10.145	1×10^{-5}	64.16	1229.7	-
Eastbound Ch. 73+200m to 73+420m	Glacial Deposits	220	3.888	1×10^{-5}	24.59	106.3	-
Eastbound Ch. 73+955m to 74+195m	Glacial Deposits	240	2.704	1×10^{-5}	17.10	80.7	-
Moor Lane Underpass EB Offslip lane Ch 00+030m to 00+520m	Glacial Deposits	490	8.529	1×10^{-5}	53.94	519.5	-
Moor Lane Underpass EB Onslip lane Ch 00+520m to to 00+030m	Glacial Deposits	490	9.601	1×10^{-5}	60.72	584.8	-
Moor Lane Link North Ch 00+020m to 00+180m	Glacial Deposits	160	8.175	1×10^{-5}	51.70	162.6	-
Moor Lane Link South Ch 00+180m to 00+020m	Glacial Deposits	160	8.319	1×10^{-5}	52.61	165.5	-
Westbound Ch. 71+237m to 72+182m	Glacial Deposits	945	11.08	1×10^{-5}	70.08	1301.7	-
Westbound Ch. 73+190m to 73+357m	Glacial Deposits	167	3.856	1×10^{-5}	24.39	80.1	-
Moor Lane Westbound Connector 00+040m to 00+240m	Glacial Deposits	200	4.7	1×10^{-5}	29.73	116.9	-
A66 De-trunked Section eastbound Ch. 00+900m to 00+275m	Glacial Deposits	625	2.411	1×10^{-5}	15.25	187.3	-
Browson Bank Farm Access Entrance Ch. 00+405m to 00+000m	Glacial Deposits	405	2.438	1×10^{-5}	15.42	122.7	-
Browson Bank Farm Access Exit Ch. 00+000m to 00+148m	Glacial Deposits	148	2.625	1×10^{-5}	16.60	48.3	-
Warrener Lane Eastbound Ch. 01+070m to 00+900m	Glacial Deposits	170	2.513	1×10^{-5}	15.89	53.1	-
Warrener Lane Eastbound Ch. 00+659m to 00+484m	Glacial Deposits	175	5.454	1×10^{-5}	34.49	118.7	-
Warrener Lane Eastbound Ch. 00+130m to Ch 00+050m	Glacial Deposits	80	3.215	1×10^{-5}	20.33	32.0	-

Cutting	Anticipated Ground Conditions	Length of Cutting (m)	Drawdown Required (m)	Hydraulic Conductivity (m/s)	Zone of Influence (m)	Maximum Inflow (m^3/d)	
						One-sided	Two-sided
Warrener Lane Westbound Ch. 00+490m to 00+640m	Glacial Deposits	150	2.565	1×10^{-5}	16.22	47.8	-
Warrener Lane Westbound Ch. 00+894m to 01+100m	Glacial Deposits	206	2.618	1×10^{-5}	16.56	67.0	-

Assessment Interpretation

14.6.8.106 The Stephen Bank to Carkin Moor scheme covers the A66 route between Chainages 69+972 and 74+998. The alignment will comprise a new carriageway running parallel to the north of the existing A66. The alignment re-joins the existing A66 at Chainage 74+300 where the existing alignment will be raised and widened.

14.6.8.107 The majority of cuttings are anticipated to be predominantly within cohesive Glacial Till deposits which will be heterogenous and anisotropic in nature; resulting in smaller zones of influence and lower flows than conservatively calculated. Bedrock is not anticipated to be encountered during construction.

14.6.8.108 The majority of identified receptors in the area (documented in section 14.6.3) are unlikely to be impacted due to their distance from the works, the majority of the cuttings being within glacial deposits and the likelihood of the groundwater level being lower than conservatively assumed. Where receptors will be potentially impacted, these are documented below.

14.6.8.109 The value of receptors in the scheme area are documented in ES Appendix 14.10 Assessment of Value (Application Document 3.4), with non-significant effects documented in ES Appendix 14.11 Non-significant Effects (Application Document 3.4).

Potential Impacts Requiring Mitigation

14.6.8.110 A principle of mitigation that needs to be adhered to, to avoid impacts, is that all intercepted groundwater would be carried from the cuttings to a surface water discharge point; generally, within the same receiving water that the groundwater would naturally have discharged to. As all groundwater will still be received by the natural receiving water there will be no net change in the total water quantities in the catchment. Where groundwater interception occurs, then the top of the groundwater table may be intercepted and seasonally decant into drainage inverts and cuttings. This has the potential to shorten the pathway from ground to watercourses, which may allow a component of groundwater to enter the watercourses more rapidly if not appropriately attenuated.

14.6.8.111 Unmapped receptors, such as groundwater-surface water interactions (springs) and unlicensed abstractions, could be located within the vicinity of cuttings, embankments or structures. The presence of these is to be considered when developing the detailed design with mitigation measures implemented as outlined in Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7).

14.6.8.112 Land drainage plays an important role in preventing localised flooding and feeding local surface water features. Any cuttings, embankments or structures may intercept localised land drainage which will need to be appropriately maintained, reinstated or compensated.

14.6.8.113 To prevent degradation of groundwater quality (i.e. runoff and spillages), best practice mitigation measures and temporary construction drainage would be implemented including comprehensive runoff control installed at the start of construction, as outlined in Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7).

A1(M) Junction 53 Scotch Corner

Assessment

14.6.8.114 The A1(M) Junction 53 scheme comprises widening of the approach road to Scotch Corner Roundabout from Middleton Tyas Lane to accommodate an additional lane. Ground conditions in the area are anticipated to comprise Made Ground (associated with the construction of the grade separated junction) overlying cohesive Glacial Deposits and bedrock.

14.6.8.115 No cuttings are proposed in the A1(M) Junction 53 area, so impacts are primarily related to temporary works during construction.

14.6.8.116 As no cuttings are anticipated and the earthworks are fairly limited, local receptors are considered unlikely to be impacted by the works on the basis that pollution prevention measures are implemented, as outlined in Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7).

Potential Impacts Requiring Mitigation

14.6.8.117 Unmapped receptors, such as groundwater-surface water interactions (springs) and unlicensed abstractions, could be located within the vicinity of cuttings, embankments or structures. The presence of these is to be considered when developing the detailed design with mitigation measures implemented as outlined in Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7).

14.6.8.118 Land drainage plays an important role in preventing localised flooding and feeding local surface water features. Any cuttings, embankments or structures may intercept localised land drainage which will need to be appropriately maintained, reinstated or compensated.

14.6.8.119 To prevent degradation of groundwater quality (i.e. runoff and spillages), best practice mitigation measures and temporary construction drainage would be implemented including comprehensive runoff control installed at the start of construction, as outlined in Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7).

14.6.8.120 The value of receptors in the scheme area are documented in ES Appendix 14.10 Assessment of Value (Application Document 3.4), with non-significant effects documented in ES Appendix 14.11 Non-significant Effects (Application Document 3.4).

Summary of potential impacts

14.6.8.121 The detailed assessment of design elements is documented in section 14.6.8 above. These are summarised as primarily localised drawdown impacts related to cuttings that may intercept the groundwater table.

14.6.8.122 Dewatering and discharge arrangements will need to be made with the Environment Agency prior to construction, as outlined in Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7).

14.6.8.123 ES Figure 14.6.2 Cuttings Assessment ZOI (Application Document 3.3) illustrates the potential zones of influence from the cuttings along the route, and receptors that could be impacted.

14.6.8.124 The majority of receptors mapped within the study area are outside the zone of influence or have subsequently been assessed as unlikely to be impacted based on the hydrogeological conceptualisation of the area. Receptors that are still at risk of impact without mitigation are detailed below.

14.6.8.125 A summary of the potential groundwater impacts (identified in Section 8.3), together with the required mitigation to prevent significant impacts are documented in Table 59: Summary of key potential impacts on the water regime from the A66 works.

14.6.8.126 With mitigation implemented as outlined below and within the EMP and Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7), no groundwater related significant impacts are assessed from the scheme.

Table 59: Summary of key potential impacts on the water regime from the A66 works

Receptor	Potential Impact	Required Mitigation
Route wide		
Groundwater Bodies	Risk of pollution of groundwater bodies during both construction and operation. Numerous cuttings along the route are likely to intercept groundwater – both perched groundwater in discrete lenses and potentially the main groundwater table which can have a detrimental impact on groundwater quality and quantity.	Mitigation as outlined in Annex B7 Ground and surface water management plan of the Environmental Management Plan (EMP) (Application Document Number 2.7). Appropriate drainage treatment design.
Surface water courses	Cuttings that intercept the groundwater table may impact baseflow to surface water features downgradient, which can have a detrimental impact on surface water quality and quantity.	Mitigation as outlined in Annex B7 Ground and surface water management plan of the EMP (Application Document Number 2.7). Appropriate drainage treatment design.

Receptor	Potential Impact	Required Mitigation
Unmapped receptors	Unmapped receptors, such as groundwater-surface water interactions (springs) and unlicensed abstractions, could be located within the vicinity of cuttings, embankments or structures and the presence of these is to be considered when developing the detailed design.	Mitigation as outlined in Annex B7 Ground and surface water management plan of the EMP (Application Document Number 2.7) Further monitoring and surveying of areas at risk during detailed design.
Licensed Abstractions and Consented Discharges	Licensed Abstractions and consented discharges are generally considered to be unimpacted by the works, due to not being in direct hydraulic continuity or at sufficient depth/distance for impacts to be negligible. Where features are within the Order Limits, the construction works may directly impact the abstraction and discharge infrastructure.	Adherence to Annex B7 Ground and surface water management plan of the EMP (Application Document Number 2.7) in particular pre, during and post construction monitoring and pollution prevention measures. Where features are directly impacted, an alternative source of supply (e.g. mains supply or alternative boreholes in a new location) is to be provided in consultation with stakeholders, as appropriate.
Land Drainage	Land drainage plays an important role in preventing localised flooding and feeding local surface water features. Any cuttings, embankments or structures may intercept localised land drainage .	Mitigation as outlined in Annex B7 Ground and surface water management plan of the EMP (Application Document Number 2.7) Any intercepted land drainage, abstractions or discharges will need to be appropriately maintained, reinstated or compensated (in consultation with the relevant stakeholders).
Kirkby Thore to Appleby		
Industrial Abstractions *(*Licence number: *277600311)*	The two industrial groundwater abstractions alongside Fell Lane may be directly impacted by the construction of the Kirkby Thore bypass and require appropriate mitigation. To prevent potential contamination risks, the boreholes will need to be appropriately decommissioned.	Adherence to Annex B7 Ground and surface water management plan of the EMP (Application Document Number 2.7) in particular pre, during and post construction monitoring and pollution prevention measures. Alternative source of supply (e.g. alternative boreholes in a new location) to be provided in consultation with stakeholders, if appropriate. Decommissioning of redundant boreholes in accordance with best practice to prevent contamination.
Private Abstraction	A private unlicensed abstraction proximal to Sleastonhow Farm will	Adherence to Annex B7 Ground and surface water management plan of the

Receptor	Potential Impact	Required Mitigation
	need to be appropriately considered when developing the methodology for the Trout Beck viaduct construction. Any works are to consider the pollution risk to the water supply.	EMP (Application Document Number 2.7) in particular pre, during and post construction monitoring and pollution prevention measures. Task specific risk assessment.
Appleby to Brough		
Flitholme Spring	Flitholme spring is located south of the A66 route, northeast of Flitholme. The 'spring' is utilised for supply of fields and buildings but may be directly impacted by the roadworks that will connect the Flitholme local road to the underpass. Appropriate mitigation and/or compensation measures will need to be implemented to ensure continued supply.	Adherence to Annex B7 Ground and surface water management plan of the EMP (Application Document Number 2.7) in particular pre, during and post construction monitoring and pollution prevention measures. Alternative source of supply (e.g. mains supply or alternative boreholes in a new location) to be provided in consultation with stakeholders, if appropriate.
Potential groundwater-surface water interaction northeast of Sandford Junction	The potential groundwater-surface water interaction northeast of Sandford Junction is located within the zone of influence of the junction cutting. The cutting has the potential to reduce baseflow to the potential spring/seepage which could result in the disappearance of the receptor or a reduced flow rate which could impact the local groundwater dependent fen habitat.	Detailed assessment undertaken at detailed design stage to identify risk. Lining of cutting to prevent groundwater ingress, and drainage blanket beneath/surrounding to prevent disruption to groundwater flow (e.g. mounding) OR scheme components redesigned within LoD to prevent impact on receptor.
Wildboar Hill Springs	Springs in the area surrounding Wildboar Hill feed local ditches that are used by livestock. Surveying of areas at risk in the area prior to commencement of construction will assist in the identification of spring locations and enable a further assessment of risk to be undertaken.	Alternative source of supply (e.g. mains supply or alternative infrastructure in a new location) provided in consultation with stakeholders, if appropriate. Adherence to Annex B7 Ground and surface water management plan of the EMP (Application Document Number 2.7) in particular pre, during and post construction monitoring and pollution prevention measures.

14.6.9 Conclusions

14.6.9.1 The purpose of this HIA is to present the current information available to inform the baseline conditions of the site and assess how the Project is likely to impact the groundwater regime with respect to levels, flow and quality.

14.6.9.2 The assessment has focussed on groundwater features including: superficial and bedrock aquifers, groundwater abstractions and discharges, environmentally sensitive sites, surface watercourses, surface water-groundwater interactions and karst features.

14.6.9.3 Based on the detailed assessment, a number of the cuttings along the route will likely intercept groundwater and locally reduce groundwater levels; modifying local hydrogeological interactions (e.g. baseflow to water courses and groundwater-surface water interactions) as summarised in section 14.6.8 Summary of Potential Impacts.

14.6.9.4 The cuttings assessment has been undertaken using high groundwater levels, maximum cutting depths and high permeability values and as such is considered conservative. Seepage rates into cuttings and excavations are likely to be significantly less than calculated; in particular, for schemes that consist primarily of online widening of the existing road scheme.

14.6.9.5 Embankments have the potential to impact groundwater-surface water interactions. Although no interactions were mapped in the location of embankments, groundwater-surface water interactions are known to be prevalent along the route; feeding local agricultural ditches and drainage. Where these features are identified, either during further assessment and surveying or during construction, appropriate mitigation is to be implemented as detailed in Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7).

