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HS2

High Speed Rail (Crewe – Manchester) Environmental Statement

Volume 5: Appendix WR-008-00001

Water resources and flood risk

MA05: Risley to Bamfurlong

Groundwater modelling report - Holcroft Moss

M342

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Department for Transport

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High Speed Two (HS2) Limited
Two Snowhill
Snow Hill Queensway
Birmingham B4 6GA

Telephone: 08081 434 434

General email enquiries: HS2enquiries@hs2.org.uk

Website: www.hs2.org.uk

A report prepared for High Speed Two (HS2) Limited:

ARUP+ ERM | FOSTER + PARTNERS | JACOBS
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MWJV
Mott MacDonald | WSP

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1 Introduction

1.1 Background

1.1.1 This appendix presents the results of the groundwater modelling carried out for the Holcroft Moss Site of Special Scientific Interest (SSSI), which is part of the Manchester Mosses Special Area of Conservation (SAC).

1.1.2 The modelling has been undertaken for Holcroft Moss to the boundary with the Glaze Brook, which is located in the following community areas (CA):

- Broomedge to Glazebrook community area (MA04); and
- Risley to Bamfurlong community area (MA05).

1.1.3 No other relevant groundwater modelling has been undertaken for this area.

1.1.4 This appendix should be read in conjunction with:

- Volume 2, Community Area reports;
- Volume 3, Route-wide effects;
- Volume 4, Off-route effects; and
- Volume 5, Appendices.

1.1.5 The water resources and flood risk assessments include both route-wide and community area specific appendices. The route-wide appendices comprise:

- a Water Framework Directive (WFD) compliance assessment (Volume 5: Appendix WR-001-00000); and
- a Draft water resources and flood risk operation and maintenance plan (Volume 5: Appendix WR-007-00000).

1.1.6 For each community area the water resources and flood risk assessments (Volume 5: Appendices WR-003 and WR-005) should also be referred to. In addition, a series of hydraulic modelling reports are included in Volume 5 Appendices WR-006 covering river catchment areas.

1.1.7 Additional information is included in Background Information and Data (BID):

- Water resources assessment baseline data (BID WR-004)[1]; and
- Water Framework Directive compliance assessment baseline data (BID WR-002-00001)[2].

1.2 Aims

1.2.1 Holcroft Moss SSSI is part of the Manchester Mosses SAC. It is a raised peat bog supporting five species of moss and has never been cut for peat. It represents a unique ecosystem that may be supported by groundwater within the superficial deposits and underlying sandstone aquifer. While it is unclear if the site is groundwater fed, it has been assessed on a precautionary basis.

1.2.2 The aim of this study was to develop a groundwater model of Holcroft Moss to determine potential hydrogeological impacts from Glazebrook North embankment and M62 West viaduct by simulating groundwater levels with and without the Proposed Scheme. Note that the groundwater modelling is not intended to be used for water quality. This report documents the methods used, the results, assumptions and limitations.

1.2.3 The outputs from the study have been used to inform the Water resources assessment Volume 5: Appendix WR-003-0MA05.

1.3 Objectives

1.3.1 The objectives of this study were to:

- develop an understanding of existing hydrogeological conditions at the Holcroft Moss, including aquifer units, groundwater flow direction and hydraulic properties, through desk study and, where possible, by conducting a site visit;
- estimate the water balance for the site, including recharge and major discharge locations; and
- develop a groundwater model, using the information available at this stage, to estimate the groundwater levels within the Holcroft Moss, both before and after construction of the Proposed Scheme.

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[1] High Speed Two Ltd (2022), High Speed Rail (Crewe – Manchester), *Background Information and Data, Water resources assessment baseline data*, BID WR-004-0MA04 and BID WR-004-0MA05. Available online at: http://www.gov.uk/government/collections/hs2-phase-2b-crewe-manchester-environmental-statement.

[2] High Speed Two Ltd (2022), High Speed Rail (Crewe – Manchester), *Background Information and Data, Water Framework Directive compliance assessment data,* BID WR-002-00001. Available online at: http://www.gov.uk/government/collections/hs2-phase-2b-crewe-manchester-environmental-statement.

1.4 Justification of approach

1.4.1 A risk-based approach has been adopted, whereby the level of modelling detail supporting the assessment at a specific site reflects the magnitude of the likely impacts of the Proposed Scheme on groundwater levels.

1.4.2 As there is little information on the groundwater levels or flows within the Holcroft Moss, a steady-state MODFLOW 6 model[3] was developed with separate layers representing the peat, the superficial deposits and the sandstone. Sensitivity testing of key parameters was carried out to understand the uncertainty in the model.

1.5 Scope

1.5.1 The scope of the study was to undertake detailed groundwater modelling to enable assessment of the impact of the Proposed Scheme on the groundwater levels in the Holcroft Moss. The model aimed to be detailed enough to allow assessment of different options for the Proposed Scheme construction.

1.5.2 This report focuses on Holcroft Moss, extending north to Glaze Brook, east to Holcroft Lane Brook, south to the edge of the superficial deposits outcrop and west to the edge of Pestfurlong Moss. A description of the location and type of scheme is provided in Section 2.

1.5.3 The scope of the report includes:

- discussion of all relevant datasets, in terms of their quality and gaps;
- details of the hydrogeological analysis undertaken, the approach used and the calculation steps;
- details of how the hydrogeological analysis has been integrated with the groundwater modelling;
- identification and justification of the groundwater modelling methodology selected; and
- a description of the groundwater modelling parameters, assumptions, limitations and uncertainty.

[3] MODFLOW 6 is a United States Geological Survey (USGS) Modular Hydrologic Model and this is considered to be the industrial standard software for groundwater modelling.

2 Qualitative description of groundwater response

2.1 Sources of information

2.1.1 The groundwater levels for observation boreholes in the Sherwood Sandstone were obtained from the Environment Agency.

2.1.2 Additional information from publicly available sources included:

- geological maps from the British Geological Survey (BGS);
- borehole logs from the BGS;
- gridded potential evapotranspiration from the Centre for Ecology and Hydrology (CEH)[4];
- gridded rainfall from the CEH[5]; and
- gauged river flows for the Glaze Brook at Little Woolden Hall (station number 69005) from the CEH National River Flow Archive.

2.2 Description of the study area

Model extent

2.2.1 Model boundaries have been assigned at known flow divides, such as rivers or streams, or at a distance from Holcroft Moss so that boundaries do not affect the results of the investigation. The boundaries are shown in Figure 1 and are defined as the:

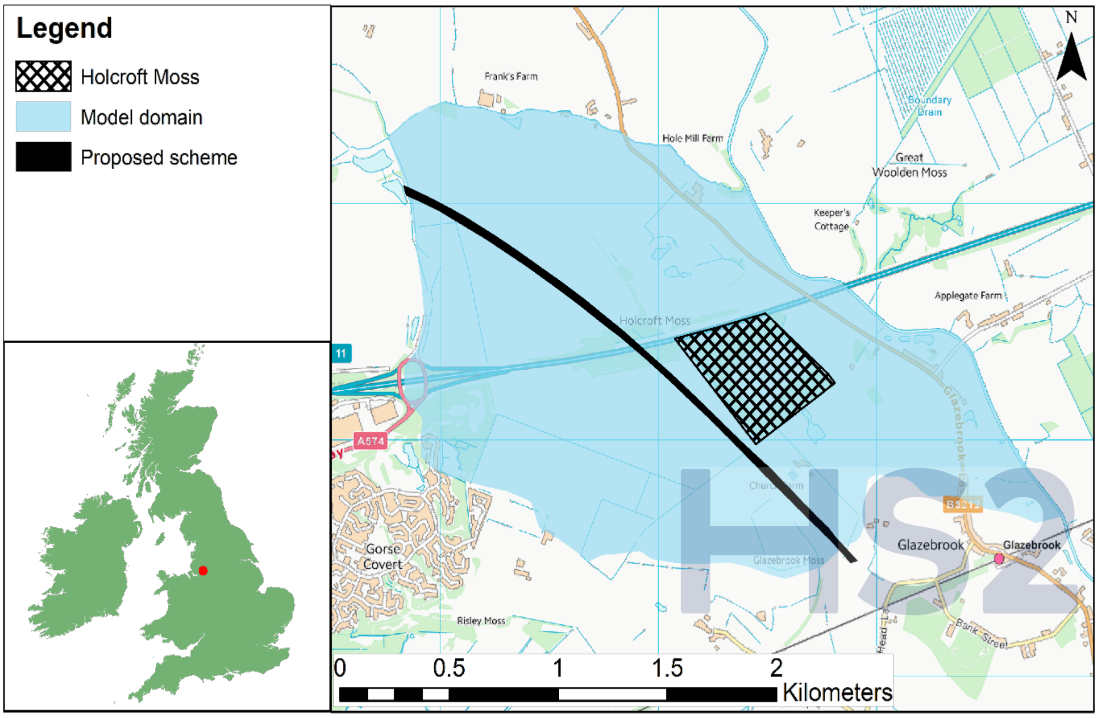
- Glaze Brook in the east;
- edge of the superficial deposits outcrop in the south;
- western extent of the Pestfurlong Moss in the west; and
- Holcroft Lane Brook in the north.

2.2.2 The route of the Proposed Scheme is 40m to the west of Holcroft Moss at its closest point and runs approximately south-east to north-west. Figure 1 shows the model domain.

[4] Climate, Hydrology and Ecology research Support System (CHESS) dataset, Robinson, E. L. et al. (2016), *Climate hydrology and ecology research support system potential evapotranspiration dataset for Great Britain (1961-2017) [CHESS-PE]*. Available online at: https://catalogue.ceh.ac.uk/documents/9116e565-2c0a-455b-9c68-558fdd9179ad.

[5] Gridded Estimates of Areal Rainfall (GEAR) dataset, Tanguy, M. et al. (2016), *Gridded estimates of daily and monthly areal rainfall for the United Kingdom (1890-2017) [CEH-GEAR]*. Available online at: https://catalogue.ceh.ac.uk/documents/ee9ab43d-a4fe-4e73-afd5-cd4fc4c82556.

Figure 1: Modelled extent of Holcroft Moss



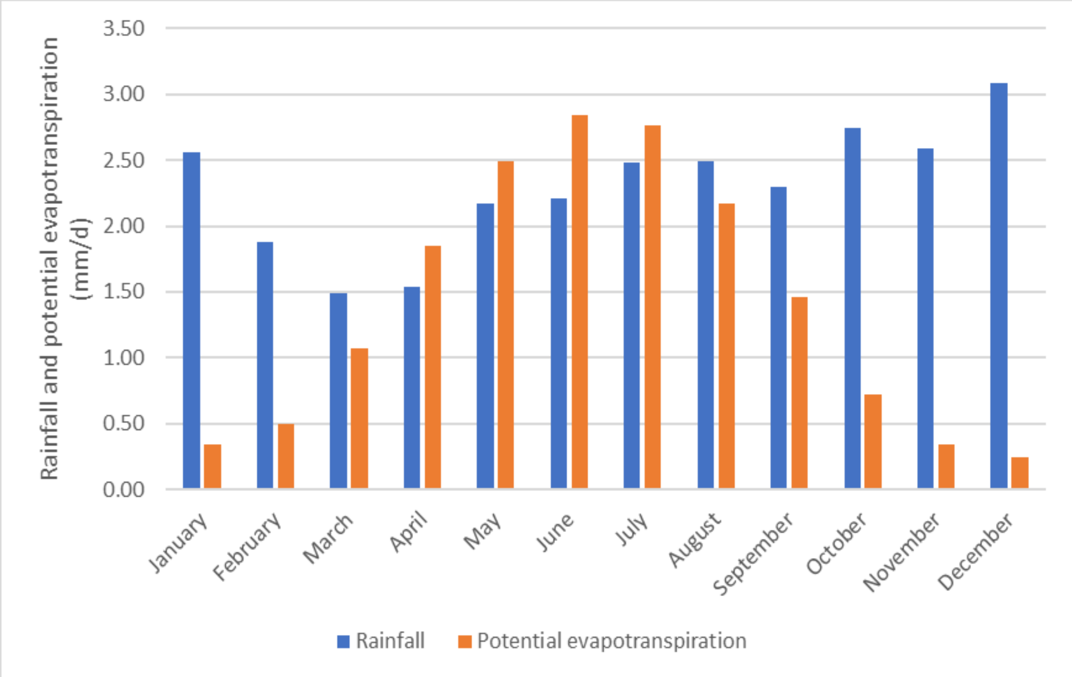
Climate

2.2.3 Rainfall in the study area, as obtained from the Gridded Estimates of Areal Rainfall (GEAR) dataset, is 840mm/year on average (2003–2015). The highest annual rainfall was recorded in 2012 (1,129mm) and the lowest in 2010 (647mm).

2.2.4 Potential evapotranspiration from the Climate, Hydrology and Ecology research Support System (CHESS) dataset for 2003–2015 is 513mm/year. There is less annual variability in the potential evapotranspiration than the rainfall; for the period considered. The highest potential evapotranspiration was observed in 2003 (551mm) and lowest in 2012 (455mm).

2.2.5 Average daily rainfall and potential evapotranspiration per month (2003–2015) is shown in Figure 2. For the period of time shown, rainfall is lowest in March and April and highest in December and January. Potential evapotranspiration is seasonal, being lowest in December and January and highest in June and July.

Figure 2: Average monthly rainfall and potential evapotranspiration (2003–2015)



Recharge

2.2.6 Rainfall was obtained from the CEH's GEAR dataset and potential evapotranspiration from the CEH's CHESS dataset for 2003–2015. These climate data were used to estimate the recharge to the model. Recharge is obtained by solving the soil-water balance where water which remains after removing the runoff, actual evapotranspiration and soil moisture deficit[6] losses becomes recharge. Actual evapotranspiration was based on a grass crop type. Recharge was calculated on a daily basis and then averaged to obtain a single value for the steady-state model.

2.2.7 The runoff coefficient for peat is generally low and the land surrounding Holcroft Moss is relatively flat. Therefore, the runoff coefficient for peat has been assumed to be 1% and for the superficial deposits 15%. These are the low-end estimates of runoff coefficients. These are considered to be a reasonable worst case, as the more groundwater recharge occurs the more likely it is that the groundwater will become an important factor in supporting water levels on Holcroft Moss.

2.2.8 Table 1 contains a summary of the climate data and estimated recharge used for the groundwater model.

[6] Allen et al. (1998), *Crop evapotranspiration. Guidelines for computing crop water requirements, FAO irrigation and drainage* paper 56, Rome: Food and Agriculture Organisation of the United Nations. Available online at: http://www.avwatermaster.org/filingdocs/195/70653/172618e_5xAGWAx8.pdf.

Table 1: Summary of climate data and estimated recharge

Parameter	Units	Value on peat outcrop (2003–2015)	Value on superficial deposits outcrop (2003–2015)
Rainfall	mm/year	840	840
Potential evapotranspiration	mm/year	513	513
Runoff	mm/year	2	35
Actual evapotranspiration	mm/year	494	494
Recharge	mm/year	344	311

Geology

2.2.9 Geology in the study area comprises the Triassic Sherwood Sandstone Group bedrock overlain by superficial glaciofluvial sands and gravels, glacial till and peat. The Sherwood Sandstone is regionally deformed by folds and north-west to south-east trending faults. South of the site, the Tarporley Siltstone Formation and Sidmouth Mudstone Formation, part of the Mercia Mudstone Group, are at subcrop beneath the superficial deposits. Bedrock dips to the south.

2.2.10 Figure 3 shows the geology of the study area. Cross sections of the geology along the northern boundary of the Holcroft Moss are shown in Figure 4 and Figure 5.

2.2.11 Superficial sands, gravels and till were deposited as the ice sheets retreated following glaciation; sands and gravels are associated with rivers that formed as the ice melted. Distribution of the superficial deposits is variable, thicker sequences are associated with erosional features in the bedrock and sands and gravels lenses or beds are interbedded with till (locally described as sandy clay or sandy stony clay, see Annex A).

2.2.12 Peat bogs initially formed in hollows in the glacio-fluvial gravels before spreading across the adjacent glacial till. Peat is formed when high water tables prevent decomposition of plant matter. Such waterlogging may occur due to low permeability deposits, which prevent water from draining through to the bedrock, or due to high water levels in the bedrock aquifer, which maintain groundwater levels above the top of the superficial deposits. It is reported that the site may have started as a lacustrine system which developed into a reed swamp before the development of ombrotrophic conditions[7].

2.2.13 Published geological cross-sections from nearby maps show that the timing and spatial deposition of glacial deposits was variable across north-west England. Glacio-fluvial sands and gravels were deposited both before and after the glacial till. In the study area, borehole logs indicate that the glacial till was deposited after the glacio-fluvial deposits and that the

[7] Leah, M. D., Wells, C. E., Appleby, C. & Huckerby, E. (1997), *Northern Mosses. In: R. Newman & M. Lister, eds*. The Wetlands of Cheshire. Lancaster: Lancaster University Archaeological Unit, pp. 19-44.

peat was deposited on top of the till. Further east, near Glaze Brook, the reverse may be true.

2.2.14 Table 2 shows the principal lithologies present in the study area including estimated thicknesses from borehole logs in the study area.

Table 2: Geological succession

Formation	Age	Description	Thickness (m)	Elevation of base of formation (mAOD)
Alluvium	Quaternary	Clays, silts and sand	<5	Variable
Peat		Organic rich layer, partially decomposed vegetation	1.4–5.2	14.71–21.96
Glacial till		Clay, silt and sand	1.4–8.2	8.64–15.94
Glaciofluvial sands and gravels		Sand and gravel	1.8–6.2	5.61–13.79
Mercia Mudstone Group	Triassic	Mudstones and siltstones	>1,350	Not proven
Sherwood Sandstone Group		Fine to medium grained sandstones of fluvial origin	>500	Not proven

2.2.15 Two cross sections have been constructed based on the borehole logs obtained from the ground investigation for the construction of the M62 (Figure 4 and Figure 5). The line of the sections is shown on Figure 3. Thicknesses and distribution of the glaciofluvial sheet deposits is based on borehole log data (see Annex A) where available with some interpretation required where data were not available. The lateral extent of the sands and gravels and till is known to vary across the site but is not well defined.

