High Speed 2 - 1MC06 - Stage One C2 - MWCC –

North Portal of Chiltern Tunnels to Brackley

Twyford Viaduct to Barton Hartshorn Embankment: Hydrogeological Appraisal Report

1MC06-CEK-EV-REP-CS06_CL10-000026

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C03	24/03/2022	S.Bainbridge	A.Cunningham	S.Wilkins	Revised in line with comments	Wendy Hogben
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Stakeholder review required (SRR)	Purpose of SRR
☐ County / District / London Borough Council	☐ Acceptance
☐ LOV	☐ Approval
☐ LUL	☐ No Objection
☐ NRL	☐ Consent
☐ TFL	
☐ Utilities Company	
☐ Other (please specify)	

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Executive Summary

An Eiffage Kier Joint Venture (EK JV) has been awarded the Main Works Civils Contract (MWCC) for the Stage 1 Scheme Design for HS2 Central Contracts C2 and C3. C2 extends 47.5 km from South Heath to Turweston (ch. 47+750 to ch. 95+340). C3 extends 31 km from Brackley to Southam (ch. 95+340 to 126+500). Note that EK JV is now known as Eiffage Kier Ferrovial BAM Nuttall Joint Venture (EKFB JV).

This report identifies risks associated with the Proposed Scheme between Twyford Viaduct and Barton Hartshorn Embankment, chainage (ch.) 82+289 to ch. 87+204 with respect to the groundwater and surface water environments. It also summarises requirements for design associated mitigation with respect to minimising impacts on that water environment. Conversely, the report also highlights the impacts on the proposed works from the water environment. This study area includes ten mainline assets consisting of two cuttings, five embankments and three viaducts. It also includes offline assets comprising one retaining wall, three overbridges and three culverts.

The review of baseline hydrogeological conditions within the study area has identified that the area is underlain by Unproductive Strata (Oxford Clay), Secondary and Unproductive Strata and one Principal Aquifer (White Limestone) within the Great Oolite Group at depth. Groundwater occurrence within the Oxford Clay is expected to be negligible with the formation confining the underlying Great Oolite Group aquifer units.

The planned excavations and cuttings are expected to be largely into the clay dominated, low permeability superficial deposits and Oxford Clay Formation. Planned piling associated with the viaduct and overbridge assets will extend deeper into the Great Oolite Group formations. Assessment of the potential effects on groundwater from the proposed design of mainline and offline assets and structures are summarised as follows:

- Where superficial and shallow formation deposits are dissected by cuttings or shallow excavate and replace, interception of localised groundwater is expected. Because of the low permeability nature of the identified superficial deposits and Oxford Clay that will be excavated, any groundwater inflows are likely to be limited and discontinuous and will likely only require minor slope drainage provision. No special drainage or mitigation measures are envisaged. The proposed cuttings are not expected to cause any significant changes in aquifer groundwater conditions;
- Confined groundwater inflows may occur during excavation at Barton Hartshorn Embankment where excavation depths intersect the CB bedrock. Emplaced fill (density and thickness of deposit) will need to account for potential hydrostatic pressure to prevent uplift;
- Piling is expected to intercept confined groundwater within the Great Oolite Group formations. Artesian conditions are not expected based on the available data, but measures should be available to control the confined groundwater and artesian flows should they be encountered during piling; and
- The pile structures are expected to result in only negligible barrier effects to groundwater flow. Potential long-term contamination risk to groundwater associated with degradation of concrete materials will be mitigated by the selection of appropriate material during scheme design.

Piling risk assessments are currently being undertaken, which will identify risks from the proposed piling and propose appropriate mitigation measures. The assessment has identified that the overall potential risk and impact on the groundwater environment associated with these assets is considered low.

The study area is located within the catchment of the Padbury Brook and its tributaries. There are also numerous lakes, ponds and small drains and ditches within the study area. Assessment of the potential effects on surface water from the proposed design of the mainline and offline structures are summarised as follows:

- The proposed Scheme intercepts the natural runoff catchments of the Padbury Brook and its tributaries. This has the potential to result in a change in the discharge locations and flow rates compared to existing conditions. It is understood that the drainage strategy is such that surface water would be captured by

the drainage network and discharged to the same receiving watercourse as would occur under existing conditions. Therefore, no overall impact on surface water flows in the Padbury Brook and its tributaries is anticipated;

- The Twyford Viaduct, Godington East Viaduct and Godington West Viaduct, as well as neighbouring sections of embankment and are in Flood Zones 3, equivalent to an annual chance of flooding of greater than 1 in 100 (1%). These structures would cause a loss of floodplain storage during extreme flood events. Flood compensation areas (FCAs) have been designed to provide equivalent flood storage area on a level-for-level basis. Bespoke flood modelling undertaken to test the design of the Scheme and associated FCAs showed that the proposed Scheme design would have no significant impact on fluvial flood risk;
- The route will cross tributaries of the Padbury Brook at the Godington West Culvert, Godington East Culvert, and the Barton Hartshorn Culvert. The culverts would convey the design flow, the 1 in 100-year flow plus an allowance for climate change and maintain 1 m freeboard to track level during the 1,000-year flood event. As such, it is considered that the culverts would have a neutral impact on flow and water levels and, therefore, no significant impact;
- Watercourse diversions and realignments associated with the proposed viaducts have the potential to impact the channel hydromorphology and aquatic habitats. It is understood that watercourse diversions/realignments would be designed to replicate the existing channel profiles and morphological characteristics where possible, therefore, it is considered there would be no significant impacts on an individual basis however the Padbury Brook WFD water body has been assessed as Amber risk of deterioration due to cumulative impacts. Further studies may be required alongside ongoing liaison with the Environment Agency during the detailed design stage to confirm this and additional mitigation measures may need to be included to ensure no deterioration of the WFD water body; and
- There is potential for surface water discharges from the track and land drainage systems to impact the water quality of the receiving surface waterbodies. It has been accepted by the Environment Agency that track and land drainage can be assumed to be of rainwater quality, therefore, there would be no significant impact on the receiving waters in normal conditions. Mitigation measures embedded in the drainage design would minimise the risk to water quality in the unlikely event of accidental spillages from the railway and associated infrastructure.

The assessment has identified that the overall potential risk and impact on the groundwater environment associated with these assets is considered low; the potential risk and impact on the surface water environment associated with these assets is considered moderate, however these impacts and risks can be managed via the implementation of appropriate mitigation and design measures.

1 Introduction

1.1 Purpose of this document

An Eiffage Kier Joint Venture (EK JV) has been awarded the Main Works Civils Contract (MWCC) for the Stage 1 Scheme Design for HS2 Central Contracts C2 and C3. C2 extends 47.5 km from South Heath to Turweston (ch. 47+750 to ch. 95+340). C3 extends 31 km from Brackley to Southam (ch. 95+340 to 126+500). Note that EK JV is now known as Eiffage Kier Ferrovial BAM Nuttall Joint Venture (EKFB JV).

This report identifies risks associated with the Proposed Scheme between Twyford Viaduct and Barton Hartshorn Embankment (the "study area") chainage (ch.) 82+289 to ch. 87+204 with respect to the groundwater and surface water environments. It also summarises requirements for design associated mitigation with respect to minimising impacts on that water environment, and mitigation of impacts on the Proposed Scheme from the water environment.

The assessment is based on consideration of the baseline conditions of the relevant surface water and groundwater bodies with respect to the Proposed Scheme design and is based on available information at the time of production of this report.

Previous consideration of groundwater risk under HS2 C23 Stage 1 works led to production of a high-level Red-Amber-Green risk assessment of cuttings and green tunnels to identify areas where groundwater is more likely than not to be affected by the scheme design (green being low risk, red being high risk) [1]. The study area considered in this report was assigned a Green rating under that assessment and so the level of assessment presented in this report is commensurate with that rating.

1.2 Objectives

The objectives of this report are to:

1. Understand the surface water and groundwater regime across the study area;
2. Understand the potential implications to the surrounding environment and surface water and groundwater users that might be caused by Proposed Scheme assets within the study area;
3. Understand the potential constraints to Proposed Scheme assets within the proposed study area in relation to surface water and groundwater; and
4. To suggest mitigation required to minimise any potential implications identified.

Note. This report considers impacts on surface water features and includes a high-level assessment of flood risk. A more detailed assessment of flood risk is provided in standard Flood Level Analysis Reports (FLARs) as referenced throughout.