14.6.9.6 The majority of mapped receptors along the route are located outside the zone of influence of the cuttings, or have subsequently been assessed as unlikely to be in hydraulic continuity.

14.6.9.7 A number of receptors (summarised in Table 59: Summary of key potential impacts on the water regime from the A66 works) will likely be directly impacted by the Project, due to their proximity to the alignment, and will require appropriate mitigation or compensation measures to be implemented.

14.6.9.8 The mitigation requirements are detailed in Annex B7 Ground and surface water management plan of the EMP (Application Document 2.7) or are embedded into the design.

14.6.10 References

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Annex A: Table of Groundwater Monitoring Installations

BH ID	Easting	Northing	mOD Top of Hole		m bgl Depth of hole		m bgl Response Zone	mOD Response Zone	Strata
BH M6J40.001	351137.1	529066.4	138.93	5.31	0.8	5	138.13	133.93	Glacial Till (Cohesive)
SD M6J40.005a	351201.9	528972.2	138.07	21.39	8	17	130.07	121.07	Glacial Till (C/G) Fluvioglacial Deposits
BH KBR003	352081.2	529098.1	134.87	14.5	1	14.2	133.87	120.67	Glacial Till + Fluvioglacial Deposits
BH KBR006	352177	529058.6	135.2	8.2	1	8.2	134.2	127	Glacial Till + Fluvioglacial Deposits
BH KBR011	352226.1	528923.2	133.99	6.02	1	6	132.99	127.99	Glacial Till + Fluvioglacial Deposits
BH KBR012	352621	529334.4	121.43	15.5	3	15.5	118.43	105.93	Fluvioglacial Deposits
SD KBR005	352134.1	529104.3	135.78	25.73	2	24.5	133.78	111.28	Glacial Till + Fluvioglacial Deposits
SD KBR007	352198.7	529140.7	135.83	25.67	4.5	15.5	131.33	120.33	Glacial Till (S/G) Fluvioglacial Deposits
BH PTS003	354474	529002.3	116.26	9.37	3	9	113.26	107.26	Glacial Till
BH PTS005	354909.2	528942.1	107.22	10.5	1.5	4	105.72	103.22	Glacial Till
BH PTS010	355966.6	528949.3	118.69	10.2	3	10	115.69	108.69	Penrith Sandstone

BH ID	Easting	Northing	mOD		m bgl		m bgl	mOD	Strata
			Top of Hole		Depth of hole		Response Zone	Response Zone	
BH PTS011	355960.2	528890.9	119.17	15.25	1	3.5	118.17	115.67	Glacial Till
BH PTS012	356162.5	528919.2	128.66	6.45	1	6	127.66	122.66	Glacial Till
BH PTS017	357112.9	528825.6	132.91	15.25	5.5	15	127.41	117.91	Penrith Sandstone
BH PTS018	357127.4	528877.9	130.09	14.8	6.5	12.5	123.59	117.59	Penrith Sandstone
BH PTS020	357966.2	528808.5	132.55	9.73	1	9.7	131.55	122.85	Glacial Till
BH KTB003	362815.1	526127.9	121.78	4.23	1	3.7	120.78	118.08	Glacial Till / Sand (Possibly Weathered Bedrock)
BH KTB005	363241.9	526201.2	117.13	5.67	4	5.5	113.13	111.63	Sand (Possibly Weathered Bedrock)
BH KTB007A	363439.5	526630.9	110.88	5.45	1	5	109.88	105.88	Glacial Till / Top of Eden Shales
BH KTB010	363525.8	526309.4	111.32	16	5	8	106.32	103.32	Penrith Sandstone
BH KTB013	363960	526268.2	126.11	10	1.5	9.5	124.61	116.61	Glacial Till (Cohesive)
BH KTB016A	364348.1	526077.4	125.79	11	3.2	7.2	122.59	118.59	Sand (Possibly Weathered Bedrock) + Penrith Sandstone
BH KTB018	364512.5	525886	127.68	6.95	1	5	126.68	122.68	Glacial Till (Sandy) + Sand (possible weathered bedrock)
BH KTB019	364510.5	525775	132.32	15.3	12	15	120.32	117.32	Penrith Sandstone
BH KTB023 mining	364665	525713.4	131	35	13	35	118	96	Glacial Till + Eden Shales Formation

BH ID	Easting	Northing	mOD Top of Hole		m bgl Depth of hole		m bgl Response Zone	mOD Response Zone	Strata
BH KTB024	364633.8	525694.5	131.26	8	1	7.5	130.26	123.76	Glacial Till + Fluvioglacial Deposits
BH KTB025	364555.2	525659.2	134.79	12.45	1	11.5	133.79	123.29	Glacial Till
BH KTB028	364590.4	525342.7	128.18	10.1	5.5	9.5	122.68	118.68	Penrith Sandstone
BH KTA004	365344.4	523797.6	121.87	16	6.3	8.8	115.57	113.07	Glacial Till + Penrith Sandstone
BH KTA015	366960.3	522442.4	170.24	8.1	5	8	165.24	162.24	Glacial Till
BH KTA018	367215.4	521870.8	166.35	16.2	9	16	157.35	150.35	Glacial Till
BH KTA021	367573.3	521568.4	148.64	4.1	1	3.6	147.64	145.04	Glacial Till
BH KTA022	367725.6	521585.8	155.8	7.45	2	7	153.8	148.8	Glacial Till
BH AB001	372022.4	517960.8	151.29	16	9.5	13	141.79	138.29	Penrith Sandstone
BH AB008 Deep	373327.4	517028.2	150.78	12	9	12	141.78	138.78	Penrith Sandstone
BH AB008 Shallow	373327.4	517028.2	150.78	12	3	4	147.78	146.78	Glacial Till (Granular)
BH AB009 Shallow	373343.3	517151.9	156.07	25.1	2	10	154.07	146.07	Glacial Till (Sandy/Granular)
BH AB009 Deep	373343.3	517151.9	156.07	25.1	12.5	25	143.57	131.07	Glacial Till + Penrith Sandstone
BH AB010 Shallow	373345.6	517085	154.21	25.8	1	8.5	153.21	145.71	Sand + Glacial Till (Cohesive/Sandy/Granular)
BH AB010 Deep	373345.6	517085	154.21	25.8	10	25	144.21	129.21	Glacial Till + Penrith Sandstone (Brockram/Conglomerate)

BH ID	Easting	Northing	mOD		m bgl		m bgl	mOD	Strata
			Top of Hole		Depth of hole		Response Zone	Response Zone	
BH AB011	373395.9	517192.6	152.66	10.45	1	10	151.66	142.66	Glacial Till (Sandy/Granular)
BH AB020	374740.6	516317.4	151.71	7.32	2	7	149.71	144.71	Glacial Till (Sandy/Granular)
BH AB021	374824.5	516244	156.72	6.45	3	5	153.72	151.72	Glacial Till (Cohesive/Sandy/Granular)
BH AB025	375216	515964.2	143.81	6.75	1.7	3.2	142.11	140.61	Fluvioglacial Deposits + Glacial Till (Granular)
BH AB026	375297.6	515896.5	142.89	8	1.5	4.5	141.39	138.39	Glacial Till (Sandy) + Fluvioglacial deposits
BH AB027	375415.9	515771	143.13	20	14	20	129.13	123.13	Penrith Sandstone
BH AB028	375449.5	515824.2	144.59	20	2	9	142.59	135.59	Sand + Glacial Till
BH AB030	375819.2	515558.6	158.06	6.1	0.75	5.5	157.31	152.56	Glacial Till (Sandy)
BH AB031	376104.1	515372.1	169.62	7.5	1	4	168.62	165.62	Glacial Till
BH AB032	376190.2	515353	172.25	8	1	6	171.25	166.25	Glacial Till
BH AB033	376286.5	515290.1	173.89	8	1	8	172.89	165.89	Glacial Till
BH AB034	376413	515265.8	172.24	7.5	3	4	169.24	168.24	Glacial Till
BH AB042	377605	515244	174.1	15	10.5	15	163.6	159.1	Glacial Till
BH AB043	377618	515202.2	164.85	18.5	7.5	18.5	157.35	146.35	Penrith Sandstone
BH AB044	377818.5	515168.1	175.26	7.5	1	7.5	174.26	167.76	Glacial Till
BH AB045	377975.3	515175.7	178.3	7.95	1	5	177.3	173.3	Glacial Till
BH BB002	398838.151	513606.272	296.211	5	3.5	4.5	292.71	291.71	Glacial Deposits - Granular

BH ID	Easting	Northing	mOD		m bgl		m bgl	mOD	Strata
			Top of Hole		Depth of hole		Response Zone	Response Zone	
BH BB003	398885.998	513564.334	287.563	15	10	12	277.56	275.56	Mudstone
BH BB004	398947.771	513636.085	288.734	5.5	1	5	287.73	283.73	Glacial Deposits - Cohesive
BH BB005	399075.055	513698.861	292.732	8.5	4.5	5.5	288.23	287.23	Glacial Deposits - Granular
BH BB006	399163.291	513717.945	291.887	6.1	4.5	5.5	287.39	286.39	Glacial Deposits - Granular + Mudstone
BH BB007	399265.479	513764.206	291.669	19.7	10	12	281.67	279.67	Mudstone / Limestone
BH BB008	399306.435	513672.558	291.185	15	2	3	289.19	288.19	Glacial Deposits - Cohesive
BH BB009	399398.261	513794.791	289.926	10.5	6	7	283.93	282.93	Mudstone
BH BB010	399516.023	513792.825	283.005	5	1	3	282.01	280.01	Mudstone
BH BB011	399543.116	513799.947	283.418	15	3.5	4.5	279.92	278.92	Mudstone
BH BB012	399514.039	513776.832	282.526	20	7	9	275.53	273.53	Limestone
BH BB013	399597.93	513848.958	290.791	5	1.5	4	289.29	286.79	Glacial Deposits - Cohesive
BH BB014	399591.392	513745.964	284.564	10.6	1.5	3.5	283.06	281.06	Glacial Deposits - Cohesive
BH BB015	8399882.78	513792.177	287.201	5.1	1	3	286.2	284.2	Glacial Deposits - Cohesive

BH ID	Easting	Northing	mOD		m bgl		m bgl	mOD	Strata
			Top of Hole		Depth of hole		Response Zone	Response Zone	
BH BB016	399992.177	513779.155	285.634	2.4	1.5	2.4	284.13	283.23	Glacial Deposits - Cohesive
BH BB018	400234.832	513712.738	271.411	15	3.5	5	267.91	266.41	Limestone
BH BB022	400853.036	513520.758	262.349	3	1.5	3	260.85	259.35	Glacial Deposits - Cohesive
BH BB023	400909.178	513595.501	265.463	17.6	5	7	260.46	258.46	Glacial Deposits - Cohesive
BH BB024	400903.112	513558.935	264.105	20.3	1	3	263.11	261.11	Glacial Deposits - Cohesive
BH BB025	400982.97	513559.178	262.943	2.5	1.5	2.3	261.44	260.64	Glacial Deposits - Cohesive
WS BB002	398646.658	513490.231	284.986	5.2	0.5	3	284.49	281.99	Glacial Deposits - Cohesive
BH CLR001A	405216.107	513887.71	206.247	20	15	16	191.25	190.25	Glacial Deposits - Cohesive
BH CLR003A	405197.201	513775.28	200.24	16.95	5	7	195.24	193.24	Glacial Deposits - Cohesive
BH CLR004A	405219.137	513701.749	198.392	20	3	5	195.39	193.39	Glacial Deposits - Granular
BH CLR010	407378.719	513660.861	171.362	7.5	1	3	170.36	168.36	Glacial Deposits - Cohesive
BH CLR011	407849.018	513699.879	156.909	6.8	1	3	155.91	153.91	Glacial Deposits - Cohesive
WS CLR001	407535.917	513613.817	166.917	3.2	1.5	2.5	165.42	164.42	Glacial Deposits - Cohesive

BH ID	Easting	Northing	mOD		m bgl		m bgl	mOD	Strata
			Top of Hole		Depth of hole		Response Zone	Response Zone	
WS CLR003	405120.026	513758.596	201.282	4.65	1	3	200.28	198.28	Glacial Deposits - Cohesive
BH SBC001	412345.573	510538.449	158.629	10	1	3	157.63	155.63	Sandstone and Mudstone
BH SBC002	412774.417	510404.811	166.931	6	3.5	4.5	163.43	162.43	Glacial Deposits - Cohesive
BH SBC005	413004.497	510273.563	178.737	8	2	3.5	176.74	175.24	Glacial Deposits - Cohesive
BH SBC006	413060.543	510206.975	179.718	8	5	7	174.72	172.72	Mudstone
BH SBC008	413311.348	510040.95	172.437	5	2	4	170.44	168.44	Glacial Deposits - Cohesive + Mudstone
BH SBC009	413293.921	5101114.31	173.519	10.5	4	6	169.52	167.52	Mudstone
BH SBC011	413958.395	509648.592	169.334	8	1	3	168.33	166.33	Glacial Deposits - Cohesive
BH SBC013	414059.539	509543.602	163.634	11	7	9	156.63	154.63	Glacial Deposits - Cohesive
BH SBC014A	414178.81	509559.834	158.931	25.6	13	15	145.93	143.93	Glacial Deposits - Cohesive
BH SBC016	414226.468	509613.037	158.127	7	4	6	154.13	152.13	Glacial Deposits - Cohesive
BH SBC017	414299.965	509465.967	151.483	8	2	4	149.48	147.48	Glacial Deposits - Cohesive
BH SBC018	414581.986	509451.486	153.639	3.5	2	3.5	151.64	150.14	Glacial Deposits - Cohesive

