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Hydrogeological conceptual model of the Gateshead Area - Project Groundwater Northumbria

Project Groundwater Northumbria

Commercial report CR/26/045



BRITISH GEOLOGICAL SURVEY

COMMERCIAL REPORT CR/26/045

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Summary

This report has been produced by the British Geological Survey (BGS) on behalf of Project Groundwater Northumbria, the Flood and Coastal Resilience Innovation Programme (FCRIP) project led by Gateshead Council. It uses existing data and information to provide a conceptual understanding of the hydrogeology of the Newcastle-Gateshead area, whilst discussing recent groundwater trends and groundwater flood susceptibility in the area. It also provides information on how historic coal mining may impact the groundwater system. The report shows two schematic cross-sectional diagrams to visually conceptualise groundwater across the area.

The Gateshead - Newcastle Upon Tyne area geology is composed of sandstones, mudstones, siltstones and coals. This results in a multi-layered aquifer system comprising permeable sandstone aquifers separated by low permeability rocks which form aquitards. Thicker and laterally extensive sandstones, which were deposited by river channels during the Carboniferous Period, form channelised, southwest-northeast orientated aquifer units situated at various depths. Aquifer units may be poorly connected or disconnected from one another, resulting in confined aquifers at depth. Fractures within the bedrock, particularly within the sandstones, and major faults such as the Ninety Fathom fault are likely to facilitate groundwater storage and movement.

Complex and often thick superficial deposits overlying the bedrock impact groundwater where recharge and discharge occur. Groundwater recharge and discharge is inhibited where thick, low permeability, clay-rich till is present. There are also buried valleys which contain complex superficial deposits, often forming a series of aquifers and aquitards. Superficial deposits form significant aquifers where they comprise of permeable sands and gravel. These deposits maybe connected to bedrock aquifers, enabling groundwater exchanges between superficial and bedrock aquifers.

Abundant mine workings across the region increase aquifer storage, and potentially form pathways for groundwater flow, connecting separate aquifer units. Since mining has ceased and pumping of mine waters has stopped or reduced in many locations, groundwater levels have risen (recovered) rapidly across most of the area. This recovery results in natural springs being reactivated as well as mine water discharge occurring via adits and old workings.

Groundwater flood risk has increased as a result, particularly in low relief areas (<10 metres above Ordnance Datum (mAOD) including the River Tyne, River Team and River Derwent valleys where groundwater levels are near or at the surface. Groundwater flooding is also possible in higher elevation areas associated with mine water discharge and where bedrock aquifers outcrop at the surface.

1 Introduction

1.1 BACKGROUND AND SCOPE

This report presents a conceptual hydrogeological model for the Newcastle-Gateshead area as part of commissioned work for Project Groundwater Northumbria (PGN), part of the Flood and Coastal Resilience Innovation Programme (FCRIP) project led by Gateshead Council. This report incorporates and builds on previous work including groundwater flood risk susceptibility work undertaken by the Environment Agency (EA) and superficial deposit hydrogeological domains work undertaken by BGS (Whitbread et al., 2024).

The PGN project work is intended to help project partners including the Environment Agency and Gateshead Council understand both spatial variations in recharge to bedrock aquifers and highlight areas where outflow from aquifer units or historic mine workings may increase risks of groundwater flooding, and/or interact with surface water systems and shallow superficial aquifers.

This report provides a conceptual understanding of regional groundwater recharge, flow and discharge for both bedrock and superficial aquifers. It also highlights mining impacts on groundwater flow, aquifer connectivity and flood susceptibility in the Gateshead and Newcastle area. Conceptual hydrogeological cross-sections have been produced to illustrate the various hydro(geo)logical processes and sources of groundwater flooding.

1.2 AREA OF INTEREST

The Area of Interest (AOI) covers that of the superficial hydro domains work by Whitbread et al. (2024) but extends 1.2 km further east. The area includes the Gateshead Council district, most of Newcastle Upon Tyne Council district, and parts of County Durham, Northumberland and Sunderland Council district.

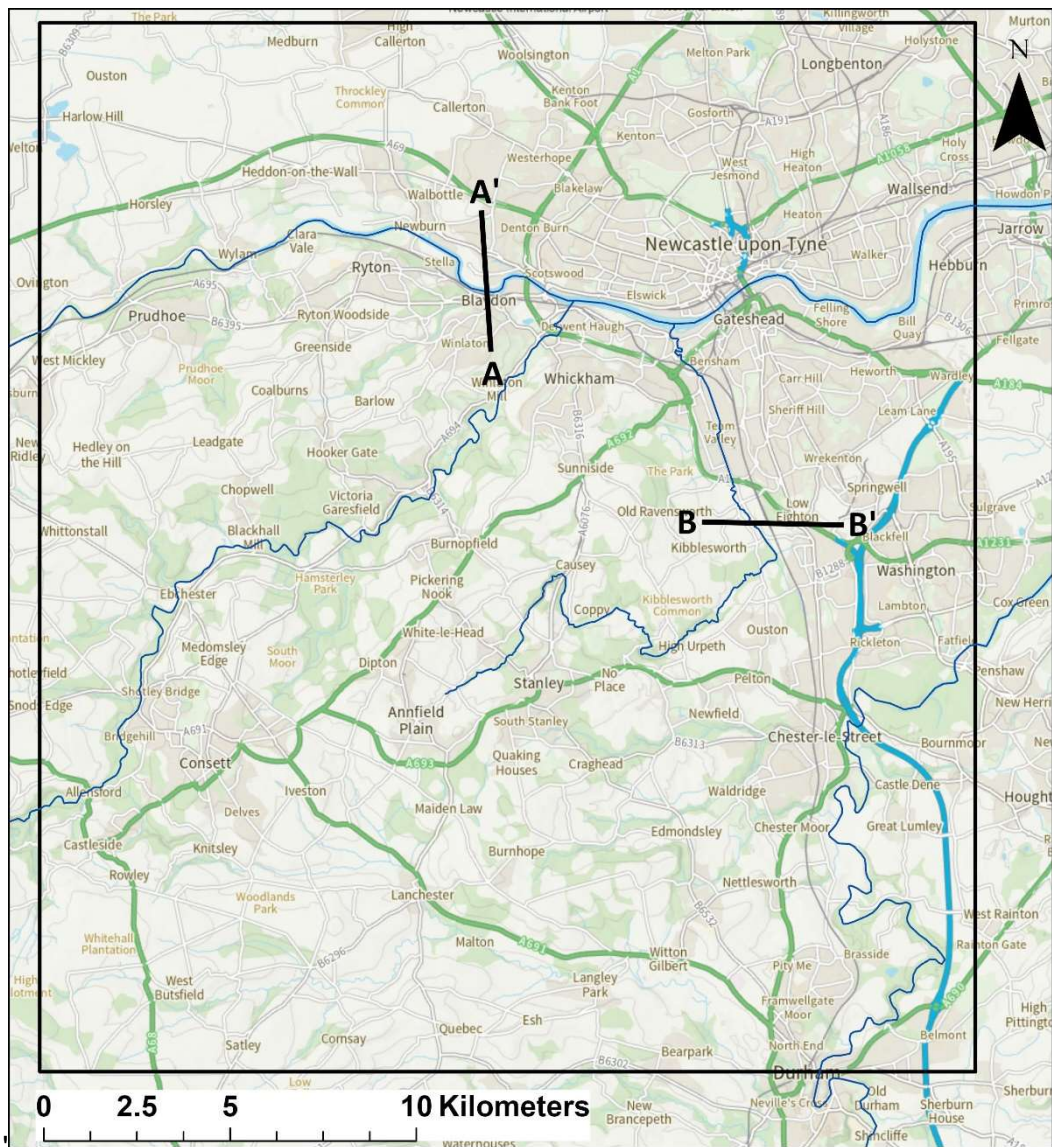


Figure 1: Area of interest used for the conceptual model, bounded by the black outline. Figures 11 and 12 cross-section locations are shown. Contains OS data © Crown Copyright and database right 2026. OS AC0000824781.

1.3 GEOGRAPHY AND CLIMATE

The AOI comprises the River Derwent and the River Team which flow approximately northeast where they join the lower reaches of the River Tyne which flows eastwards into the North Sea. Part of the River Wear (flowing northwards) is also in the AOI. The UK National River Flow Archive (Nfra) have calculated a base flow index for these rivers. Baseflow Index (BFI) ranges between 0 and 1 reflecting approximate relative contributions of groundwater and surface water to river flow; a BFI of 0 would indicate 100% surface water derived flow, whilst a BFI of 1 indicates 100% groundwater derived flow. The River Tyne at Bywell has a baseflow index of 0.39, the Derwent at Rowlands has a BFI of 0.58 and the River Team at Team Valley has a BFI of 0.69 (Nfra, 2026), suggesting it receives the largest groundwater contribution.

These river valleys form the lowest relief areas, particularly along the Tyne which is tidal as far upstream as Wylam. The highest elevations of 250-350 mAOD are found to the west and southwest (Figure 2). The large urban areas of Gateshead and Newcastle Upon Tyne are situated in the northeast of the AOI, whilst other urban centres include Washington, Prudhoe, Ryton, Blaydon, Consett, Stanley, Kibblesworth, Whickham, Lanchester, Chester-Le-Street and Durham.

The area has a mild, temperate, maritime climate with precipitation occurring year-round, but peaking in the autumn and winter months. Annual rainfall varies from >800 mm/yr in the higher elevations to the west and southwest, to <700 mm/yr further east around Newcastle Upon Tyne (Met Office, 2025). Actual evaporation in the region is around 470-530 mm/yr (Kay et al., 2013), indicating that approximately 170-330 mm/yr is available for potential recharge. Most aquifer recharge occurs during the winter months when precipitation is typically higher, and evaporation is significantly lower than during the summer months.

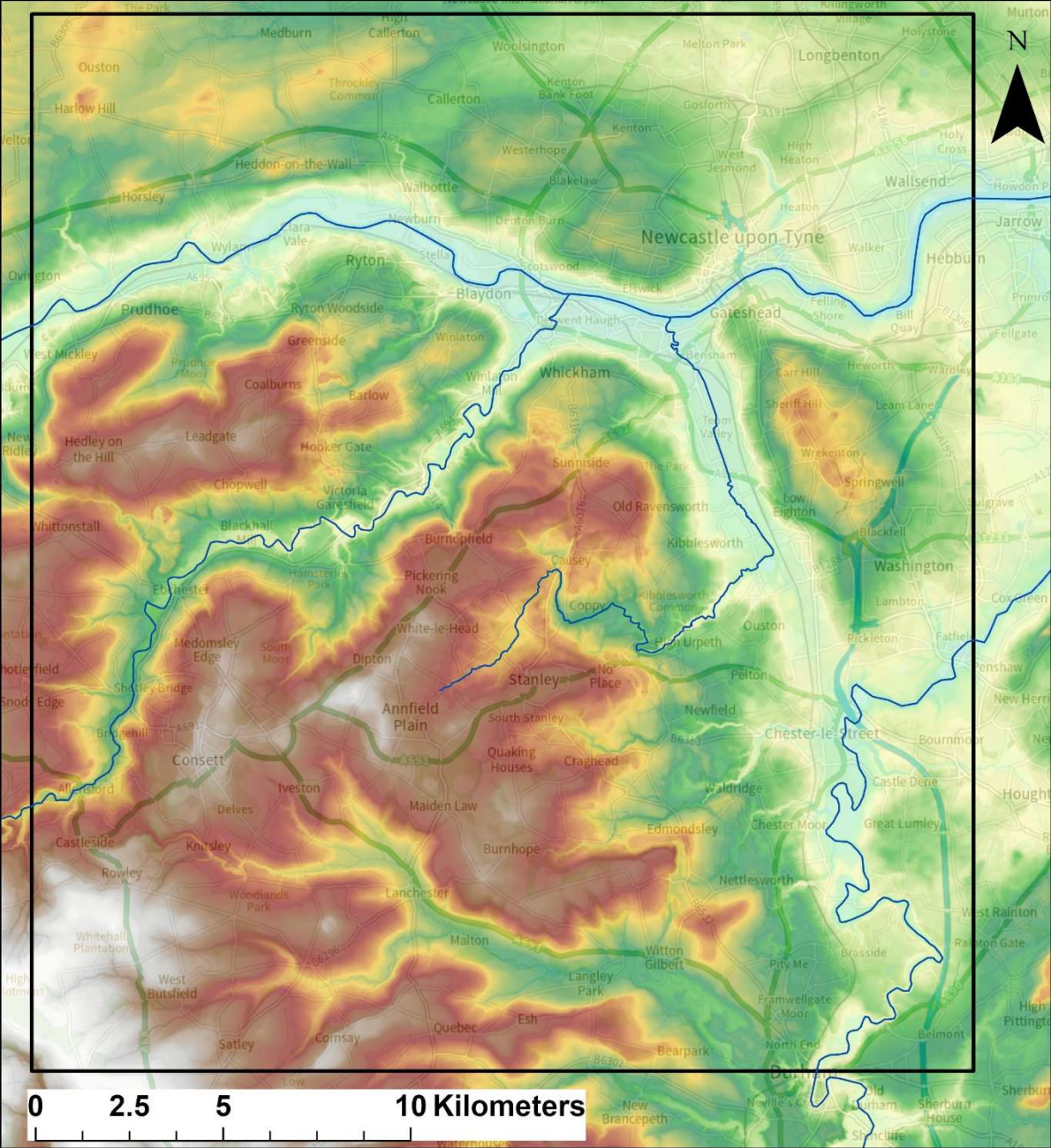


Figure 2: Topographic map of the AOI and main rivers. Topographic map data modified from © Environment Agency copyright and/or database right 2022. All rights reserved. Contains OS data © Crown Copyright and database right 2026. OS AC0000824781.