1.3 Document structure

This report is divided into the following sections:

1. Section 1 – the purpose and structure of this report;
2. Section 2 – an overview of the study area and the Proposed Scheme assets within it;
3. Section 3 – a description of the baseline hydrological and hydrogeological conditions;
4. Section 4 – an assessment of design, groundwater and surface water interdependencies and associated potential impacts;
5. Section 5 – suggested mitigation to be included at detailed design to mitigate any groundwater and surface water or design related impacts; and
6. Section 6 – the conclusions of the report and recommendations for further work if required.

1.4 Review of supporting information

1.4.1 Information sources

The sources of information reviewed for this report and used to establish the design of this section of the HS2 route include:

1. Geotechnical Design Reports (GDR):
    a. Twyford Cutting GDR [2];
    b. Chetwode Cutting GDR [3];
    c. Barton Hartshorn Embankment GDR [4];
    d. Chetwode Embankment GDR [5];
    e. Cowley Embankment GDR [6];
    f. Godington East Embankment GDR [7]; and
    g. Godington West Embankment GDR [8].
2. Ground Investigation Report for C2S3, Section 3 Twyford to Turweston [9];
3. Design Review Report IDR C2-11 [10] and C2-12 [11];
4. Drainage drawings [12];
5. Geotechnical information provided for viaduct piling depths [13] and overbridge piling depths [14]; and
6. Drainage Design Report – Twyford to Turweston [15].

The sources of information reviewed for this report and associated with establishing groundwater conditions includes:

1. The Physical Properties of Major Aquifers in England and Wales. British Geological Survey (BGS), 1997 [16];
2. The Physical Properties of Minor aquifers in England and Wales. BGS, 2000 [17];
3. Environmental Statement. Volume 2. Community Forum Area Report. CFA13 - Calvert, Steeple Claydon, Twyford and Chetwode report [18] and associated water resources assessment [19];
4. Contaminated land GIS shapefile [20];
5. Aylesbury Railway Link and Dismantled Great Central Railway Geoenvironmental Assessment Report [21];
6. The HS2 Technical Standards for Water Framework Directive compliance process [22];
7. Environment Agency Catchment Data Explorer [23];
8. British Geological Survey Geology and Hydrogeology Map Sheets and Lexicon [24] [25];
9. British Geological Survey “Aquifer Designation Map Bedrock” (GIS polygon data for HS2) [26]
10. Groundwater Dependent Terrestrial Ecosystems (England only) [27];
11. Groundwater level monitoring data provided by EK between July 2016 and March 2018 [28]; and
12. Arcadis boreholes, wells, and springs database [29].

The additional sources of information reviewed for this report and associated with establishing surface water conditions includes:

1. Environment Agency Flood Map for Planning (Rivers and Sea) map [30];
2. Environment Agency Main River map [31];
3. Defra MAGIC map [32];
4. Centre for Ecology and Hydrology, Flood Estimation Handbook Web Service [33];

5. Environment Agency Drinking Water Safeguarding Zones and Nitrate Vulnerability Zones [34];
6. Environment Agency River Basin Management Plan Part 1: Anglian River Basin District [35];
7. The London-West Midlands Environmental Statement Volume 5 Technical Appendices CFA13 Calvert, Steeple Claydon, Twyford and Chetwode Water Resource assessment (WR-002-013) [19];
8. HS2 Addendum to Flood Level Analysis Report for the Padbury Brook [36]; and
9. HS2 Addendum to Flood Level Analysis Report for the Tributary of Padbury Brook [37].

1.5 Assumptions and limitations

The assessment presented within this Hydrogeological Appraisal Report (HAR) is based on the ground investigation (GI) data received from HS2 and the ASC Supplementary Ground Investigation (GI). This includes the data received up to the 28th February 2019 (Scheme Design GI cut-off date) and Supplementary GI data available up until September 2021. All available groundwater monitoring data has been considered for this report. Whilst additional GI may have been undertaken since this date, we have taken the view that from a hydrogeological conceptual understanding the data up until that point is largely sufficient. Therefore, the conceptual understanding does not change.

This document considers components of contaminated land reports but does not include a review of land contamination risks, which are reported on separately within geo-environmental reports. The geoenvironmental report for this section is covered in Aylesbury Railway Link and Dismantled Great Central Railway Geoenvironmental Assessment Report [21].

The report has considered the HS2 Scheme Design that has achieved L3 Certificate sign-off obtained in July 2020 ("Scheme Design"). However, the design is subject to change as liaison with the wider design and environmental team is ongoing and further specific mitigation measures will be developed as detailed design progresses and following consultation with the Environment Agency and other key consultees.

2 Study area and asset description

2.1 Study area

The study area for Twyford Viaduct to Barton Hartshorn Embankment is located between ch. 82+289 to ch. 87+204 on the HS2 mainline route, as shown in Figure 1. As defined in the HS2 Phase One Environmental Statement the study area is located within Community Forum Area 13 [18].

The spatial scope of the study area used in this report is generally based on the identification of surface water and groundwater features within 1 km of the centreline of the route. The actual study area used is though subject to the sensitivity of hydrological, geological, and hydrogeological features within it. For example, the study area may be extended in our assessment for key assets where a significant impact is identified or may be reduced where there is clearly no hydraulic connectivity.

2.2 Asset description

2.2.1 Mainline assets

Mainline assets located within the study area are listed in Table 1, in order where they occur from southeast to northwest.

Table 1: Summary of mainline assets within study area

Asset Identification	Legacy Asset ID	Asset Name	Asset Length (m)	Chainage (m)	Max Height/Depth (-m bgl/+m agl)*
HS2-000001046	082-L1	Twyford Viaduct	60	82+289 to 82+351	+5.40 (Viaduct height) -24 (Pile depth)
HS2-000001047	086-L1	Cowley Embankment	396	82+351 to 82+800	5.80/E&R -1.0 m bgl
HS2-000001048	082-L3	Twyford Cutting	1141	82+800 to 83+900	-5.80/ E&R -2.0 m bFL
HS2-000001049	083-L2	Godington East Embankment	184	83+900 to 84+071	4.50/ E&R -2.0 m bgl
HS2-000001050	083-L1	Godington East Viaduct	75	84+071 to 84+146	+4.50 (Viaduct height) -17.20 (Pile depth)
HS2-000001051	083-L2	Godington West Embankment	247	84+146 to 84+393	+4.60/ E&R -2.0 m bgl
HS2-000001052	084-L4	Godington West Viaduct	75	84+393 to 84+468	+5.10 (Viaduct height) - 20.2 (Pile depth)
HS2-000001053	084-L1	Chetwode Embankment	458	84+468 to 84+900	+4.80/ E&R 1.0 m bgl
HS2-000001054	084-L2	Chetwode Cutting	1927	84+900 to 86+880	-8.80/ E&R 2.0 m bFL

Asset Identification	Legacy Asset ID	Asset Name	Asset Length (m)	Chainage (m)	Max Height/Depth (-m bgl/+m agl)*
HS2-000001055	086-L1	Barton Hartshorn Embankment	352	86+880 to 87+185	+4.6/ E&R 2.5 m bgl

**Note: +ve denotes height above existing ground level (track level of embankments and viaducts), -ve denotes depth below existing ground level (cuttings (including Excavate and Replace (E&R) ground improvement measures which includes proposed below track drainage), the base of viaduct piles, or E&R ground improvement works for embankments).*
m bFL= meters below formation level

2.2.2 Offline assets and structures

Offline assets and structures within the study area are detailed in Table 2 (overbridges) and Table 3 (culverts). Infiltration basins and balancing ponds are listed in Table 4. The most pertinent information for each offline asset type is presented below. Locations are shown on Figure 1.

2.2.2.1 Overbridges

Table 2 summarises the overbridges planned across the study area.

Table 2: Summary of overbridges within study area

Asset Identification	Legacy Asset ID	Asset Name	Chainage (m)	Total no. of piles	Max piling depth (m bgl)
HS2-000001320	083-S1	PBI/5A Accommodation Overbridge	83+131	8	16.26
HS2-000001321	085-S3	Footpath CHW/18 Accommodation Overbridge	85+500	8	27.2
HS2-000001322	086-S2	School End Overbridge	86+400	12	14

2.2.2.2 Retaining walls

At the time of writing it is understood that one retaining wall is planned to be located adjacent to pond P-RAI-0840. The asset ID and details of design are unknown. However, it is likely that it would be a retaining wall of vegetated wall system construction (Setec, personal communication, 09/07/2020).

2.2.2.3 Culverts

Table 3 summarises the culverts planned across the study area.