Figure 3: Geological map

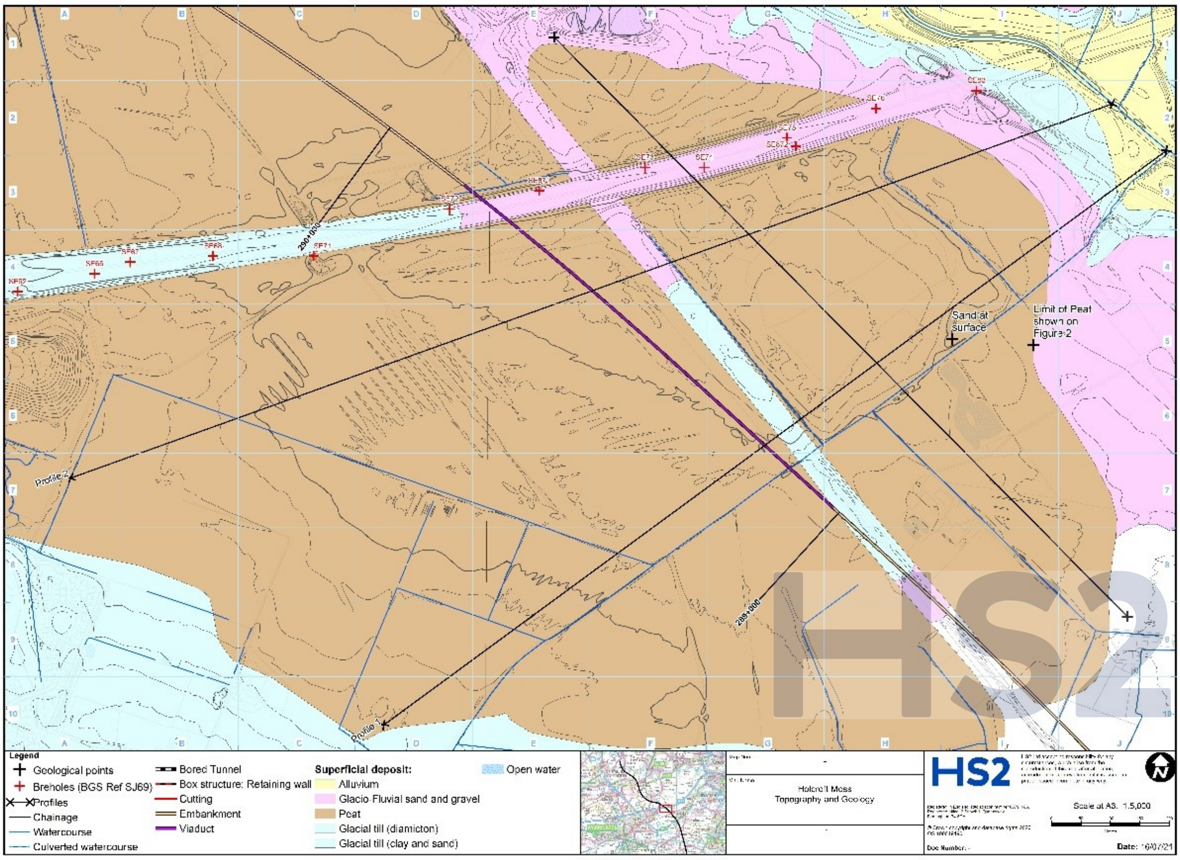


Figure 4: Geological cross section: east-west section (profile 1)

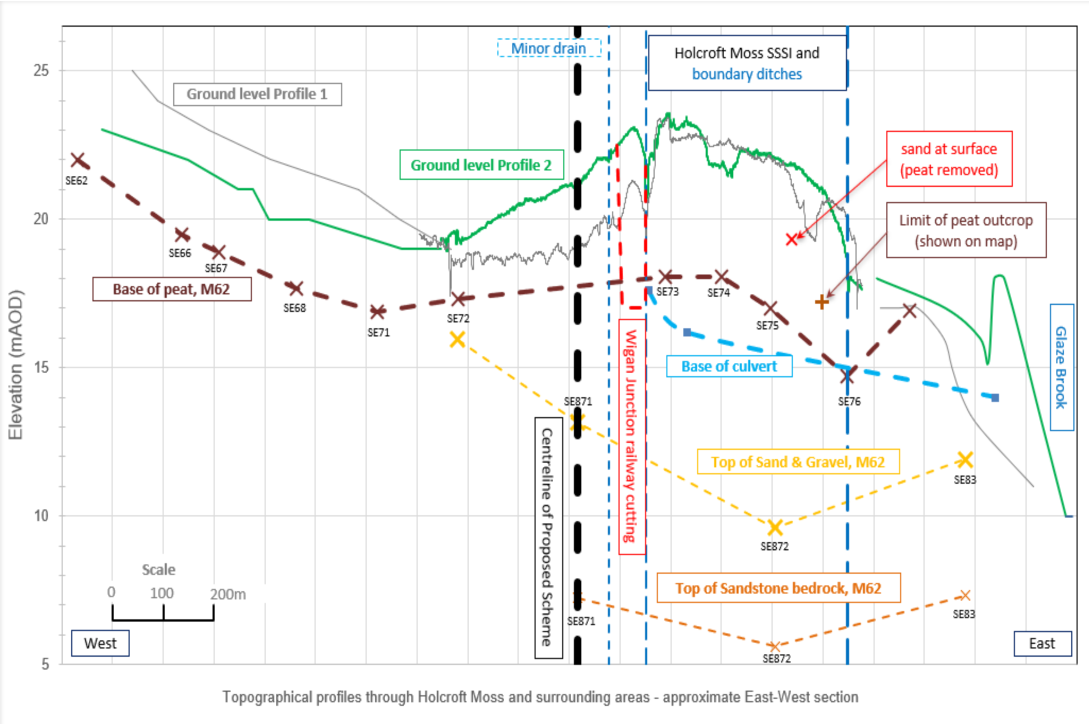
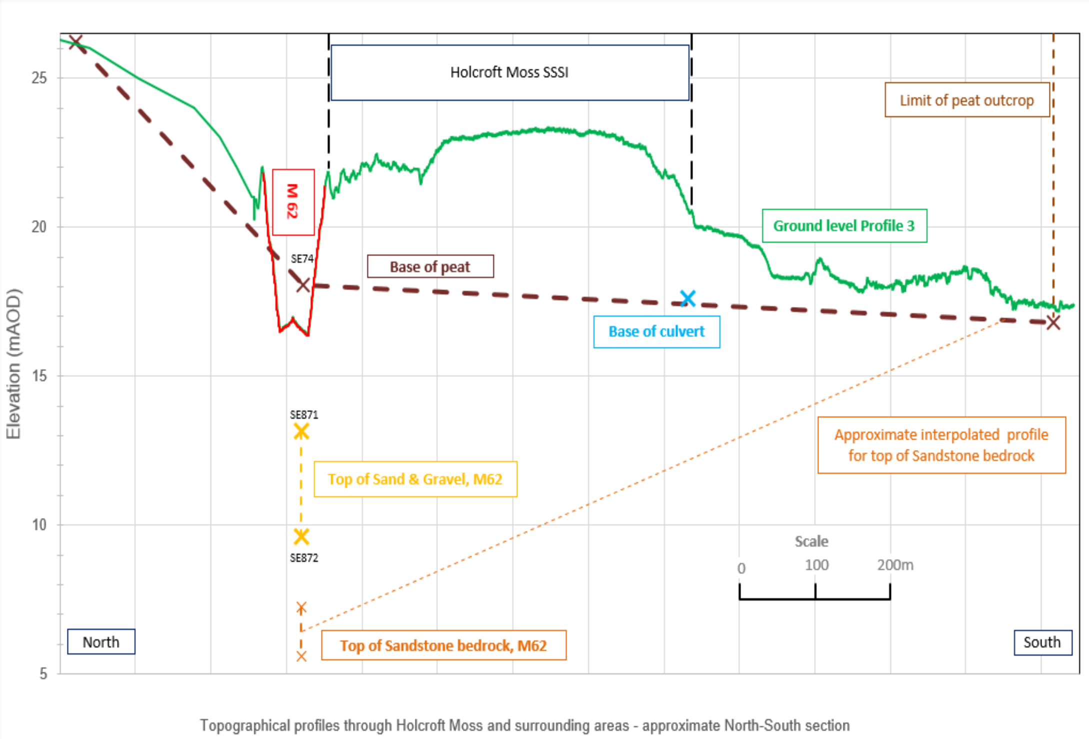


Figure 5: Geological cross section: north-south section (profile 3)



Topography and drainage

2.2.16 Ground elevations in the study area generally fall towards the east. The highest elevations are recorded where the peat is at outcrop; the site forms a raised bog at an elevation of c.23mAOD. Lowest elevations (c.12mAOD) are at the river, which captures runoff from the study area and flows in a southerly direction.

2.2.17 As the site forms a topographic high in the study area, natural drainage flows away. Drainage is then east or south towards. During the site visit September 2018 (see Section 2.3 for details), it was noted that the ditches appeared to drain towards the river.

2.2.18 Various ditches, culverts and other drainage features have been constructed across the study area, including:

- Wigan Junction branch line cutting, which was constructed in the late 19th century and runs in an approximately north-south orientation. Drainage ditches were constructed along its length. The branch line has since been decommissioned and backfilled with unknown material;
- the M62 motorway, which was constructed in the 1960s when the whole thickness of the peat was removed along the motorway, which runs approximately from east to west. There is no record of any retaining structure between the M62 and Holcroft Moss, although there is some evidence[8,9] that the clayey deposits excavated as part of the motorway construction were used to form a partial barrier between the two features;
- a culvert along the southern edge of the Holcroft Moss (likely installed for the crossing of the historical Wigan Junction branch line); and
- a ditch along the eastern edge of the Holcroft Moss.

2.2.19 Other minor ditches have been constructed across the study area, which may affect surface and shallow groundwater flow.

2.2.20 Mean flow in Glaze Brook at Little Woolden Hall[10] is 3.336m^3/s (288,230m^3/day) and its baseflow index is 0.5. The catchment of Glaze Brook is 152km^2, compared with the study area, which is 3.87km^2, and the Holcroft Moss, which is 0.227km^2. Using this information, baseflow to the Glaze Brook from the study area is expected to be approximately 3,700m^3/day.

[8] Highways England (2019), *M62 junction 10 to 12 smart motorway*. Available online at: https://highwaysengland.co.uk/our-work/north-west/m62-junction-10-to-12-smart-motorway/.

[9] Natural England (1981), *Holcroft Moss Citation.* Available online at: https://designatedsites.naturalengland.org.uk/PDFsForWeb/Citation/1006461.pdf.

[10] National River Flow Archive (2017), *69005 - Glaze Brook at Little Woolden Hall.* Available online at: https://nrfa.ceh.ac.uk/data/station/meanflow/69005.

2.2.21 Flows within the smaller drains and culverts have not been measured. Observations from the site visit in September 2018 were that:

- the smaller drains and ditches did not have any flow in them although there were areas with standing water; and
- flow with the culvert was observed from a manhole and was of the order of 2–5 litres per second.

Hydrogeology

2.2.22 There are three aquifer systems in the study area[11], which may or may not be hydraulically connected:

- peat;
- superficial deposits; and
- Sherwood Sandstone Group.

2.2.23 Borehole logs (see Annex A) from along the route of the M62 indicate that the peat has formed on top of the glacial till, forming a perched aquifer. To the east, the glacial till thins and the peat may have formed on top of the glacio-fluvial sands and gravels; the peat and sands and gravels may be in hydraulic continuity in this area.

2.2.24 Glaciofluvial sands and gravels support groundwater flow and may be in hydraulic continuity where they lie directly on the Sherwood Sandstone. The presence and extent of the low permeability glacial till is an important control on the vertical connection between the superficial deposits and the Sherwood Sandstone or peat.

2.2.25 The Sherwood Sandstone Group is a Principal Aquifer, capable of supporting regional water supply. Groundwater levels for the Sherwood Sandstone Group are above the top of the formation, leading to a confined aquifer in the study area. In the south of the study area, the Mercia Mudstone Group confines the Sherwood Sandstone as the beds dip southwards.

2.2.26 The study area considered as part of the development of the proposed groundwater model is 3.87km^2, as shown in Figure 1. There are five Environment Agency observation boreholes within the study area, all of which monitor the Sherwood Sandstone Group (see Table 3). Data was provided for four of these observation boreholes.

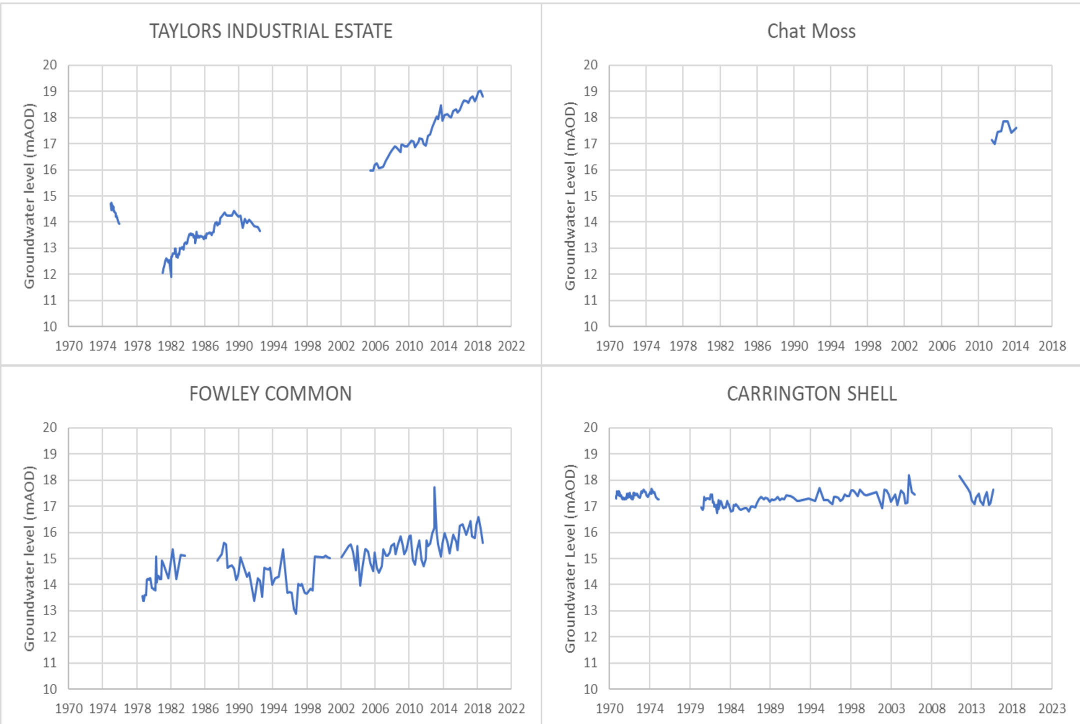
[11] Aquifers are designated by the Environment Agency. Details are provided in Water resources assessment baseline data (BID WR-004-0MA05).

Table 3: Environment Agency observation boreholes

Name	Easting	Northing	Distance from Holcroft Moss (km)	Length of record	Groundwater level range (mAOD)
Taylors Industrial Estate	366040	394400	2.67	29 November 1974 to 06 September 2018	8.77–19.01
Chat Moss	370420	395620	3.06	28 June 2011 to 16 February 2014	16.98–17.86
Fowley Common	366920	396200	3.31	06 September 1978 to 06 September 2018	12.90–17.72
Carrington Shell	374720	392240	6.34	15 October 1970 to 22 December 2015	16.73–22.29
Holcroft Lane	368550	393720	0.23	Not provided	Not provided

2.2.27 Data from these boreholes is presented in Figure 6.

Figure 6: Environment Agency observation borehole hydrographs



2.2.28 Cheshire Wildlife Trust provided groundwater dip monitoring data from 36 piezometers installed across Holcroft Moss. As the piezometers are not secured to the bedrock, they may rise and fall as the peat saturates and desaturates; therefore, these data can only be used to provide an estimate of water levels below ground level. A summary of the information is provided in Table 4; monthly monitoring data were provided from August 2001 until October 2006.

Table 4: Cheshire Wildlife Trust monitoring data

Name	Easting	Northing	Minimum dip (mbgl)	Maximum dip (mbgl)	Average dip (mbgl)
1	368408	393375	0.01	0.39	0.11
2	368447	393342	0.00	0.44	0.13
3	368502	393301	0.00	0.39	0.12
4	368559	393240	-0.02	0.43	0.15
5	368576	393220	-0.01	0.37	0.13
6	368628	393357	0.02	0.54	0.19
7	368569	393306	0.02	0.47	0.16
8	368526	393277	0.01	0.45	0.14
9	368483	393252	-0.02	0.34	0.10
10	368440	393224	-0.05	0.27	0.05
1	368735	393264	0.00	0.30	0.10
2	368726	393259	-0.01	0.34	0.09
3	368717	393251	0.00	0.37	0.14
4	368705	393244	-0.02	0.40	0.13
5	368719	393244	0.05	0.39	0.14
6	368719	393250	0.03	0.35	0.14
7	368720	393263	0.00	0.31	0.11
8	368715	393272	0.02	0.45	0.16
1A	Not provided	0.11	0.79	0.47	
1B		0.24	0.90	0.60	
2A		0.11	0.73	0.39	
2B		0.36	1.01	0.74	
3A		0.05	0.71	0.27	
3B		0.25	0.91	0.45	
4A		0.08	0.90	0.27	
4B		0.19	0.95	0.37	
5A		0.01	0.47	0.18	
5B		0.05	0.61	0.28	
6A		0.06	0.62	0.27	
6B		0.07	0.67	0.30	
7A		0.02	0.44	0.17	
7B		0.00	0.78	0.27	
8A		0.02	0.59	0.18	
8B		0.04	0.74	0.31	
9A		-0.02	0.51	0.16	
9B		0.03	0.73	0.33	
Average			0.05	0.56	0.23

2.2.29 The data in Table 4 indicate that groundwater levels in the peat are 0.23mbgl on average although this can be as deep as 1.01mbgl during dry periods or at or above surface during wet periods. Groundwater levels are a function of rainfall and potential evapotranspiration.

2.2.30 It is not possible to discern the groundwater flow direction in the peat from the data provided as no data are available as level above datum.

Proposed Scheme

2.2.31 The route of the Proposed Scheme crosses 40m to the west of Holcroft Moss at its closest point. Further detail on the Proposed Scheme can be found in Volume 2, Map Books: maps CT-05-326b and CT-06-326b.

2.3 Site visit

2.3.1 A site visit was undertaken on 5 September 2018.

2.3.2 Holcroft Moss was visited and the ditches, drains, underground utilities and culverts around the site boundary were inspected.

