A57 Link Roads

TR010034

9.43 Environmental Statement Appendix 13.2 Hydrogeology Risk Assessment

Rule 8(1)(k)

Planning Act 2008

Infrastructure Planning (Examination Procedure) Rules 2010

January 2022

Infrastructure Planning

Planning Act 2008

The Infrastructure Planning (Examination Procedure) Rules 2010

A57 Link Roads

Development Consent Order 202[x]

9.43 Environmental Statement
Appendix 13.2 Hydrogeology Risk Assessment

Rule Number:	Rule 8(1)(k)
Planning Inspectorate Scheme Reference	TR010034
Application Document Reference	TR010034/EXAM/9.43
Author:	A57 Link Roads Project Team, National Highways

Version	**Date**	**Status of Version**
1.0	January 2022	Deadline 3

Table of Contents

1. Introduction

1.1. Scope

1.1.1. This document assesses the potential impacts on surface and groundwater receptors, and in terms of flood risk, relating to changes in the groundwater environment as a result of the construction of the A57 Link Roads (hereinafter referred to as 'the Scheme'). The Scheme is a Nationally Significant Infrastructure Project (NSIP) and this Hydrogeological Risk Assessment has been developed in support of National Highways' application for a Development Consent Order (DCO) to authorise construction, operation and maintenance of the Scheme.

1.1.2. At the point of Development Consent Order (DCO) submission to the Planning Inspectorate (scheme reference TR10034, June 2021) additional ground investigation was ongoing. This document presents an updated groundwater conceptual model that accounts for the additional information gathered during the 2021 ground investigation. It also presents the results of three-dimensional groundwater modelling informed by this updated conceptual understanding which has been used to assess potential long-term impacts of the Scheme on the groundwater environment. In accordance with a commitment made in Chapter 13 Road drainage and the water environment of the Environmental Statement (ES) (APP-069) for the Scheme, this appendix has been prepared as a new submission document after the DCO application was made, to support the examination process.

1.1.3. The scope of this document is to:

- summarise the conceptual understanding of the groundwater system based on a review of historical ground investigations and recent additional data gathered in 2021. The updated conceptual model is presented in Section 2.
- summarise the approach to groundwater modelling used to represent the groundwater system, and the scenario implemented to simulate the changes on the groundwater environment as a result of the Scheme. The groundwater modelling approach is presented in Section 3.
- assess potential long-term impacts to groundwater and surface water receptors that may be caused by the operational phase of the Scheme based on the results of the groundwater modelling. This Hydrogeological Risk Assessment is presented in Section 4.

1.1.4. Potential impacts relating to groundwater have been identified and, in some cases assessed, elsewhere in the submission, namely in the following which are referenced throughout this document:

- ES Chapter 13 – Road Drainage and the Water Environment (APP-069).
- Water Framework Directive (WFD) Assessment Compliance Report (APP-055)
- Flood Risk Assessment (FRA) (APP-056)
- ES Appendix 13.1 - Water Environment Data and Assessments (APP-178)

1.1.5. All potential impacts relating to groundwater, during construction and operation, are summarised in Table 1.1~~Table 1.1~~. Where an impact has been assessed sufficiently elsewhere in the submission it is identified in the table and is not re-assessed herein. This document focuses on the long-term impacts that could only be assessed through additional work –either the additional ground investigation and updated conceptual model described in Section 2 of this document, or the groundwater modelling described in Sections 3 and 4.

1.1.6. This document does not assess potential temporary impacts from dewatering during construction. These impacts will be assessed during detailed design as part of the permitting process for construction dewatering once the temporary dewatering design is available. Mitigation measures would be included in the Construction Water Management Plan.

1.1.7. The impact assessment presented in Section 4 has been carried out in accordance with Environment Agency guidance for hydrogeological impact assessment[1]. The relevant chapters of the ES have been updated based on this impact assessment.

1.1.8. Throughout this document references are made to the following key features of the Scheme that have the greatest potential to impact the groundwater environment:

- Mottram Underpass (works 32 and 33) – a new two-cell reinforced concrete underpass carrying the carriageway mainline beneath Roe Cross Road, Old Road and the community of Mottram. The top of the underpass would be 2 m below ground level.
- Eastern cutting (works 5 and 6) - earthworks associated with the rock cutting to the east of Mottram Underpass which is cut into Millstone Grit.

1.1.9. The work numbers listed above refer to the Work Plan and Work Plans Schedule (APP-008).

Table 1.1: Potential impacts to groundwater associated with the Scheme

Phase	Potential impact	Document in which impact is assessed	Assessed significance	Further assessment
Construction	Accidental release of untreated run-off being discharged to aquifer.	• WFD Assessment Compliance Report • ES Chapter 13: Road Drainage and the Water Environment	Slight adverse	None
	Accidental release of contaminants (oils/fuels) to surface water and infiltration to groundwater.	• ES Chapter 13: Road Drainage and the Water Environment	Slight adverse	None

[1] Environment Agency. 2007. Hydrogeological impact appraisal for dewatering abstractions. Science Report – SC040020/SR1.

Phase	Potential impact	Document in which impact is assessed	Assessed significance	Further assessment
	Temporary dewatering causing drawdown which may impact baseflow contributions to surface water courses and local groundwater abstractions.	• WFD Assessment Compliance Report • ES Chapter 13: Road Drainage and the Water Environment	Slight adverse. No measurable WFD impact on regional water body.	During permitting for temporary dewatering works.
	Discharge of abstracted groundwater to surface water bodies may impact surface water quality.	• WFD Assessment Compliance Report • ES Chapter 13: Road Drainage and the Water Environment	Slight adverse. No measurable WFD impact on regional water body.	During permitting for temporary dewatering works.
	Installation of deep foundations mobilising contaminated run-off to depth within aquifer.	Subject to further assessment	N/A	Piling risk assessment
Operation	Deep foundations may act as barriers to groundwater and permanently alter groundwater flow pathways, this may have knock-on impacts on baseflow to surface water courses and local groundwater abstractions.	• WFD Assessment Compliance Report • ES Chapter 13: Road Drainage and the Water Environment • This document.	Slight adverse – reviewed within this document.	Yes – within this document
	Deep foundations may act as barriers to groundwater and result in increased groundwater levels, increasing groundwater flood risk.	• FRA • This document	Slight adverse – reviewed within this document	Yes – within this document
	Drainage of groundwater (passive dewatering) associated with cuttings may cause reduction of groundwater levels which could have impacts on baseflow	• WFD Assessment Compliance Report • This document	No measurable impact on regional groundwater body. No assessment of local impacts.	Yes – within this document

Phase	Potential impact	Document in which impact is assessed	Assessed significance	Further assessment
	to surface water courses and local groundwater abstractions.			
	Discharge of groundwater derived from long-term groundwater drainage to surface water bodies and potential impact on surface water quality.	Subject to further assessment	N/A	Yes – within this document Further assessment during permitting process at detailed design stage
	Potential for road run-off to enter groundwater bodies and impact groundwater quality.	• WFD Assessment Compliance Report • ES Appendix 13.1	Neutral	None
	Potential for spillages on the roadway to enter groundwater bodies and impact groundwater quality.	• ES Chapter 13: Road Drainage and the Water Environment • Appendix 13.1	Neutral	None
	Potential for permanent deep piled foundations to create a vertical pathway into the groundwater body for contaminated run-off.	Subject to further assessment	N/A	Piling risk assessment

1.2. Previous work

1.2.1. Several phases of groundwater assessment have been carried out based on historical ground investigation information and previous road alignments. The following documents have been reviewed and pertinent information included as part of this assessment:

- Ground Investigation Report[2] and Factual Report[3] from the 2018 ground investigation.
- 2017 Arcadis Groundwater Modelling Report[4]

[2] Highways England, 2018. Trans-Pennine Upgrade, 7.6 Ground Investigation Report. TR010034/APP/7.6
[3] Socotec, 2018. A57/A628 Trans Pennine Upgrade Programme, Factual Report on Ground Investigation, Report No A8001-18.
[4] Arcadis, 2017. Detailed groundwater flow modelling for Mottram tunnel. CDF lot 1 pc 1004 – AS14 Phase 2 – Options Selection – North West.

- 2007 Hyder Consulting Reports[5],[6]
- 2006 Carillion and Hyder Consulting Report[7]
- 2005 Mott MacDonald Report[8].
- 1995 Soil Mechanics Report[9].

1.2.2. Additional ground investigation was undertaken between February and July 2021 to fill data gaps and has been used to inform the conceptual model presented here. The reporting for these supplementary surveys will be submitted as a new supporting document for the DCO during the examination once it is available, and before the examination is due to close in May 2022.

2. Hydrogeological conceptual model

2.1.1. This Section summarises the key components of the hydrogeological conceptual model. Conceptual drawings of the hydrogeological setting are shown in Insert 2.1 and Insert 2.2.

2.1.2. Reference to Chainages throughout this document have been made to indicate the location of some design features along the proposed route. These are measures, in metres, from the commencement of the Scheme at the M67 Junction 4 (chainage 0.000) to Woolley Bridge Junction (chainage 3167.604). Chainage values are shown on the Scheme General Arrangement (ES Figure 2.2, APP-074).

2.2. Geology

Bedrock

2.2.1. Detailed description of the geology along the Scheme is provided in the ES Geology and Soils (Chapter 9, APP-065). Only information relevant to the hydrogeological assessment has been presented here.

2.2.2. The bedrock which underlies the Scheme is the Carboniferous Millstone Grit Group. The Millstone Grit Group comprises interbedded siltstone, sandstone and mudstone, which generally dip to the south at between 5 and 15 degrees.

2.2.3. The region is characterised by a high degree of faulting in the bedrock, often offsetting sandstone and mudstone units against one another and creating a block-like sub-crop pattern. In the Mottram area, the presence of geological faulting has a significant effect on the groundwater regime (see section 2.3), and within the fault zone itself the Millstone Grit is recorded as dominated by clays – likely a combination of weathered mudstone and fault gouge.

[5] Hyder Consulting, 2007. A57/A628 Mottram Tintwistle Bypass and A628/A616 Route Restraint Measures. A Geotechnical Report on the Assessment of Potential Settlement due to Tunnel Construction. Report no. 7579-NH50845-GDR-02.

[6] Hyder Consulting, 2007. A57/A628 Mottram Tintwistle Bypass and A628/A616 Route Restraint Measures. Tunnel and Cutting Dewatering Impact Assessment. Report no. 0001-NH50845-DVR-01.

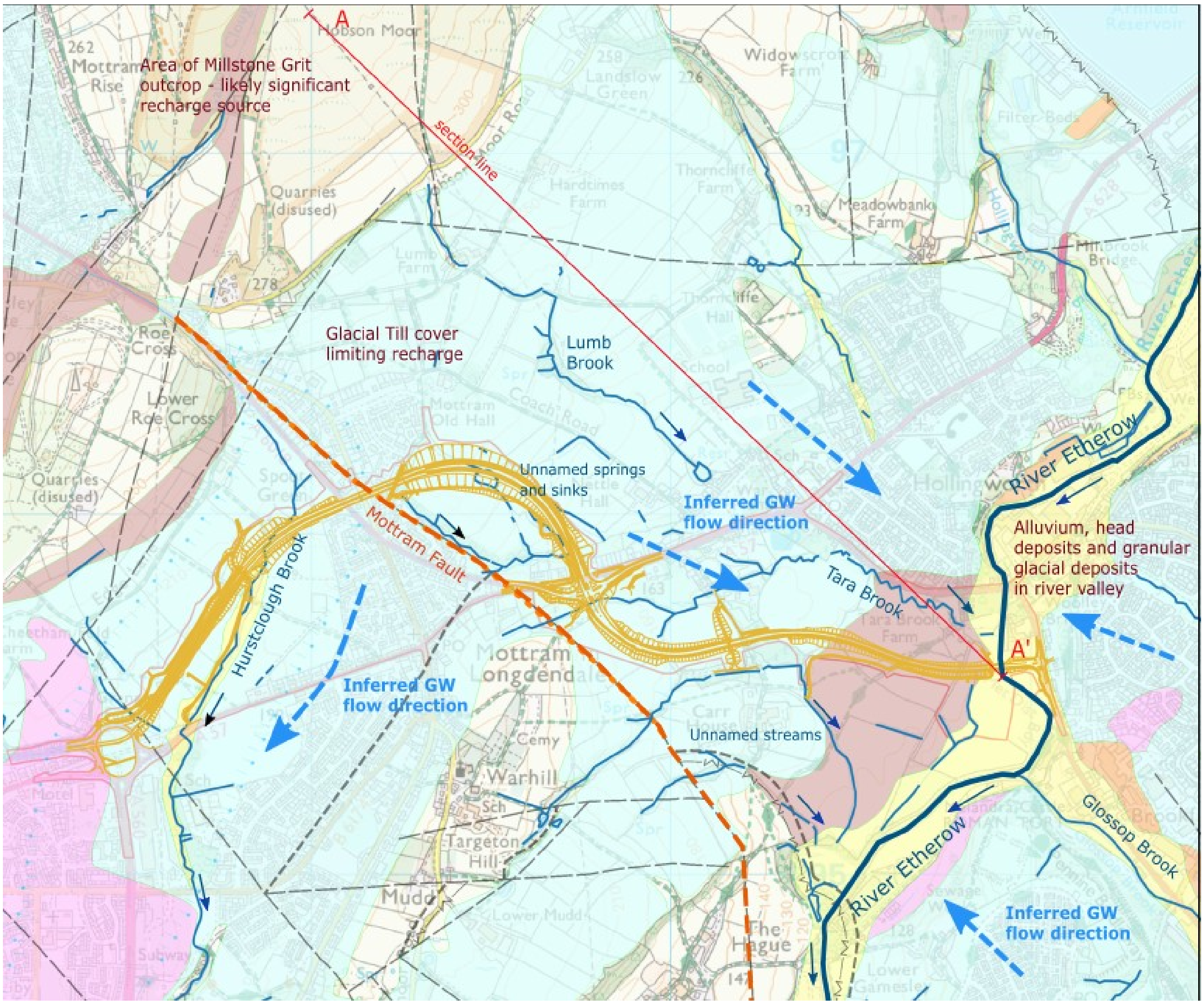
[7] Carillion and Hyder Consulting, 2006. A57/A628 Mottram – Tintwistle Bypass & A628/A616 Route Restraint Measures Private Groundwater Sources: Assessment of Mitigation Options. Report no. 7497-NH50845-NHR-01-F

[8] Mott MacDonald, 2005. A57/A628 Mottram Tintwistle Bypass and A628/A616 Route Restraint Measures. Geotechnical Interpretative Report, Ground Investigation 1 and 2, Volume 4: Annex A -Assessment of potential settlement due to dewatering during tunnel construction

[9] Soil Mechanics, 1995. A57/A628 Mottram to Tintwistle Bypass Ground Investigation Survey No 1, Report No 7925/1

2.2.4. The Millstone Grit Group is classified as a Secondary A aquifer, which is defined as permeable layers capable of supporting water supplies at a local rather than strategic scale[10], and in some cases forming an important source of baseflow to rivers. Groundwater flow in the Millstone Grit Group is dominated by fracture flow with a lesser component of intergranular flow through sandstone strata. As a result, permeability is greatest in the top portion of the aquifer and reduces with depth as fracture apertures and frequency reduce, and cementation increases. In the area of the Scheme, the Millstone Grit Group is several hundreds of metres thick[11], but studies elsewhere within the Millstone Grit group have shown that flow decreases with depth and likely becomes insignificant beneath 200 m[12].

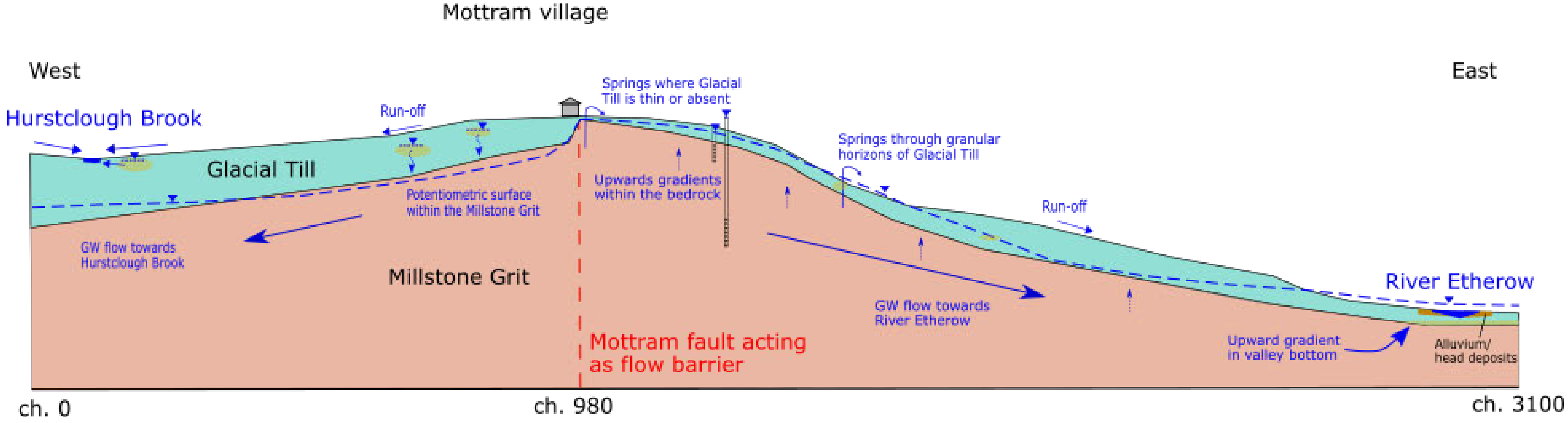
Insert 2.1: Hydrogeological conceptual model – plan view



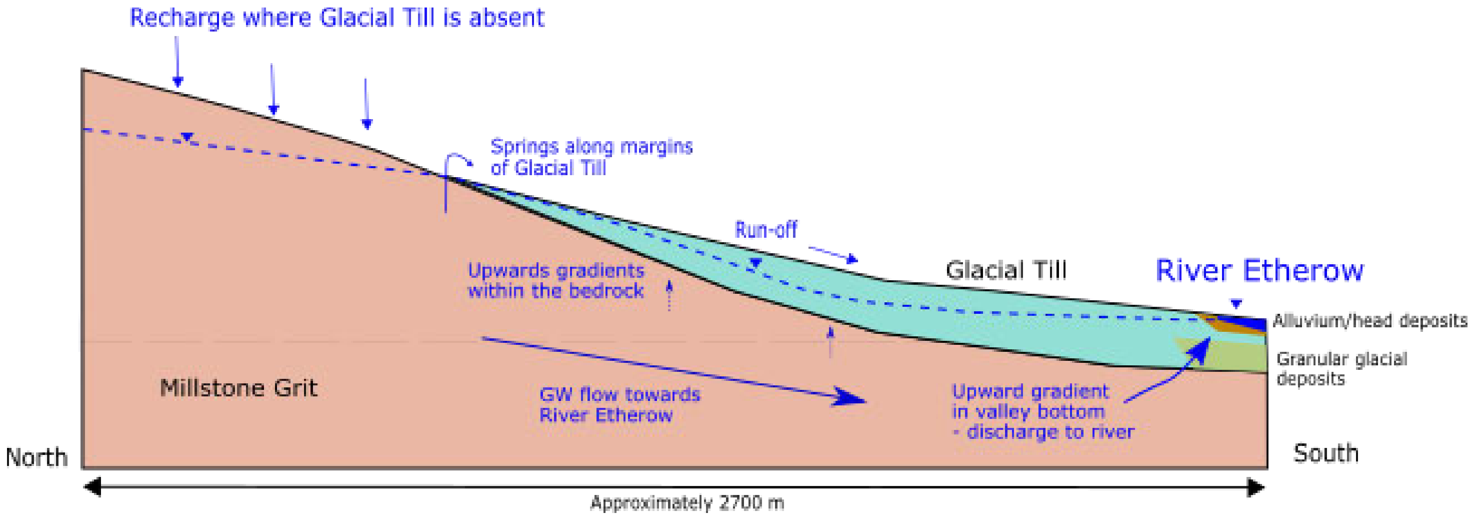
[10] Environment Agency, 2017. Protect groundwater and prevent groundwater pollution. Protect groundwater and prevent groundwater pollution - GOV.UK (www.gov.uk) [Accessed 01/09/2021].
[11] British Geological Survey. 2021 [redacted] [Accessed 01/09/21].
[12] British Geological Survey. 2000. The physical properties of minor aquifers in England and Wales. British Geological Survey Technical Report, WD/00/4. Environment Agency R&D Publication 68.

Insert 2.2: Hydrogeological conceptual cross-sections (not to scale)

A - Along road alignment



B – Along section A-A' in Insert 2.1



Superficial deposits

2.2.5. The Millstone Grit Group is overlain by Glacial Till across large parts of the Scheme. The Till is predominantly cohesive, dominated by variably sandy, variably gravelly clay, with occasional lenses of granular material. The Glacial Till is classified as a Secondary (undifferentiated) aquifer.

2.2.6. The thickness of the Till varies along the Scheme – in the far west of the Scheme to the west of the Mottram Underpass (ch. 0-800) the Till is >20 m thick, it thins to <1 m in some locations close to the eastern portal of the underpass, then thickens eastward to a maximum of 22.9 m at chainage 1795, south of Mottram Junction, before thinning once more towards the River Etherow.

2.2.7. Alluvium and Head Deposits are present in the far east of the Scheme around the River Etherow, overlying cohesive Glacial Till and then granular glacial deposits. The Alluvium and Head Deposits are dominated by cohesive material, <3 m thick. The underlying granular material is dominated by sands and gravels, and is up to 3.5 m thick.

2.3. Groundwater flow

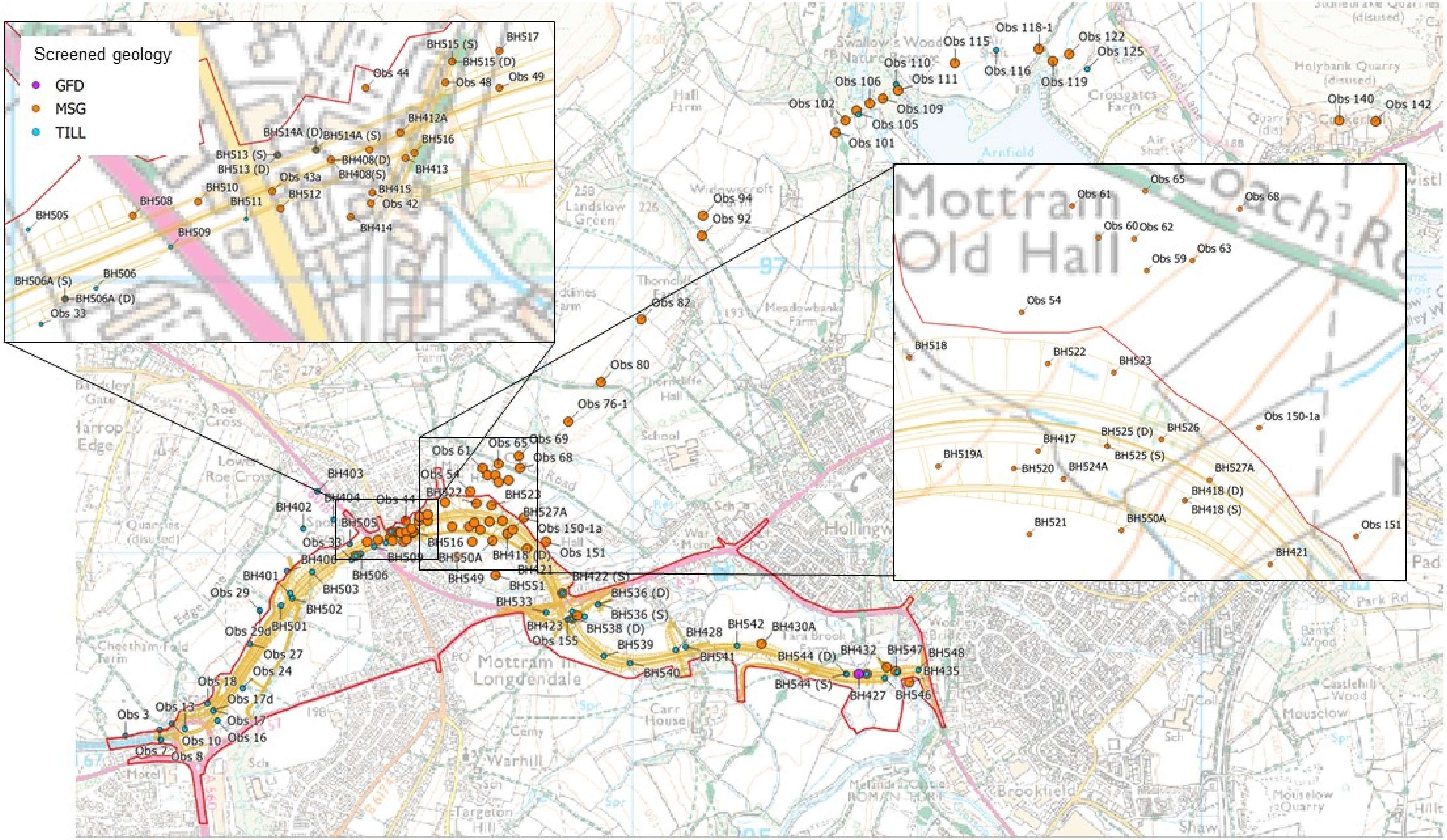
2.3.1. Several phases of groundwater data collection have been reviewed to inform this section – including groundwater level information from ground investigations in 2018 and 2021, and historical average monitoring data from 1994 to 2007[4] along a previous alignment. All available historical and recent groundwater monitoring locations are shown on Insert 2.3.