Table 3: Summary of culverts within study area

Asset Identification	Legacy ID	Asset Name	Chainage (m)	Maximum culvert depth (m)	Key culvert features
HS2-000001430	083-S4	Godington East Culvert	84+015	3.0	Box culvert 3 m high by 2.5 m wide. Total length 25.7 m.

Asset Identification	Legacy ID	Asset Name	Chainage (m)	Maximum culvert depth (m)	Key culvert features
					Design includes mammal provision but none for bats.
HS2-000001431	084-S4	Godington West Culvert	84+600	3.0	Box culvert 3 m high by 2.5 m wide. Total length 19.6 m. Design includes mammal and bat provision.
HS2-000001432	087-S3	Barton Hartshorn Culvert	87+070	3.0	Box culvert 3 m high by 2.5 m wide. Total length 21.8 m. Design includes mammal and bat provision.
HS2-00002CW16	-	Offline culvert - Godington West Viaduct Access Drainage System	84+500	-	No details available
-	-	Offline culvert - Unnamed Padbury Brook culvert under maintenance access road	84+450	-	Structure to consist of two 2 m x 1 m box culvert units

2.2.2.4 Balancing ponds and infiltration basins

The Scheme drainage design utilises drainage ponds to manage surface water runoff from track, land and highways. These ponds will either discharge to surface watercourses or to ground, via infiltration.

Table 4 summarises the surface water attenuation ponds planned across the study area [12]. Discharges from attenuation ponds, where connected into the wider drainage system, would be limited to greenfield runoff rates.

There are no infiltration basins or infiltration ponds in the area. They do not form part of the hydrogeological assessment as they are not designed to infiltrate into the ground.

Table 4: Summary of balancing ponds and infiltration basins within study area

Asset Identification	Asset use	Chainage (m)	Pond storage (m^3)	Max depth (m)	Receiving system	Source of runoff
P-RAI-0822	Railway storage pond	82+290	137	2.0*	Padbury Brook	Track drainage
P-RAI-0825	Railway drainage hybrid pond storage	82+600	4242	1.0	Tributary of Padbury Brook	Track and land drainage

Asset Identification	Asset use	Chainage (m)	Pond storage (m^3)	Max depth (m)	Receiving system	Source of runoff
P-RAI-0840(1)	Railway storage pond	83+975	87	0.5	Tributary of Padbury Brook	Track drainage
P-RAI-0840(2)	Railway storage pond	84+050	35	0.5	Tributary of Padbury Brook	Track drainage
P-RAI-0841	Railway storage pond	83+975	34	0.5	Tributary of Padbury Brook	Track drainage
P-RAI-0842	Railway storage pond	84+050	51	0.5	Padbury Brook	Track drainage
P-RAI-0843	Railway storage pond	84+250	280	0.5	Padbury Brook	Track drainage
P-RAI 0844	Railway storage pond	84+250	180	0.5	Padbury Brook	Track drainage
P-RAI 08455	Railway drainage hybrid pond	84+500	102	2.0*	Tributary of Padbury Brook	Track drainage
P-RAI 08458	Railway drainage hybrid pond	84+500	141	2.0*	Padbury Brook	Track drainage
P-RAI-0846	Railway drainage hybrid pond storage	84+840	10198	1.0	Tributary of Padbury Brook	Track and land drainage
P-LAN-0859	Railway drainage hybrid pond storage	85+900	766	0.5	Tributary of Padbury Brook	Land drainage
P-LAN 0868	Land drainage hybrid pond storage	86+880	308	0.5	Tributary of Padbury Brook	Land drainage
P-RAI-0869	Railway drainage hybrid pond storage	86+950	187	0.4	Tributary of Padbury Brook	Track and land drainage
P-LAN-0870	Land drainage hybrid pond storage	86+975	151	0.5	Tributary of Padbury Brook	Land drainage
P-RAI-0870	Railway storage pond	87+000	139	0.5	Tributary of Padbury Brook	Track drainage

Asset Identification	Asset use	Chainage (m)	Pond storage (m^3)	Max depth (m)	Receiving system	Source of runoff
P-RAI-0871	Railway drainage hybrid pond storage	87+150	8516	1.2	Tributary of Padbury Brook	Track and land drainage
P-LAN 0873	Land drainage hybrid pond storage	87+200	973	1.4	Tributary of Padbury Brook	Land drainage

** No information available, depth assumed based on maximum range of pond design*

2.2.2.5 Borrow pits

No borrow pits are proposed within the study area.

2.2.2.6 Underbridges and Underpasses

No underbridges or underpasses are planned within the study area.

2.2.2.7 Flood Storage and Flood Compensation Areas

Six flood compensation areas (FCAs), FCA 34 to FCA 39, were originally proposed at Scheme Design within the study area. Following modelling of the watercourse crossings, it was concluded that FCA 35, located upstream of Godington West Viaduct at approximate chainage 84+300 was not required [36] to mitigate impacts of the proposed scheme. The five remaining FCAs are listed below:

1. FCA 34 is located immediately upstream of the Twyford Viaduct at approximate chainage 82+400. The FCA is located on the northern (left) bank of the Padbury Brook, and between the Padbury Brook and a small tributary to the north. The FCA has a capacity of 19,553 m^3.
2. FCA 36 is located approximately 200 m upstream of the Godington West Viaduct and immediately upstream of the existing (but derelict) railway line and at approximate chainage 84+400. The FCA is located on the southern (right) bank of the Padbury Brook and has a capacity of 56,099 m^3.
3. FCA 37 is located immediately upstream of the Godington West Viaduct at approximate chainage 84+500. The FCA is located on the northern (left) bank of the Padbury Brook, between the Padbury Brook a small tributary to the north. The FCA has a capacity of 17,610 m^3.
4. FCA 38 is located approximately 200 m downstream of Barton Hartshorn Culvert at approximate chainage 86+600. The FCA is located on the eastern (left) bank of a small tributary of the Padbury Brook.
5. FCA 39 is located approximately 200 m upstream of the Barton Hartshorn Culvert at approximate chainage 87+100. The FCA is located between two minor tributaries of the Padbury Brook.

For further information on the FCAs, refer to the Padbury Brook Addendum to FLAR [36] and the Tributary of Padbury Brook Addendum to FLAR [37].

2.2.2.8 Watercourse Diversions

The Twyford Viaduct, Godington East Viaduct and Godington West Viaduct will cross the Padbury Brook. The channel of the watercourse will be realigned to flow perpendicularly beneath the viaduct to facilitate access between the riverbank and viaduct piers.

At the Twyford Viaduct, two tributaries of the Padbury Brook (IDs 05 and 06 shown on the figure in Appendix A) would be diverted around the track embankment and under the viaduct.

A watercourse currently flows southwards along the existing discussed railway embankment at the Barton Hartshorn Embankment. A realignment of this watercourse would be required due to the proposed widening of the embankment structure.

For further details on the watercourse diversions, refer to the Padbury Brook Addendum to FLAR [35] and the Tributary of Padbury Brook Addendum to FLAR [36].

3 Baseline data

3.1 Regional topography

The study area is located approximately 7.5km south west of Buckingham and is largely open and rural, comprising agricultural land interspersed with woodland. The land is gently undulating with an elevation range from approximately 110 m aOD in the north of the study area to 83 m aOD in the central section of the study area. The planned alignment crosses Padbury Brook on three occasions across the central section of the study area. The main topographical features within the study area are presented in Figure 2. The site setting of each asset is summarised below:

1. Twyford Viaduct: The area surrounding the site is the flood plain of the Padbury Brook and its tributaries. The flood plain is in agricultural land which contains minor watercourses and field drains. The area is flat at an elevation of approximately 83 m aOD;
2. Cowley Embankment: The land gently slopes down from east to west with an elevation of approximately 85 m aOD. The village of Twyford is located to the south. Several small holdings exist in proximity including Cowley Old House, Cowley Farm and Twyford Mill;
3. Twyford Cutting: The area is predominantly rural in character comprising agricultural land with the historic village of Twyford to the south. The redundant former Great Central Mail Line (GCML) railway line runs parallel to the HS2 route. The landform is characterised by smoothly undulating low hills and shallow valleys. There is a slight gradient to the north with an elevation of approximately 90 m aOD;
4. Godington East Embankment: Godington East Embankment will be built on the alluvial plain of Padbury Brook which is located immediately to the north of the embankment. The topography is generally flat with an elevation of approximately 85 m aOD. The land use comprises open agricultural fields. The former GCML track bed runs parallel to the location of the proposed embankment;
5. Godington East Viaduct: The topography of the land is generally flat with an elevation of approximately 85 m aOD. The area either side of the structure is a floodplain;
6. Godington West Embankment: Godington West Embankment will be built on the alluvial plain of Padbury Brook which meanders either side of the embankment. The topography is generally flat with an elevation of approximately 86 m aOD. The land use comprises open agricultural fields. The former GCML track bed runs parallel to the location of the proposed embankment;
7. Godington West Viaduct: The topography of the land is generally flat with an elevation of approximately 89 m aOD. The area either side of the structure is a floodplain;
8. Chetwode Embankment: Chetwode Embankment is located on the alluvial flood plain on the north side of the Great River Ouse Valley. The land slopes gently to the south with an elevation of approximately 87 m aOD;
9. Chetwode Cutting: Comprises gently undulating agricultural land. The land slopes gently to the south with an elevation of approximately 94 m aOD. The village of Chetwode is located to the northeast and several farm buildings are situated in proximity. These include Rosehill Farm, Sunflower Farm, Manthorn Farm, Barton Hill Farm; and
10. Barton Hartshorn Embankment: The land generally comprises open fields used for agricultural purposes with a small dense area of woodland and a small lake just south of the wooded area. The land slopes gently to the north with an elevation of approximately 101 m aOD. The disused GCML railway line runs parallel to the HS2 route in this location.

3.2 Geology and hydrogeology

3.2.1 Geology

3.2.1.1 Superficial geology

Mapped superficial deposits present across the study area are shown on Figure 3. The superficial deposits include the following units are discontinuous across the study and overall comprise the following:

1. Alluvium (ALV): clay, silt, sand and gravel. They occur to the south of the study area, at ch. 84+500 and intercepting Barton Harston Embankment;
2. River Terrace (RTD) deposits: sand and gravel fluvial deposits. They occur to the south of the study area and at ch. 84+500;
3. Glacial Till (TILMP): glaciogenic deposits, Pleistocene till, diamicton. Intercepts the Scheme between ch. 85+000 and 86+700; and
4. Glaciofluvial deposits (GFDMP): sand and gravel, Mid Pleistocene deposits. They are present within 1 km of the route and intercept the Scheme at ch. 86+500.

3.2.1.2 Bedrock geology

The mapped bedrock geology within the study area is underlain by the Oxford Clay Formation, the Kellaways Formation and thereafter formations belonging to the Great Oolite Group as detailed in Table 5. The Great Oolite Group component formations (Cornbrash Formation, Forest Marble Formation, White Limestone Formation, Rutland Formation, Taynton Limestone Formation and Sharp's Hill Formation) are individually identified where possible otherwise the definition Great Oolite Group Undifferentiated (GOG) has been applied. A geological map for the area is presented in Figure 4. Geological cross sections of bedrock and superficial geology are presented in Figure 5a-d; the section was produced from the ground investigation data and includes borehole and groundwater information. The geological formations dip gently to the south; the Oxford Clay Formation and the Kellaways Formation are absent across the northern portion of the study area and the Cornbrash Formation is directly present below the superficial deposits in this area.

As shown in Figure 5a, the RLD, TY and SHHB occur in the northern portion of the study area at depth (20 m bgl+) and are not expected to be affected by the planned works. As such these formations are not detailed further within this report.

Table 5: Summary of the bedrock geology within study area

Mapped unit (chronological order)	Component Formation	Description
Oxford Clay Formation	OXC	Silicate-mudstone, grey, generally smooth to slightly silty, with sporadic beds of argillaceous limestone nodules.
Kellaways Formation	KLB	Mudstone, grey, commonly silici-silty, or silici-sandy, with (predominantly in the upper part) beds of generally calcareous siltstone and sandstone.
Cornbrash Formation	CB	Limestone, medium- to fine-grained, predominantly bioclastic wackestone and packstone with sporadic peloids.
Forest Marble Formation	FMB	Silicate-mudstone, greenish grey, variably calcareous and in the south notably sandy, with lenticular typically cross-bedded limestone units that form banks and channel-fills, especially in lower part.

Mapped unit (chronological order)	Component Formation	Description
White Limestone	WHL	A pale grey to off-white or yellowish limestone, peloidal wackestone and packstone with subordinate ooidal and shell fragmental grainstone; with recrystallised limestone and/or hardgrounds at some levels with rare sandy limestone, muddy limestone, calcareous mudstone, and silicate mudstone/clay.
Rutland Formation	RLD	Grey marine mudstone passing up into non-marine mudstone and siltstone.
Taynton Limestone Formation	TY	White to pale brown, typically well-sorted medium- to coarse-grained, moderately to highly shell-detrital ooidal grainstone.
Sharp's Hill Formation	SHHB	Varied sequence of greenish grey, silty, moderately shelly, and calcareous mudstones, pale greenish grey shelly marls, and fine-grained shelly limestones.

3.2.1.3 Geology by asset

Table 6 summarises the superficial deposits and bedrock units encountered during the ground investigation across the study area in relation to each asset.

Table 6: Geological summary in relation to each asset

Asset	Superficial deposits	Bedrock
Twyford Viaduct	Up to 3 m thick ALV underlain by up to 1.5 m RTD.	Comprises clays of the OXC (approximately 7m thick) underlain by the KLB Formation (7 m thick). CB typically 3 m thick (approx. 19.5 m bgl+ at base) FMB typically 4.5 m thick. (approx. 24 m bgl+ at base) WHL 10+m thick and 34 m bgl+ at base
Cowley Embankment	The GI established ALV deposits, (approximately 1m thick) between ch. 82+349 and ch. 82+650 and RTD (approximately 1-2 m thick).	Weathered and unweathered clays of the OXC (typically 7 m thick), overlying rocky unit of the KLB (7 m thick). GOG undifferentiated (limestones and siltstones) with typical thickness of 24 m+
Twyford Cutting	None present beneath asset	The underlying solid geology comprises weathered and then firm to stiff laminated clays of the OXC up to 13 m thick. KLB 5 m thick (18 m bgl+ at base) CB typically 3 m thick (21 m bgl+ at base) FMB typically 3 m thick (24 m bgl+ at base) WHL typically 15 m+ thick and 39 m bgl+ at base

Asset	Superficial deposits	Bedrock
Godington East Embankment	The GI established drift deposits comprise ALV and RTD (typically around 4 m thick) comprising firm to stiff clays and medium dense gravelly sands, respectively	The underlying solid geology comprises firm to stiff clays of the OXC (typically 1 m thick) underlain by clayey sand and gravels and stiff clays of the KLB Formation (up to approximately 5 m thick). CB typically 4 m thick (14.3m bgl+ at base) FMB typically 3 m thick (17.3m bgl+ at base) WHL typically 13 m thick (28.3mbgl+ at base) RLD typically 5 m+ thick (28.3mbgl+ at base)
Godington East Viaduct	Up to 2 m thick ALV underlain by up to 1.5 m RTD,	Comprises clays of the OXC (approximately up to 1.5 m thick) underlain by the KLB Formation (5 m thick). CB up to approx. 4 m thick (approx. 13.5 m bgl+ at base) FMB up to approx. 3 m thick. (approx. 17 m bgl+ at base) WHL 10+m thick and 27 m bgl+ at base
Godington West Embankment	The GI established drift deposits comprise ALV and RTD (typically around 2 m thick) comprise firm to stiff clays and medium dense gravelly sands.	The underlying solid geology comprises soft to firm clays of the OXC (typically up to 3m thick and base at 4.3mbgl) underlain by sandy gravels of the KLB (typically 5m thick and base approximately 9.3m). CB typically 3.5 m thick (12.8 m bgl+ at base) FMB typically 3 m thick (15.8 m bgl+ at base) WHL typically 16 m+ thick and 31.8 m bgl+ at base
Godington West Viaduct	Up to 2m thick ALV underlain by less than 1m thick RTD.	Comprises clays of the OXC (approximately up to 3m thick) underlain by the KLB Formation (up to 6m thick). CB up to approx. 4 m thick (approx. 13.5 m bgl+ at base) FMB up to approx. 3 m thick. (approx. 16 m bgl+ at base) WHL 10+m thick and 26 m bgl+ at base
Chetwode Embankment	The GI established ALV and RTD deposits, (typically around 2.5 m thick) comprising firm to soft clays and medium dense gravelly sands,	Comprises firm to stiff clays of OXC (typically 2.5 m thick) underlain by clayey sand and gravels and stiff clays of the KLB (about 5 m thick). This is underlain by the GOG Formation (15 m+ thick) with base at 20 m+ bgl.
Chetwode Cutting	The GI established TILMP and GFDMP deposits with 4m average thickness where present.	Comprises clay and mudstones units of the OXC (typically 11 m thick) and KLB (typically 4 m thick) comprising alternating slightly sandy clays and extremely weak thinly laminated mudstones, with some sands and sandstones beds
Barton Hartshorn Embankment	GI established up to 2.5m ALV (silty to sandy clay) and up to 4m TILMP (slightly gravelly slightly sandy silts/clays)	KLB up to 2m thick (base 6mbgl) although absent from the northern portion of this asset. CB typically 3m thick (9m bgl at base) FMB typically 3.3m thick (12m bgl+ at base) WHL typically 10m+ thick (22mbgl+ at base)

3.2.2 Hydrogeology

3.2.2.1 Aquifer status

A hydrogeological map for the study area is presented in Figure 6 and aquifer designations are presented in Figure 7 (superficial deposits) and Figure 8 (bedrock geology). The aquifer status of the superficial deposits is classified by the BGS [26] as “Secondary A”. Bedrock deposits present within the study area are classified by the BGS [26] as “Principal” aquifer, “Secondary A” aquifer, “Secondary B” aquifer and “Unproductive” strata.