BH ID	Easting	Northing	mOD Top of Hole		m bgl Depth of hole		m bgl Response Zone	mOD Response Zone	Strata
BH SBC019	415150.058	509205.044	141.622	6.5	3	4	138.62	137.62	Glacial Deposits - Cohesive
BH SBC020	415309.083	509026.222	148.393	8.5	5	6	143.39	142.39	Glacial Deposits - Cohesive
BH SBC021	415408.013	508988.822	148.438	8	2	3	146.44	145.44	Glacial Deposits - Cohesive
BH SBC022	415492.715	508861.032	146.029	8	1	2	145.03	144.03	Glacial Deposits - Cohesive
BH SBC023A	415595.532	508773.188	145.359	16.8	7.5	9	137.86	136.36	Glacial Deposits - Cohesive and Granular
BH SBC024	415588.616	508835.171	145.897	25	14	16	131.9	129.9	Glacial Deposits - Cohesive
BH SBC025	415672.321	508692.299	142.968	25	3	5	139.97	137.97	Glacial Deposits - Cohesive
BH SBC026	415642.362	508897.999	143.638	8	4	5	139.64	138.64	Glacial Deposits - Cohesive
BH SBC027	415722.683	508806.881	141.958	7	2	3	139.96	138.96	Glacial Deposits - Cohesive
BH SBC029	415821.53	508545.109	150.166	10.5	3	5	147.17	145.17	Glacial Deposits - Cohesive
BH SBC030	415947.189	508485.383	150.261	10.5	2	4	148.26	146.26	Glacial Deposits - Cohesive
BH SBC031	416167.109	508277.034	155.627	17	5	8	150.63	147.63	Glacial Deposits - Cohesive and Granular

BH ID	Easting	Northing	mOD		m bgl		m bgl	mOD	Strata
			Top of Hole		Depth of hole		Response Zone	Response Zone	
BH SBC032A	416374.536	508155.959	147.467	10	4	7	143.47	140.47	Glacial Deposits - Cohesive

Annex B: Rainfall Hydrographs

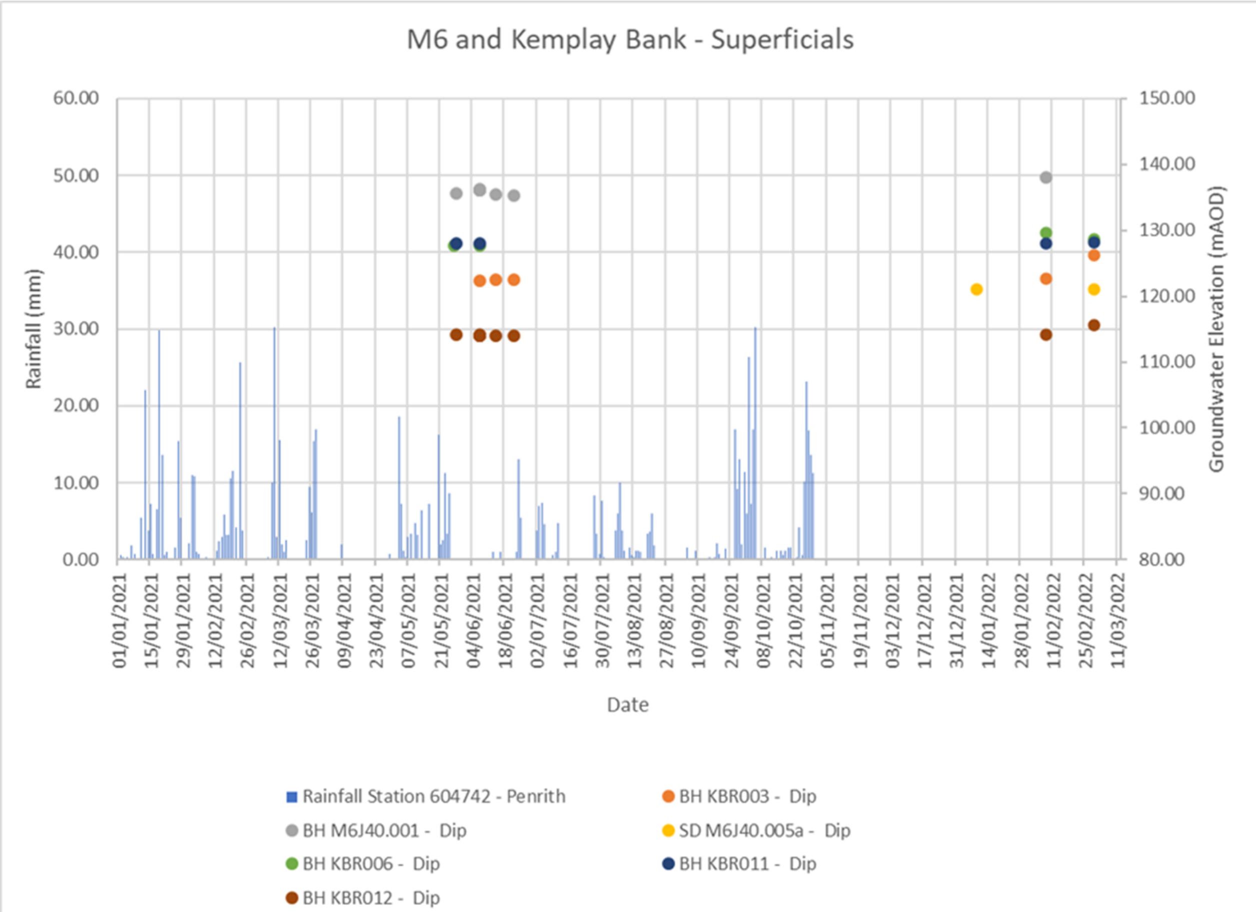

Plate 1: Hydrograph for M6 J40 and Kempley Bank Project study area - Groundwater Monitoring in Superficial Deposits with Rainfall Data from Station 604742 - Penrith

(Note that rainfall data has been requested up to the end of February 2022, but had not been received at the time of this report)

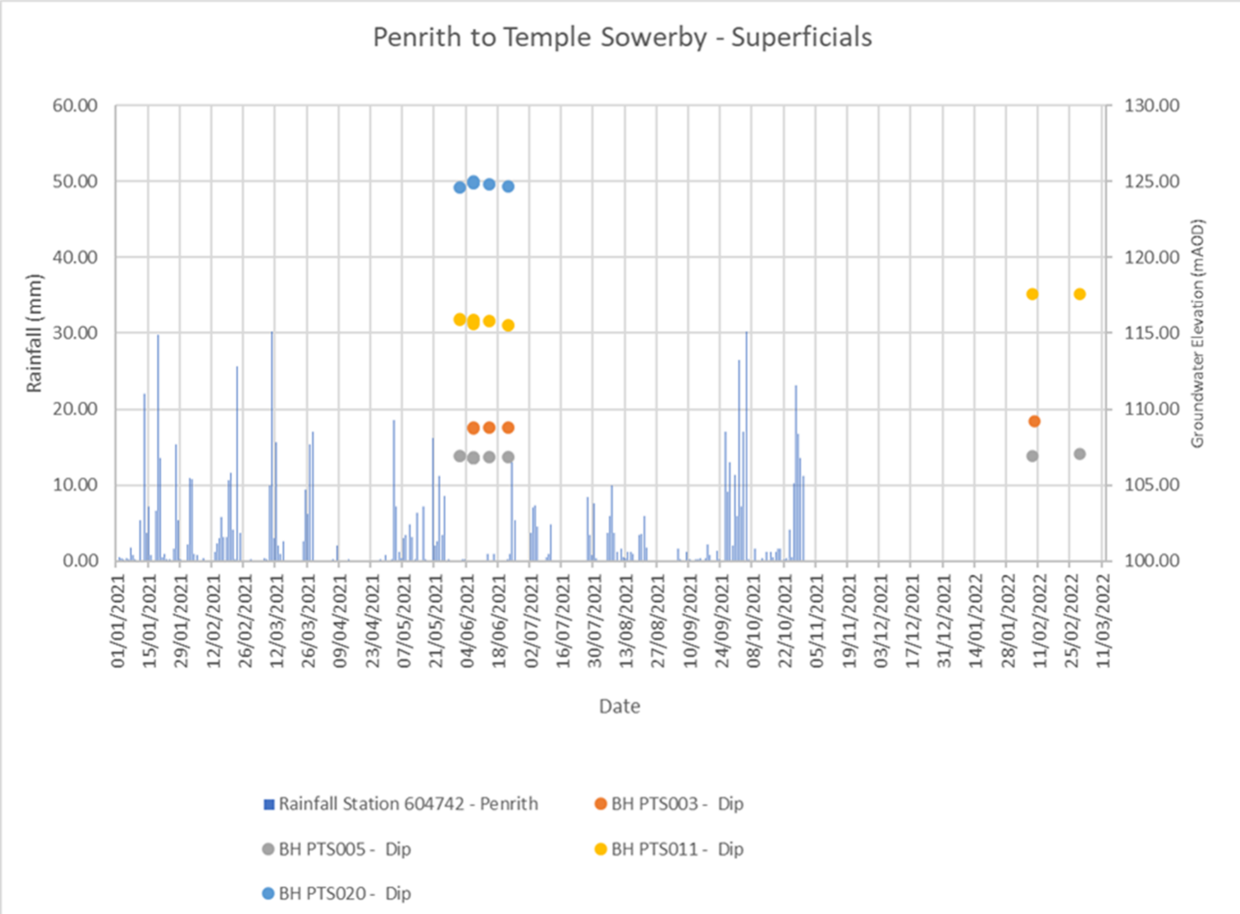

Plate 2: Hydrograph for Penrith to Temple Sowerby Project study area - Groundwater Monitoring in Superficial Deposits with Rainfall Data from Station 604742 - Penrith

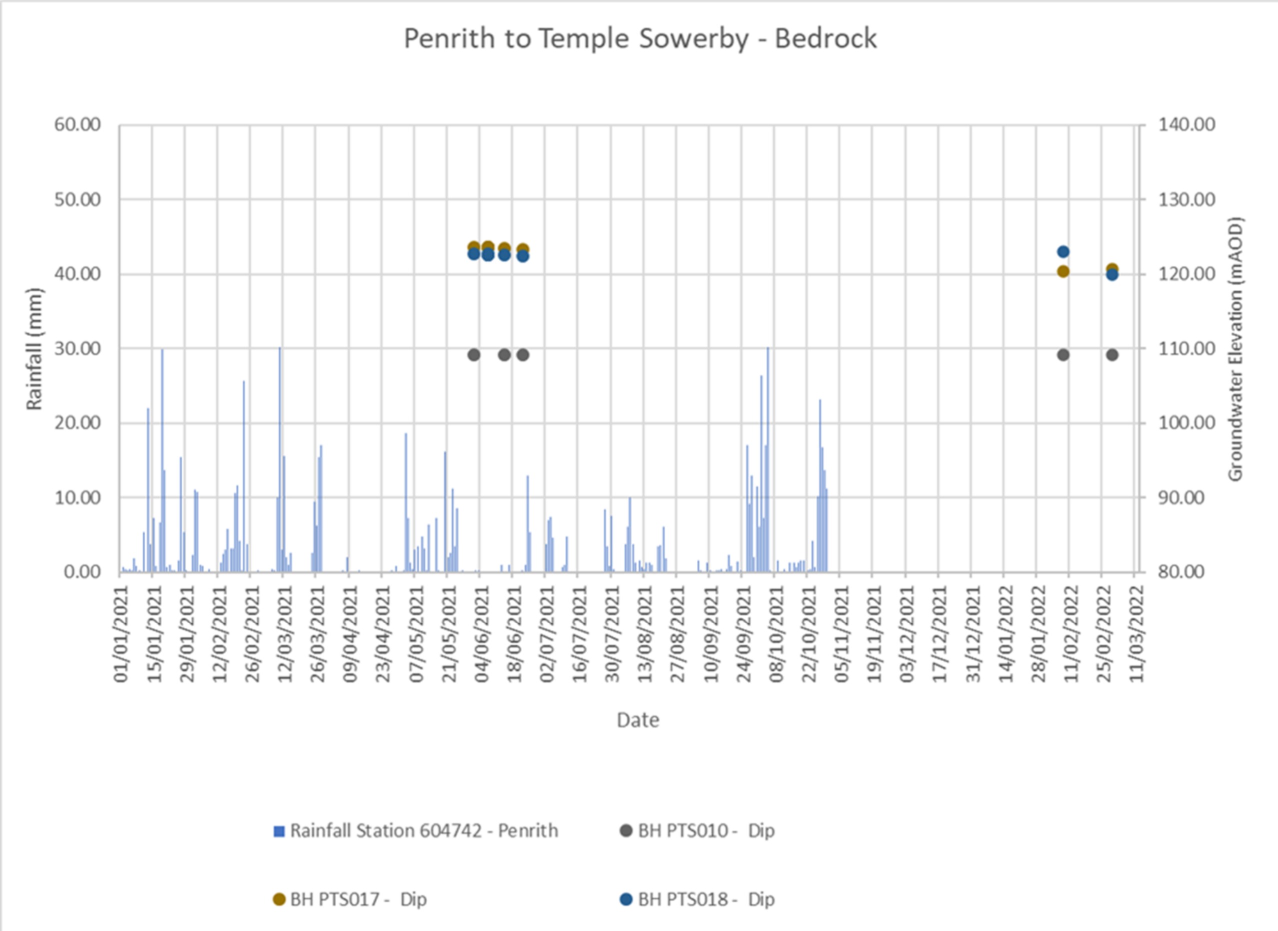

Plate 3: Hydrograph for Penrith to Temple Sowerby Project study area - Groundwater Monitoring in Bedrock Deposits with Rainfall Data from Station 604742 - Penrith