2.3.2. Inferred groundwater flow contours within the Millstone Grit, based on data collected during July 2021, are shown in Insert 2.4. In areas where no data are available from the 2021 monitoring locations, average water levels from the 2018 ground investigation have been used to infer the position of contours. Groundwater levels during the same monitoring visits in locations installed in the Glacial Till are shown on Insert 2.5 – inferred contours have not been drawn from these water levels as lateral connectivity within the Glacial Till is likely to be limited due to its low permeability. Observed average groundwater levels from the historical groundwater record (1994 to 2007) are shown in Insert 2.6.

2.3.3. All available groundwater level data is based on manual dip measurements. The 2018 and 2021 datasets only include dip measurements recorded in the spring-summer of these years. The historical monitoring data covers the period 1994-2007 and at most locations, measurements were taken throughout the year and therefore represent long term average including for seasonal variation.

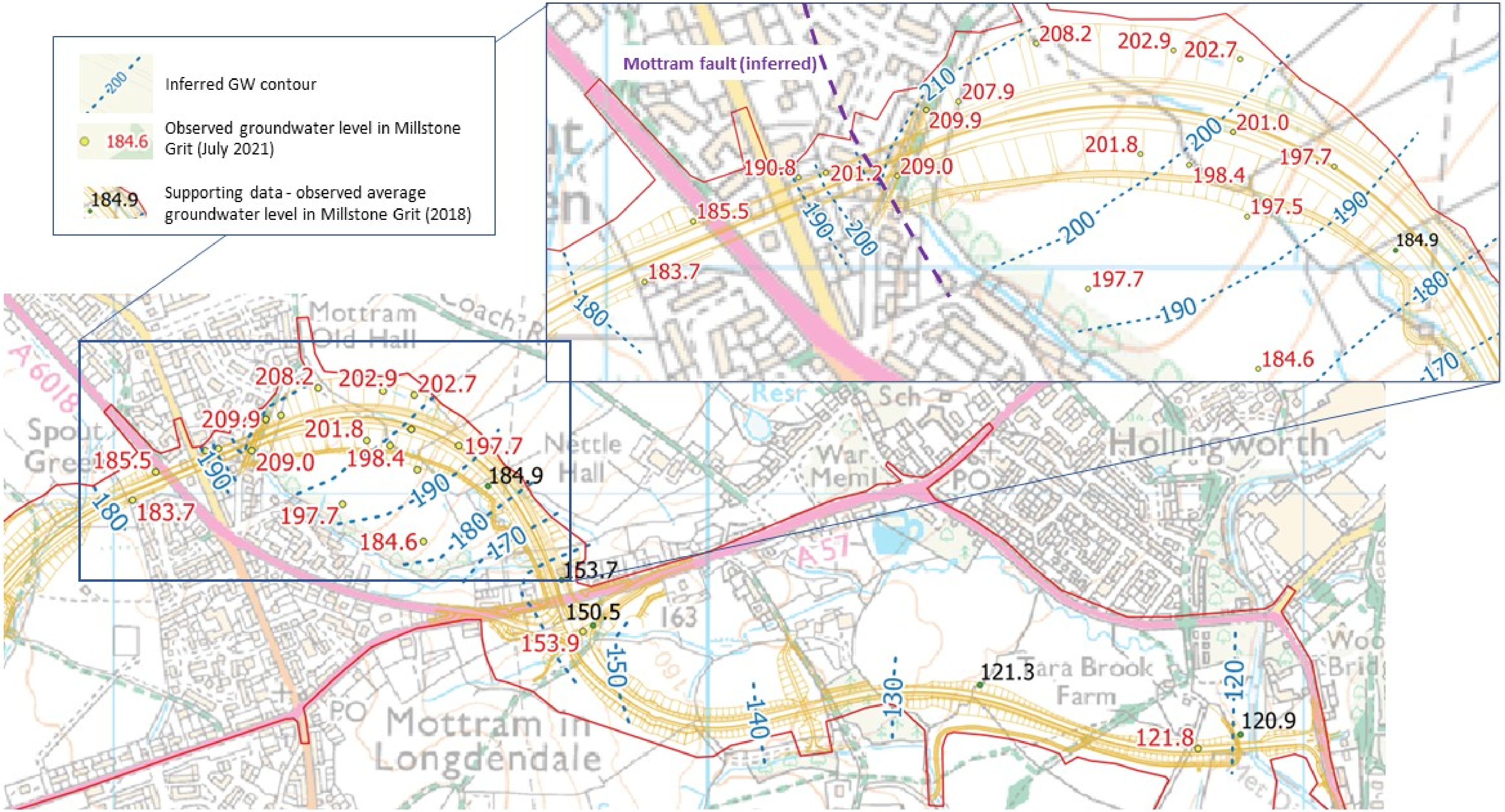
2.3.4. Overall groundwater flow along the route is towards the River Etherow. There is a flow divide in the vicinity of Old Hall Lane, associated with the Mottram fault zone and groundwater flow to the west of Old Hall Lane is to the south-west, towards Hurstclough Brook, while flow to the east of Old Hall Lane is to the south-east towards the River Etherow (Insert 2.1).

Insert 2.3: All historical and recent monitoring well locations from 2018 and 2021 ground investigations



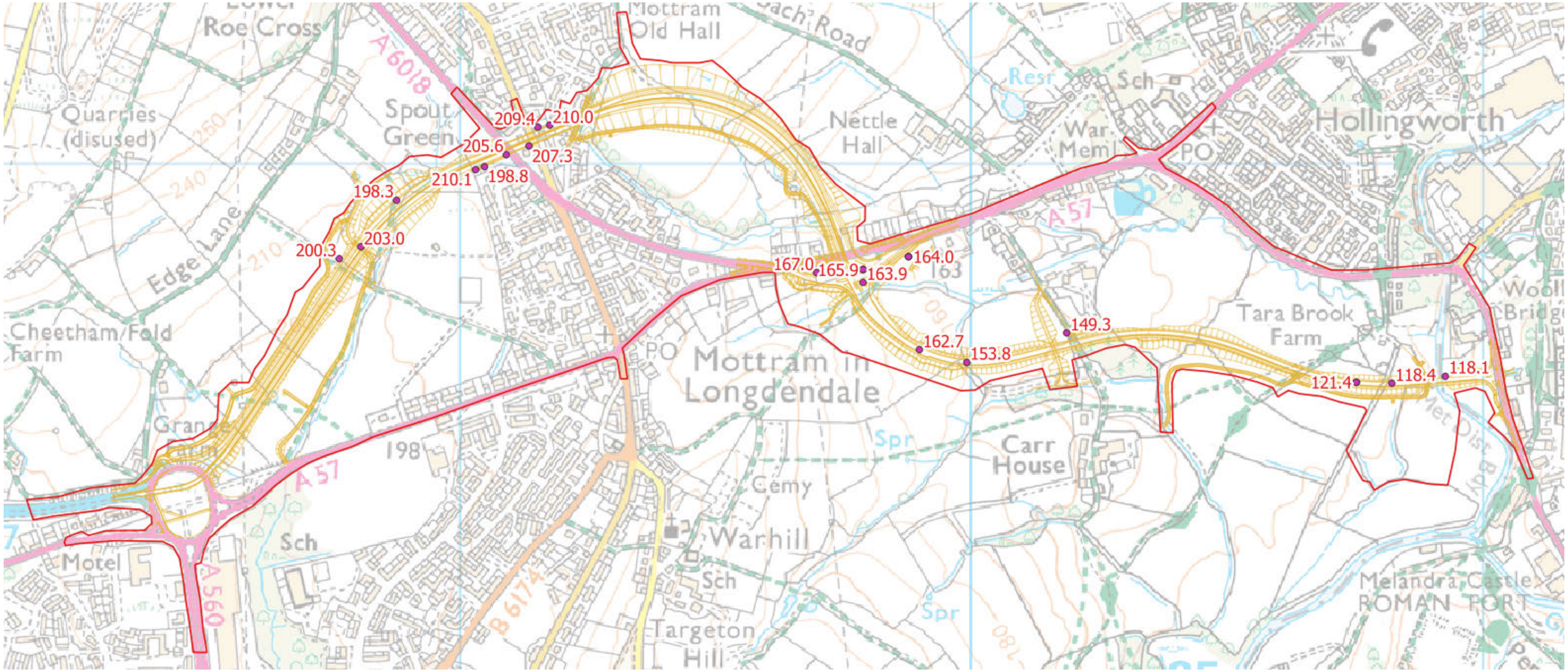
Contains Ordnance Survey data © Crown copyright 2021.

Insert 2.4: Inferred groundwater contours (m AOD) in Millstone Grit bedrock along the Scheme based on groundwater data collected during July 2021 with supporting data to fill data gaps from 2018



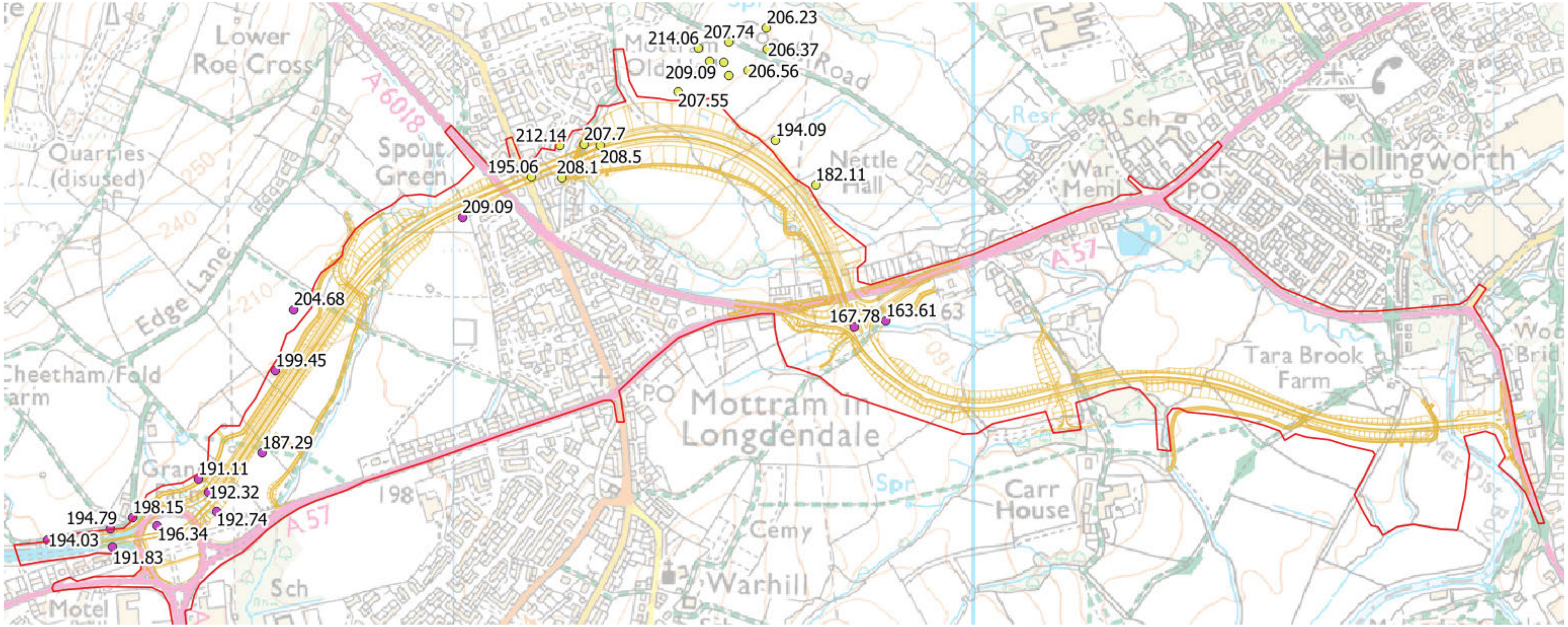
Contains Ordnance Survey data © Crown copyright 2021.

Insert 2.5: Observed groundwater levels (m AOD) in Glacial Till in July 2021



Contains Ordnance Survey data © Crown copyright 2021.

Insert 2.6: Average observed groundwater level 1994-2007 (Glacial Till in pink, Millstone Grit in yellow)



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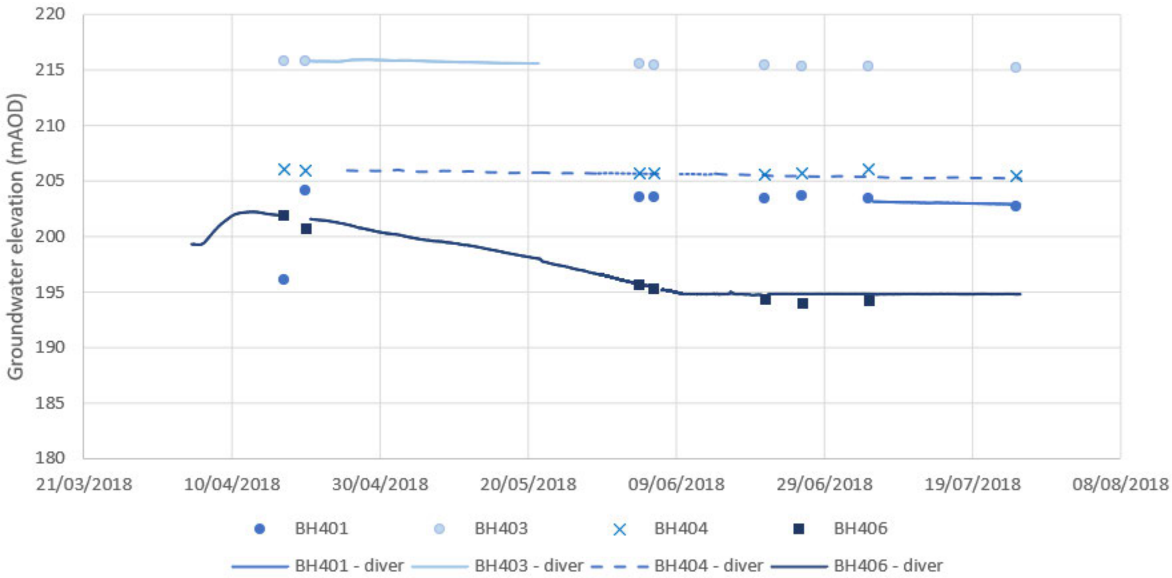
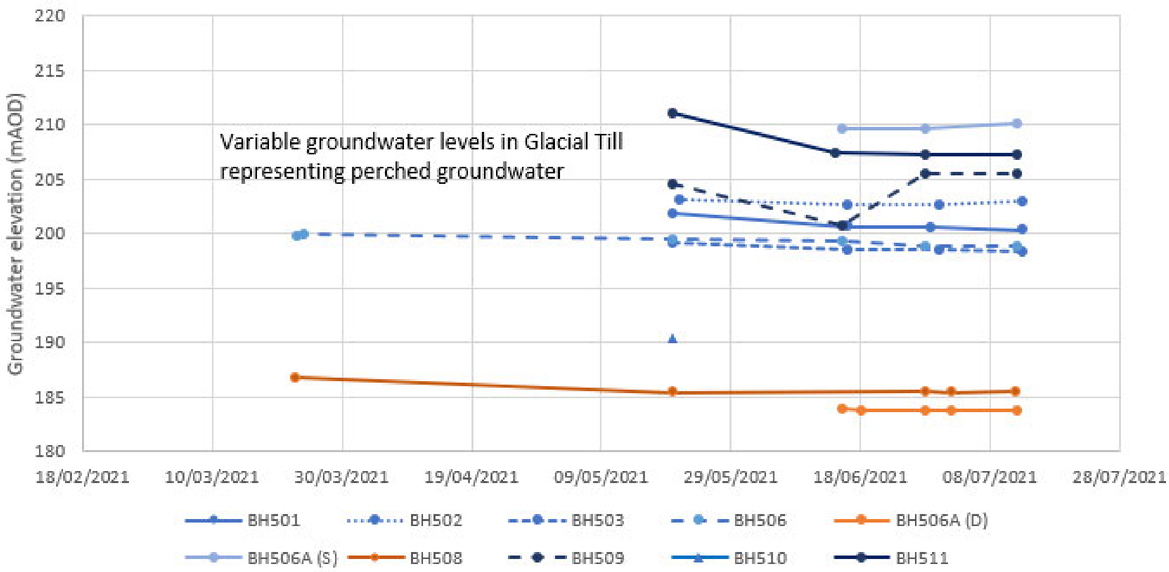
West of Mottram fault (west of Old Road (ch. 0 - 980))

2.3.5. Along the Scheme to the west of the Mottram fault, groundwater levels within the Millstone Grit are below rockhead, therefore any groundwater in the overlying Glacial Till is likely to be perched lenses. These lenses may have lateral connectivity to some degree, and connectivity with Hurstclough Brook, as well as providing limited recharge to the underlying Millstone Grit. Groundwater within the Millstone Grit is unlikely to have any connectivity with the Brook at this location due to the thickness of overlying Till.

Insert 2.7: Observed water levels west of Mottram fault from 2018 and 2021 ground investigations





2.3.6. Groundwater levels and inferred flow direction within the Millstone Grit imply that groundwater is likely discharging to the Hurstclough Brook in its lower reaches down gradient from, and to the south of, the Scheme. Groundwater levels in this area are approximately 15 m lower than those in equivalent strata to the east of the fault zone. This is likely due to the fault zone having a relatively low permeability and limiting flow from the east, an area ultimately receiving recharge from the north of the Scheme (around Hollingworthall Moor and Hobson Moor).

2.3.7. Groundwater levels to the west of the Mottram fault during the 2018 and 2021 ground investigations are shown in Insert 2.7. Boreholes installed in Glacial Till are shown in blue, and those installed in Millstone Grit shown in orange.

Mottram fault (between Old Road and Old Hall Lane (ch. 980 - 1040))

2.3.8. The Mottram fault zone was identified during ground investigation works as an area of tectonic deformation between chainage 980 and 1040. Groundwater elevation contours on Insert 2.4: Inferred groundwater contours (m AOD) in Millstone Grit bedrock along the Scheme based on groundwater data collected during July 2021 with supporting data to fill data gaps from 2018~~Insert 2.4: Inferred groundwater contours (m AOD) in Millstone Grit bedrock along the Scheme based on groundwater data collected during July 2021 with supporting data to fill data gaps from 2018~~ imply that the fault coincides with a flow divide running parallel to (and to the east of) Old Road as shown on Insert 2.1. There are several lines of evidence that demonstrate that the Mottram fault acts as a barrier to groundwater flow:

- Piezometric levels within the Millstone Grit were recorded as approximately 15 m lower on the western side of the fault zone compared to the east during the 2021 ground investigation, even when comparing boreholes with screen depths at similar elevations. For example, BH508 and BH516 are both installed at approximately 185-189 m AOD. During the July monitoring round, water levels within BH508 were at 185.51 m AOD, compared to BH516 where water levels were at 209.01 m AOD. To create such a steep hydraulic gradient across the fault zone, the permeability within the Millstone Grit across the fault in the west-east direction must be extremely low.
- The Glacial Till is much thicker on the west side of the fault zone than on the east, as shown on Insert 2.2A. This means that moving from east to west, the more permeable sandstones, siltstone and mudstones of the Millstone Grit are juxtaposed against lower-permeability clay within the Glacial Till, which will in turn drive groundwater south-east, along the fault, rather than across it, at shallow depths.
- The pumping test in 2018 was carried out in BH414, installed within the Millstone Grit to 30.5 m below ground level on the eastern edge of the fault zone. During this test no response was observed in monitoring wells to the west of the fault zone – instead drawdown propagated parallel to the fault zone, implying that there is very low connectivity across the fault in the Millstone Grit at this depth.

2.3.9. The Mottram fault terminates against a NE-SW trending fault to the north-west of the Scheme.

East of Mottram fault (between Old Hall Lane and north of Mottram Moor Road (ch. 1040 – 1700))

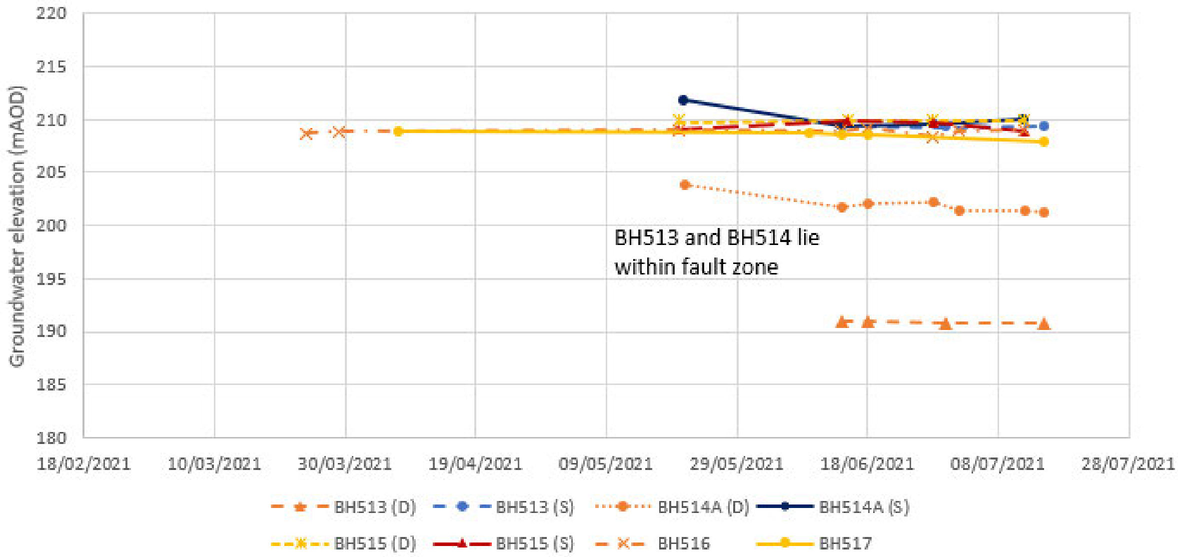
2.3.10. In this area the Glacial Till is variably 0.30 - 7.75 m thick and the Till confines groundwater within the underlying Millstone Grit. Piezometric heads within the Millstone Grit are above the top of the bedrock, generally at, or immediately below, ground surface. Groundwater levels fall to the south-east with the topography. Water levels within this area are shown on Insert 2.8 and Insert 2.9.

2.3.11. The Millstone Grit is also a self-confining aquifer, and piezometric levels have been observed to increase with depth into the aquifer, creating upward hydraulic gradients. Upward hydraulic gradients can be observed at BH515D&S and BH525D&S, as shown in Insert 2.10. Vertical gradients demonstrate that the Millstone Grit has a relatively low vertical hydraulic conductivity, likely as a result of mudstone and siltstone horizons.

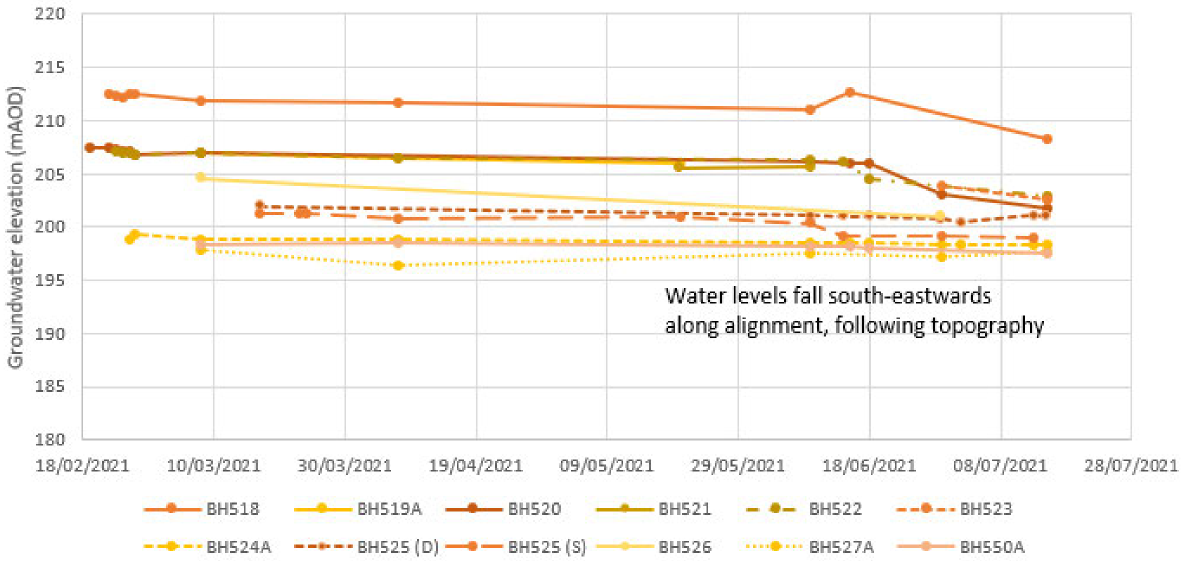
2.3.12. At some locations, piezometric groundwater levels were shown to be above ground level (artesian) during groundwater monitoring. This was observed in boreholes located in topographic depressions, where groundwater levels are similar to surrounding boreholes but are artesian due to a deviation in topography. Artesian conditions are also apparent in boreholes with the deepest screen sections, which intersect higher groundwater levels at depth. The observed vertical hydraulic gradients suggest that it is likely that elevated groundwater levels are present at depth throughout this area, but have only been identified as artesian at monitoring locations that penetrate to the greatest depth within the Millstone Grit aquifer.