The aquifer types are defined as follows:

- Principal Aquifer: These are layers of rock or drift deposits that have high intergranular and/or fracture permeability - meaning they usually provide a high level of water storage. They may support water supply and/or river base flow on a strategic scale. In most cases, principal aquifers are aquifers previously designated as major aquifer;
- Secondary A Aquifer: These are permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers. These are generally aquifers formerly classified as minor aquifer;
- Secondary B Aquifer: predominantly lower permeability layers which may store and yield limited amounts of groundwater due to localised features such as fissures, thin permeable horizons, and weathering. These are generally the water-bearing parts of the former non-aquifers;
- Secondary (Undifferentiated): has been assigned in cases where it has not been possible to attribute either category A or B to a rock type. In most cases, this means that the layer in question has previously been designated as both minor and non-aquifer in different locations due to the variable characteristics of the rock type; and
- Unproductive Strata: These are rock layers or drift deposits with low permeability that have negligible significance for water supply or river base flow.

The aquifer classification status by the BGS in relation to each of the assets within the study area are detailed in Table 7.

Table 7: Aquifer designation summary in relation to each asset

Asset	Aquifer status - superficial deposits	Aquifer status - bedrock
Twyford Viaduct	ALV – Secondary A Aquifer RTD - Secondary A Aquifer	OXC – Unproductive strata KLB – Secondary A Aquifer CB – Secondary A Aquifer FMB – Secondary A Aquifer WHL - Principal Aquifer
Cowley Embankment	ALV – Secondary A Aquifer RTD - Secondary A Aquifer	OXC – Unproductive strata GOG - Secondary B Aquifer
Twyford Cutting	Absent	OXC – Unproductive strata GOG - Secondary B Aquifer
Godington East Embankment	ALV – Secondary A Aquifer RTD - Secondary A Aquifer	OXC – Unproductive strata KLB – Secondary A Aquifer CB – Secondary A Aquifer FMB – Secondary A Aquifer WHL - Principal Aquifer

Asset	Aquifer status - superficial deposits	Aquifer status - bedrock
Godington East Viaduct	ALV – Secondary A Aquifer RTD - Secondary A Aquifer	OXC – Unproductive strata KLB – Secondary A Aquifer CB – Secondary A Aquifer FMB – Secondary A Aquifer WHL - Principal Aquifer
Godington West Embankment	ALV – Secondary A Aquifer RTD - Secondary A Aquifer	OXC – Unproductive strata KLB – Secondary A Aquifer CB – Secondary A Aquifer FMB – Secondary A Aquifer WHL - Principal Aquifer
Godington West Viaduct	ALV – Secondary A Aquifer RTD - Secondary A Aquifer	OXC – Unproductive strata KLB – Secondary A Aquifer CB – Secondary A Aquifer FMB – Secondary A Aquifer WHL - Principal Aquifer
Chetwode Embankment	ALV – Secondary A Aquifer RTD - Secondary A Aquifer	OXC – Unproductive strata KLB – Secondary A Aquifer CB – Secondary A Aquifer FMB – Secondary A Aquifer WHL - Principal Aquifer
Chetwode Cutting	TILMP/GFDMP - Secondary A Aquifer	OXC – Unproductive strata KLB – Secondary A Aquifer CB – Secondary A Aquifer FMB – Secondary A Aquifer WHL - Principal Aquifer
Barton Hartshorn Embankment	ALV – Secondary A Aquifer TILMP - Secondary A Aquifer	KLB – Secondary A Aquifer CB – Secondary A Aquifer FMB – Secondary A Aquifer WHL - Principal Aquifer

No Environment Agency published source protection zones exist in proximity to the study area.

3.2.2.2 Aquifer properties

The alluvium is classified as a Secondary A Aquifer, however due to the heterogeneous nature of the deposits permeabilities can range from highly permeable to effectively impermeable depending on the lithology [38]. As such there are no published values for these deposits. The GI data between ch.82+000 and ch. 86+999 includes 162 field description entries for alluvium, 144 of which are recorded as 'clay'; The clay-dominated nature of the alluvium means that groundwater flow will be limited.

The OXC is the shallowest formation that will principally be affected by the planned works and is classified as Unproductive status. Limited published data is available for this formation, but the available data indicates that low permeability conditions will predominate across the OXC.

The KLB is classified as a Secondary A aquifer. Published hydraulic conductivity measurements indicate the formation's productivity is variable subject to the local geological conditions. The underlying Great Oolite Group formations are more productive; Table 8 summarises the available published data for these formations. No data is available for the shallow superficial deposits.

Table 8: Summary of hydraulic parameters from the BGS Minor Aquifers Manual and Major Aquifers Manual

Formation	Porosity	Hydraulic conductivity (m/d)	Transmissivity (m^2/d)	Storage
KLB	4.3 – 43%	5.5^{-6} to 2.5×10^{-2}	Unknown	Unknown
CB	5.8%	7.6×10^{-5} to 1.7	Unknown	2.2×10^{-6} to 2.2×10^{-2}
FMB	Not available	Not available	20 – 35.3	1.0×10^{-3} to 0.16
WHL	No published hydraulic parameter values are available for the specific WHL unit. However bulk values for the Great Oolite Group are extremely wide ranging controlled by the presence/absence of fractures within the limestone units; a measured hydraulic conductivity range of 2×10^{-4} to 1×10^{4}m/d illustrates the variability.			

In-situ testing, predominantly falling head tests, have been undertaken for superficial deposits and OXC at various locations along the route. The results of these tests between ch.82+000 and ch.87+000, which includes all locations within the study area plus some additional locations to the north and south, are summarised in Table 9. Results for these strata indicate that low permeability conditions prevail across the tested formations. No permeability tests were undertaken within formations other than those listed below across the study area.

Table 9: In-situ testing summary

Geology	Locations	Number of tests	Range in permeability values (m/d*)	Geometric mean of permeability (m/d*)
TOPSOIL	ML082-WS004 ML082-WS010	1	2.76×10^{-2} to 6.65×10^{-2}	4.29×10^{-2}
TILMP	ML084-WS007 ML085-WS005 ML085-WS009 ML086-CR400 ML086-WS008 ML086-WS013 ML086-WS014 ML087-WS005	1 all boreholes 2 in ML086-CR400	4.75×10^{-5} to 4.15×10^{-2}	1.40×10^{-3}
GFDMP	ML087-WS009	1	5.44×10^{-3}	n/a
OXC	ML083-WS002 ML083-WS004	5 falling head tests 1 rising head test in ML086-CR400	4.75×10^{-5} to 1.81×10^{-1}	2.94×10^{-3}

Geology	Locations	Number of tests	Range in permeability values (m/d*)	Geometric mean of permeability (m/d*)
	ML083-WS005 ML083-WS007 ML083-WS012 ML086-CR400			
KLB CB FMB WHL RLD TY SHHB	None	n/a	n/a	n/a

Notes:
**Converted from m/s to m/d for consistency throughout report.*

3.2.2.3 Groundwater occurrence and flow

Maximum and average groundwater levels for borehole locations produced from the ground investigation are provided in Table 10. Average groundwater levels range from approximately 0.05 m bgl to 19 m bgl. These are shown plotted on the long sections in Figure 5a-d, along with the locations of screened intervals in each borehole.