2.3.3 The following observations made during the site visit are of interest to the groundwater modelling study:

- most boundary ditches drain towards the Glaze Brook in the east;
- northern section of ditches to the east and west of the site drain towards the motorway;
- ditches were inspected at various locations during the visit. Ditches had no flow where inspected, but there were patches of standing water;
- ditches are plugged at various points with massive peat bunds;
- the western ditch is deeper than the eastern ditch, estimated visually to be approximately 2m–3m (western), compared to approximately 1m–2m (eastern);
- overall, Holcroft Moss is on higher ground and slopes in all directions from the central area where the peat has been drained/dried. Therefore, the ground surface is lower at the edges, and then drops away steeply into the ditches;
- there is a Victorian brick-lined culvert along the southern edge of the site. The flow into the culvert was in the order of 2–5 litres/second. Seepage through the brickwork lining the manhole chamber was observed during the visit. The water level was approximately 4.7m below the top of the manhole which is approximately 0.8m above ground level. The water was approximately 0.1m deep; and
- with rewetting, the surface of the peat can rise by up to 0.5m.

2.4 Conceptual model of groundwater flow

Geological sequence

2.4.1 Based on the geological maps and available borehole logs, it is suggested that the peat is underlain by lenses of sand and gravel which are separated by relatively continuous deposits of glacial till.

2.4.2 In the west, the geological sequence is sandstone overlain by sands and gravel then glacial till followed by peat. Between the site and the river, the sandstone is overlain by sands and gravel, followed by glacial till with a later deposition of fluvial sands and gravel to the surface, which may be associated with the proto river. The valley of the river has eroded through the surface sands and gravel to the glacial till below and the depositional sequence is sandstone, glacio-fluvial sands and gravels, till then alluvium at the surface.

Groundwater flow mechanisms

2.4.3 Regional groundwater flow within the Sherwood Sandstone Group is well understood and has been described in literary sources. Groundwater flow occurs mainly within the matrix of the sandstone although it may be controlled by the position of faults. The effective aquifer thickness is reported to be approximately 200m although the total thickness of the group may be in excess of 3km[7].

2.4.4 Groundwater flow within the superficial deposits is not well understood. However, it is expected that local perched aquifers have developed where more permeable glacio-fluvial sands and gravels overlie the low permeability till deposits. Where sands and gravels are in contact with the bedrock sandstone aquifer and groundwater levels in the sandstone are above the base of the superficial deposits, the two formations are expected to be in hydraulic continuity.

2.4.5 Where the sands and gravels overlay the sandstone, the two formations are expected to be hydraulically linked. Similarly, where the peat lies on top of the sands and gravel, the peat and sands and gravel will be hydraulically connected. The presence of the glacial till both above and below the sands and gravel restricts vertical flow of groundwater. It is therefore considered unlikely that the sandstone aquifer is hydraulically linked to the peat.

Analysis of historical groundwater flow

2.4.6 Groundwater levels from the Environment Agency's network of observation boreholes were provided (Table 3 and Figure 6). Historically, groundwater flow was towards the cone of depression in the west, associated with the large industrial abstractions. Since the cessation of abstraction in the 1980s, there has been a rise in groundwater levels so that groundwater flow in the study area is currently towards the east.

2.4.7 Groundwater levels in the sandstone are above the base of the peat although the Sherwood Sandstone Aquifer may be confined by the glacial till deposits, where present.

2.4.8 No historical groundwater level data are available for the superficial deposits. It is assumed that flow is towards the Glaze Brook in the east.

2.4.9 Groundwater levels in the peat have been measured relative to the ground surface without a reference ground elevation so it is not possible to obtain information on groundwater flow direction. It is assumed that groundwater drains into the culverts and drains that bisect the peat.

Availability of existing groundwater models

2.4.10 The Environment Agency's Lower Mersey regional groundwater model includes Holcroft Moss. Superficial deposits are not explicitly represented in the groundwater model, which simulates flow in the Sherwood Sandstone Group Aquifer, although they are included in the recharge model for the sandstone.

Review of existing groundwater models

2.4.11 The Environment Agency regional groundwater model was not provided for the study.

Water balance

2.4.12 A water balance was estimated for Holcroft Moss (see Table 5). The following assumptions were made:

- recharge is calculated using the FAO methodology[6], which assumes that recharge occurs once the crop requirements, soil moisture deficit and runoff have been satisfied;
- the proportion of runoff across the peat is assumed to 1% of rainfall. Runoff is only generated if the soil moisture deficit has been satisfied;
- vertical flow between the superficial deposits and the peat is controlled by the vertical permeability of the glacial till and is assumed to be in an upwards direction; and
- flow in the culvert to the south of the site was observed as being approximately 2–5l/s during the site visit in September 2018. For the purposes of the water balance calculation, this is assumed to be 2–3l/s (173–259m^3/d).

Table 5: Estimated water balance

Parameter	Units	Value	Notes
Area of Holcroft Moss SSSI	m^2	191,295	Natural England Site of Special Scientific Interest (SSSI) citation[9]
Recharge	mm/year	344	Remaining water available following soil balance (Table 1)
Recharge	m^3/day	179	
Drain and culvert flow	m^3/day	216	Estimated from observations during site visit (2.5l/s)
Vertical flow from superficial deposits	m^3/day	52	Calculated using Darcy's Law, assuming a vertical head difference of 1m and a vertical conductivity of 0.001m/d
Balance	m^3/day	15 (3%)	Sum of recharge and vertical flow minus discharge to the drain and culvert

2.4.13 The water balance indicates that Holcroft Moss is supported predominantly by rainfall recharge. The biggest uncertainty is in the discharge volumes to the culvert and drains across the site as well as any contributions to or from the superficial deposits. It should be noted that any significant change in the estimated contribution from the superficial deposits would be balanced by a change in discharge to the drains, which are currently in line with observations made during the site visit.

3 Model approach and justification

3.1 Model conceptualisation

3.1.1 The hydrogeological system is conceptualised as a three-layer system, comprising the peat, superficial deposits and Sherwood Sandstone Group. No flow cells are used to delineate the extent of the model layer where appropriate. Aquifer properties are modified to reflect the geology of each layer, such as hydraulic conductivity and vertical leakance.

3.1.2 Boundary conditions are used to represent the Glaze Brook as well as the various ditches, drains and culverts that cross the study area. The regional groundwater throughflow in the sandstone aquifer is also represented using boundary condition cells.

3.1.3 A steady-state model was used as there are no data available to inform or calibrate a transient model.

3.2 Software

3.2.1 MODFLOW6 has been used. This methodology is in line with standard practice to use the latest available build at the time modelling commenced. MODFLOW is industry standard software.

3.3 Input data

3.3.1 Elevations of the top and base of the geological formations in the model were taken from boreholes logs and geological maps available from the BGS. Other model parameters such as aquifer properties were assigned based on literature sources.

3.3.2 Ground elevations from Light Detection and Ranging (LiDAR) were used to estimate the stage of boundary conditions. Groundwater levels provided by the Environment Agency were used to inform the groundwater throughflow in the sandstone aquifer.

3.4 Convergence criteria

3.4.1 Convergence criteria for the model were set at 0.001m (1mm) for groundwater levels and 0.1m^3/day for flows. These values are considered to be stringent and to ensure repeatability between model runs and consistent model results.

3.4.2 For groundwater levels, the modelled simulations are, therefore, accurate to the nearest 1mm. This is particularly important when comparing the results of model runs for different development scenarios. Differences in simulated levels of less than 1mm between model runs would be within the error in convergence for each run. These differences cannot, therefore, be used to quantify accurately such marginally small impacts.

4 Technical method and implementation

4.1 Groundwater model build – baseline model

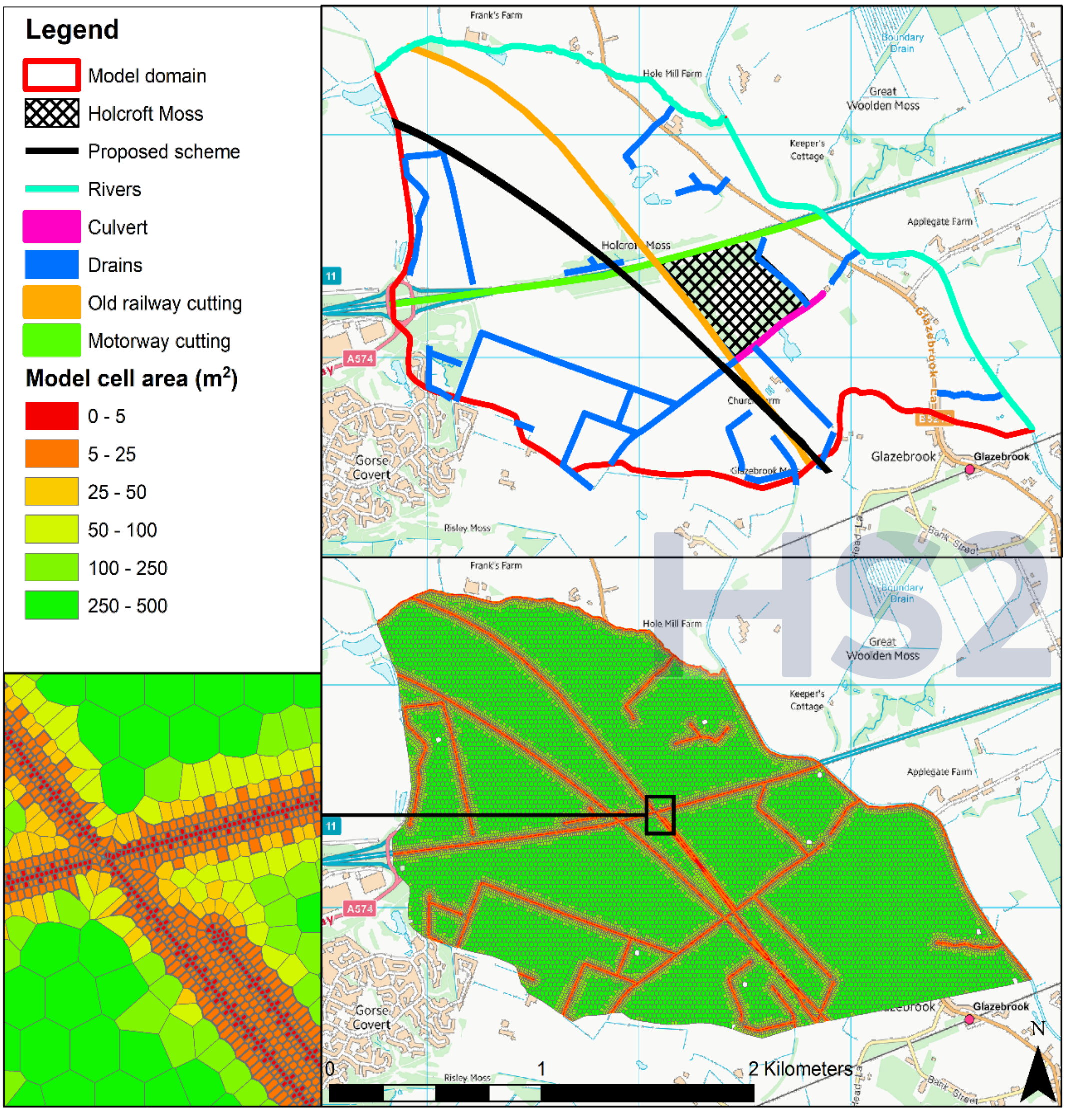
Grid and geometry

4.1.1 Three model layers were used to simulate flows in the:

- peat;
- glacial superficial deposits, including the glacial till and sands and gravels; and
- Sherwood Sandstone Group.

4.1.2 The model cell size ranged from $2m^2$–$470m^2$ and an unstructured model grid was used, with cell refinement along the key features within the model area such as the M62, the Wigan Junction and culverts, drains and ditches (see Figure 7).

Figure 7: Model refinement around key features



Aquifer properties

4.1.3 Aquifer properties assigned to the model layers are shown in Table 6.

Table 6: Aquifer properties used in groundwater model

Property	Layer 1–Peat	Layer 2– Glacial deposits	Layer 3–Sherwood Sandstone Group
Top of layer	Ground surface	Base of peat or ground surface	Base of superficial deposits.
Base of layer	Top of glacial deposits	Top of sandstone	Top of sandstone minus 20m.
Thickness (m)	Approximately 5m where the peat crops out	Approximately 18m	Transmissivity set to represent an effective thickness of 200m.
Extent of layer	Restricted to the peat outcrop	Whole model layer	No flow cells to south where the sandstone is confined by the Mercia Mudstone Group.

Property	Layer 1–Peat	Layer 2– Glacial deposits	Layer 3–Sherwood Sandstone Group
Hydraulic conductivity (m/d)	Peat: 0.5 Wigan junction: 2 Motorway cutting: 50	0.01–5	N/A
Transmissivity (m^2/d)	N/A	N/A	100
Vertical leakance	0.01–0.1	0.001–0.1	N/A
Recharge (mm/year)	343	304	N/A

4.1.4 Sensitivity testing was carried on the aquifer properties within the bounds shown in Table 6 as part of the model verification.

Boundary conditions

4.1.5 River cells were used to represent the Glaze Brook and the Holcroft Lane Brook, which form the eastern and northern boundaries of the model. Stage elevations of the river cells were obtained from LiDAR data, and flow depth estimated as 1m below LiDAR levels.

4.1.6 Drain cells simulate the flow along the various ditches, drains and culverts which cross the peat and form the boundaries to the site. Further drain cells were used to allow water to exit the model along the M62 where the peat was removed. Using the observations made during the site visit in September 2018, the following assumptions were made:

- the ditch along the western boundary of the Holcroft Moss is at an elevation of 2.5mbgl;
- on the eastern boundary of the Holcroft Moss, the elevation of the ditch is 1.5mbgl;
- all other minor ditches are assumed to be at an elevation of 2mbgl, which is an average of those observations made during the site visit; and
- the culvert, which forms the southern boundary of the site, is at an elevation of 15.5mAOD.

4.1.7 Boundary inflows were also applied to the superficial deposits layer in the west based on observed water strike levels in borehole logs (see Annex A). The inflow across the boundary was calculated using Darcy's Law as 70m^3/day. The following assumptions were made to determine the inflow across the western boundary:

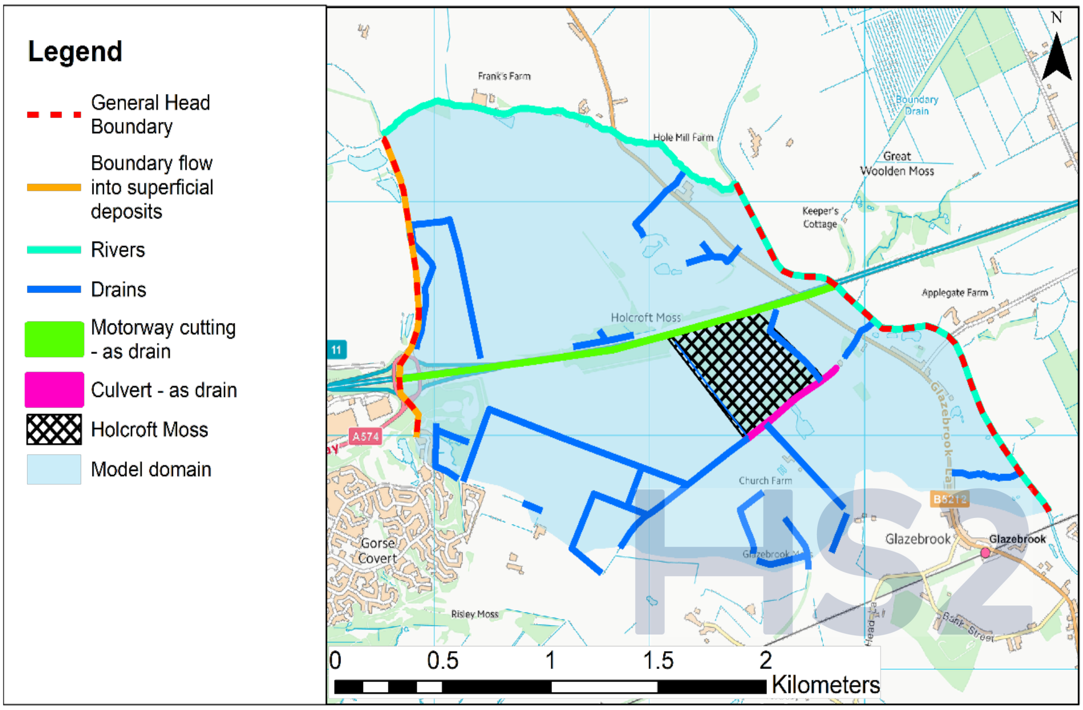
- the glaciofluvial sheet deposits are continuous across the western boundary, which has a length of 1,360m;
- groundwater flow occurs over the full thickness of the glaciofluvial sheet deposits (i.e. the sands and gravels are fully saturated), which varies over the length of the western boundary but is typically 4m;
- head at the western boundary of the model can be approximated as the top of the sands and gravels (15mAOD);

- the hydraulic gradient is calculated as the difference between the head on the western boundary and the stage of the Glaze Brook (9mAOD) divided by the distance between the two boundaries; and
- hydraulic conductivity of the sands and gravels is 5m/d.

4.1.8 General head boundaries were used to simulate the regional flow through the Sherwood Sandstone Group aquifer. Observed groundwater levels from the Environment Agency's observation borehole network were used to assign the regional groundwater gradient across the model.

4.1.9 Model boundary conditions are shown in Figure 8.

Figure 8: Model boundaries



4.2 Groundwater model build – Proposed Scheme

4.2.1 The Proposed Scheme model has been edited from the baseline to include the M62 West viaduct which would be constructed adjacent to Holcroft Moss. The model has also been run with the option of an embankment. Both options include piling, which may affect groundwater flow. An embankment will be constructed in the northern and southern sections of the Proposed Scheme where it crosses the study area.

M62 West viaduct

4.2.2 The M62 West viaduct adjacent to Holcroft Moss connects to the embankments in the north and south. The footprint of the viaduct is based on the details shown in the Volume 2, Map Books: maps CT-06-326b and CT-06-327.

4.2.3 The span length for the Proposed Scheme viaduct is 40m. Piles will be sunk through the superficial deposits approximately 8m into the Sherwood Sandstone Group bedrock and each pile has a diameter of 1.2m. Lines of three to four piles across the viaduct will be constructed beneath each pile cap. It is expected that the piles will comprise approximately 10% to 25% of the cross-sectional area along the length of the viaduct. This range in values took into account the possible variations in span length, pile caps and pile layout considered in design.