1.4 GEOLOGY OF THE AREA

The bedrock geology of the area is briefly summarised here as it has been discussed and examined in detail in the following reports:

- Project Groundwater Northumbria (FCRIP) – Phase 1 Geological Cross-sections report (CR/22/136) by Kearsley et al. (2023) and
- Bedrock Sandstone channel subsurface mapping for the Gateshead area – Project Groundwater Northumbria (CR/24/080) by Kearsley et al. (2024).

The superficial geology of the area has also been examined in detail, including in the following report:

- Superficial hydrogeological domains for the Gateshead area – Project Groundwater Northumbria (CR/24/066) by Whitbread et al. (2024).

1.4.1 Structural Geology

There are hundreds of mapped faults in the area, ranging from minor faults to major faults such as the Ninety Fathom fault. Major faults with stratigraphic throws >100 m identified by Kearsley et al. (2023) are highlighted in Figure 3. Sedimentary deposits generally dip to the east unless affected by smaller scale structures.

Major faults form important structural controls on regional groundwater flow as their displacement is likely to subdivide any aquifer units which would otherwise be laterally and / or vertically continuous. However, faults and their associated damage zones can also act as conduits for groundwater flow as groundwater can be stored in between the fractures if they have not been infilled by fault rocks (e.g. clay-rich fault gouge) or precipitated minerals (Bense et al., 2013). Major faults in this area have wide damage zones (~80m) with minimal gouge development (Stephens et al., 2026).

1.4.2 Bedrock Geology

The geology of the area comprises sedimentary strata from the Namurian and Westphalian stages of the Carboniferous period (Stone et al., 2010). Sedimentary sequences generally dip to the east and are typically thickest in the east – northeast. The oldest rocks in the AOI outcrop in the west, whilst the youngest strata outcrop in the east. The oldest exposed strata comprise the Millstone Grit of the Stainmore Formation which surfaces in the far west of the AOI and in the Derwent valley (Figure 3).

Above this formation lie the Pennine Lower Coal Measures (PLCM), exposed in valleys in the west but found at increasing depths further east towards the coast. The PLCM comprise interbedded Sandstones, Mudstones, Siltstones and Coals. Prominent coal seams include the Brockwell, Busty and Harvey seams which have been extensively mined, especially in the west of the AOI.

Above the PLCM lie the Pennine Middle Coal Measures (PMCM) which are exposed extensively at the surface, where not buried beneath superficial deposits. The PMCM also generally dip and thicken to the east, whilst the upper parts have been eroded out in the west and in some river valleys. The PMCM comprise interbedded Sandstones, Mudstones, Siltstones and a higher proportion of Coal seams compared to the PLCM. Worked coal seams include the Hutton, Durham Low Main, Maudlin and High Main coals. Prominent sandstones include the High Main Post Member and Grindstone Post Member which are exposed in parts of the Tyne Valley in the east, but they are absent further west where they have been eroded out (Figure 3).

The Pennine Upper Coal Measures (PUCM) and a minor outcrop of Permian age strata are present at the surface in the far northeast of the AOI to the north of the Ninety Fathom Fault.

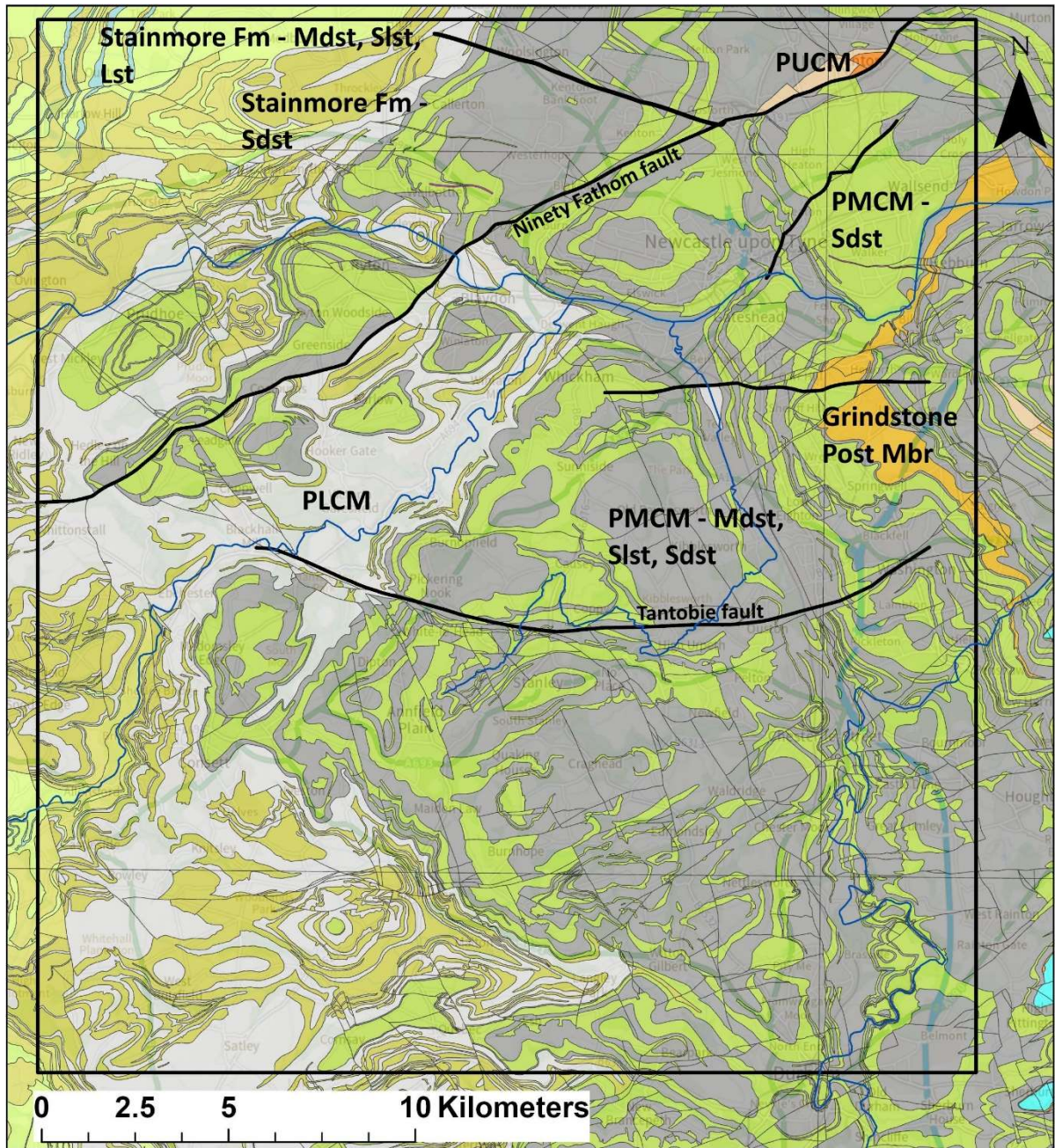


Figure 3: Bedrock (1:50 000 scale) geology showing the main formations (labelled) and major faults (black lines). Mdst = mudstone, Slst = siltstone, Sdst = sandstone, Lst = limestone. BGS © UKRI 2026. Contains OS data © Crown Copyright and database right 2026. OS AC0000824781.

1.4.3 Superficial Geology

Superficial deposits cover much of the AOI (Figure 4). They overlie the bedrock and are therefore commonly exposed at the surface. Superficial deposits in the AOI comprise glacial and postglacial sediments deposited during and after the last glaciation period in the Late Devensian. Deposits include an extensive cover of glacial till, glaciofluvial (typically sand & gravel), and glaciolacustrine (typically silt and clay) deposits (Whitbread et al., 2024). Glacial deposits are overlain by modern river terraces and alluvium along river courses (Whitbread et al., 2024). As Figure 4 shows, superficial deposits cover much of the AOI but are thickest in the valleys and palaeo-valleys and in lower elevation areas in the east.

The distribution and architecture of superficial deposits reflect the geological evolution of the area, particularly the processes and events occurring during deglaciation (Whitbread et al., 2024). As glaciers retreated to the north and west, a large glacial lake developed in the Tyne-Wear lowlands as drainage was blocked to the east by the presence of ice in the North Sea (Davies et al., 2019; Livingstone et al., 2012, 2015). During and following the glacial retreat, glaciofluvial sands and gravels were deposited at the margins of the Tyne and North Pennines glaciers (Yorke et al., 2007, 2012), and laminated glaciolacustrine silts and clays were deposited within the glacial lake (Whitbread et al., 2024). This lake extended along a network of deep buried valleys along the Rivers Tyne, Team and Wear (cf. Mills and Holliday, 1998). Following deglaciation of the area, river terrace deposits and alluvium have been deposited along rivers and streams, particularly along the Rivers Tyne, Team, Wear and Derwent. These river deposits may have locally reworked the earlier glaciofluvial and glaciolacustrine deposits in these areas.

For Project Groundwater, the BGS characterised superficial deposits found across the area into superficial hydrogeological domains to help understand the influence of complex superficial deposit sequences on groundwater recharge and discharge from underlying bedrock aquifers (Whitbread et al., 2024). Hydro-domains are discussed in section 3.2.

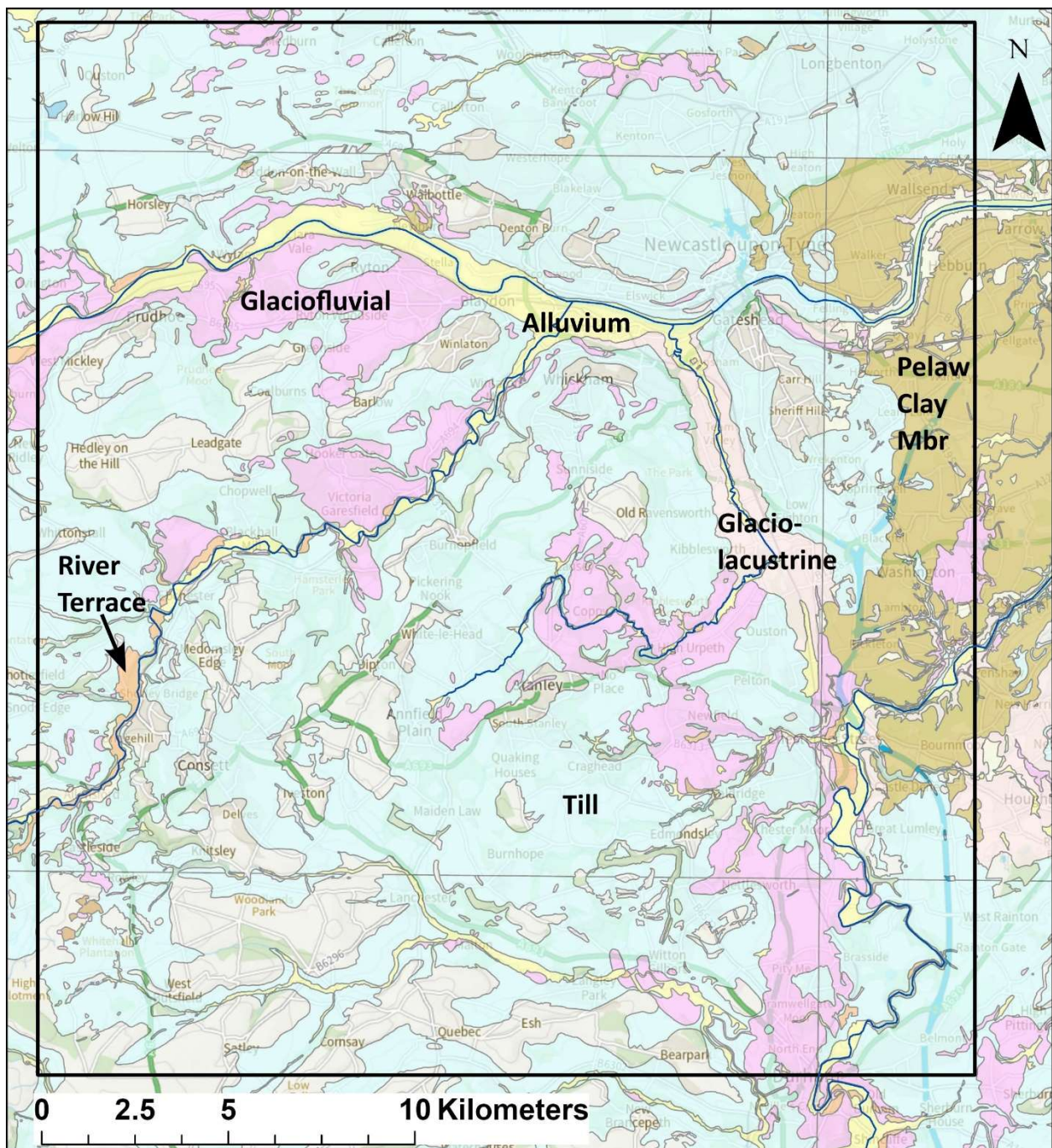


Figure 4: Mapped superficial deposits (1:50 000 scale) in the AOI. BGS © UKRI 2026. Contains OS data © Crown Copyright and database right 2026. OS AC0000824781.

