HS2

Crewe to Manchester

Understanding the Ground Risk across the Cheshire Plain

3rd March 2023

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1 Executive Summary

1.1.1 The High Speed Rail (Crewe to Manchester) Bill, together with the first Additional Provision 1 deposited with Parliament, (hereafter referred to as the Proposed Scheme) comprises the section of the proposed High Speed 2 (HS2) rail network that will connect with Phase 2a south of the existing Crewe Station and continue through to Manchester, including:

- new stations at Manchester Airport and Manchester Piccadilly;
- a rolling stock depot north of Crewe;
- infrastructure maintenance facilities north of Crewe and at Ashley;
- Crewe Northern Connection (CNC), connecting the route of the Proposed Scheme with the West Coast Mainline (WCML) and enabling future Northern Powerhouse Rail (NPR) services to connect with HS2;
- provision for the NPR London to Liverpool, Manchester to Liverpool, and Manchester to Leeds junctions, so as to enable these future NPR routes to connect with HS2.

1.1.2 The alignment of the Proposed Scheme passes across the Cheshire Plain in areas of former salt mining and other areas where salt mining is ongoing. This report addresses geological concerns in this area and sets out:

- HS2 Ltd's understanding and interpretation of the existing ground conditions;
- How the route alignment and developed design has taken account of those ground conditions; and
- How HS2 Ltd plans to gather further information, develop the design, construct, and operate the Proposed Scheme.

1.1.3 Based on interpretations of information obtained to date and the derived engineering approach, HS2 Ltd, in conjunction with its designers and technical advisors, considers that the route alignment is appropriate for the intended purpose, and that geological challenges can be both managed and mitigated during detailed design and construction so as to provide a safe operational railway.

1.1.4 HS2 Ltd considers that the scale of the ground related challenges and their solutions are commensurate with the purpose of the Proposed Scheme as critical national infrastructure, and comparable to the scale of other ground related challenges that can be encountered in the operation of other high-speed railways.

1.1.5 HS2 Ltd is satisfied that the Proposed Scheme has been designed with sufficient in-built resilience, along with practical measures for routine maintenance and adaptive design, which can be put in place in achievable timeframes, to mitigate against climate change during operation.

2 Introduction

2.1 The purpose and structure of this report

2.1.1 Through the consultation and petition process, local communities and representatives have raised concerns regarding the Proposed Scheme and the underlying ground conditions of the current alignment north of Crewe and across the Cheshire Plain through to Rostherne Mere.

2.1.2 In response, this report has been prepared to substantiate the design development undertaken to date and demonstrate the knowledge, understanding and interpretation of the geological conditions underneath the Proposed Scheme to support the conclusions that the current alignment in this area is the preferred route, and that the railway can be delivered, operated and maintained safely in the context of the ground conditions on that route.

2.1.3 This report includes a summary of the route optioneering process carried out to derive the Proposed Scheme; detail on the ground conditions and the interface with the Proposed Scheme and how HS2 Ltd has used (and continues to use) this information in order to plan, design, construct and safely operate the railway.

2.1.4 The report begins by defining the Area of Interest and describing the Proposed Scheme within it. It then continues with a comprehensive review of the ground conditions across the Area of Interest and how understanding these influences have shaped the route optioneering and design development process.

2.1.5 The report then provides a section on how the design considerations will then allow the Proposed Scheme to be successfully constructed and operated. A summary of the consultation, engagement and information gathering process undertaken is provided. This indicates how the hybrid Bill and the Additional Provision 1 schemes have been informed, and how future phase of design will be informed by further level of data gathering as the Proposed Scheme matures.

2.1.6 Appendices accompanying this report provide:

- glossary and abbreviations;
- the history of route development;
- further supplementary technical information.

2.2 The Proposed Scheme and Area of Interest

2.2.1 The High Speed Rail (Crewe to Manchester) Bill (hereafter referred to as the Proposed Scheme) comprises the section of the proposed HS2 rail network that will connect with Phase 2a south of the existing Crewe Station to Manchester, including:

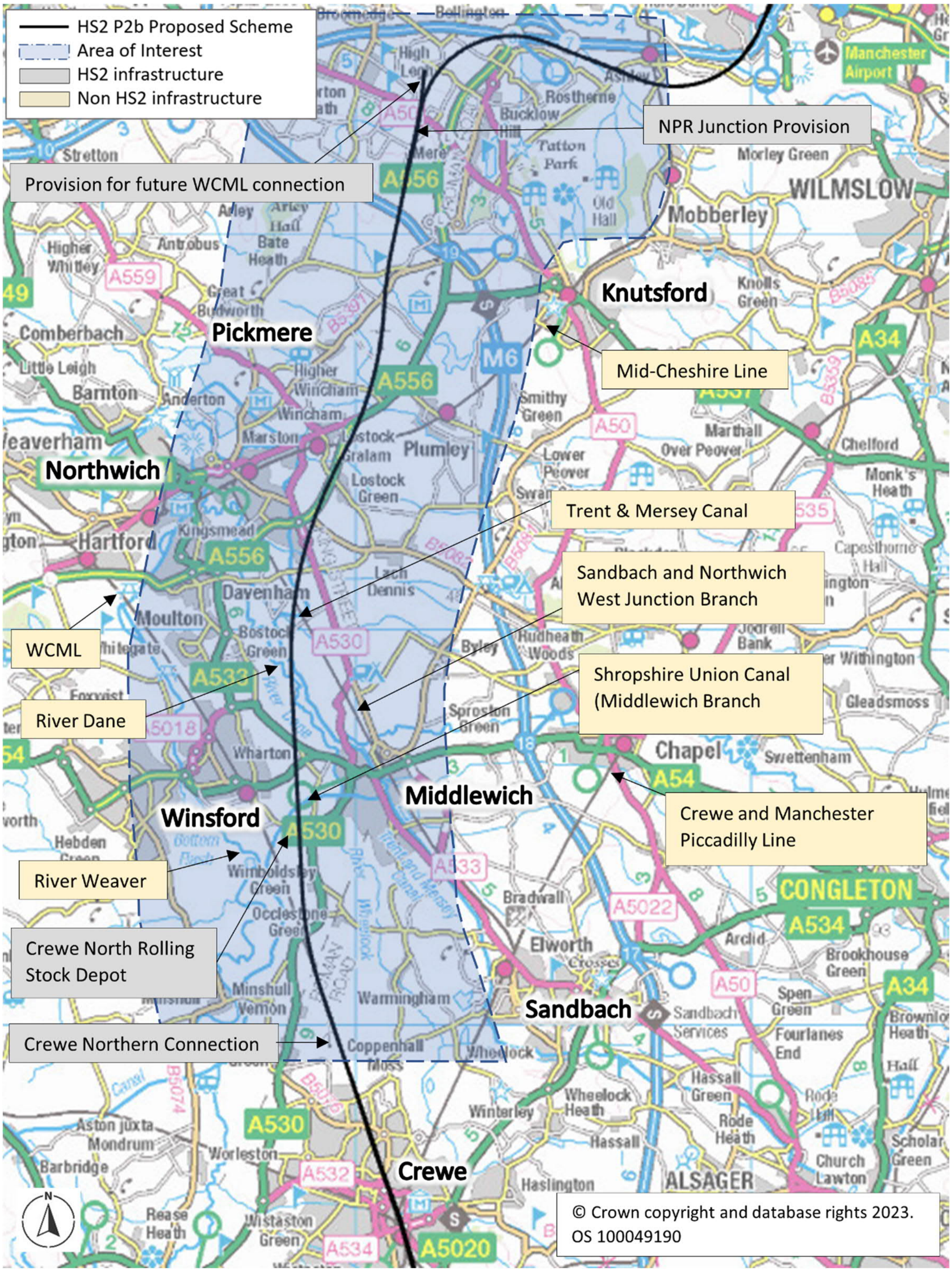
- new stations at Manchester Airport and Manchester Piccadilly;
- a rolling stock depot north of Crewe;
- infrastructure maintenance facilities north of Crewe and at Ashley;
- Crewe Northern Connection (CNC), connecting the route of the Proposed Scheme with the WCML and enabling future NPR services to connect with HS2;
- provision for the NPR London to Liverpool, Manchester to Liverpool, and Manchester to Leeds junctions, to enable these future NPR routes to connect with HS2.

2.2.2 The Proposed Scheme referred to within this report is that presented as part of the Supplementary Environmental Statement 1 and Additional Provision 1 Environmental Statement (2022)[1].

2.2.3 From both geological and geographical aspects, the area of consideration in this report is that shown in Figure 1 (hereafter referred to as the 'Area of Interest'). This area extends approximately 4 km either side of the Proposed Scheme alignment and extends from north of Crewe through to Rostherne Mere. The Proposed Scheme begins with the emergence of the HS2 rail tracks from Crewe tunnel and extends to North of Parkers Road.

[1]Link to access in the public domain: https://www.gov.uk/government/collections/hs2-phase-2b-crewe-manchester-supplementary-environmental-statement-1-and-additional-provision-1-environmental-statement

Figure 1: 2022 AP1 Proposed Scheme across the Cheshire Plain



3 Understanding the ground condition and risk

3.1 Introduction

3.1.1 The overall geology of the Cheshire Plain is comprehensively understood from published accounts and site investigations. A summary of information gathering carried out by HS2 Ltd to support the deposit of the hybrid Bill is set out in Section 5.

3.1.2 The geology will present certain geological risks within the Area of Interest, that can variously manifest as ground surface subsidence. Section 4 sets out how HS2 Ltd will plan the high speed railway and its infrastructure, and develop the design, the construction, and the operation of the Proposed Scheme in order to fully account for and address these risks.

3.1.3 This section of the report sets out to detail the risks. These include:

- Buried (infilled) deep valleys created during glacial periods;
- Dissolution of salt rock layers at depth as a natural ongoing process;
- Potential dissolution of the salt wet rockhead layer at depth as a result of historical brine extraction between the 18th century through to the early 21st century;
- Historical salt mining between the 17th century and early 20th century;
- Current brine mining and salt mining activity; and
- Climate change interaction.

3.1.4 In order to provide context for these aspects and a summary of the arising engineering challenge, the following sections provide:

- Section 3.2 A summary of the geological and hydrogeological conditions within the Area of Interest and introduces the concept of salt dissolution;
- Section 3.3 Historical and current day mining of salt within the Area of Interest; and
- Section 3.4 Considerations for climate change.

3.2 Geology and Hydrogeology

Surface Form

3.2.1 The Cheshire Plain is an area of relatively flat topography comprising in the main, rural pasture and crop fields. Whilst there are no regional topographic expressions directly reflecting the underlying layers of rock salt, there are occurrences of local scale topographical subsidence features (surface depressions) that are known to reflect processes of the glacial periods and ancient, recent, and ongoing salt dissolution effects.

3.2.2 These topographical features include flashes, meres, linear subsidence troughs, and subsidence basins.

Superficial Deposits

3.2.3 The ground conditions in the Area of Interest comprise a covering of superficial deposits typically formed of sand, gravel and clay to depths varying between 5 m and 30 m. Figure 2 shows the plan distribution of these deposits in terms of where they outcrop below topsoil layers. The superficial deposits are underlain by solid geology (bedrock).

3.2.4 Most of the superficial deposits were deposited at the end of the last glacial period (around 10,000 years ago), at a time when glaciers advanced and retreated across the wider Cheshire Plain. The arising deposits comprise stiff clays interspersed with firm to stiff clays and loose to dense sand and gravel deposits.

3.2.5 Alluvial Deposits (soft and potentially organic clays and loose sands and gravels) have subsequently been deposited in ribbon alignments beneath the existing river and stream systems.

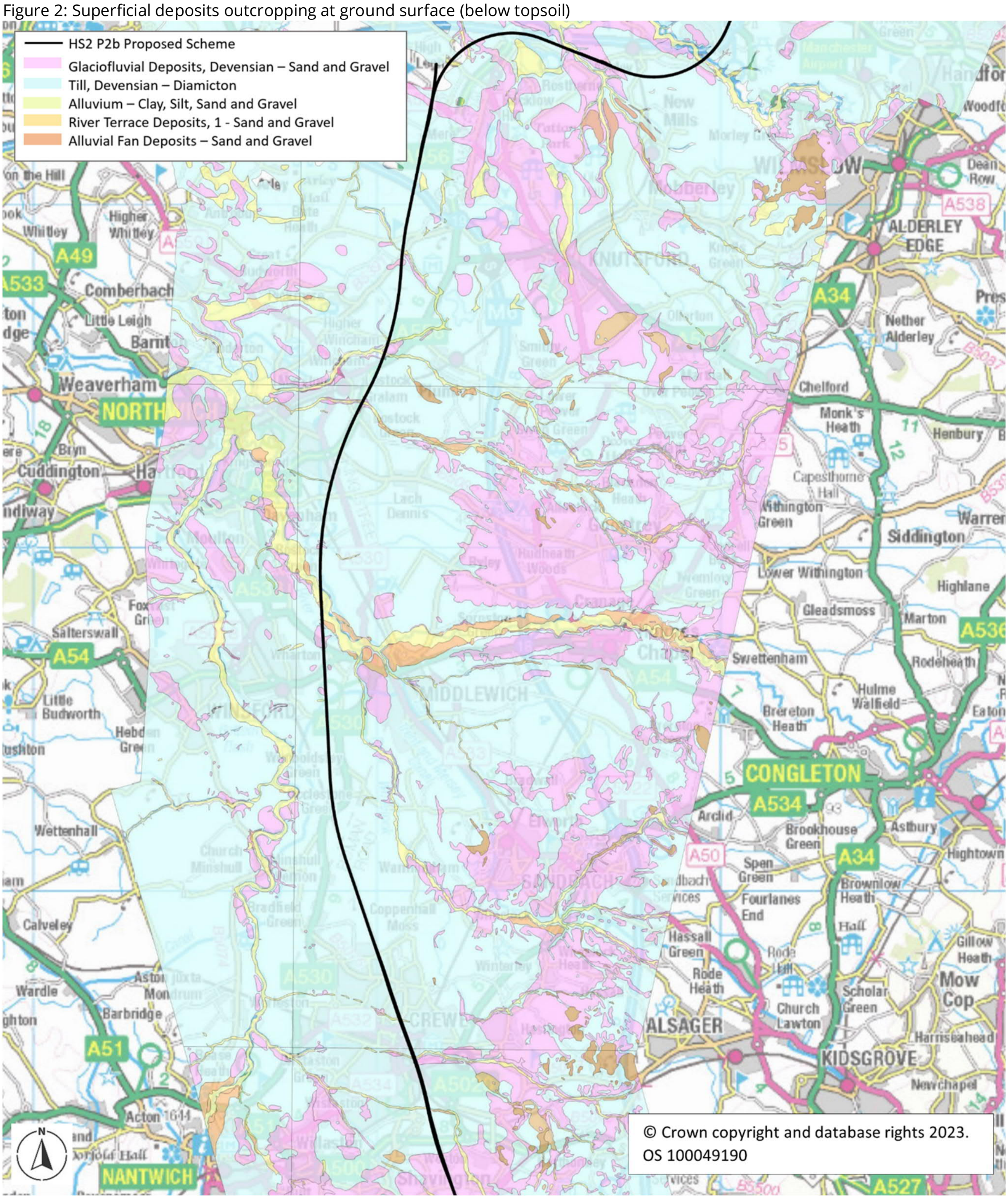
3.2.6 Localised thickening of the superficial deposits occurs where glacial activity eroded deeper valleys to maximum depths of the order of 100 m (approximately 40 m AOD). This depth of erosion reflects the conditions in the last glacial period, where so much seawater was locked in ice, sea levels were tens of metres lower than now.

3.2.7 These deepened valleys were subsequently backfilled with predominantly sands and gravels, before being capped over by later stage glacial deposits (stiff clays).

3.2.8 The localised deep valleys are termed 'glacial buried valleys' as there is little if any ground surface expression as to where these valleys exist. Along with scheme specific ground investigations, HS2 Ltd has carried out a comprehensive assessment of ground investigation records and other evidence for the Area of Interest so as to build knowledge on the distribution of such glacial buried valleys.

3.2.9 The ground in the Area of Interest has a cover of stiff glacial clay (blue areas in Figure 2) with localised sand and gravel deposits (pink areas in Figure 2). This clay cover completely masks the underlying bedrock and the glacial buried valleys.