2.3.13. High piezometric groundwater levels within the Millstone Grit are likely driven by recharge to the north of the Scheme where Millstone Grit outcrops around Hobson Moor and Hollingworthall Moor, combined with the presence of the Mottram fault, preventing flow to the west.

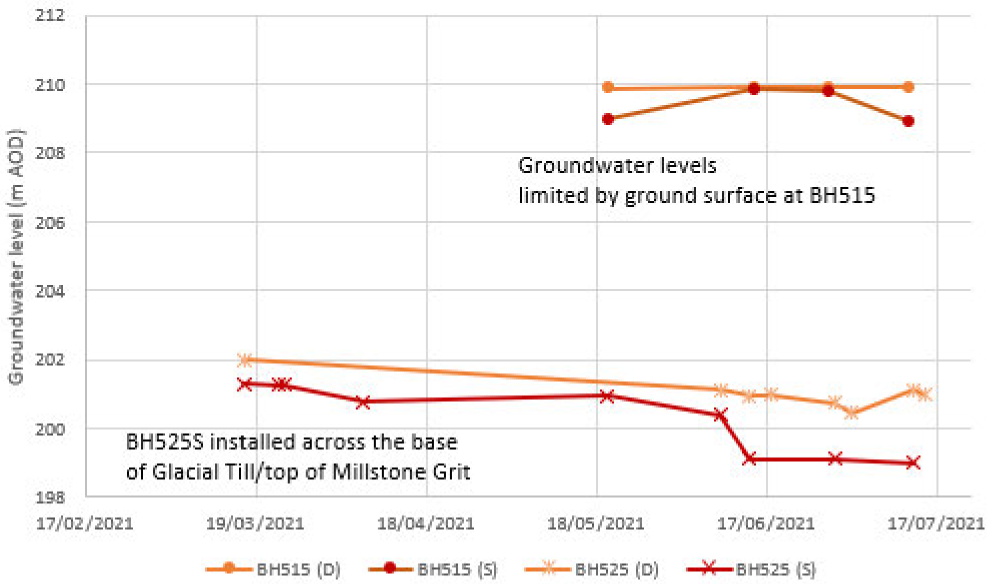
Insert 2.8: Observed water levels from 2021 within fault zone and immediately east of Mottram fault (chainage 980-1100)



Insert 2.9: Observed water levels from 2021 east of Mottram fault (chainage 1100-1510)



Insert 2.10: Water levels in dual installations from 2021 east of Mottram fault.



BH515S is installed 3 m shallower than BH515D; BH525S is installed 6.5 m shallower than BH525D.

Between Mottram Moor Road and Tara Brook Farm (ch. 1700 - 2800)

2.3.14. The majority of monitoring wells between chainages 1700 and 2800 are installed in the superficial deposits. Data from these wells show that groundwater in the superficial deposits flows towards the River Etherow (Insert 2.5) and water levels are generally within a few metres of ground level. Although horizontal flow within the Till is likely to be limited due to its low hydraulic conductivity, the overall gradient reflects the regional groundwater flow direction towards the River Etherow. Where Head Deposits and Alluvium are present, lateral permeability will likely be greater.

2.3.15. Limited groundwater monitoring data is available from the Millstone Grit between chainages 1700 and 2800. Groundwater levels were recorded during May-June 2018 from several vibrating wire piezometers installed at the top of the Millstone Grit bedrock in this area (shown in black on Insert 2.4). Measured groundwater levels at these locations are not artesian but approximately level with the top of the bedrock or just above (approximately 10-20 m bgl), and therefore >10 m below groundwater levels in the overlying Till, implying Till groundwater is perched. Groundwater levels that are well below ground level suggests a shallower hydraulic gradient in this area that may be attributed to increased hydraulic conductivity of the Millstone Grit or a loss of water. It is likely that there is some connectivity between groundwater and the United Utilities Mottram Longdendale Aqueduct, a major service which runs through this area and is thought to be a cut and cover tunnel into the top of the Millstone Grit where it crosses the Scheme.

Approaching River Etherow (ch. 2800 - 3116)

2.3.16. Several groundwater monitoring locations have been installed in the Millstone Grit close to the River Etherow. These locations show artesian piezometric levels in some cases of several metres above ground level, greatest in the locations with the deepest screen sections. Upward head gradients and artesian groundwater levels are common in valley bottoms in confined aquifers. Upward gradients will drive discharge of groundwater into the River Etherow through any granular lenses in the Till, Head Deposits and Alluvium (Insert 2.1 and Insert 2.2). Groundwater monitoring from granular layers at the base of the Till show that, where present, these layers are in connectivity with the underlying Millstone Grit aquifer and are also artesian. Groundwater levels within cohesive Till deposits are close to ground level.

2.4. Recharge

2.4.1. Recharge to the bedrock aquifer is likely to be predominantly through windows in the Glacial Till where Millstone Grit outcrops at surface (Insert 2.1). These windows are generally on high ground. For the Scheme, the most important recharge window is likely to be that at Hobson Moor and Hollingworthall Moor, to the north of the Mottram Underpass and eastern cutting.

2.4.2. Recharge through the Glacial Till itself is likely to be relatively low, due to the low permeability nature of the unit and its thickness. High runoff was observed on site in areas of Glacial Till cover during rainfall events.

2.5. Interaction with surface water

Sinks and springs

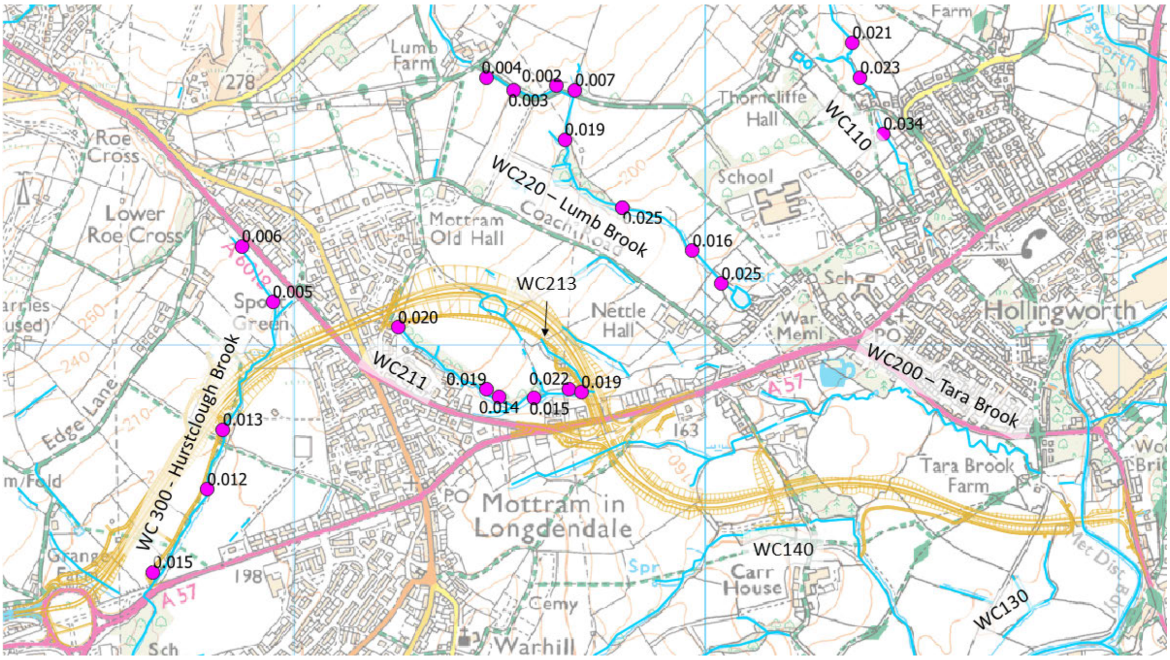
2.5.1. Many water sources and sinks are marked on Ordnance Survey mapping in the vicinity of the Scheme (see ES Chapter 13 (APP-069). Two watercourses (WC) in the vicinity of the Mottram Underpass and eastern cutting that have been observed to flow even during summer months, and are therefore likely to have a groundwater component, are WC_211 and WC_213 (see section 13.3 of ES Chapter 13, APP-069, for naming convention), these are shown on Insert 2.11.

2.5.2. WC_211 emerges immediately east of Old Hall Lane at 399250 396055. Hyder[5] attributed the flow in this watercourse to be dominated by surface water drainage from the Mottram area. Recent survey work by United Utilities confirmed that there was a connection. However, it emerges from within Millstone Grit immediately to the east of the fault zone, and has been observed to flow even during dry summer conditions so it is likely that groundwater baseflow contributes to this source. During the United Utilities survey the operatives noted that the water was unusually clear and that the pipework was in a poor state of repair of which would support the hypothesis of groundwater contribution to the source of this watercourse.

2.5.3. WC_213 emerges from a small pipe approximately 1.0 m below ground at 399602 396015. Monitoring of this location during July 2021 indicated it had seasonally low flows of approximately 0.05 l/s.

2.5.4. There are also several springs used as private water supplies in the area. The closest is at Mottram Old Hall, a spring used to feed a pond, which is approximately 75 m to the north of the red line boundary of the Scheme. This spring is likely to be where Glacial Till cover is either thin, or locally granular.

Insert 2.11: 2006 spot surface water monitoring data (m³/s)



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2.5.5. Available surface water monitoring data are limited to spot flow monitoring carried out in December 2006. Monitoring locations and measured flows are shown on Insert 2.11. As these data were recorded in winter they are likely to be peak flows, but no information is available about conditions during, or prior to, the collection of these measurements.

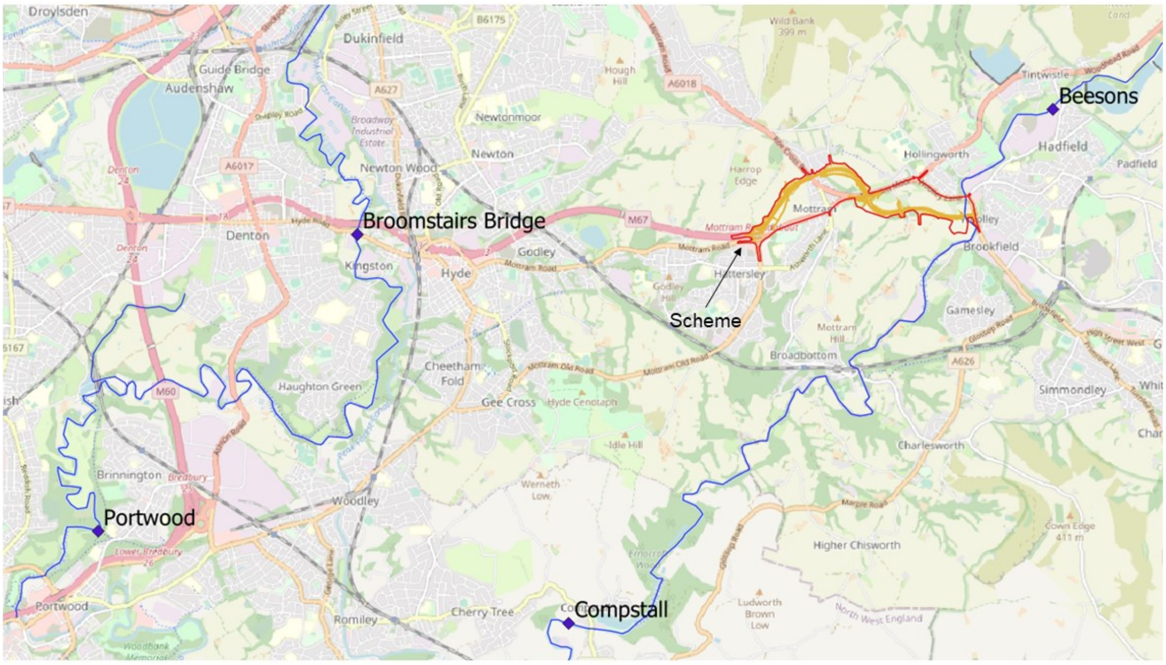
Contribution to river baseflow

2.5.6. Based on observed groundwater levels it is likely that groundwater from the Millstone Grit in the vicinity of the Scheme discharges to the River Etherow and the lower reaches of Hurstclough Brook (Insert 2.1).

2.5.7. Baseflow indices (BFI - the proportion of river flow derived from groundwater baseflow) were estimated for the Etherow using the Institute of Hydrology Low Flow method[13]. Flow data[14] was taken from Environment Agency weir gauges at Beesons waste site, upgradient of the Scheme at 401962 390763, and Compstall, down gradient of the Scheme at 396234 390763. In order to remove any influence on calculated baseflow from discharge associated with the reservoirs upstream of the Scheme, baseflow was calculated on a derived hydrograph of the difference in daily flow between the two gauges, i.e. the inflow into the Etherow between the gauges. Derived BFI for the period 2001 and 2020 were 0.37-0.54, with an average of 0.45. A BFI of 0.48 was derived for the Tame based on data from the Environment Agency gauge[15] at Broomstairs Bridge (393728 395360). These values align with previous work[4] which estimated BFI for the Tame and the Etherow of between 0.39 and 0.58.

2.5.8. Shallow, and perched groundwater within granular lenses of the Glacial Till may be connected to local water courses, for example in the upper reaches of the Hurstclough Brook. There will likely be a contribution to baseflow in smaller watercourses from the Millstone Grit via granular lenses in the Till in areas where the Millstone Grit is confined, but no continuous monitoring data are available to assess baseflow contributions to these watercourses.

Insert 2.12: Locations of Environment Agency river gauges



Contains Ordnance Survey data © Crown copyright 2021.

13 Institute of Hydrology, 1980. Low flow studies. Report No. 3 Catchment characteristic estimation manual.
14 Department for Environment Food and Rural Affairs, 2021. [redacted] [Accessed 01/09/2021].

2.6. Hydraulic parameters

Hydraulic conductivity – Millstone Grit Group

2.6.1. Hydraulic conductivity values for the Millstone Grit Group have been derived via small- and large-scale hydraulic testing across several phases of ground investigation. The range of derived values is summarised in Table 2.1.

2.6.2. During 2018, a pumping test was carried out at BH414, on the eastern edge of the Mottram fault zone. Although hydraulic parameters were derived from this test, there were problems with pump failure and difficulties maintaining flow rates, which may have affected the validity of the derived values. An analysable response was also only observed in three monitoring wells, so the derived values are based on limited data.

2.6.3. An additional pumping test was carried out in 2021 to verify derived hydraulic parameters. This test was successful and produced typical Theis curve confined responses in multiple monitoring wells for analysis, as well as recovery analysis at the abstraction well.

2.6.4. The 2018 test of BH414 demonstrated that there was limited hydraulic connectivity across the Mottram fault zone – no response was seen in nearby monitoring wells on the other side of the fault zone during pumping. The values quoted in Table 2.1 are from monitoring wells parallel to the fault zone.

Table 2.1: Derived hydraulic conductivity in the Millstone Grit Group

Data source	Hydraulic conductivity (m/s)	Transmissivity (m^2/d)
Historical (pre-2018) packer and rising head tests, and 2018 packer and variable head tests[2]	Min: 4.6×10^{-10} (4×10^{-5} m/d) Max: 5.5×10^{-5} (4.75 m/d) Geomean: 1.6×10^{-6} (0.14 m/d)	-
2021 GI – falling and rising head tests	Min: 2.4×10^{-9} (2×10^{-4} m/d) Max: 3.6×10^{-6} (0.31 m/d) Geomean: 1.6×10^{-7} (0.01 m/d)	-
2018 GI[2] – pumping test*	Min: 2.3×10^{-7} (2×10^{-4} m/d) Max: 7.2×10^{-5} (6.22 m/d) Geomean: 1.6×10^{-7} (0.01 m/d)	Not provided
2021 GI – pumping test**	Min: 1.3×10^{-6} (0.11 m/d) Max: 3.8×10^{-6} (0.33 m/d) Geomean: 2.4×10^{-6} (0.21 m/d)	Min: 3.3 Max: 9.9 Geomean: 6.3

*Derived K values were based on the assumption that aquifer thickness was equivalent to screen length
** Derived K values from 2021 were based on the assumption of a 30 m thickness of tested aquifer – based on screen lengths across the pumping and observation well and the l kelihood of limited vertical connectivity.

2.6.5. Literature values[11] for transmissivity in the Millstone Grit are in the range 0.6 m^2/d – 1059 m^2/d, with a geometric mean of 25 m^2/d – the derived values from the 2021 pumping test are within the lower end of this range.

2.6.6. It is likely that vertical hydraulic conductivity is lower than horizontal hydraulic conductivity within the Millstone Grit Group, due to the presence of low permeability siltstone and mudstone strata. The results of hydraulic testing is likely to reflect horizontal hydraulic conductivity, and therefore vertical hydraulic conductivity will likely be lower than the values presented in Table 2.1.

Hydraulic conductivity – Glacial Till

2.6.7. Hydraulic conductivities for the Glacial Till have been derived by small-scale in-situ hydraulic testing and particle size distribution analysis across several phases of ground investigation. The range of derived values is summarised in Table 2.2.

Table 2.2: Derived hydraulic conductivity in the Glacial Till

Data source	Hydraulic conductivity (m/s)	
Historical (pre-2018) rising and falling head test[4]	Min: 2.5×10^{-10} Max: 2.2×10^{-7} Geomean: 2.6×10^{-8}	(2.1×10^{-5} m/d) (0.019 m/d) (0.002 m/d)
2018 – rising and falling head tests[4]	Min: 1.0×10^{-11} Max: 5.7×10^{-8} Geomean: 1.5×10^{-9}	(8.6×10^{-7} m/d) (4.9×10^{-3} m/d) (1.3×10^{-4} m/d)
2018 – particle size distribution analysis[4]	Min: 9.8×10^{-11} Max: 5.9×10^{-6} Geomean: 3.2×10^{-8}	(8.5×10^{-6} m/d) (0.51 m/d) (2.8×10^{-3} m/d)

Hydraulic conductivity – other superficial deposits

2.6.8. Samples of Glaciofluvial Deposits were tested via particle size distribution analysis during the 2018 GI. The range of derived hydraulic conductivity values were between 4.3×10^{-6} and 6.9×10^{-4} m/s, with a geometric mean of 7.0×10^{-5} m/s.

2.6.9. No permeability testing of Alluvium or Head Deposits has been carried out during the phases of investigation. Where recorded, Alluvium and Head Deposits are described as variably sandy, variably gravelly clay. Based on literature, hydraulic conductivities are likely to be of the order of 10^{-9} - 10^{-6} m/s[15].

2.6.10. Glaciofluvial Deposits and River Terrace Deposits are are mapped adjacent to the Scheme area along the River Tame and River Etherow. Literature values for hydraulic conductivity suggests it is likely to be in the order of 10^{-5} - 10^{-2} m/s[13].

Storage

2.6.11. Limited storage data are available for the Millstone Grit from the pumping tests carried out in 2018 and 2021. These are summarised in Table 2.3. Only storativity and not specific yield was derived during the 2021 pumping test as water levels within the observation boreholes did not drop below rockhead.

2.6.12. The Minor Aquifer Properties Manual[3] lists three records for storage coefficients for the Millstone Grit in the range 0.013 to 0.0001. The maximum represents likely specific yield (1.3%) and the minimum, storativity.

[15] Fetter, 2001. Applied Hydrogeology – 4th ed. Prentice-Hall Inc. New Jersey.

Table 2.3: Derived storage coefficients for the Millstone Grit Group

Data source	Storativity (-)	S_Y (%)
2018 pumping test[4]	Min: 0.0002 Max: 0.0003	0.35
2021 pumping test[10]	Min: 0.00022 Max: 0.00164 Geomean: 0.00040	-

3. Groundwater modelling

3.1. Introduction

3.1.1. A 3D groundwater flow model has been developed based on the conceptual understanding presented in section 1. This model has been calibrated against observed data to simulate the baseline groundwater flow regime in the Scheme area prior to the Scheme development (the baseline model). Key elements of the Scheme that may impact groundwater have been implemented in the baseline model to generate a scenario model, which has been used to assess the long-term impacts of the Scheme on the water environment. This section describes the construction and calibration of this model, as well as the results of the scenario modelling.

3.2. Model setup

Model domain

3.2.1. Groundwater modelling was carried out using DHI FEFLOW 7.1. The model is a steady state model that uses inputs based on long term average (LTA) rainfall and is calibrated to average groundwater levels and average baseflow in monitored watercourses.

3.2.2. The model domain area, mesh and edge boundary conditions are shown in Insert 3.1. The edges of the model were defined by catchment boundaries and selected to be far enough from the Scheme to ensure no impact on the model results from the boundary conditions.

Mesh construction

3.2.3. The model mesh is shown in Insert 3.1 and in cross section in Insert 3.2. The mesh was refined around water courses, the road scheme and major faults in the area, including the Mottram fault. During calibration the mesh was regenerated to allow for the inferred position of the United Utilities aqueduct. Largest element widths are 200 m near the periphery of the model domain, with minimum element widths of <1 m within the aforementioned features of interest.

3.2.4. The model uses four layers and five slices (surfaces at the top and bottom of the layers). The layering is summarised in Table 3.1.

Table 3.1: Summary of model slices and layers

Slice	Layer	Details
1		Represents topographic surface – elevation defined at each node based on Ordnance Survey 5 m Terrain DTM product[16]
	1	0.5 m thick - to enable Cauchy boundary conditions with constant area to represent water courses in layer 1.
2		0.5 m below slice 1.
	2	Variable depending on thickness/presence of superficial deposits. Where bedrock outcrops at surface, Millstone Grit properties are applied in L1 and L2, and slice 3 is only 0.1 m below slice 2.
3		Represents top of bedrock (Millstone Grit Group). Elevation defined using BGS mapping and borehole logs.
	3	20 m thick to represent most permeable portion of Millstone Grit Group and to allow 20 m pile depths to be represented in scenario model
4		20 m below slice 3
	4	180 m thick to represent a total active thickness of 200 m of Millstone Grit Group.
5		Base of model – 180 m below slice 3

3.2.5. A total active thickness of 200 m of Millstone Grit is modelled in line with the likely 200 m active thickness of the aquifer identified within the literature (see 2.2.4).

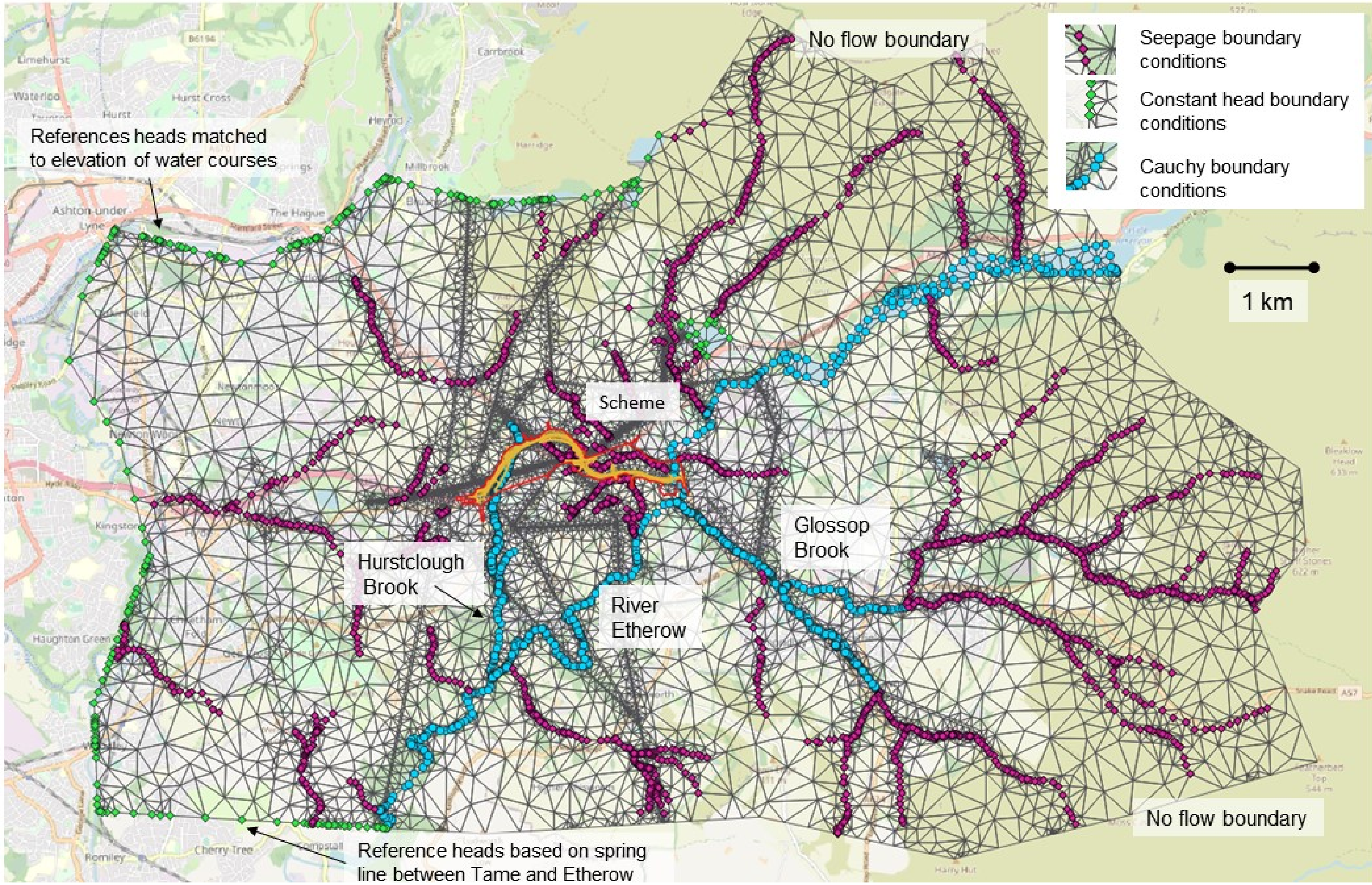
3.2.6. The top slice represents the ground surface and topography was assigned to each node using the elevation from the Ordnance Survey 5 m Digital Terrain Model[17] (DTM).