1.5 SUMMARY OF MINING IN THE AREA

The AOI comprises part of the Northumberland and Durham coalfield. Coal mining was prevalent throughout most of the area except in western fringes and parts of the Derwent Valley.

Coal throughout the Pennine Coal Measures Group, from the Brockwell and Victoria seams to the High Main seam were worked, initially targeting easily accessed seams close to, or at, the surface and in proximity to transport routes (e.g. the River Tyne and coast). However, deeper seams were mined in the 19th and 20th century. Mining methods initially began as drift mining and bell pits before pillar and stall mining took over (Smailes, 1935). More efficient longwall mining took place towards the end of 19th century and into the 20th century, whilst open cast mines were also present in some locations. During mining operations, large volumes of groundwater were pumped or drained out of the mines to enable operations. Groundwater

levels in the Durham Coalfield were maintained at around 150 m below ground level (Downing, 1998).

Once deep mines closed, many were backfilled with local material, whilst others were left open. Many mines became flooded as pumping ceased and the groundwater levels recovered. In places, this has led to mine water discharge causing flooding and deterioration in water quality (Younger, 2003).

The terms mine water and groundwater are both used in this report. The term mine water is used when specific to mines, whilst the term groundwater is used more generally and when not specifically linked to mines. Mine water is essentially groundwater that has seeped into mine workings through fractures, joint and pore spaces from the surrounding rock, sometimes combined with surface water (e.g. rainwater, stream water etc) which has entered mine workings through shafts, boreholes or other disturbances at the surface.

1.6 GROUNDWATER FLOODING

Groundwater flooding is the emergence of groundwater at the ground surface away from perennial river channels or the rising of groundwater into man-made ground, under conditions where the 'normal' ranges of groundwater level and groundwater flow are exceeded.

Unlike surface water flooding (e.g. rivers or surface runoff) which is highly responsive to rainfall events, groundwater flooding occurs following long periods (months or sometimes years) of above average rainfall. Groundwater flooding most commonly occurs in the late winter and spring following high winter rainfall combined with low evapotranspiration resulting in significant aquifer recharge. Groundwater flooding may happen slowly and often less frequently than river flooding, but when it does occur, it can persist for weeks or even months.

2 Datasets and methods

Numerous data sets have been used to develop this hydrogeological conceptual understanding of the Gateshead area. Key datasets are listed below.

BGS datasets

- Bedrock (1:50 000) geology, superficial (1:50 000) geology, and structural geology maps
- Depth to groundwater (gwlevel_v4) raster dataset
- Groundwater Flooding susceptibility map (50 m resolution, v6.1)
- Groundwater recharge and discharge model raster dataset
- SOBI borehole logs
- Permeability dataset (1:50 000)
- Aquifer properties data (Jones et al., 2000)
- Spring locations dataset

Project Groundwater datasets (including BGS and EA)

- Project Groundwater Northumbria - Geological Cross-sections (Kearsey et al., 2023)
- Project Groundwater Northumbria - Superficial hydrogeological domains for the Gateshead area (Whitbread et al., 2024)
- Project Groundwater Northumbria - Bedrock Sandstone channel subsurface mapping for the Gateshead area (Kearsey et al., 2024b)
- Groundwater level data at two monitoring boreholes
- Project Groundwater Northumbria: Gateshead Study Area Mine Water Flood Susceptibility Map (EA, 2025)

Environment Agency (EA) datasets

- Groundwater level data at 10 monitoring boreholes (Hydrology explorer)
- Rainfall data (Hydrology Explorer)

- Mine discharge locations
- Spring locations (Hydronodes)
- Flood susceptibility spatial data and methodology report
- Shallow mine workings

Mining Remediation Authority (MRA) datasets

- Mine Water block areas (2022)
- MRA mine water block hydrogeological conceptual model reports (Wyatt, 2022; Marchi-Smith & Wyatt, 2022)
- MRA water level and abstraction data, NE England monitoring sites list, NE England discharges list, Chemistry data
- Mine water contours (current and future)

Gateshead Living Lab

- Groundwater level data at four monitoring boreholes

Gateshead Council

- Gateshead Council Level 1 Strategic Flood Risk Assessment, 2018 (JBA consulting)

Information from these datasets were used to develop conceptual cross-sections showing hydrological and hydrogeological processes, the hydrogeological impacts of mining and how these relate to groundwater flood susceptibility.

3 Hydrogeology

3.1 BEDROCK HYDROGEOLOGY

The PLCM and PMCM are considered a moderately productive aquifer with most flow occurring through fractures and discontinuities. Naturally, the sedimentary sequence comprises a complex multi-layered aquifer, with moderate yields from the sandstone beds (aquifer units), separated by low productivity coal seams, mudstones and siltstones. Groundwater is likely to be confined at depth when beneath low permeability layers, but unconfined where sandier strata outcrop near / at the surface often forming springs. The hydrogeology of superficial deposits is discussed in section 3.2.

Aquifer units within the PLCM and PMCM are likely to occur within the sandstone layers, particularly where they are thicker and more laterally extensive. However, many of these sandstones are vertically and horizontally separated by low permeability mudstones, siltstones and coal seams. This results in aquifer units being disconnected from one another. The PLCM and PMCM strata are also extensively folded and faulted, creating isolated blocks of aquifer with limited lateral water movement (Jones et al., 2000).

3.1.1 Sandstone aquifer units

Kearsey et al. (2024b) found that 41% of the PLCM and PMCM formations comprised sandstone across the Gateshead and Newcastle Upon Tyne part of the AOI. The median thickness of these sandstone beds was 2.1 m (Kearsey et al., 2024).

Many of the sandstones are fine grained, well cemented, hard and dense with very little porosity or intergranular permeability (Jones et al., 2000; Ó Dochartaigh et al., 2011), however, as sandstones are typically harder and more brittle compared to surrounding mudstones and siltstones, they preferentially fracture (Aydin et al., 2023). Consequently, significant groundwater flow may occur through fractures within the sandstones, even when the primary porosity and permeability is low.

Sandstone channel subsurface mapping by Kearsey et al. (2024b) for PGN has improved understanding of the lateral extent and size of sandstone layers, and how they may act as groundwater conduits across the AOI, whilst potentially also connecting different mining areas

known as mine water blocks. Although the distribution and number of borehole logs across the area was insufficient to comprehensively map the number and size of channels, major distributary channel sandstones were identified at various stratigraphic levels (see Kearsley et al., 2024). The largest major channel sandstones (e.g. above the Durham Low Main Coal) are estimated to be >4 km wide and >10 m thick, however, it may be that 70-80% of sandstone bodies are <400 m wide (Kearsley et al. (2024b).

Major distributary channel sandstones likely form the most productive and highest yielding bedrock aquifer units in the AOI. Kearsley et al. (2024b) identified channel sandstones (aquifer units) at seven intervals within the PMCM and PLCM. This section describes the location and extent of these major channel sandstone aquifer units.

The main aquifer unit in the PMCM above the High Main Coal is situated east of Gateshead and Newcastle Upon Tyne where it can exceed 5 km in width and 20-30 m thickness (Kearsley et al., 2024; Richardson, 1983). This sandstone is mapped as the High Main Post Member. This unit is also present but less extensive immediately west of the centre of Newcastle. It is also found north of the Ninety Fathom fault which likely separates the aquifer here. Another separate aquifer unit is found to the south of Pickering Nook.

Three separate aquifer units are found above the Maudlin Coal; one situated east of the River Team and south of the River Tyne, another around Gateshead and Newcastle Upon Tyne and the third running parallel to the Ninety Fathom Fault on its north side.

Perhaps the most extensive channel sandstone aquifer unit is situated above the Durham Low Main Coal. It is found both sides of the Ninety Fathom Fault, beneath Newcastle Upon Tyne, the eastern side of Gateshead, Whickham, Burnopfield, Kibblesworth, Beamish and Chester-Le-Street. As the aquifer unit is offset by the Ninety Fathom Fault there may be limited hydraulic connectivity across the fault zone. There may also be limited hydraulic connectivity across this aquifer unit between the western and eastern sides of the River Team. Three small aquifer units are present above the Hutton Coal, all with southwest – northeast orientations. (Figure 5).

In the PLCM, aquifer units are present above the Harvey Coal in southwest – northeast orientations. One extensive unit is found beneath Newcastle Upon Tyne, Gateshead, Sunnyside, Burnopfield and Beamish, whilst other likely separate aquifer units are found north of the Ninety Fathom Fault and around Birtley (Figure 5). Aquifer units present above the Busty Coal are discontinuous and southwest – northeast orientated, largely comprising <10 m thick sandstones. They are observed north of Newcastle Upon Tyne to the Ninety Fathom Fault, around Gateshead to Sunnyside and near Birtley (Figure 5). The stratigraphically lowest mapped aquifer units are situated above the Brockwell Coal and comprise three separate south-north orientated areas further broken up by the Ninety Fathom Fault.

Lower permeability deposits such as overbank deposits (clays and silts), swamp deposits (coal), and lake deposits (clays, mudstones) surrounding these channel sandstones are likely to reduce or prevent lateral and vertical groundwater connectivity. Therefore, groundwater flow direction within these channel sandstones is likely to follow their orientation, which is generally southwest – northeast, but with considerable local variability.

Three of the seven mapped major channel sandstone areas identified within the PMCM and PLCM stratigraphy are shown in Figure 5. It indicates how the channel sandstones, situated at different depths, exhibit different orientations, widths (and thicknesses). The location and orientation of these channel sandstones probably exert a strong control on groundwater flow direction and on where groundwater discharge may occur. Significant faults intersecting these channel sandstones are likely to alter regional groundwater flow through these units. Major faults may compartmentalise aquifer units into smaller blocks, but horizontal and vertical groundwater movement along fault damage zones could potentially connect otherwise separate aquifer units.

In addition to the mapped major distributary channel sandstones, there are many smaller sandstone deposits throughout the PMCM and PLCM (Kearsley et al., 2024b). Smaller channel sandstones maybe well connected to the main channel sandstone aquifers, but even when they are not associated with major channel sandstones, they may still form local aquifers.

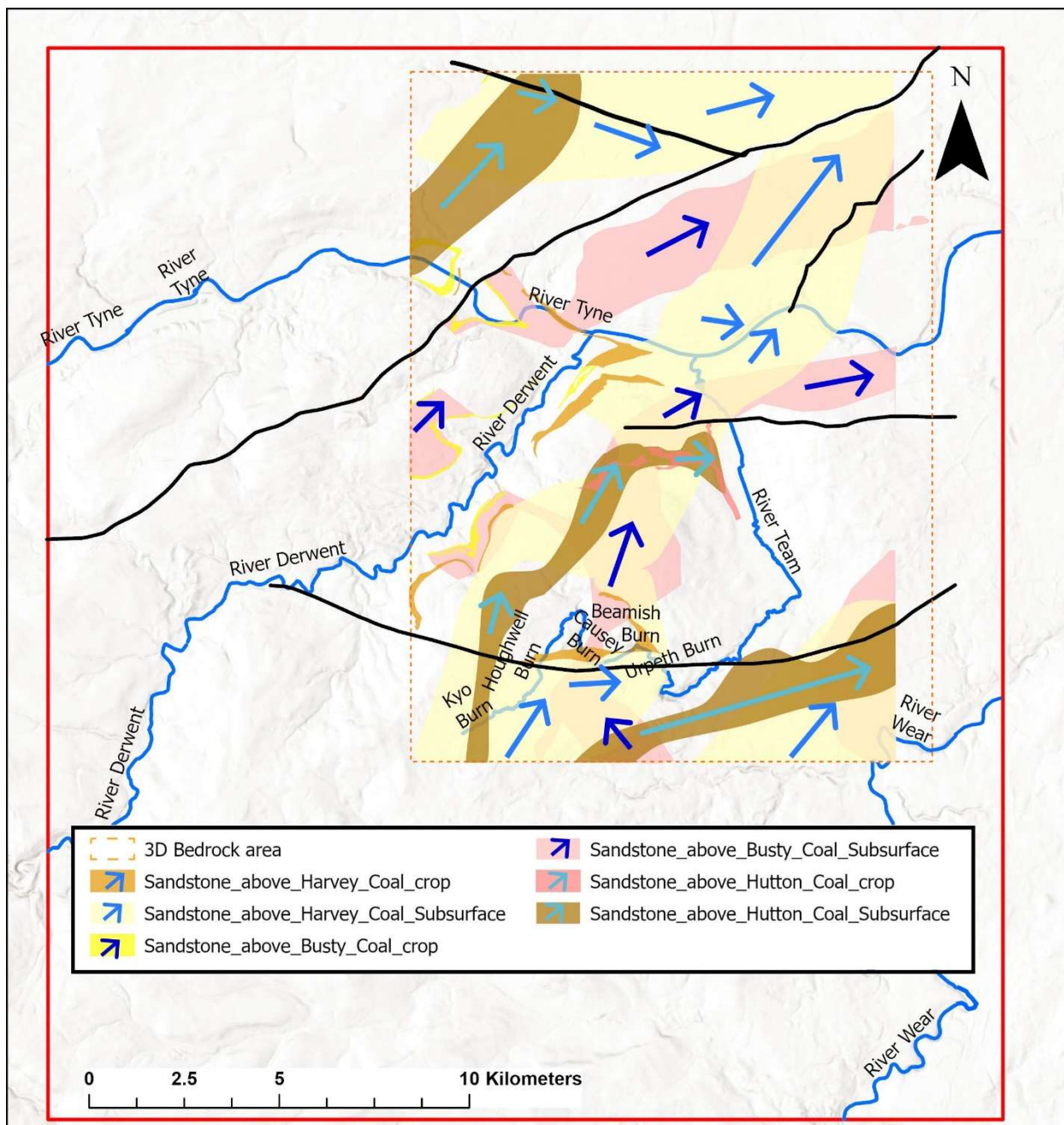


Figure 5: Some of the major distributary channel sandstones mapped by Kearsey et al., 2024b with arrows indicating possible groundwater flow directions. Channel sandstones at three stratigraphic intervals are shown. They are situated above the Hutton Coal (youngest rocks), above the Harvey Coal and above the Busty Coal (oldest rocks). It highlights how channel sandstones overlap but often have different orientations at different depths. This has implications for the direction of groundwater flow paths (and aquifer depths) across the AOI. As described in section 3.1.1, there are many other mapped sandstone channels within the PMCM and PLCM Formations which have been omitted from the figure to simplify it. Contains OS data © Crown Copyright and database right 2026. OS AC0000824781

3.1.2 Mine water blocks

Mine water blocks have been devised by the Mining Remediation Authority (MRA) based on areas with distinct properties and connectivity (Figure 6). Each block is a set of flooded collieries which are well interconnected, so they exhibit a continuous gradient of water level across their area (Wyatt et al., 2022). Blocks maybe hydraulically disconnected from others due to unworked coal areas or fault zones acting as barriers; however, other blocks exhibit various degrees of connectivity to others, e.g. through natural aquifer properties, unrecorded workings or through

leaky dams which were sometimes installed between workings / collieries to prevent passage of people, water or gas between different parts of the mine system (Wyatt et al., 2022).