Figure 2: Superficial deposits outcropping at ground surface (below topsoil)



Solid Geology (Bedrock)

3.2.10 Beneath the superficial deposits, solid geology (bedrock) is encountered. This bedrock is from the Mercia Mudstone Group (MMG) and comprises an interbedded sequence of clays, silts and evaporites (salts) deposited between 247 and 228 million years ago within a series of fault bounded subsidence basins akin to the desert environment of the East African Rift system today. With burial over geological time, pressure, temperature and cementation effects have lithified these sediments to form solid rock, referred to as mudstone, siltstone, and rock salt (halite).

3.2.11 The sequence of rock layers (members) within the MMG is presented in Table 1. The plan distribution of the uppermost members (i.e., those which directly underlie the superficial deposits) is shown in Figure 3. The Byley Mudstone Member (pink colour) and the Northwich Halite (rock salt) Member (blue colour) variously occur within the Area of Interest.

3.2.12 There can be areas where lower parts of the Byley Mudstone have been undermined by salt dissolution of the underlying Northwich Halite Member. This lower part is referred to as `foundered', and in subsiding, has in places altered the original rock structure. This foundering has occurred over more than 100 million years, and in more recent times accelerated in response to human activities between the late 18th century and the mid-late 20th century (refer to section 3.3). This lower part is termed Collapse Breccia and is discussed further in sections 3.2.34 to 3.2.37.

Structural Geology

3.2.13 Within the Area of Interest, the Proposed Scheme traverses bedrock contained by two bounding main faults; the King Street Fault to the east, and the Winsford Fault to the west (see Figure 3). The bedrock layers within this section of the basin have a typical gentle dip (slope) in the order of 5° to 10° towards the south-west. Steeper and more variable dips of the layers are recorded at and near the faulted contact.

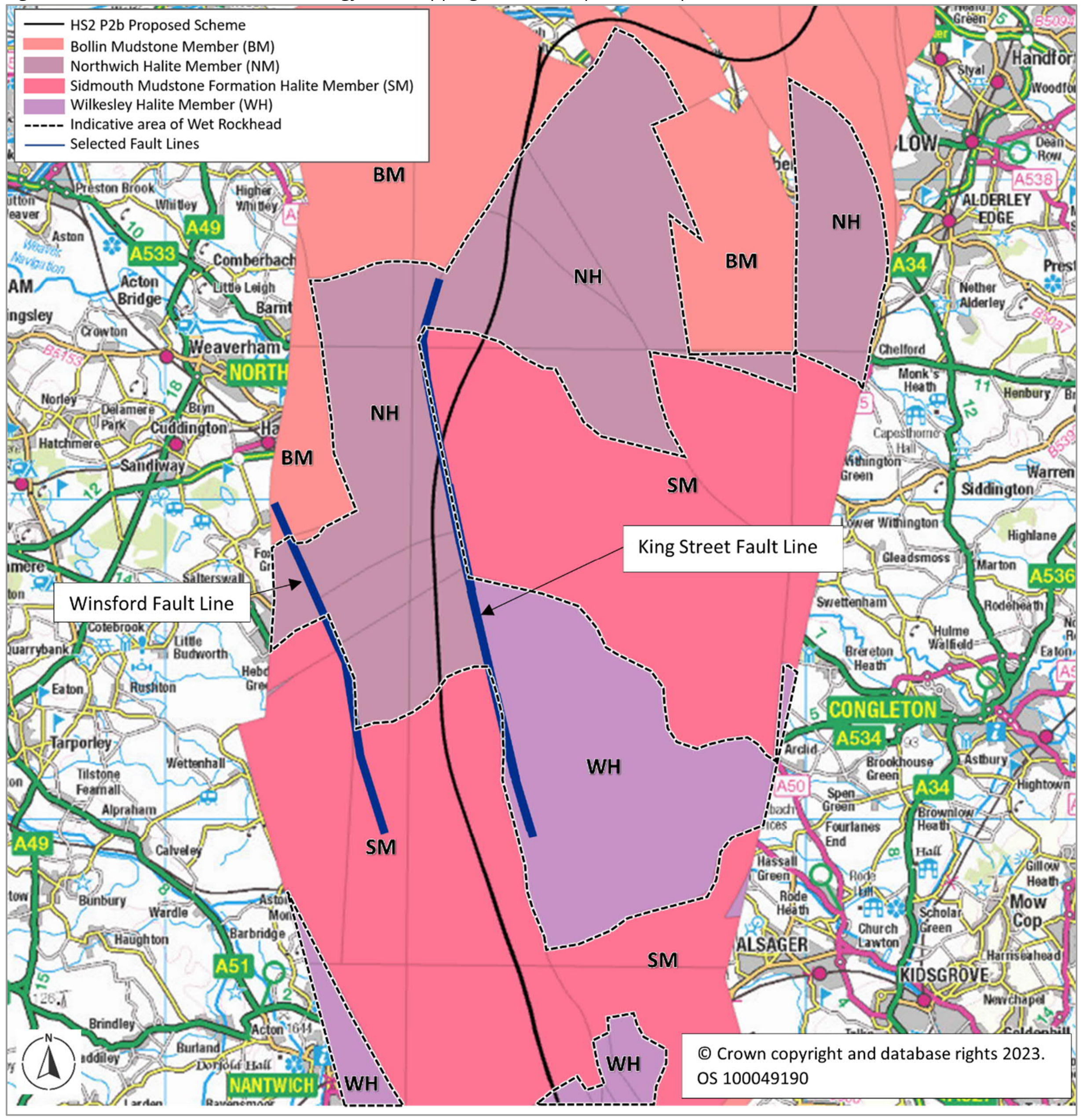
3.2.14 The King Street Fault is traversed by the Proposed Scheme. This fault vertically displaces the sequence of rocks by 200 m to 500 m (depending on locality) downwards on the east side. Hence, the Northwich Halite is encountered at shallower depth to the west and at much deeper levels to the east of the King Street Fault.

3.2.15 Within the area bounded by the main faults, several minor east-west striking (trending) faults are indicated by the British Geological Survey (BGS) data. It is understood that these minor faults are likely to be fold structures.

Table 1: Stratigraphy of the Mercia Mudstone at the Cheshire Plain

Period	Group	Formation	Member	Lithology
Permo- Triassic	Mercia Mudstone Group {Formerly Keuper Marl]	Sidmouth Mudstone (Mercia Mudstone Group Unit B)	Wilkesley Halite (WH)*	Halite of varied purity, interbedded with mudstone partings. Generally, does not occur at or near surface due to dissolution and is instead there a breccia of collapsed mudstones. [Formerly known as Upper Keuper Saliferous Beds]
			Wych Mudstone (SM)*	Mudstones - block reddish brown with anhydrite/gypsum nodules up to 0.2m in diameter and numerous gypsum veins mostly in uppermost two thirds [Formerly known as the upper part of the Middle Keuper Marl]
			Byley Mudstone (SM)*	Alternations of structureless reddish brown mudstones (lithofacies B) with laminated greenish grey and blocky reddish-brown mudstones (lithofacies C). [Formerly known as the lower part of the Middle Keuper Marl]
			Northwich Halite (NH)*	Halite with partings of mudstone. Generally, does not occur at or near surface due to dissolution and is instead there a breccia of collapsed mudstones. Is 283m thick, approx. 15km north of Crewe [Formerly known as Lower Keuper Saliferous Beds]
		** Map Reference*	Bollin Mudstone (BM)*	Upper part is dominantly laminated reddish-brown and greenish-grey mudstone with siltstones, with desiccation cracks, ripple laminations and halite pseudomorphs. Lower part dominantly laminated reddish-brown mudstone. The base of the sequence corresponds to an increasing proportion of siltstones and sandstone beds [Formerly known as Lower Keuper Marl]
		Tarporley Siltstone (Mercia Mudstone Group Unit A) [in Sherwood Sandstone by some sources e.g. BGS Sheet 123]		Interlaminated and interbedded siltstones and mudstones, with beds of sandstones up to 1m thick. The base of the sequence corresponds to an increased proportion of sandstones and is complex and variable laterally. [Formerly known as Keuper Waterstones]

Figure 3: Mercia Mudstone Solid Geology sub cropping beneath Superficial deposits



Hydrology (Surface Water)

3.2.16 The Proposed Scheme crosses rivers and streams. These water courses are surface water fed and generally flow from east to west across the Cheshire Plain. The River Dane runs within a 10 m to 20 m deep valley, whilst several named brooks typically run within 5 m to 10 m deep valleys. The rivers through the region drain areas with silt and clay as the dominant soil material, hence sedimentation of these fine deposits forms a relatively low permeability seal to the riverbed. Infiltration rates of surface water from the river into the sub-surface environment are therefore low, though localised leakage could increase where sub-surface sands and gravels are traversed.

3.2.17 The main artificial water courses are the Trent and Mersey Canal and Shropshire Union Canal (Middlewich Branch). For the Proposed Scheme within the Area of Interest, canals as a source for generating low salinity groundwater is considered limited.

3.2.18 Throughout the Area of Interest, there are flashes and meres. Flashes are current day water bodies which have formed as a result of ground settlement, induced by either historic mining collapse or historic mining induced acceleration of salt dissolution. Billinge Flash northeast of Winsford is the only such body crossed by the Proposed Scheme. For historical mining refer to section 3.3.

3.2.19 Meres are shallow lakes considered to have originated as depressions formed from glacial scouring. They are backfilled with compressible soils and have subsequently flooded. In recent times, they have been subject to ground subsidence associated with salt dissolution at their base. There are meres situated within the northern part of the Area of Interest, including Tabley Mere, Pick Mere, Tatton Mere and Rostherne Mere.

3.2.20 In summary and in principle, the main rivers, flashes, and meres have potential to feed surface waters into the ground and so generate fresh groundwater. The canal network has limited potential to do the same. If the main rivers, flashes, and meres are coincident with granular superficial deposits, there will be increased potential to generate fresh groundwater.

Hydrogeology (Sub-surface groundwater)

3.2.21 Water stored below the ground in rocks or other geological layers is called groundwater. This water is sourced from either atmospheric rainfall or from former ancient ice melt, which has drained into the ground and stored within pore spaces (similar to how a sponge may hold water) and within the fracture network of the bedrock.

3.2.22 Groundwater flows in the ground under differences in pressure gradient, such as flow created by water at high elevation flowing to water at a lower elevation, and preferentially along permeable deposits, through open fractures in rock, and through interconnected void networks.

3.2.23 It is typically the case that there is a near ground surface (upper) hydrogeological system in superficial deposits, and a deeper hydrogeological system in bedrock. In the Area of Interest, the predominance of glacial clay and mudstones act as low permeability aquicludes which typically separate (isolate) the upper and lower hydrogeological systems from each other.

3.2.24 The upper hydrogeological system includes superficial deposits such as stiff clays, with some layers of sand and gravel deposits. Surface rainwater can readily accumulate in the sand and gravel layers, and where these layers outcrop at lower elevations in valley sides, freshwater spring lines are formed. Surface rainwater falling over the large areas of glacial clay runs off to the local drainage and river networks.

3.2.25 The lower hydrogeological system includes the bedrock layers of mudstone, collapse breccia and rock salt layers. In this system, groundwater flow is understood to be active to depths varying between about 60 and 120 mbgl. Groundwater flow will be via localised open fractures in bedrock and through any interconnected void network. The intact halite beds are of sufficiently low permeability that they form a barrier to vertical flow. The interaction between lower hydrogeological system and the solid geology / bedrock system is further explained below.

3.2.26 The buried glacial valleys effectively connect the upper and lower hydrogeological regimes with high permeability infill deposits. These valleys can be considered as major conduits for groundwater flow and allow the upper hydrogeological system to connect locally with the lower hydrogeological system, such that the upper system can pressurise the lower system.

3.2.27 In summary, there is an upper (shallow) hydro-geological system with groundwater stored and flowing within near surface sand and gravel layers. There is a lower (deeper) hydro-geological system with groundwater stored and flowing in bedrock via open fractures and interconnected voids. The two systems are mostly separated by an impermeable barrier of mudstones. Along the courses of deep buried glacial valleys, the two systems may be locally connected.

Natural Salt Dissolution

3.2.28 The MMG is considered to have undergone maximum burial some 145 million years ago, since when gradual exhumation by erosion of overlying layers has been an ongoing process. Halite is extremely soluble in fresh water (7,500 times more soluble than limestone), hence over this geological timescale where halite members of the MMG are exhumed back into groundwater flow zones, they have been subjected to fluctuating levels of groundwater flows which has resulted in natural dissolution of the halite.

3.2.29 As groundwater cannot flow through intact salt, it is only the upper surface of the salt which is progressively dissolved with groundwater flow following preferential pathways driven by hydraulic gradient and preferential pathways of greatest solubility such as those in which open rock fractures are present. This surface is known as the salt rockhead and may be considered as a corroded surface at depth.

3.2.30 Dissolution can only occur where there is an active (refreshing) groundwater flow path. Water saturated with salt is known as brine. As salinity of groundwater increases through ongoing dissolution, its ability to dissolve further underlying salt diminishes and its fluid density increases. Once brine is fully saturated (super saturated) with salt, it cannot further dissolve salt and forms a dense fluid which less dense under-saturated groundwaters cannot displace. For dissolution to continue, supersaturated brine must therefore be able to outflow to some discharge point, such that under-saturated brine can move in and take its place. If the flow stops (such as if the flow path is not available), super-saturated brine will sit above the salt rockhead, and dissolution will stop. The super-saturated brine then forms a protective cap to the salt rockhead.

3.2.31 Over millennia, a protective brine cap formed over the surface of the Northwich Halite, explaining why Northwich Halite is preserved at relatively shallow depth within the Area of Interest.

3.2.32 The area of upper salt surface that has been subject to dissolution has historically been termed wet rockhead because this was where the commercially attractive overlying protective brine could be found and most easily extracted by Wild Brining. Further details of the Wild Brining operation are provided in section 3.3.

3.2.33 Where the salt surface was at greater depths and below the zones of groundwater circulation, and under higher ground pressures, dissolution was not possible, and this surface is called dry rockhead. There is no brine at this surface. In the Area of Interest, the depth at which dry rock head can be found is thought to be around 80 to 100 m.

3.2.34 The natural dissolution process has resulted in long continued, very gradual subsidence over a timescale of millions of years. According to the BGS Sheet Memoirs, up to 200m of salt has been removed due to dissolution at the salt rockhead over the past 140 million years. Dissolution occurs at the salt rockhead as it enters the groundwater mobilisation zone, hence the overlying mudstone layer is undermined. The overlying mudstone therefore fractures and founders as it moves downward to infill the voids created by the dissolved salt. This fractured and foundered mudstone is termed 'Collapse Breccia'.

3.2.35 By definition, Collapse Breccia, has been displaced, and in a very strict geological sense, cannot be considered as intact *in situ* solid rock. The first encounter of intact solid rock is then that at wet rockhead level below, i.e. intact halite members. The BGS generate their bedrock geological map (see Figure 3 above) on the basis of rock meaning the intact solid rock, so the mapping of rock is based on the 'wet rockhead', and not on the occurrence of Collapse Breccia. Hence, in Figure 3, where Northwich Halite and Wilkesley Halite are shown, this defines the extent of the 'wet rockhead' area associated with those halite members. In these regions, for the most part, an extensive thickness of Collapse Breccia separates the superficial deposits from the halite members.

3.2.36 To date, intrusive investigations (boreholes) undertaken for the Proposed Scheme within the Area of Interest and within wet rockhead areas, reveal that the Collapse Breccia should be considered as intact rock. The recovered cores typically reveal a 20 to 40 m thickness of cemented mudstone and siltstone layers, similar in overall nature to that of *in situ* layers belonging to the Byley Mudstone Member. This suggests that there are foundered sizeable rafts of intact rock at the project scale and scale applicable to engineering, and which can be considered to essentially possess very nearly the same strength and load bearing characteristics of fully *in situ* rock.

3.2.37 Ancient degradation of the Collapse Breccia has taken place in a zone within a depth of about 5 m to 10 m above the salt rockhead, with rock cores showing fragments (breccia) of mudstone and siltstone cemented together to provide a stable competent cemented rock. There is then a transition in the condition of the Collapse Breccia, such that for the zone within 2 m to 3 m above the wet rockhead level, rock cores show a stiff clay bound breccia. This transitioning sequence is considered typical within the Collapse Breccia.