3.2.7. Layer 1 is uniformly 0.5 m thick – this allows Cauchy boundary conditions to be used to represent rivers, with a constant area for transfer of water between the boundary condition and the model, representing river bed conductance (see section 3.2.13). This in turn allows uniform river bed conductance to be implemented through assignment of uniform hydraulic conductivity values.

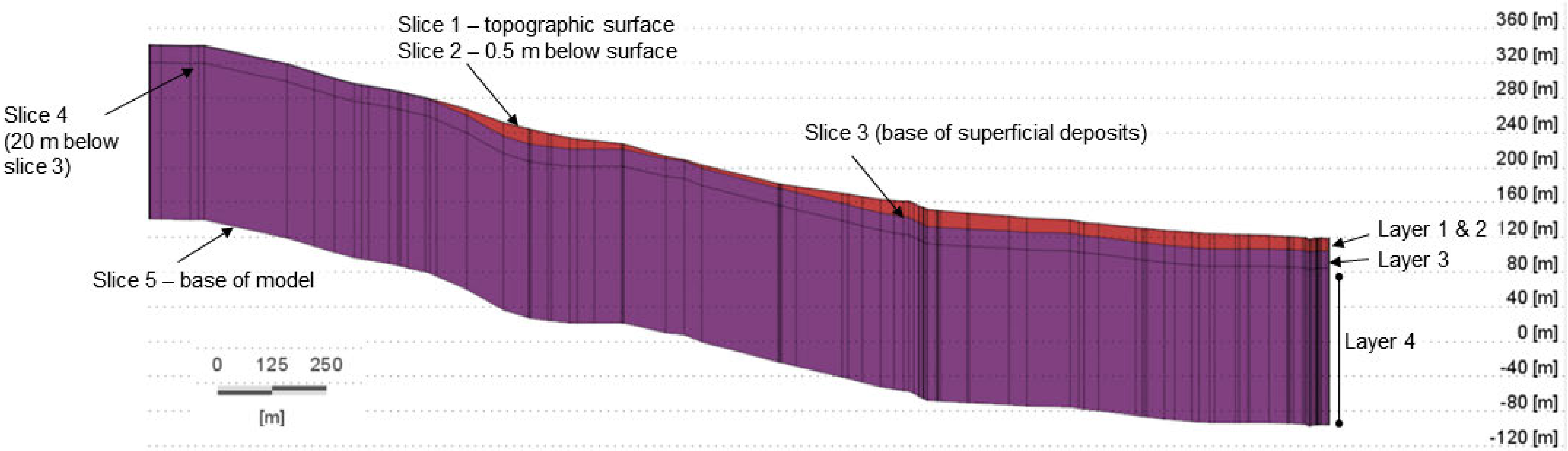
3.2.8. Slice 3 represents the top of bedrock. Its elevation was defined using borehole records from ground investigation in the vicinity of the Scheme, and from publicly available BGS borehole records[17] away from the Scheme that record depth to bedrock. A value of zero thickness was applied along mapped boundaries. Where no BGS borehole records were available, a thickness value was assigned to the centre of the superficial cover based on the closest datapoint, and mapped topography. These data were used to generate a map of thickness of superficial cover by kriging. This thickness was then subtracted from the ground surface elevation at each node in the model to generate a surface that represents top of bedrock. Therefore, the thickness of layer 2 varies according to the thickness of superficial deposits.

[16] Ordnance Survey, 2021. [redacted] [Accessed on 04/09/2021].
[17] British Geological Survey, 2021. [redacted] [Accessed 04/09/2021]

Insert 3.1: Model mesh and boundary conditions

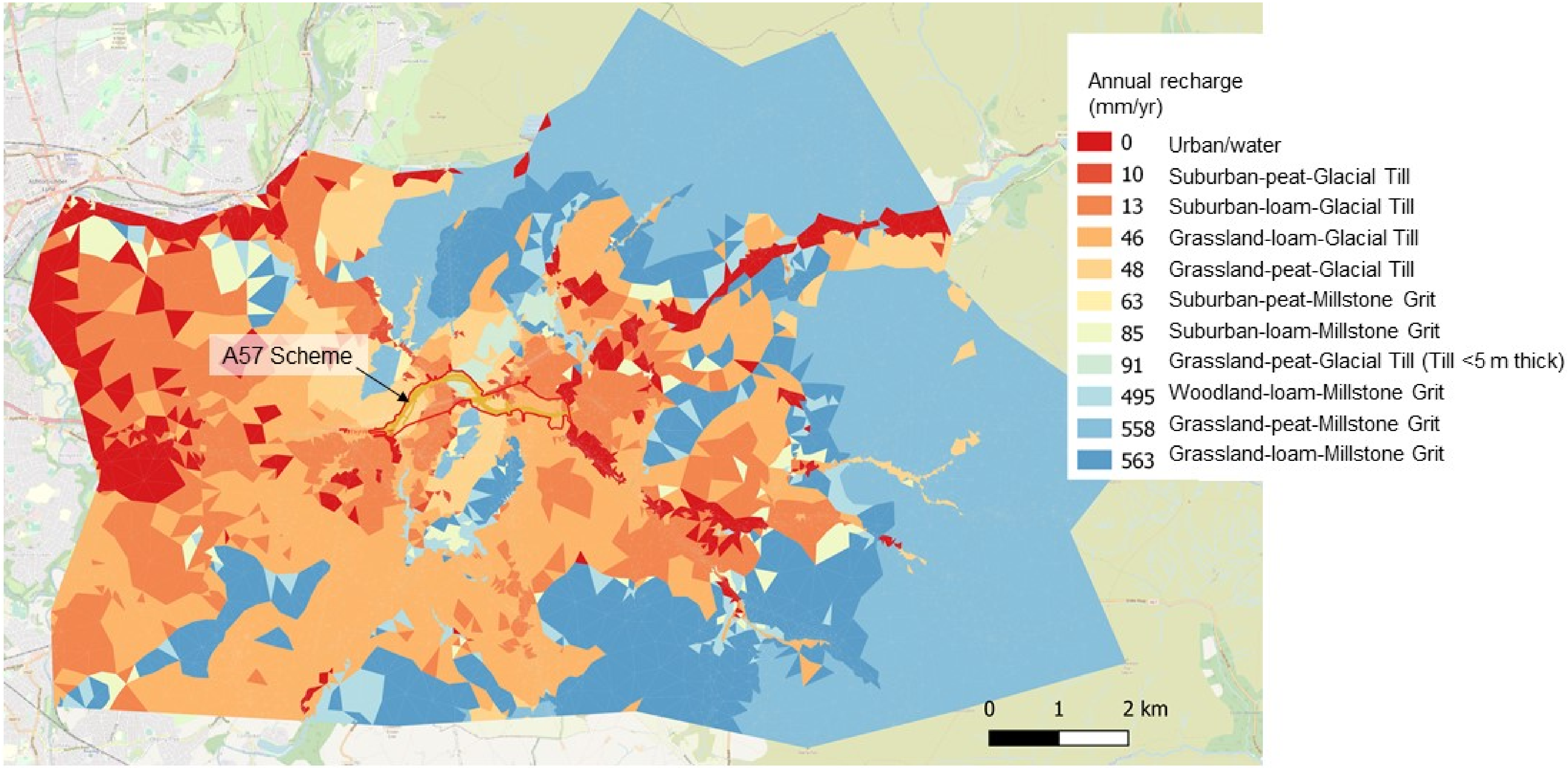


Insert 3.2: Cross section of model mesh (through section line A-A' on Insert 2.1)



Millstone Grit layers are shown in purple, and superficial deposits in red. Slice 1 and 2 cannot be differentiated at this scale as layer 1 is only 0.5 m thick (see section 3.2.7).

Insert 3.3: Applied recharge zones



3.2.9. Where superficial cover is present, both layer 1 and 2 are assigned properties to represent these units. Where no superficial cover is present, layer 2 is assigned a thickness of 0.1 m, and hydraulic properties of Millstone Grit Group are applied in both layer 1 and 2.

3.2.10. Across the Scheme, superficial cover is dominated by Glacial Till. The spatial extent of other superficial sediments (such as Alluvium, Head Deposits, granular Glaciofluvial Deposits) was defined based on BGS mapping or, where available, ground investigation data records. Initial parameters for modelled units are summarised in Table 3.3 and calibrated parameters in Table 3.6.

Boundary conditions

3.2.11. Boundary conditions along the edges of the model are no-flow with the exception of the River Tame along the north-western and western model domain boundaries where constant head (Dirichlet) boundaries were applied, using the elevation along each watercourse, and in the south-western edge of the model parallel to the River Etherow as it approaches the River Tame, informed by mapped locations and elevations of springs. Boundary conditions are shown in Insert 3.1.

3.2.12. Watercourses in the model domain are represented by either seepage boundary conditions or Cauchy boundary conditions as shown in Insert 3.1. Seepage boundary conditions are used for all small watercourses as in most locations, watercourses are gaining from groundwater, as demonstrated by the widespread occurrence of springs. A seepage boundary condition allows groundwater to discharge to the boundary condition if the calculated head exceeds ground level. Along narrow, incised watercourses the DTM was compared with mapped contours to ensure that an appropriate ground level reference head was applied.

3.2.13. Cauchy boundary conditions were used for three watercourses in the model - the River Etherow, Glossop Brook and Hurstclough Brook. Cauchy boundary conditions allow a degree of separation between reference heads at the boundary condition and calculated head in the model via a transfer rate term, representing riverbed conductance. This allows water to be lost from the boundary condition to the model if the heads are below river level. It also means that artesian heads can be represented immediately beneath the boundary conditions – as is the case at the River Etherow.

Cauchy boundary conditions were applied in slices 1 and 2 (see section 3.2.7) so that groundwater discharge can occur when modelled head is within 0.5 m of ground surface (the assumed depth of watercourses). Reference hydraulic heads applied at the Cauchy boundary conditions were taken from the DTM elevation at that point (minus 0.5 m).

3.2.14. Cauchy boundary conditions were also used to represent the United Utilities aqueduct during calibration (see Appendix A of this document).

3.2.15. Seepage boundary conditions were applied at the ground surface in marshy areas where springs were frequently mapped and groundwater levels are known to be close to ground level to allow release of water at surface.

3.2.16. No licensed abstractions with abstraction volumes of >20 m^3/d are present within the vicinity of the Scheme. There are several private abstractions with licensed volumes <20m^3/d as discussed in ES Chapter 9 (APP-065) and section 4.5 of the risk assessment below. These are included in the model as points of interest to allow assessment of impacts but not as groundwater abstractions, as abstraction volumes at these locations are unknown and likely insignificant in terms of the wider model calibration.

Recharge

3.2.17. A spreadsheet soil moisture balance model (SMBM) was developed to calculate recharge to groundwater. The SMBM uses the HadUK rainfall dataset from the Met Office[18] and evapotranspiration data from publicly available Environment Agency datasets[19] for the area and incorporates spatial variability in land use (including vegetation type), geology and soil type to estimate recharge to groundwater. Publicly available datasets for soil type[20], land use[21] and geology[22] were used to define the recharge zones. Recharge zones are shown in Insert 3.3.

3.2.18. The SMBM uses the standard Food and Agriculture Organisation (FAO) methodology to estimate evapotranspiration from the root zone, which is a significant control on the proportion of rainfall converted to recharge[23]. Details of the SMBM methodology and input parameters are provided in Appendix A of this document.

3.2.19. Recharge was calculated on a daily basis for each zone for the period January 1990 to December 2020 and then average annual recharge was derived from this dataset and applied in the model. Annual average recharge values for each recharge zone are summarised in Table 3.2. For context, annual average rainfall for the Scheme from the HadUK dataset is 1100 mm/yr for the period 1990-2020[15].

3.2.20. To calibrate the calculated recharge derived from the SMBM, derived baseflow volumes from observed flow data for the Etherow catchment between the Beesons and Compstall surface water gauges were compared against the total recharge volume for this area of the catchment (see section 2.5.7). Baseflow contribution to surface water represents long-term average recharge volumes assuming that all groundwater recharge in the catchment ultimately discharges to surface water courses. This calculation indicates that average recharge across the whole catchment should be approximately 360 mm/year. By adjusting for the areal coverage of each of the derived recharge zones, the average for this part of the catchment from the calculated recharge data was 355 mm/yr, very similar to the expected recharge based on baseflow.

[18] Met Office; Hollis, D.; McCarthy, M.; Kendon, M.; Legg, T.; Simpson, I., 2018: HadUK-Grid gridded and regional average climate observations for the UK. Centre for Environmental Data Analysis. [redacted] Accessed 23/09/2021].
[19] Environment Agency, 2021. [redacted] [Accessed 23/09/2021].
[20] National Soil Resources Institute - Cranfield University LandIS, 2021. The National Soil Map. [redacted]
[21] Morton, R. D., Marston, C. G., O'Neil, A. W., & Rowland, C. S., 2020. Land Cover Map 2019 (25m rasterised land parcels, GB) [Data set].
[22] BGS, 2021. Geology 50K WMS dataset [redacted] [Accessed 01/09/2021].
[23] Allen, R., Pereira, L. S., Raes, D., & Smith, M., 1998. Crop evapotranspiration guidelines for computing crop water requirements. Irrigation and Drainage Paper 56. Rome, Italy: FAO.

Table 3.2: Annual recharge for modelled recharge zones

Zone	Modelled recharge applied (mm/year)
Urban/water*	0
Grassland on peat soils over Glacial Till	48
Grassland on peat soils over Glacial Till where Till <5 m thick	91
Suburban areas with peat soils over Glacial Till (50% runoff applied)**	10
Grassland on loam soils over Glacial Till	46
Suburban areas with loam soils over Glacial Till (50% runoff applied) **	13
Grassland with peat soils over Millstone Grit	558
Suburban areas with peat soils over Millstone Grit (50% runoff applied) **	63
Grassland on loam soils over Millstone Grit	563
Woodland on loam soils over Millstone Grit	495
Suburban areas with loam soils over Millstone Grit (50% runoff applied) **	85

* Zero recharge has been applied to water bodies as input water levels are already controlled by boundary conditions at these locations.
** Suburban recharge has been calculated by applying 50% runoff to grassland recharge calculations for the same geology and soil type.

3.2.21. Recharge is considerably higher in areas of Millstone Grit outcrop than in areas of Glacial Till cover. This reflects the low permeability of the compacted clays of Glacial Till deposits and therefore its low infiltration capacity of 0.5 mm/day. An infiltration capacity of 50 mm/day was applied to the Millstone Grit. Infiltration capacity is a calibration parameter and during calibration it was increased to 1 mm/d in areas where Glacial Till was less than 5 m thick (see Appendix A of this document).

3.2.22. The SMBM accounts for run-off via the applied infiltration capacity, which reflects the underlying geology. In areas defined as “urban” in land use mapping, zero recharge was applied assuming that impermeable cover would be present. In areas defined as “suburban”, it was assumed that 50% run-off would occur prior to any infiltration. This runoff is applied to daily rainfall at the start of the recharge model and does not affect the other calculations in the SMBM.

Initial parameterisation

3.2.23. The initial parameters applied in the groundwater model are summarised in Table 3.3. These are based on field data and literature values as discussed in section 2.6. Vertical hydraulic conductivities were uniformly applied as one order of magnitude lower than horizontal, unless otherwise stated. These parameters were further refined during calibration as discussed in section 3.3.

Table 3.3: Summary of initial parameters

Parameter	Value applied and reasoning
Millstone Grit hydraulic conductivity	K_h: 2.4 × 10^{-6} m/s – based on geometric mean from 2021 pumping test K_v: 2.4 × 10^{-7} m/s
Glacial Till hydraulic conductivity	K_h: 1 × 10^{-8} m/s – based on data range from historical and 2018 rising and falling head tests. K_v: 1 × 10^{-9} m/s
Millstone Grit hydraulic conductivity within the Mottram fault zone	K_h and K_v: 1 × 10^{-8} m/s – at minimum range for Millstone Grit as recorded in field testing and within range of literature hydraulic conductivity for clays, as identified within Mottram fault zone.
Alluvium around River Etherow, Glossop Brook and River Tame	K_h: 1 × 10^{-6} m/s – based on literature values[13] K_v: 1 × 10^{-7} m/s
Glaciofluvial and River Terrace Deposits around River Etherow and River Tame	K_h: 1 × 10^{-5} m/s – based on literature values[13] K_v: 1 × 10^{-6} m/s
In/out transfer rate at Cauchy boundary conditions	1×10^{-7} 1/s to represent hydraulic conductivity of 1×10^{-7}m/s (equivalent to silt[13]) over a 1 m thickness of river bed.

K_h – lateral hydraulic conductivity; K_v – vertical hydraulic conductivity;
Storage parameters are not used in steady state calculations of groundwater flow.

3.3. Calibration

3.3.1. Calibration is the process of adjusting model properties in order to match simulated groundwater levels to observed data. Calibration has been undertaken to ensure that the baseline model simulates the observed historical groundwater conditions to an appropriate degree of accuracy. Calibration has used the following observed and derived data to achieve this:

- Average recorded groundwater levels at observation boreholes
- Groundwater contours based on observed groundwater levels
- Baseflow for major rivers, derived from gauged flows and BFI

Calibration targets – Groundwater levels

3.3.2. Groundwater monitoring data from historical and recent ground investigation were used as calibration targets. Historical data from boreholes along a previous alignment of the A57 form a long-term groundwater record for the period 1994-2007. Data from 2018 and 2021 each cover short monitoring periods, comprising several visits over a few months in the spring-summer of these years.

3.3.3. Average groundwater levels were taken as the calibration target for all monitoring locations. For the 2018 and 2021 data, the limited length of the monitoring period is not likely to represent the long-term average or seasonal range. For these locations the groundwater levels were compared with nearby historical monitoring wells installed at similar depth with a longer data record and, where appropriate, the calibration targets were adjusted in line with these.

3.3.4. Where there are two separate groundwater bodies (e.g. west of Mottram fault there is groundwater within the Millstone Grit, and perched groundwater within the Glacial Till (see section 2.3.5)), calibration was focused on the Millstone Grit groundwater as it is considered to have greater potential to impact receptors.

3.3.5. The observed data from the monitoring network used as calibration targets are shown in Insert 3.4~~Insert 3.4~~ alongside key features of the Scheme that may impact groundwater. There are very few monitoring wells installed in the Millstone Grit to the west of the Mottram fault. In this area records of water strikes in the Millstone Grit from borehole logs were used to inform model calibration. There is a good distribution of calibration targets close to all the key features of the Scheme.

Calibration targets – Surface water baseflow

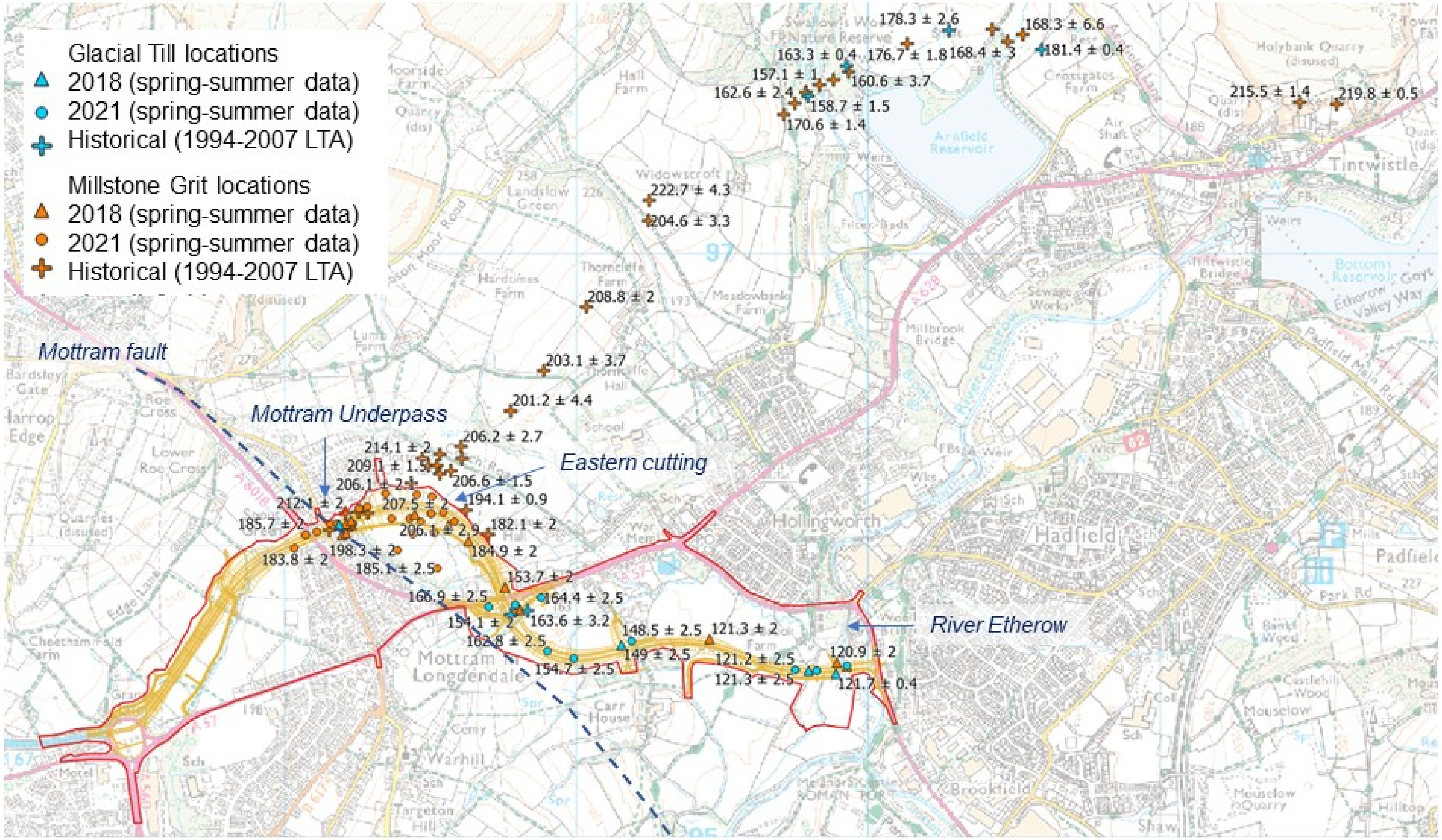
3.3.6. Derived baseflow values for the period 2001-2020 for Environment Agency gauging stations in the vicinity of the Scheme are presented in Table 3.4. These values were calculated using the method described in section 2.5.7. Locations of these gauges are shown on Insert 2.12.

Table 3.4: Summary of Environment Agency surface water flow data for the River Etherow, 2001 to 2020[15]

Gauging station	Average daily flow (m^3/s)	Derived BFI	Calculated baseflow (m^3/s)
River Etherow at Beesons Waste Site	2.0	0.45	0.9
River Etherow at Compstall	4.1	0.45	1.85
River Etherow (Compstall minus Beesons)	2.1	0.45	0.95
River Tame at Portwood	4.2	0.48	2.0
River Tame at Broomstairs Bridge	3.6	0.48	1.7
River Tame (Portwood minus Broomstairs Bridge	0.6	0.48	0.3

For the smaller watercourses within the vicinity of the Scheme only spot flow measurements are available, as discussed in section 2.5.5 and shown on Insert 2.11. These data do not represent long term average flows as they were taken on a single day in December 2006. BFI are unknown for these watercourses and therefore these have not been used in the calibration.