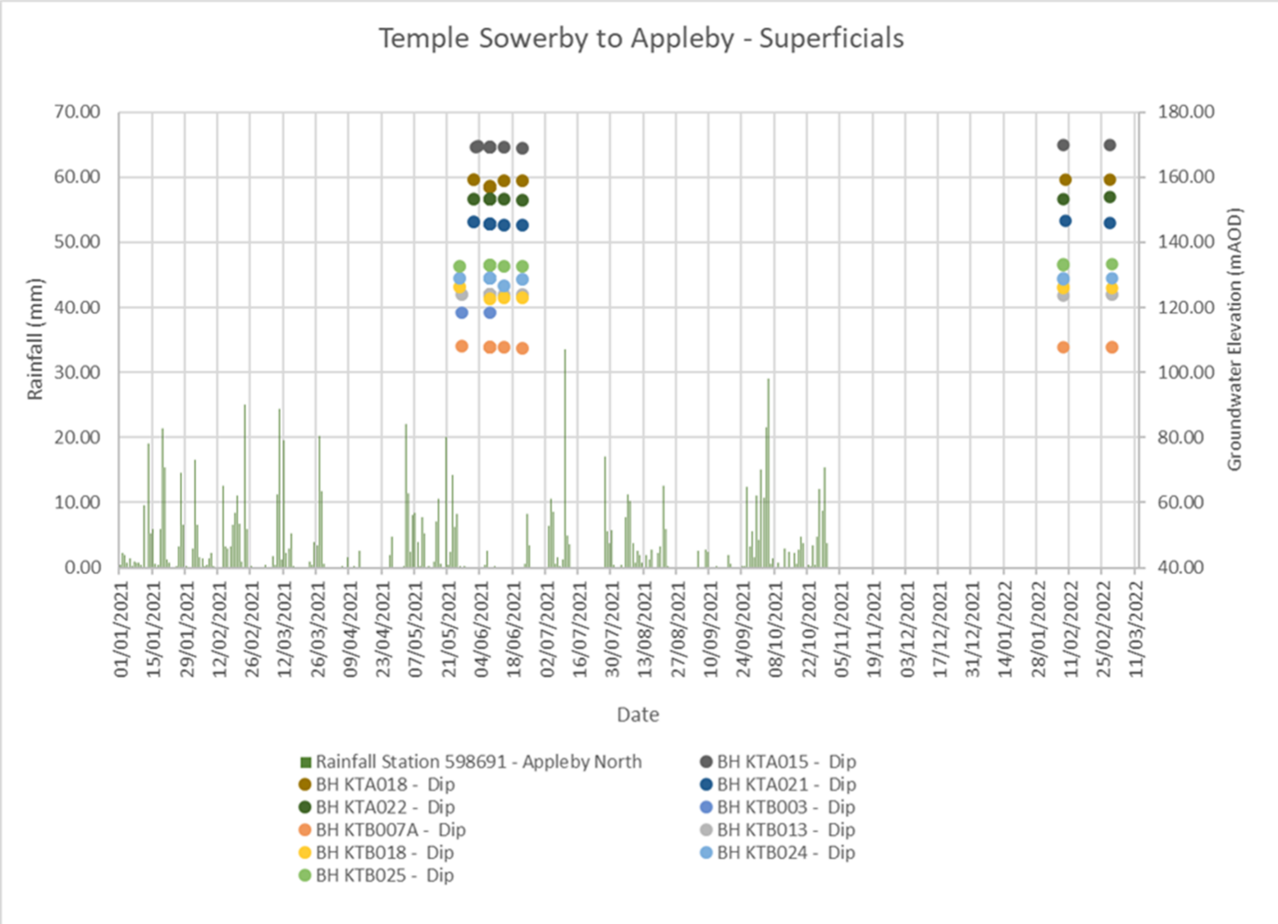

Plate 4: Hydrograph for Temple Sowerby to Appleby Project study area - Groundwater Monitoring in Superficial Deposits with Rainfall Data from Station 598691 - Appleby N

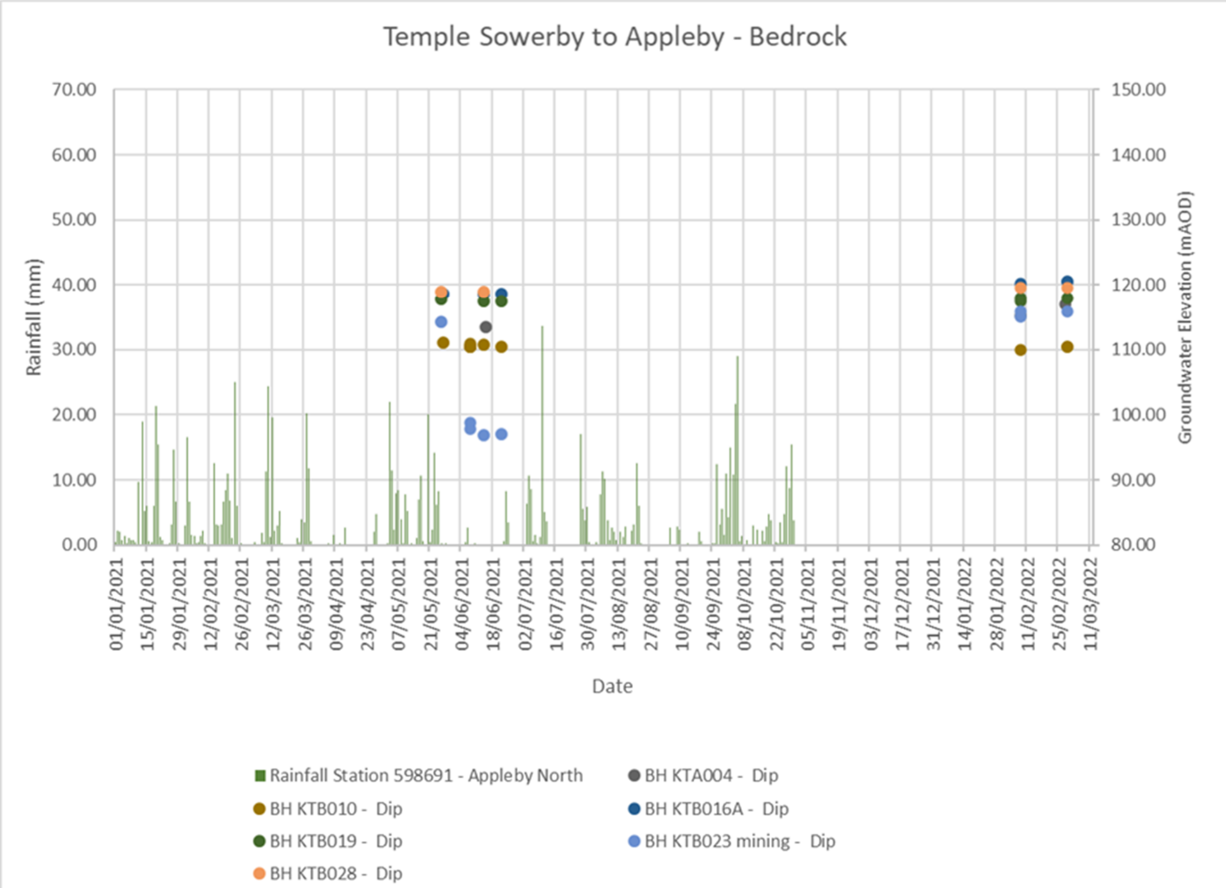

Plate 5: Hydrograph for Temple Sowerby to Appleby Project study area - Groundwater Monitoring in bedrock Deposits with Rainfall Data from Station 598691 - Appleby N

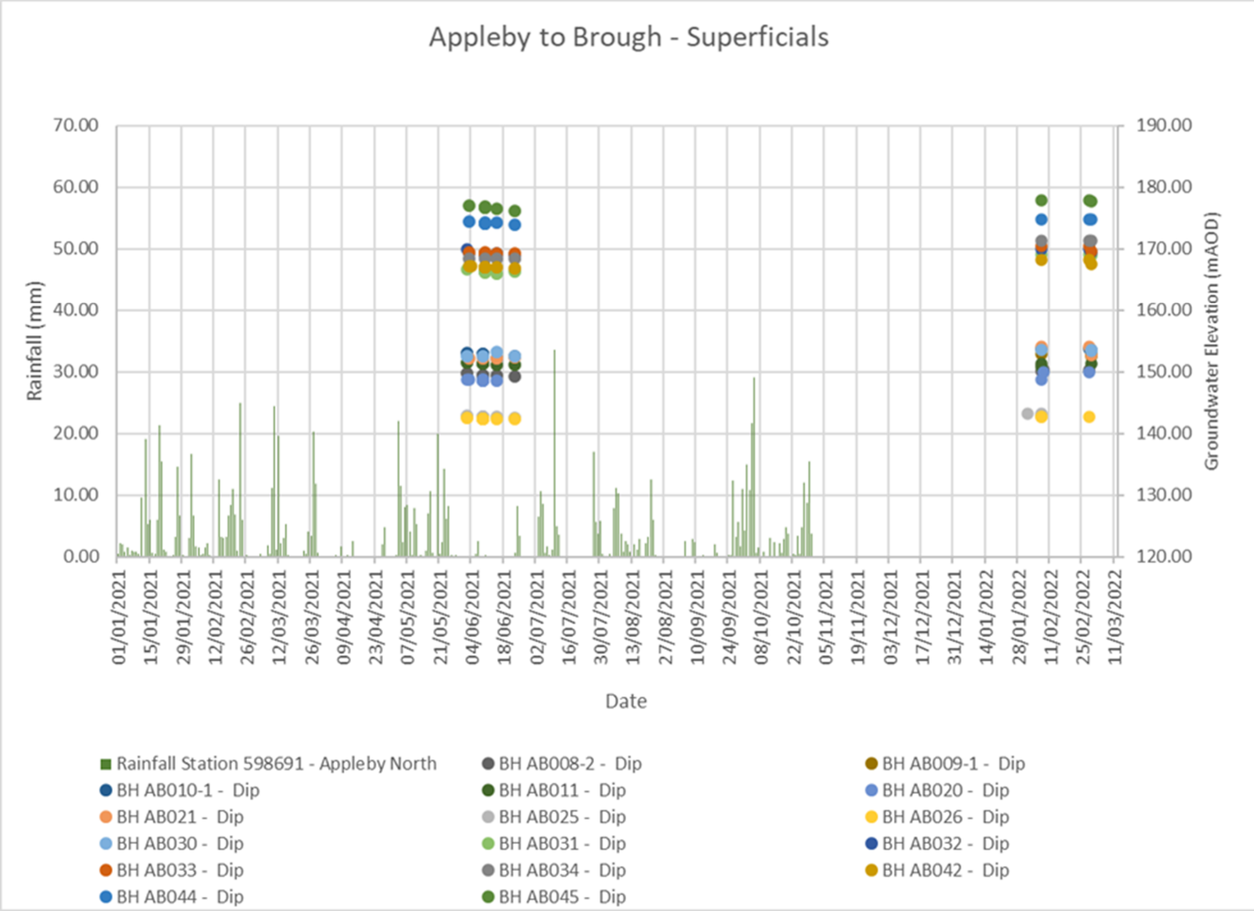

Plate 6: Hydrograph for Appleby to Brough Project study area - Groundwater Monitoring in superficial Deposits with Rainfall Data from Station 598691 - Appleby N

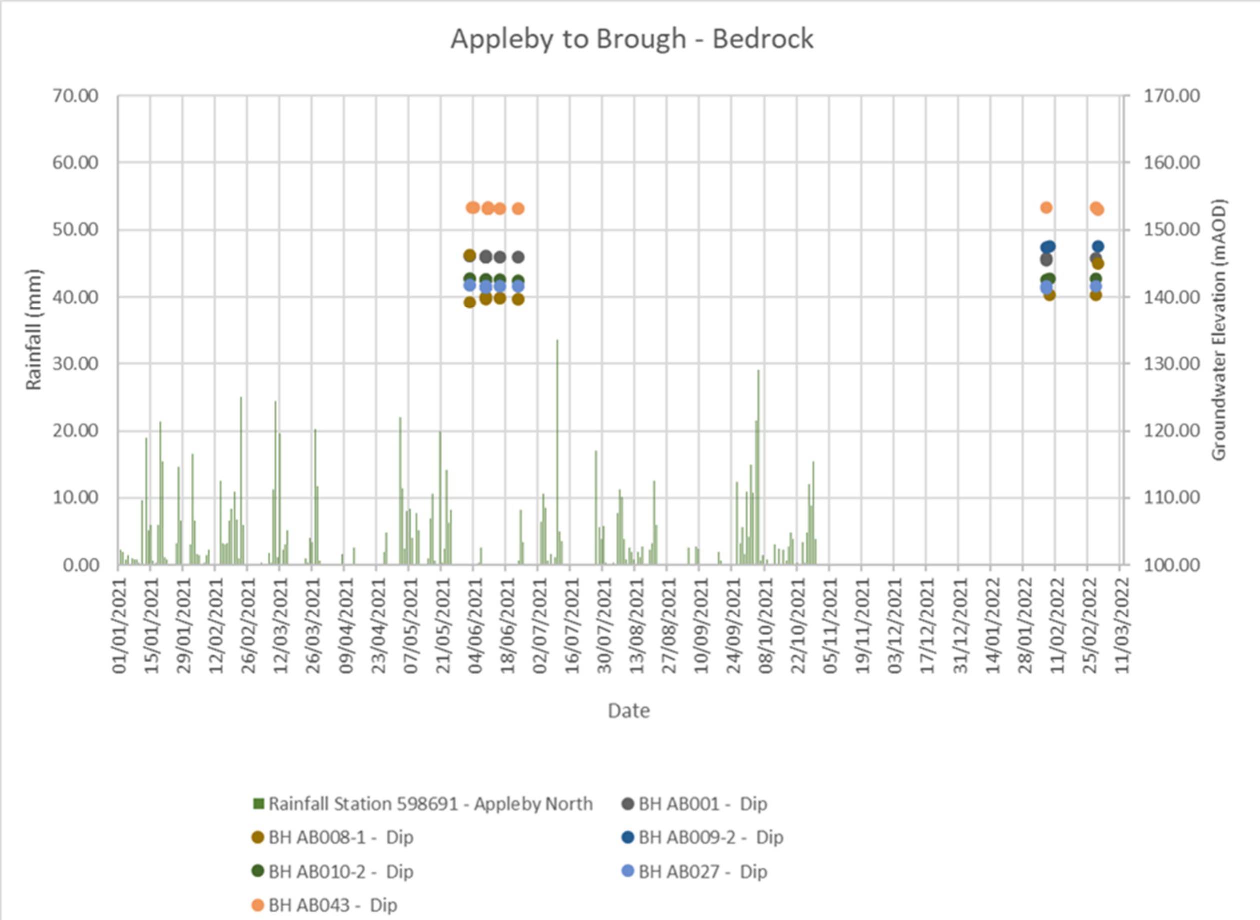

Plate 7: Hydrograph for Appleby to Brough Project study area - Groundwater Monitoring in bedrock deposits with Rainfall Data from Station 598691 - Appleby N