3.2.38 Cores of the Collapse Breccia and fully intact mudstone members show that the natural fractures and joints are orientated both horizontally and vertically and are nearly always infilled with the mineral gypsum (calcium sulphate). This suggests that there were long periods in ancient times in which mineral rich groundwaters flowed and precipitated in the fractures. The cemented nature of the Breccia and the infills of gypsum in the fractures and joints mean that current day groundwater flow in the collapse breccia is expected to be very low.

3.2.39 The non-intrusive and intrusive investigations for the Proposed Scheme do not indicate any voids in the Collapse Breccia at a scale of engineering concern. *In situ* (down borehole) water permeability tests return very low values confirming that groundwater flow is expected to be very low in the Collapse Breccia, and when drilling to form the boreholes, there are very few losses of the drilling fluid in use to open fractures, again suggesting that the fractures and joints have been closed up by mineralisation in ancient times.

3.2.40 Preferential areas of natural dissolution likely persist where active groundwater flow paths are established, either in connection with wet rockhead in the vicinity of the deeper reaches of the Glacial Buried Valleys or via open fracture networks within the very base of the Collapse Breccia. This dissolution results in void networks at the Collapse Breccia – salt rockhead interface termed brine runs, where active groundwater flow and ongoing dissolution can take place. This was an entirely natural process in ancient geological times. The process was subsequently accelerated by wild brining (see Section 3.3), and now that wild brining has ceased for around four decades or more, it can be considered as a new and much slower natural process of ongoing dissolution.

3.2.41 As such, four essential conditions need to be present for ongoing salt rock dissolution, including 1) presence of wet rockhead with salt rock present, 2) open fracture networks in the rock, 3) water pressure head difference to drive groundwater flow, and 4) an ongoing supply of low salinity groundwater. These conditions are rarely all met, and so ongoing salt dissolution does not take place in a widespread fashion across the Area of Interest. Accordingly, potential instances of ground subsidence are expected to be related to particular locations and not as a widespread phenomenon. This accords with the relatively few case histories or reported occurrences of salt dissolution related problems across the Cheshire Plain in modern times.

3.2.42 The four conditions can be met in specific cases relating to certain established brine runs and where buried glacial valleys cross areas of wet rockhead. Buried glacial valleys are expected to also play a role in the conditions needed for salt dissolution on brine runs.

3.2.43 In summary, in those areas where the Proposed Scheme traverses the Northwich Halite 'wet rockhead', approximately 40% of the Area of Interest, ground conditions comprise Glacial superficial deposits overlying Collapse Breccia, overlying Northwich Halite (salt rock), with salt rock head levels ranging between 70 and 100 mbgl. The Collapse Breccia may be considered as intact rock with a mineralised and closed fracture network. In places and related to trends in the structural geology such as rock jointing and open fractures, networks of interconnected voids, known as 'brine-runs', thought to be metres in width and typically less than 1 m in height are present at the base of Collapse Breccia (which is the wet rockhead surface).

3.2.44 There can be ongoing dissolution of rock salt along parts of a brine run provided that a number of conditions exist: there is wet rockhead with rock salt present; a water pressure head difference exists along parts of a brine run; there is an ongoing supply of incoming low salinity groundwater; and a pathway is available for ongoing groundwater flow.

3.2.45 The conditions are rarely all met and hence the occurrence of ongoing dissolution (and hence ground subsidence) is quite rare across the Area of Interest. Along the lines and flanks of buried glacial valleys, there can be salt dissolution in places where the same conditions are met. Again, the occurrences are rare. With the cessation of wild brining more than four decades ago, ongoing dissolution along brine runs is expected to be at a slow natural rate.

Impact at Ground Surface from Ongoing Salt Dissolution

3.2.46 In brine runs with ongoing salt dissolution, the interconnected void network can continue to slowly extend laterally. Should the brine run reach sufficient width, the rock above may have insufficient strength to arch (bridge over) that brine run. At this point, a process of slow void migration towards the ground surface may be triggered. In this scenario, ground surface depression or surface subsidence will develop once the effects of the void migration process reaches to the ground surface.

3.2.47 Within the Area of Interest, salt rockhead is overlain by a significant thickness of foundered mudstone (Collapse Breccia). Where this mudstone has been subject to natural cementation effects, the rock will have good strength and may well arch over brine runs that have reached significant width.

3.2.48 In other situations, the Collapse Breccia can contain horizontal thinly spaced bedding planes (60 mm to 200 mm vertical spacing) that are not cemented, and these are then planes of weakness. Thin rock layers can split in tabular form and be released from these planes once the strength of the plane to span an underlying brine run void is exceeded. The thin slabs of rock will then fall into void spaces, and so a new void forms above, in effect, thin voids move upwards as the cycle repeats. As such, lack of cementation in Collapse Breccia is another condition for ground surface subsidence to manifest over time. Even where this condition is present, the void remains thin, and large tall voids do not form in the overlying rocks or just below the ground surface.

3.2.49 Should the void migration process as described in section 3.2.50 above reach to the base of the stiff glacial clay layer of the superficial deposits, this layer will tend to then pliably subside in response, and hence whilst the subsidence at ground surface above a brine run is linear in plan, it takes the profile of a gentle bowl in a cross section perpendicular to the main axis of the brine run. The pliable subsidence of the glacial clay layer expands the zone of deformation such that the surface width of the basin profile can be tens of metres and the total historical amount of settlement along the centre line can be in the order of 1 to 2 m. The time taken for a void to initiate at salt rock head level and then migrate to ground surface is expected to be slow, and likely on the timescale of a decade to many decades.

3.2.50 Theoretically, where salt dissolution is taking place in the vicinity or base of Glacial Buried Valleys, sands and gravels of the infill that are present at the level of dissolution would tend to flow downwards into the void spaces. It is possible that there would be no significant arching effect (like that described for brine runs beneath collapse breccia). The lateral extent of ground loss would then be much larger, controlled by the lateral extent of rock salt layer that is present within the influence of the buried valley. The migration of the loss of support to the ground surface would then be more rapid (likely decades) and both conical shaped and wider settlement troughs could be anticipated at the ground surface.

3.2.51 The ground surface subsidence mechanisms described above, only occur where active dissolution continues, requiring a mobile under-saturated groundwater environment. If a protective brine cap exists with low groundwater pressure gradients, dissolution and hence subsidence will desist.

3.2.52 For the range of mechanisms as described in section 3.2.46 to 3.2.50 above, no sizeable void forms just beneath the ground. It is important to draw the clear distinction between the effect of these mechanisms described above, and the specific geological conditions which can lead to the kind of dramatic collapses at the ground surface commonly referred to as “sink holes”. There is no evidence to suggest the existence of those specific geological conditions within the Area of Interest. There have been no reported instances of sink hole formation arising out of natural salt dissolution across the Area of Interest.

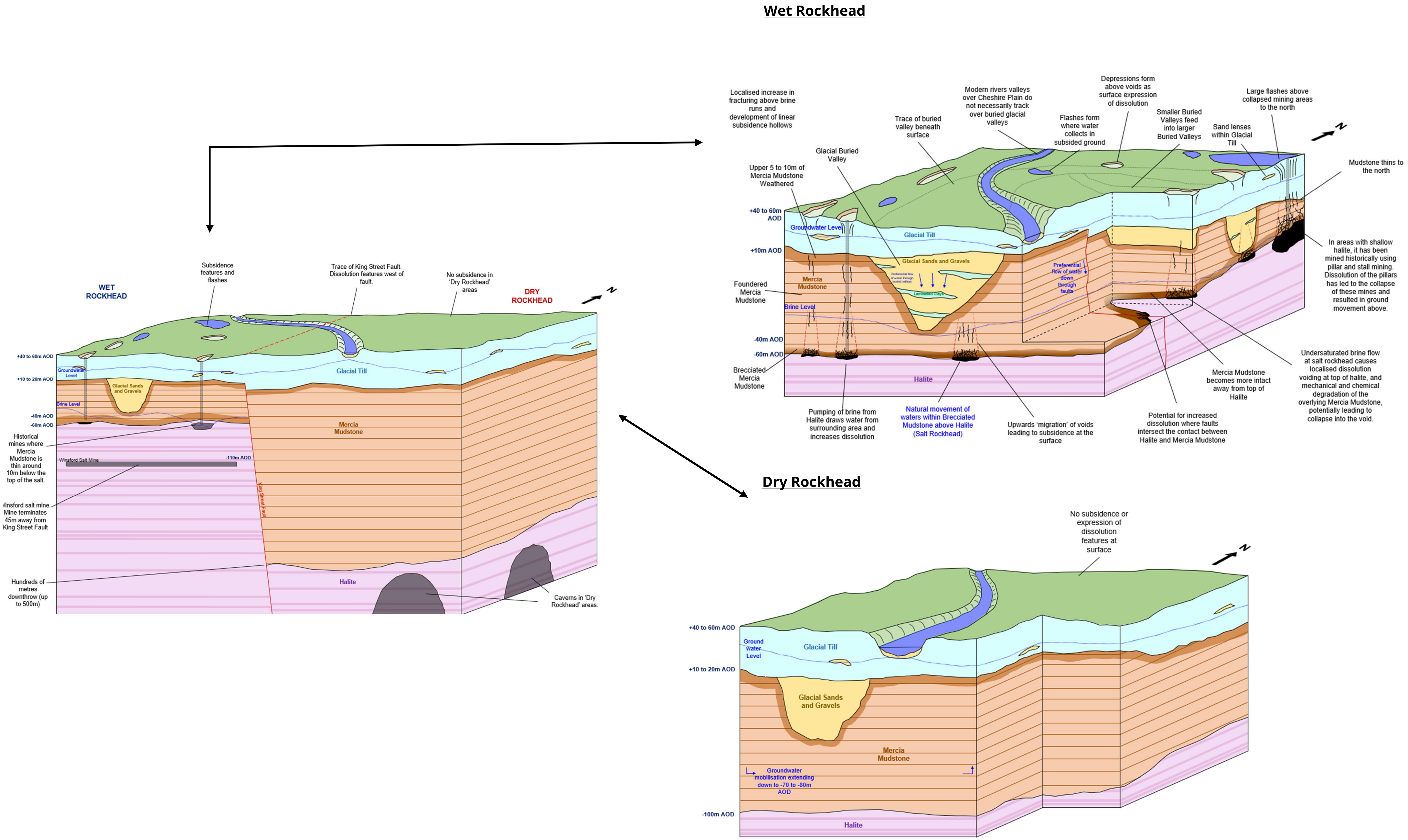
3.2.53 Figure 4 provides schematic block diagrams illustrating wet rockhead and dry rockhead, and salt dissolution effects. Schematic details of former and current mining are also shown. A discussion on Mining is provided in the following section 3.3.

3.2.54 In summary, the process by which salt dissolution at depth (at wet rockhead) can give rise to ground surface depressions or subsidence is different for the setting of a brine run and the setting of a buried glacial valley. The processes also have different timescales. For a brine run, surface subsidence may not develop if the brine run is too narrow. Also, for a brine run over naturally cemented cover rock, there is much reduced potential for ground subsidence. Conversely, uncemented cover rock over a wide brine run may lead to a void migration process to ground surface, resulting in ground surface subsidence.

3.2.55 For salt dissolution at or on the flanks of a buried glacial valley, the uncemented granular infill to the valley enables a groundwater flow path to the salt rockhead and permits downward slumping. Void migration through Collapse Breccia will likely be on the scale of decades; void migration through buried glacial valleys may be anticipated to be more rapid, on the scale of years. Neither of the processes leads to the formation of a sizable (tall height) void that could give rise to a sink hole at the ground surface.

3.2.56 Noting that four conditions are needed in order for salt dissolution to take place (section 3.2.41), and then additional conditions are needed as described above, there are between 5 and 6 conditions that need to be met at a location in order for there to be ongoing and future ground surface subsidence. It is only very rarely that those 5 or 6 conditions will occur in any given location; and hence the occurrence of ongoing dissolution (and ground subsidence) is very rare across the Area of Interest.

Figure 4: A schematic block diagram for ground conditions encountered in the Area of Interest



3.3 Industrial Salt Extraction

3.3.1 This section considers the four different types of salt extractions from the historical uncontrolled ones to the recent regulated controlled ones, either by brine extraction or by mining. A summary chronology of these industrial activities within the Area of Interest is show on Figure 5.

Historical Brine Extraction

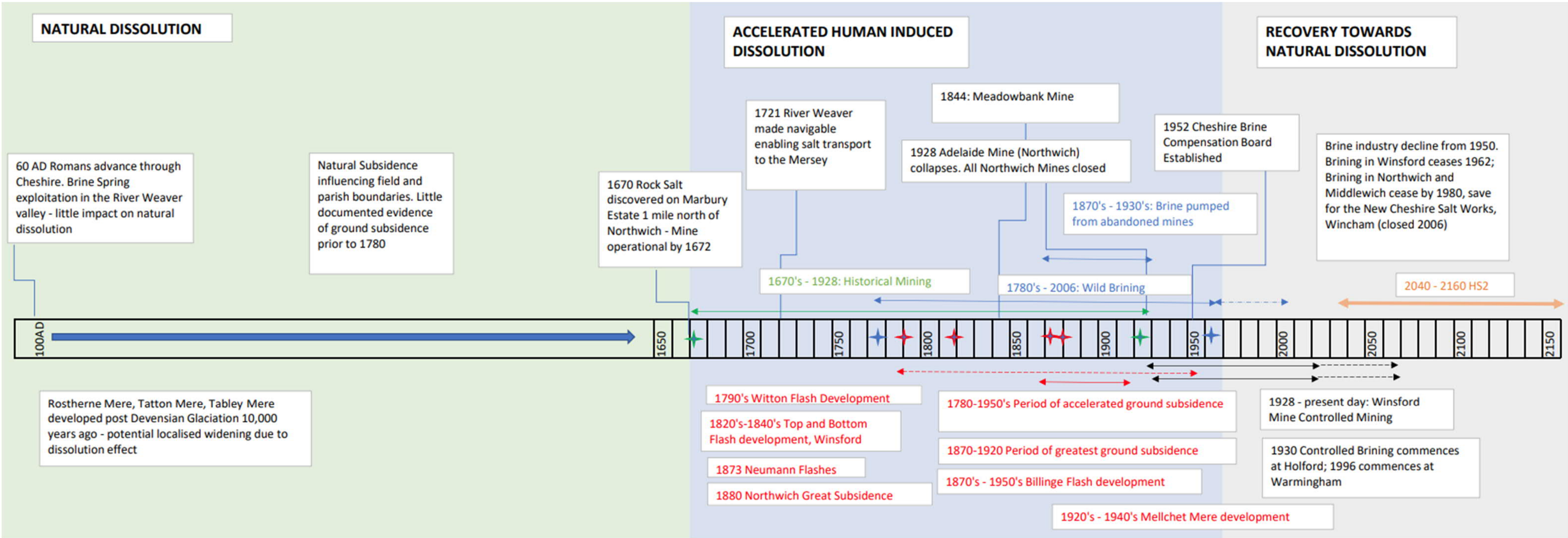
3.3.2 Natural brine 'pooled' above the salt rockhead developed during the post glacial period as the hydrogeological pressure gradients reduced from an active state. This provided a dense protective layer which prevented significant further dissolution at the salt rockhead.

3.3.3 Industrial extraction of this natural brine cover above the 'wet rockhead' commenced in the late 18th Century with brine wells constructed through the superficial deposits and Collapse Breccia to tap into the natural brine. The natural brine which had been accumulated through a slow process over millennia was pumped from the brine-wells and transferred to salt evaporation pans, where salt was won.

3.3.4 Clusters of wells developed along the banks of the River Weaver in Northwich and Winsford, and later in the first half of the 20th century, adjacent to the River Dane at Middlewich. The most successful brine extraction arose from wells along the lines of pre-existing natural brine-runs. There was little engineering consideration given to the operation hence it can be thought of as 'uncontrolled'. This uncontrolled extraction of concentrated brine from the 'Wet Rockhead' zone, referred to as 'wild' or 'natural' brine pumping, accelerated the rate of subsidence within the brine runs by accelerating groundwater flow and pulling less saline and freshwater into the runs. During periods of wild brining, subsidence rates were in the order of hundreds of millimetres per year along the brine runs. Brine pumping had largely ceased by the 1960s.