Insert 3.4: Average observed groundwater monitoring data used as calibration targets (m AOD, with inferred/observed seasonal range) and key features of the Scheme relating to groundwater



Ranges have been based on observed range of data where long-term average data has been collected. For limited datasets average ranges were applied based on observed long-term average from monitoring wells installed in the same unit. Contains Ordnance Survey data © Crown copyright 2021..

Quality of baseline model calibration

3.3.7. Insert 3.5~~Insert 3.5~~ and Insert 3.6~~Insert 3.6~~ summarise the overall quality of the calibration of the baseline model. Insert 3.5~~Insert 3.5~~ shows a plot of the residuals (difference between observed groundwater levels and modelled levels) at all groundwater calibration targets in the model. Insert 3.6~~Insert 3.6~~ shows modelled hydraulic heads[24] against observed hydraulic heads at the calibration targets – modelled heads within the observed range are shown in black, outside the range in red. There is a good match between the observed and modelled groundwater levels when considering absolute level. Furthermore, modelled groundwater levels are largely within the range of the observed data.

3.3.8. Modelled groundwater level contours in the Millstone Grit alongside observed groundwater calibration targets are shown along the Scheme in Insert 3.7~~Insert 3.7~~ to Insert 3.9~~Insert 3.9~~. Comparison of observed data with modelled contours demonstrate that the calibration along, and close to, the Scheme is good – around Mottram Underpass and the eastern cutting residuals are largely within the observed range. The model represents well the hydraulic gradient along the Scheme and the change in water levels across the Mottram fault. The residuals are greatest (up to 4 m outside the observed seasonal range) for monitoring wells drilled deep (30-40 m) into the Millstone Grit where groundwater has significant artesian head. However, this should not limit the ability of the model to assess impacts from the Scheme as the shallow aquifer is where the greatest proportion of flow takes place and has greatest connectivity with receptors (such as springs and watercourses), it is also the portion of the aquifer most likely to be directly affected by structures or cuttings associated with the Scheme and as discussed, the model represents water levels in the top 20 m of the aquifer well.

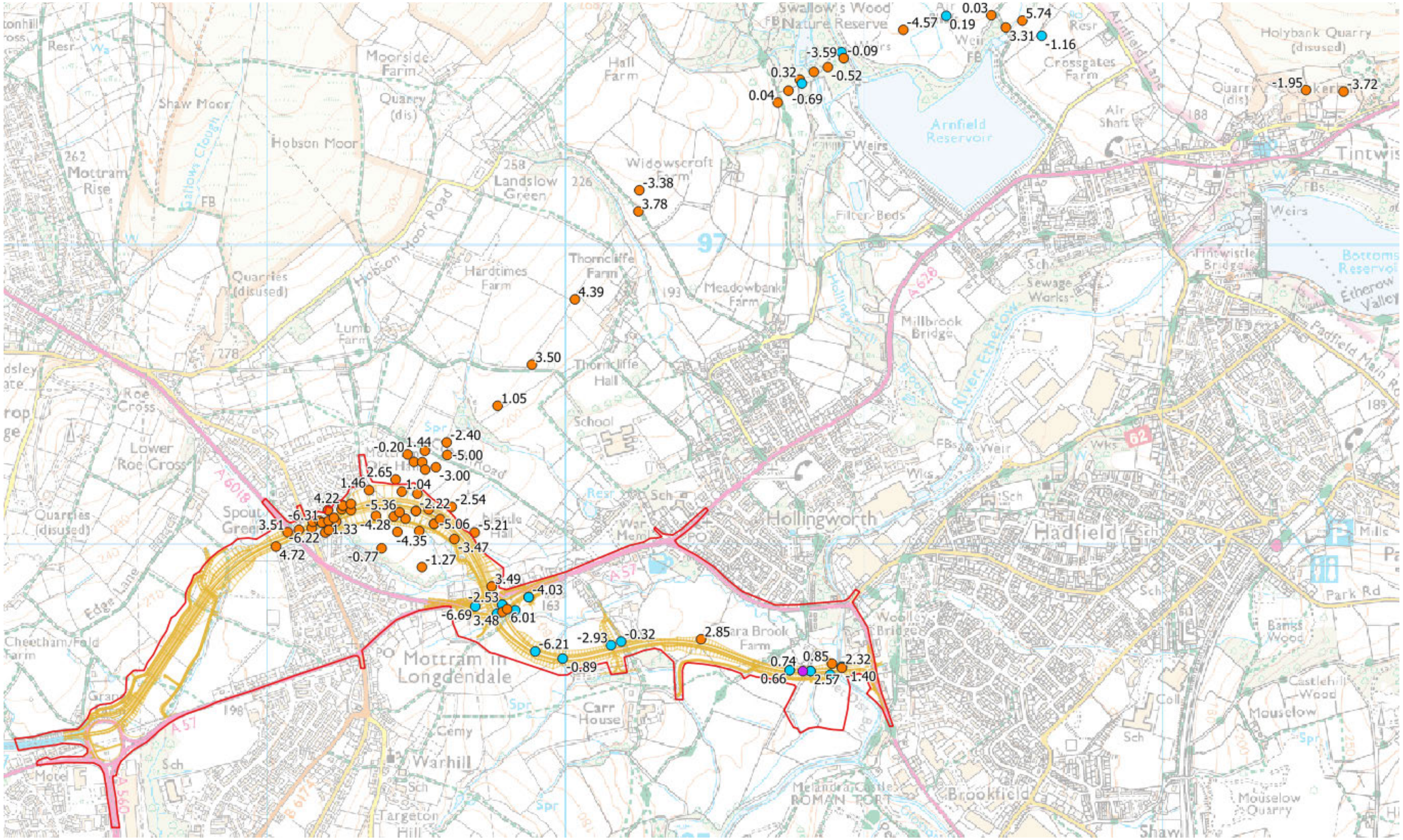
3.3.9. Table 3.5 shows the modelled groundwater discharges to the River Etherow and the Tame. At a catchment scale, the model provides a good match for baseflow to these main watercourses. There is no available long term average flow data for smaller watercourses so it is not possible to assess how well the model represents any spatial variability in baseflow across the catchment.

Table 3.5: Modelled contributions to baseflow in watercourses close to the Scheme

Watercourse	Modelled groundwater baseflow (m^3/s)	Comparison to calculated baseflow
River Etherow (between Beesons and Compstall gauges)	0.86	Good match to observed baseflow for this part of catchment (0.95 m^3/s).
River Tame	0.14	Only eastern side of Tame catchment modelled. Observed data for catchment between Portwood and Broomstairs Bridge estimates baseflow of 0.3 m^3/s – assuming half of this is from eastern catchment, then good match between modelled and observed data.

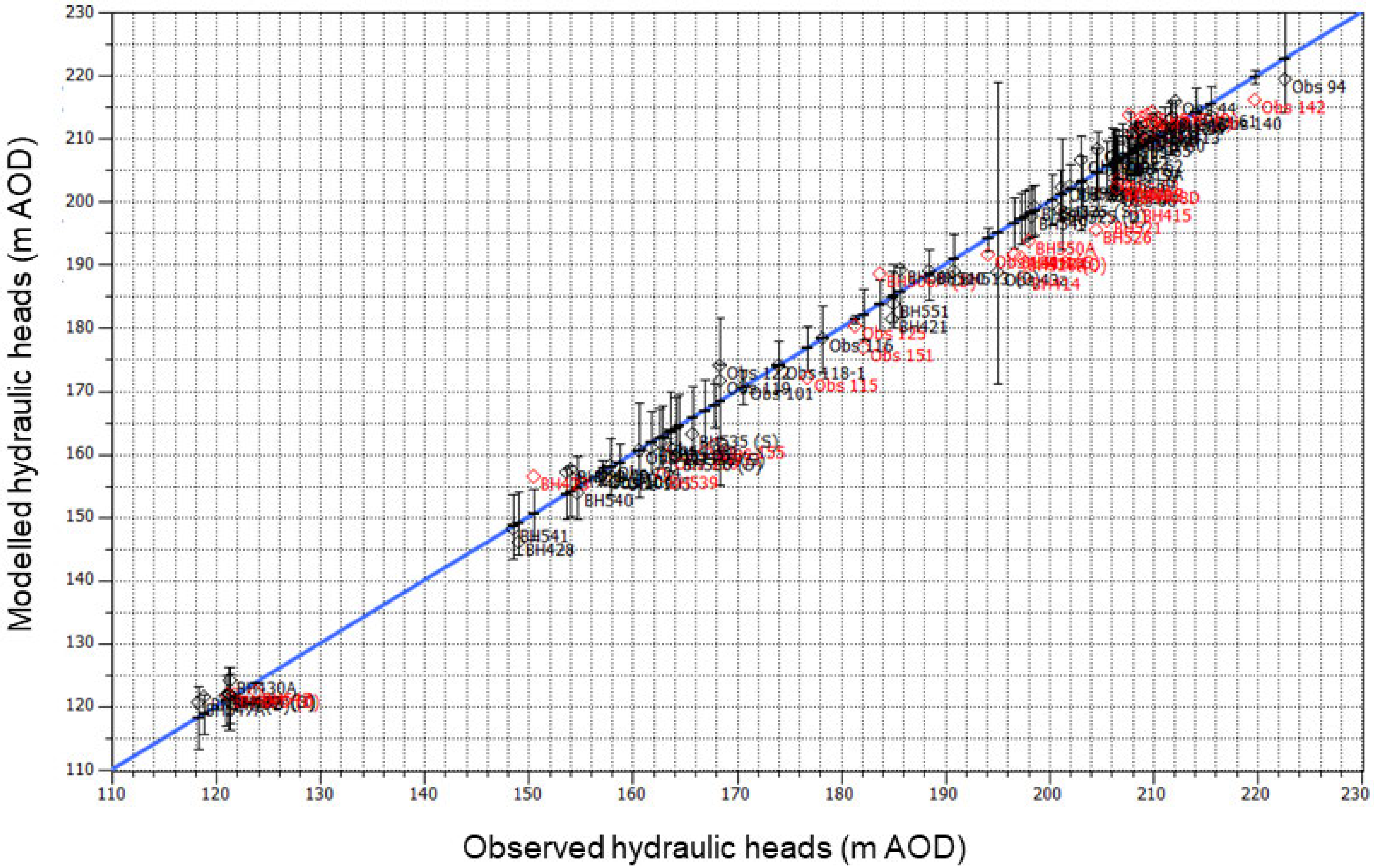
[24] Hydraulic heads are the level that groundwater would rise to within a monitoring well at a particular point. In an unconfined aquifer this would be the water table, in a confined aquifer it may be above the top of the aquifer. This terminology is used here as groundwater is often confined.

Insert 3.5: Residuals between modelled and observed groundwater levels



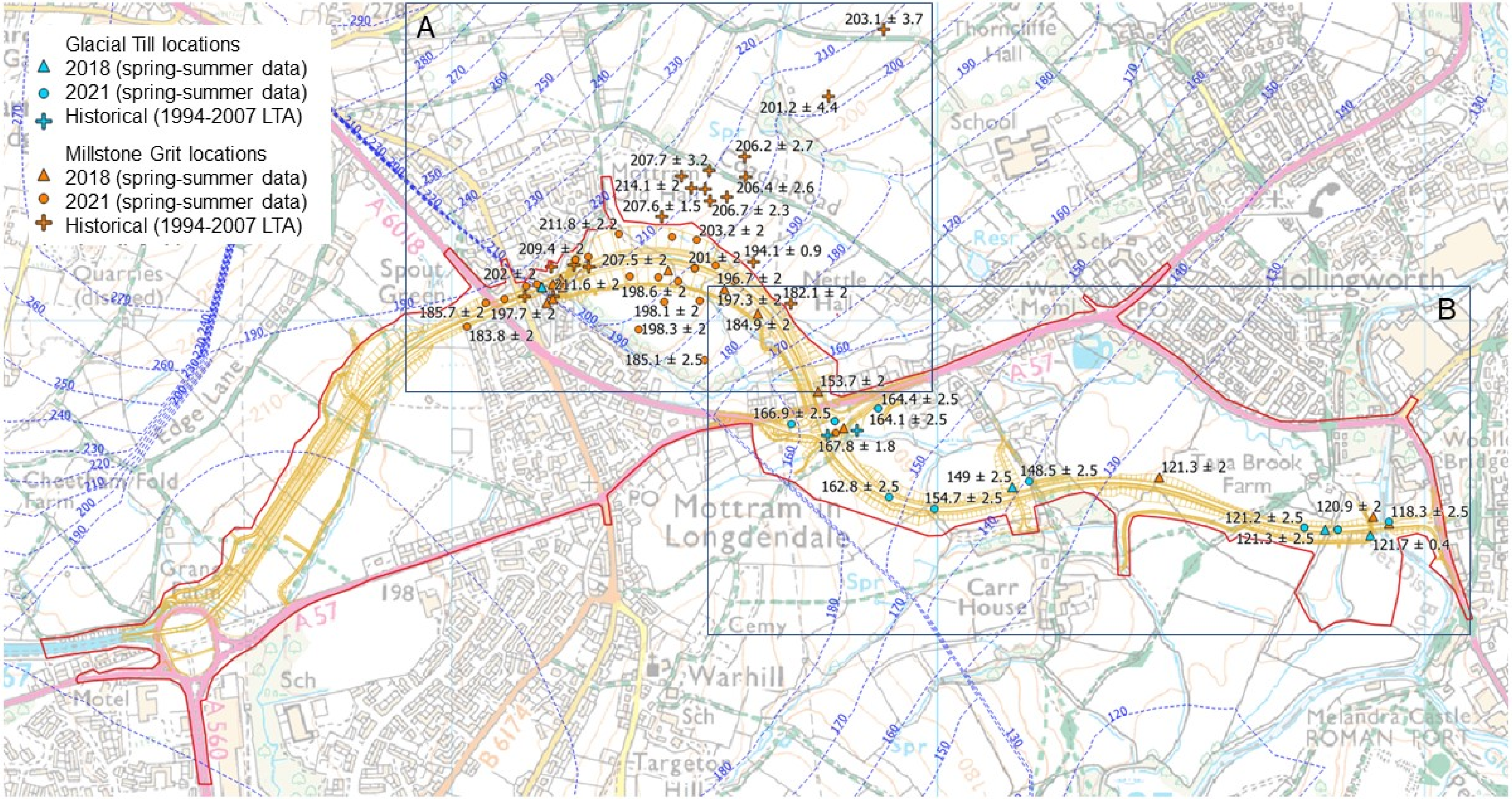
Residuals are shown as observed heads minus modelled heads - positive residual means modelled heads are higher than observed and negative lower than observed.
Millstone Grit locations shown in orange, Glacial Till in blue. Contains Ordnance Survey data © Crown copyright 2021

Insert 3.6: Modelled hydraulic heads vs observed hydraulic heads (m AOD)



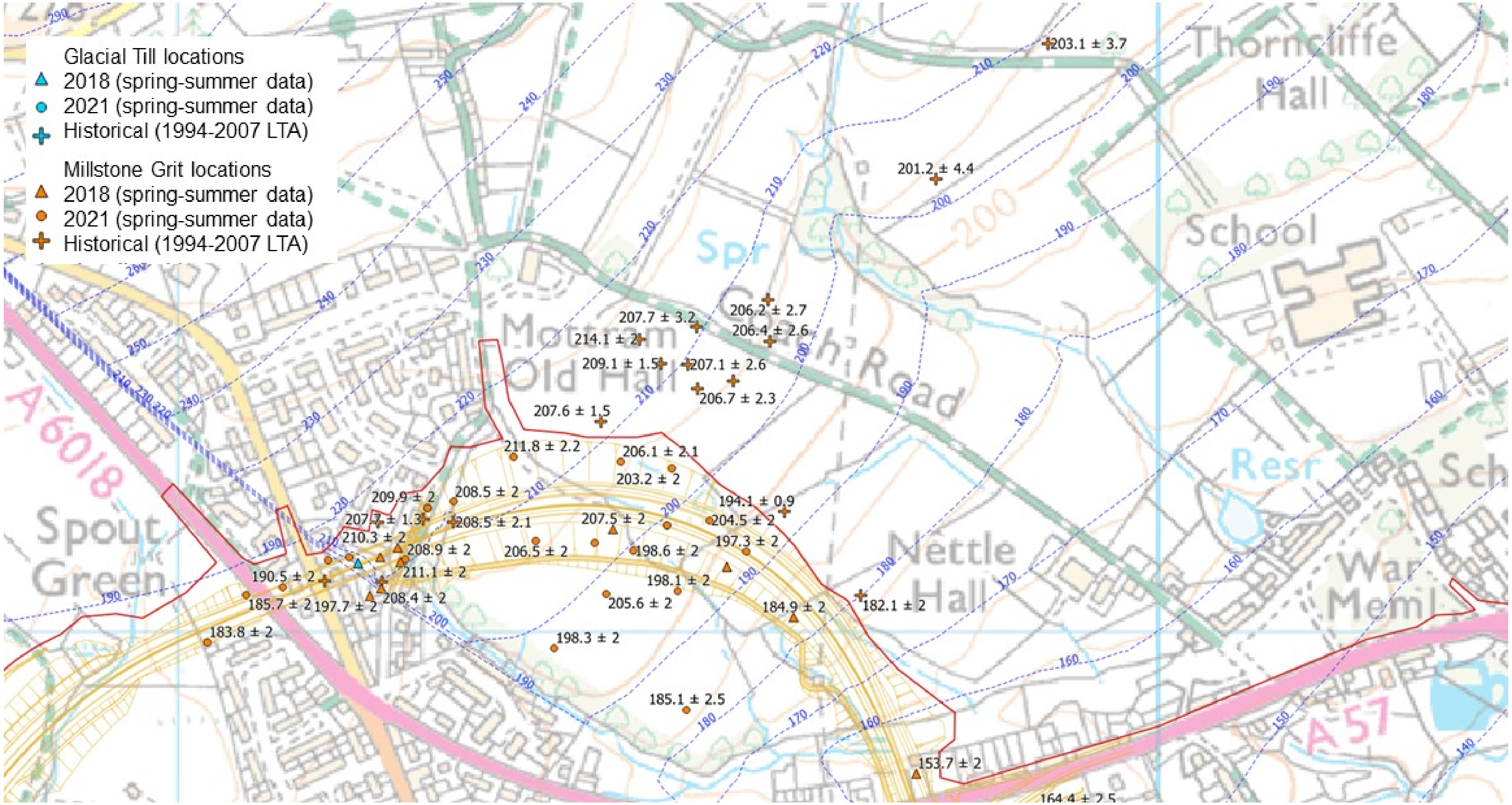
Error bars represent the observed data range. Modelled hydraulic heads within the observed data range are shown in black, those outside the range in red.

Insert 3.7: Modelled groundwater level contours and observed monitoring data (m AOD).

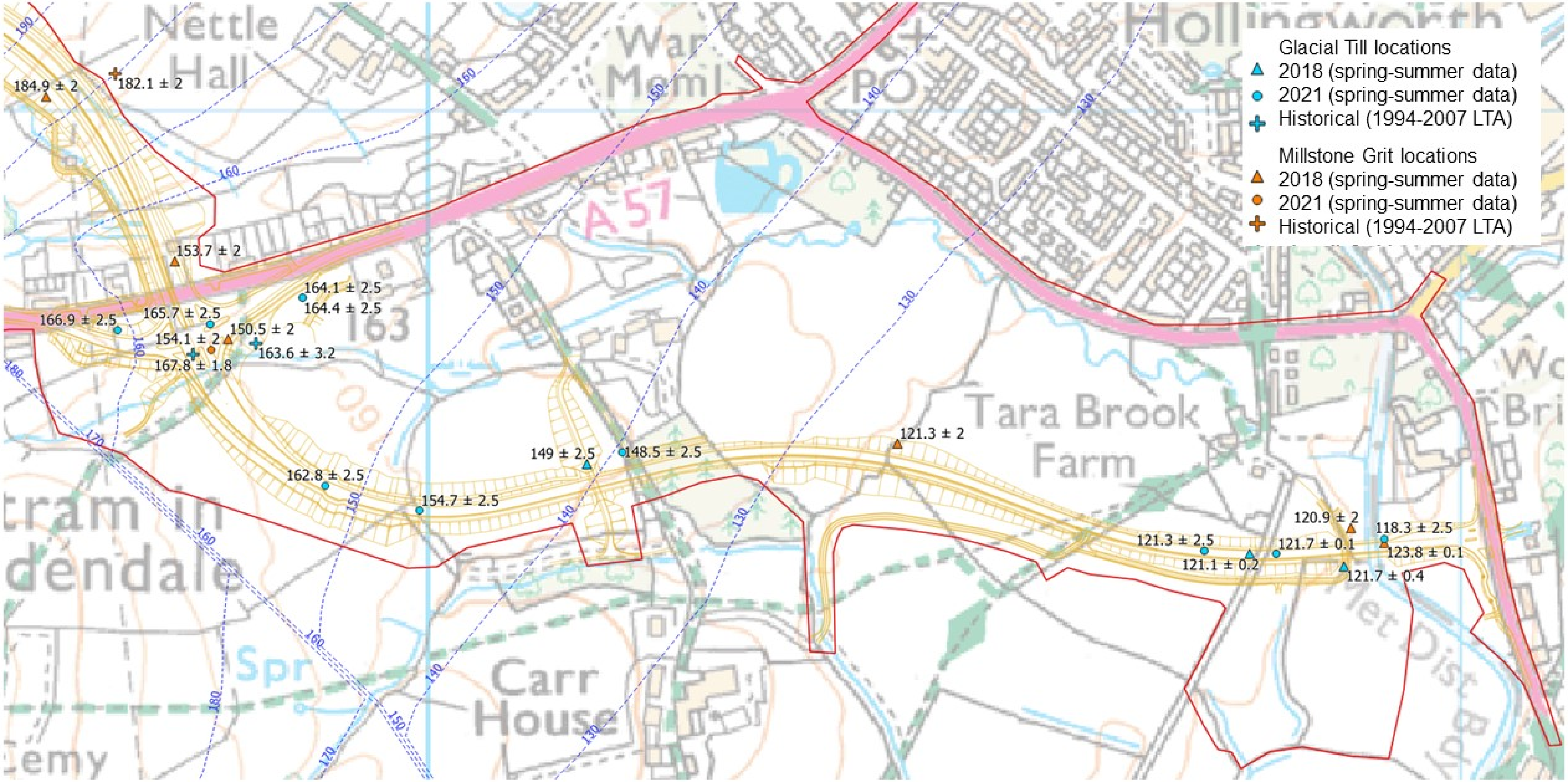


Contains Ordnance Survey data © Crown copyright 2021.

Insert 3.8: Modelled groundwater level contours and observed monitoring data (m AOD) – box A.



Insert 3.9: Modelled groundwater level contours and observed monitoring data (m AOD) – box B.



3.3.10. The good match between modelled and observed groundwater levels and baseflow to main rivers within the baseline groundwater model indicates that the model is a good representation of the groundwater system and is therefore appropriate for use in assessing the potential impact of the Scheme on the wider groundwater environment.

3.3.11. It should be noted that a steady state model, calibrated to long term average groundwater levels provides a useful indication of potential long-term average impacts of the Scheme but does not allow for impacts under seasonally varying conditions (e.g. excessively wet or dry periods) to be assessed.

3.3.12. The numerical water balance of the baseline model was checked to ensure that the model is functioning correctly and there are no unexpected losses or gains of water that are not accounted for in the conceptual model. The water balance is included in Appendix A.3 of this document.

Calibrated model parameters

3.3.13. Building on the initial estimates given in Table 3.3, model parameters were varied during calibration within the range of published or site-specific values for each geological unit. The calibrated hydraulic conductivity ranges are summarised in Table 3.6 and shown in Insert 3.10~~Insert 3.10~~ and Insert 3.11~~Insert 3.11~~, with ranges reflecting heterogeneity, or zoning, across the model domain. Note that as the baseline model is a steady state model, storage parameters are not required.