Groundwater levels are managed within most mine water blocks in the AOI through pumping, gravity discharges, or via overflows into neighbouring blocks (Figure 6). However, some blocks such as Blackburn Fell, Redheugh and Walker have no known water level management and therefore may have recovered to a natural equilibrium (Wyatt et al., 2022). Where mine water blocks are connected, pumping within one block may remove water from neighbouring interconnected blocks.

Some mine water blocks overlap at different depths, so there can be vertical connectivity between blocks as well as horizontal connectivity. Interconnected mine workings do not necessarily result in mine water connectivity, as workings may be above the groundwater level or they could be dammed / blocked. Also, sealed mines were not necessarily intended to restrict groundwater flow and were installed for other reasons (e.g. to prevent human access) and therefore may not prevent groundwater movement and or discharge.

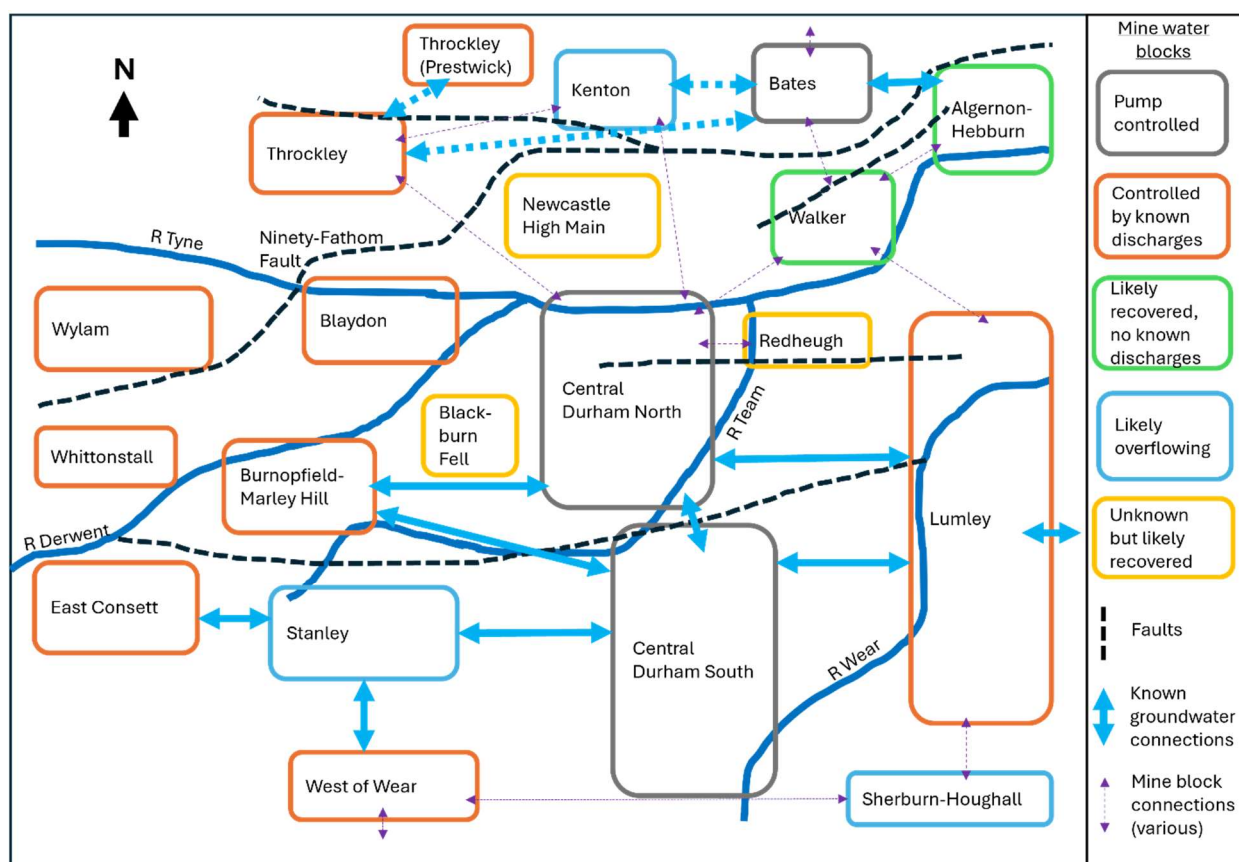


Figure 6: A conceptual diagram showing mine water blocks in the AOI and their groundwater connectivity. Based on MRA data (Wyatt, 2022). It highlights known groundwater connections, probable groundwater connections (dashed blue arrows) and mine block connections (roadways, collapsed or backfilled shafts / tunnels, narrow barriers, boreholes) which may enable mine water connectivity.

3.2 HYDROGEOLOGY OF SUPERFICIAL DEPOSITS

Superficial deposits composed of sand and gravel are permeable, often forming perched aquifers above the bedrock. These aquifers are regularly and rapidly recharged by rainfall and are therefore typically more responsive to hydrological conditions compared to bedrock aquifers.

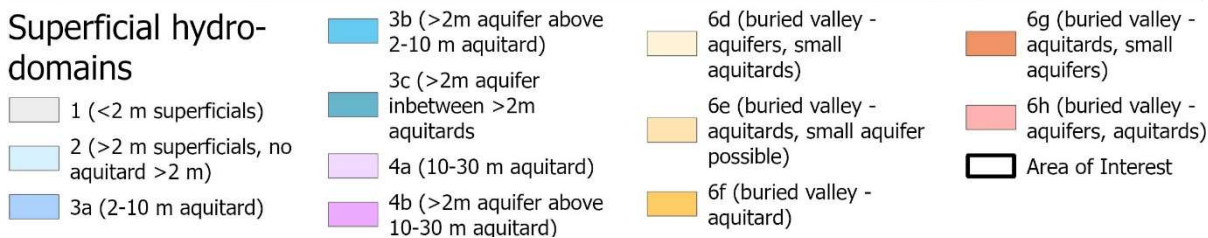
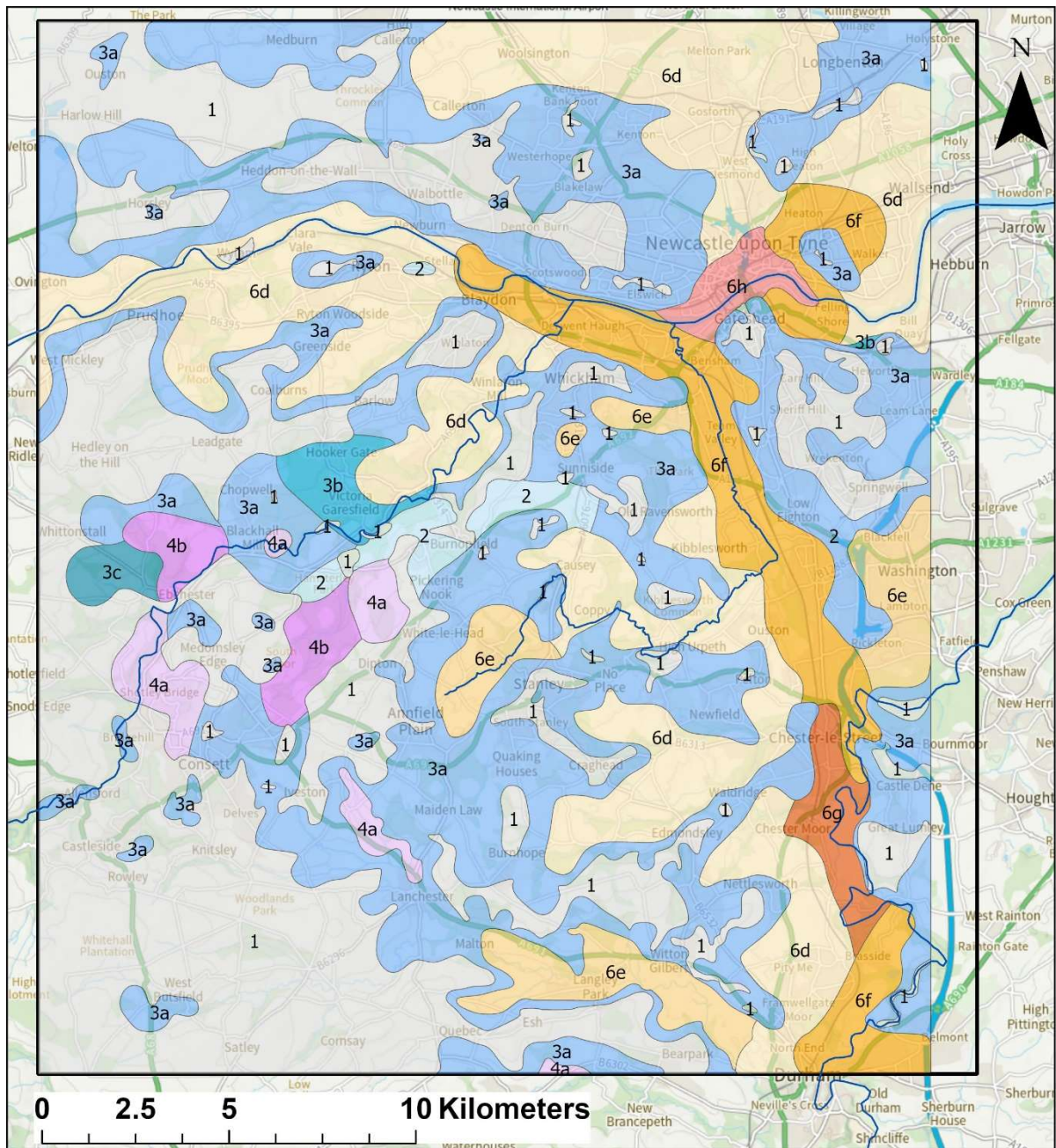


Figure 7: Superficial hydrogeological domains for the Gateshead area. Modified from Whitbread et al. (2024). Note that domains were not mapped in the eastern edge of the AOI. BGS © UKRI 2026. Contains OS data © Crown Copyright and database right 2026. OS AC0000824781.

Superficial deposits in the AOI vary from thin hilltop cover, to >100 m thick, complex valley fill deposits. Clay-rich, low permeability glacial till and low permeability lacustrine deposits are predominant in the north and east of the area. However, moderate – highly permeable alluvium, glaciofluvial deposits, and sandier glacio-lacustrine deposits which form productive aquifers are also present (Whitbread et al., 2024) (Figure 7).

The distribution, extent and connectivity of sand and gravel deposits is important for the presence and movement of groundwater. Where sand / gravel bodies are well connected, such as where they form laterally extensive buried palaeochannels, they are probably conduits to lateral groundwater flow. Where such deposits are connected to surface water bodies (e.g. rivers, streams) and / or the bedrock aquifer, they may play an important role in groundwater discharge and potentially, groundwater flooding.

The present River Tyne valley forms a major buried valley, whilst another buried valley is present from the River Tyne- River Team confluence, south-southeast to the River Wear towards Durham (Figure 7). The buried valleys comprise a mixture of superficial deposits including till, sands and gravels which can locally exceed 100 m thickness (Whitbread et al., 2024). Whitbread et al. (2024) developed five hydro domains to reflect hydrogeological differences in the buried valley deposits. In the Tyne valley around Gateshead-Newcastle, the buried valley deposits identified comprise complex layers of clay-rich glaciolacustrine and till interspersed with silts and sands. Thick sand and gravel deposits observed at the base of the superficial succession are likely to form aquifers in hydraulic continuity with underlying bedrock aquifer units. It is likely that groundwater will discharge at the surface where sands and gravels are not confined by low permeability sediments.