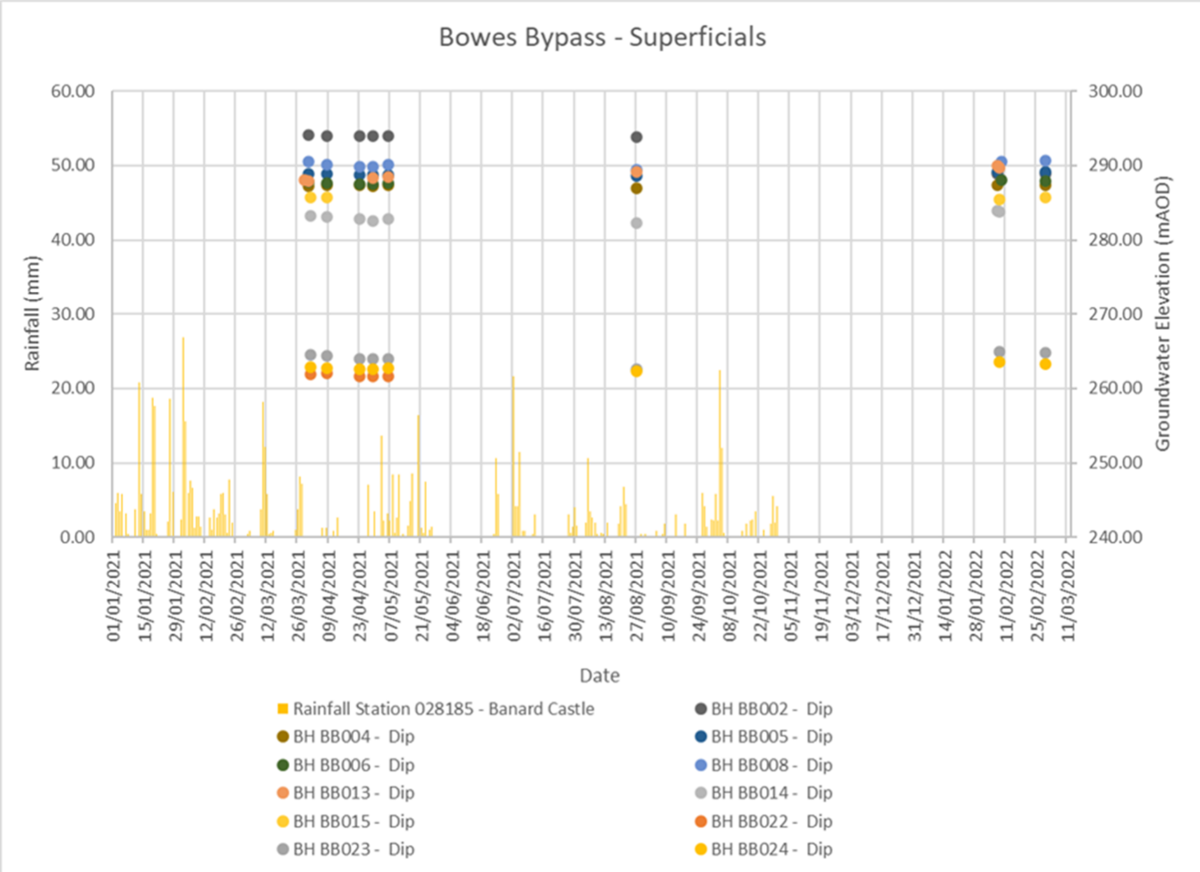

Plate 8: Hydrograph for Bowes Bypass Project study area - Groundwater Monitoring in superficial deposits with Rainfall Data from Station 028185 - Barnard Castle

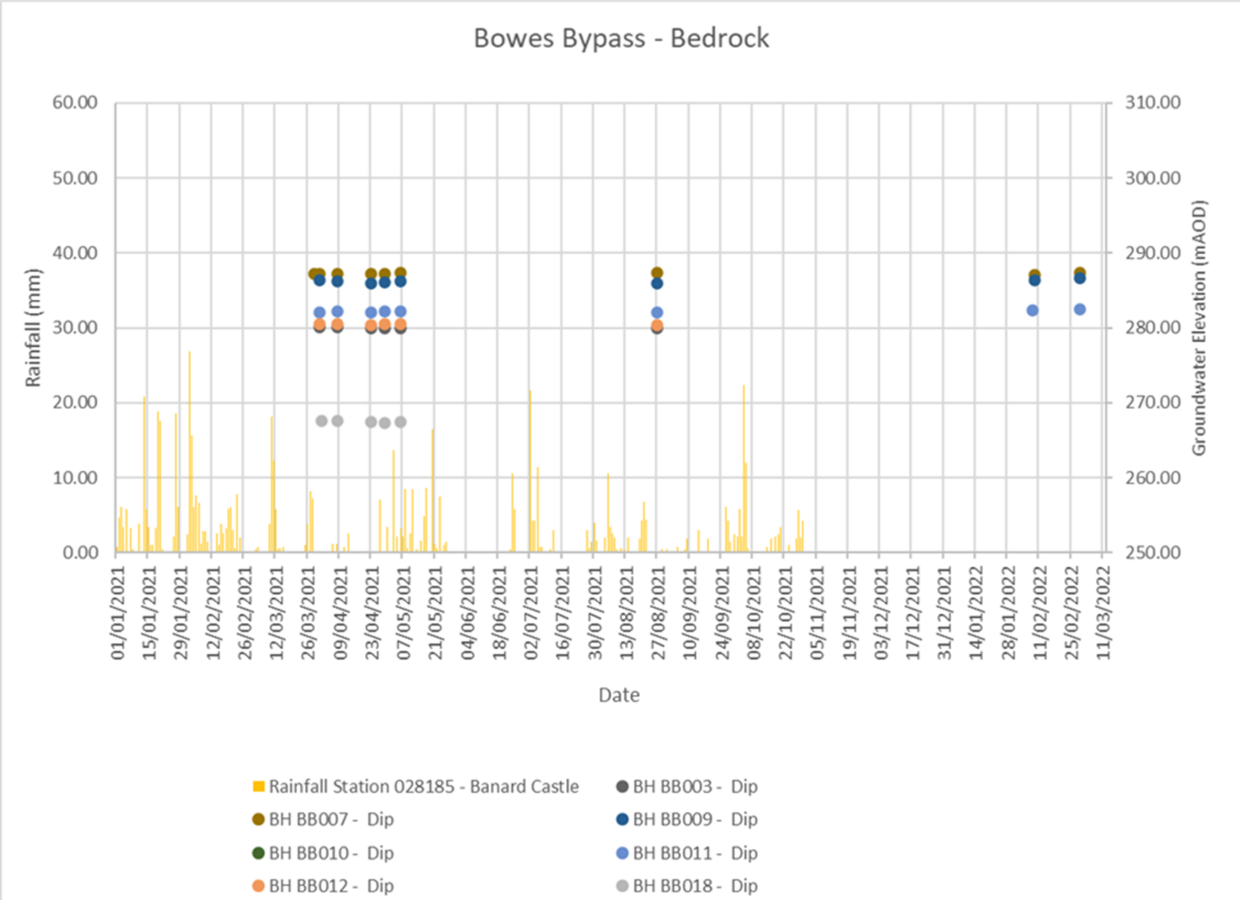

Plate 9: Hydrograph for Bowes Bypass Project study area - Groundwater Monitoring in bedrock deposits with Rainfall Data from Station 028185 - Barnard Castle

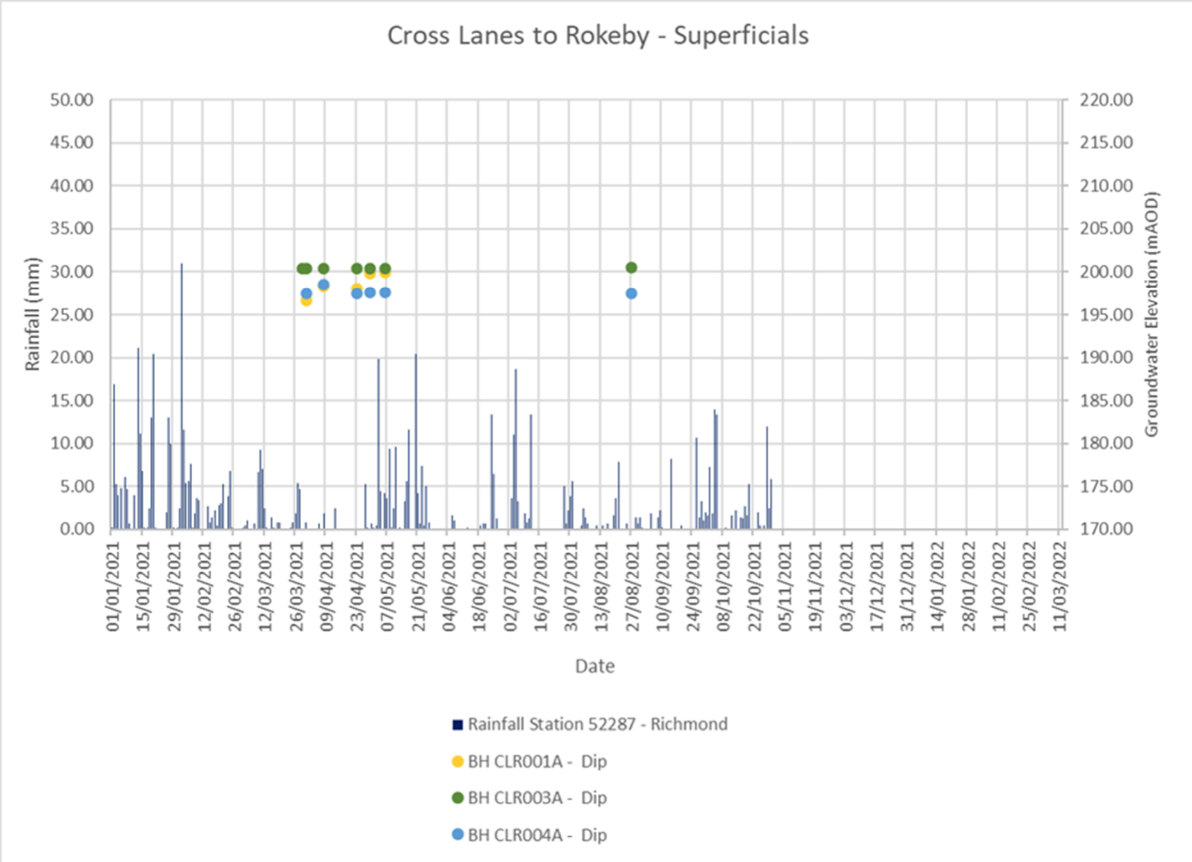

Plate 10: Hydrograph for Cross Lane to Rokeby Project study area - Groundwater Monitoring in superficial deposits with Rainfall Data from Station 52287 - Richmond

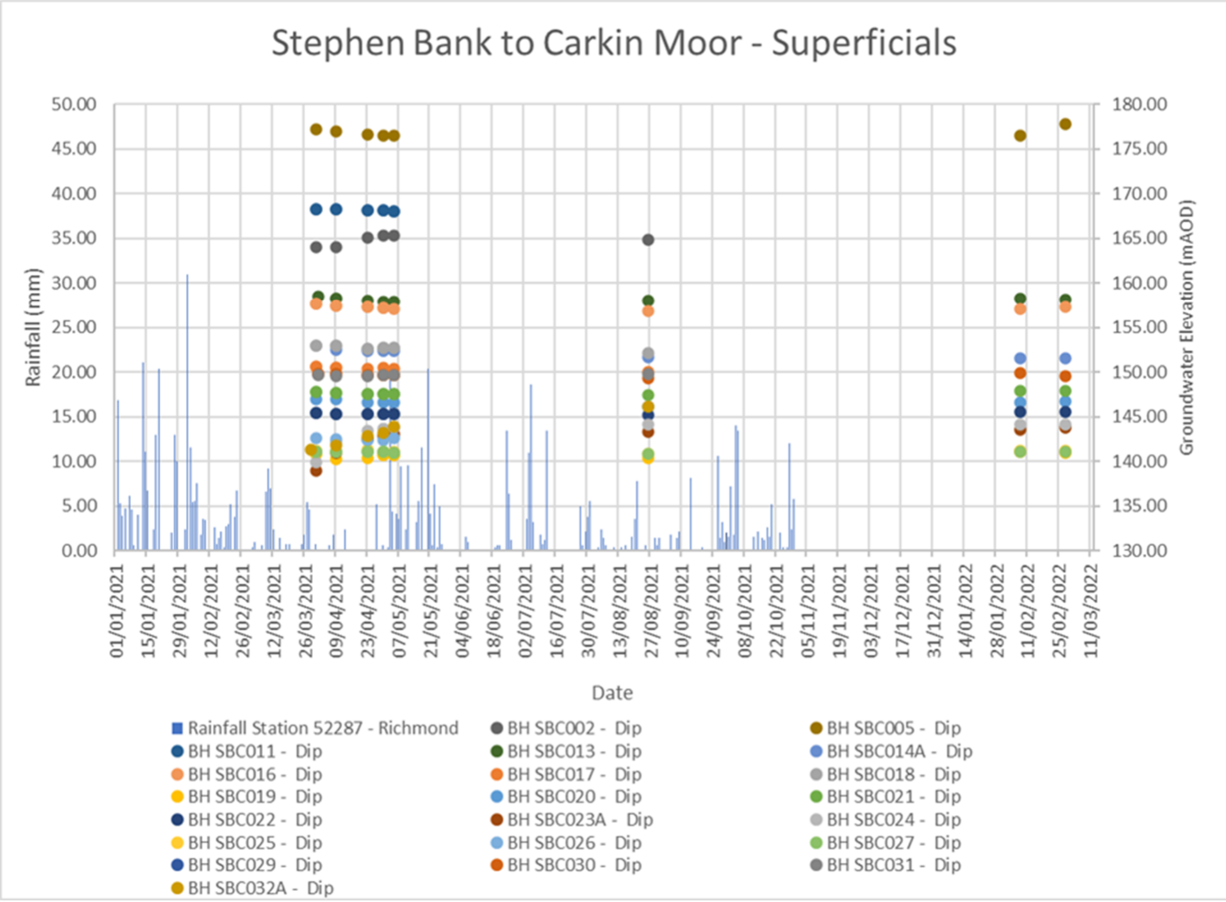

Plate 11: Hydrograph for Stephen Bank to Carkin Moor Project study area - Groundwater Monitoring in superficial deposits with Rainfall Data from Station 52287 - Richmond