Table 3.6: Summary of calibrated hydraulic conductivity values

Geological Unit	Parameter	Range (m/s)
Millstone Grit	K_h	1.0×10^{-7} - 5.0×10^{-5}
	K_v	5.0×10^{-9} – 7.0×10^{-7}
Millstone Grit within fault zones	K_h and K_v	5.0×10^{-10} – 5.0×10^{-9}
Glacial Till	K_h	2×10^{-8}
	K_v	2×10^{-9}
Alluvium	K_h	2.0×10^{-5} – 2.5×10^{-5}
	K_v	1.5×10^{-7} – 3.5×10^{-7}
Glaciofluvial deposits	K_h	2.0×10^{-6} – 1.0×10^{-5}
	K_v	2.0×10^{-8}* – 1.0×10^{-6}
Head deposits	K_h and K_v	1.0×10^{-6}

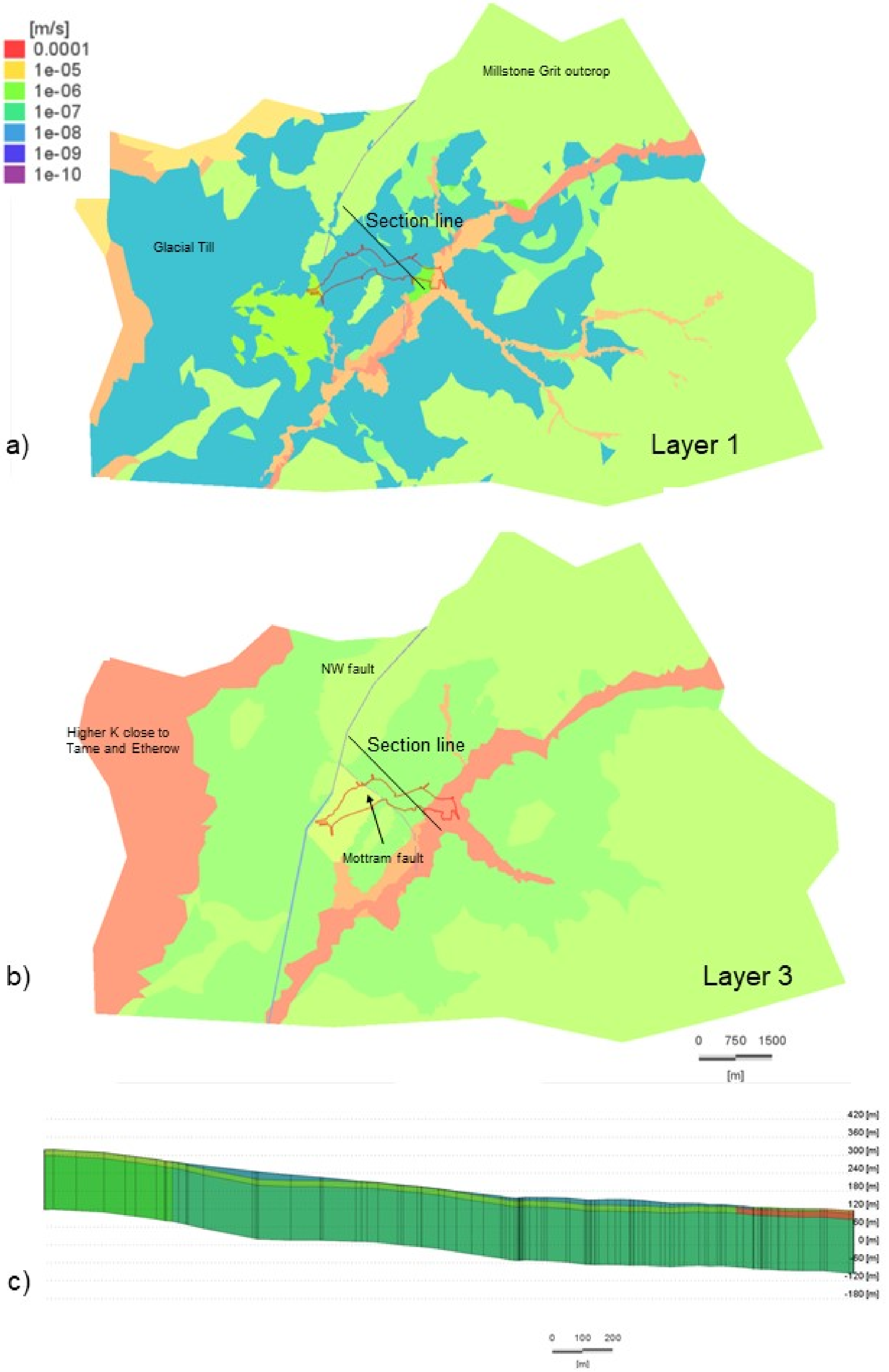
*low range for Kv used for glaciofluvial deposits which overlie Glacial Till, reducing Kv.

3.3.14. The parameters that were adjusted to improve model calibration are summarised below and the changes made are described in more detail in Appendix A.4 of this document.

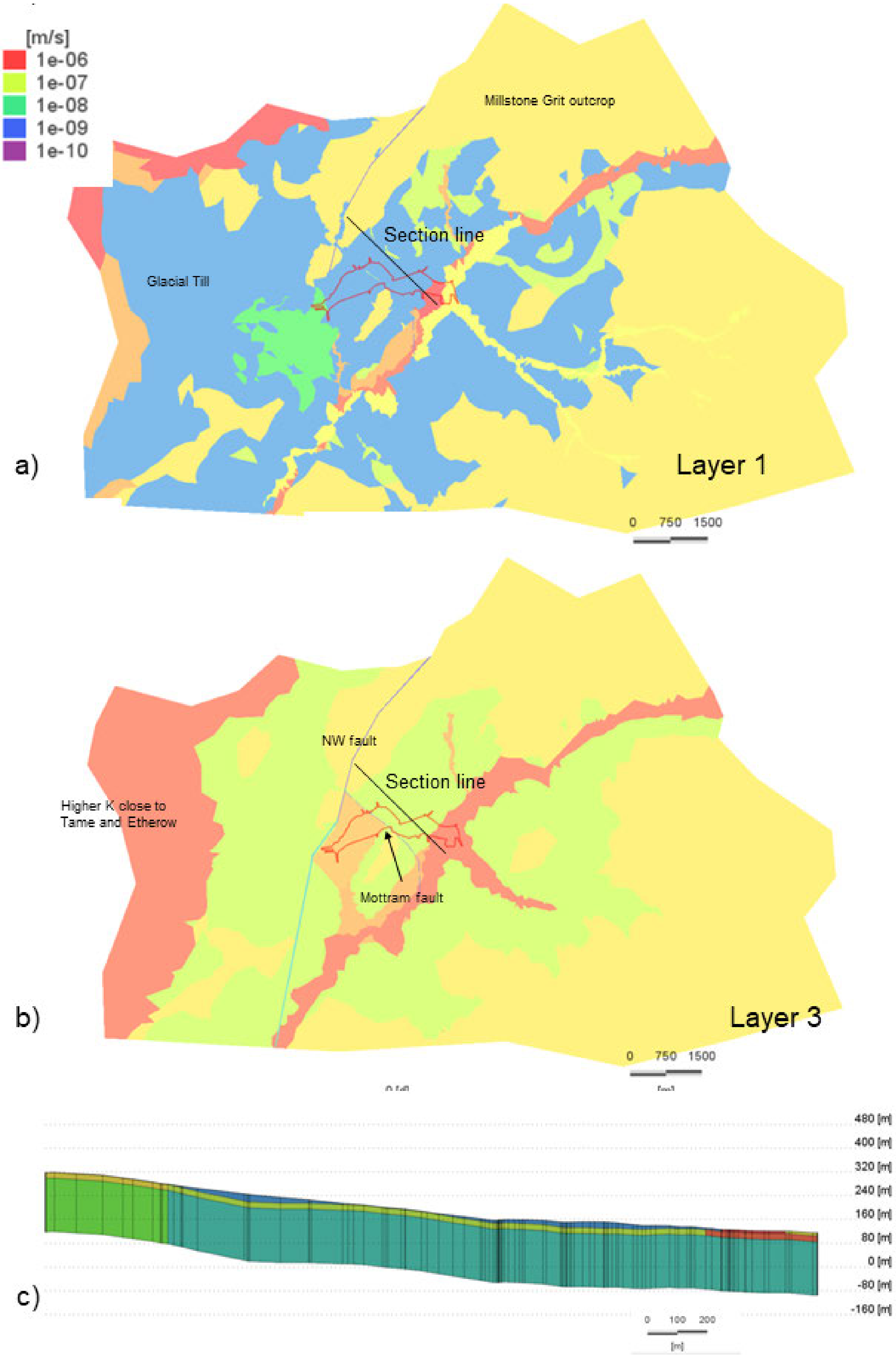
- Hydraulic properties of the Millstone Grit.
- Fault parameterisation in the Millstone Grit
- Hydraulic properties of the superficial deposits.

- Representation of the United Utilities aqueduct.
- Representing the connection between groundwater and urban surface water drainage along Old Hall Lane.
- Transfer rate along watercourses
- Infiltration capacity of Glacial Till.

Insert 3.10: Calibrated lateral hydraulic conductivity distribution (K_h)



Insert 3.11: Calibrated vertical hydraulic conductivity distribution (K_v)



3.4. Scenario modelling

Operational Scheme scenario

3.4.1. The Scheme has been modelled in a single scenario, representing the potential long-term impacts post-construction, without mitigation (termed “scenario model” here). This is a precautionary approach as the greatest potential for impact is considered to be in the long-term, following the installation of permanent drainage and pile walls. The impact assessment of this scenario is presented in Section 4, whilst details of its representation in the model are provided here.

3.4.2. The aspects of the Scheme represented in the scenario model are detailed in Table 3.7 and shown on Insert 3.12~~Insert 3.12~~. The design details implemented in the scenario are based on the design as presented in Engineering Drawings and Section Plans (APP-012) and Culvert and Drainage Plans (APP-017).

Table 3.7: Features of the Scheme represented in scenario model

Feature	Detail
Low permeability secant pile walls along the sides of Mottram Underpass	In the model a K_h and K_v of 1 × 10^{-9} m/s was applied to the elements along the secant pile walls to represent the low permeability of the concrete forming the piles. The wall has been modelled as 1.5 m thick. The anticipated pile toe depth is <20 m bgl. As the model slices do not exactly align with the toe depth of the piles, the following approach is deemed to be a conservative representation: • East of Mottram fault, low permeability was applied in layers 1, 2 and 3 (superficial deposits and the top 20 m of Millstone Grit). In some locations this means the pile depth is modelled as slightly deeper than reality. • West of Mottram fault, low permeability was applied in layers 1, 2 and layer 3 in areas where rockhead is shallower than 15 m bgl. At the far west of the underpass rockhead is deeper than 15 m bgl and the toe of the piles would only just penetrate the top of bedrock. In these areas the piles were represented only within the superficial deposits, layers 1 and 2.
Drainage through the eastern cutting	Seepage boundary conditions applied throughout the eastern cutting where passive groundwater drainage will be in place. Reference hydraulic heads were matched to 1 m below road elevation to represent the likely invert level of drainage collector pipes. Elevation of the top surface of the model was adjusted to match cutting elevation. Millstone Grit properties applied in layers 1 and 2 within cutting, as bedrock is anticipated to be exposed in the cutting.
Realignment and channel loss of watercourses	New watercourse immediately to the north of the eastern cutting applied with seepage boundary conditions. Reference heads within these boundary conditions were set to 0.5 m bgl to allow for 0.5 m depth of watercourse. Removal of boundary conditions for watercourses that fall under the footprint of the Scheme and will be removed or realigned (WC_212, WC_213, upper reach of WC_214).

3.4.3. Simulated difference in groundwater levels between the baseline model and scenario model within the Millstone Grit is shown in Insert 3.13Insert 3.13. The results are summarised below. As the baseline model is calibrated to long term average groundwater levels, the results from the scenario model represent the likely impact of the Scheme but does not allow for impacts under extreme conditions (e.g. excessively wet or dry periods) to be assessed.

- Hydraulic heads increase by up to 2 m immediately outside the secant pile walls of the underpass, these increases are restricted to within the red line boundary.
- Hydraulic heads decrease in the area to the north of the cutting. Changes in hydraulic head that are >1 m extend to a radius from the Scheme boundary of up to 330 m.
- Maximum drawdown in the centre of the cutting is approximately 11 m.
- Estimated flows during the operational phase from drainage within the cutting are 63.5 m^3/d equivalent to 0.7 l/s. Initial flows during construction are likely to be higher than this as water is released from storage which is not accounted for in this steady state model.
- Low permeability of the Mottram fault reduces modelled impacts within Mottram village (see sections 3.4.5 to 3.4.8).

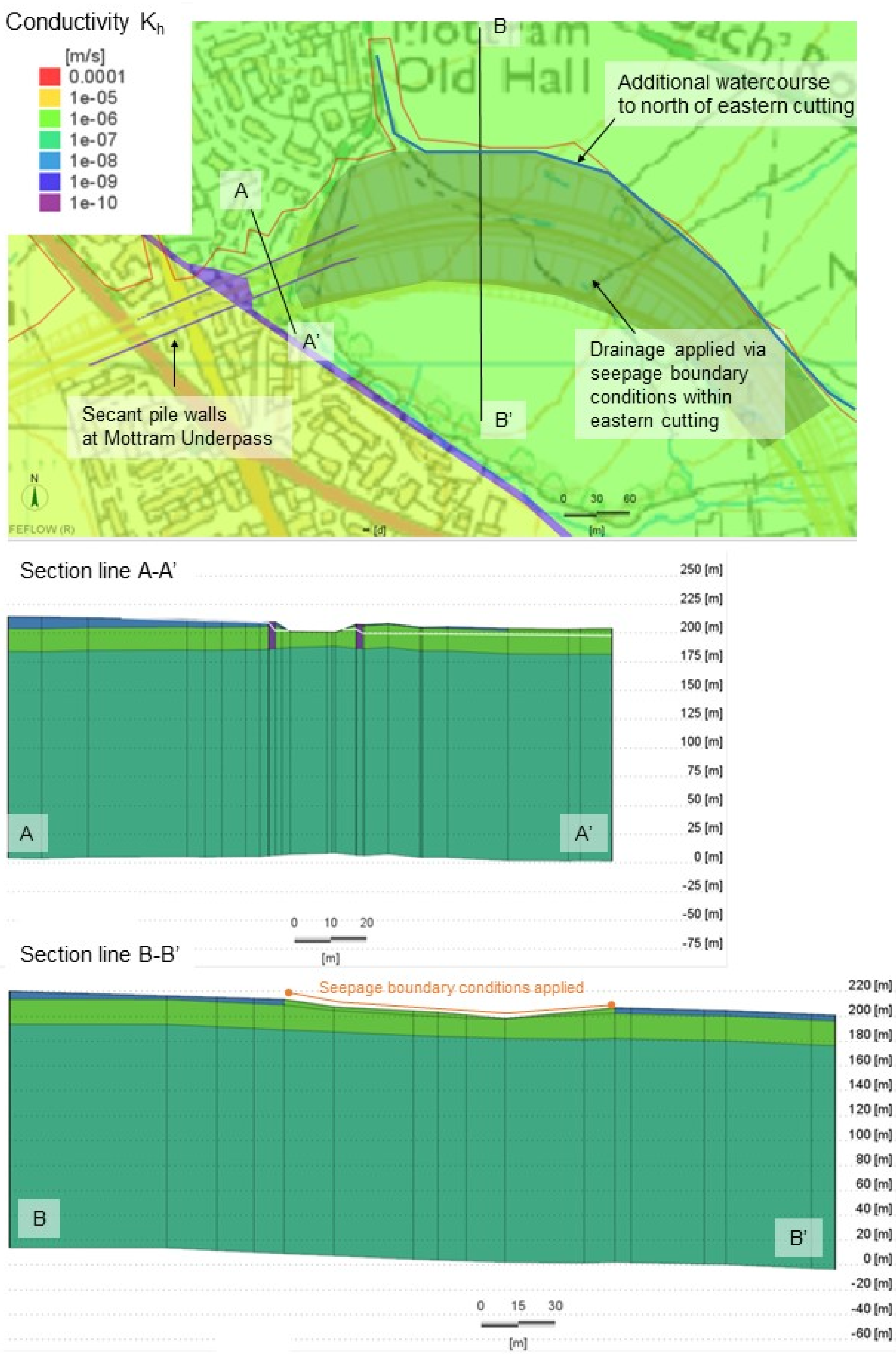
The changes to modelled river baseflow as a result of the Scheme have been considered for all watercourses within 500 m of the red line boundary in line with the methodology present in ES Chapter 13 (APP-069). Watercourses where a change in modelled baseflow is observed are shown in Insert 3.14Insert 3.14. These changes in baseflow do not account for any mitigating effects of discharge of drained groundwater. Refer to ES Figure 13.1 (APP-148), for watercourse locations.

3.4.4. Several watercourses pass directly through the road alignment and the eastern cutting and will be realigned, culverted or removed during construction works. As would be expected, it is these watercourses that experience the greatest loss in LTA baseflow. WC_212 and WC_213 are removed as part of the Scheme development so changes in baseflow to these watercourses have not been assessed.

Characterising uncertainty in the representation of the Mottram fault

3.4.5. The Mottram fault strongly influences the distribution of impacts from the Scheme as shown in Insert 3.13Insert 3.13. However, there is uncertainty surrounding the width and permeability of the fault zone. Although the calibration of the baseline model to observed data indicates that the model represents the parameters of the fault zone well where it crosses the Scheme, it is likely that the connectivity across the fault will vary spatially, which would in turn affect impacts from the Scheme.

Insert 3.12: Changes made in scenario model

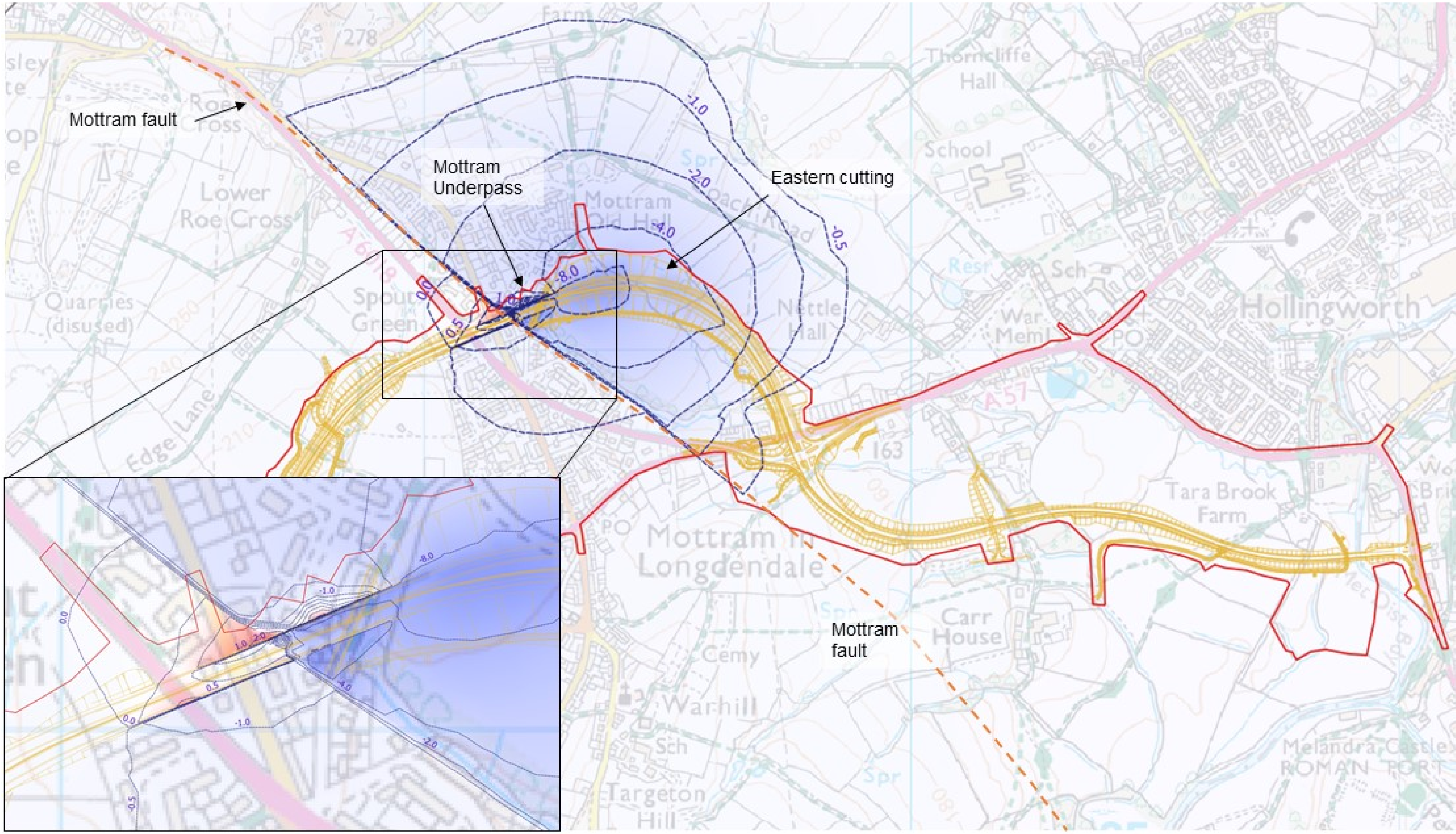


3.4.6. In order to account for the uncertainty in the parameterisation of the Mottram fault zone, an additional model run has been carried out to assess the sensitivity of the modelled impacts to the hydraulic conductivity applied in the Mottram fault.

3.4.7. To do this, the vertical and horizontal hydraulic conductivity in the fault zone was increased by one order of magnitude (from 5×10^{-10} m/s to 5×10^{-9} m/s) in both the baseline and scenario model. The results from these models were then compared to assess the change in hydraulic heads resulting from the Scheme if the Mottram fault permeability were higher than the calibrated model suggests.

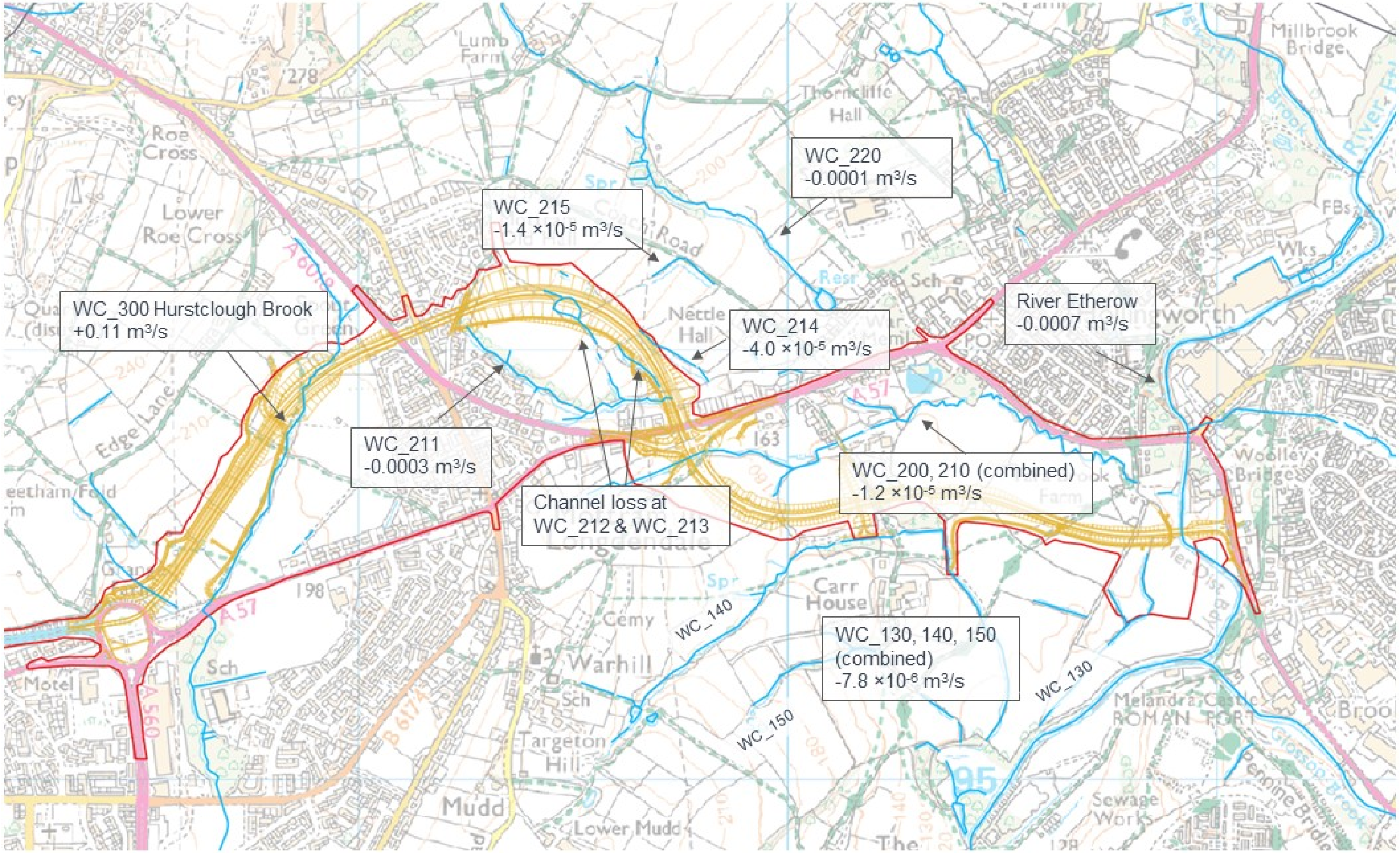
3.4.8. The results from this exercise are shown in Insert 3.15~~Insert 3.15~~. Comparing these results to those presented in Insert 3.13~~Insert 3.13~~, the drawdown on the east side of Mottram fault is slightly reduced in spatial extent, and drawdown has a greater extent to the west of Mottram fault. The results of this sensitivity analysis have been used to inform the impact assessment in section 4.