In the River Team valley, most of the superficial deposits comprise low permeability clay-rich till and lacustrine sediments, however, groundwater is likely to be present in permeable sandier lenses, particularly along the valley flanks. The predominantly low permeability sediments may prevent groundwater recharge (or discharge) and increase surface runoff.

Of the valley fill deposits, hydro domains 6d and 6g (Figure 7) are likely to form the most productive superficial aquifers due to their higher sand and gravel composition. Where these deposits are present in lower elevation areas (away from hill tops) such as the Tyne valley floor, they are likely to be partially-fully saturated. Buried palaeochannel deposits along infilled valleys may form laterally extensive and well-connected aquifer lenses which may be well connected to surface water bodies and bedrock aquifer units where present.

The most extensive superficial aquifers are probably situated along the River Tyne valley west of Blaydon and east of Gateshead, along the lower reaches of the River Derwent, the mid-upper River Team valley, around the River Browney and along Cong Burn. However, smaller, often perched aquifers are also present in areas such as the lower River Team valley and River Tyne valley from Blaydon to Gateshead.

3.3 AQUIFER PROPERTIES

3.3.1 Bedrock groundwater properties

There is limited information regarding aquifer properties in the AOI. However, a study into lithofacies types of a sandstone (Table Rocks Sandstone) within the Pennine Coal Measures just north of the Ninety Fathom Fault, revealed a well sorted, but cemented composition with all facies exhibiting a low primary porosity (<1%). However, most facies samples had a secondary porosity of over 10% and up to 18.8% (Turner & Tester, 2006). Estimated permeability values ranged between 0-8.3 x 10⁻¹⁴ m².

Sparse borehole yield data from the AOI indicate that obtainable yields vary significantly. The highest yield observed during a pumping test (grid reference 410500 557100) was 17.7 l/s for 48 hrs before being reduced to 12.6 l/s for 24 hrs. Pumping at 17.7 l/s resulted in a drawdown of 14.3 m, whilst the drawdown reduced to 10.6 m following the lower pumping rate. Data from a pumping test on another borehole (grid reference 422350 568630) showed yields of 1.2-6.7 l/s over 48 hours. Other recorded yield data ranges from 0.31 – 0.75 l/s. Yields of 1 to 10 l/s are considered moderate productivity, whilst 0.1-1 l/s are considered low productivity (MacDonald et al., 2005). Observed yields highlight the variability but typically low-moderate productivity of the aquifer. Groundwater yields are therefore likely to be highly dependent on the secondary porosity, particularly the fracture density and the extent of mining in the sandstones.

3.3.2 Bedrock groundwater quality

Borehole records and mine water quality data often suggest the water is hard, and often saline at depth due to very little meteoric groundwater circulation (Younger, 1993). However, the mining legacy has connected naturally disconnected aquifers, resulting in the mixing of different waters.

Groundwater quality data in the Pennine Coal Measures (PCM) aquifer further south in the Midlands and South Yorkshire is derived from rainfall recharge but shows signs significant impacts from the coal mining legacy, with interaction of the aquifer matrix (Mallin Martin & Smedley, 2021). The aquifer structure appears similar to that of the AOI, comprising sandstone layers interbedded with low permeability mudstones and coal seams.

The MRA reported water quality data at 17 boreholes across the area between 2015-2023. Most boreholes monitored mine water quality in shafts associated with coal seams, although one borehole sampled from an aquifer. Maximum admissible concentrations and values for public water supply drinking water in England and Wales (2018) are shown in italics to provide context to the reported values below. Data from these boreholes showed median conductivity values ranging from approximately 500 - 91000 $\mu\text{s/cm}$ (*2500 $\mu\text{s/cm}$*), median Fe values between 0.09 - 97.6 mg/l (*0.2 mg/l*), median Na values of 16 - 22400 mg/l (*200 mg/l*), median SO_4 values of 7 - 3160 mg/l (*250 mg/l*) and median pH values of 6.3 - 8.7 (*6.5 - 9.5*). Values from the aquifer borehole were towards the lower end of the reported values above, and it had a pH of 7.4. High concentrations of Fe, Na, SO_4 , and high conductivity values observed in some mine waters indicate contamination associated with historic mining.

3.3.3 Superficial groundwater properties

One borehole (grid reference 414830, 563690) into superficial deposits (categorised as hydro domain 6d- buried valley domain - sand and gravel over till) recorded particle size distribution data. The sandy sediments with fines comprised on average 21% silt/clay, 65% sand (mostly medium-grained), and 14% gravel at a depth of 2.1-2.7 m below ground level. Sediments at this site were unsaturated but would likely form a productive aquifer if saturated.

Glaciofluvial sands and gravels and alluvium can be high yielding; particularly where they are thick and / or there is good hydraulic connectivity to adjacent water courses (MacDonald et al., 2005). However, yields within these deposits may be low where they are thin and laterally discontinuous. Meanwhile, till and lacustrine deposits are either non aquifers (unproductive) or low yielding where they contain more silt and sand (MacDonald et al., 2005).

There is no information on superficial deposit groundwater quality, however, these shallow aquifers are generally prone to surface contamination and therefore can suffer from groundwater quality issues.

3.4 RECHARGE

Recharge to bedrock aquifer units is likely to predominantly occur over the higher ground, especially in the west of the AOI in places where bedrock at the surface is moderately to highly permeable (Figure 8). These more permeable bedrock areas represent sandstones which are discussed in 3.1.1. The distribution and type of superficial deposits overlying the bedrock have a strong control on whether percolating water reaches the bedrock aquifer. Most groundwater recharge occurs where superficial deposits are absent or permeable (shaded solid blue hydro-domains in Figure 8), and recharge is highly likely where permeable superficial deposits (hydro-domains) overlie moderate-highly permeable bedrock. Areas characterised by shallow surface workings are also likely to form zones of preferential recharge.

Hydro-domains developed by Whitbread et al. (2024) were categorised based on different sedimentological and hydrological properties. Table 1 provides an overview whether hydro-domains are conducive to groundwater recharge (and discharge).

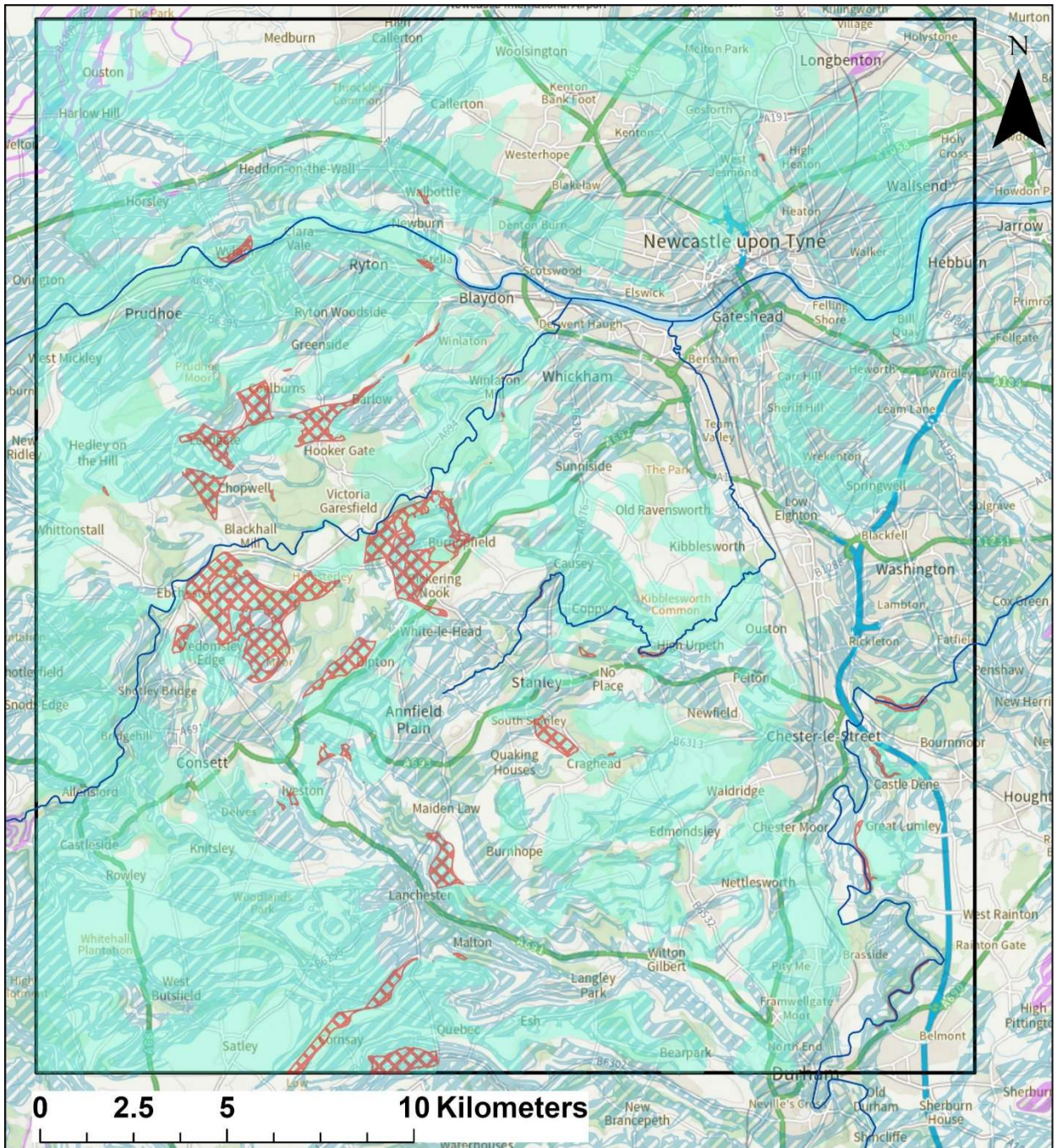


Figure 8: Map showing permeable superficial hydro-domains BGS bedrock permeability and shallow mine workings (Marchi-Smith & Hallam, 2025). Permeable superficial hydro-domains include areas with no superficial cover. BGS © UKRI 2026. Contains OS data © Crown Copyright and database right 2026. OS AC0000824781.

Table 1: Summary of whether superficial domains categorised by Whitbread et al. (2024) enable potential recharge to the bedrock aquifer.

Hydro-domain	Domain Name	% coverage	Conductive to bedrock recharge / discharge?
1	Superficial deposits absent or < 2 m	31	Yes
2	Aquifer > 2 m Aquitard < 2 m	1	Yes
3a	2-10 m aquitard	33	No
3b	Aquifer > 2 m overlying aquitard 2-10 m	<1	No
3c	Aquifer > 2m between aquitard 2-10 m	<1	No
4a	Aquitard 10-30 m	1	No
4b	Aquifer > 2m overlying aquitard 10-30 m	1	No
6d	Buried valley - sand & gravel over till	31 (total for domains 6d-6h)	GW Interactions with bedrock likely where basal till is thin or absent
6e	Buried valley - till dominant		Unlikely
6f	Buried valley - Glaciolacustrine (clay dominant) and till		No
6g	Buried valley - Glaciolacustrine (sand dominant) and till		Yes
6h	Buried valley - complex		Possible

Zones of focussed recharge are likely along faults and their associated damage zones. Some of the major faults (>150 m vertical displacement) in the AOI include the southwest - northeast trending Ninety Fathom Fault, the west - east trending Tantobie fault and several others around Gateshead and Newcastle Upon Tyne (Figure 3). Numerous other faults across the AOI may also act as recharge pathways.

Abundant abandoned mine entrances (over 7000 mapped in the AOI) and surface workings in the region provide artificial recharge pathways. As coal seams throughout the PLCM and PMCM were extensively mined, the underground cavities now form man-made aquifers, whilst potentially also increasing connectivity between natural aquifer units. The extent to which recharge occurs through mine entrances depends on whether, and how well, mines and their entrances have been sealed. Mine entrance locations may strongly control the volume of surface water entering the mine. Mine entrances situated at higher elevations (recharge areas e.g. hill tops) and where runoff is likely to flow into the mine (via surface runoff or streams) are going to provide areas of focussed recharge; meanwhile, mine entrances on lower valley slopes or in valleys are more likely to form preferential discharge pathways (section 4).

3.5 GROUNDWATER LEVELS AND TRENDS

Measured groundwater levels vary across the region from around 0 mAOD to over 60 mAOD. This depends on which aquifer is being intercepted and monitored, whether it is confined or unconfined, the elevation of the site (groundwater levels are typically higher further south and west), and whether abstractions are taking place. Groundwater levels in valleys are typically nearer to the surface and maybe in connectivity with surface water bodies. Therefore, groundwater levels in valleys typically fluctuate less, but may reach the surface resulting in groundwater discharge and associated flooding.

Groundwater level monitoring boreholes report groundwater levels from within bedrock aquifers rather than superficial aquifers. However, bedrock groundwater levels equate to overlying superficial aquifer levels where there is hydraulic continuity. Other boreholes target specific worked coal seams to monitor mine water levels and water quality.

Overall, there has been a significant rise in groundwater levels across the region since the 1990s. Groundwater levels in the area were drastically lowered during mining through pumping and gravity-fed drainage. However, since mining ceased and pumping stopped, groundwater levels have recovered across the region. During the past 10-15 years, groundwater level data suggests that this rising trend has slowed, and in some areas stabilised or even reversed. Available groundwater level data for this report was spatially limited, therefore groundwater level trends particularly in the west of the AOI are poorly constrained.