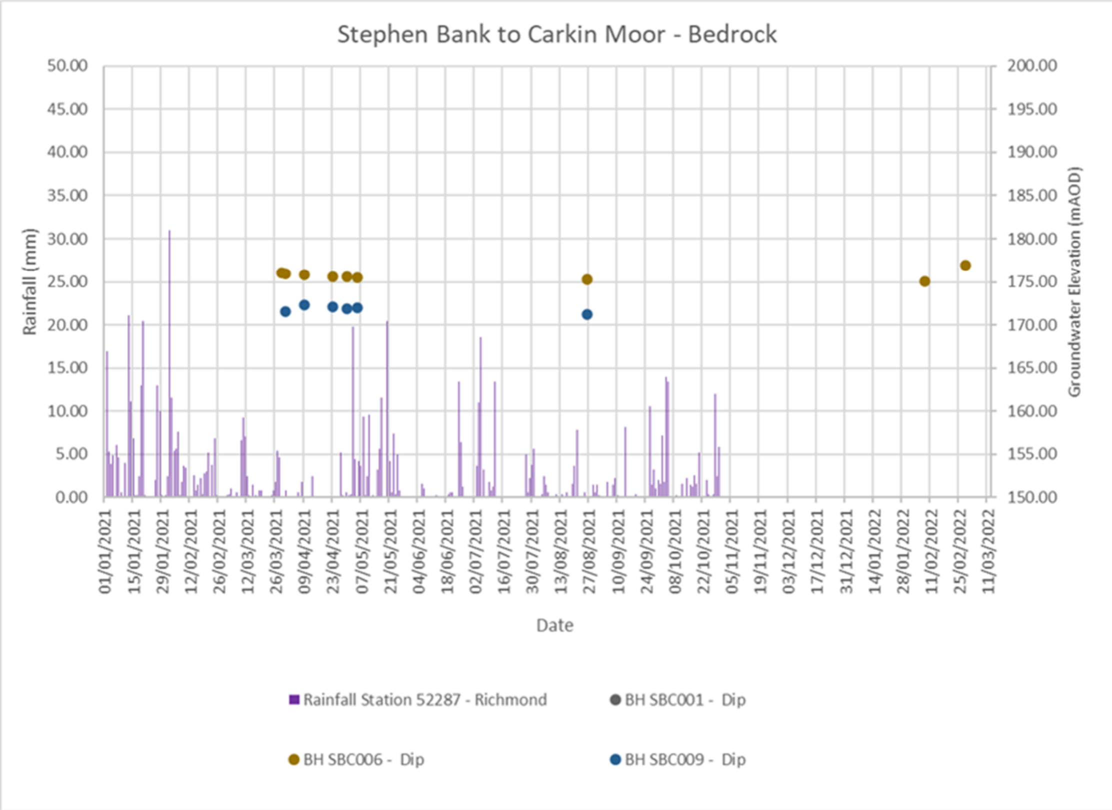

Plate 12: Hydrograph for Stephen Bank to Carkin Moor Project study area - Groundwater Monitoring in bedrock deposits with Rainfall Data from Station 52287 - Richmond

Annex C: Piper Plots

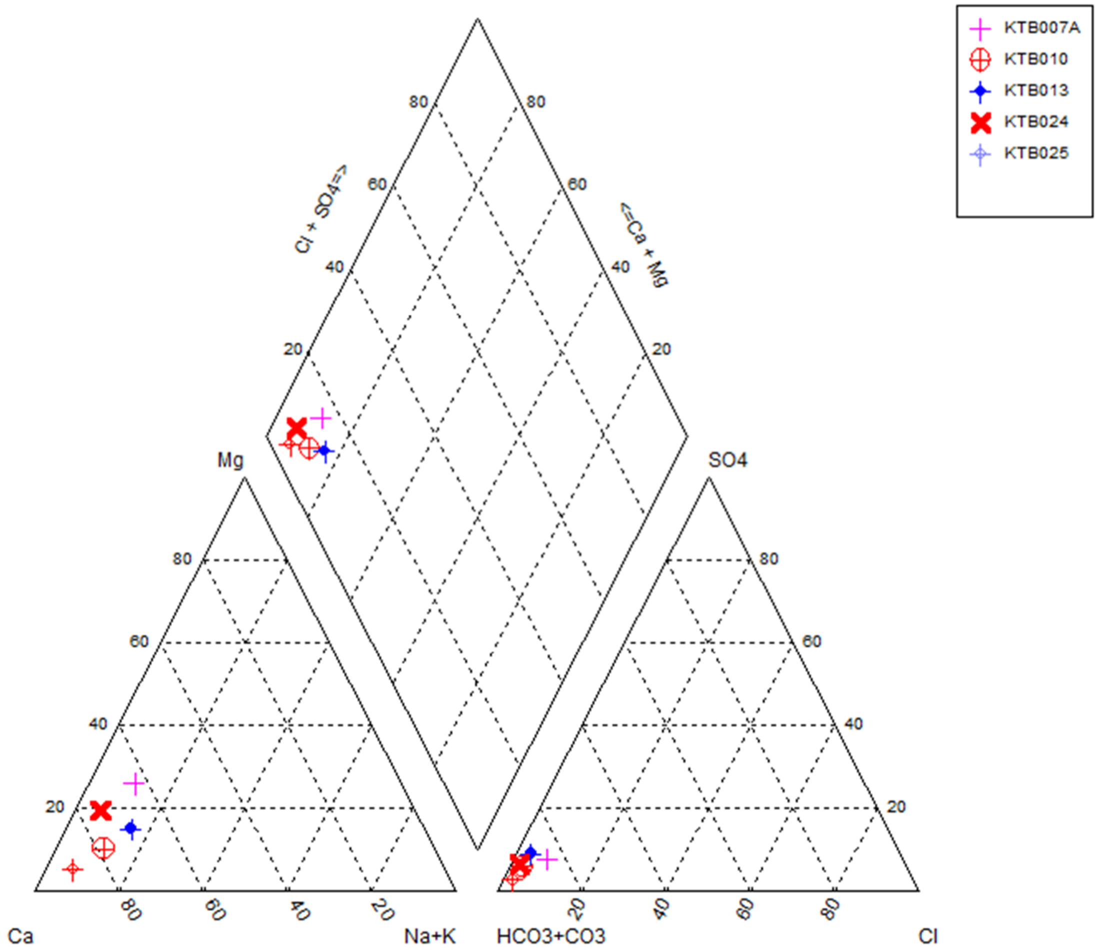

Plate 13: Piper Plot of groundwater chemistry in Kirkby Thore Bypass area

Annex D: Hydrogeological Conceptual Models

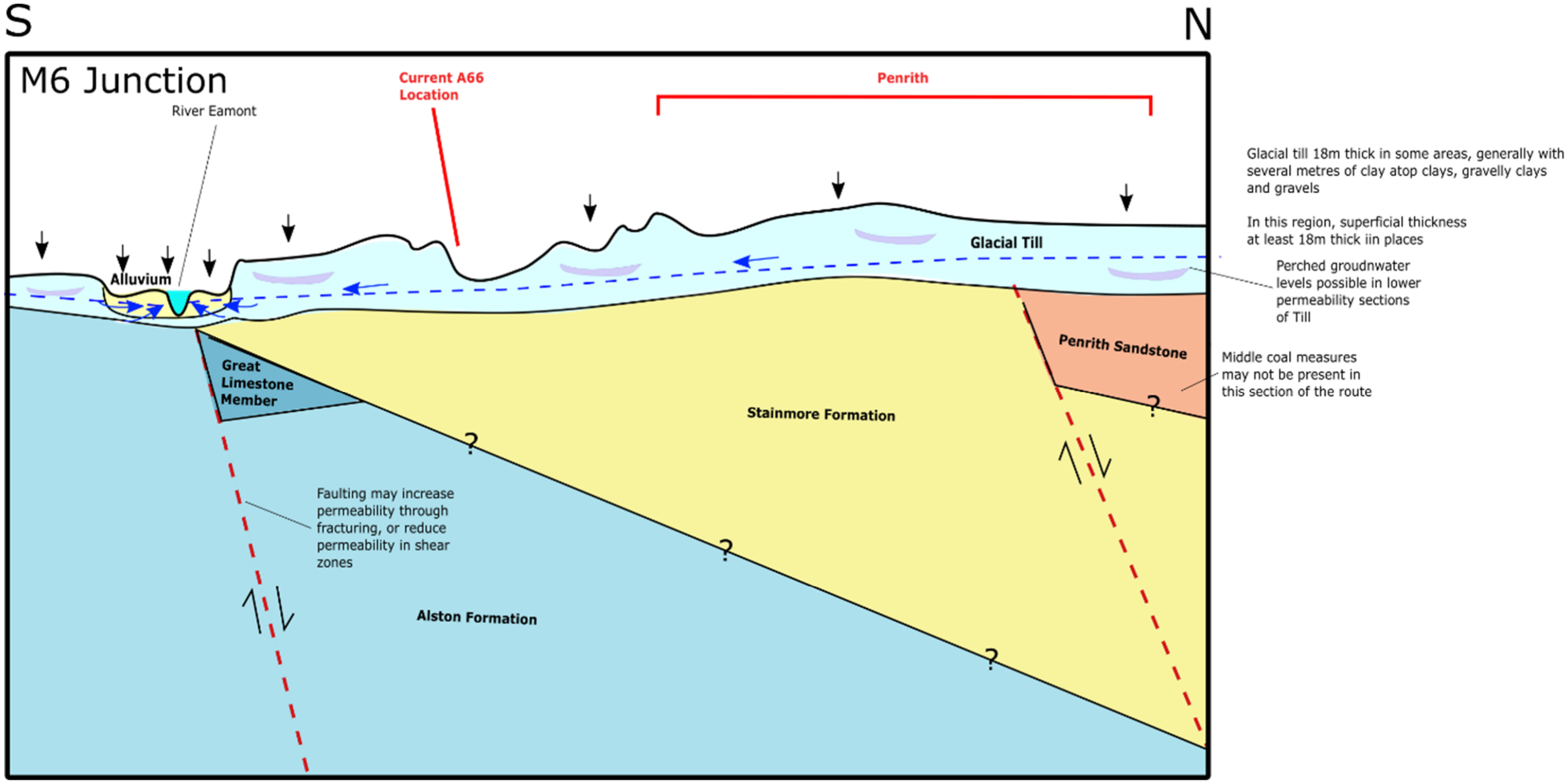

Plate 14: Hydrogeological Conceptual Model in M6 Junction 40 to Kemplay Bank Roundabout Project study area (M6 Junction 40 area)

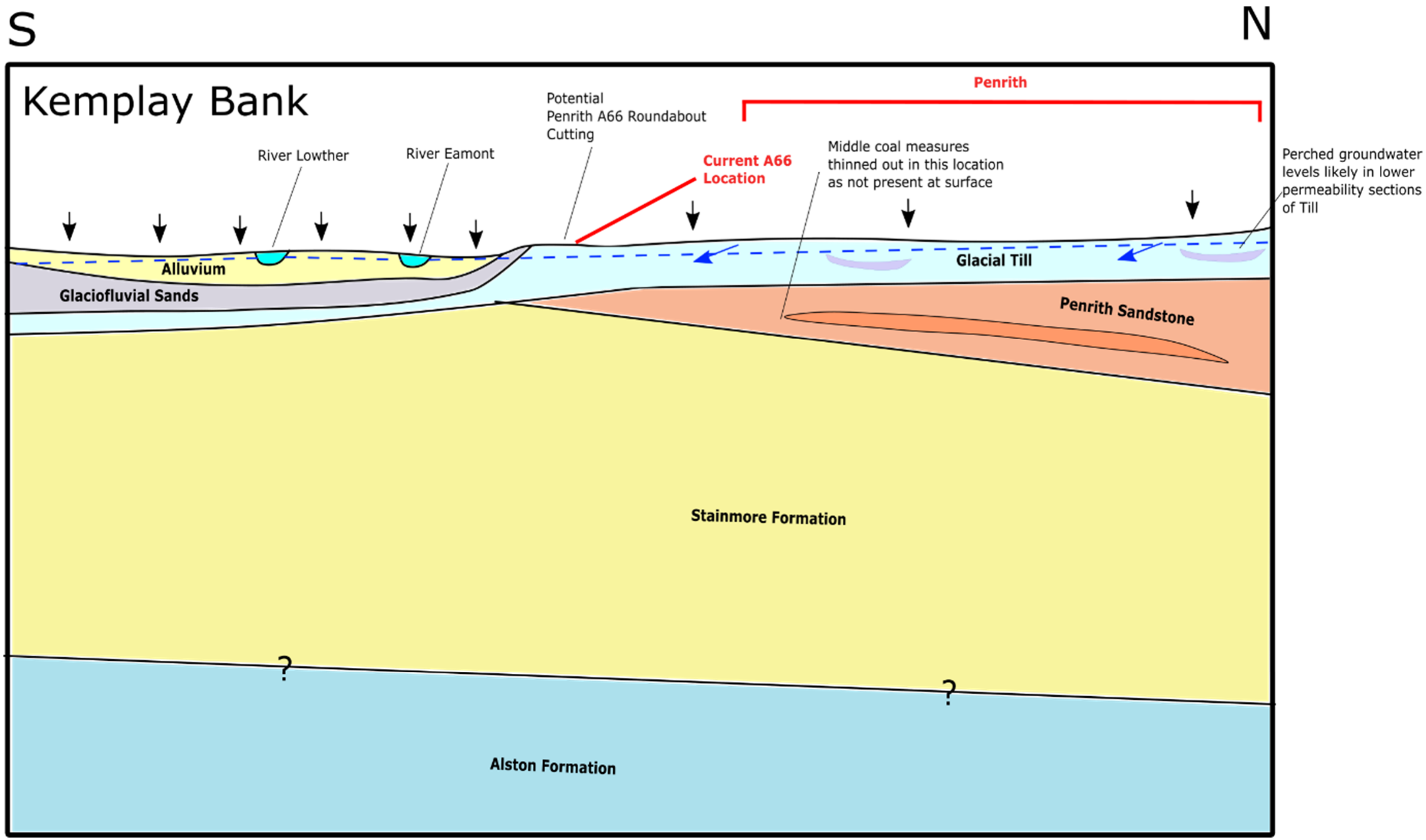

Plate 15: Hydrogeological Conceptual Model in M6 Junction 40 to Kemplay Bank Roundabout Project study area (Kemplay Bank Roundabout area)