Insert 3.13: Difference in hydraulic head (m) between baseline and scenario model



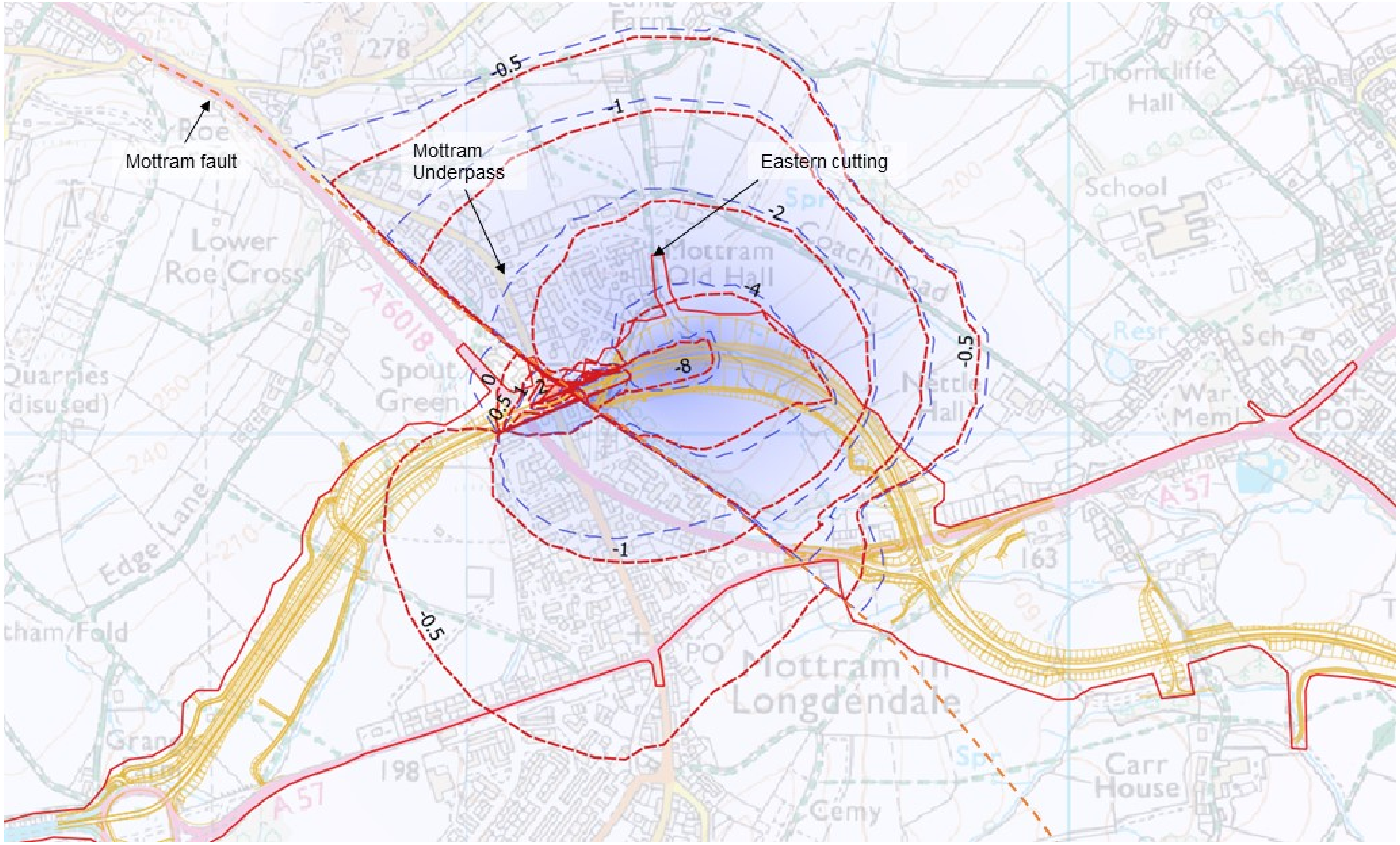
Drawdown shown in blue, increase in hydraulic heads shaded red. Contains Ordnance Survey data © Crown copyright 2021.

Insert 3.14: Watercourses where change in baseflow is modelled between baseline and scenario model



Changes in baseflow represent changes across the whole reach of the watercourse. Contains Ordnance Survey data © Crown copyright 2021.

Insert 3.15: Difference in hydraulic head (m) between baseline and scenario model with hydraulic conductivity of Mottram fault increased by one order of magnitude (shown in red)



Contours shown in red represent the model run where fault permeability has been increased by one order of magnitude. Contours in blue are the l kely scenario as presented in Insert 3.13~~Insert 3.13~~. Contains Ordnance Survey data © Crown copyright 2021.

4. Hydrogeological Risk Assessment

4.1. Introduction

4.1.1. This section assesses the potential impacts of the Scheme on surface and groundwater receptors, and in terms of flood risk, based on the modelled quantitative changes to groundwater levels and flows presented in Section 3.4.

4.1.2. It also presents an assessment of potential water quality impacts associated with the operation of the Scheme based on water quality data collected during 2018 and 2021.

4.1.3. This assessment focuses on potential long-term impacts associated with the operational phase of the Scheme that may cause permanent changes to the water environment. The potential for short-term impacts during the construction phase has already been assessed elsewhere or will be assessed via permitting routes during detailed design. Table 1.1~~Table 1.1~~ summarises all identified potential impacts to groundwater and identifies which application documents include their assessment.

4.1.4. This assessment follows Environment Agency guidance for hydrogeological impact assessment (HIA)[1]. This guidance was issued to support the risk assessment of dewatering activities that may have a long-term impact on the water environment. In this assessment, the guidance framework has been used to assess potential impacts both from drawdown and discharge of groundwater associated with dewatering, and also potential increases in groundwater level associated with piling and the implications for groundwater flood risk. Table 4.1 shows which sections of the current document address the recommended steps from this guidance.

4.1.5. Impacts have been assessed for a buffer of 500 m from the Scheme boundary for surface water, and for within 1 km from the Scheme boundary for groundwater in line with the methodology presented in the WFD Assessment Compliance Assessment Report.

4.1.6. The assessment of significance of effects uses the methodology described in Chapter 13 of this Environmental Statement.

Table 4.1: Structure of risk assessment

Section	Steps of HIA guidance
4.2 Regional water resource status	Step 1 - Establish the regional water resource status.
4.3 Conceptual site model	Step 2 – Develop a conceptual model for the abstraction and the surrounding area
4.4 Potential flow impacts	Step 3 – Identify all potential water features that are susceptible to flow impacts
	Step 4 – Apportion the likely flow impacts to the water features
	Step 5 – Allow for the effects of any measures being taken to arrive at net flow impacts

Section	Steps of HIA guidance
	Step 6 – Assess significance of net flow impacts
	Step 7 – Define the search area for drawdown impacts
4.5 Potential drawdown impacts	Step 8 – Identify all features within the search area which could potentially be impacted by drawdown
	Step 9 – For all these features, predict the likely drawdown impacts
	Step 10 – Allow for the effects of measures being taken to mitigate drawdown impacts
	Step 11 – Assess the significance of net drawdown impacts
4.6 Water quality impacts	Step 12 – Assess the water quality impacts
4.7 Mitigation measures	Step 13 – If necessary, redesign the mitigation measures to minimise impacts.
4.7.1 Proposed monitoring	Step 14 – Develop a monitoring strategy.

4.2. Regional water resource status

4.2.1. The bedrock aquifer under the Scheme is the Millstone Grit Group. This is a Secondary A Aquifer, which is defined as permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of baseflow to rivers. The Millstone Grit Group is overlain by Glacial Till across large parts of the Scheme. The Glacial Till is classified as a Secondary (undifferentiated) aquifer due to its relatively low permeability. This impact assessment focuses on potential impacts associated with changes to the groundwater within the Millstone Grit aquifer.

4.2.2. Groundwater within the Millstone Grit Group forms part of the Manchester and East Cheshire Carboniferous Aquifers (WFD ID: GB41202G102900). This water body is classified as Good for quantitative status for all measures and Poor for chemical classification[25] as discussed in the WFD Assessment Compliance report.

4.2.3. The regional Catchment Abstraction Management Strategy for the Lower Mersey region[26] does not classify the water resource availability at the location of the Scheme for the Millstone Grit aquifer. The Environment Agency HIA guidance states that where no status is defined, it is likely that the abstraction is located within unproductive strata and the focus of the HIA should be on specific impacts at the local scale. In this case it likely implies that the groundwater body is not of regional significance. Based on the WFD classification, the regional water resource status is considered to be good, with water available.

[25] Environment Agency, 2021. Catchment data explorer - Manchester and East Cheshire Carboniferous Aquifers Water Body. [redacted] [Accessed 15/10/2021].
[26] Environment Agency, 2013. Upper Mersey abstraction licensing strategy. Environment Agency, Bristol.

4.3. Conceptual site model

4.3.1. The groundwater conceptual site model is discussed in detail in Section 2 of this document and shown in Insert 2.1 and Insert 2.2. Information pertaining to water quality is included in Section 4.6.

4.3.2. The features of the Scheme that have the greatest capacity to affect groundwater during the operational phase and are assessed herein are:

- Installation of deep piled foundations and underground concrete structures that may act as a permanent groundwater barrier and alter baseline groundwater flows, specifically at Mottram Underpass (works 32 and 33).
- Excavation of rock cuttings that will result in drainage of groundwater, and a permanent change in groundwater levels associated with lowering of the ground surface, specifically at the eastern cutting (works 5 and 6).
- Any discharges associated with permanent groundwater drainage within the eastern cutting.

4.3.3. The work numbers listed above refer to The Work Plans and Work Plans Schedule (REP1-002).

4.3.4. Drainage within the cutting will release groundwater that will need to be intercepted and discharged. Discharge routes and permits will be agreed with Tameside Metropolitan District Council and the Environment Agency through the permitting process. It is anticipated that any discharges would be within the catchment to mitigate or prevent any potential reduction in baseflow.

4.3.5. In addition to Mottram Underpass, there are two other small underpasses along the Scheme at Old Mill Farm (work 31) and Carrhouse Farm (work 34). These underpasses are constructed from pre-cast concrete units that are installed wholly within the Glacial Till and do not include any piling. As such, potential impacts on the groundwater environment from these structures are considered to be negligible and they have not been included in this assessment.

4.4. Potential flow impacts

4.4.1. Baseline and scenario models have been developed to assess potential flow and drawdown impacts from the Scheme as described in section 3 and in the absence of any mitigation measures. The specific elements of the Scheme that have been modelled are summarised below, and more details on how they have been represented in the model described in Table 3.7:

- Mottram Underpass
- eastern cutting
- realignment of watercourses under the footprint of the Scheme

4.4.2. Potential flow impacts from the Scheme in the absence of mitigation are reductions in groundwater baseflow to watercourses as a result of the drawdown associated with the groundwater drainage in the eastern cutting.

4.4.3. Water features within 500 m that may be impacted by the Scheme were identified in the ES Chapter 13 and ES Figure 13.1 (APP-148). All of these water features are represented in the baseline and scenario groundwater models.

4.4.4. Changes in modelled baseflow to watercourses in the scenario model for the operational scheme were compared to those in the baseline model. WC_212 and WC_213 are removed as part of the Scheme development so changes in baseflow to these watercourses have not been assessed. All watercourses where a change in modelled baseflow was identified are shown in Table 4.2. Several watercourses pass directly through the road alignment and the eastern cutting and will be realigned, culverted or experience channel loss during construction works as summarised in the table.

4.4.5. A new watercourse will be constructed along the northern edge of the eastern cutting as shown in the Culvert and Drainage Plans (APP-017). This watercourse will outfall into WC_214 and any baseflow to this new watercourse has been included as part of WC_214 in Table 4.2.

4.4.6. The modelled changes presented in Table 4.2 do not account for the mitigating effects of discharge of abstracted groundwater to surface watercourses, which would offset some or all of the modelled loss in baseflow.

4.4.7. It should be noted that surface water courses and their interaction with groundwater is represented only by an applied head at the boundary condition within the groundwater model and although the groundwater model represents groundwater-surface water interactions well on a catchment scale, there is not enough observed data to calibrate modelled interactions with small water courses. As such the values presented in Table 4.2 should be viewed as indicative only.

Table 4.2: Modelled contributions to baseflow in watercourses within 500 m of the Scheme in baseline and scenario model

Watercourse	Planned changes to alignment of watercourse with Scheme	Modelled groundwater baseflow (m^3/s) – baseline model	Modelled groundwater baseflow (m^3/s) – scenario model	Difference (m^3/s)
River Etherow	None	1.01	1.01	-0.0007
WC_130, 140, 150 combined	None	0.0028	0.0028	-7.8×10^{-6}
WC_200 and WC_210 (Tara Brook)	Permanent culverting of WC_210 within Scheme footprint to tie-in to existing culverted reach downstream, and permanent loss of length of existing WC_210.	0.00062	0.00061	-1.2×10^{-5}
WC_211	Permanent loss of length of existing open channel within Scheme footprint.	0.0003	$<1 \times 10^{-6}$	-0.0003

Watercourse	Planned changes to alignment of watercourse with Scheme	Modelled groundwater baseflow (m^3/s) – baseline model	Modelled groundwater baseflow (m^3/s) – scenario model	Difference (m^3/s)
WC_214	Permanent loss of length of existing WC 214 open channel within Scheme footprint.	0.00006	0.00002	-4.0×10^{-5}
WC_215	None	0.00008	0.00007	-1.4×10^{-5}
WC_220	None	0.0028	0.0027	-0.0001
WC 300 (Hurstclough Brook)*	Permanent realignment of Hurstclough Brook (WC 300) within Scheme footprint, and associated culverts.	-8.18	-8.07	0.11

Water is lost from Hurstclough Brook to the model, this input is reduced in the scenario modelling

4.4.8. The potential significance of the identified impacts on baseflow from the groundwater model is summarised in Table 4.3 based on the modelled changes in baseflow in Table 4.2. Sensitivity of surface water receptors is based on the sensitivity assigned in ES Chapter 13.

4.4.9. Of the watercourses identified in Table 4.2, the model indicates that WC_211, WC_214 and WC_215 will be most affected by a reduction in groundwater baseflow due to the Scheme. These watercourses are all shallow drainage ditches, described in the WFD Assessment Compliance report as <1 m wide and with little observed flow when surveyed.

4.4.10. WC_211 and WC_214 are both heavily modified and realigned as part of the Scheme development. The significance of potential impact on the surface water environment due to channel loss and realignment in these watercourses has already been assessed in ES Chapter 13 and is designated as either neutral or slight adverse for considerations of water quality, hydromorphology and flood risk.

4.4.11. The greatest proportional impact on flow is on WC_211 where baseflow reduces from 0.0003 m^3/s to $<1\times10^{-6}$ m^3/s. However, this watercourse is known to already be impacted by anthropogenic activity as it currently receives a significant flow input from the urban surface water drainage system to the north-west of Old Hall Lane (see section 2.5.2), and change in baseflow therefore may be small by comparison to any changes to this connection to the surface water drainage network.

4.4.12. It should be noted that losses in baseflow identified here are to watercourses on a local scale. It is anticipated that water from groundwater drainage will be discharged to surface water courses, which would prevent any overall loss of water from the catchment. The location of this discharge has not yet been finalised and is subject to permitting agreement with Tameside Metropolitan Borough Council and the Environment Agency. Consultations to agree these are currently ongoing with both stakeholders, and the permits will be secured through the Environmental Management Plan (First iteration) (APP-183) as required by Requirement 4 in Schedule 2 of the draft Development Consent Order (DCO) (REP1-041). As the lost baseflow from the catchment will be compensated by discharge of drained groundwater, the residual magnitude of impact to the Etherow would be reduced to no change, and the significance to neutral. All residual effects to other receptors are either neutral or slight adverse.

Table 4.3: Potential significance of flow impacts as a result of reduction in baseflow

Receptor	Sensitivity	Residual magnitude of impact	Residual significance of effect	Comments
River Etherow	High	Negligible	Slight adverse	Very small reduction in baseflow – likely to be mitigated by discharge of drained groundwater within catchment.
WC_130, 140, 150 combined	Medium	Negligible	Neutral	
WC_200	Medium	Negligible	Neutral	
WC_210	Medium	Minor adverse	Slight adverse	Reduction in modelled baseflow along this watercourse, partly associated with culverting and permanent loss of length of existing WC_210 within Scheme footprint.
WC_211	Medium	Minor adverse	Slight adverse	Reduction in modelled baseflow along this watercourse, partly associated with permanent loss of length of existing open channel. This watercourse is known to receive input from urban surface water drainage network west of Old Hall Lane – the relative importance of groundwater baseflow compared to this input is not known and may be small.
WC_214	Medium	Minor adverse	Slight adverse	New watercourse will connect with current WC_214 to capture water in catchment draining to WC_212, WC_213 and WC_214. Nonetheless, a reduction in baseflow is modelled along this watercourse. This is partly associated with permanent loss of length of existing WC_214 open channel within Scheme footprint.

Receptor	Sensitivity	Residual magnitude of impact	Residual significance of effect	Comments
WC_215	Low	Minor adverse	Neutral	No changes to alignment/channel of this watercourse but will experience notable reduction in baseflow.
WC_220	Low	Negligible	Neutral	
WC_300 (Hurstclough Brook)*	High	Negligible	Slight adverse	

4.5. Potential drawdown impacts

Drawdown impacts associated with groundwater drainage in eastern cutting

4.5.1. Water features that may be affected by drawdown were initially identified in a water feature survey in 2018. In 2021 this water features survey was reviewed and supplemented by additional desk-based survey as summarised in Chapter 9 of this Environmental Statement. Tameside Metropolitan District Council confirmed that no additional records of private water supplies had been added since the 2018 survey.

4.5.2. Drawdown impacts have been assessed for all receptors within 1 km of the Scheme. There are no licensed abstractions or groundwater dependent terrestrial ecosystems within the study area. Receptors are all private abstractions and springs. Identified water features that are disused for water supply are not included as receptors in the assessment.

4.5.3. Modelled drawdown impacts from the scenario model at these receptors are summarised in Table 4.4 and shown on Insert 4.1~~Insert 4.1~~. These impacts are considered the likely case based on the calibrated groundwater scenario model. In order to account for the uncertainty surrounding the representation of the Mottram fault and the potential this could have on modelled impacts from the Scheme, an additional model run was carried out where the fault hydraulic conductivity was increased by one order of magnitude (see sections 3.4.5 to 3.4.8). Modelled drawdown impacts from this exercise are also presented in Table 4.4.

4.5.4. It should be noted that the groundwater model is a steady state model calibrated to average groundwater levels. The modelled impacts presented here represent likely impacts under average conditions.

4.5.5. Insert 3.13~~Insert 3.13~~ shows the greatest modelled drawdown is close to the eastern cutting and radiates north and eastward. The modelling suggests changes in groundwater level due to groundwater drainage in the eastern cutting would be >1 m up to a distance of 330 m from the Scheme. Impacts to the west are reduced by the low permeability of the Mottram fault.

4.5.6. Of the identified receptors, the greatest drawdown is modelled at Mottram Old Hall where a spring feeds a small stream and a pond in the garden. The spring is assumed to be sourced from the Millstone Grit aquifer and is upgradient of the pond and stream. At the spring the modelled drawdown impact is between 1.50 and 1.65 m, and between 1.80 and 2.65 m at the stream and pond, which are closer to the Scheme. These modelled drawdown values could have an impact on the flow from the spring, which in turn may impact water levels in the stream and pond. Additional monitoring at this location would likely be required to establish a baseline dataset and then monitor any impacts during dewatering trials in order to assess in more detail the likely impact at this location, such that suitable mitigation measures can be optimised ahead of construction.

4.5.7. At all other locations modelled drawdown is <0.5 m. Observed long term average groundwater level data has an average seasonal range in the Millstone Grit of 4 m, with some locations varying as much as 8 m. As such, a change in water levels of <0.5 m is not considered to pose a significant risk of derogation to the identified water supplies and has been assigned a residual magnitude of minor adverse, which is considered worst case.

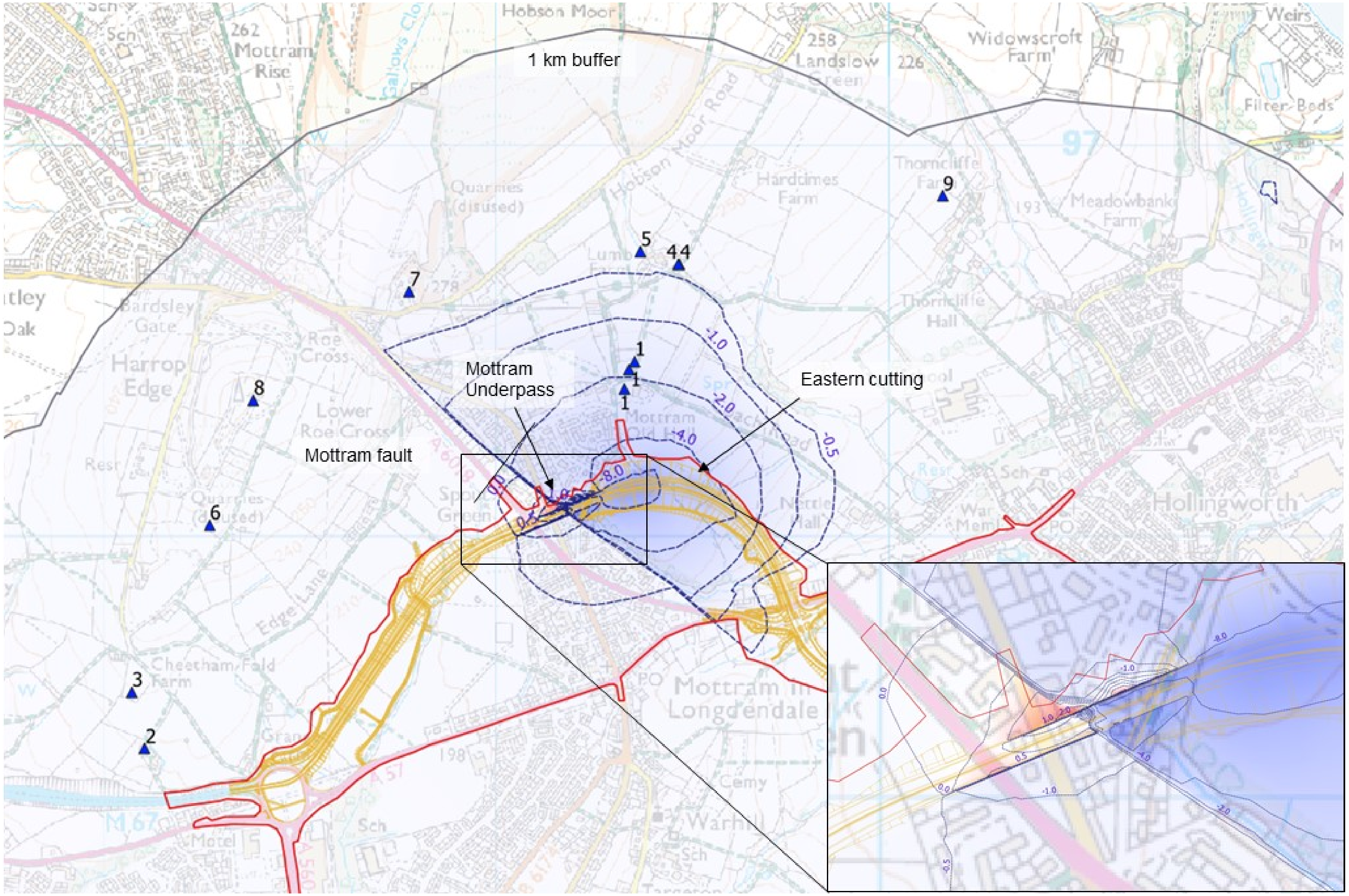
Table 4.4: Identified receptors that may be subject to drawdown impacts

ID	Location	Distance outside closest red line boundary (m)	Type	Description and use	Designated sensitivity	Modelled change in groundwater level (m)	
						Likely scenario	Increased fault permeability
1	Mottram Old Hall (3 records)	75	Spring, stream and pond	Spring feeds short stream and pond in garden. Not used for any other purpose. Hall is connected to mains water. Spring is fed from collection chamber up-gradient.	Low	Spring: -1.65 Stream: -2.00 Pond: -2.65	Spring: -1.50 Stream: -1.80 Pond: -2.40
2	Miniature Castle Farm	130	Spring/borehole	Non-potable domestic. Farm is connected to mains water.	Medium	< -0.10	< -0.10
3	Golden Springs Farm	270	Borehole	No details available	Medium	< -0.10	< -0.10
4	Lumb Cottage (2 records)	420	Borehole and spring located on adjacent land	Borehole reportedly 33.5 m deep fitted with electrical pump, supplies tank for potable and domestic use. No mains water connection. Spring historically runs dry in dry periods	High	-0.45	-0.40
5	Lumb Farm	430	Spring fed collection chamber	Potable. Overflows into animal trough and into Lumb Brook. Mains nearby but not connected.	High	-0.40	-0.30
6	Paddock Farm	510	Spring & well with electric pump	Potable. Spring historically runs dry in dry periods. Property not connected to mains water.	High	< -0.10	< -0.10
7	4 Hobson Moor Road	520	Spring	Spring disused. Borehole fitted with electric pump and used for	High	-0.40	-0.35

ID	Location	Distance outside closest red line boundary (m)	Type	Description and use	Designated sensitivity	Modelled change in groundwater level (m)	
						Likely scenario	Increased fault permeability
			Borehole	potable supply. No mains installed.			
8	Farm (north of paddock farm)	575	Borehole	Potable. Property not connected to mains water.	High	< -0.10	< -0.10
9	Thorncliffe Hall Farm and Nursery/Cottage	830	Borehole and spring	Borehole reportedly 80 m deep. Borehole used for agricultural use. Spring for potable, located uphill at Hard Times Farm.	High*	< -0.10	< -0.10

*high sensitivity has been assigned to those locations that use a groundwater source for potable supply and do not have any access to alternative sources.