4.2.4 Hydraulic conductivity was reduced in those model cells beneath the Proposed Scheme to represent the reduced ability for groundwater flow as a result of the piles. Reductions in hydraulic conductivity were estimated assuming zero hydraulic conductivity for each pile. The obstructed proportion of each cell containing a pile has been calculated as the ratio of the pile diameter (1.2m) to the width of the cell perpendicular to the predominant flow direction. The width of the cell has been approximated from the cell area, assuming a circular cell shape as representative of the typical hexagonal cells contained within the model. For a $4m^2$ cell this results in a blockage of 53%. This method is conservative compared to a simple cross-sectional area ratio which would give a blockage ratio of 28%.

4.2.5 In the peat and superficial deposits layers, the whole layer is affected. However, the piles are only expected to be constructed into the top 8m of the Sherwood Sandstone Group aquifer. The reduction in transmissivity in the Sherwood Sandstone is therefore applied only to a proportion of the thickness of the sandstone.

4.2.6 Embankments have been incorporated into the model to the north and south of the proposed viaduct reach.

Glazebrook embankment

4.2.7 A second scenario has been considered in order to understand the potential impact of an embankment adjacent to Holcroft Moss, rather than a viaduct, on groundwater levels within the Holcroft Moss.

4.2.8 It is assumed that piles would be constructed beneath the embankment, comprising up to 33% of the cross-sectional area along the length of the Proposed Scheme (0.6m diameter piles at a spacing of 1.8m).

4.2.9 Hydraulic conductivity along the route of the embankment was reduced by 33% to reflect the impact of the embankment piles. As for the simulation of the viaduct, the reduction in hydraulic conductivity was applied to the full thickness of the peat and superficial deposit layers and to 4% of the thickness of the sandstone layer.

Modelling assumptions made

4.2.10 Existing LiDAR is assumed to be correct as no other information is available.

4.2.11 Aquifer properties obtained from literature are appropriate for the study area as no other information is available.

4.2.12 Runoff from the peat is low and the FAO methodology is an appropriate method to determine recharge.

4.2.13 Drains and the culvert that were observed during the site visit exist only in the peat layer and do not penetrate the superficial deposits.

4.2.14 No flow will occur through the piles and a reduction in the hydraulic conductivity of the model cell is an appropriate reflection of the impact that the piles will have on groundwater flow.

4.2.15 Groundwater flow is towards the Glaze Brook.

4.2.16 It is appropriate to use groundwater levels at observation boreholes distant from the site to determine the regional groundwater gradient in the Sherwood Sandstone Group.

4.2.17 Conductance of drains reflect the hydraulic conductivity of the formation which they are in.

4.2.18 MODFLOW assumes that:

- groundwater flow can be represented by a mathematical expression;
- the three-dimensional movement of groundwater can be described by Darcy's Law;
- fluid is of constant density;
- the aquifer can be represented as a homogeneous porous media;
- principal axes of hydraulic conductivity are aligned to the coordinate directions when representing anisotropy; and
- groundwater levels are calculated at the central point of a cell using a finite difference equation.

5 Model results

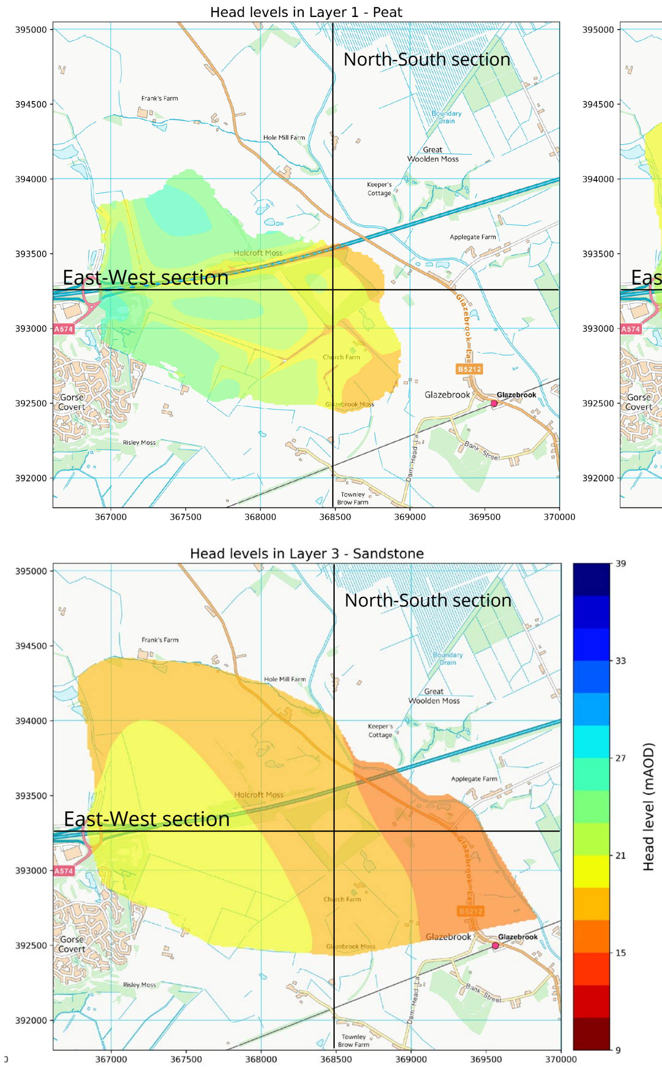
5.1.1 The baseline model was run for a steady-state scenario, which represents the current conditions at the site. Following sensitivity testing and verification, the baseline model was varied to include the Proposed Scheme and an embankment option.

5.1.2 The difference between baseline and design element simulations of the Proposed Scheme are shown in Annex B.

5.2 Baseline scenario

5.2.1 The modelling indicates that, in the baseline scenario, groundwater levels in the Sherwood Sandstone Group decrease from west to east in line with the regional groundwater levels. In the superficial deposits, levels also decrease from west to east, with flow discharging into Holcroft Lane Brook to the north and Glaze Brook to the east. In the peat, water levels are typically raised in areas of higher ground and decrease with proximity to ditches and drains. Overall levels are higher in the west than the east within the peat (see Figure 9).

Figure 9: Modelled groundwater levels for baseline scenario

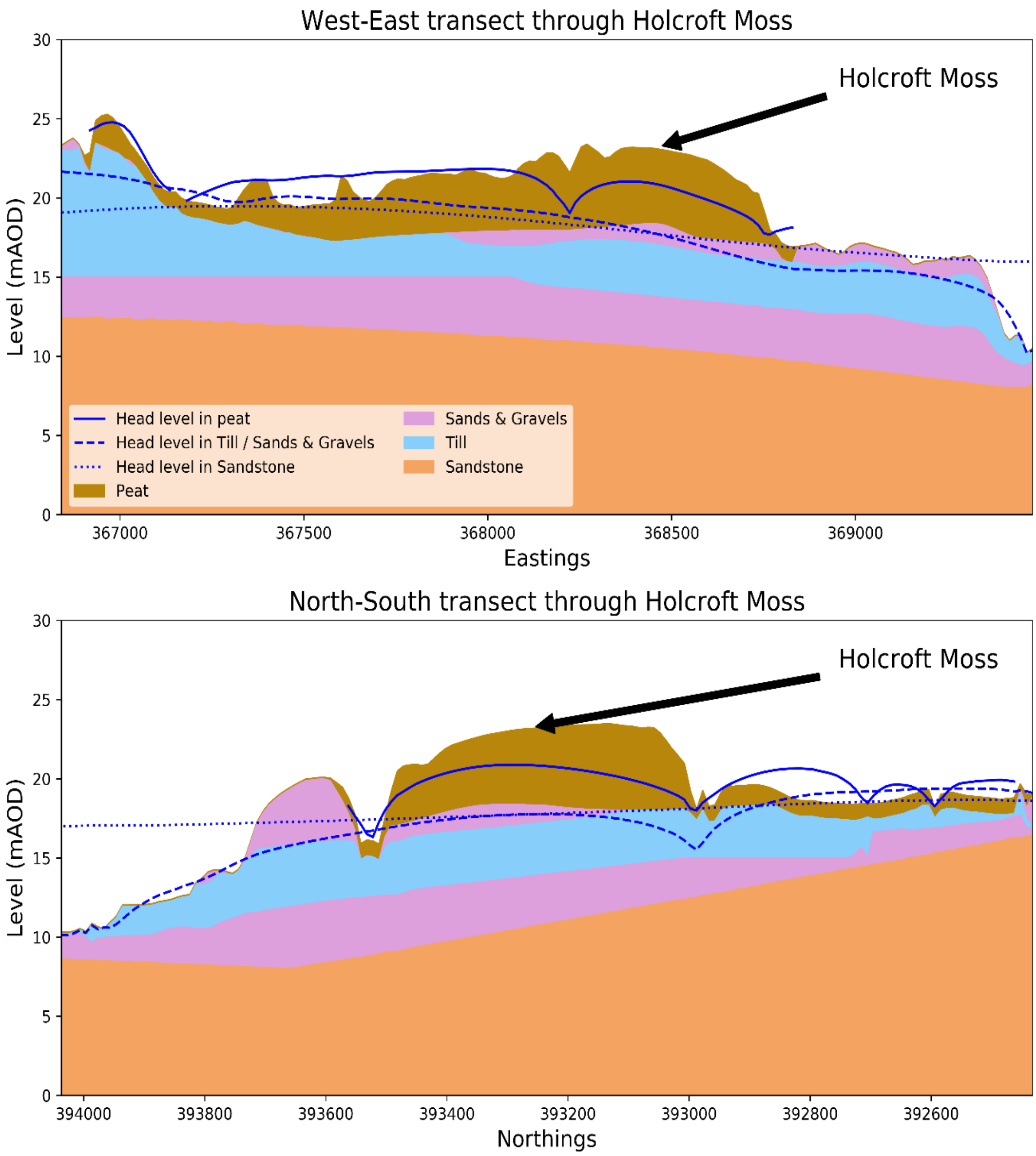


5.2.2 Transects of the modelled results through Holcroft Moss from north to south and from west to east are provided in Figure 10. It should be noted that the relative thickness and distribution of glaciofluvial sheet deposits (sands and gravels) and glacial till is shown in the figures for illustration purposes, based on available borehole log data, but is not explicitly represented in the model.

5.2.3 Groundwater levels within the Sherwood Sandstone Group are simulated above the top of the sandstone indicating a confined aquifer. Modelled groundwater levels in the superficial deposits layer (glacial till and glaciofluvial sheet deposits - sands and gravels) are raised in the west and fall towards Glaze Brook in the east, and Holcroft Lane Brook in the north.

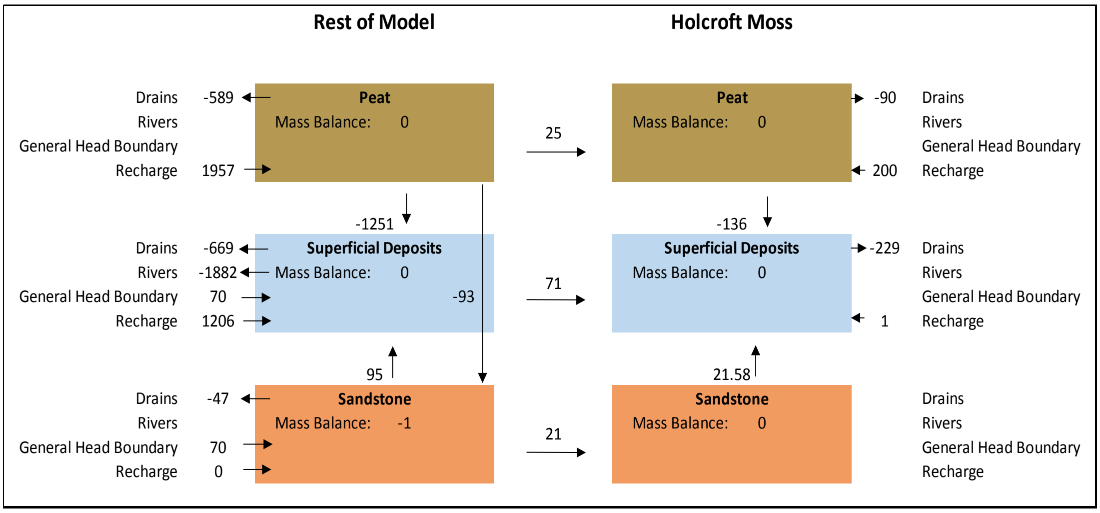
5.2.4 Within the peat outcrop, modelled groundwater levels fall towards drain locations and at the Wigan Junction cutting which lies parallel to a drain as it passes Holcroft Moss. To the west of Holcroft Moss and to the south, groundwater levels in the peat exceed ground levels. This could be due to uncertainty in ground levels, which can vary seasonally as the peat saturates and desaturates. The raised levels may also be due to several drains that are outside of the model domain which would allow the peat to drain more efficiently. It should also be noted that areas of peat which are not part of the Holcroft Moss are farmed and may be drained via sub-surface drainage, which is not mapped or included in the model.

Figure 10: Modelled transect through Holcroft Moss for baseline scenario



5.2.5 Zone budget (mass balance) analysis has been carried out on the baseline results to show movement of flow between layers and in and out of the Holcroft Moss area (see Figure 11). The predominant source of water to Holcroft Moss is through recharge (200m^3/day), with 25m^3/day coming in laterally from outside of Holcroft Moss. Roughly half discharges through drains (90m^3/day) with the remaining (136m^3/day) passing through to the superficial deposits.

Figure 11: Modelled zone budget for baseline scenario (units in m³/day)



5.3 Proposed Scheme

5.3.1 Modelled impacts on groundwater levels, due to the inclusion of the Proposed Scheme, are included in Annex B. Table 7 shows the maximum simulated decrease in groundwater levels in Holcroft Moss for various scheme options. For each modelled option, the maximum decrease occurs in the south west corner, adjacent to the culvert that runs along the southern boundary of the SSSI.

5.3.2 For the full embankment option, the simulated decrease in levels is up to about 6mm in the south-western corner of Holcroft Moss. In this option, groundwater levels within the superficial deposits are also impacted, although to a lesser degree; no impact is seen within the Sherwood Sandstone Group. For the viaduct option, the maximum impact is close to the error of convergence of the model (1mm).

5.3.3 Groundwater levels in the peat are simulated to decrease across more than 80% of Holcroft Moss for the full embankment option. In contrast, for the viaduct option, groundwater levels are modelled to decrease over about 4% of the SSSI. It should be noted, however, that areas shown in Table 7 are the areas in which the simulated impact is greater than 1mm, the error of convergence for the model.

5.3.4 The decrease in groundwater levels modelled for the viaduct option are associated with impacts from the Glazebrook embankment north, located just to the south of Holcroft Moss, and not the M62 West viaduct itself. Model scenarios have therefore also been considered to assess whether relatively simple measures, such as a gravel-filled trench around the end of the embankment, could be utilised as effective mitigation.

5.3.5 The simulated mitigation scenario indicated in Table 7 incorporated a gravel-filled trench around the end of the Glazebrook embankment north, near the south-west corner of Holcroft Moss. The intention of the trench is to encourage groundwater flow within the peat layer from the west of the embankment to the east.

5.3.6 The trench has been modelled as 10m wide, with a conductivity of 30m/d representing coarse gravel. The trench extends 30m across the end of the embankment. The full depth of the peat has been replaced by the trench.

5.3.7 With the trench in place, the maximum impact on groundwater levels in the peat in Holcroft Moss is assessed to be less than the model error of convergence (1mm). As a result, Table 7 indicates that groundwater levels are not affected in the SSSI by the viaduct option with mitigation. However, as for the other model runs, the assessment does not take into account any areas in which the modelled impact may be less than the model error of convergence.

Table 7: Proposed Scheme – reductions in groundwater level

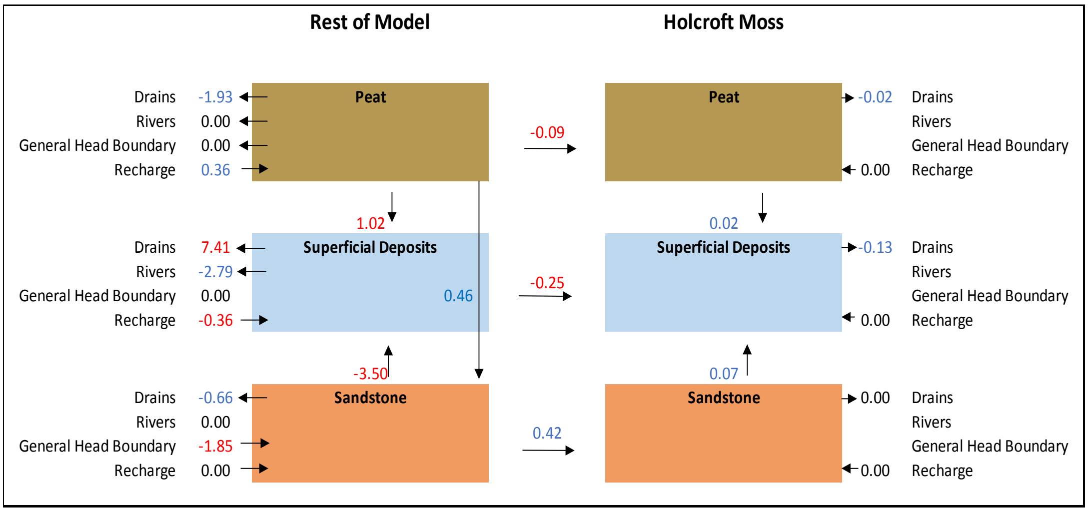
Scenario	Run	Comparison with modelled baseline (no Scheme in place) Area of Holcroft Moss affected by reduction in groundwater level greater than the model error of convergence (as % of total area of SSSI)	Maximum reduction in groundwater level on Holcroft Moss (in south west corner of SSSI)
Proposed Scheme	Full embankment	82%	6mm
	Viaduct	4%	1mm
	Viaduct with mitigation (gravel-filled trench)	0%	Below model error of convergence (1mm).

5.3.8 Zone budget outputs for the Proposed Scheme scenarios are very similar to those of the baseline model suggesting that the overall flow dynamics remain the same. Differences in flows compared to the baseline scenario are detailed in Figure 12, Figure 13 and Figure 14, for the full embankment, viaduct and viaduct with gravel trench options respectively. Table 8 summarises the change in lateral flows into the peat and superficial deposits.