The long sections also show the elevation of the proposed rail level, the maximum potential excavation depth reached for each asset (assumed across the whole length of the asset), and maximum piling depths. Given the linear nature of GI monitoring points it is not possible to accurately provide a groundwater contour plan due to the large degree of interpolation outside of the immediate line of monitoring. The available data suggests that groundwater flow directions broadly follow topographical gradients.

Hydrographs of all available groundwater levels recorded at ground investigation locations between June 2017 and September 2021 are presented in Figure 9a-d

Superficial deposits

Groundwater flow through the superficial deposits will be limited due to the largely clay dominated nature of the deposits. Intergranular flow will occur through the ALV and RTD where locally present. It is likely that shallow perched groundwater will occur in more permeable shallow superficial deposits present across lower permeability deposits in localised areas; shallow groundwater levels within the GFMP at approximately ch. 85+350 are likely to be perched within these superficial deposits.

Bedrock

Due to the clay-dominated nature of the OXC, groundwater levels from boreholes installed within this formation are unlikely to represent a continuous coherent groundwater level across the area but rather an indication of shallow localised perched groundwater levels. Where sharp rises in groundwater levels are recorded in Figure 9 at boreholes screened in the OXC, these are likely to represent water seepages into the boreholes from the surrounding poorly connected pore space in the OXC, filling the borehole standpipe with water towards ground surface.

Groundwater occurrence and flow through the OXC is expected to be negligible due to the extremely low hydraulic conductivity and cohesive nature of the formation. Some intergranular groundwater flow can be expected through the underlying KLB although this will be controlled by the sand content of the formation in the area which is understood to be regionally variable.

Groundwater flow through the underlying Great Oolite Group (GOG) formations in this area will be controlled by the extent of secondary permeability development present within the limestone units. Where fracturing is developed this will likely result in high permeability conditions with interbedded low permeability units potentially acting as leaky aquifer units. The WHL Principal Aquifer is likely to be the most productive aquifer within the study area.

For this study it is assumed that the GOG formations are in hydraulic continuity and are confined by the overlying OXC and KLB as detailed further in Section 3.4. The inferred potentiometric surface of the GOG is presented on Figure 5a to Figure 5d.

Regional groundwater level monitoring by the EA c. 3.5km to the east, within the White Limestone, at Fringford and c. 32km to the southeast, in the Chalk, in the Missenden Valley have been reviewed to put the 2020 seasonal groundwater level variations into a longer inter-annual context (see Appendix B). Clear multiannual trends are present that are consistent between both the Chalk and White Limestone with noticeable groundwater level highs in Spring 2001 and Spring 2014. The regional groundwater levels in 2021 are the highest since the Spring of 2014 and are the third highest in the last 30 years. More recently, a typical groundwater level period is seen throughout 2016/2017 and a low groundwater level period is seen throughout 2019. This shows that the recent site-specific monitoring data collected between June 2017-September 2021 covers a period of regionally average groundwater levels with:

- the data recovered during October 2018-October 2019 covering a low groundwater level period;
- the data recovered during 2021 covering a high groundwater level period.

The data therefore represents likely extremes.

Table 10: Groundwater levels recorded at GI locations within the study area (ch. 82+000 to 87+000 inclusive)

Location ID	Borehole Depth (m bgl)	Final Depth (m aOD)	Geological Unit Screened in	Ground Level (m aOD)	Number of readings	Average groundwater level (m bgl)	Maximum groundwater level (m bgl)
ML082-CO407	35	48.02	Alluvium to 'Grey Clay' (Drillers description)	83.02	1 (+1 dry)	82.52	82.52
ML082-CP016	10	73.97	RTD to OXC	83.97	15 (+1 dry)	83.09	83.27
ML082-CR002	35	47.99	OXC	82.99	10	82.73	82.99
ML082-CR003	35.1	47.87	OXC	82.97	16	82.06	82.87
ML082-CR006	30	57.5	CB to WHL	87.5	15	80.70	80.9
ML082-CR008	25	58.97	KLB*	83.97	15	81.50	82.5
ML082-CR400 (1)	35.5	47.25	Alluvium to OXC	82.75	3	78.09	78.14
ML082-CR400 (2)	35.5	47.25	OXC to KLB	82.75	3 dry	All dry	All dry
ML082-CR402a	30.6	55.55	Till to OXC	86.15	9	85.49	85.64
ML082-CR403 (1)	29.9	58.76	OXC	88.66	7	86.29	86.82
ML082-CR403 (2)	29.9	58.76	Alluvium	88.66	2 (+2 dry)	87.41	87.55
ML082-CR410	35	48.51	OXC to KLB	83.51	3	83.06	83.19
ML082-CR419	15	68.12	Alluvium to RTD	83.12	8 (+1 dry)	82.02	82.52
ML082-CR437	30	53.21	Alluvium to CB	83.21	7 (+1 dry)	82.85	83.16
ML082-RC012	10	79.83	OXC	89.83	15 (+1 dry)	88.65	89.2
ML083-CP416 (1)	9.24	76.65	OXC	85.89	6 (+1 dry)	85.64	85.81
ML083-CP416 (2)	9.24	76.65	OXC	85.89	11 (+1 dry)	85.33	85.55
ML083-CR003	25.2	60.42	RLD	85.62	16	82.86	83.3
ML083-CR004	30	60.78	KLB	90.78	15	85.32	85.52

Location ID	Borehole Depth (m bgl)	Final Depth (m aOD)	Geological Unit Screened in	Ground Level (m aOD)	Number of readings	Average groundwater level (m bgl)	Maximum groundwater level (m bgl)
ML083-CR400	40.3	51.83	OXC	92.13	11 (+1 dry)	90.60	90.99
ML083-CR401	30.6	61.52	Alluvium to OXC	92.12	8 (+1 dry)	90.79	91.96
ML083-CR410	20	75.2	OXC	95.2	9	94.09	94.85
ML084-CP021	9.5	77.64	OXC to KLB	87.14	16	86.81	87.14
ML084-CP439	11.05	76	OXC	87.05	9	86.52	87.05
ML084-CP441	10.78	77.46	OXC	88.24	3 (+1 dry)	87.65	87.78
ML084-CP445a (1)	13.15	77.21	OXC	90.36	10 (+1 dry)	88.68	88.92
ML084-CP445a (2)	13.15	77.21	OXC	90.36	10 (+1 dry)	89.52	89.8
ML084-CR003	35	50.59	WHL to TY	85.59	16	83.67	84.52
ML084-CR005	35.7	50.31	FMB to WHL	86.01	16	83.09	83.33
ML084-CR008	30	56.1	RLD	86.1	17	83.58	85.93
ML084-CR406	30	55.83	KLB	85.83	11	85.29	85.67
ML084-CR408	30	55.91	CB to FMB	85.91	10	85.35	85.91
ML084-CR409	30	55.97	OXC to KLB	85.97	10	85.58	85.81
ML084-CR412	30	57.72	Alluvium	87.72	3 (+1 dry)	87.24	87.63
ML084-CR413	30	58.48	WHL	88.48	6 (+1 dry)	87.95	88.38
ML085-CP007	15	89.72	Glaciofluvial deposits to OXC	104.72	14 (+1 dry)	99.00	100.12
ML085-CR004	34.9	67.89	KLB to CB	102.79	16	92.91	93.23
ML085-CR008	30	71.45	OXC to KLB	101.45	15	93.30	93.67
ML085-CR009	20	84.87	OXC to KLB	104.87	15	94.89	95.53
ML085-CR400 (1)	40.1	63.83	Till to OXC	103.93	2	98.59	100.25