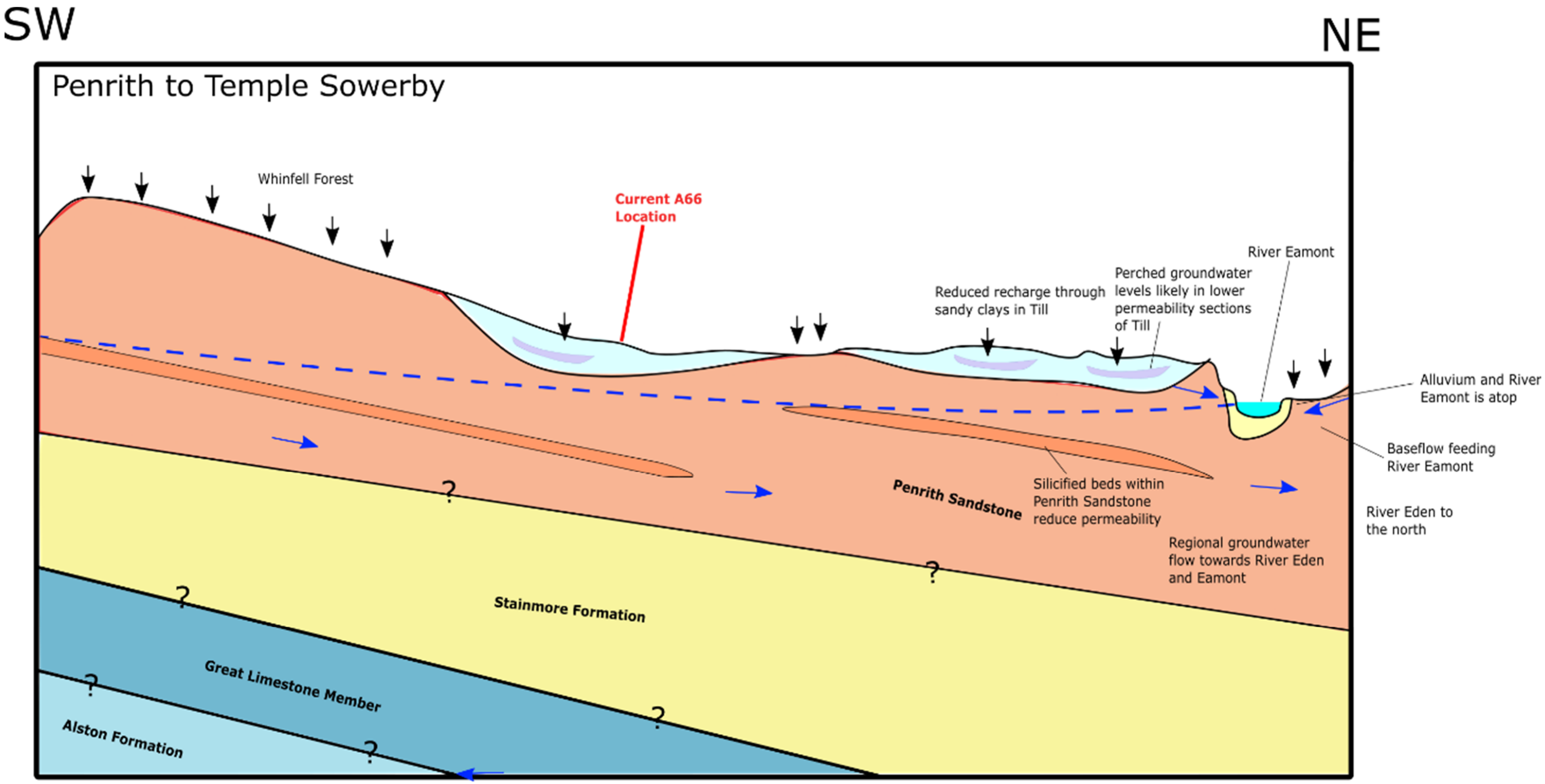

Plate 16: Hydrogeological Conceptual Model in Penrith to Temple Sowerby Project study area

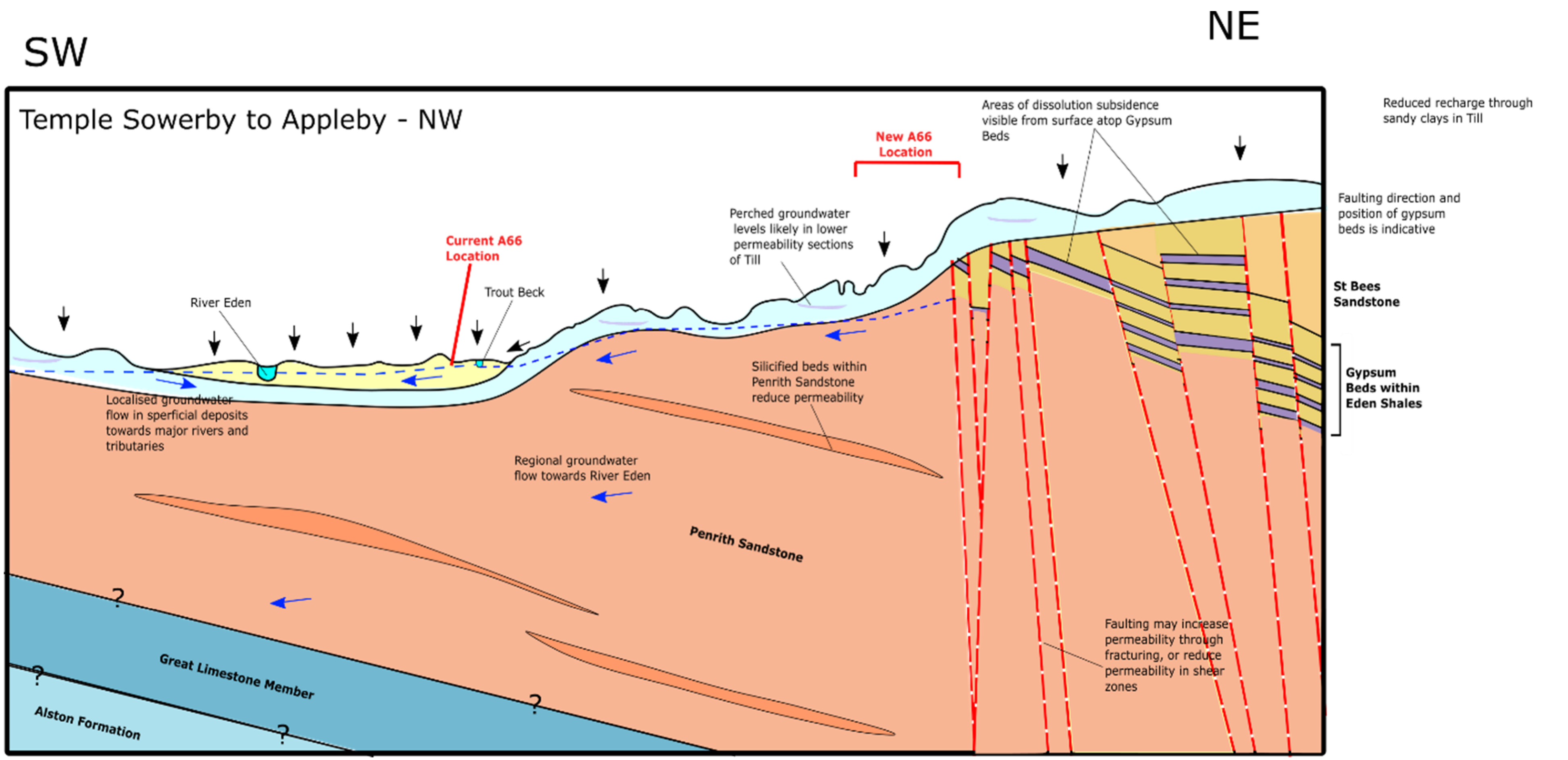

Plate 17: Hydrogeological Conceptual Model in Temple Sowerby to Appleby Project study area (Kirby Thore Bypass area)

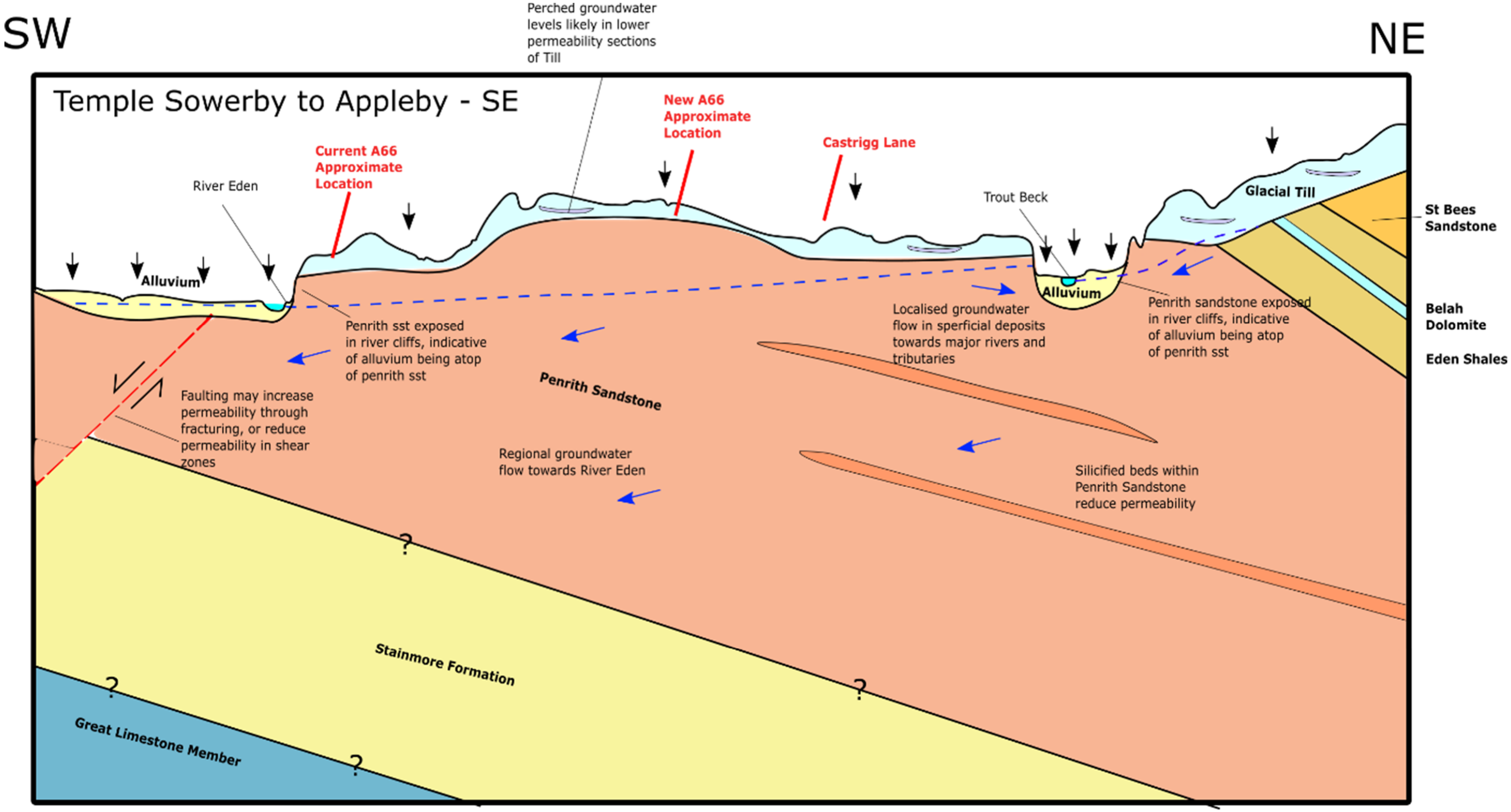

Plate 18: Hydrogeological Conceptual Model in Temple Sowerby to Appleby Project study area (southeast area)