Table 8: Proposed Scheme flow budget comparison

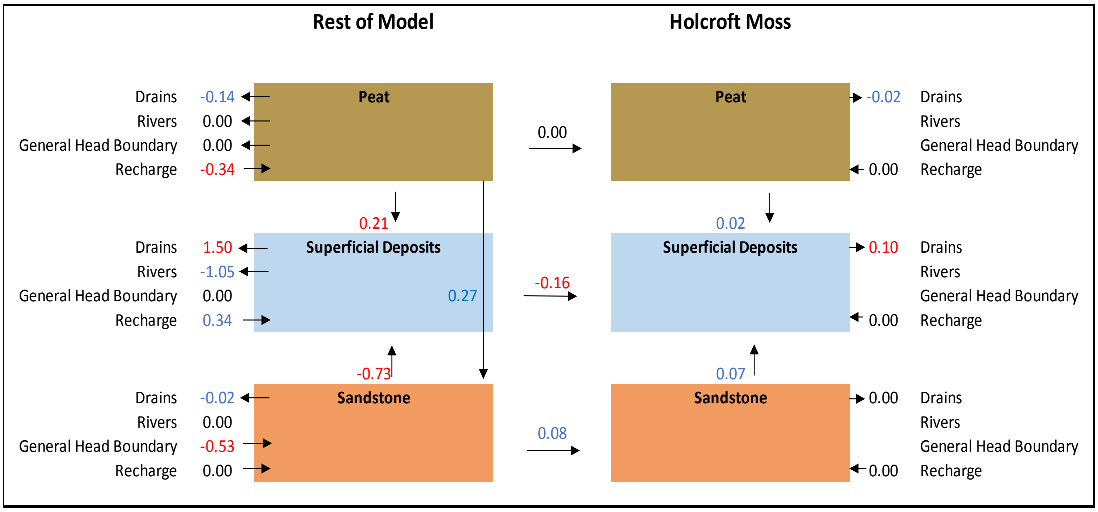
Scenario	Run	Lateral flow into Holcroft Moss through the peat		Lateral flow into Holcroft Moss through the superficial deposits	
		Volume (m^3/day)	Percentage change	Volume (m^3/day)	Percentage change
Baseline	Baseline	24.85	N/A	135.59	N/A
Proposed Scheme	Viaduct	24.85	0.0%	135.57	-0.0%
	Full embankment	24.76	-0.3%	135.48	-0.1%
	Viaduct with gravel trench	24.85	0.0%	135.58	-0.0%

Figure 12: Difference in modelled flows between the full embankment option and baseline (units in m^3/day)



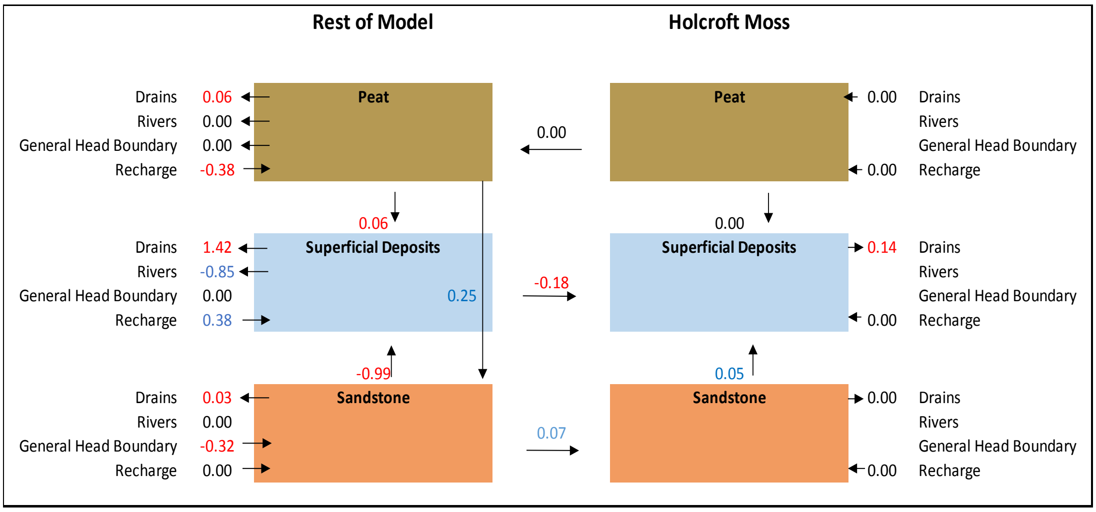
Note: Blue text indicates flow rates have increased, red text indicates flow rates have decreased. Arrows represent the overall flow direction.

Figure 13: Difference in modelled flows between the viaduct option and baseline (units in m^3/day)



Note: Blue text indicates flow rates have increased, red text indicates flow rates have decreased. Arrows represent the overall flow direction.

Figure 14: Difference in modelled flows between the viaduct with gravel trench option and baseline (units in m^3/day)



Note: Blue text indicates flow rates have increased, red text indicates flow rates have decreased. Arrows represent the overall flow direction.

6 Model proving

6.1 Run performance

6.1.1 As indicated in Section 3, convergence criteria for the model were 0.001m for groundwater levels and 0.1m^3/day for flows. These values are considered to be stringent and will ensure repeatability between model runs and consistent model results.

6.1.2 Final cumulative mass balance error is within +/-1.0% for all model runs undertaken. Mass balance errors for the baseline, scenarios and sensitivity models are provided in Table 9.

Table 9: Cumulative mass balance error

Scenario	Run	Mass balance error (%)
Baseline	Baseline	-0.01%
Sensitivity	Recharge increased	0.00%
	Recharge decreased	-0.01%
	Horizontal conductivity increased	0.00%
	Horizontal conductivity decreased	-0.01%
	Vertical leakance increased	-0.02%
	Vertical leakance decreased	-0.01%
	Wigan Junction conductivity increased	-0.01%
	Wigan Junction conductivity decreased	-0.01%
Proposed Scheme	Viaduct option	-0.01%
	Full embankment option	-0.01%
	Viaduct with gravel trench	-0.01%

6.2 Calibration and verification

6.2.1 There are no groundwater level observation boreholes situated within an appropriate distance of this location to provide calibration or verification data.

6.3 Validation

6.3.1 The groundwater level plots and cross-sections generated by the model were validated against the conceptual model and data provided in Table 3 and Table 4 to assess their accuracy. Modelled groundwater levels and the water balance are not dissimilar to those estimated using on-site data:

- flow within the culvert was estimated at approximately 2–5l/s during the site visit, compared to a modelled flow of 3.28l/s;

- river flow contribution has been estimated as 3,700m^3/day based on the observed mean flow at Little Woolden Hall on Glaze Brook and a comparison of relative catchment areas. The combined modelled flow to rivers and drains, which are assumed to discharge to the river, is 3,187m^3/day; and
- groundwater levels within Holcroft Moss are modelled to be 2.14mbgl which is lower than those measured by the Cheshire Wildlife Trust, which suggest water levels are typically between 0.5–1mbgl. There is however uncertainty in the ground level used in the model, as ground levels can rise and fall as the peat saturates and desaturates. The LiDAR elevation data only provides a snapshot in time of the ground elevations on Holcroft Moss.

6.4 Sensitivity analysis

6.4.1 Analysis was undertaken to assess the sensitivity of the baseline model outputs to the scenarios shown in Table 10. Groundwater levels in the peat layer within Holcroft Moss have been extracted from the model to assess the sensitivity of the model to the parameters.

Table 10: Sensitivity analysis

Scenario	Parameter details	Groundwater level in Holcroft Moss (mAOD)	Difference compared to Baseline (m)
Baseline	Baseline	20.86	N/A
Sensitivity	Recharge increased (400.8m^3/day on the peat and 267.2m^3/day on superficial deposits)	21.47	0.61
	Recharge decreased (373.2m^3/day on the peat and 248.8m^3/day on superficial deposits)	19.98	-0.88
	Horizontal conductivity increased Conductivity - peat 1.5, glacial till 1, glaciofluvial sheet deposits 15m/d Transmissivity - Sandstone 400m^2/d	19.44	-1.42
	Horizontal conductivity decreased Conductivity - peat 0.25, glacial till 0.005, glaciofluvial sheet deposits 2.5m/d Transmissivity - Sandstone 50m^2/d	22.31	1.45
	Vertical leakance increased Peat to glacial till - 1 Peat to glaciofluvial sheet deposits - 10 Superficial deposits to Sandstone - 0.1 Peat to Sandstone - 10	Dried out	N/A
	Vertical leakance decreased Peat to glacial till - 0.0001 Peat to glaciofluvial sheet deposits - 0.001 Superficial deposits to Sandstone - 0.00001 Peat to Sandstone - 0.001	27.08	6.22

Scenario	Parameter details	Groundwater level in Holcroft Moss (mAOD)	Difference compared to Baseline (m)
	Wigan Junction conductivity increased to 5m/d	20.84	-0.02
	Wigan Junction conductivity decreased to 0.01m/d	20.73	-0.13

6.4.2 The model is sensitive to all the parameters changed.

6.4.3 Due to the uncertainty surrounding the spatial extent of the superficial deposits, as part of the sensitivity testing, the permeability of the glacial till was increased to 1m/d (within the same order of magnitude as the hydraulic conductivity of the glaciofluvial deposits 5m/d). This sensitivity run showed that with the assumption that the site is underlain by higher permeability deposits then water levels on the site would be reduced. Therefore, the assumption that clay underlies the site provides a worst-case modelling scenario.

6.4.4 Increasing horizontal conductivity and vertical leakance both result in large decreases in head levels within the peat, with the peat either drying out or coming close to drying out. Based on observations from the Cheshire Wildlife Trust and from the site visit this is unlikely to be the case and therefore the values for horizontal conductivity and vertical leakance are likely to be lower than those chosen for the sensitivity test.

6.4.5 Decreasing vertical leakance results in very limited connectivity between the layers and significant standing water over the peat. Decreasing horizontal conductivity has a similar impact as recharge cannot move horizontally through the peat and into the drains.

6.4.6 Increasing and decreasing the recharge by 20% results in a change of groundwater level within the peat of 0.62m and -0.88m respectively. This gives an indication of how much the groundwater levels within the peat could vary with changing hydrological conditions, which are likely to be within the limits of annual seasonal variations.

6.4.7 The sensitivity tests indicate that there is sensitivity to the key input parameters, however values have been chosen that reflect the observed data as much as possible and are consistent with typically expected hydrogeological conditions. The study is a comparative study to assess the potential impact of the Proposed Scheme, and therefore the sensitivity of final head levels to changes in key parameters is of less importance than the relative change in levels due to the Proposed Scheme.

6.4.8 Uncertainty in the model parameters used would be reduced if further data were available to the study to refine the realistic bounds of model parameters.

6.5 Run parameters

6.5.1 There is no deviation from default run parameters recommended in MODFLOW for all model runs.

7 Limitations

7.1.1 Land access for new topographic survey was not possible and so the model was built using available LiDAR information supplemented by on site observations.

7.1.2 All channels have been represented in 2D. Channel conveyance will therefore not be fully represented in the model. This is likely to have resulted in a conservatively high estimate of peak flood levels.

7.1.3 Geological interpretation is based upon site information available at the time of this report.

7.1.4 Pumping test analysis was not available such that aquifer properties were obtained from literature sources rather than site data.

7.1.5 Calibration was not possible due to a lack of available historical data.

8 Conclusions and recommendations

8.1.1 The largest modelled decreases in groundwater levels in Holcroft Moss for Proposed Scheme options are in the south-western corner of the SSSI, adjacent to the culvert running along the southern boundary. Groundwater levels are simulated to decrease by up to about 6mm for the full embankment option. For the viaduct option, the maximum impact is close to the error of convergence of the groundwater model (1mm).

8.1.2 For the full embankment option, groundwater levels in the peat are simulated to decrease across more than 80% of Holcroft Moss. The affected area reduces to about 4% of the SSSI for the viaduct option. It should be noted, however, that the areas indicated are areas in which the simulated impact is greater than 1mm, the error of convergence for the model.

8.1.3 The changes in groundwater levels for the viaduct option are attributed to the proximity of the Glazebrook embankment north, located to the south of Holcroft Moss, and not to the M62 West viaduct itself.

8.1.4 The simulated changes in groundwater levels on Holcroft Moss for the viaduct option with mitigation in the form of a gravel-filled trench close to the Glazebrook embankment north is assessed to be less than the model error of convergence (1mm). As a result, the modelling indicates that groundwater levels across the SSSI are not affected by the viaduct option with this mitigation in place. However, as for the other model runs, the assessment cannot take into account any areas in which the modelled impact may be less than the model error of convergence.

8.1.5 On the basis of these modelling results, it should be possible to mitigate for the impact of the current design of the Glazebrook embankment north and M62 West viaduct on peat groundwater levels in Holcroft Moss. The mitigation would comprise a gravel-filled trench around the northern end of Glazebrook embankment north. The precise design of the trench would be based on the finding of ground investigations planned for the area, together with further detailed groundwater modelling.

Annex A: Borehole logs

Figure A 1: Borehole log SJ69 SE62

CONTRACT. LANCASHIRE YORKSHIRE MOTORWAY M62 | SHEET No. 1
LOCATION. CROFT TO WORSLEY (Site 35B) BH No – 0107 | No. of sheets 1

CLIENT. SJ 69 SE/62 6710.9325 MINISTRY OF TRANSPORT

PERCUSSION: U, D, SPT, B | Casing: Size 6" to. Size to.

Ground level. 76.65
Commenced. 23/4/68
Completed. 23/4/68

Weather. FINE

ROTARY: Cored runs, O/H

STRATUM (Scale: ¼ inch to 1 foot) 1	Thickness	Depth 2	Sample No. 3	S.P.T. Blow Count (N) LL/PL/PI 4	LEGEND 5	M.C. % / Core Rec. % 6	Type of Test 7	Grading % passing sieve (3" N.7, 1½" 25, ¾" 52, ⅜" 100, 3/16" 200) 8	TAQ. or U.C.T.: Bulk Density p.c.f. / Shear /o° p.s.f.	Dev. Stress p.s.i.	Lat. Pres. p.s.i. / U.C.T. Stren. p.s.f. / Shear/L° p.s.f. 9	WATER REMARKS 10
Top soil	1'0"	1'0"										
Soft brown peat		2'0"	M1			783.2						
		3'6"	B1			81.7						
	3'6"	4'6"										
Firm brown sandy stony clay		7'0"	M2			17.6						
		8'6"	U1	24/13/11 (CL)		15.7 / 15.1 / 16.1	UCT		134.5 / 135.9 / 134.3		2402 / 2402 / 2882	
		10'0"	A1									
		12'0"	M3			15.0						
		13'0"	B2			13.7						
		14'0"	U2			14.1 / 13.4 / 13.6	UCT		135.0 / 135.7 / 136.2		7086 / 8287 / 7206	
	11'0"	15'6"	A2									Water Table not encountered
				BOREHOLE COMPLETED								

REMARKS:

Sample	Depth	M.C. % D.W.	S.G.	Air Voids	Type	C.B.R. TOP 0.1	C.B.R. TOP 0.2	C.B.R. BOTTOM 0.1	C.B.R. BOTTOM 0.2	Value	COMPACTION B.S. 1377 No	Max. Dry Density	Optm M.C.

Figure A 2: Borehole log SJ69 SE66

GEO RESEARCH LTD. B.H. No. D111

CONTRACT.	LANCASHIRE YORKSHIRE MOTORWAY M62
LOCATION.	CROFT TO WORSLEY (Site 36) BH No D111
CLIENT.	SJ 69 SE/66 6723.9328 MINISTRY OF TRANSPORT
Weather.	FINE
SHEET No.	1
No. of sheets.	1
Ground level.	75.89
Commenced.	22/4/68
Completed.	22/4/68

PERCUSSION: U, D, SPT, B — Casing: Size 6" to. Size to. — ROTARY: Cored runs, O/H

STRATUM (Scale: ¼ inch to 1 foot)

1 Stratum	Thickness	2 Depth	3 Sample No.	4 S.P.T. Blow Count (N) LL/PL/PI	5 Legend	6 M.C. % / Core Rec. %	7 Type of Test	8 Grading % passing sieve (3" N.7, 1½" 25, ¾" 52, ⅜" 100, 3/16" 200) / Results of any other tests	9 TAQ or UCT: Bulk Density p.c.f.	9 Dev. Stress p.s.i.	9 Lat. Pres. p.s.i. / UCT Stren. p.s.f.	10 Water Remarks
Soft damp brown peat		2'0"	M1			847.0						
		3'6"	B1			642.3						
		7'0"	M2			797.0						
		8'6"	B2			871.4						
	12'0"	12'0"										Damp
Firm brown sandy stony clay		12'6"	M3			28.5						
		14'0"	B3			24.3	UCT		129.5		2261	
						24.3			122.8		2148	
						23.1			125.9		2374	
		16'0"	U1			23.1	UCT		125.4		1441	
						20.2			129.3		3002	
	5'6"	17'6"	A1			22.5			128.3		1201	
BOREHOLE COMPLETED												Water table not encountered

REMARKS:

Sample	Depth	M.C. % D.W.	S.G.	C.B.R. Air Voids	C.B.R. Type	C.B.R. Top 0.1	C.B.R. Top 0.2	C.B.R. Bottom 0.1	C.B.R. Bottom 0.2	C.B.R. Value	Compaction B.S. 1377 No	Compaction Max. Dry Density	Compaction Optm M.C.
B3	14'0"	24.4	2.7	4.5	STATIC	0.6	0.6	0.7	0.6	0.7			

Figure A 3: Borehole log SJ69 SE67

CONTRACT. LANCASHIRE YORKSHIRE MOTORWAY M62
LOCATION. CROFT TO WORSLEY (Site 36) BH N° 0112
CLIENT. SJ 69 SE/ 67
MINISTRY OF TRANSPORT
6729.9330

SHEET No. 1
No. of sheets 1
Ground level. 78.95
Commenced. 28/4/68
Completed. 28/4/68

PERCUSSION U D SPT B
Casing. Size 6" to. Size to.