Location ID	Borehole Depth (m bgl)	Final Depth (m aOD)	Geological Unit Screened in	Ground Level (m aOD)	Number of readings	Average groundwater level (m bgl)	Maximum groundwater level (m bgl)
ML085-CR400 (2)	40.1	63.83	Head	103.93	1	96.92	96.92
ML085-CR401 (1)	40	63.16	KLB to FMB	103.16	5	92.35	94.76
ML085-CR401 (2)	40	63.16	Alluvium	103.16	5	100.19	101.08
ML085-CR414 (1)	30	73.68	OXC	103.68	12 (+1 dry)	99.23	101.52
ML085-CR414 (2)	30	73.68	Glaciofluvial deposits	103.68	4 (+7 dry)	101.22	101.52
ML085-RC009	20	83.83	Till to Glaciofluvial deposits	103.83	15	100.25	100.73
ML085-RO411 (1)	30	74.41	CB to FMB	104.41	14	93.15	93.31
ML085-RO411 (2)	30	74.41	Till to Clay (Drillers description)	104.41	15	101.33	101.81
ML086-CP413	15	91.85	Till to Glaciofluvial Deposits	106.85	8	103.12	103.4
ML086-CR005	40	69.54	FMB to WHL	109.54	14 (+1 dry)	95.55	97.03
ML086-CR007	30	69.08	CB to WHL	99.08	16	98.80	99.08
ML086-CR009	20	86.19	OXC to KLB	106.19	19	95.16	95.51
ML086-CR010	30	76.63	KLB to FMB	106.63	16 (+1 dry)	94.71	95.62
ML086-CR014	30	79.41	KLB to CB	109.41	15 (+1 dry)	97.02	97.51
ML086-CR401	30	75.28	Till	105.28	4	101.77	102.51
ML087-CP009	2.8	96.47	Alluvium to CB	99.27	16	98.18	98.58
ML087-CR444 (1)	20.25	85.71	CB to FMB	105.96	7 (+2 dry)	98.10	98.16
ML087-CR444 (2)	20.25	85.71	Made Ground	105.96	6 (+2 dry)	104.24	105.29
ML087-WS007	2.5	96.03	Till to KLB	98.53	18	97.95	98.48

3.2.2.4 Rainfall and recharge

Monthly rainfall data is available from the Met Office for the Oxford monitoring station (the closest station to the study area, approximately 26 km to the southwest). Rainfall data is available for the period 1853 to 2020. Of approximately 2009 readings, the monthly total rainfall values vary between 0.5 mm and 193 mm with the average monthly total rainfall rate at approximately 55 mm. Annual rainfall values vary between 379 mm (recorded in 1921) and 965 mm (recorded in 1960) with an average annual rainfall rate of approximately 655 mm/year.

Due to the clay dominated superficial strata and widespread OXC across the study area it is assumed that aquifer recharge will be limited, with potentially increased recharge rates in localised areas with outcrops of relatively high permeability subunits within the clay. The GOG formations may be subject to higher aquifer recharge rates in the northern portion of the study area where OXC and KLB are absent although recharge will be controlled by the thickness and nature of the superficial deposits in this area.

3.2.2.5 Regional groundwater resource status

The route section within the study area crosses one Water Framework Directive (WFD) groundwater body, as shown in Figure 10. The WFD body risk of deterioration and classification in relation to each asset is summarised in Table 11 and is correct at the time of this report.

Table 11: WFD groundwater body details

Asset	Groundwater WFD body	HS2 WFD Groundwater Risk of Deterioration [39]	EA WFD Cycle 2 classifications 2019 Overall Classification [40]	Notes
Barton Hartshorn Embankment	Upper Bedford Ouse Oolite Secondary	Yellow	Good	Effect insufficient to affect element at water body scale. Risks not considered further.
Chetwode Cutting				
Rating system is, in order of best to worst quality; Green, Yellow, Amber, Red.				

The WFD risk of deterioration, as taken from the HS2 Water Framework Directive Compliance Process Technical Standard [27], are defined as follows:

- Green: no measurable change to (or effect on) water body (certain);
- Yellow: minor localised and/or temporary effect when balanced against likely embedded mitigation – insufficient to affect an element at a water body scale (certain);
- Amber: an adverse effect is possible when balanced against likely embedded mitigation – the extent of effect is uncertain, and there remains a potential to affect water body status (uncertain); and
- Red: adverse effect of sufficient scale to impact on a quality element at a water body scale (certain).

The Upper Bedford Ouse Oolite Secondary groundwater body (GB40502G401300) is a Drinking Water Protected Area. The Environment Agency state "*the Secondary Oolite is largely confined across the outcrop by low permeability superficial drift cover. In the absence of low permeability drift, usually in the river valleys where the rivers have incised through the drift, the aquifer is vulnerable to polluting activities on the surface.*" The water body was last assessed in the 2019 Water Framework Directive (WFD) Cycle 2 classification where it had an overall status of Good [23].

3.2.2.6 Groundwater quality

A geo-environmental assessment was undertaken for areas of land across the study section related to the dismantled Great Central Main Line (GCML). The GCML runs sub-parallel to the planned new rail alignment at between 50 m and 200 m. The GCML crosses the new rail alignment in the northern portion of the study area at the Barton Hartshorn Embankment. The geo-environmental assessment is detailed in the following report:

- Ch. 80+100 and ch. 88+000, *[Aylesbury Link and Dismantled Great Central Railway Geo-Environmental Assessment Report]* [21].

Reference to the report should be made for detailed findings; a summary of the results of the geo-environmental assessments undertaken in the study area is presented in Table 12.

The assessment appears to show a moderate/low risk to controlled waters with further groundwater sampling and testing ongoing to target the contaminative sources. Pending the outcome of the ongoing testing, remediation may be required

Note: the geo-environmental report has not yet been finalised and at time of writing has not yet been issued. Any fundamental changes to the conclusions of that report may differ to that presented here. Reference should therefore be made to the geo-environmental report once formally approved and issued.

Table 12: Summary of geo-environmental assessments in study area

Site / Asset	Ground investigation	Geology encountered during GI	Groundwater encountered during GI	Contamination encountered during GI
All assets across study area. Aylesbury Link and Dismantled Great Central Railway Geo-Environmental Assessment Report	• 36 cable percussion boreholes drilled to a maximum depth of 15 m bg ; • 16 cable percussion with follow-on rotary cored boreholes to a maximum depth of 40.55 m bgl; • 24 cone penetration tests (CPT) advanced to a maximum depth of 21.05 m bgl; • 21 inspection pits (IP) excavated to a maximum depth of 1.5 m bgl; • 10 pavement cores excavated to a maximum depth of 0.3 m bgl; • 11 rotary cored boreholes drilled to a maximum depth of 35.2 m bgl; • 8 trial pits excavated to a maximum depth of 4 m bgl; and • 88 dynamic (windowless) sample holes drilled to a maximum depth of 8.2 m bgl.	In terms of superficial deposits: Ground conditions encountered during the investigation comprised predominantly Topsoil underlain by superficial deposits which included Alluvium, Head and Till. Made Ground was encountered at 26 locations within roads and agricultural fields as well as along the track within the western LOD of the Bridleway QUA/28A Overbridge at ch.72+950 In terms of bedrock: West Walton Formation and Oxford Clay were encountered.	Groundwater was encountered as strikes in 10/214 exploratory holes during the investigations, all located outside the identified potentially contaminative areas of concern/ LQ areas. All 10 encounters were within the bedrock (6 within WWB, 4 within OXC) ranging from 73.10 m bgl to 83.59 m AOD (1.20 m bgl to 7.70 m bgl). Monitored groundwater elevation levels ranged between 53.18 m aOD to 88.05 m AOD (0.06 m bgl to 27.88 m bgl) with 5 exploratory holes recorded as dry on one occasion.	No olfactory evidence of contamination was noted during the ground investigation works apart from the anthropogenic material within Made Ground and slight to strong hydrocarbon odours noted in the surfacing or within the underlying gravels of the pavement cores, potentially associated with the bonding medium. A total of 31 groundwater samples have been tested for organic and inorganic contaminants, of which none were taken within the identified potential sources of contamination/ LQ areas. Exceedances were recorded for cadmium. copper, nickel, zinc. These were all recorded in ML075-CR401 and ML075-WS400, located approximately 30 m southwest and 20 m northeast of the existing Aylesbury Link railway.

3.2.3 Groundwater features

This section sets out all water features identified within the study area, including unlicensed and licensed abstractions, discharges, and Groundwater Dependent Terrestrial Ecosystems (GWDTE). U&A requirements are also recognised. Consideration of the following documents were included in the collation of water features identified:

a. The Water Resources assessment previously undertaken for the Environmental Statement for CFA 13 [19] identified unlicensed and licensed abstractions, discharge permits and Groundwater Dependent Terrestrial Ecosystems (GWDTE) within the study area.
b. Additional potential water features identified during a review of available OS mapping and BGS data [24] and not recorded in these Water Resources Assessments are also present.

All identified features are summarised in the following sections and shown on Figure 11.

3.2.3.1 Unlicensed and licensed abstractions

Unlicensed and licensed groundwater abstractions (including commercial (previously public) water supply abstractions and Private Water Supplies (PWS) or Source Protection Zones (SPZ) located within 1 km of the route in the study area have been assessed. These are summarised in Table 13 [29].

There is potential for further unlicensed abstractions to exist however, as a licence is not required for abstraction volumes below 20 m^3 per day. The abstraction horizons are unknown for all supplies, but it is reasonable to assume that the supplies are installed into the productive aquifer units below the OXC.