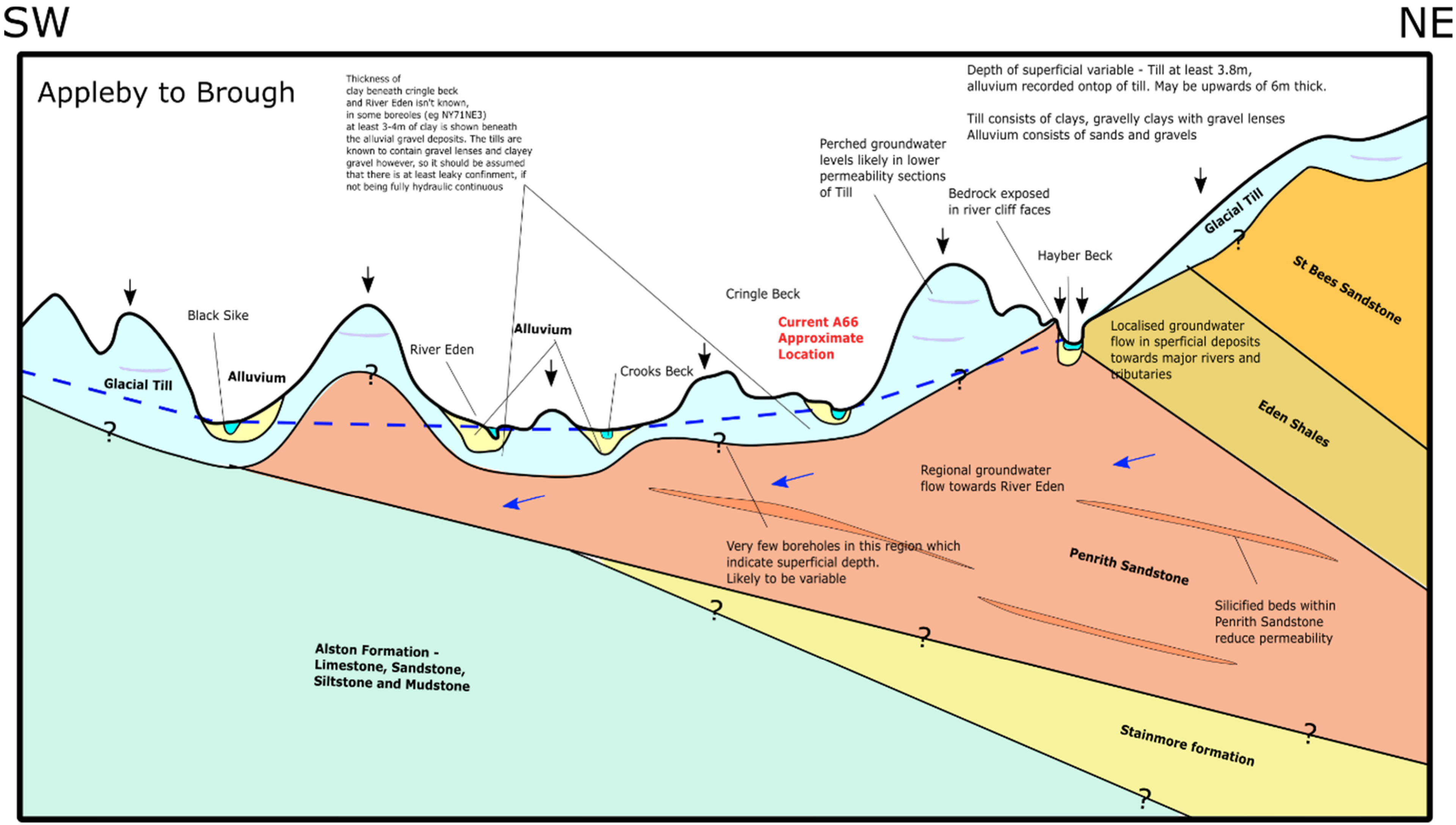

Plate 19: Hydrogeological Conceptual Model in Appleby to Brough Project study area

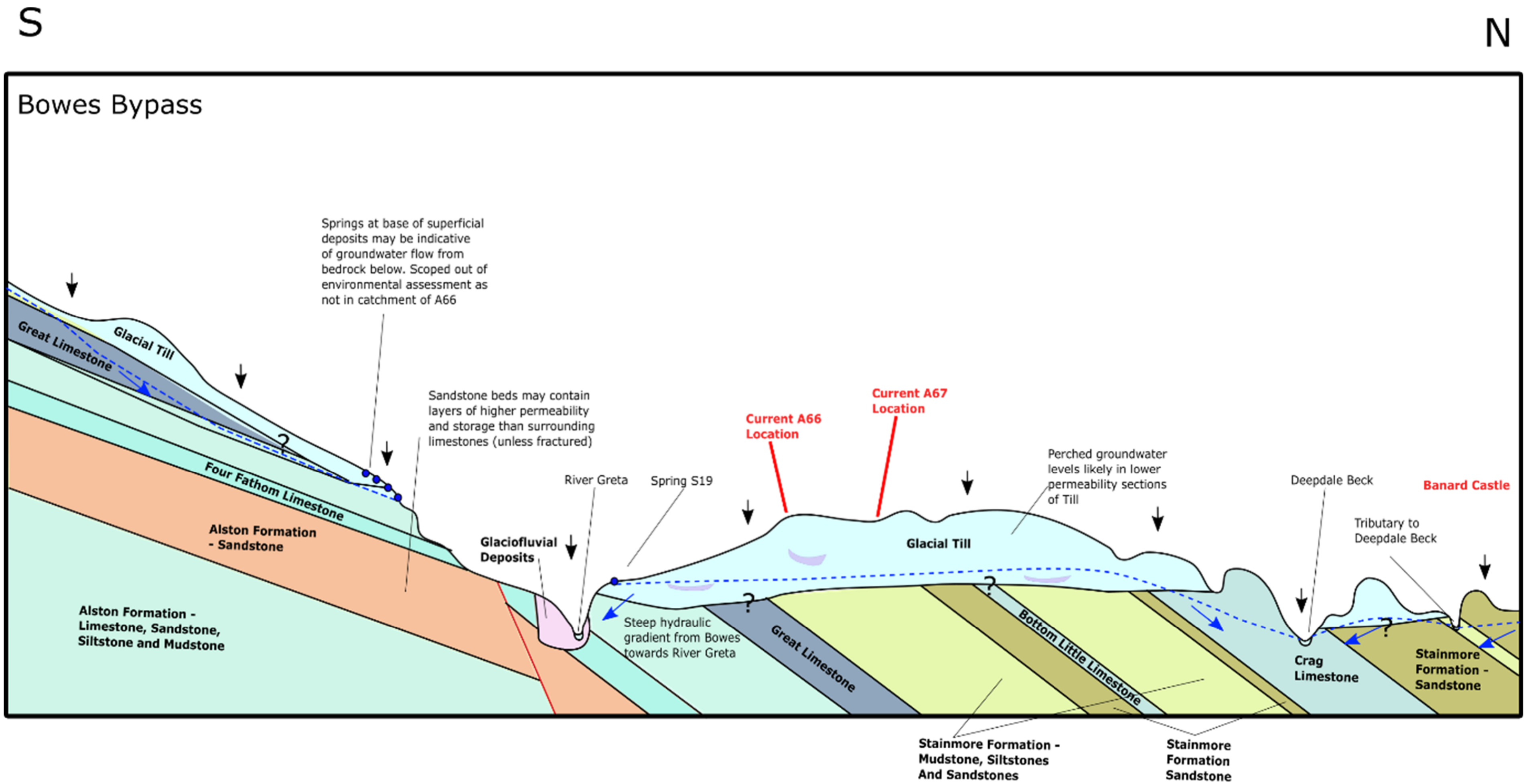

Plate 20: Hydrogeological Conceptual Model in Bowes Bypass Project study area

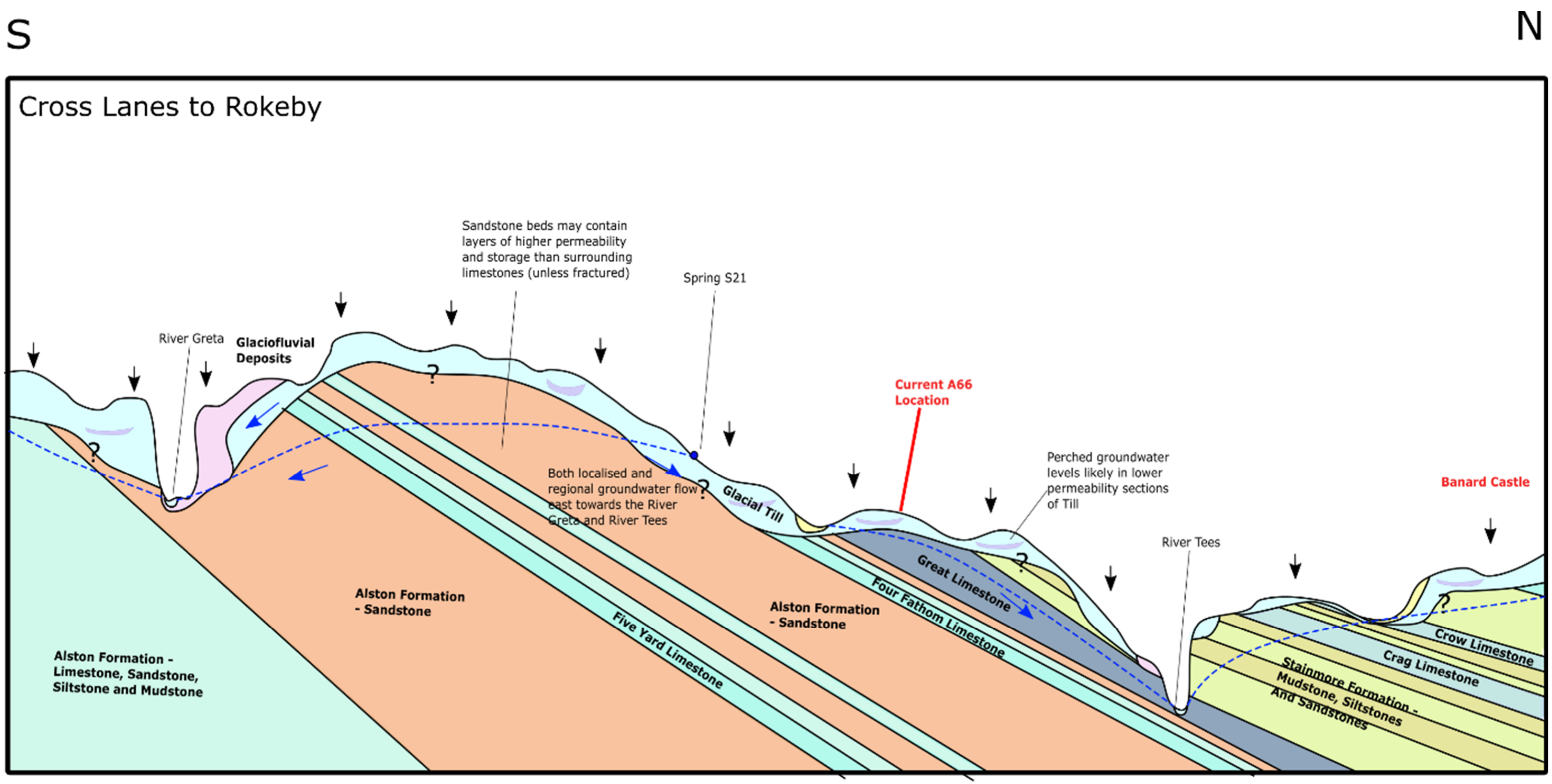

Plate 21: Hydrogeological Conceptual Model in Cross Lanes to Rokeby Project study area

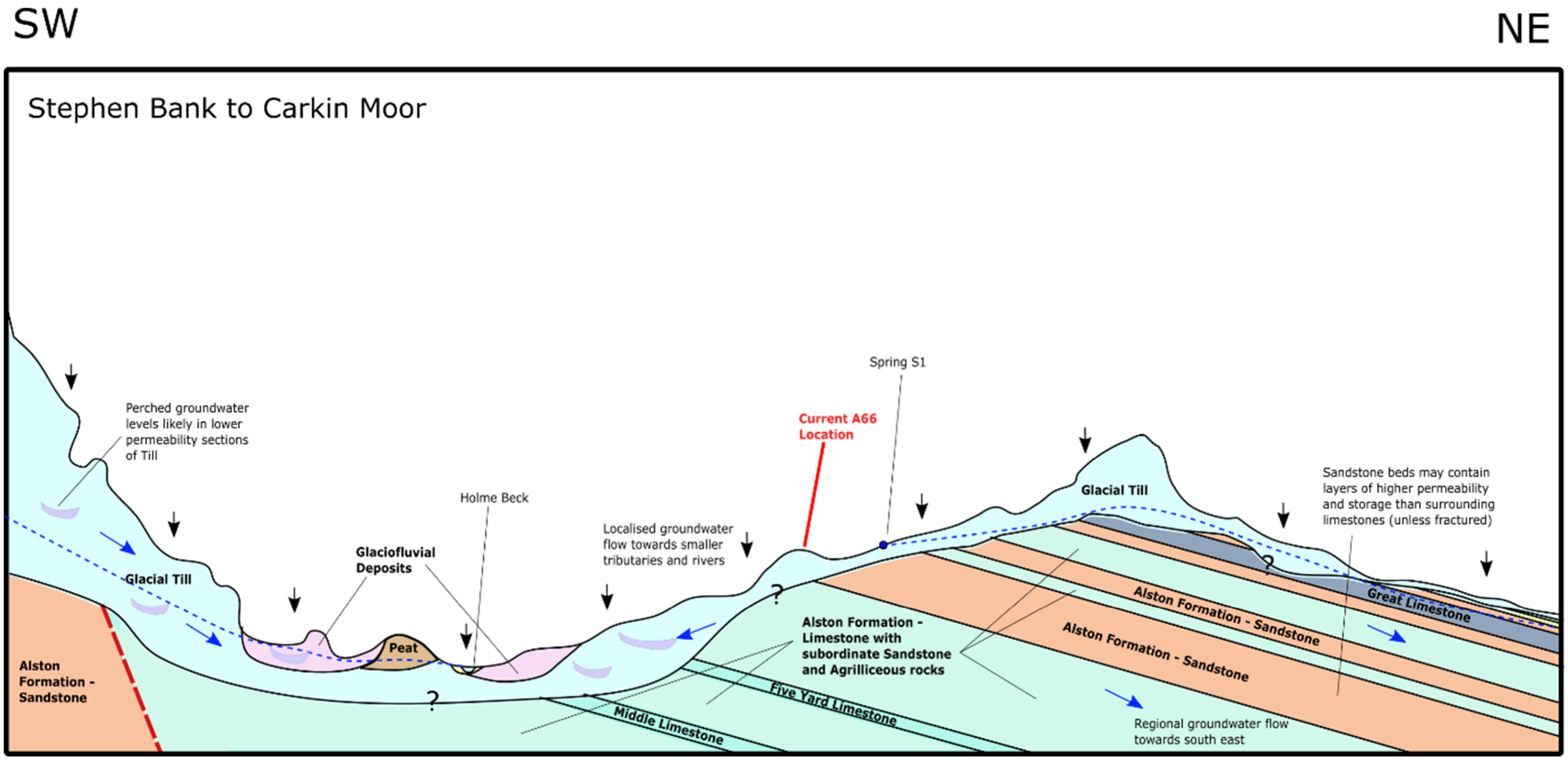

Plate 22: Hydrogeological Conceptual Model in Stephen Bank to Carkin Moor Project study area