3.3.5 The most severe subsidence was at the head and sides of the brine run where the freshwater was drawn in to replace the extraction of concentrated brine. Consequently, surface subsidence often occurred at significant distances, as much as 5 to 9 km away from the brine well.

Figure 5: Timeline of Industrial Activity



3.3.6 Due to the number of independent brine pumpers and the distance of surface subsidence from the pumping centres the attribution of responsibility for the cause of surface subsidence was virtually impossible. Land subsidence and consequent damage ultimately resulted in the introduction of the Cheshire Brine Pumping (Compensation for Subsidence) Act 1952 and establishment of the Cheshire Brine Subsidence Compensation Board (the Board, CBSCB). The current role of the Board includes the administration of a compensation scheme for land and property affected by the legacy of pumping of brine. The area covered by the 1952 Act, known as the "Compensation District" is essentially limited by the geological occurrence of the Saliferous Beds in Cheshire.

3.3.7 In addition to the role associated with compensation claims, the Board is a statutory consultee (1952 Act, Section 38) in relation to planning applications and building regulations. The Board is required to notify the local planning authorities of those areas within the Compensation District within which the Board wish to be consulted (areas which are subsiding or liable to subside). These areas are known as the Consultation Areas.

3.3.8 Areas of subsidence were recorded in historical BGS geological maps of the 1950s and 1960s. The mapped subsidence reflected both natural dissolution and wild brine pumping impacted areas. Figure 6 below shows the collective record of the locations of subsidence hollows and features as taken from the historic mapping. The greatest concentration of recorded subsidence features is in the area west of Sandbach and south of Middlewich, which are situated significantly away from the Proposed Scheme. The BGS named these areas as 'Karst Doline' where doline is a geological term for a hollow or basin in a karstic region. The terms Karst and karstic originates from the Germanic form of the name of a region in northeastern Italy impacted by dissolution of soluble carbonate rock (the Kras region). Figure 6 below shows that the Proposed Scheme alignment avoids significant clusters of subsided areas.

3.3.9 The proposed alignment is not situated within any of the Consultation Areas indicating that the route is not considered from a planning perspective to be in an area at significant risk from ongoing ground subsidence arising out of brine mining activities (see Figure 7 below). This in itself does not mean that ground subsidence cannot occur along the alignment and ground subsidence risk from brine runs is considered in further detail in section 4.

3.3.10 During the design development for hybrid Bill an area of subsidence adjacent to Clive Green Lane was identified and showing signs of recent (and ongoing) growth. Changes were made to the proposed highway realignment design to move it away from this subsidence.

3.3.11 Wild brine operations were mostly phased out during the 1960s, with all but one operation having ceased by the 1980s, and closure of the final wild brine operator (The New Cheshire Salt Works) situated to the northeast of Northwich occurred in 2006.

3.3.12	In summary, wild brining primarily took place and very significantly impacted parts of the Area of Interest between 1790 and the mid-1980s. Pumping of brine accelerated salt dissolution along natural brine runs and also created new brine runs. Significant linear ground subsidence developed at ground surface with historical subsidence of hundreds of millimetres per year during periods of wild brining. In consequence, the Cheshire Brine Compensation Board was established. Following cessation of wild brining, any ongoing subsidence along the brine runs is at a very much lower rate. The Proposed Scheme alignment avoids significant mapped clusters of formerly subsided ground.

Figure 6: Dissolution features and subsidence hollows from historic BGS mapping relative to the Proposed Scheme.

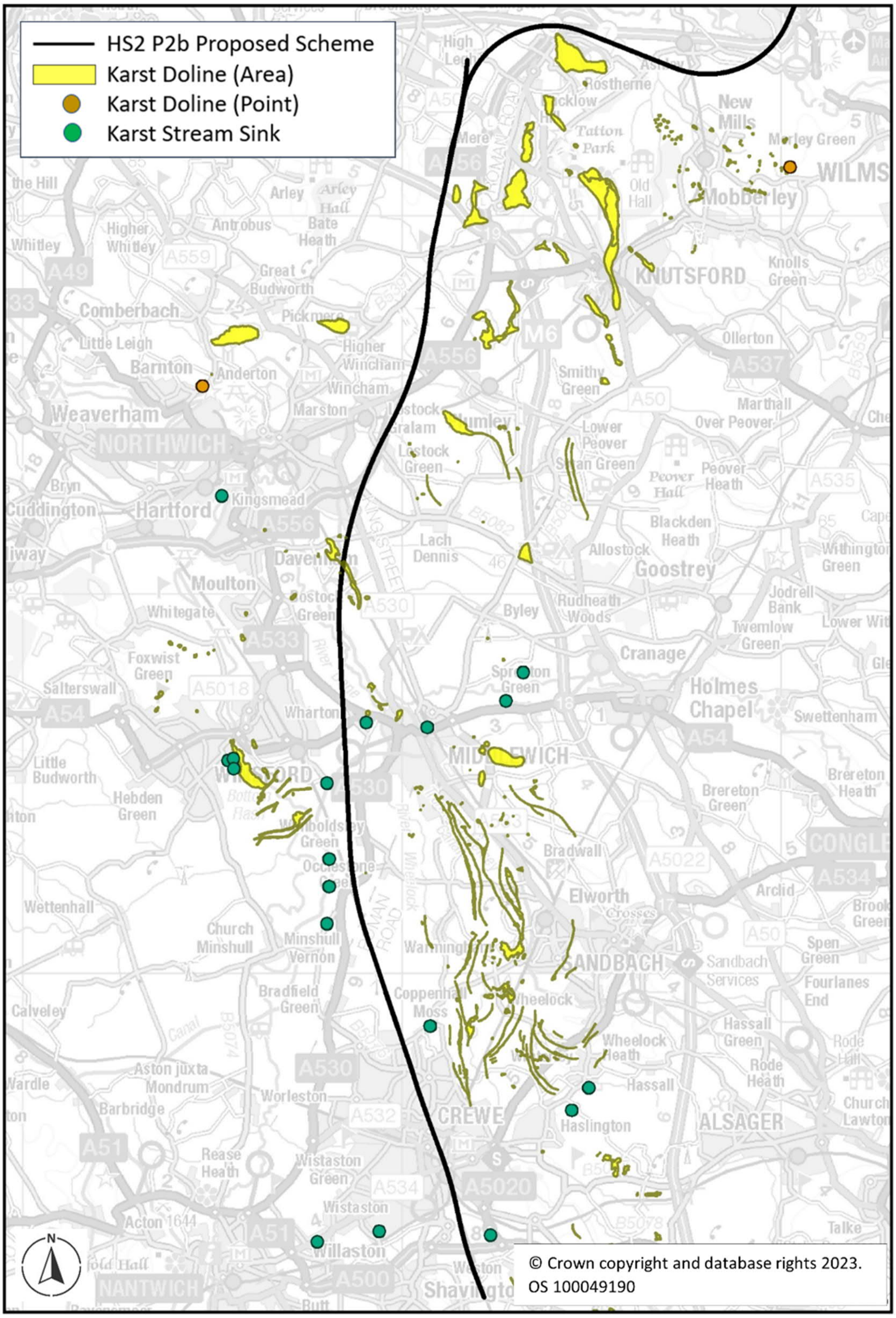
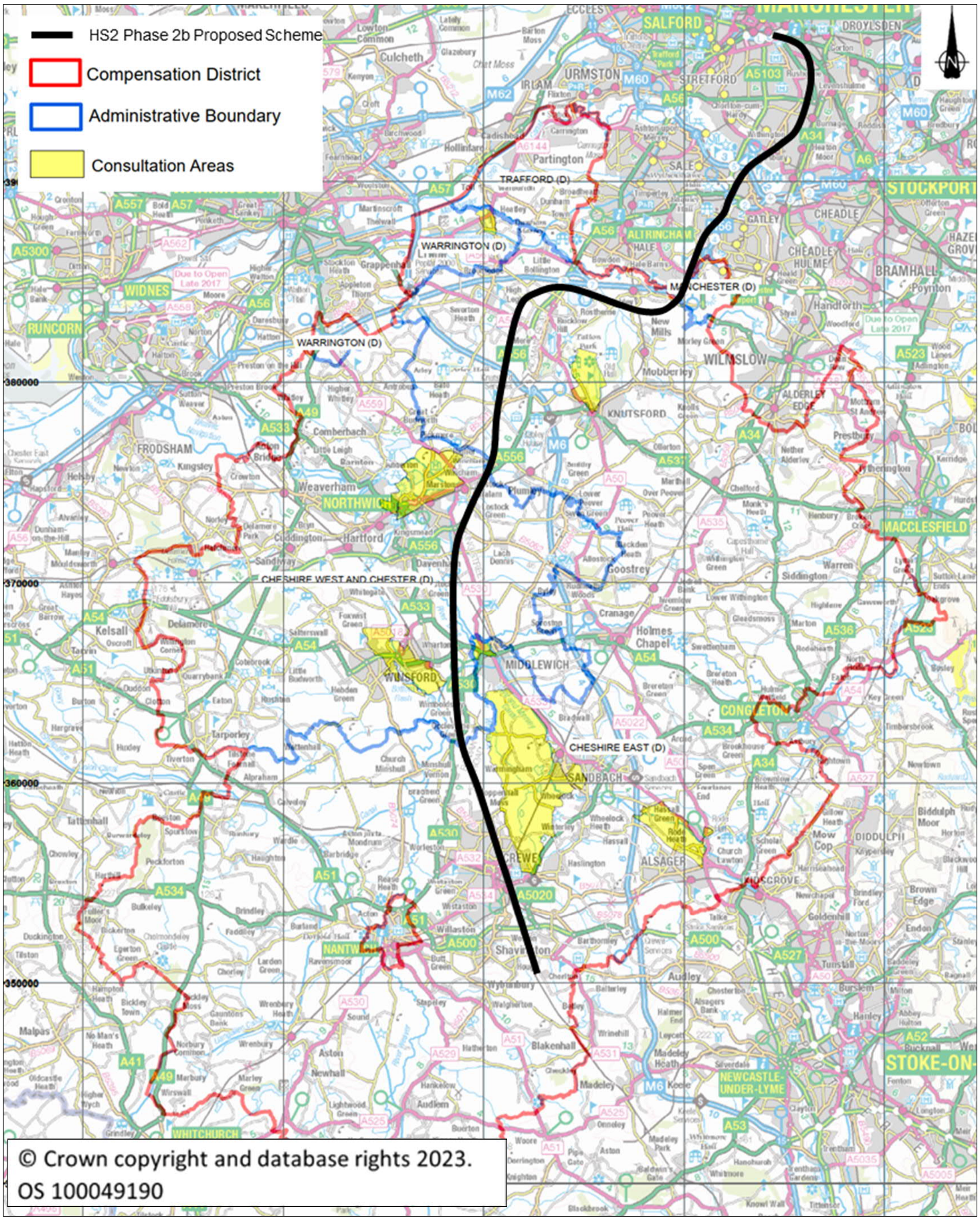


Figure 7: Proposed Scheme alignment over the CBSCB Compensation District and Consultation Area



Base map from: http://www.cheshirebrine.com/history/brine-pumping-initial-development

Historical Mining

3.3.13 HS2 Ltd has undertaken a comprehensive review of historical records to identify the location of historical salt mines within the Area of Interest. The route alignment has been selected such that it does not traverse within 2km of historical mines.

3.3.14 Dry salt mining commenced from 1682 (at Marbury, Northwich) and continued as a major form of salt extraction through to 1928 when collapse of the Adelaide Mine in Marston caused cessation of this early mining phase. Mining was situated within the area of shallow salt deposits to the west of the King Street Fault. East of the King Street Fault, Northwich Halite is around 200m deeper and hence in an area of dry rockhead which was too deep for historical mining.

3.3.15 Mine shafts were dropped down to the Northwich Halite whereby 'pillar and stall' mining was undertaken along salt rock layers. Typically, between 85% and 95% of the salt seam was excavated with the remaining salt left *in situ* to act as supporting pillars for the rock above. Most mines were constructed in and around Northwich where salt was encountered at the shallowest depths and typically the mined seams were at shallow depth below salt rockhead.

3.3.16 The very high extraction rates resulted in localised pillar failure and ensuing roof collapse and undermining of nearby salt rockhead. In turn, this then resulted in consequential in-rushes of water. Consequently, most mines had a limited lifespan of around 30 to 40 years. Upon abandonment, mines were allowed to flood with brine.

3.3.17 By the mid-19th Century, the pumping of brine runs in Northwich had ceased due to diminishing brine levels caused by a combination of over-pumping and flooding of underlying mines. The various salt companies then turned to extract brine directly from the flooded salt mines. This in turn caused rapid dissolution of the mine pillars and consequential dramatic collapse of a number of mines from around 1870 onwards. These collapses created havoc to buildings and services within Northwich, as sinkholes (large open voids) metres across and metres in depth opened up to the ground surface within a timescale of hours and days following initial ground surface movement.

3.3.18 The last Northwich based mine closed in 1929, with all mines flooded and abandoned. The risk of future pillar collapse, and ongoing compression type deformation of the pillars (creep) blighted development through the centre and north of Northwich (towards Marston) where many of the shallow mines were located. More recently, circa 2006, a mine stabilisation programme comprising backfilling of mines with grout was undertaken for four mines.

3.3.19 In summary, the Proposed Scheme alignment is offset 2 km to the east of Northwich. Within the vicinity of the historical mining centres close to Northwich, the alignment sits to the east of the King Street Fault (see Figure 8 below). On this side of the fault, the Northwich Halite is around 200m lower than on the west side of the fault. This means that the salt is fully intact with a dry rockhead and without historical mining. The risk of subsidence due to nearby historical mines is therefore avoided.

Controlled Brine Extraction

3.3.20 Controlled pumping was developed by Imperial Chemical Industries during the 1920s to enable safe brine extraction from brine wells, resulting in the formation of the Holford Brinefield (a series of caverns), east of Northwich. The brinefield remains in operation to the current day.

3.3.21 The drilling techniques and technologies enabled caverns to be dissolved from the salt body, with freshwater introduced down an inner string of metal pipe casing and brine removed via an outer string. The caverns are located fully within extremely low permeability salt rock, and hence are completely closed systems. A minimum thickness of salt rock is always maintained above the roof of the caverns such that the closed system is kept in a fully stable condition.

3.3.22 All controlled brine caverns are located in dry rockhead areas, where salt is encountered at significant depth well below the zone of mobile groundwater flow and hence the caverns are not subject to natural dissolution processes. Cavern size, spacing, and shape is carefully engineered in order to ensure cavern stability. The caverns are designed subject to the salt depth and thickness, and caverns are subject to periodic sonar monitoring to verify size and stability. Cavern development is undertaken as part of a coordinated controlled and assured programme.

3.3.23 The brinefields at both Holford and Warmingham comprise controlled brine caverns. At Holford caverns are typically 200 mgbl with cavern heights between 150 to 200m, and varying maximum diameters from 90 to 110 m. A second brinefield of controlled brine caverns exists at Warmingham, where caverns are of similar size to Holford have been constructed at depths more than 200 m.

3.3.24 Both cavern fields have surface infrastructure situated above and adjacent to them. The Holford brinefield is situated surrounding the village of Lostock Green, extending down to Lach Dennis, with multiple farmhouses situated above the brinefield. The A556 borders the brinefield to the west, with cavern walls situated within 20m offset from the road.