Weather. FINE

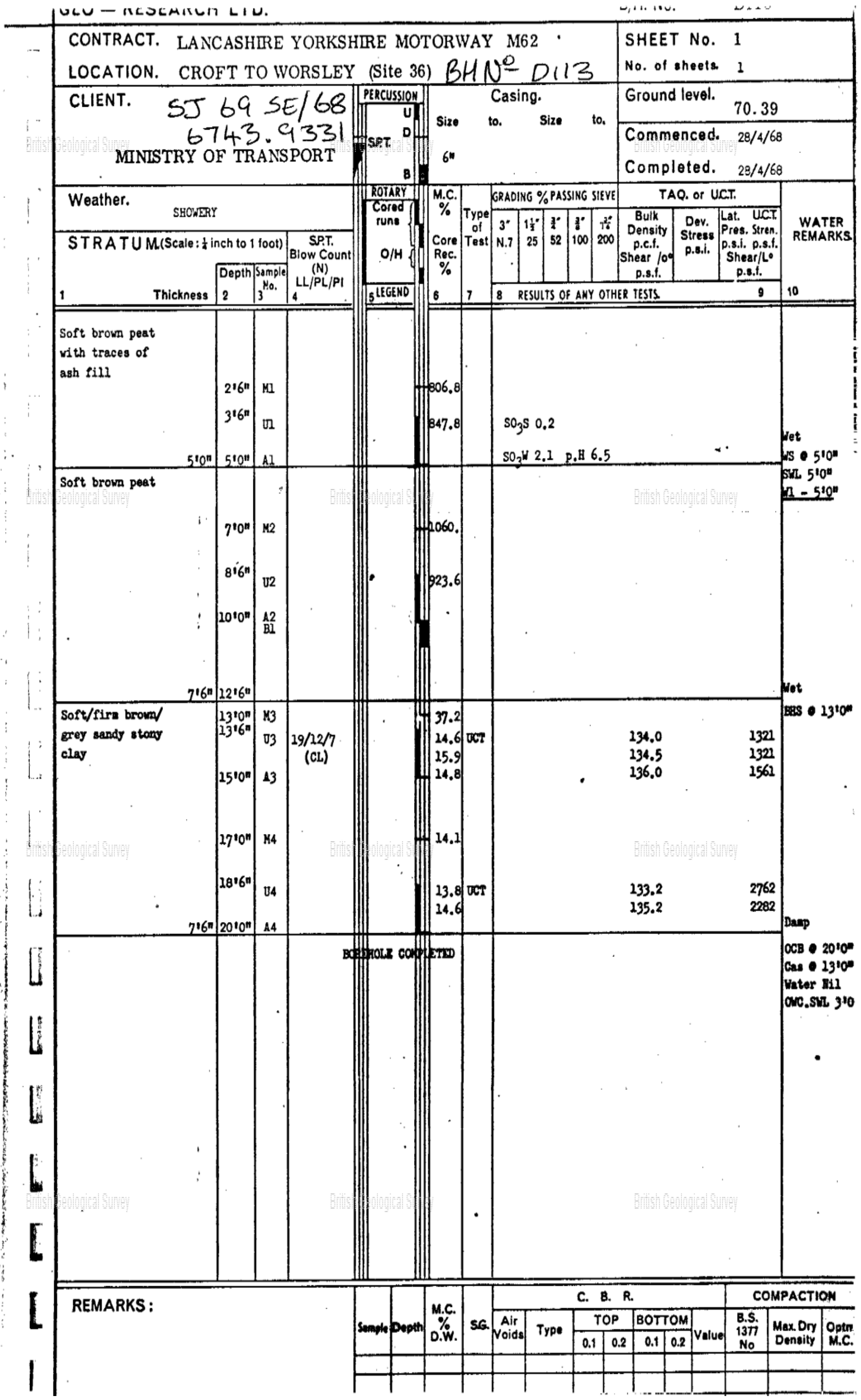
ROTARY Cored runs O/H

STRATUM (Scale: ½ inch to 1 foot) 1 Thickness	Depth 2	Sample No. 3	S.P.T. Blow Count (N) LL/PL/PI 4	LEGEND 5	M.C. % Core Rec. % 6	Type of Test 7	GRADING % PASSING SIEVE (3" N.7, 1½" 25, ¾" 52, ⅜" 100, 3/16" 200) / Bulk Density p.c.f. Shear /o° p.s.f. / Dev. Stress p.s.i. / Lat. Pres. p.s.i. / UCT Stren. p.s.f. Shear/L° p.s.f. — 8 RESULTS OF ANY OTHER TESTS 9	WATER REMARKS 10
Soft wet brown peat								
	2'0"	M1			1085.			
	3'6"	B1			1047.			
							SO_3W 4.1 p.H 7.0	WS @ 5'6" SWL 4'0" WL - 4'0"
	7'0"	M2			1217.			
	8'0"	B2			1490.			
	10'0"	B3			1173.			
	12'0"	M3			1377.			
	13'6"	B4						
17'0"	17'0"							Wet
Firm brown and grey sandy clay	17'6"	M4			27.7			
	18'6"	U1	44/16/28 (CI)		23.8	UCT	125.6 2522	
					24.9		124.2 2402	
	20'0"	A1			24.7		125.4 2402	
5'0"	22'0"							Damp
BOREHOLE COMPLETED								OCB @ 22'0" Cas @ 17'6" Water Nil OMC.SWL 5'0"

REMARKS:

Sample	Depth	M.C. % D.W.	S.G.	Air Voids	C.B.R. Type	TOP 0.1	TOP 0.2	BOTTOM 0.1	BOTTOM 0.2	Value	COMPACTION B.S. 1377 No	Max. Dry Density	Optm M.C.

Figure A 4: Borehole log SJ69 SE68



GEO — RESEARCH LTD.

CONTRACT. LANCASHIRE YORKSHIRE MOTORWAY M62
LOCATION. CROFT TO WORSLEY (Site 36) BH No D113
CLIENT. SJ 69 SE/68 6743.9331 MINISTRY OF TRANSPORT

SHEET No. 1
No. of sheets 1
Ground level. 70.39
Commenced. 28/4/68
Completed. 28/4/68

PERCUSSION U D SPT B — Casing. Size to. Size to. 6"
Weather. SHOWERY
ROTARY Cored runs O/H

STRATUM (Scale: ¼ inch to 1 foot) Thickness 1	Depth 2	Sample No. 3	S.P.T. Blow Count (N) LL/PL/PI 4	M.C. % Core Rec. % 6	Type of Test 7	Results of any other tests 8	TAQ. or U.C.T. 9	WATER REMARKS 10
Soft brown peat with traces of ash fill	2'6"	M1		806.8				
	3'6"	U1		847.8		SO_3S 0.2		Wet
5'0"	5'0"	A1				SO_3W 2.1 p.H 6.5		WS ● 5'0" SWL 5'0" WL – 5'0"
Soft brown peat	7'0"	M2		1060.				
	8'6"	U2		923.6				
	10'0"	A2 B1						
7'6"	12'6"							Wet BHS ● 13'0"
Soft/firm brown/grey sandy stony clay	13'0"	M3		37.2				
	13'6"	U3	19/12/7 (CL)	14.6 15.9 14.8	UCT	134.0 134.5 136.0	1321 1321 1561	
	15'0"	A3						
	17'0"	M4		14.1				
	18'6"	U4		13.8 14.6	UCT	133.2 135.2	2762 2282	
7'6"	20'0"	A4						Damp OCB ● 20'0" Cas ● 13'0" Water Nil OWC.SWL 3'0

BOREHOLE COMPLETED

REMARKS:

Figure A 5: Borehole log SJ69 SE71 Sheet 1 of 2

CONTRACT. LANCASHIRE YORKSHIRE MOTORWAY M62
LOCATION. CROFT TO WORSLEY (Site 36) BH N° 5697/3
SHEET No. 1
No. of sheets 2
CLIENT. SJ 69 SE/71
MINISTRY OF TRANSPORT
6760.9331
PERCUSSION (U, D, SPT, B) — Casing. Size 6" to. Size to.
ROTARY — Cored runs, O/H
Ground level. 67.37
Commenced. 6/5/68
Completed. 9/5/68
Weather. WET, FINE

STRATUM (Scale: ½ inch to 1 foot) — 1 Thickness	Depth 2	Sample No. 3	S.P.T. Blow Count (N) LL/PL/PI 4	5 LEGEND	M.C. % Core Rec. % 6	Type of Test 7	8 Grading % passing sieve / Results of any other tests	9 TAQ or UCT (Bulk Density p.c.f. / Dev. Stress p.s.i. / Lat. Pres. p.s.i.)	10 WATER REMARKS
Soft brown peat	2'0"	M1			276.				
	3'6"	B1			1075.				
	7'0"	M2			365.		SO_3W 4.8 p.H. 6.5		WS @ 5'6" SWL 3'0" WL – 3'0"
	8'6"	B2			825.8				
12'0"	12'0"								Wet
Stiff brown sandy stony clay	12'6"	M3			31.9				
	13'6"	U1	46/21/25 (CI)		21.9 / 22.1 / 21.0	TAQ		126.8 31.9 20 / 128.9 29.5 40 / 127.0 38.6 60 / 2405/0°	
	15'0"	A1							
	17'6"	M4			26.9				
	18'6"	U2			18.1				
	20'0"	A2							
	22'6"	M5			9.9				
	23'6"	U3			12.9				
	24'6"	A3							
16'0"	27'6" 28'0"	M6			11.3				Damp 7/5/68 BH @ 28'0" Cas @ 13'0" Water Nil
Very stiff brown sandy stony clay, with sandy bands 2'0"	30'0"	M7			11.3				8/5/68 SWL 20'0" Wet
Continued on Sheet 2									

REMARKS:

Sample	Depth	M.C. % D.W.	S.G.	Air Voids	C.B.R. Type	TOP 0.1	TOP 0.2	BOTTOM 0.1	BOTTOM 0.2	Value	COMPACTION B.S. 1377 No	Max. Dry Density	Optm. M.C.

Figure A 6: Borehole log SJ69 SE71 Sheet 2 of 2

CONTRACT. LANCASHIRE YORKSHIRE MOTORWAY M62
LOCATION. CROFT TO WORSLEY (Site 36) BH No 5697/3
SHEET No. 2
No. of sheets. 2

CLIENT. SJ 69 SE/71
6760.9331
MINISTRY OF TRANSPORT

PERCUSSION: U, D, S.P.T., B
Casing. Size 6" to. Size to.

Ground level. 67.37
Commenced. 6/5/68
Completed. 9/5/68

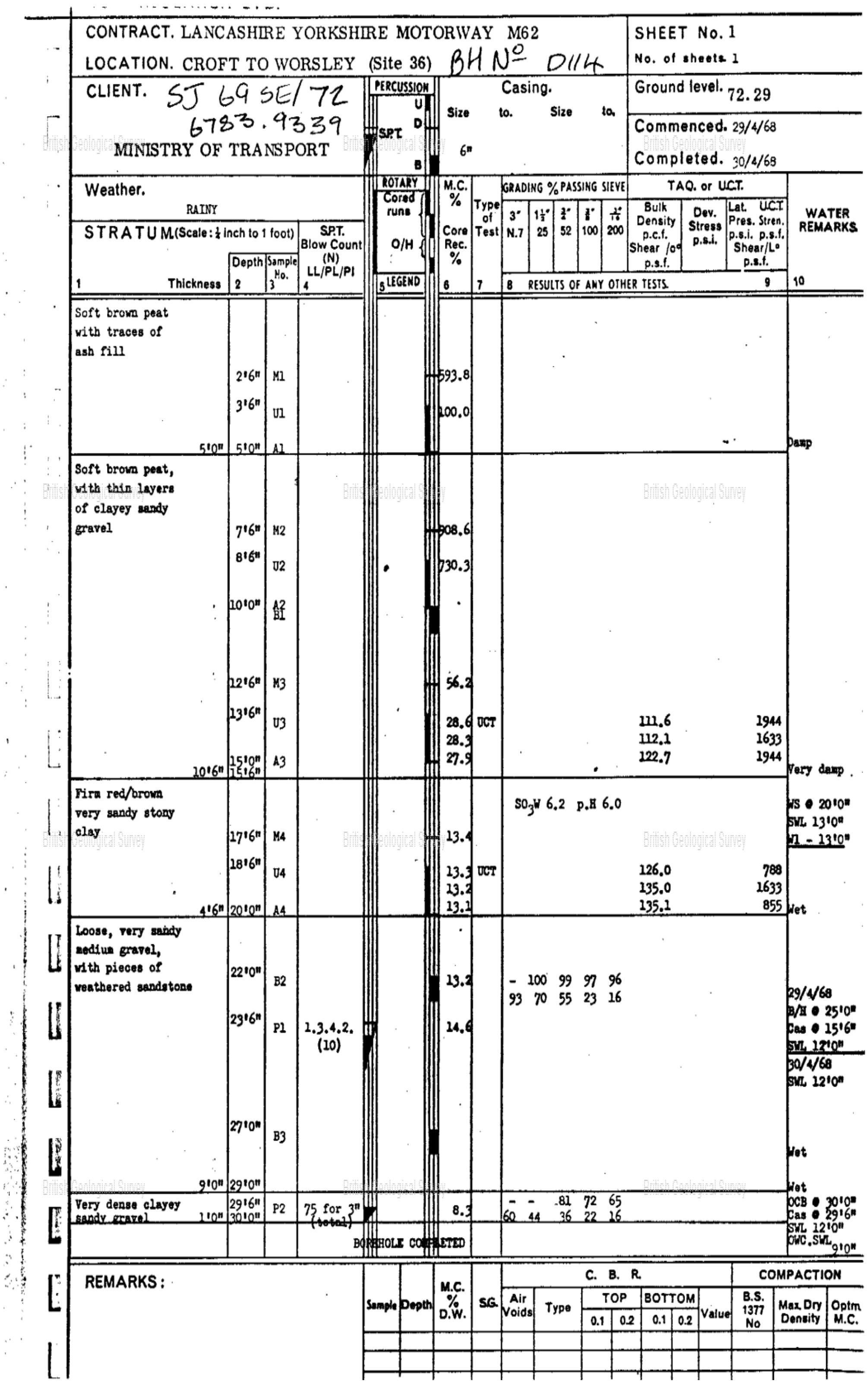
Weather. WET, FINE

STRATUM (Scale: ¼ inch to 1 foot) / Thickness (1)	Depth (2)	Sample No. (3)	S.P.T. Blow Count (N) LL/PL/PI (4)	M.C. % (6)	Type of Test (7)	Grading % passing sieve / Results of any other tests (8)	Bulk Density p.c.f.	Dev. Stress p.s.i.	Lat. Pres. p.s.i.	Water Remarks (10)
Very stiff brown sandy stony clay, with sandy bands	30'0"									
	31'0"	U4		9.3	TAQ		138.9	175.7	20	
	32'0"	A4		9.1			137.5	152.2	40	
									11808/0°	
	35'0"	M8		11.3						
	36'6"	U5		11.0	TAQ		137.6	46.1	20	
				11.1			134.0	40.0	40	
	38'0"	A5		10.6			141.1	57.1	60	
* See Remarks Below — 9'0"	39'0"								3442/0°	Wet
Loose sand and gravel (clayey)	40'0"	M9		21.2						8/5/68 BH @ 42'0" Cas @ 40'0" SWL 30'0" 9/5/68 SWL 25'0"
	43'0"	P1	10.9.15.20 (54)	8.8						
	45'0"	B3		17.4		3": –, 1½": –, ¾": 97, ⅜": 93, 3/16": 89; N.7: 86, 25: 67, 52: 25, 100: 7, 200: 5				
	48'0"	P2	8.14.19.24 (65)	8.8						
11'0"	50'0"									Wet
			BOREHOLE COMPLETED							OCB @ 50'0" Cas @ 47'6" SWL 32'6" OWC B/H Collapsed to 25'0" SWL 5'0"

REMARKS:
* Sand & Gravel came up Casing to 28'0" and water had to be added to balance Water pressure

C.B.R.: Sample, Depth, M.C. % D.W., S.G., Air Voids, Type, Top 0.1 0.2, Bottom 0.1 0.2, Value
COMPACTION: B.S. 1377 No, Max. Dry Density, Optm M.C.

Figure A 7: Borehole log SJ69 SE72



CONTRACT. LANCASHIRE YORKSHIRE MOTORWAY M62 — SHEET No. 1 — No. of sheets 1

LOCATION. CROFT TO WORSLEY (Site 36) BH No D114

CLIENT. SJ 69 SE/72 6783.9339 MINISTRY OF TRANSPORT

PERCUSSION: SPT, Size 6" — Casing: Size / to. / Size / to.