Groundwater trends are described for three EA groundwater level monitoring boreholes in the AOI (Figure 9). In the River Tyne valley just east of Newcastle Upon Tyne, the EA Riverside borehole shows current groundwater levels of around 3-3.5 mAOD (Figure 9), or 5.5-6 m below the surface (2024-2025). Data shows a rising trend since 1997 (start of record) when levels were 8 m lower, however, the rate of increase has slowed significantly since around 2012. At Birtley near the River Team (surface 16.8 mAOD), groundwater levels are currently around 0 mAOD and exhibit a slight falling trend since peaking at 9 mAOD in 2012, having previously risen from -33 mAOD in the late 1990s (Figure 9). Ongoing pumping nearby at Kibblesworth is likely to impact groundwater levels in this area.

In most higher elevation areas away from the main river valleys, groundwater levels in EA monitoring boreholes have risen >30 m since the mid-1990s, however, maximum recorded groundwater levels in all these boreholes remain 10s of metres beneath the surface. Groundwater levels at Plawsworth situated 92.6 mAOD, have risen from <-40 mAOD in 1995 to 13 mAOD in May 2025 (Figure 9), but have broadly stabilised since around 2010. This stabilising trend indicates that groundwater levels in many areas have fully recovered from the mining, or they are still being controlled by active pumping to prevent further rises.

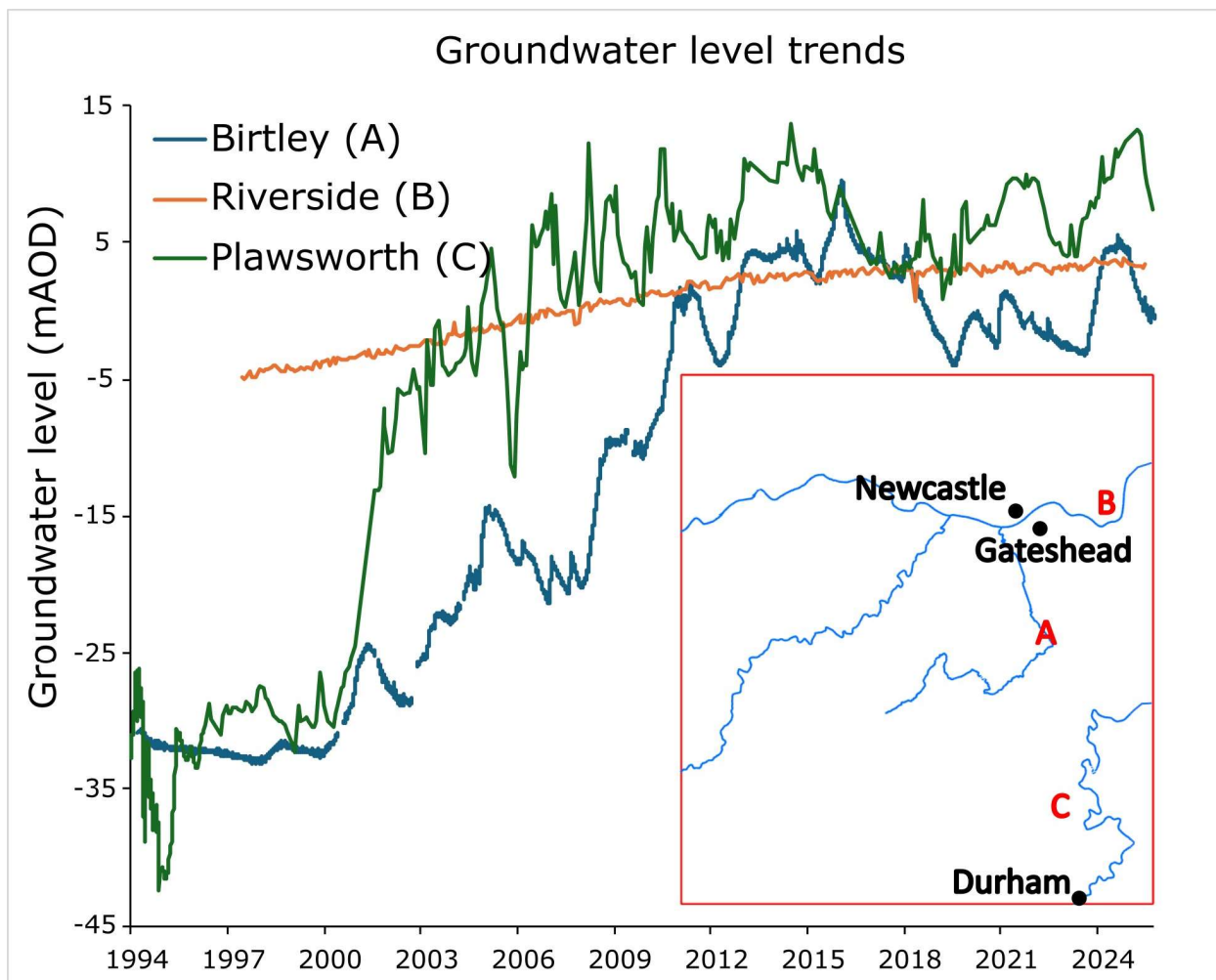


Figure 9: Groundwater level data from three boreholes in the AOI, ranging from 1994-2025 (EA, 2026). Contains public sector information licensed under the Open Government Licence v3.0.

Mine water levels are also monitored at two borehole pairs drilled to different depths near Bede Primary School and the Gateshead National Sports Stadium. Water level data and water quality data (Table 2) has been collected for the Gateshead Living Laboratory since 2023 / 2024 (MRA, 2025).

Table 2: Summary of the Gateshead Living Laboratory mine water level monitoring data. © The Mining Remediation Authority 2025. All rights reserved. Contains public sector information licensed under the Open Government Licence v3.0.

Site	Ground level (mAOD)	Borehole depth	Target geology intercepted	Maximum water level (mAOD)	Mean water level (mAOD)
Bede BT	33.2	136	Brass Thrill Coal	11.5	8.4
Bede HM	33.2	56	High Main Coal	8.7	6.2
Stadium H	27.2	188	Hutton Coal	10.2	7.4
Stadium HM	27.2	82	High Main Coal	6.4	5.7

Mine water levels in the intercepted workings remain significantly below the surface, with the highest observed mine water level in the Brass Thrill being 21.7 m below ground level. This suggests there is not a groundwater flood risk here, however, areas near the River Tyne situated below this observed level could be at risk of flooding from mine water discharge. Note that the borehole pairs exhibit notably different water levels despite being co-located. This highlights the disconnection between aquifers at different depths, in this case, probably man-made aquifers from mine workings. The length of records for these boreholes was insufficient to describe trends.

4 Groundwater discharge and cross-sections

Groundwater discharge occurs where groundwater reaches the surface because of water levels in an aquifer reaching a certain level. Groundwater discharge naturally occurs in the form of springs but also occurs because of human activity. Groundwater can flow out of old mine drainage adits and unsealed shafts, the sewerage network, and potentially via boreholes which penetrate through the subsurface into confined aquifers.

Groundwater springs mapped by the EA are widely distributed throughout the AOI (Figure 10), however, springs tend to be concentrated along stream and river valleys and geological features. There is a high concentration of springs along the River Derwent valley, but also along the break-in-slope in the River Tyne valley upstream of where the River Derwent joins, and in the River Wear valley. Springs are found throughout the PMCM and PLCM and commonly occur in linear patterns along areas of similar elevation. It is likely that springs are present where permeable fractured sandstones overlying low permeability mudstones, siltstones and coals, outcrop at the surface. There was no clear relationship between mapped faults and springs, however, it is likely that some faults create pathways for groundwater to reach the surface.

Aside from valley fill deposits, springs also occur across all superficial hydro-domains, both permeable and impermeable. The presence of springs occurring in 'low permeability' superficial deposits could be a result of permeable sand and gravel lenses (e.g. hydro-domain 3b in Figure 7) forming small, perched aquifers within the low permeability sediments. It is also likely that there are areas where the generally thick superficial cover locally thins or is absent, allowing confined bedrock groundwater to upwell to the surface.

The EA indicate that land with an elevation of <10 mAOD is prone to groundwater discharge (Marchi-Smith & Hallam, 2025) as here, groundwater is likely to be closer to the surface. However, there are fewer recorded springs found along the lower Tyne and Team valleys (<10 mAOD). This could be due to the presence of thick, low permeability valley fill deposits (hydro-domains 6f and 6h) preventing groundwater upwelling, or they have been built over during urbanisation. In urban areas, groundwater may also discharge into the subsurface drainage (sewer) network rather than at the surface. Nevertheless, the springs that are present in these valleys may pose a groundwater flood risk.

Preceding hydrological conditions play an important role on whether groundwater discharges. Many springs are seasonal, only activating during the winter and spring months when groundwater levels are at their highest. Other springs only activate during extreme conditions following months of above average rainfall (and subsequent recharge). It is therefore important to understand areas which are susceptible to groundwater discharge, even if there are no known records of groundwater flooding.

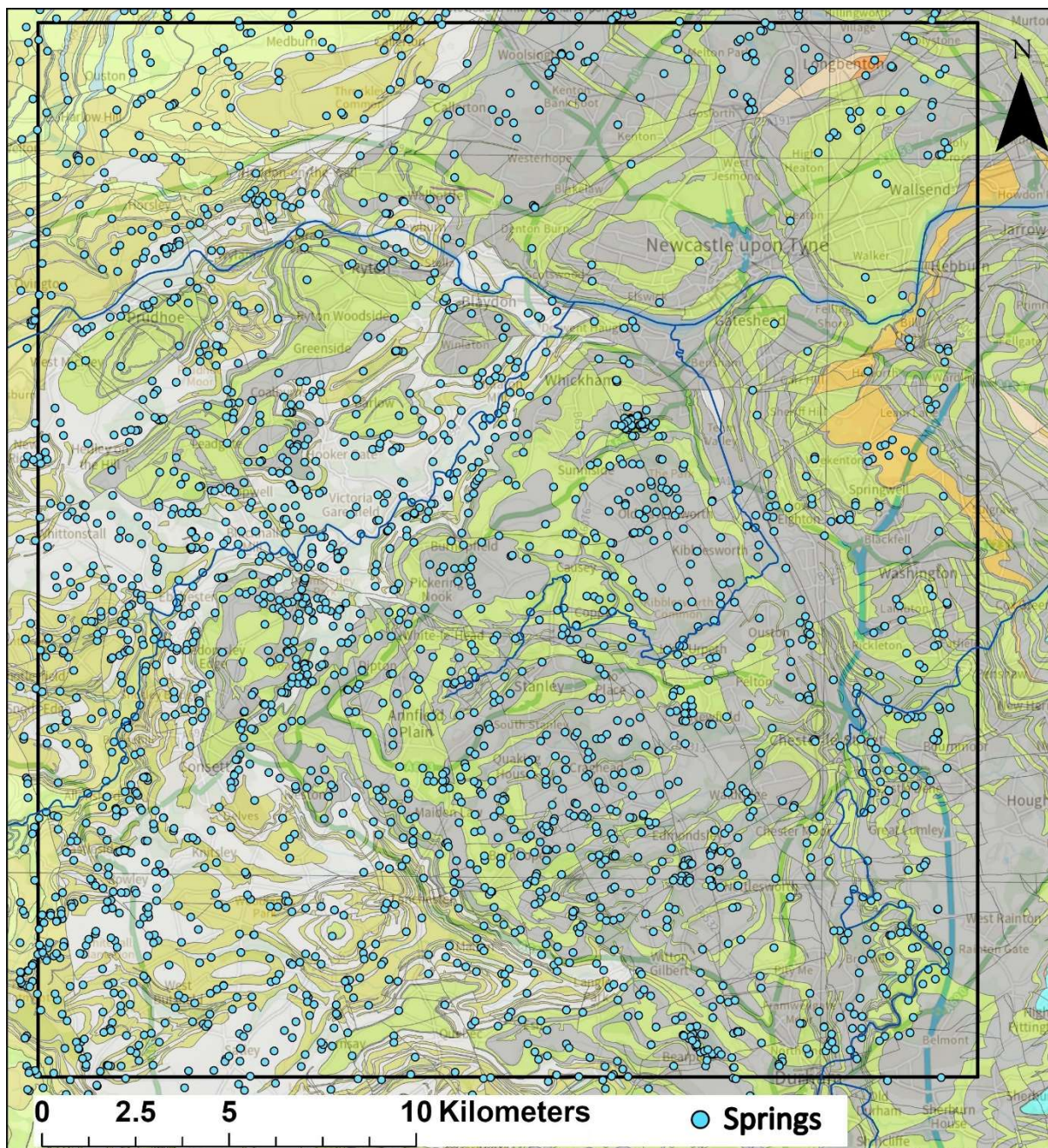


Figure 10: Springs identified by the Environment Agency (Hallam, 2025). Contains data from © Environment Agency copyright and/or database right 2025. All rights reserved. 50k geological map: BGS © UKRI 2026. Contains OS data © Crown Copyright and database right 2026. OS AC0000824781.

Some mapped springs are un-natural having formed because of the mining legacy. Continued mine water level recovery in some mine water blocks is likely to result in groundwater discharging more frequently and in greater volumes, particularly via old workings, which could lead to an increased risk of future groundwater flooding. This highlights the need to continue monitoring mine water levels in areas which are still recovering.

4.1.1 Conceptual cross-sections

The following figures conceptualise the hydrogeological understanding and likely processes in the River Tyne and River Team valleys, and highlight areas of groundwater discharge and flood susceptibility. Diagrams are schematic but broadly show part of geological cross-sections from the report by Kearsy et al. (2023).