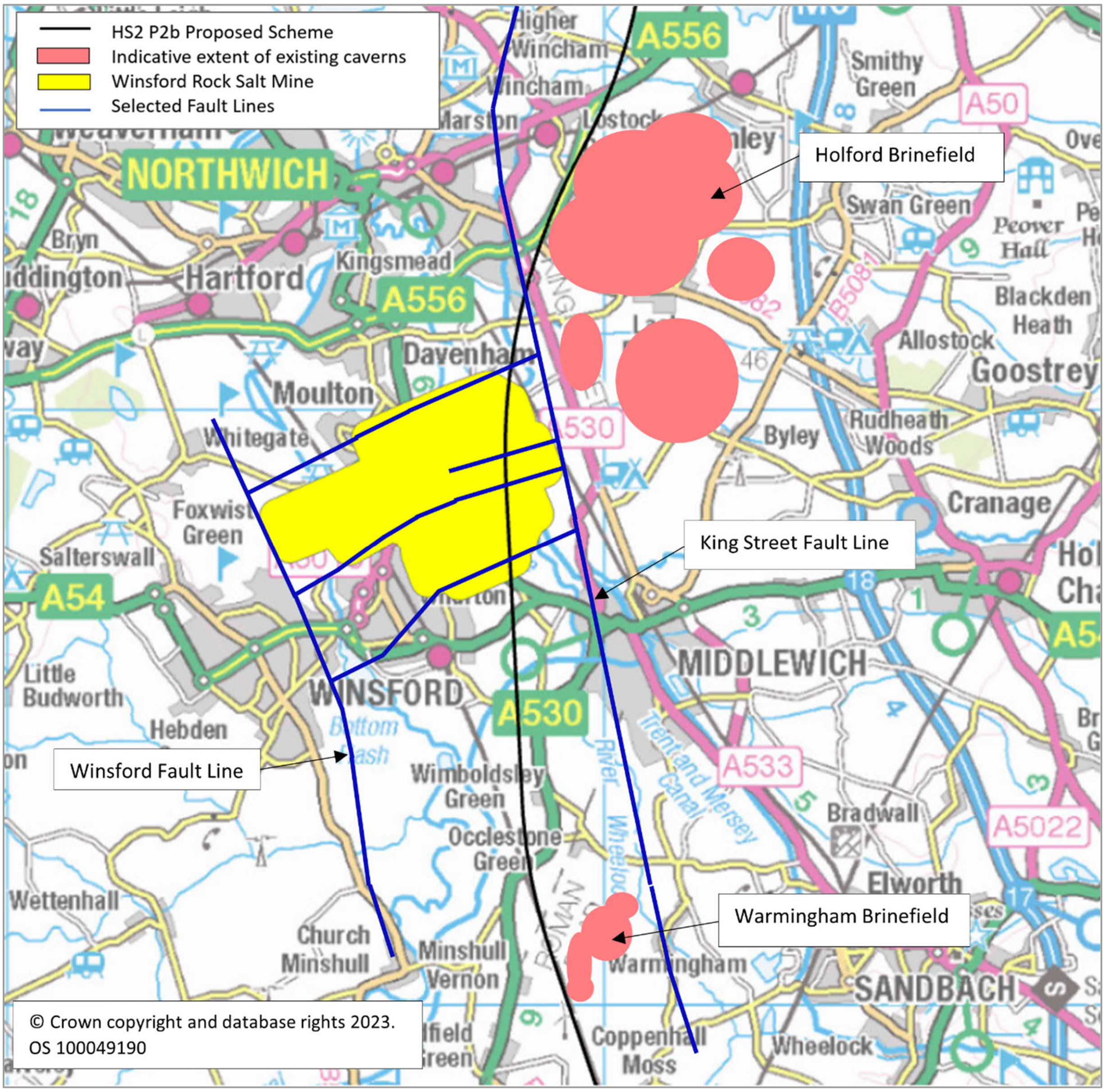
3.3.25 Upon completion of the brine caverns to their maximum size, the caverns are either capped-off, remaining full of saturated brine or re-purposed for storage of waste or gas (natural gas or hydrogen). The retention of a closed off pressurised environment within the caverns ensures ongoing stability of the ground and suitable control of ground surface movements.

3.3.26 The Proposed Scheme alignment avoids the existing brine extraction caverns by traversing just west and northwest of Warmingham and Holford brinefields respectively. Figure 8 below provides the localities of the brinefields; the red clusters to the north representing the Holford Brinefield and the cluster to the south, the Warmingham Brinefield.

3.3.27 Controlled brining planning requirements include ongoing ground surface settlement monitoring programmes. From a review of the body of evidence considered to analyse interaction effects between the Proposed Scheme alignment and the brinefield operations, interaction effects are understood, modest and manageable.

3.3.28 In summary, controlled brine extraction continues and HS2 Ltd has engaged with the brinefield operators to determine the interaction effects with the existing cavern fields. The Proposed Scheme alignment has been designed to avoid direct conflict with existing cavern well-heads and underlying caverns. The caverns are situated within the dry rockhead and at depths typically greater than 200 mbgl. They are operated under managed protocols, with caverns maintained at a pressurised state to minimise ground movement. Impact analyses show ground settlement conditions across the brinefields in the context of the Proposed Scheme to be manageable.

Figure 8: Location of the Winsford Rock Salt Mine , Holford Brinefield and Warmingham Brinefield



Controlled Mining

3.3.29 Winsford Rock Salt Mine is the only active salt mine within Cheshire and has been in continuous operation since the 1930s. The mine provides 75% of the rock salt market of the UK and hence is of strategic national importance. The mine is traversed by the Proposed Scheme for a distance of 3 km as shown in Figure 8.

The mine is situated within the wet rockhead area between the King Street Fault to the east and the Winsford Fault to the west. The mine experienced a period of expansion and modernisation in the 1960s which was preceded by an investigation phase comprising 20 boreholes constructed through the superficial deposits, foundered mudstone, Collapse Breccia and Northwich Halite, through to the underlying Bollin Mudstone. Salt is worked from two levels, at considerable depth ranging between 140 m and 280 m below ground level.

3.3.30 The mine utilises pillar and stall dry mining techniques as per the historical mines of the district but in a controlled and regulated procedure. The mine is operated in accordance with the Mine Regulations 2014; Regulation 35 stipulates that no mining can take place within 45m (vertically) of the salt rockhead.

3.3.31 Additionally, the Mines Regulations 2014 provides at Regulation 7(3) that "The mine operator must ensure that, in the event of the abandonment or ceasing of operations at a mine, the mine is left, so far as is reasonably practicable, in a safe condition".

3.3.32 Underground vertical deformation monitoring within the mine galleries has taken place since 1963 and has been subject to research projects by the University of Newcastle upon Tyne over the intervening period. Recently geo-mechanical studies have been carried out to verify the safety case for the 2nd deeper mine gallery and geo-mechanical modelling undertaken to assess future settlement risk at ground surface.

3.3.33 Controlled mining planning requirements include ongoing ground surface settlement monitoring programmes. HS2 Ltd has undertaken impact analyses to assess for ground movement interaction between the mine and the Proposed Scheme. Interaction effects are considered to be modest and manageable. It is relevant to note that the operators of Winsford Rock Salt Mine have not petitioned against the Proposed Scheme.

3.3.34	In summary, HS2 Ltd has engaged with Winsford Rock Salt Mine to determine the interaction effects of the Proposed Scheme with the existing mine. Hazard boundaries apply to mining associated with the overlying wet salt rockhead, bounding faults and historical exploration boreholes. The mine operates a programme of ground settlement monitoring and has been subject to extensive geo-mechanical research since the 1960s. Impact analyses undertaken by HS2 Ltd show interaction effects between the mine and the proposed high speed rail operation are modest and manageable.

3.4 Consideration of Climate Change

3.4.1 As reported in the High Speed Rail (Crewe – Manchester) Environmental Statement Route-wide effects, Volume 3[2], of the main Environmental Statement, a climate change resilience assessment was undertaken by HS2 Ltd in order to consider potential climate change impacts on the design, construction and operation of the Proposed Scheme.

3.4.2 The assumptions in the assessment included factors such as; increased global carbon emissions will lead to increased global temperatures, resulting in more climate extremes with drier summers and wetter winters.

3.4.3 As reported, the mitigation of climate change related risks during operation is provided through the following categories of resilience measures:

- measures embedded within the developed design of the Proposed Scheme.
- measures which will be considered and developed during detailed design of the Proposed Scheme.
- measures which will be implemented within the construction phase of the Proposed Scheme; and
- measures which will be included in the development of maintenance, monitoring and/or replacement strategies for operational phase of the Proposed Scheme.

3.4.4 The outcome of the climate change resilience assessment, which identified and assessed potential climate change risks for HS2 Ltd assets within the Proposed Scheme is summarised as follows:

- All climate change related risks to HS2 Ltd assets and infrastructure during construction have been assessed to be 'low' or 'medium' risk, managed by the implementation of measures contained within the draft Code of Construction Practice and in adherence to relevant health and safety standards. Therefore, no

[2] Link to access in the public domain: https://www.gov.uk/government/publications/volume-3-route-wide-effects--2

significant climate change resilience effects have been found and no further climate change resilience measures are required or proposed; and

- All climate change related risks during operation have been assessed to be 'low' or 'medium' due to the range of mitigation measures summarised above. Therefore, no significant climate change resilience effects have been found and no further climate change resilience measures are required or proposed.

3.4.5 There is potential for climate change to result in increased levels of salt dissolution and ground surface subsidence but other scenarios suggest a reduction of this effect. In both cases change is expected to be limited. In terms of the generation of subsidence, climate change is not expected to impact the salt extraction industries.

4 Proposed Scheme Response

4.1 Overview

4.1.1 The following section explains how the Proposed Scheme takes account of the ground conditions in the Area of Interest, as set out in the preceding section of this report. This section explains:

- How the route of the Proposed Scheme was selected;
- How the scheme has been designed; and
- How the scheme will be constructed and operated to take account of ground conditions.

4.2 Route Selection

4.2.1 Development of the preferred route between Crewe and Manchester, began in 2010. Details of the development of the route from 2010 to the Proposed Scheme as amended by Additional Provision 1 is provided in Appendix A and is also contained within the Alternatives Report, Volume 5, of the main Environmental Statement (2022)[3].

4.2.2 Between 2010 and 2012 an optioneering process was undertaken to identify, develop and appraise potential routes from the West Midlands to Manchester as part of what was then HS2 Phase 2, culminating in the announcement of the initial preferred scheme for Phase 2 in January 2013.

4.2.3 In July 2013, the government announced the 2013 proposed HS2 Phase 2 scheme for consultation which included a route from the West Midlands to Manchester via Crewe as the best overall option to meet government objectives[4]. These objectives included providing the necessary capacity to meet longer term rail demand and improve resilience and reliability as well as improved connectivity by delivering better journey times and making travel easier.

4.2.4 It was concluded that a route via Crewe, with a connection to the WCML south of Crewe, provided greater strategic benefits than other options considered including providing connectivity to northwest England (including Chester, Liverpool and Warrington) and north Wales. The decision to serve Crewe was confirmed by the

[3] Note: Link to access in the public domain: Alternatives report (CT-003-00000) - GOV.UK (www.gov.uk) & HS2 Phase 2b SES1 and AP1 ES Alternatives report (CT-003-00000) - GOV.UK (www.gov.uk)
[4]Note: Link to access in the public domain: High Speed Two Ltd (2013), High Speed Rail, Investing in Britain's Future – Phase Two: The route to Leeds, Manchester and beyond

Secretary of State in 2015 as part of a wider announcement to accelerate delivery of part of the Phase 2 route from West Midlands to Crewe, which subsequently became Phase 2a. Phase 2b became the section of route between Crewe and Manchester alongside the route between the West-Midlands and Leeds.

4.2.5 In response to consultation on the 2013 Proposed Scheme and as part of on-going design development for the section of route north of Crewe, further investigation took place into concerns raised by local stakeholders regarding geological conditions and brining and gas storage infrastructure across the Cheshire Plain.

4.2.6 Following further design development, in 2016, as part of the announcement on the 2016 post-consultation preferred route for Phase 2b[5], the government recommended a number of refinements for further consultation. This included a revised route in the Middlewich to Pickmere area to avoid brining and gas storage infrastructure, reduce the risk of subsidence due to underlying geological conditions, and to raise the route onto a series of embankments and viaducts in the area between Middlewich and Pickmere to allow better management of drainage and geological risk and provide more flexibility with regards to ground stability mitigation options.

4.2.7 Following further review of previous route options and alternatives proposed during the 2016/17 consultation, in July 2017, the government announced its decision to proceed with the recommended refinements[6] introduced through the Middlewich to Pickmere area as part of the 2016 Post-Consultation Preferred Route.

4.2.8 In supporting the recommendation, it was stated that the 2016 post-consultation preferred route carried the least risk regarding the construction, operation and long-term maintenance of the railway and in order to minimise impacts on existing brining and gas storage caverns in the area.

4.2.9 Further route refinements were undertaken following the announcement of the 2017 Preferred Route as part of the continuing design development of the Proposed Scheme. These focussed on the opportunity to reduce the height of the embankments between Wimboldsley and Lostock Gralam, and Lostock Gralam to Lostock Green as well as the introduction of the Crewe Northern Connection north

[5] Note: Link to access in the public domain: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/897407/high-speed-two-crewe-manchester-west-midlands-leeds-document.pdf

[6] Note: Link to access in the public domain: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/628605/CS848_Phase_2b_2016_17_Route_Refinement_Advice_FINAL_WEB_170713.pdf

of Crewe tunnel, providing connectivity to the WCML and enabling future NPR services to connect with HS2.

4.3 Route Alignment

4.3.1 The route of the Proposed Scheme was selected to minimise the risks posed by ground conditions in the Area of Interest. In particular, the route selected:

- Avoids major areas of former high subsidence as marked by flashes (see Figure 6), with the one exception of Billinge Flash (refer to section 3.2 and 4.4);
- Avoids a line of Meres that broadly align southeast of Rostherne Mere (refer to section 3.2 and Figure 6);
- Avoids areas of ground subsidence such as those which the Cheshire Brine Compensation Board defines as requiring statutory consultation in relation to any new development (see Figure 7 and refer to section 3.3.12);
- Does not pass within 2 km of any known former locations of historical wild brine well pumping sites, with one possible exception, a suspected brine well in the vicinity of Clive Green Lane (refer to section 3.3.10 and 4.4.14);
- Avoids clusters of subsidence features as historically mapped by BGS (refer to Figure 6);
- Avoids historical and controlled salt mines, whether remediated or not (refer to section 3.3.19); with the exception of Winsford Salt mine (refer to section 4.4.19); and
- Avoids existing brining extraction and gas storage caverns, passing just west and northwest of Warmingham and Holford brinefields respectively (refer to section 3.3.28).

4.3.2 It has not been possible to select a route which avoids entirely all possible sources of risk posed by the ground conditions in the Area of Interest. However, HS2 Ltd is satisfied that the Proposed Scheme can be designed, constructed, safely operated and maintained, as set out in the following sections.

4.4 Design Response

4.4.1 The Proposed Scheme has been designed to account for the risks posed by ground conditions in the Area of Interest as outlined below.

Risk mitigation by designing the horizontal and vertical alignment

4.4.2 As stated in section 4.3, the design of the horizontal alignment has avoided the majority of the geological risks described in section 3. In the Area of Interest, the vertical alignment of the Proposed Scheme has, where possible, been designed to be supported by earthworks. The embankments typically range between 1m and 10 m in height (measured from ground level to rail level); 10m would be typically the embankment height, at which point the railway would transition to viaduct. This design retains:

- the cover of glacial deposits above any dissolution features to remove the increased possibility of salt dissolution;
- existing groundwater flows and so avoids concentrating rainwater into specific places and changing the pattern of any potential dissolution.

4.4.3 In certain places, it will be necessary for the Proposed Scheme to be carried on viaducts, bridges and box structures (short tunnels) or in cutting.

4.4.4 The selection of structural infrastructure including viaducts and bridges is driven by the need to cross over existing natural features such as rivers and existing major infrastructure. The viaducts typically range between 10 to 15 metres in height so as to provide necessary headroom. This infrastructure will be designed to account for the risks posed by ground conditions, as explained in the following section of this report.

4.4.5 Where the Proposed Scheme continues north and has passed beyond the area of wet rockhead (as shown on Figure 3 above) long cuttings can be incorporated without risk of salt dissolution. At Hoo Green Lane and Rostherne the design has lowered the alignment to pass under the A556 and M56. The cuttings reach a maximum of 10 mbgl.

General risk mitigation by design

4.4.6 For the majority of the route in the Area of Interest, adapted precautionary mitigation measures against the risk of subsidence, which are typical for the construction of infrastructure in these types of ground condition, or for high-speed rail systems in general, are proposed as follows.