Ground level. 72.29 — Commenced. 29/4/68 — Completed. 30/4/68

Weather. RAINY

STRATUM	Thickness	Depth	Sample No.	SPT Blow Count (N) LL/PL/PI	M.C. %	Type of Test	Results of other tests	Water remarks
Soft brown peat with traces of ash fill		2'6"	M1		593.8			
		3'6"	U1		100.0			
	5'0"	5'0"	A1					Damp
Soft brown peat, with thin layers of clayey sandy gravel		7'6"	M2		608.6			
		8'6"	U2		730.3			
		10'0"	A2 B1					
		12'6"	M3		56.2			
		13'6"	U3		28.6	UCT	Bulk density 111.6; Shear 1944	
					28.3		112.1; 1633	
					27.9		122.7; 1944	
	10'6"	15'0" 15'6"	A3					Very damp
Firm red/brown very sandy stony clay							SO_3W 6.2 p.H 6.0	WS @ 20'0" SWL 13'0" WL - 13'0"
		17'6"	M4		13.4			
		18'6"	U4		13.3	UCT	126.0; 788	
					13.2		135.0; 1633	
					13.1		135.1; 855	
	4'6"	20'0"	A4					Wet
Loose, very sandy medium gravel, with pieces of weathered sandstone		22'0"	B2		13.2		Grading: - 100 99 97 96 / 93 70 55 23 16	29/4/68 B/H @ 25'0" Cas @ 15'6" SWL 12'0" 30/4/68 SWL 12'0"
		23'6"	P1	1,3,4,2, (10)	14.6			
		27'0"	B3					Wet
	9'0"	29'0"						Wet
Very dense clayey sandy gravel	1'0"	29'6" 30'0"	P2	75 for 3" (total)	8.3		Grading: - - 81 72 65 / 60 44 36 22 16	OCB @ 30'0" Cas @ 29'6" SWL 12'0" OWC.SWL 9'0"
BOREHOLE COMPLETED								

REMARKS:

Figure A 8: Borehole log SJ69 SE871 Sheet 1 of 2

SJ 69SE 871

ALLIED EXPLORATION & GEOTECHNICS LTD

BOREHOLE RECORD

Status:- **FINAL**
Date:- 02/07/97

Project: NMCS2 M62/CCTV Ground Investigation - Contract 2			BOREHOLE No BH-11
Client: Highways Agency	Location: M62 MP 34/5+00A		
Method & Equipment: Cable Percussion using a Pilcon Wayfarer 1500	Ground Level(m(AOD)): 17.04	Date: 15-04-97	Sheet: 1 of 2

Depth	Type No	Test Result	Water	Reduced Level	Depth (Thickness)	DESCRIPTION
0.10-0.80	B1				(0.80)	MADE GROUND (Brown silty fine to medium sand with occasional coarse angular limestone gravel. Some rootlets - Topsoil).
				16.24	0.80	
0.80-1.30	B2					MADE GROUND (Medium dense grey silty gravelly fine to coarse sand with occasional cobbles. Gravel is fine to coarse angular to rounded and consists of limestone, sandstone, mudstone, basalt and clinker. Cobbles consist of limestone - Roadstone).
1.50-1.95 1.60	CB3 W6	N23	1		(1.70)	below c.1.50m BGL ... occasional pockets of firm brown sandy clay.
2.00-2.45	B4					below c.2.00m BGL ... becoming brown.
				14.54	2.50	
2.55-3.00	SJ5	N39	1			Stiff brown sandy CLAY with occasional gravel and occasional lenses of light brown fine to coarse sand. Gravel is fine to coarse rounded to subangular and consists of basalt and sandstone. (Glacial Till)
3.00-3.50	B7				(1.40)	below c.3.00m BGL ... occasional lenses of thinly laminated brown clay.
3.55-4.00	U8	(110)				
				13.14	3.90	
4.10 4.15 4.40-4.85	J9 W11 SJ10	N69	2 2			Very dense brown gravelly fine to coarse SAND with some cobbles. Gravel is fine to coarse rounded to angular and consists of sandstone, basalt, quartzite and concrete. (Possible Contamination from above strata)
5.00-5.50	B12				(2.10)	
5.55-6.00	SJ13	N61				
				11.04	6.00	
6.00-6.90	B14					Very dense brown gravelly fine to coarse SAND. Gravel is fine to coarse rounded to subrounded and consists of basalt, quartzite and sandstone. (Fluvio-glacial)
7.15-7.30	SJ15	56 for 145mm*				
7.50-8.00	B16				(3.00)	

Boring Progress and Water Observations

Date		Depth	Casing	Casing Dia	Water Depth
15/04/97		0.00	0.00		
15/04/97		5.00	5.00	150mm	4.15
16/04/97		5.00	5.00	150mm	
16/04/97		10.50	10.35	150mm	2.60

Chiselling

From	To	Hours
4.60	5.00	1.00
10.00	10.50	1.00

Water Added

From	To

GENERAL REMARKS

1) Inspection pit dug prior to drilling -1.20m. 2) Water strikes at 2.70m rose to 1.60m and 4.50m rose to 4.15m BGL (20 minutes). 3) Depth of piezo tip = 7.00m.

All dimensions in metres Scale 1:25	For Explanation of Symbols and Abbreviations see Key Sheets	Checked By:	Logged By: A. Latimer	Contract No. 1718

Date Printed:- 05/08/97

Form AEG21/2

Figure A 9: Borehole log SJ69 SE871 Sheet 2 of 2

SJ69SE 871

ALLIED EXPLORATION & GEOTECHNICS LTD

BOREHOLE RECORD

Status:- **FINAL**
Date:- 02/07/97

Project: NMCS2 M62/CCTV Ground Investigation - Contract 2			BOREHOLE No BH-11
Client: Highways Agency	Location: M62 MP 34/5+00A		
Method & Equipment: Cable Percussion using a Pilcon Wayfarer 1500	Ground Level (m(AOD)): 17.04	Date: 15-04-97	Sheet: 2 of 2

SAMPLES & TESTS			Water	STRATA				Instrument Backfill
Depth	Type No	Test Result		Reduced Level	Legend	Depth (Thickness)	DESCRIPTION	
8.00-8.50	B17						(As sheet 1 of 2) Very dense brown gravelly fine to coarse SAND. Gravel is fine to coarse rounded to subrounded and consists of basalt, quartzite and sandstone. (Fluvio-glacial)	
8.60-9.05	SJ18	N57		8.04		9.00	below c.8.00m BGL ... becoming very sandy gravel.	
9.30-9.70	J19			7.24		(0.80) 9.80	Red brown slightly gravelly fine to coarse SAND. Gravel is fine to medium angular and consists of red sandstone. (Fluvio-glacial/Bedrock Interface)	
10.05-10.20	SJ20	83 for 105mm*				(0.70)	Red brown and green grey moderately weathered silty SANDSTONE very weak. (Recovered as very dense silty slightly gravelly fine sand. Gravel is fine to medium angular and consists of sandstone lithorelicts).	
10.45-10.50	SJ21	50 for 49mm*		6.54		10.50	(Sherwood Sandstone)	
							Borehole complete at 10.50m BGL.	

Boring Progress and Water Observations						Chiselling			Water Added	
Date		Depth	Casing	Casing Dia	Water Depth	From	To	Hours	From	To
15/04/97		0.00	0.00			4.60	5.00	1.00		
15/04/97		5.00	5.00	150mm	4.15	10.00	10.50	1.00		
16/04/97		5.00	5.00	150mm						
16/04/97		10.50	10.35	150mm	2.60					

GENERAL REMARKS

1) Inspection pit dug prior to drilling -1.20m. 2) Water strikes at 2.70m rose to 1.60m and 4.50m rose to 4.15m BGL (20 minutes). 3) Depth of piezo tip = 7.00m.

All dimensions in metres Scale 1:25	For Explanation of Symbols and Abbreviations see Key Sheets	Checked By:	Logged By: A. Latimer	Contract No. 1718

Date Printed:- 05/08/97

Form AEG21/2

Figure A 10: Borehole log SJ69 SE73

GEO — RESEARCH LTD.

CONTRACT. LANCASHIRE YORKSHIRE MOTORWAY M62
LOCATION. CROFT TO WORSLEY (Site 36) BH Nº D115
SHEET No. 1
No. of sheets 1
CLIENT. SJ 69 SE/73
MINISTRY OF TRANSPORT
6816.9346
PERCUSSION: U, SPT, D, B
Casing. Size 6" to. Size to.
Ground level. 75.74
Commenced. 18/5/68
Completed. 20/5/68
Weather. WET

STRATUM (Scale: ¼ inch to 1 foot) (1)	Thickness	Depth (2)	Sample No. (3)	S.P.T. Blow Count (N) LL/PL/PI (4)	M.C. % / Core Rec. % (6)	Type of Test (7)	Bulk Density p.c.f. (8)	U.C.T. Stren. p.s.f. (9)	WATER REMARKS (10)
Brown peat		2'0"	M1		1065.				
		3'6"	P1	2.1.1.- (4)	761.7				
With clay		8'6"	M2		192.5				
		13'0"	B1		370.0				
	16'6"	16'6"							Moist
Firm brown/grey mottled sandy stony clay		17'0"	M3		37.5				
		18'6"	U1	24/13/11 (CL)	20.9	UCT	122.7	1555	
					21.0		124.8	1166	
		20'0"	A1						
	6'6"	23'0"							Damp
Sandy stony clay with bands of sand		23'3"	M4		35.4				
		23'6"	B2		37.8				
		24'6"	P2	4.2.4.4. (14)	21.6				
		28'6"	P3	3.3.6.9. (21)	16.4				
	7'0"	30'0"							Moist Water table not encountered

BOREHOLE COMPLETED

REMARKS:

Sample	Depth	M.C. % D.W.	S.G.	C.B.R. Air Voids	C.B.R. Type	C.B.R. Top 0.1	C.B.R. Top 0.2	C.B.R. Bottom 0.1	C.B.R. Bottom 0.2	C.B.R. Value	Compaction B.S. 1377 No	Compaction Max. Dry Density	Compaction Optm M.C.

Figure A 11: Borehole log SJ69 SE74

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CONTRACT. LANCASHIRE YORKSHIRE MOTORWAY M62
LOCATION. CROFT TO WORSLEY (Site 36) BH N° D116
CLIENT. SJ 69 SE/74 6826.9346 MINISTRY OF TRANSPORT

SHEET No. 1
No. of sheets. 1
Ground level. 75.14
Commenced. 16/5/68
Completed. 16/5/68

PERCUSSION: U, D, SPT, B
ROTARY: Cored runs, O/H
Casing. Size to. Size to. 6"

Weather. WET

STRATUM (Scale: ¼ inch to 1 foot) 1	Thickness	Depth 2	Sample No. 3	S.P.T. Blow Count (N) LL/PL/PI 4	5 LEGEND	M.C. % / Core Rec. % 6	Type of Test 7	8 Results of any other tests (Grading % passing sieve: 3" N.7, 1½" 25, ¾" 52, ⅜" 100, 3/16" 200)	TAQ. or U.C.T. (Bulk Density p.c.f.; Shear /o° p.s.f.; Dev. Stress p.s.i.; Lat. Pres. p.s.i.; U.C.T. Stren. p.s.f.; Shear/L° p.s.f.) 9	WATER REMARKS 10
Brown peat										
		2'6"	M1			1383.				
								SO_3^W 3.4 p.H 4.0		WS @ 4'0" SWL 3'0" W1 - 3'0"
		8'0"	M2			1307.				
		10'6"	B1			789.2				
		13'0"	M3			545.7				
		14'6"	B2			575.7				
	16'0"	16'0"								Wet BHS @ 16'0"
Firm brown mottled sandy stony clay		16'6"	M4			17.7				
		18'6"	U1	21/14/7 (CL)		17.8	UCT		124.7 … 1633	
						16.6			128.1 … 1633	
		20'0"	A1			17.1			128.1 … 1477	
		22'0"	M5			31.5				
		23'6"	B3			26.7				
		24'0"	U2			20.1				
	9'0"	25'0"	A2							Damp
Brown clayey sand		26'0"	M6			21.5				
		28'6"	P1	2,2,3,4 (11)		16.3				Moist
	5'0"	30'0"								OCB @ 30'0" Cas @ 20'0"
					BOREHOLE COMPLETED					Water Nil CWC.SWL 3'C"

REMARKS:

Sample	Depth	M.C. % D.W.	S.G.	Air Voids	C.B.R. Type	C.B.R. TOP 0.1	C.B.R. TOP 0.2	C.B.R. BOTTOM 0.1	C.B.R. BOTTOM 0.2	C.B.R. Value	COMPACTION B.S. 1377 No	COMPACTION Max. Dry Density	COMPACTION Optm. M.C.
B3	23'6"	26.7	2.65	6.5	STATIC	2.3	2.2	2.4	2.2	2.4			

Figure A 12: Borehole log SJ69 SE75

GEO — RESEARCH LTD.

CONTRACT. LANCASHIRE YORKSHIRE MOTORWAY M62

LOCATION. CROFT TO WORSLEY (Site 36) BH No P117

SHEET No. 1
No. of sheets 1

CLIENT. SJ 69 SE/75
6840.9351
MINISTRY OF TRANSPORT

PERCUSSION: U, D, SPT, B
Casing. Size 6" to. Size to.

Ground level. 69.36
Commenced. 14/5/68
Completed. 14/5/68

Weather. FINE

ROTARY: Cored runs, O/H

STRATUM (Scale: ¼ inch to 1 foot)

STRATUM (1)	Thickness	Depth (2)	Sample No. (3)	S.P.T. Blow Count (N) LL/PL/PI (4)	M.C. % / Core Rec. % (6)	Type of Test (7)	Results of any other tests (8, 9)	Water Remarks (10)
Brown peat		2'6"	M1		1241.			
		3'6"	P1	1.-.-.- (1)				
		9'0"	M2		1508.		SO_3W 4.1 p.H 4.0	WS @ 10'0" SWL 7'0" WL - 7'0"
	12'6"	12'6"						
Sandy peat	1'0"	13'0" / 13'6"	M3		78.8			SWS @ 13'0"
Light grey clayey sand	1'9"	14'0" / 15'3"	P2	2.2.1.2. (7)	17.2			Moist
Light brown clayey sand, with traces of gravel		17'6"	M4		20.6			WS @ 18'0" SWL 17'6"
		19'0"	P3	2.2.4.7. (15)	18.5			
		20'0"	B1					
		24'0"	P4	7.5.6.8. (26)	27.2			
	9'9"	25'0"						
BOREHOLE COMPLETED								DCB @ 25'0" Cas @ 15'0" SWL 24'6" DWC.SWL 5'0"

GRADING % PASSING SIEVE: 3" N.7; 1½" 25; ⅜" 52; 3/16" 100; 3/16" 200

TAQ. or U.C.T.: Bulk Density p.c.f.; Shear /o° p.s.f.; Dev. Stress p.s.i.; Lat. Pres. p.s.i.; U.C.T. Stren. p.s.f.; Shear/L° p.s.f.

REMARKS:

Sample	Depth	M.C. % D.W.	S.G.	Air Voids	C.B.R. Type	TOP 0.1	TOP 0.2	BOTTOM 0.1	BOTTOM 0.2	Value	COMPACTION B.S. 1377 No	Max. Dry Density	Optm M.C.

Figure A 13: Borehole log SJ69 SE872 Sheet 1 of 2

SJ 69SE 872

ALLIED EXPLORATION & GEOTECHNICS LTD

BOREHOLE RECORD

Status:- **FINAL**
Date:- 02/07/97

Project: NMCS2 M62/CCTV Ground Investigation - Contract 2			BOREHOLE No BH-12
Client: Highways Agency	Location: M62 MP 34/9+30B		
Method & Equipment: Cable Percussion using a Pilcon Wayfarer 1500	Ground Level(m(AOD)): 15.61	Date: 25-04-97	Sheet: 1 of 2

SAMPLES & TESTS				STRATA			Instrument/Backfill
Depth	Type No	Test Result	Water	Reduced Level	Depth (Thickness)	DESCRIPTION	
				15.31	(0.30) 0.30	(1) MADE GROUND (Topsoil).	
0.60-1.05	B1	N19				MADE GROUND (Medium dense brown clayey sandy fine to coarse angular to rounded gravel. Gravel consists of limestone and sandstone - field drain).	
1.50-1.95	SJ2				(2.20)		
1.95-2.50	B3						
2.10	W17						
				13.11	2.50		
2.50-3.00	B4 U*	(100)				Very stiff red brown sandy CLAY with occasional gravel. Gravel is fine to coarse rounded to subangular and consists of sandstone, basalt, quartzite and coal. (Glacial Till)	
3.05-3.50	SJ5	N80					
4.00-4.50	B6 U*	(110)			(3.50)		
4.65-5.10	SJ7	N50					
			▽ (5.10)				
5.50	J8						
			▼ (6.10)	9.61	6.00		
6.10-6.55	SB9	N44				Dense brown sandy fine to coarse rounded to subrounded GRAVEL. Gravel consists of sandstone, basalt, quartzite and conglomerate. (Fluvio-glacial Gravel)	
6.75-7.50	B10						
7.50-8.00	SB11	N63				below c.7.50m BGL ... very dense.	
					(4.00)		

Boring Progress and Water Observations

Date	Time	Depth	Casing	Casing Dia	Water Depth
25/04/97		0.00	0.00		
25/04/97		10.50	10.00	150mm	2.10

Chiselling

From	To	Hours
10.00	10.50	1.00

Water Added

From	To

GENERAL REMARKS

1) Description derived from drillers daily report.
2) Water strike at 6.10m rose to 5.10m BGL (20 minutes).

All dimensions in metres Scale 1:50	For Explanation of Symbols and Abbreviations see Key Sheets	Checked By: [signature]	Logged By: A. Latimer	Contract No. 1718

Date Printed:- 03/07/97

Form AEG21/2

Figure A 14: Borehole log SJ69 SE872 Sheet 2 of 2

SJ 69 SE 872

ALLIED EXPLORATION & GEOTECHNICS LTD

BOREHOLE RECORD

Status:- **FINAL** Date:- 02/07/97

Project: NMCS2 M62/CCTV Ground Investigation - Contract 2	BOREHOLE No BH-12
Client: Highways Agency	Location: M62 MP 34/9+30B
Method & Equipment: Cable Percussion using a Pilcon Wayfarer 1500	Ground Level(m(AOD)): 15.61
Date: 25-04-97	Sheet: 2 of 2

Depth	Type No	Test Result	Water	Reduced Level	Depth (Thickness)	Description
8.20-9.00	B12					(As sheet 1 of 2) Dense brown sandy fine to coarse rounded to subrounded GRAVEL. Gravel consists of sandstone, basalt, quartzite and conglomerate. (Fluvio-glacial Gravel)
9.00-9.45	SB13	81 for 150mm*				
9.45-10.00	B14			5.61	10.00	
10.00-10.20	SJ15	50 for 71mm			(0.50)	Green grey fine to medium grained moderately weathered SANDSTONE weak to very weak. (Recovered as very dense silty sandy fine to medium angular to subangular gravel of sandstone lithorelicts weak to very weak). (Sherwood Sandstone)
10.45-10.50	SJ16	50 for 50mm*		5.11	10.50	Borehole complete at 10.50m BGL.