Insert 4.1: Difference in hydraulic head (m) between baseline and scenario model and locations of receptors



Drawdown shown in blue, increase in hydraulic heads shaded red. Contains Ordnance Survey data © Crown copyright 2021.

Table 4.5: Potential significance of drawdown impacts

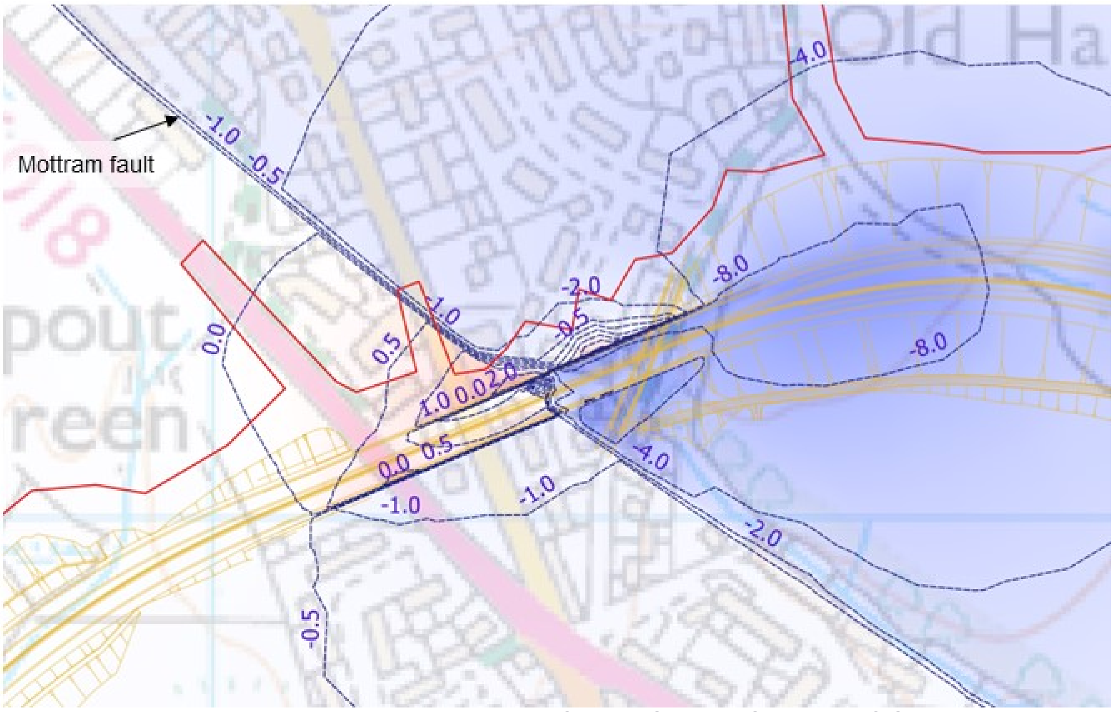
Receptor ID	Sensitivity	Residual magnitude of impact	Residual significance of effect	Comments
1	Low	Minor/moderate adverse	Slight adverse	Modelled drawdown of 1.65 m could impact flow in spring at this location. Spring feeds a pond in the garden.
2	Medium	Negligible	Neutral	
3	Medium	Negligible	Neutral	
4	High	Minor adverse	Slight adverse	Modelled drawdown of 0.4 m not anticipated to cause any significant derogation of water supply.
5	High	Minor adverse	Slight adverse	Modelled drawdown of 0.4 m not anticipated to cause any significant derogation of water supply.
6	High	Negligible	Slight adverse	
7	High	Minor adverse	Slight adverse	Modelled drawdown of 0.4 m not anticipated to cause any significant derogation of water supply.
8	High	Negligible	Slight adverse	
9	High	Negligible	Neutral	

Potential impacts associated with increased groundwater levels arising from secant pile walls through Mottram Underpass

4.5.8. Groundwater modelling identified potential increases in groundwater level behind the secant piles along the northern wall of the Mottram Underpass. Increases of up to 2 m were identified within the Millstone Grit immediately behind the wall as shown in Insert 4.2~~Insert 4.2~~. In this area baseline groundwater conditions are already artesian, commonly at or just below ground level (see Section 2.3). Depending on the hydraulic properties of near-surface deposits, this has the potential to cause discharge of groundwater at the surface, although the rate of any discharge would be limited by the low permeability of Glacial Till in this area.

4.5.9. An increase of 2 m is within the seasonal variability of the groundwater levels within the Millstone Grit aquifer. These increases are very localised and limited to within the red line boundary of the Scheme and therefore are not shown in the modelling to increase the risk of groundwater flooding to the area outside the Scheme. Outside the DCO boundary, the dominant effect is a modelled decrease in water levels resulting from drawdown associated with the eastern cutting. This is because of the extensive nature of groundwater drainage in the cutting compared to the short section of secant piling.

Insert 4.2: Difference in hydraulic head (m) between baseline and scenario model around Mottram Underpass



Drawdown in blue, increase in hydraulic heads shaded red. Contains Ordnance Survey data © Crown copyright 2021.

4.5.10. Groundwater flood risk was initially assigned a significance of slight adverse in Chapter 13 of this ES. Following that original assessment, the significance has been updated to neutral as the magnitude to the impact has been reduced from minor adverse to negligible. Groundwater flood risk is discussed further in the Flood Risk Assessment.

4.5.11. Permanent changes in groundwater levels can also be associated with ground settlement. Settlement assessment will be carried out during detailed design based on the outputs of groundwater modelling as detailed in Chapter 9 of this ES.

4.6. Water quality impacts

4.6.1. Discharge of groundwater from the eastern cutting to the surface water environment may pose an impact to surface water receptors. Groundwater sampling data collected in 2018 are summarised in Chapter 9. Additional data from samples collected in 2021 are summarised in the 2021 Ground Investigation Report[27].

4.6.2. Pertinent data relating to water quality samples collected from the area around the Mottram Underpass and cutting as part of the 2021 ground investigation are presented in this section.

4.6.3. Groundwater flowing into the drainage system along the cutting will be from the Millstone Grit aquifer. Samples collected from monitoring wells installed in the Millstone Grit in the area of the underpass and cutting have been screened against Environmental Quality Standards (EQS) as presented in “The Water

[27] Ground Investigation Report will be submitted to the Examining Authority as a supporting document during the examination before May 2022.

Framework Directive (Standards and Classification) Directions (England and Wales) 2015" (WFD Directions 2015)[28] which are protective of surface watercourses. The results of this screening exercise are presented in Table 4.6.

Table 4.6: Screening of 2021 groundwater samples against EQS

Determinand	No. of exceedances out of 35 samples	EQS (mg/l)	Max. value (mg/l)	Location
pH	1 out of 35 samples	6-9	9.4 (BH516)	Underpass/Cutting
Chloride	1 out of 35 samples	250	350 (BH513)	Underpass
Ammonium	26 out of 35 samples	0.26	2.0 (BH514A(D))	Underpass
Nitrite	24 out of 35 samples	0.01	2.2 (BH520)	Cutting
Cadmium	7 out of 35 samples	0.00008	0.0019 (BH551)	South of Cutting
Manganese	1 out of 1 samples	0.123	1.06 (BH519A)*	Cutting
Zinc	5 out of 35 samples	0.0123**	0.035 (BH551)*	South of cutting

*bioavailable concentration calculated using the WFD-UK metal bioavailability tool[29]
**EQS corrected for catchment background concentration as per WFD 2015[28]

4.6.4. Of the results presented in Table 4.6, two samples were taken during the 2021 pumping test. Samples collected during the pumping test are deemed to be more representative of likely discharged water from long-term groundwater drainage than those collected during routine monitoring rounds. The exceedances identified in the pumping test samples are summarised in Table 4.7.

Table 4.7: Screening of 2021 pumping test samples against EQS

Determinand	No. of exceedances	EQS (mg/l)	Max. value (mg/l)
Ammonium	1 out of 2 samples	0.26	1.5
Ammoniacal Nitrogen	1 out of 2 samples	0.20	1.6
Zinc	1 out of 2 samples	0.0123**	0.0196*

*bioavailable concentration calculated using the WFD-UK metal bioavailability tool[29]
**EQS corrected for catchment background concentration as per WFD 2015[28]

4.6.5. The screened data identify exceedances of several determinands that may pose a risk to surface water courses. All of these determinands are likely to be naturally occurring within the aquifer, and do not indicate the presence of any point source contamination that could be mobilised during dewatering activities. The greatest impact is anticipated to be from ammonium which was identified in multiple locations across the site. Samples from the pumping test indicate that ammonium concentrations are above the EQS and therefore that discharge of groundwater may pose a risk to surface water receptors.

[28] Water Resources, England and Wales, 2015. The Water Environment (Water Framework Directive) (England and Wales) Regulations.
[29] WFD UK TAG, 2014. The importance of dissolved organic carbon in the assessment of environmental quality standard compliance for copper and zinc.

4.6.6. The water quality of any potential discharged water would be assessed in detail as part of any permit application associated with the dewatering works during detailed design. Additional groundwater sampling, including during dewatering trials, is proposed to ensure water quality is in line with permit requirements.

4.7. Mitigation measures

4.7.1. It is anticipated that water from groundwater drainage will be discharged to surface water courses. The location of this discharge has not yet been finalised and is subject to permitting agreement with Tameside Metropolitan Council and the Environment Agency. In this case, the lost baseflow from the catchment will be compensated by discharge of drained groundwater. The exact location of the discharge will affect which watercourses benefit from the compensated baseflow.

4.7.2. In the WFD Assessment Report (APP-055) it was stated that where impacts associated with increases in groundwater levels in the Mottram area were significant due to the use of secant piles, alternative pile designs could be used instead. Modelled changes in groundwater levels in the Mottram area are dominated by drawdown associated with the drainage in the eastern cutting. The model does not indicate that groundwater flood risk would be significantly increased outside of the DCO boundary as a result of a secant pile design. Within the DCO boundary any groundwater contributions to surface water flows would be incorporated into drainage design.

4.7.3. These measures will be secured through the EMP (Second iteration), which will be updated at Detailed Design stage based on the EMP (First iteration) (APP-183), to incorporate the Register of Environmental Actions and Commitments (REAC) (REP1-037). This will be secured by Requirement 4 in Schedule 2 of the draft Development Consent Order (DCO) (REP1-041).

4.8. Proposed monitoring

4.8.1. A groundwater monitoring strategy for the Scheme will be prepared during Detailed Design and agreed with the Environment Agency. This will be a live document that may be updated throughout the duration of the Scheme. This will be secured through the REAC in the EMP (Second iteration) and secured by Requirement 4 in Schedule 2 of the draft Development Consent Order (DCO) (REP1-041).

4.8.2. It is anticipated that a proposed monitoring strategy would include:

- Baseline groundwater level monitoring prior to the start of construction.
- Baseline flow monitoring at receptors that may be impacted by the Scheme, namely the spring at Mottram Old Hall.
- Three rounds of groundwater sampling following completion of construction works.
- Ongoing groundwater sampling and level monitoring during construction.
- Sampling of any abstracted groundwater prior to discharge to surface water courses, in line with any permit requirements.

- Monitoring of identified groundwater receptors during dewatering trials that may be subject to drawdown impacts, namely the spring at Mottram Old Hall. Monitoring during construction would inform likely impacts from long-term groundwater drainage and inform any long-term monitoring strategy.
- Post-construction groundwater monitoring for six months following completion of the works.

4.8.3. Several rounds of groundwater sampling and groundwater level measurements were undertaken in 2021 as part of the additional ground investigation and form the start of baseline monitoring record. Continuous groundwater level monitoring along the Scheme is being installed at ten locations in spring 2022 and will remain in place for at least one year to establish a baseline record of seasonal variability in groundwater. Monitoring will continue during construction and used to inform any further mitigation measures that may be required.

5. Summary and conclusions

5.1.1. This HRA presents an update to the groundwater conceptual model for the Scheme based on a review of historical ground investigation data, and additional ground investigation carried out in 2021.

5.1.2. This conceptual site model was used to inform the setup and calibration of a 3D numerical groundwater model to represent the area of the Scheme in the baseline case. Changes were then implemented in a scenario model to represent the key features of the Scheme which may impact the groundwater system in the long term. This scenario model was used to simulate potential impacts on identified receptors in the operational phase of the Scheme. The results of the groundwater modelling were used to inform an HRA, in line with Environment Agency guidance.

5.1.3. The overall significance of impacts relating to groundwater as assessed in this document are summarised in Table 5.1~~Table 5.1~~. This document has assessed long-term impacts from the Scheme in the operational phase only. This assessment has not identified any significant impacts (i.e. greater than moderate) from the Scheme relating to groundwater.

5.1.4. Further assessment of water quality impacts associated with potential discharge of groundwater to surface water courses is required and will be addressed through the permitting process for any discharge.

5.1.5. In order to understand the true impacts from the Scheme as it is developed, a monitoring strategy will be prepared. This will be a live document that may be updated throughout the development of the Scheme. It is anticipated that a proposed monitoring strategy would include:

- Baseline groundwater level monitoring prior to the start of construction.
- Three rounds of groundwater sampling following completion of construction works.
- Ongoing groundwater sampling and level monitoring during construction

- Sampling of any abstracted groundwater prior to discharge to surface water courses, in line with any permit requirements.
- Post-construction groundwater monitoring for six months following completion of the works.
- Recommendations for baseline and construction monitoring for receptors that have been identified in this document which may be impacted by the Scheme, namely the spring at Mottram Old Hall.

Table 5.1: Significance of overall impacts to groundwater associated with the Scheme assessed herein

Phase	Potential impact	Previous assessed significance	Assessed significance based on HRA herein
Operation	Deep foundations may act as barriers to groundwater and permanently alter groundwater flow pathways, this may have knock-on impacts on baseflow to surface water courses and local groundwater abstractions.	Slight adverse – reviewed within this document.	Neutral to slight adverse
	Deep foundations may act as barriers to groundwater and result in increased groundwater levels, increasing groundwater flood risk.	Slight adverse – reviewed within this document	Neutral
	Drainage of groundwater (passive dewatering) associated with cuttings may cause reduction of groundwater levels which could have impacts on baseflow to surface water courses and local groundwater abstractions.	No measurable impact on regional groundwater body. No assessment of local impacts.	Neutral to slight adverse
	Discharge of groundwater derived from long-term groundwater drainage to surface water bodies and potential impact on surface water quality.	N/A	Further assessment during permitting process

Please refer to Table 1.1~~Table 1.1~~ for impacts assessed in other submission documents.

Appendix A. Groundwater modelling

A.1 Recharge methodology

A.1.1 The spreadsheet SMBM used in this work is a modified version of the method described by Rushton[30].

A.1.2 The SMBM approach only allows recharge to occur when the soil exceeds its field capacity; during drier periods, a soil moisture deficit (SMD) occurs. The soil moisture deficit is a function of the vegetation and soil type and rainfall in the preceding days. The SMD cannot exceed zero – when the soil is fully saturated any additional precipitation is assigned to recharge up to the infiltration capacity of the underlying geology. Once the infiltration capacity is exceeded, additional precipitation is designated as surface runoff and does not affect subsequent calculations within the SMBM.

A.1.3 The value of SMD_i for a given day, i, is calculated based on the following factors (given as equivalent water depths in millimetres):

- daily precipitation (P)
- the soil moisture deficit from the previous day (SMD_{i-1})
- total available water (TAW), which represents the total amount of water that can be removed from the soil by transpiration
- readily available water (RAW), which represents the amount of water that can transpire from the soil before transpiration is reduced
- potential evapotranspiration (ET_0) which describes the rate of evapotranspiration that would occur from well-watered grass
- actual evapotranspiration (AE), which differs from ET_0 when SMD exceeds RAW

30 Rushton, K. R., Eilers, V. H. M. & Carter, R. C., 2006. Improved soil moisture balance methodology for recharge estimation. Journal of Hydrology, pp. 318:379-399.

A.1.4 SMD_i is given by:

$$\mathrm{SMD}_i = \mathrm{SMD}_i - \mathrm{P}_i + AE_i$$

A.1.5 In the SMBM, values of SMD_i cannot exceed zero. Any additional precipitation is assigned to recharge, up to the infiltration capacity of the underlying geology. Once the infiltration capacity of the soil is exceeded, additional precipitation is designated as surface runoff and does not affect subsequent calculations within the SMBM.

A.2 Input parameters for the SMB model

A.2.1 Daily precipitation values were obtained from the HadUK[20] dataset for the period 1990-2020.

A.2.2 Potential evaporation data were obtained from the Environment Agency[16] for a hypothetical well-watered grass crop. The dataset is a catchment averaged value for the model domain area extracted from a 1 km gridded dataset and provided on a daily basis for the period 1990-2020.

A.2.3 ET_0 was converted to AE using:

$$AE = K_c \times K_s \times ET_0$$

where K_c is a crop coefficient, that reflects seasonally-varying differences in evapotranspiration between the well-watered grass reference and any given vegetation and K_s is a water stress coefficient, that reflects the reduction in evapotranspiration that occurs when plants are under drought stress (i.e. SMD exceeds the RAW).

A.2.4 The water stress coefficient K_s is applied when RAW < SMD_{i-1} < TAW and is given by:

$$K_s = \frac{TAW - SMD_{i-1}}{TAW - RAW}$$

A.2.5 TAW is calculated as follows[17]:

$$TAW = 1000(\theta_{FC} - \theta_{WP})Z_r$$

where θ_{FC} is the moisture content of the soil at field capacity, θ_{WP} is the wilting point (m^3/m^3) and Z_r is the rooting depth (m). Values for θ_{FC}, θ_{WP} and Z_r were taken from the FAO56 document[17].

A.2.6 RAW is calculated as follows[24]:

$$RAW = pTAW$$

where p is derived from values listed in the FAO56 document[24].

A.3 Water balance – baseline model

Table 5.2: Groundwater balance for model domain

Component	In (m^3/d)	Out (m^3/d)	Net (m^3/d)
Groundwater recharge	94,200	-	94,200
North-western boundary	2,000	5,000	-3,000
Western boundary	16,000	21,000	-5,000
South-western boundary	6,000	3,300	2,700
Small water courses and springs (Seepage boundary conditions)	-	69,300	-69,300
River Etherow, Hurstclough Brook, Glossop Brook (Cauchy boundary conditions)	5900	25,000	-19,100
United Utilities Aqueduct (Cauchy boundary conditions)	-	500	-500
Imbalance	0		

A.4 Changes made during model calibration

Hydraulic properties of the Millstone Grit

A.4.1 Calibrated hydraulic conductivity of the Millstone Grit in layer 3 is shown in Insert 3.10~~Insert 3.10~~ and Insert 3.11~~Insert 3.11~~. The range of values is summarised in Table 3.6, all values lie within the range of field data, as discussed in section 2.6.1.

A.4.2 Groundwater flow is known to decrease with depth within the Millstone Grit as discussed in section 2.2.4. As such, a lower hydraulic conductivity was applied in layer 4 than in layer 3 to represent more active flow in the upper 20 m of the aquifer.

A.4.3 The hydraulic conductivity of the Millstone Grit is zoned in order to represent the observed hydraulic gradient across the Scheme area which is flatter on the valley floor than in the valley sides. To match the hydraulic gradient across the valley floor between the River Etherow and the A57 Mottram Moor Road, a zone of higher hydraulic conductivity within the Millstone Grit was applied around the Etherow. The same properties were applied around the River Tame for the same reason. A review of the BGS water well database[31] was carried out to inform the values applied - at Mossley, a pumping test close to the River Tame quoted a transmissivity of 12 m^2/d. In the Etherow valley, water levels and pumping rates are available from the BGS database[33] which indicate transmissivities up to 90 m^2/d. For the 20 m flow horizon in layer 3 this equates to K of up to 5×10^{-5} m/s. Hydraulic conductivity was also zoned in layer 3 of the Millstone Grit along Hollingworth Brook, Glossop Brook and the lower reaches of Hurstclough Brook to facilitate improved calibration.

A.4.4 Millstone Grit hydraulic conductivity was also zoned to represent likely differences in permeability between Millstone Grit that is covered by glacial deposits, and therefore has been buried under ice during Quaternary glaciation, and that on high ground that has not been glaciated. The rationale for this is that where bedrock has been buried under thick ice sheets, it will also have had subglacial sediments forced into fractures and fissures , thereby reducing its permeability. Post-glaciation, Millstone Grit bedrock exposed at outcrop on high ground will have been subject to weathering which will open fractures, increasing permeability and exacerbating the contrast between its hydraulic properties and those of the strata buried beneath thick clay..

A.4.5 The fault block immediately to the west of the Mottram fault has been assigned a higher hydraulic conductivity than that to the east of Mottram fault in order to represent the shallow hydraulic gradient west of the fault. The extent of this zone was determined by the extent of the mapped fault block.

[31] British Geological Survey, 2021. [redacted] SD90SE20 [Accessed 04/09/2021]

Fault parameterisation within the Millstone Grit

A.4.6 The Mottram fault and other mapped faults within the vicinity of the Scheme are represented in the model mesh based on BGS mapping as can be seen on Insert 3.11~~Insert 3.11~~. Fault properties were used as a calibration parameter and, where the Mottram Fault crosses the Scheme, the fault extent and exact location was adjusted to match observed water level and borehole records where evidence of faulting was identified. The Mottram fault was assigned a hydraulic conductivity of 5×10^{-10} m/s.

A.4.7 Reduced permeabilities (5×10^{-9} m/s) were applied to a second fault, trending N-S immediately to the west of the Scheme, as shown on Insert 3.11~~Insert 3.11~~. The Mottram fault terminates against this second fault. This fault also cuts through the Millstone Grit and has been assigned reduced permeabilities to act as a flow barrier in the same way as the Mottram fault. It is likely that other faults in the region exhibit similar behaviour but these have not been represented as they are away from the area of interest and do not impact the calibration of the model in the vicinity of the Scheme.

Hydraulic properties of the superficial deposits

A.4.8 Hydraulic conductivity of the superficial deposits in layer 1 is shown on Insert 3.10~~Insert 3.10~~ and Insert 3.11~~Insert 3.11~~.

Representation of the United Utilities Aqueduct

A.4.9 Modelled groundwater levels in the vicinity of the United Utilities Aqueduct were initially markedly higher than observed groundwater levels within the Millstone Grit. Observed groundwater levels were similar to the likely invert level of the aqueduct and substantially lower than might be expected from the prevailing hydraulic gradient across the wider area. This implies there is connectivity between the aquifer and the aqueduct, which is known to have water levels close to the invert level for at least part of the time. Where it crosses the Scheme, the aqueduct is a cut and cover tunnel at the top of the Millstone Grit. Further west, underneath Mottram, it is a bored tunnel within the bedrock – in some places it is thought to be brick-lined, and elsewhere cut directly into the rock, but in either case it is likely to receive contributions from groundwater.

A.4.10 The exact location and depth of the aqueduct is classified information. Its location in the model was based on publicly available information about its construction[13]. It was represented in the model mesh using Cauchy boundary conditions to allow a transfer rate to be applied to control the degree of connectivity between the model and the aqueduct. Hydraulic heads at the boundary conditions were applied to approximate the invert level of the tunnel. Water levels within the tunnel are unknown but it is approximately 2 m high and inspection photographs show water depths of several tens of centimetres.

A.4.11 The aqueduct was applied in either slice 3 (at the interface of superficial deposits and bedrock) or at slice 4 (20 m deep within bedrock) according to which was closer to its true depth. The transfer rate (see section 3.2.13) was then defined as φ = K/d where K was taken as the vertical permeability of the layer and d as the vertical distance between the slice and the aqueduct elevation and adjusted during calibration to reflect uncertainty and spatial variations in the aqueduct lining.

Drainage at Old Hall Lane

5.1.6. To the east of Old Hall Lane United Utilities has recorded likely connectivity between the surface water drainage system and groundwater which discharges at the source of WC_211 (section 2.5.2). Site inspection works have shown a drainage connection between collection chambers on Old Hall Lane. Modelled groundwater levels in this area are notably higher than observed data – the calibration in this area was improved by applying a seepage boundary condition along the line of the drain in slice 3 to represent this drainage system.

Transfer rate

5.1.7. Transfer rate along the Etherow was a calibration parameter and varied to improve calibration. The calibrated value is 1×10^{-6} s^{-1}, equivalent to a 1 m thick clogging layer of material with K = 1×10^{-6} m/s, such as a sandy silt.

Infiltration capacity

5.1.8. Infiltration capacity is a calibration parameter that represents the capacity of underlying geology to accept recharge in mm/d. Initially the Glacial Till was assigned an infiltration capacity of 0.5 mm/d, during calibration this was increased to 1 mm/d in areas where the Till was <5 m thick.

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National Highways Limited registered in England and Wales number 09346363