4.4.7 The viaducts will be supported by piers (vertical columns). Due to the considerable weight of the structure focussing at the base of the supporting piers, The viaducts are proposed to be supported on piled foundations because of the potentially relatively low strength of the near-surface soils. Piled foundations can be safely constructed in these ground conditions (refer to section 4.5 below). The most common piling approach will be bored piles which are formed by making a borehole and then inserting steel reinforcement and concrete so as to form the piles (cylinders) in the ground. The piles work by transferring the weight of the structure into the ground primarily along the sides of pile. If subsidence is expected, these piles can be lengthened into more stable ground.

4.4.8 The Proposed Scheme provides for the surface rainwater run-off from embankments, and viaducts to be collected by lined drainage systems and held temporarily in lined balancing ponds, before discharge to river courses. This means that rainwater is not concentrated into locations which might otherwise then percolate through the ground and give rise to the risk of salt dissolution.

4.4.9 HS2 Phase 2b Information Paper E15: Water Resources, Flood Risk and Authorisation of Related Works outlines how it is the design aim of the Proposed Scheme for there to be no increase in the risk of flooding from all sources during the lifetime of the Proposed Scheme. This includes vulnerable receptors such as residential property during the lifetime of the development, taking projected climate change impact into account. HS2 Ltd will continue to engage with the statutory authorities, including the Environment Agency and Lead Local Flood Authorities during the development of the Proposed Scheme to discuss and resolve potential issues.

4.4.10 The track forms under consideration by HS2 Ltd has built in design features so as to allow for corrections of rail geometry in operation, primarily in terms of lifting. Differential settlements arising from the ground can be addressed through the design and routine maintenance aspects of the track form.

4.4.11 The Overhead Catenary System (OCS) is the system which provides the overhead wires which power the train locomotives. If the track form needs to be lifted the OCS may also need to be adjusted and mechanisms will be built into the OCS support system to allow this.

Site Specific Risk Mitigation Design Considerations

4.4.12 Further to the desk-top studies, stakeholder consultation and advanced ground investigation (refer to section 5 below) only two areas have been identified as requiring further levels of mitigation for ground movement. The first area herein referred to as Clive Green Lane Area, located between Winsford and Middlewich. The second area, Billinge Flash, located just under 5 km northeast of Winsford. These two areas include around 2 km of the proposed alignment in total (around 6.5% of the alignment in the Area of Interest). Additional risk mitigation measures within the Proposed Scheme design are given below for both areas.

4.4.13 Within the Clive Green Lane area, the Proposed Scheme would comprise Clive Green South and North Embankments (1 m to 3 m high embankments), the Shropshire Union Canal Viaduct and a new over bridge to carry Clive Green Lane over the main line. Further information can be found in HS2 Phase 2b plan and profile maps: Crewe to Manchester (2022) - GOV.UK (www.gov.uk)

4.4.14 The proposed foundation solution for the new Clive Green Lane overbridge would comprise piled abutments and three piled piers for the new overbridge. The bridge design would account for future ground movement by providing the ability to raise the vertical profile through the provision of bridge decks that can be periodically jacked up. The proposed foundation solution for the Shropshire Union Canal Viaduct comprises bored piles. The Proposed Scheme viaduct design would account for future ground movement via track lifting as an adaptable design measure, or (as for Clive Green Lane bridge above) through provision of bridge decks that can be periodically jacked up.

4.4.15 The Proposed Scheme would use a dig and replace mitigation measure to remove poor quality founding ground. This would consist of excavating out soft (near surface) compressible soils or made ground and replacing it with granular aggregate and a geogrid reinforcement to form a stiff foundation.

4.4.16 Further potential solutions to regulate the settlement to manageable levels in the operation stage include additional geogrid reinforced layers, within the embankment to increase its stiffness; piled foundations beneath the embankment to support the embankment in deeper, more stable strata; and the injection of cementitious grout deep into the ground to prevent the migration of any subsidence to the surface.

4.4.17 The final choice of mitigation solution will be based on interpretation of the further ground investigation (refer to section 5.2.5 below). The implementation of any adaptive measures in the operation stage will also be taken into consideration (refer to section 4.6 below).

4.4.18 At Billinge Flash, the Proposed Scheme comprises the Trent and Mersey Canal Viaduct up to 12 m in height. The proposed foundation solution is also bored piles to varying depths. The Proposed Scheme viaduct design would account for future ground movement via track lifting as an adaptable design measure, or by providing the ability to raise the vertical profile through provision of bridge decks that can be periodically jacked up.

Crossing of Winsford Rock Salt Mine

4.4.19 As noted in section 4.3.1 and 3.2.29 to 3.3.34 the Proposed Scheme alignment crosses Winsford Rock Salt Mine for an approximate length of 3 km. Whilst ground movement is not an anticipated design risk at this location consideration has been given to the best design solution.

4.4.20 Two piled viaduct structures and an intermediate section of embankment are proposed over the mine. The piles of the viaduct structures will not reach the wet rockhead level, nor any of the salt layers. The depth of the piles will be designed to ensure that the mine will not be compromised. Any material load increase caused by the pile will not be significant and will not impact the structural integrity of the mine. The design of the Proposed Scheme is consistent with the status of Winsford rock salt mine being a controlled mine. (refer to section 3.3.28 above).

Climate Change resilience

4.4.21 HS2 Ltd design standards have been developed based on providing railway infrastructure with resilience in terms of future climate change scenarios such as heavier rainfall and higher temperatures. These standards have informed the developed design for the Proposed Scheme.

4.4.22 The detailed design stage will be informed by further information gathering and HS2 Ltd technical standards applicable at the time. In addition, consideration will be given to the European Commission technical guidance on the climate proofing of infrastructure in the period 2021-2027. In this guidance, it is advised that infrastructure owners and operators consider both robust detailed design (an approach of least regrets measures) to account for a range of plausible future climate change scenarios in a conservative manner, and a relatively new adaptive design approach, whereby designers identify a number of contingency elements that can be introduced to the asset during the operational stage, if and as the need arises.

4.4.23 The adaptive design approach offers significant benefit in so far as there is a cost-effective approach in responding to the unpredictable effects of climate change, in which additional adaptive elements are only introduced should they be so required.

4.4.24 The implementation of an element of adaptive design would be based on ongoing monitoring of the asset into operation and a pre-determined decision making process embedded in the overall operations and maintenance procedures.

4.5 Construction Stage Response

4.5.1 Background levels of ground movement are generally expected to be sufficiently low that no special measures will need to be deployed in relation to ground movement in the Area of Interest.

4.5.2 The impact of ongoing ground subsidence on site compounds, access and haul roads, overall site logistics, and temporary works is considered to be manageable due to the temporal nature and flexibility of these elements.

Risk mitigating measures by compliance to the Code of Construction Practice

4.5.3 The draft CoCP is part of the environmental and sustainability commitments that HS2 Ltd will enter into through the hybrid Bill process. These commitments are known as Environmental Minimum Requirements (EMRs) and consist of a framework of documents which will cover how HS2 Ltd will engage with affected people and control the impacts of the Proposed Scheme on local communities and the environment.

4.5.4 The draft Code of Construction Practice (CoCP) Section 11 references measures to be implemented which include, as appropriate, undertaking ground investigation work, risk assessments, monitoring of ground movement, groundwater and ground gas, and undertaking structural or condition surveys of buildings or structures adjacent to the works where there may be potential risks of ground movements which may damage structures (as set out in Section 10 of the draft CoCP).

4.5.5 Ground movement will be monitored using a master network of positional and level datums which would be tied into national level bedrock datums. In the interests of both protecting and re-assuring landowners and other asset owners, INSAR and LiDAR surveys would be used during the construction stage to inform all parties that ground movements are not accelerating in direct response to construction stage activities.

Risk mitigating measures by controlled water management

4.5.6 The forming of borrow pits in the upper 5 m or so of ground is not predicted to give rise to the risk of aggravating any background salt solution process due to its temporal nature and limited depth. The construction stage specifications shall dictate that surface rainwater runoff into borrow pits is to be properly managed via collector drains and accumulating rainwater shall be assisted by pumping. The water shall be directed via pipework and not disposed via soakaways.

4.5.7 The permissible extent and duration of any temporary diverted water course will be managed as detailed in the draft CoCP. This will protect the quality of surface water and groundwater resources from other adverse effects, including significant changes to the hydrogeological regime. All permanent diverted courses will be permanently lined so as to minimise the leakage of surface water into the ground.

Risk mitigating measure by adapting piling works

4.5.8 Piling works will be controlled by specially developed contract provisions. Bored piles will be the typical form of pile. Bored piles will need to be carefully monitored for bore fluid support losses during installation. In situations of bore fluid loss, the mitigating measure is to use pile casing to stem the losses and so not aggravate the risk of localised salt dissolution at or below pile bores. Pile bore shape surveys can be used to verify on site that such dissolution is not taking place.

4.6 Operational Stage response

4.6.1 A pro-active approach to asset management will be taken during the operational stage and service life of the railway. The as built form of the railway will be captured as digital information, in which all of the asset components will be tagged, spatially identified, described, and detailed for maintenance characteristics and needs.

Risk mitigating measures by near real time monitoring of the infrastructure assets

4.6.2 A near real time ground movement monitoring scheme coupled with a documented response plan for both anticipated and unexpected ground movement will be used to manage the overall asset throughout the operational stage.

4.6.3 In the operational phase, the Proposed Scheme will be monitored by remote sensing ground surface survey techniques, including INSAR and lower frequency cross checking drone enabled LiDAR along its full length (refer to Section 5).

4.6.4 Already planned for HS2 Phase 1, fibre optic cable type instrumentation will be installed in the ground so as to additionally monitor for ground movement via changes in straining of the fibre optic cable as ground deforms. The data can be collected automatically and fed back to a central control centre.

4.6.5 In operation there will be train-borne monitoring of the infrastructure consisting of train dynamic ride quality monitoring and high resolution cameras. These will be part of the digital information which can be processed to provide early signs of deterioration of the infrastructure either from natural wear or external effects. All the collected data can be processed using the digital information in a manner that affords the Promoter with near real time and continuous information regarding the ongoing performance of the asset components and so allowing the Promoter to plan the overall ongoing maintenance regime in a tailored and best-informed fashion.

Risk mitigating measures by adaptive interventions

4.6.6 The operation and maintenance of the railway will make use of the digital information and monitoring techniques to detect ground movements that may arise in relation to the legacy of salt brining activity and salt dissolution or from climate change impacts. The data acquired will allow early decisions on the application of the adaptive design elements built into the infrastructure and hence avoid unnecessary interruptions to operations.

4.6.7 Due to the transient nature of surface settlement, the operational safety of the railway will need to be assured by solutions which make corrections for settlements which are outside of expectation. These solutions could be considered as adaptive measures in response to changes in the dissolution regime at depth. Adaptive measures will be a combination of the design mitigations in 4.4.7 to 4.4.11 and future ‘new technology’ that will occur during the lifetime of the railway.

5 Information gathering

5.1 Overview

5.1.1 Information gathering consists of two parts. The information to support the development of the Proposed Scheme; and the information from stakeholders of the wider context which could affect the Proposed Scheme.

5.2 Ground investigation and other information gathering

5.2.1 Ground investigation (GI) is the examination and study of the soil, rocks and groundwater below the surface. A number of methods are used to obtain samples and to monitor and test them. Boreholes are usually formed by a mechanical rig however in all instances this is preceded by surveys and hand digging a pit to avoid interference to existing utilities. Ground investigation may also require manual or mechanical excavation of a trial pit or trench. Laboratory tests are also carried out on many of the samples to supplement the information gathered on site. The aim is to discover the properties, the strength of the soils and rocks and the nature of the groundwater, in order to provide information for the detailed design development. Refer to Phase 2b Non-Technical Ground Investigations[7].

Desktop study

5.2.2 HS2 Ltd has carried out detailed reviews of published data sources and a series of consultations with mining companies operational within the area so as to establish the ground conditions in the Area of Interest.

5.2.3 The desk study activities including geomorphological mapping have informed high priority locations for carrying out ground investigation pertaining to the salt dissolution hazard.

Advance ground investigation works

5.2.4 Subsequently, advanced ground investigations were undertaken at targeted locations in 2020 and 2021. The data from these investigations has been used to reinforce the understanding from the desktop study, refine risk assessments, and will contribute to informing the detailed design development.

[7] Link to access in the public domain: https://assets.hs2.org.uk/wp-content/uploads/2021/08/CS986-Phase-2b-Non-technical-ground-investigations-2020.pdf

Future ground investigation works

5.2.5 HS2 Ltd now plans for a route wide ground investigation to further understand the nature of the ground conditions underlying the Proposed Scheme. In combination, these investigations will yield sufficient ground information to support development of the design.

5.2.6 Supplementary ground investigations will also be scheduled by the Main Works Civil Contractor in support of the detailed design approach and for construction stage verification.

5.2.7 Investigations will further inform the design development post Royal Assent, including:

- Refining ground movement assessments (GMAs) to provide more realistic (less conservative) estimates and informing any required mitigation works;
- The collection and analysis of LiDAR and InSAR data for the Area of Interest to gain information on the natural background vertical movement of the ground surface. Further information on this is provided in Appendix C;
- Reducing earthworks (e.g. steepening earthworks slopes and reducing excavation volumes, where further ground investigation shows this to be feasible);

5.2.8 These opportunities will be explored during detailed design by HS2 Ltd and the contractors, in due course, taking account of the balance of engineering, environmental and construction requirements and cost, in accordance with the HS2 Phase 2b Environmental Minimum Requirements (EMR).

5.3 Consultation and engagement

5.3.1 HS2 Ltd's approach to stakeholder engagement and consultation on the Proposed Scheme is set out in Volume 1, Section 3 of the High Speed Rail (Crewe – Manchester) Environmental Statement[8]. This also includes a full list of key engagement and consultation activity to the hybrid Bill deposit date for Phase 2b.

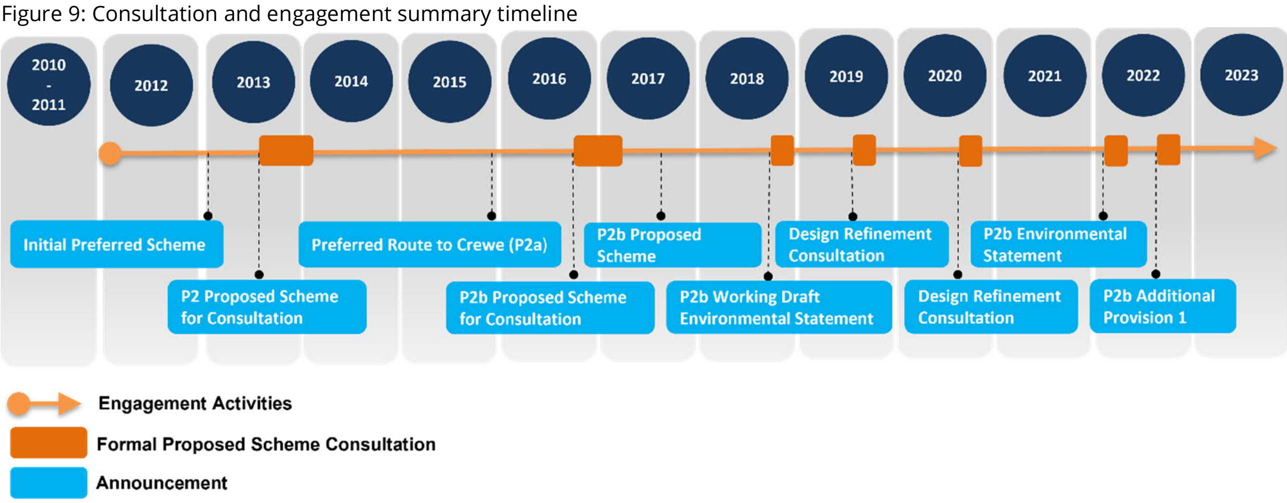
5.3.2 Stakeholder engagement is an integral and ongoing part of the process of designing and assessing the full Phase 2b scheme adopted since the inception of the Proposed Scheme. The engagement process has enabled local communities and

[8] Note: Link to access in the public domain: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1046285/M14.pdf

representatives, businesses, local authorities, statutory bodies, and expert, technical and specialist stakeholders to respond to, and inform the design development.