Boring Progress and Water Observations

Date	Depth	Casing	Casing Dia	Water Depth
25/04/97	0.00	0.00		
25/04/97	10.50	10.00	150mm	2.10

Chiselling

From	To	Hours
10.00	10.50	1.00

Water Added

From	To

GENERAL REMARKS

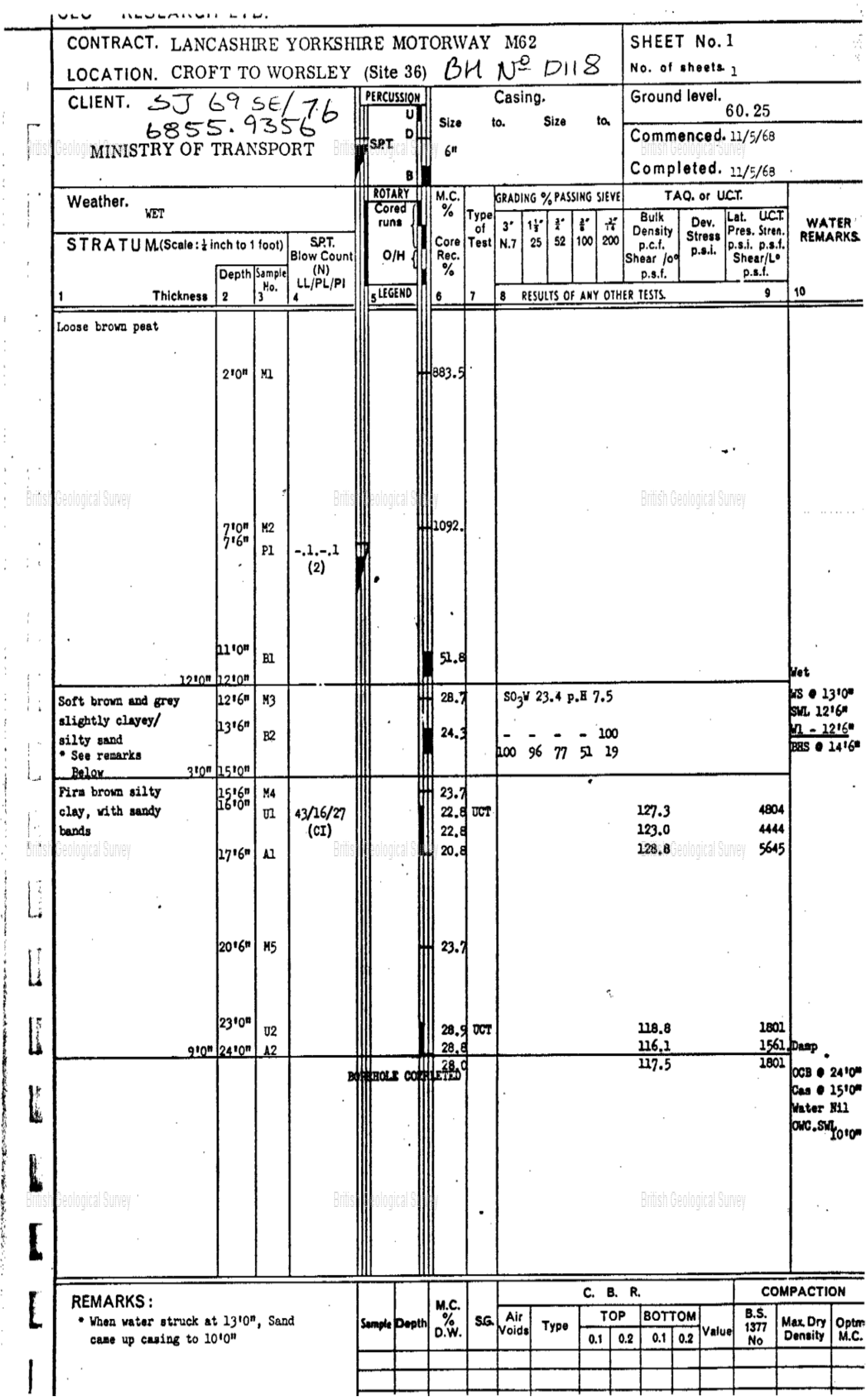
1) Description derived from drillers daily report.
2) Water strike at 6.10m rose to 5.10m BGL (20 minutes).

All dimensions in metres Scale 1:50 | For Explanation of Symbols and Abbreviations see Key Sheets | Checked By: [illegible] | Logged By: A. Latimer | Contract No. 1718

Date Printed:- 03/07/97

Form AEG21/2

Figure A 15: Borehole log SJ69 SE76


CONTRACT. LANCASHIRE YORKSHIRE MOTORWAY M62
LOCATION. CROFT TO WORSLEY (Site 36) BH No D118
SHEET No. 1
No. of sheets 1
CLIENT. SJ 69 SE/76
6855. 9356
MINISTRY OF TRANSPORT
PERCUSSION U D SPT B
Casing. Size to. Size to. 6"
Ground level. 60.25
Commenced. 11/5/68
Completed. 11/5/68
Weather. WET
ROTARY Cored runs O/H
STRATUM (Scale: ¼ inch to 1 foot) Thickness 1 | Depth 2 | Sample No. 3 | S.P.T. Blow Count (N) LL/PL/PI 4 | LEGEND 5 | M.C. % Core Rec. % 6 | Type of Test 7 | 8 GRADING % PASSING SIEVE 3" N.7, 1½" 25, ¾" 52, ⅜" 100, 3/16" 200 — RESULTS OF ANY OTHER TESTS | T.A.Q. or U.C.T. Bulk Density p.c.f. Shear /o° p.s.f., Dev. Stress p.s.i., Lat. Pres. p.s.i., U.C.T. Stren. p.s.f. Shear/L° p.s.f. 9 | WATER REMARKS 10

Stratum	Thickness	Depth	Sample No.	S.P.T. / LL/PL/PI	M.C. %	Type of Test	Results of other tests	Bulk Density	U.C.T.	Water remarks
Loose brown peat		2'0"	M1		883.5					
		7'0"	M2		1092.					
		7'6"	P1	-.1.-.1 (2)						
		11'0"	B1		51.8					
	12'0"	12'0"								Wet
Soft brown and grey slightly clayey/ silty sand * See remarks Below		12'6"	M3		28.7		SO_3 W 23.4 p.H 7.5			WS ● 13'0" SWL 12'6" WL - 12'6" BHS ● 14'6"
		13'6"	B2		24.3		- - - - 100 / 100 96 77 51 19			
	3'0"	15'0"								
Firm brown silty clay, with sandy bands		15'6"	M4		23.7					
		16'0"	U1	43/16/27 (CI)	22.8	UCT		127.3	4804	
					22.8			123.0	4444	
		17'6"	A1		20.8			128.8	5645	
		20'6"	M5		23.7					
		23'0"	U2		28.9	UCT		118.8	1801	
					28.8			116.1	1561	Damp
	9'0"	24'0"	A2		28.0			117.5	1801	OCB ● 24'0" Cas ● 15'0" Water Nil OWC.SWL 10'0"

BOREHOLE COMPLETED

REMARKS:
* When water struck at 13'0", Sand came up casing to 10'0"

Sample | Depth | M.C. % D.W. | S.G. | Air Voids | C. B. R. Type | TOP 0.1 0.2 | BOTTOM 0.1 0.2 | Value | COMPACTION B.S. 1377 No | Max. Dry Density | Optm M.C.

Figure A 16: Borehole log SJ69 SE83

CONTRACT. LANCASHIRE YORKSHIRE MOTORWAY M62
LOCATION. CROFT TO WORSLEY (Site 37) BH No 5696/3
SHEET No. 1
No. of sheets 1
CLIENT. SJ 69 SE /83
6872.9359
MINISTRY OF TRANSPORT
PERCUSSION U D SPT B
Casing. Size to. Size to. 6"
Ground level. 49.03
Commenced. 24/10/67
Completed. 25/10/67
Weather. SHOWERY, FINE
ROTARY Cored runs O/H

STRATUM (Scale: ¼ inch to 1 foot) 1	Thickness	Depth 2	Sample No. 3	S.P.T. Blow Count (N) LL/PL/PI 4	5 LEGEND	M.C. % Core Rec. % 6	Type of Test 7	Grading % passing sieve (3" N.7, 1½" 25, ¾" 52, ⅜" 100, 3/16" 200) 8 Results of any other tests	TAQ or U.C.T. (Bulk Density p.c.f. / Dev. Stress p.s.i. / Lat. Pres. p.s.i. / U.C.T. Stren. p.s.f.; Shear /o° p.s.f.) 9	WATER REMARK 10
Black top soil	2'6"	2'6"								
Soft/firm brown laminated silty mottled clay	2'0"	3'6" 4'6"	U1			30.7 28.2 28.7	TAQ		123.2 / 14.1 / 20 119.5 / 19.5 / 40 120.2 / 19.5 / 60 1282/0°	
Compact clayey sand and gravel	5'6"	5'0" 9'6" 10'0"	A1 P1 B1	6.6.6.6 (24)		23.3 10.1		- 97 94 90 85	SO_3W 13.0 p.H 7.0	WS @ 9'0" SWL 7'0" W1 - 7'0"
Compact brown sand	4'6"	13'6" 14'6"	P2* B2			18.2		35 71 48 26 18		
Very dense sand and gravel	4'0"	15'0" 18'6" 20'0" 23'6" 25'0"	P3 B3 CP4 B4	16.20.32.36 (104) 75 for 11" (total)				100 86 68 48 43 39 32 19 6 4		24/10/67 BH @ 21'0" CAS @ 20'6 SWL 9'0" 25/10/67 SWL 9'0"
Yellow and red sandstone	5'3"	27'6" 30'0" 30'3"	P5 P6 P7	75 for 7½" (total) 75 for 3" (total) 75 for 3" (total)		17.9 10.5 12.2				OCB @ 30'3 Cas @ 25'6 SWL 23'0" OWC.SWL 7'0"
BOREHOLE COMPLETED										

REMARKS:
* Sample P2 Depth 10'0"
Grading Percentage Sieve Analysis
- - - - 100
97 91 58 18 9

Sample	Depth	M.C. % D.W.	S.G.	Air Voids	C.B.R. Type	TOP 0.1	TOP 0.2	BOTTOM 0.1	BOTTOM 0.2	Value	COMPACTION B.S. 1377 No	Max. Dry Density	Opt. M.C.

Annex B: Groundwater level impact maps

The groundwater level difference in each of the three model layers has been mapped for the two Proposed Scheme options as described in Section 5.

Figure B 1: Holcroft Moss impact map for the viaduct option

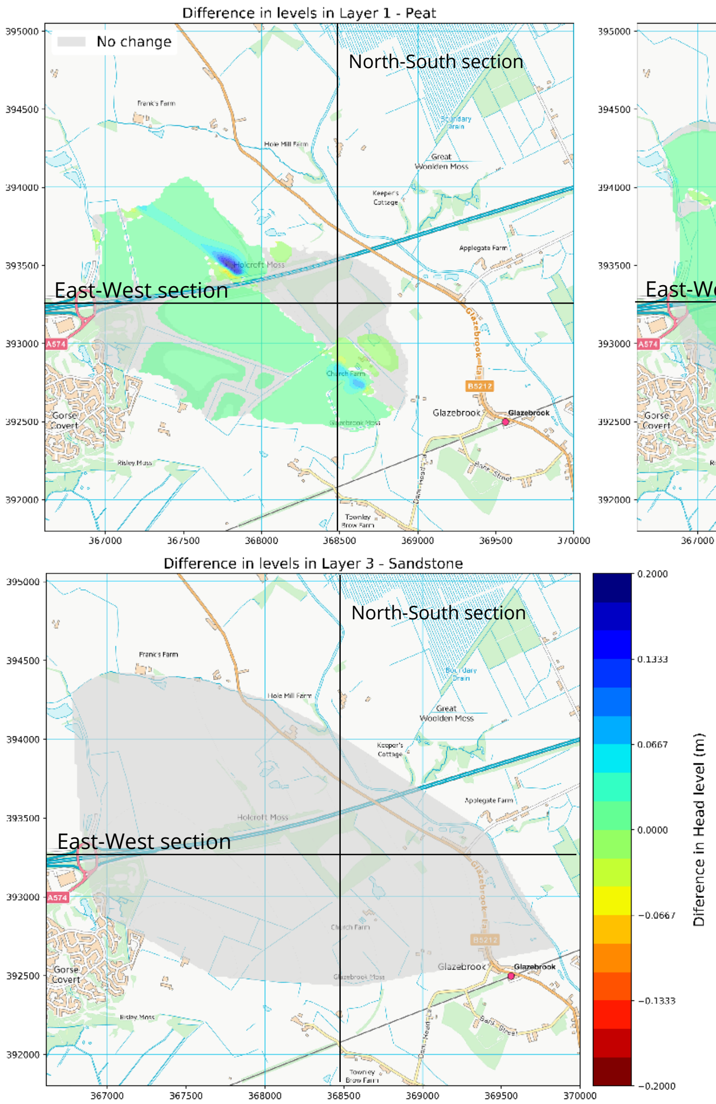


Figure B 2: Holcroft Moss impact map for the full embankment option

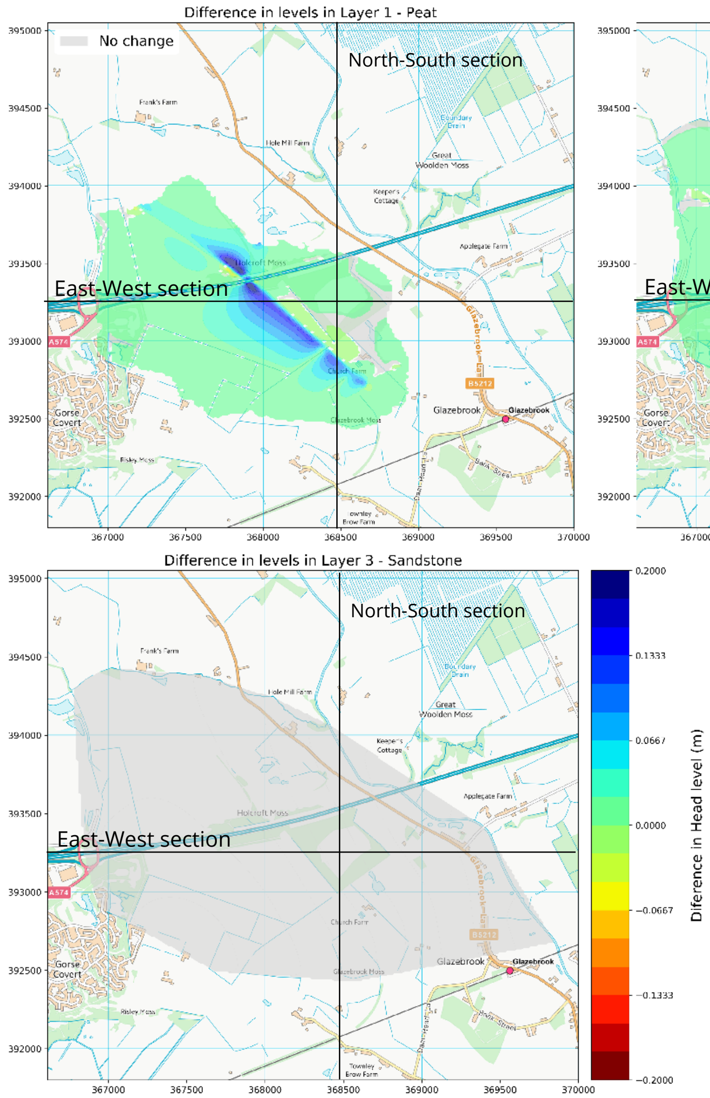
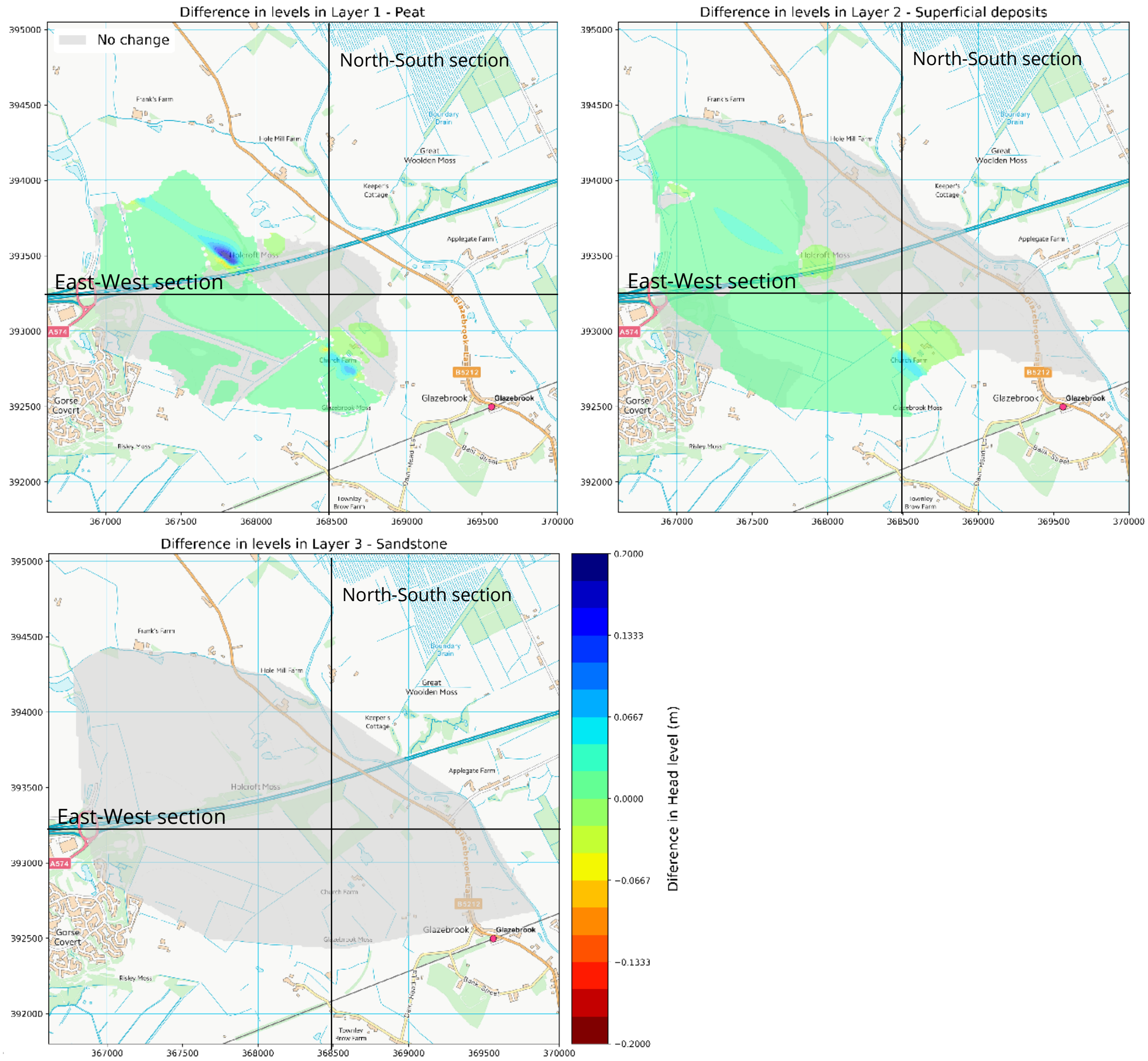


Figure B 3: Holcroft Moss impact map for the viaduct option with gravel trench



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High Speed Two (HS2) Limited
Two Snowhill
Snow Hill Queensway
Birmingham B4 6GA
Freephone: 08081 434 434
Minicom: 08081 456 472
Email: HS2enquiries@hs2.org.uk