Figure 11 depicts the River Tyne valley to the west of Newcastle (see Figure 1 for location). It shows the PMCM comprising channel sandstones, siltstones/mudstones and mostly worked

coal seams. The sandstones are highly fractured and form aquifers whilst there is limited fracture flow through the surrounding low permeability deposits. The mine workings have flooded forming manmade aquifers which are sometimes connected where the mines have not been sealed, whilst historic mine water pumping has resulted in depressed mine water levels which are recovering. The Ninety Fathom Fault has a significant offset forming a major hydrogeological boundary. Its associated damage zone may form a productive aquifer, potentially enabling groundwater flow along the fault whilst also creating vertical connectivity between sandstone aquifer units (Figure 11).

The cross-section also depicts a sustainable drainage system (SUDS) pond installed on a housing development to manage surface water runoff. SUDS infiltration contributes recharge to a sandstone aquifer unit below, potentially increasing discharge volumes at a spring further down the valley. Superficial deposits comprise thick low permeability glaciolacustrine clays with some glaciofluvial sands and gravels forming small, perched aquifers, some of which are hydrogeologically connected to the River Tyne. Springs form at the boundaries between the glaciofluvial and glaciolacustrine deposits. The sandstone bedrock aquifer beneath the superficial deposits is disconnected from the River Tyne due to thick clay-rich deposits.

Groundwater flood risks on this cross-section occur via groundwater discharge where the sandstone aquifer and small, perched aquifers are exposed at the surface. River flooding and surface water flooding via runoff over the clay-rich superficial deposits are also risks.

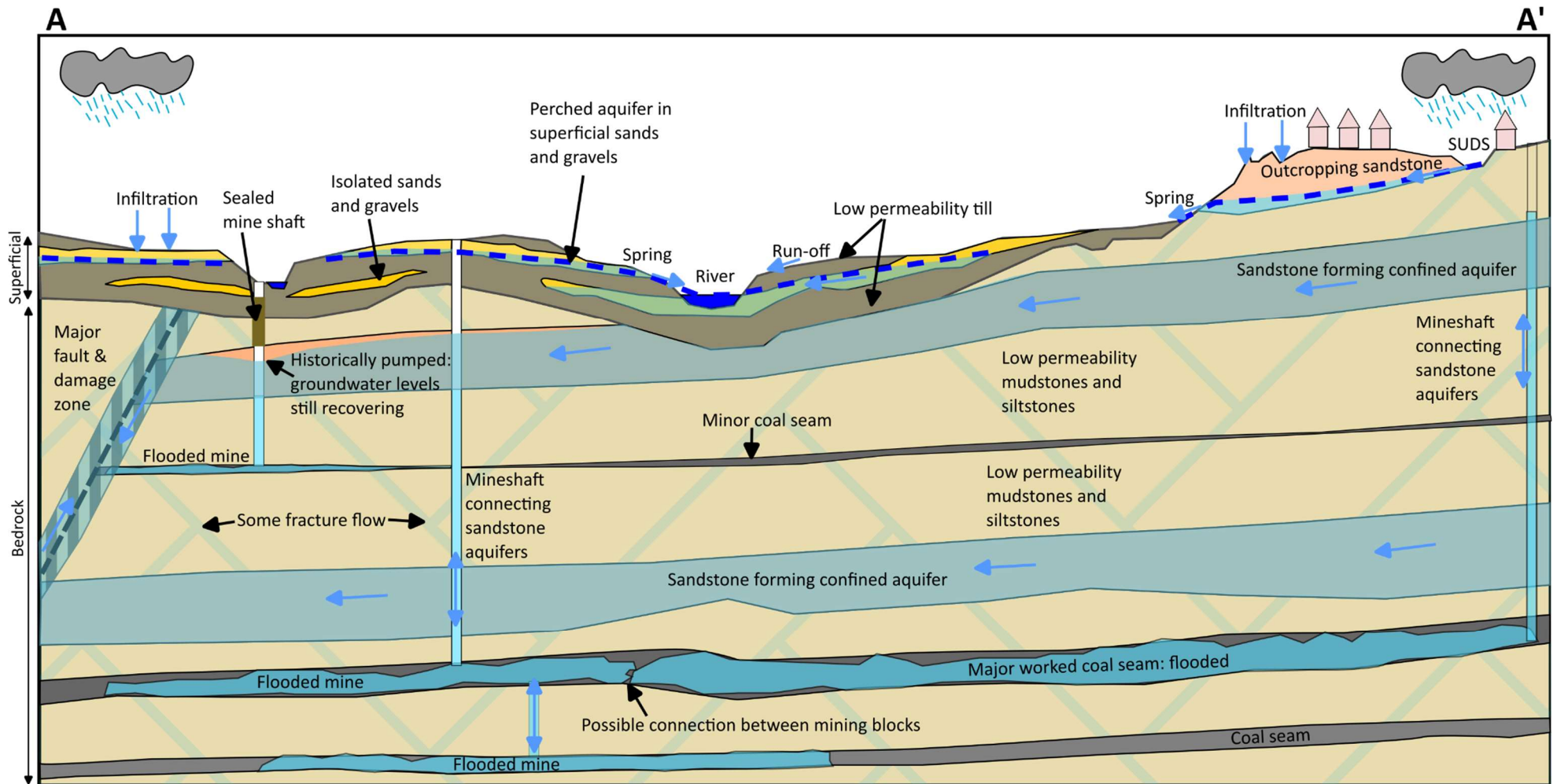


Figure 11: Schematic cross-section depicting the River Tyne valley in a south-north orientation. It shows hydrological and hydrogeological processes and the interactions between historic mining activities and groundwater. The blue dashed line indicates the water table across the area, whilst blue arrows depict groundwater movement. Cross-section shows 150-200 m of stratigraphy. It is not to scale but is broadly based on an extract from a geological cross-section developed by Kearsey et al. (2023).

The following cross-section (Figure 12) depicts the River Team valley around Birtley and Kibblesworth (see Figure 1 for location). It shows the PMCM comprising siltstones/mudstones, sandstones and coal seams which have been extensively worked at shallower depths. There are no major faults along this cross-section.

Groundwater recharge occurs predominantly via surface workings but also where sandstones and superficial sands outcrop.

The sandstone bedrock is highly fractured and forms an aquifer which is connected to mine workings through unsealed shafts which have now flooded. One backfilled mine shaft remains largely free of water as it hydrogeologically disconnected from mine workings and from aquifer units. Mine water levels continue to recover on the western side of the valley. On the eastern side of the valley, mine water is being actively pumped to prevent groundwater discharge further down the valley which could result in flooding in an urban setting (Figure 12). Springs are present where the sandstone outcrops at the surface, whilst mine water from flooded workings discharges via adits on the valley sides. Low permeability bedrock underlies this section of the River Team, therefore here, the river does not interact with bedrock groundwater.

Superficial deposits comprising low permeability glaciolacustrine clay and till have largely infilled the present River Team valley, however, some glaciofluvial sands and gravels present on the valley sides form perched aquifers. One of these perched aquifers is partially recharged by groundwater discharging from a mine adit further up the valley side. This perched superficial aquifer is hydrogeologically connected to the River Team; and discharges on the valley floor, resulting in a potential flood risk to developments in the valley. In this area, there is also a risk of river flooding in the valley and surface water flooding via runoff over the clay-rich superficial deposits.

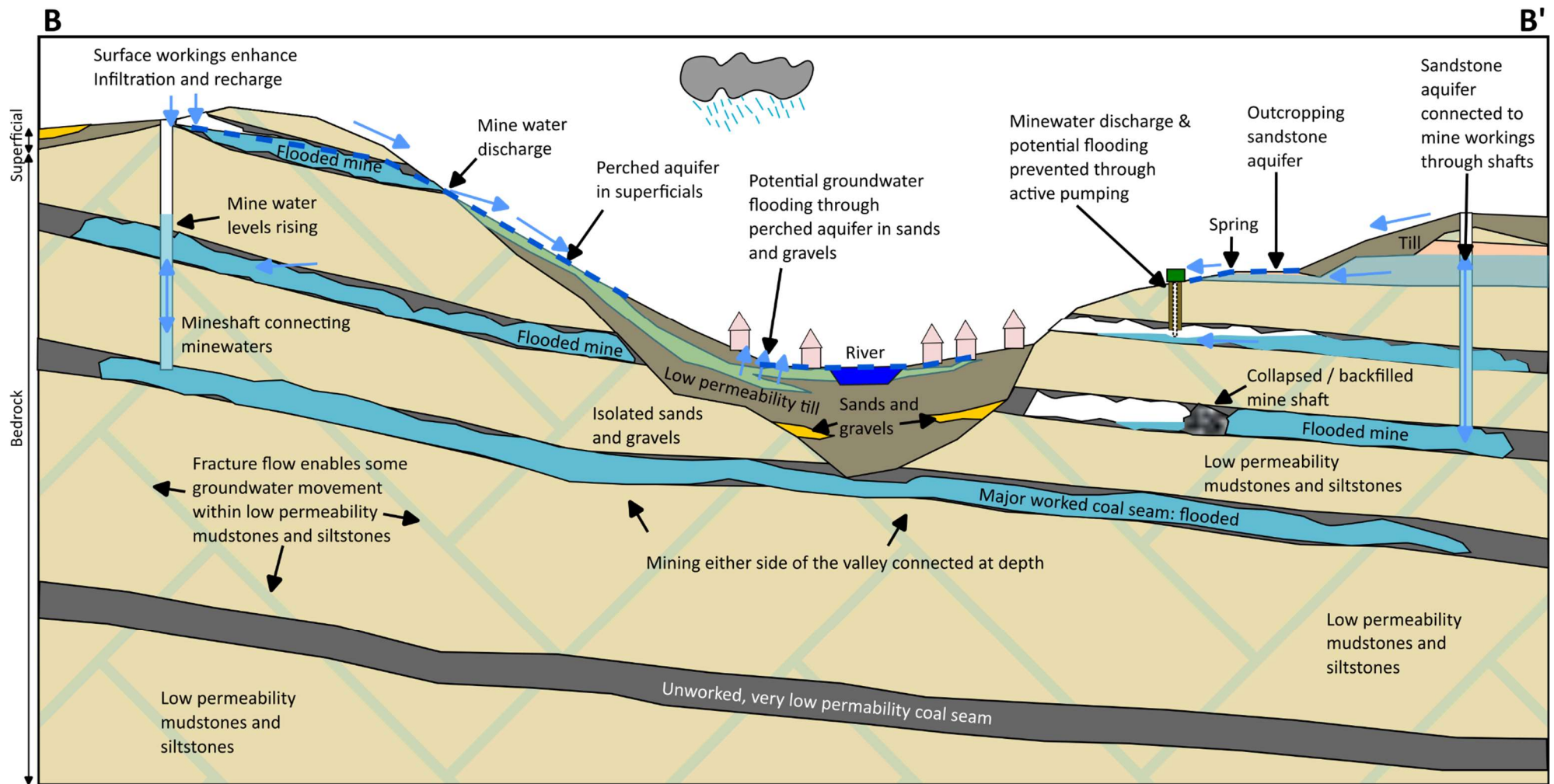


Figure 12: Schematic cross-section depicting the River Team valley in a west-east orientation. It shows hydrological and hydrogeological processes and the interactions between historic mining activities and groundwater. The blue dashed line indicates the water table whilst blue arrows depict groundwater movement. Cross-section shows 150-200 m of stratigraphy. It is not to scale but is broadly based on an extract from a geological cross-section developed by Kearsey et al. (2023).

5 Groundwater flood susceptibility

5.1 CURRENT GROUNDWATER FLOOD SUSCEPTIBILITY

For Project Groundwater Northumbria, the EA developed flood susceptibility maps for the AOI (Figure 13) through compiling various hydrological and hydrogeological datasets, elevation-based filtering, and use of the superficial hydro-domains and identification of potential pathways (Marchi-Smith & Hallam, 2025).