5.3.3 Figure 9 illustrates some of the key periods of formal consultation activities (and associated key public announcements) that have taken placed relating to the Phase 2b Scheme, in addition to the on-going engagement activities throughout the design development and assessment process.

Figure 9: Consultation and engagement summary timeline



5.3.4 HS2 Ltd has and continues to actively engage with the current salt extraction companies. Studies and assessments have been carried out for the determination of the salt dissolution hazard by deploying rigorous desk study and consultation activities in accordance with good industry practice. This has included consultation with infrastructure utility companies and asset owners, and also with the owners and operators of the salt mining businesses, landowners, and other members of the public who have provided eyewitness accounts.

6 Conclusion

6.1.1 The Proposed Scheme has been developed with consideration of the ground conditions inherent in the identification and development of the route alignment so as to reduce any impact to levels that are as low as is reasonably practicable, commensurate with the level of controls and assurance to be expected for a high speed railway.

6.1.2 The geology of the Cheshire Plain has been studied from published accounts and site investigations. Based on the factual information and interpretations obtained, HS2 Ltd, in conjunction with its designers and technical advisors, have developed the design for the Proposed Scheme.

6.1.3 It is considered that the designed route alignment is appropriate and that the geological challenges can be both managed and mitigated during detailed design and construction so as to provide a safe operational railway. The scale of challenge is commensurate with the function of the Proposed Scheme as critical national infrastructure, and comparable to the scale of challenge that is encountered by other high speed railways.

6.1.4 HS2 Ltd is satisfied that the Proposed Scheme has been designed with sufficient in-built resilience, along with practical measures for routine maintenance and adaptive design, which can be put in place in achievable timeframes, to mitigate against climate change during operation.

Appendix A Glossary and Abbreviations

Table 2: A list of Abbreviations and Descriptions

Term	Abbreviation	Description
Above Ordnance Datum	AOD	Indicating a level given above the British Ordnance Datum which is a vertical datum using in surveying. Datum being the fixed reference point for a vertical scale.
Additional Provision	AP	An amendment to a hybrid Bill being considered by Parliament. Additional Provisions cover changes which involve the acquisition or use of land outside the original limits of the Bill, additional access rights, or other extensions of the powers conferred by the Bill.
Aquifer	-	An aquifer is a body of rock and/or sediment that holds and allows transmission of groundwater, and from which groundwater can generally be extracted by pumping.
Area of Interest	-	An area extending 4 km either side of the Proposed Scheme alignment extending from north of Crewe, Warmingham through to Rostherne Mere.
Breccia	-	Breccia is a rock composed of large angular broken fragments of minerals or rocks cemented together by a fine-grained matrix.
Brine Brine Run Wild Brining Controlled Brining	-	Brine – groundwater with a high concentration of dissolved salt. Brine Run - a series of interconnected voids at the surface of a salt bearing rock bed that allows for the preferential flow of groundwater, formed either naturally or by wild brining. Wild Brining – A historical and now ceased human practice of pumping for brine from wells. Controlled Brining –A historical and ongoing human practice of extracting brine to create engineered underground caverns
British Geological Survey	BGS	A partly publicly funded body which aims to advance, record, and disseminate geoscientific knowledge of the United Kingdom landmass and its continental shelf by means of systematic surveying, monitoring, research, and release of publications in the public domain.
Cheshire Brine Subsidence Compensation Board	CBSCB	In 1952, the Cheshire Brine Compensation Board was created to provide financial compensation for subsidence induced damages caused by brine extraction within the Cheshire Brine Subsidence District.

Code of Construction Practice	CoCP	The draft Code of Construction Practice forms part of Volume 5 of the Environmental Statement.
Collapse Breccia	-	A particular type of rock layer, sometimes found above a rock salt layer that has undergone dissolution. The rock has moved downwards in the past (hence the term Collapse) due to undermining by the dissolution and so may be disturbed (hence the term Breccia). The term Collapse does not mean that ground surface above this rock layer is going to collapse.
Crewe Northern Connection	CNC	The Proposed Scheme will include a connection to the WCML for future NPR services to connect with HS2.
Depression	-	A landform (ground surface) which is sunken or depressed below the surrounding area.
Design Refinement Consultation	DRC	Public consultation on proposed refinements to the design of the Phase 2b railway.
Detailed Design	-	Detailed design will be completed after Royal Assent to allow construction of the Proposed Scheme.
Dissolution	-	Dissolution means the dissolving of salt by groundwater.
Earthwork	-	Either an embankment built up from fill material (such as soils or crushed rock) or a cutting excavated into existing ground that support the routing of the high speed railway.
Environmental Impact Assessment	EIA	Assessment of the likely significant effects of the Proposed Scheme on the environment, in accordance with the Town and Country Planning (Environmental Impact Assessment) Regulations 2017.
Environmental Statement and Additional Provision 1 Environmental Statement	ES	A suite of documents providing the required for EIA of the Proposed Scheme.
Evaporite		A salt rock formed directly via solar evaporation of hypersaline waters at the earth's surface.
Fault / Geological Fault	-	A planar fracture or discontinuity in rock across which there has been significant relative displacement on either side of the plane as a result of rock mass movement
Flashes	-	Lakes formed in ground depressions associated with anthropogenic (human) extraction of brine (wild brining) or collapse of historical mine workings.
Fresh water Under-saturated water	-	Fresh water – water that is essentially without salinity (salt). Under-saturated water – water with a salinity intermediate between that of fresh water and brine.

Geogrid	-	Geogrid- A product made of strong plastics (geo-synthetic) which is used to reinforce soil fill materials by providing tensile strength.
Glacial Buried Valley	-`	An ancient river or stream valley formed in glacial periods that has been infilled with sediments such as gravel and sand, with some silt and clay. The sediments can store and transmit groundwater acting as valley shaped aquifers. The valley is covered over by other soil deposits (buried) and is not visible at ground surface.
Glacial Till	-	A deposit created in glacial periods, derived from the erosion and entrainment of soils and rocks and by the moving ice of a glacier above. The soils and rocks are then deposited some distance down-ice to form new deposits of variable characteristics (tills).
Halite		Evaporite salt rock deposit or rock salt deposit of NaCl (sodium chloride), formed from evaporation from a hypersaline solution.
Interferometric Synthetic Aperture Radar	INSAR	A technique for mapping the ground surface using radar images of the Earth's surface that are collected from orbiting satellites. A comparison of images at different times allows for determination of ground movement over time.
Light Detection and Ranging	LiDAR	A technique for mapping the ground surface by a laser and measuring the orientation of the beam and the time for the reflected light to return to the receiver, conducted from an aeroplane or drone. A comparison of images at different times allows for determination of ground movement over time.
Lithified	-	The process in which sediments (soils) are compacted under pressure, with removal of pore fluids becoming cemented to form rock.
Metres below ground level	mbgl	A vertical distance from the ground surface measured in metres
Mercia Mudstone Group	MMG	Mercia Mudstone Group comprises an interbedded sequence of clays, silts and evaporites (salts) deposited between 247 and 228 million years a
Mere	-	A lake that has formed in a depression which has formed in connection with glacial processes. Some meres in Cheshire have increased in size due to Dissolution.
Open Fractures	-	An open discontinuity usually of planar form in soil or rock and representing a plane of high Permeability.
Permeability	-	The ability (and measurement) of the ability of a soil or rock to transmit groundwater over distance and time. `Permeable' means good

		transmission, and `Impermeable' means very low transmission.
Pillar and Stall Mining Extraction Ratio	-	An underground mining technique where a layer of the target rock is partially extracted (forming a void (stall). Pillars are columns of rock left in place to provide support to the void roof. Extraction ratio relates to the percentage of target rock removed. The higher the ratio, the smaller the pillar support.
Proposed Scheme	-	HS2 Phase 2b Western Leg from Crewe to Manchester.
Rolling Stock Depot	RSD	A rolling stock depot at Crewe North will be the operational and maintenance hub for the Proposed Scheme.
Sink hole		Collapse void at the ground surface. Often circular in shape with steep sides caused by collapse of near surface soils into large underlying voids as a result of chemical dissolution.
Superficial deposits	-	Superficial deposits refer to recent geological deposits (<2.6 million years old) which are unconsolidated and not lithified (i.e. sand, gravel, silt, clay).
Void Migration	-	A process by which a void formed at depth in the ground triggers deformations or voiding in the ground above the void, ultimately resulting in ground surface subsidence without a catastrophic collapse of the ground into any void.
Wet Rockhead Dry Rockhead	-	Wet Rockhead - A surface of salt rock where Dissolution has previously taken place or may be ongoing. Collapse breccia may or may not be present above this surface. Dry Rockhead – A surface of salt rock where Dissolution has not taken place in the past and is unlikely to take place in the future. Collapse Breccia is not present above this surface. The historical term `Dry' comes from the fact that Brine cannot be readily extracted from the surface – the surface is essentially Impermeable

Appendix B History of Route Development

B.1 Development of Route Alignment

B.1.1 Development of the preferred route between the West Midlands and Manchester, covers a period from 2010 through to the Proposed Scheme presented as part of the HS2 Phase 2b Crewe – Manchester Supplementary Environmental Statement 1 and Additional Provision 1 Environmental Statement[9].

B.1.2 Between 2010 and 2012, a series of option long listing and short listing was undertaken of route combinations from Birmingham to Manchester as part of what was then Phase 2. In 2012 (March) HS2 Ltd published the Options for Phase Two report[10,] which included a summary of the route optioneering process and rationale for corridors and route sections considered and those progressed (see Figure 10 below).

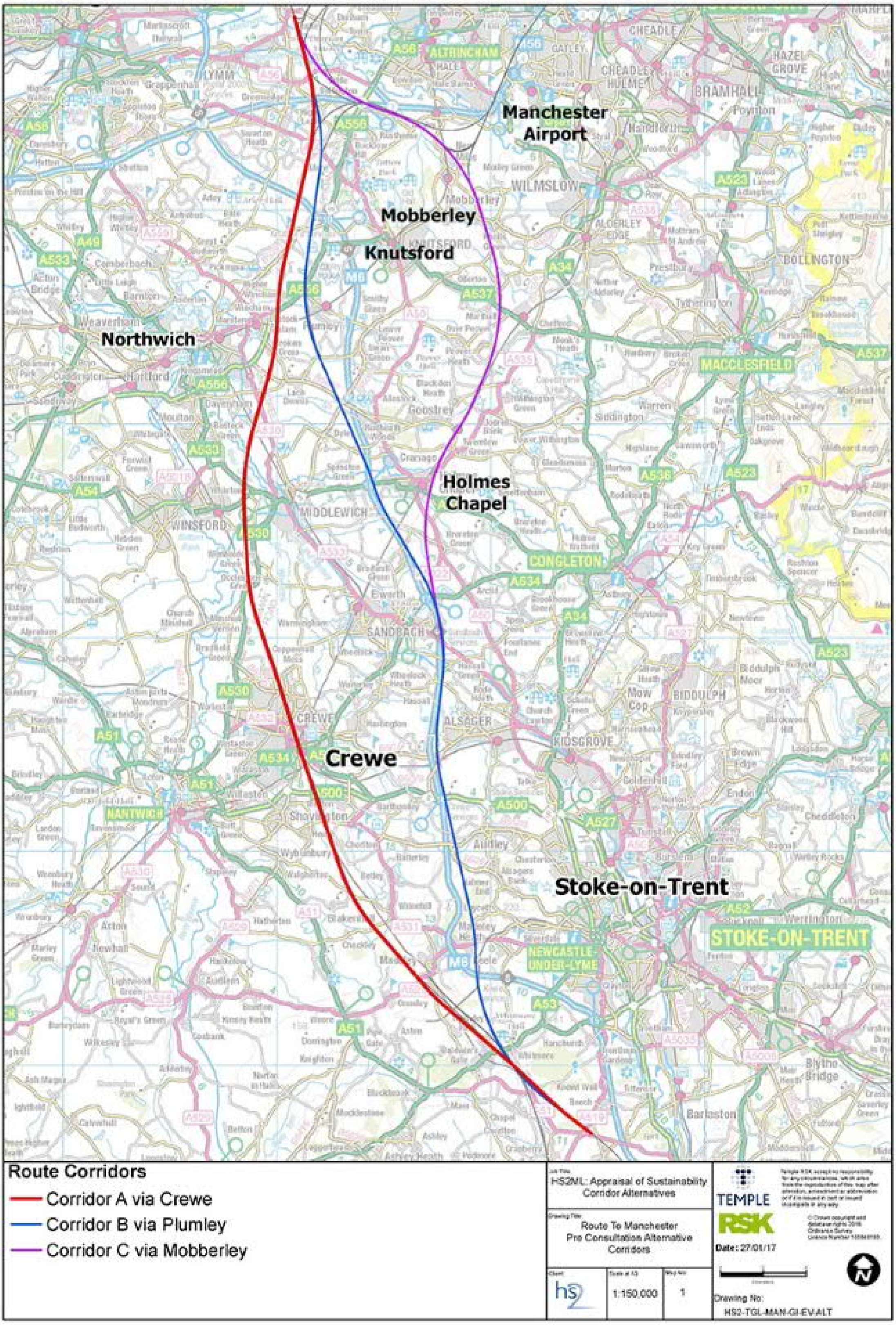
B.1.3 For the area including the Cheshire Plain north of Crewe, termed the Approaches to South Manchester, three main corridors were considered, including a corridor broadly following the M6. Each was an aggregation of individual route sections that were developed to the same set of engineering standards and subjected to an equivalent level of appraisal.

B.1.4 Following the submission of advice to Government in 2012, the Secretary of State carried out consultation which led to further refinement and route development. A number of design reviews were undertaken by HS2 Ltd to consider whether improvements could be made in terms of cost, simplification of construction and sustainability.

[9]Link to access in the public domain: https://www.gov.uk/government/collections/hs2-phase-2b-crewe-manchester-supplementary-environmental-statement-1-and-additional-provision-1-environmental-statement

[10]Link to access in the public domain: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/68965/options-for-phase-two-of-the-high-speed-rail-network.pdf

Figure 10: Preferred route corridor alternatives as part of the South Manchester Approaches



B.1.5 In July 2013 the Government announced the 2013 Proposed Scheme for consultation which included a proposed a route to Manchester via Crewe as the best overall option to meet the Government's objectives[11]. These included providing the necessary capacity to meet longer term rail demand and improve resilience and reliability as well as improved connectivity by delivering better journey times and making travel easier.

B.1.6 The proposed route via Crewe with a connection with the WCML near Crewe provided greater strategic benefit including connectivity to northwest England (including Chester, Liverpool and Warrington) and north Wales. This route also performed more favourably from a sustainability perspective compared with the other alternative routes including the M6 corridor, as it would require fewer demolitions and would be further away from a number of settlements across the Cheshire plain.

B.1.7 Routes following the M6 corridor would have similar impacts geological challenges associated with passing over the Cheshire Plan but would require a less favourable location for the junction of the HS2 WCML connection and the HS2 Manchester spur.

B.1.8 It was later recommended by HS2 Ltd Chairman, David Higgins, in reports 'HS2 Plus, March 2014[12], and 'Rebalancing Britain, October 2014[13], that the proposed North- West Hub should be at Crewe, as it would not only serve the local region but also provide services into the rest of the Northwest, North Wales and Merseyside. The decision to serve Crewe was confirmed by the Secretary of State in 2015. Neither of the alternative corridors (via the M6 or Airport) served Crewe.

B.1.9 Following the period of public consultation on the 2013 Proposed Scheme between July 2013 and January 2014, further route refinement work was undertaken. This included further consideration of the underlying geology of the area north of Crewe through to Pickmere and associated industrial salt extraction activity.

B.1.10 Exploiting deep layers of rock salt, there are two areas of ongoing controlled brining and gas storage operations (Warmingham and Holford) and the 2013 Proposed Scheme for consultation would have significant impacts on the infrastructure related

[11] Link to access in the public domain: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69738/hs2-phase-two-command-paper.pdf

[12] Link to access in the public domain: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/374695/HS2_Plus_-_A_report_by_David_Higgins.pdf

[13] Link to access in the public domain: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/374709/Rebalancing_Britain_-_From_HS2_towards_a_national_transport_strategy.pdf

to these operations and the impact on the operability of the Proposed Scheme railway. Of particular concern was the direct crossing of sub-surface brine extraction and gas storage caverns, raising aspects of operability of these assets.