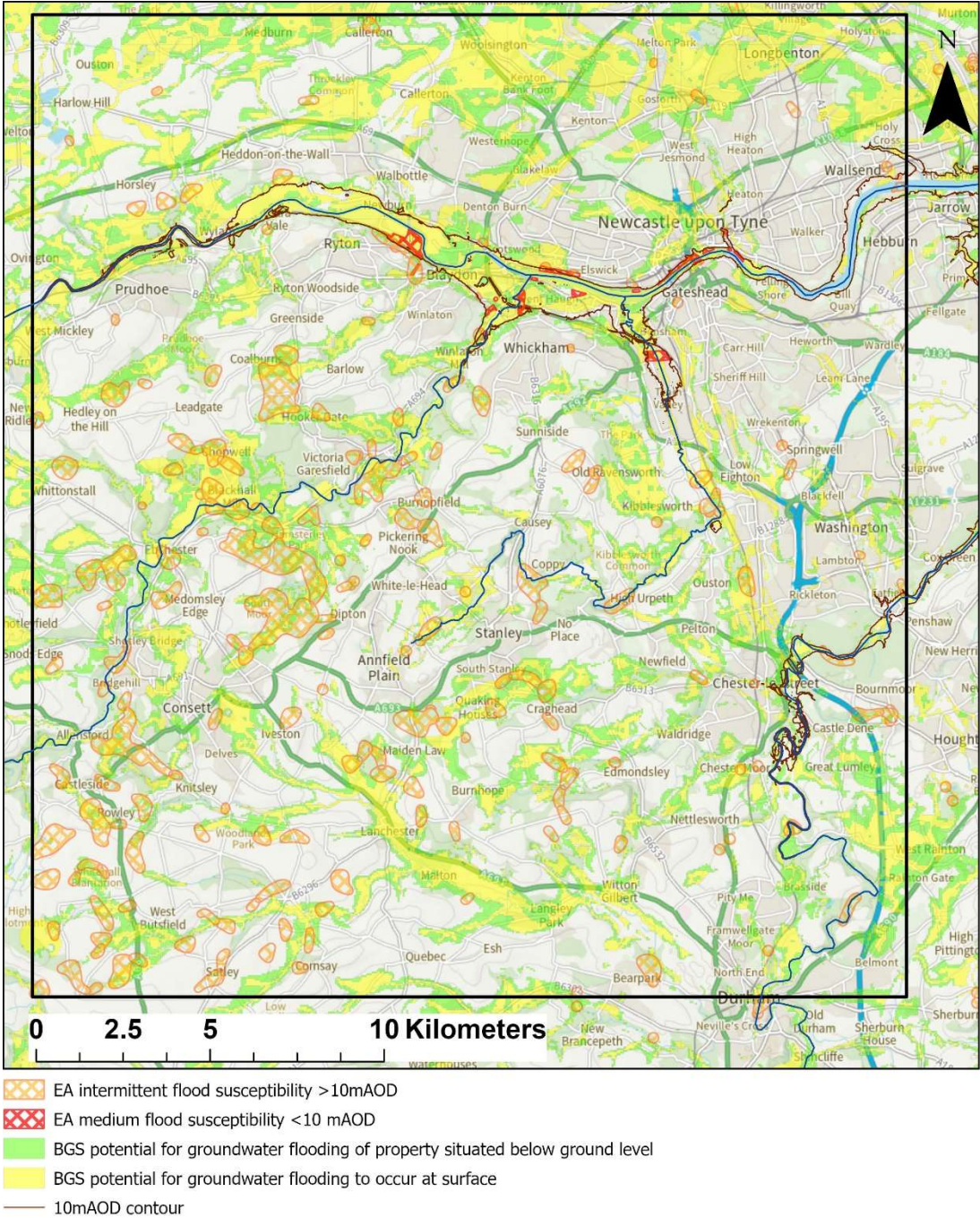


Figure 13: Groundwater flood susceptibility mapped by the EA (red and orange) for Project Groundwater (Marchi-Smith & Hallam, 2025), the 10 m elevation contour, and BGS mapped groundwater flood susceptibility areas (Green & yellow). Contains data from © Environment Agency copyright and/or database right 2025. All rights reserved. BGS © UKRI 2026. Contains OS data © Crown Copyright and database right 2026. OS AC0000824781.

The 10 mAOD contour was identified as a critical level, below which groundwater could discharge from new areas, and flows from existing discharges may increase from excessive rainfall / recharge of mine water pump failures (Marchi-Smith & Hallam, 2025). Within these <10 mAOD areas, specific locations of increased groundwater flood susceptibility were identified based on sandstone outcrops, mine adits and other features which enhance the likelihood of groundwater emergence (Figure 13 & Figure 14). Areas of medium flood susceptibility are found in the River Tyne and lower River Team valleys (Figure 14).

Areas above 10 mAOD and vulnerable to intermittent groundwater flooding were also identified and mapped using similar criteria (Marchi-Smith & Hallam, 2025). These areas are spatially scattered with more locations in the south and west of the AOI (Figure 13).

The BGS also have a dataset which highlights areas of groundwater flood susceptibility including both subsurface flooding (e.g. basements, cellars, sewers) and surface flooding at a 50 m grid scale (Figure 13 & Figure 14). This is a national-scale dataset based on surface contours and depth to groundwater. It is in good agreement with the EA flood susceptibility maps for the River Tyne valley (Figure 14) and some of the other major river valleys, highlighting the increased flood susceptibility in areas <10 mAOD. The BGS dataset does not align as closely with the EA Intermittent flood susceptibility areas >10 mAOD, probably due to the higher resolution of the EA data and the EA's approach to include mining impacts. The BGS groundwater flood susceptibility map shows areas of potential groundwater flooding in areas where sandstone bedrock outcrops and springs are found. There is possibly also an increased groundwater flood risk along faults and their damage zones as faults can provide a preferential pathway for groundwater to reach the surface.

Of the current monitoring boreholes in the AOI, only one EA monitoring borehole, Birtley, is situated within an area identified by the EA as an intermittent flood susceptibility area. The surface level is around 17 mAOD, whilst the highest recorded GWL is 9 mAOD, 8 m below the surface. As of early 2026, GWL were 16.5 m below the surface, probably suppressed by MRA mine water pumping near Kibblesworth.

The Walker Riverside borehole in the River Tyne valley is located within an area identified by the BGS dataset for potential groundwater flooding to occur at the surface, and is below the 10 mAOD contour threshold identified by the EA. The long-term groundwater level trend is rising at this location, however, current maximum GWL are still 5 m below the surface.

It must be noted that many of these areas <10 mAOD identified by the EA and BGS as susceptible to groundwater flooding are probably also susceptible to surface water flooding from the rivers Tyne, Team and Derwent, smaller streams and from surface run-off in urban areas.

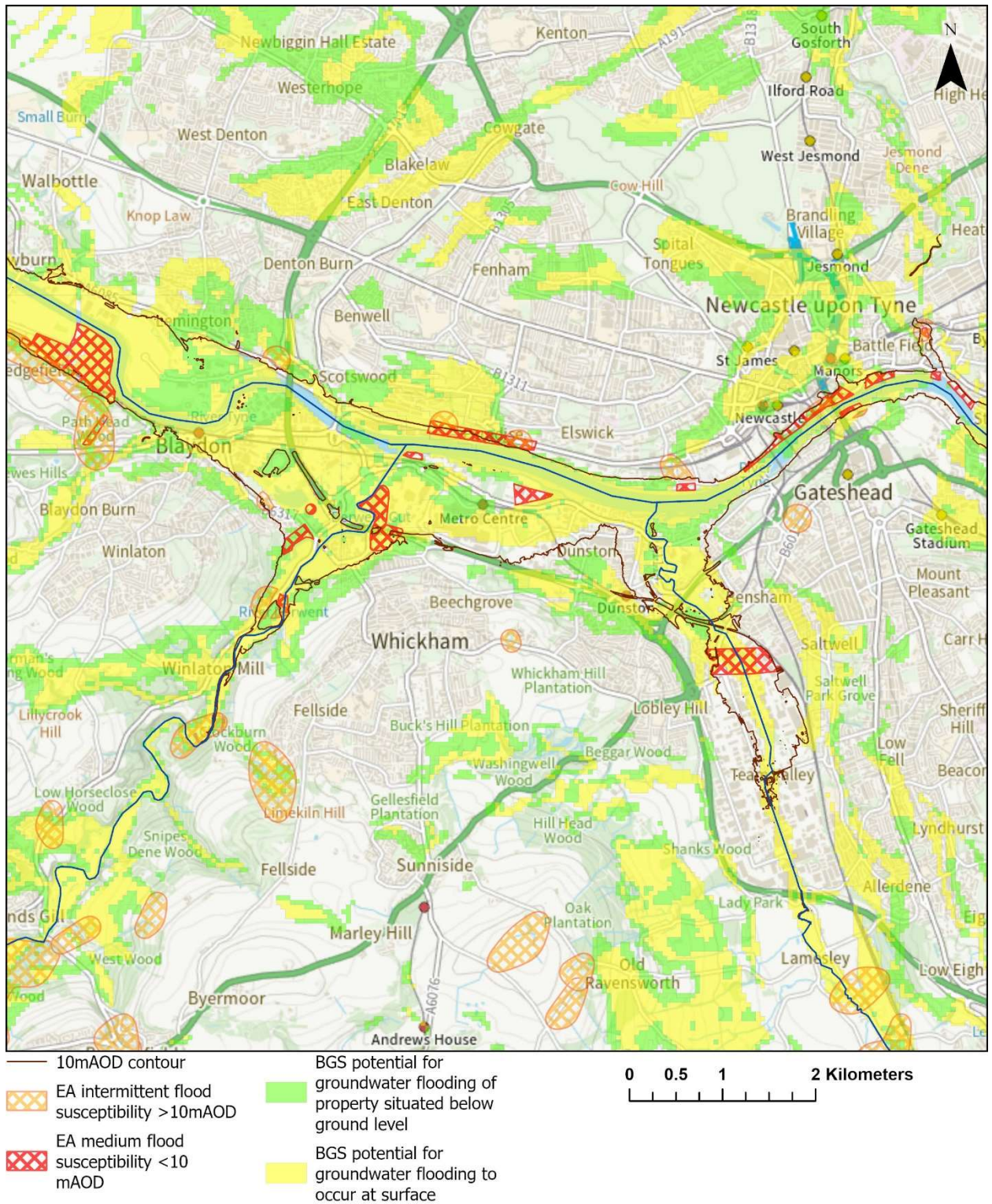


Figure 14: Detailed view of groundwater flood risk areas in the Gateshead area mapped by the EA (red and orange) for Project Groundwater (Marchi-Smith & Hallam, 2025), the 10 m elevation contour, and BGS mapped groundwater flood susceptibility areas (Green & yellow). Contains data from © Environment Agency copyright and/or database right 2025. All rights reserved. BGS © UKRI 2026. Contains OS data © Crown Copyright and database right 2026. OS AC0000824781.

5.2 LIMITATIONS AND UNCERTAINTY

Flood susceptibility maps provide a useful insight as to where groundwater flooding is possible, however, there remain significant uncertainties regarding the likelihood, extent and severity of

flooding which may occur in these locations. This is due to the complex spatial distribution of outcropping aquifer units, the extensive but still not fully mapped mine workings across the AOI and their interactions with hydrological and meteorological processes (e.g. rainfall, infiltration, recharge, connectivity with surface water bodies etc). This combined with limited groundwater level monitoring in these susceptible areas and sparse observational records of historic groundwater flooding make it difficult to validate these mapped areas.

5.3 FUTURE GROUNDWATER FLOODING

As mine water levels continue to recover in some mine water blocks following the cessation of historic pumping, there is a risk of groundwater emerging in areas previously not subjected to flooding. The MRA actively monitor water levels in some blocks to maintain mine water levels to prevent future flooding, however, other mine water blocks are not actively managed. Future groundwater flooding is likely to become more frequent and severe as winter rainfall is expected to increase due to climate change (Bednar-Friedl et al., 2022; Met Office, 2022).

6 Recommendations

Installing a shallow groundwater level monitoring network in areas identified as being susceptible to groundwater flooding could help better understand groundwater trends at these locations and provide an early warning system for groundwater flooding.

Groundwater emergence observations during groundwater flooding events (images, location, duration, flows) would provide physical evidence which could better inform the conceptual understanding and help refine any future numerical modelling. This would require community engagement and perhaps trained citizen scientists who could feed information into a database.

Sampling and chemical analyses of groundwater discharging from flood-prone areas could help determine where the water is originating from (i.e. mine water, natural groundwater) and how it is reaching the discharge points. This evidence would be valuable for considering flood mitigation options.

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Glossary

Aquifer: a rock formation that is sufficiently porous and permeable to yield a significant quantity of water to a borehole, well or spring. The aquifer may be 'unconfined' beneath a standing water table, or 'confined' by an impermeable or weakly permeable horizon.

Confined aquifer: an aquifer whose upper and lower boundaries are low-permeability layers that confine the groundwater under greater than atmospheric pressure. These aquifers are sometimes called artesian aquifers, the term first being used where the pressure surface was above ground level resulting in overflow under artesian pressure.

Groundwater recharge: the inflow of water to a groundwater body from the surface. Infiltration of precipitation and its movement to the water table is one form of natural recharge. Many methods have been devised to increase natural recharge to utilise aquifer storage, termed artificial or managed aquifer recharge. Measured in mm/d or mm/yr.

mAOD – metres above Ordnance Datum

Permeability (K): the term permeability, used in a general sense, refers to the capacity of a rock to transmit water. Such water may move through the rock matrix (intergranular permeability) or through joints, faults, cleavage or other partings (fracture or secondary permeability). A more strict definition is a measure of the relative ease with which a porous medium can transmit a fluid under a potential gradient. It is the property of the medium only and is independent of the fluid. Commonly, but imprecisely, taken to be synonymous with the term hydraulic conductivity, which implies the fluid is water. Measured in m^2 .

Porosity: The ratio of the volume of the interstices to the total volume of rock expressed as a fraction. Effective porosity includes only the interconnected pore spaces available for groundwater transmission; measurements of porosity in the laboratory usually exclude any void spaces caused by cracks or joints (secondary porosity).

Recharge: the quantity of water that is added to a groundwater reservoir from aurally distributed sources, such as the direct infiltration of rainfall or leakage from an adjacent formation or from a watercourse crossing the aquifer.

SuDS: sustainable drainage systems (sometimes sustainable urban drainage systems).

Unconfined aquifer: a partially saturated aquifer containing a water table that is free to fluctuate vertically under atmospheric pressure in response to discharge or recharge.

Water table: the surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere; the static water level in a well in an unconfined aquifer.

Yield (Q): the volume of water pumped or discharged from a borehole, well or spring. Measured in l/s or m^3/d .