B.1.11 In addition to salt related industries, aspects of former salt bedrock dissolution and associated ground surface subsidence posed a challenge to the operation and management of the Proposed Scheme through this area. Work was undertaken to identify the corridors through the area that should carry the least risk with regards to salt-related subsidence, however, it was recognised that some of these aspects would require additional mitigation and work would continue to understand and develop engineering solutions.

B.1.12 The Western Leg of the 2013 Proposed Scheme for consultation was divided into geographically based refinement areas that were subject to further design and appraisal, including the area 'Middlewich to Pickmere' (routes through salt mining areas).

B.1.13 The 'Middlewich to Pickmere' refinement area covered approximately 26km of the route from the tunnel portal south of Crewe to the M6 crossing north of Pickmere. As part of the refinement, a further comprehensive review of alternative route corridors from Crewe including heading northeast towards Manchester Airport via Mobberley was undertaken.

B.1.14 HS2 Ltd considered three options as part of alternative routes towards Manchester Airport via Mobberley. These were taken to an intermediate sift based on a review of previous evidence, which reaffirmed the original conclusions that these alternative routes were less viable from a cost, engineering and/or sustainability perspective, when compared with the then preferred route.

B.1.15 Following more detailed investigation into concerns raised regarding geological salt and gas storage risk, some further refinement work was undertaken. A further six options were considered as alternatives to the route across north Cheshire to join with the Manchester junction at Hoo Green, with three options progressing to full sift. A revised route, which included a horizontal realignment further west and raising throughout, was taken forward as the preferred option due to the lower geological risk associated with avoiding disused salt mines and gas storage areas. Further details on the options considered can be found in the High Speed Rail Crewe – Manchester) Environmental Statement in January 2022[14.]

14

B.1.16 In 2016, as part of the announcement on the 2016 post-consultation preferred route for Phase 2b[15], the government recommended a number of refinements for further consultation. This included the revised route in the Middlewich to Northwich area to avoid brining and gas storage infrastructure, minimise the risk of subsidence due to underlying geological conditions, and to raise the route onto a series of embankments and viaducts in the area between Winsford and Middlewich to allow better management of drainage.

B.1.17 The 2016 post-consultation preferred route avoided direct interfaces with existing brining and gas storage infrastructure, such as caverns, wellheads and surface infrastructure, and would minimise the risk of subsidence from ground movements in the brinefield site. This reduced construction and operational risk and addressed specific concerns over the long-term liability to HS2 Ltd as a result of passing over underground caverns.

B.1.18 In response to the formal consultation, local community stakeholders including Mid-Cheshire Against HS2, further raised concerns regarding the geological challenges associated with the proposed route. In March 2017 Mid-Cheshire Against HS2 (MCAHS2) proposed an alternative route to the published 2016 post-consultation preferred route that ran northeast from Crewe across towards and along the M6 corridor.

B.1.19 In response to feedback from the 2016/2017 consultation, HS2 Ltd undertook a strategic review of all previous route options in this area, including the previous route refinement options considered following the 2013/2014 consultation. In addition, consideration was given to alternatives suggested as part of consultation feedback, including a route closer to the M6 corridor, a tunnelled route under Sandbach, a route east of Middlewich and a route that followed the A556.

B.1.20 Following further review of previous route options and alternatives proposed during the 2016/17 consultation, in July 2017 the government announced its decision to proceed with the recommended refinements[16] introduced through the Middlewich to Pickmere area as part of the 2016 Post-Consultation Preferred Route.

B.1.21 In supporting the recommendation, it was stated that the 2016 post-consultation preferred route carried the least risk regarding the construction, operation and long-

[15] Link to access in the public domain:
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/897407/high-speed-two-crewe-manchester-west-midlands-leeds-document.pdf

[16] Link to access in the public domain:
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/628605/CS848_Phase_2b_2016_17_Route_Refinement_Advice_FINAL_WEB_170713.pdf

term maintenance of the railway. In order to successfully avoid existing brining and gas storage caverns in the area, the 2016 post-consultation alignment was the preferred route.

B.1.22 The route was raised throughout the Middlewich to Pickmere area to a minimum of one metre above ground, so removing all cuttings to allow for careful management of surface water drainage and provide more flexibility with regards to ground stability mitigation options. Commitment was made to undertake further detailed consideration of the specific salt dissolution risks and the possible range of alternative risk mitigation measures, with a view to developing a design solution where the Proposed Scheme route can be lowered in the vicinity of local communities.

B.1.23 Further route refinements were undertaken following the announcement of the 2017 Preferred Route. These focussed on the opportunity to reduce the height of the embankments between Wimboldsley and Lostock Gralam, and Lostock Gralam to Lostock Green. These are detailed within the High Speed Rail (Crewe – Manchester) Environmental Statement in January 2022.

Appendix C – Supplementary Information

C.1 Light detection and ranging survey

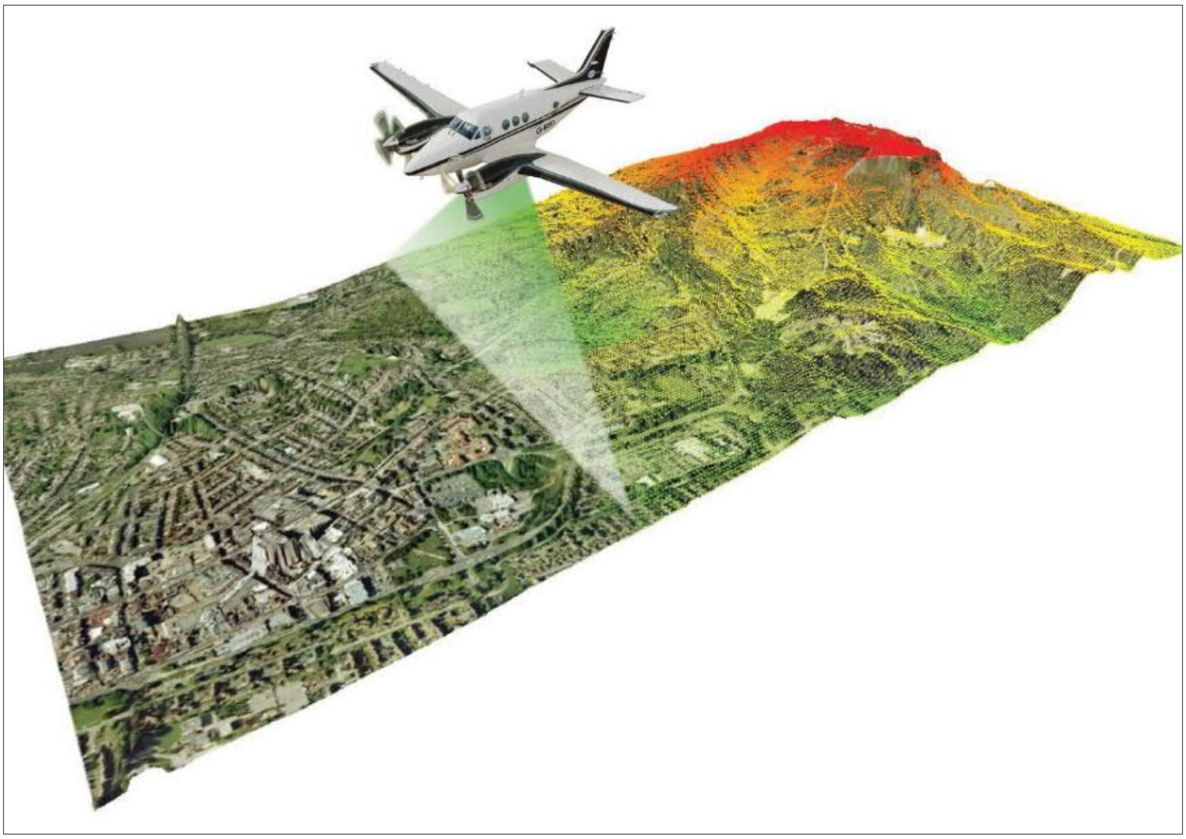
C.1.1 Light Detection and Ranging (LiDAR) is part of a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. The scanner fires and records infrared laser pulses (light) 100,000 to 400,000 times a second, and generates precise, three-dimensional information about the shape of the Earth and its surface characteristics (see Figure 11 below).

C.1.2 LiDAR often works in conjunction with other technologies that give it the ability to calculate the precise location of that measurement: GPS (Global Positioning System) = for X,Y location of instrumentation; IMU (Inertial measurement unit) = measures pitch/roll/heading of the aeroplane.

C.1.3 The HS2 LiDAR data is a 200mm horizontal resolution digital terrain model (DTM) and digital surface model (DSM). The DTM represents a bare-earth version of the DSM, where buildings, vegetation, etc., have been digitally stripped so that the elevations represent a closer approximation to the true ground surface. LiDAR data has been obtained for a 500 m zone either side of the Proposed Scheme alignment.

C.1.4 The Environment Agency (EA) routinely flies LiDAR surveys to collect elevation information along UK surface water courses. The data collected is used to generate DTMs. That data is open source and freely available for commercial use; it has been downloaded for use on this project from the data.gov.uk website.

Figure 11: Lidar illustration acquisition technique[17]



Source: National Oceanic and Atmospheric Administration - 26 February 2021. "What is LIDAR". oceanservice.noaa.gov. US Department of Commerce. Retrieved 15 March 2021; https://pdskc.maps.arcgis.com/).

C.1.5 The horizontal resolution of EA DTMs varies from 250 mm to 2000 mm. In the area of the Proposed Scheme alignment, the surveys have been obtained at various times from 1998 to the present. The coverage of those individual surveys varies and no single survey covers the full extent of the alignment, noting that the EA surveys are generally focussed on surface water courses.

C.1.6 The point cloud data that forms the basis of LiDAR surveys is obtained using laser pulses that measure distance from the aerial source to the earth surface. Each laser pulse may be associated with one or more 'returns' depending upon the nature of the Earth's surface; for example, the first return may be from the top of a vegetation canopy and subsequent returns from the vegetation layers and ground surface beneath. The returns can be characterised according to the nature of the ground

[17] Airplanes and helicopters are the most commonly used platforms for acquiring lidar data over broad areas.

surface; 'final' returns can be used to build a DTM by stripping vegetation effects and other selected returns can be used to remove the profiles of buildings.

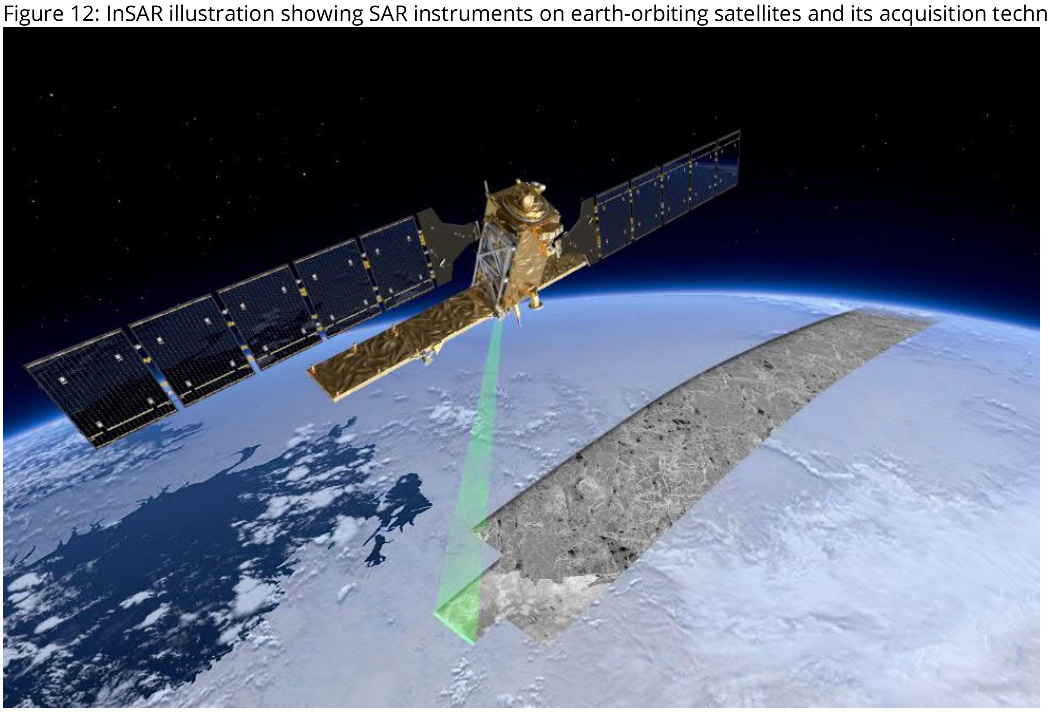
C.1.7 LiDAR interpretation for the alignment DTM allows ground elevation variation to be detected over a horizontal distance of 0.6m. Vertical accuracy of +/- 150 mm applies to EA data, and +/- 50mm for HS2 data.

C.2 InSAR

C.2.1 Interferometric Synthetic Aperture Radar (InSAR) is a family of remote sensing techniques used to monitor ground movement.

C.2.2 Synthetic-aperture radar (SAR) is a technique used to generate high-resolution images using radio and microwaves. By mounting SAR instruments on earth-orbiting satellites, very large areas of the ground and surface infrastructure can be regularly imaged at high resolution (see Figure 12 below).

Figure 12: InSAR illustration showing SAR instruments on earth-orbiting satellites and its acquisition technique over Earth



Source: https://www.esa.int/

C.2.3 InSAR is a technique to measure ground movement through analysis of the interference between SAR signal measurements. The phase difference between signals in two SAR images is proportional to a change in the observed distance between the sensor and a target object known as a 'scatterer' (see Figure 13 below).

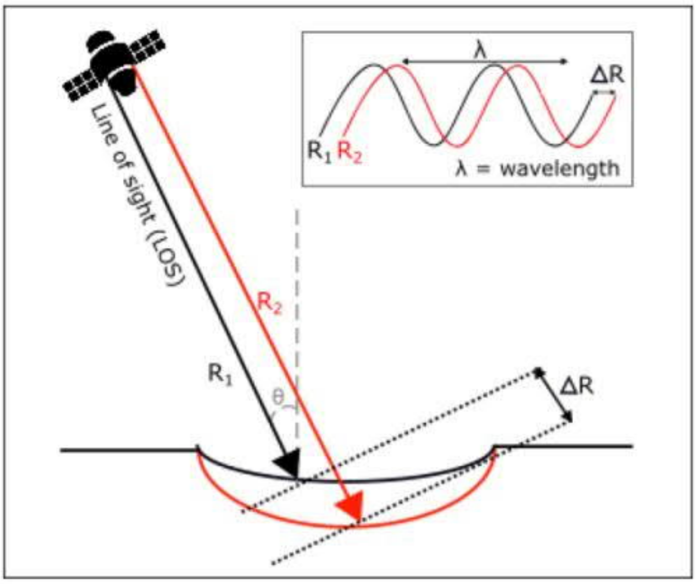
C.2.4 InSAR is increasingly being adopted for remote infrastructure assessment. Lateral resolution of ground elevation can be determined for areas of the order of 5 m by 20 m and vertical accuracy of the order of +/-5 mm is available, improving where ground scatterer objects are fixed (such as existing roads). Data can be obtained for each satellite pass by; in the case of the Area of Interest, data sets are available at 6-day intervals, allowing a near real time assessment of ground movement trends.

C.2.5 HS2 Ltd has procured and analysed InSAR data from the following satellites:

Satellite	Cover period
ERS	May 1995 – November 2000
Envisat	December 2002 – June 2007
Sentinel 1 Ascending	March 2015 – April 2020
Sentinel 1 Descending	May 2015 – April 2020

C.2.6 HS2 Ltd are in the process of analysing the InSAR and LiDAR data in combination, so as to provide wide-scale information on ground movement rate across the zone 500 m either side of the proposed alignment. This will provide important quantitative data which can be consider alongside the qualitative information as gathered by HS2 Ltd through both the consultation process and via desk study based research.

Figure 13: InSAR technique - measurement of ground deformation via change in phase of a radar signal



Source: InSAR Ground Deformation Analysis for HS2 Phase 2b Crewe to Manchester: Factual Report 05/04/2022