Table 13: Summary of unlicensed and licensed abstraction within study area

Figure ID	Licence identifier or another identifier	Distance and direction from route (m)	Abstraction horizon	Maximum annual abstraction quantity (m^3)	Maximum daily abstraction quantity (m^3/d)	Purpose	Number of boreholes
Water features identified in the Environmental Statement (Water Features Assessments) [19]							
1	6/33/02/G/0044 PWS071, PWS074, PWS075, PWS077	700 m NE of Twyford Cutting	Unknown	Unknown	Unknown	Farm wells. Cowley Farm	4
2	6/33/02/G/0041 PWS082	600 m NE of Godington East Embankment	Unknown	Unknown	Unknown	Farm wells. Casemore Farm	2
3	SP62NW20/BJ PWS070	870 m SW of Godington West Embankment	Unknown	Unknown	Unknown	Water well. Grange Farm	Unknown
4	6/33/02/S/0125 PWS083	300 m SW of Chetwode Embankment	Unknown	4550	436.40	Agriculture, spray irrigation. Drain at Chetwold 'B'	2

Figure ID	Licence identifier or another identifier	Distance and direction from route (m)	Abstraction horizon	Maximum annual abstraction quantity (m^3)	Maximum daily abstraction quantity (m^3/d)	Purpose	Number of boreholes
5	SP62/NW27/BJ PWS072	650 m SW of Chetwode Embankment	Unknown	Unknown	Unknown	Unknown. Moat Farm	Unknown
Other potential abstractions identified in this assessment [29]							
6	PSW084	700 m SW of Chetwode Cutting	Unknown	Unknown	Unknown	Single domestic dwelling with well supply	Unknown
7	PSW085	860 m SW of Chetwode Cutting	Unknown	Unknown	Unknown	Single domestic dwelling with well supply	Unknown
8	PSW086	348 m E of Chetwode Cutting	Unknown	Unknown	Unknown	Likely Disused well – Priory House	Unknown
9	PSW088	250 m E of Chetwode Cutting	Unknown	Unknown	Unknown	Likely Disused – Monks Garden	Unknown
10	PSW089	250 m E of Chetwode Cutting	Unknown	Unknown	Unknown	Unknown – Well	Unknown
11	PSW090	320 m WSW of Chetwode Cutting	Unknown	Unknown	Unknown	Unlicensed abstraction – well at Barton Hill Farm	Unknown
12	PSW091	1000 m NE of Chetwode Cutting	Unknown	Unknown	Unknown	Unknown – Well Manor House Chetwode	Unknown
13	PWS093	680 m NE of Barton Hartshorn Embankment	Unknown	Unknown	Unknown	Unknown – Historical well	Unknown
14	PWS162	120 m NE of Chetwode Cutting	Unknown	Unknown	Unknown	Unknown status	Unknown

3.2.3.2 Discharge permits

There are no groundwater discharge permits to groundwater directly or via land within 1 km of the route in the study area [19].

3.2.3.3 Groundwater dependent habitats

Groundwater Dependent Terrestrial Ecosystems (GWDTEs) are wetlands which critically depend on groundwater flows and/or chemical inputs to maintain them in favourable ecological condition [41]. GWDTEs are defined based on their groundwater dependency and connectivity with a Water Framework Directive (WFD) groundwater body.

The summary of water dependent habitats within 1 km of the route is shown in Table 14 [19] [42]. The table identifies where a water dependency exists.

Table 14: Potentially water dependent habitats in the study area

Figure ID	Name/Location	Designation	Distance and direction from route (m)	Comments
1	Field A Cowley Farm, approximately 100 m southwest of Cowley Farm.	LWS	400 m east of the Scheme.	Damp unimproved grassland.
2	Field B Cowley Farm, approximate 300 m southwest of Cowley Farm	BNS	200 m east of the Scheme.	The southern corner of this field contains a pocket of damp grassland.
3	Railway cutting north of Twyford	BNS	Adjacent to route on western boundary at ch. 83+000.	A section of disused railway line, of interest for neutral grassland and ponds.
4	Chetwode Cutting, located between Rosehill Cottages and Chetwode Grange to the southwest of Chetwode.	BNS	Partially within the extent of the consolidated construction boundary of the Scheme.	A section of disused railway line, of interest for neutral grassland and ponds.

LWS – Local Wildlife Site
BNS – Biological Notification Site

Barton Hartshorn Railway Wood, approximately 500 m southwest of Barton Hartshorn, is a Local Wildlife Site (LWS) previously identified as being potentially groundwater dependent. Following a National Vegetation Classification (NVC) Survey report in July 2021 [43], this site has not been determined to not be groundwater dependent:

> *'As there was a clear surface water inflow, it was considered that the moist soil conditions were likely to be due to impeded surface- water drainage, perhaps backing up against the edge of the disused railway embankment, rather than indicating any kind of groundwater-dependence.'* [43]

This LWS is not a potential GWDTE and is not taken forward for assessment.

3.2.3.4 Groundwater Undertakings and Assurances

A list of groundwater related Undertakings and Assurances (U&A) from the 'Phase 1 HS2 Register of Undertakings and Assurances' *[44]* that relate to this section of the Scheme are provided in Table 15.

Table 15: Undertakings and Assurances within study area

Reference	Location	Description
Assurance 49	Route Wide	General protection of groundwater. Potential significant adverse effects on groundwater, due to construction, (such as excavations to form cuttings or tunnels, including green tunnels), will be mitigated locally wherever reasonably practicable.
Assurance 2256	Route Wide	National Farmers Union. Related to the protection and maintenance of farm water supplies during construction
Assurance 2783	Route wide	Provision of suitable groundwater monitoring.
Assurance 10807	The Watergate property, Chetwode Parish, approx. ch. 86+500	Assessment of the impacts of the HS2 works on the well water supply of The Watergate property. If deemed impacted, take appropriate measures to safeguard existing water connection or provide a new water supply.
Assurance 1610	Buckingham County Council, ch. 39+000 to 88+000	To engage with Buckingham County Council in respect of requirements of groundwater monitoring and identification of risk from groundwater flooding.

3.3 Hydrology

3.3.1 Surface water features

3.3.1.1 Water bodies

All waterbodies in this area fall within the catchment of the Padbury Brook waterbody, which is located in the Great Ouse Upper Operational Catchment within the Anglian River Basin District (RBD) as defined under the Water Framework Directive (WFD) and are covered by the Anglian River Basin Management Plan [35].

The Padbury Brook was assessed in the 2019 Water Framework Directive (WFD) Cycle 2 classification. The Padbury Brook, classed as a heavily modified waterbody, has an overall Moderate ecological status [23]. The assessed reach, watercourse ID and water quality classification, as extracted from the EA Catchment Data Explorer [23], are outlined in Table 16 below. Surface water WFD waterbodies are shown in Figure 12.

Table 16: Waterbody WFD details

Watercourse	ID	HS2 WFD Surface Water Risk of Deterioration [39]	Classification		Notes
			Ecological	Chemical	
Padbury Brook	GB105033038210	Amber	Moderate	Fail	Amber classification based on potential cumulative impacts on hydromorphology. Risks are unrelated to groundwater and

					are therefore not assessed further.

The Padbury Brook WFD water body has been assessed as Amber risk of deterioration due to the potential for cumulative impacts of minor adverse effects to have an impact on hydromorphology on a water body scale. This is primarily related to diversion of the main watercourse and presence of multiple culverts and is not influenced by the hydrogeological regime.

All surface water features within 1 km of the route are presented in Table 17 below and shown in Appendix A.

Information in the table, including WFD status and receptor value have been extracted from the Environmental Statement [19] and supplemented using the EA Catchment Data Explorer [23], FEH Web Service [33], the Padbury Brook and Tributary of Padbury Brook Addendums to the FLARs [36] [37] and OS Mapping.

Table 17: Surface water features across the study area

ID*	Water Feature	Location description	Watercourse classification	WFD water body and current overall status	WFD RBMP 2027 status objective	Receptor value	Q95 (m^3/s)	Catchment area at crossing (km^2)	Notes
04 08 09	Padbury Brook	Padbury brook north of Twyford (SWC-CFA13-04) and north-east of Godington (SWC-CFA13-08 and SWC-CFA13-09)	Main river	Padbury Brook (WFD ID: GB105033038210) Moderate	Good potential	High	0.045 (SWC-CFA13-04) 0.042 (SWC-CFA13-08) 0.036 (SWC-CFA13-09)	73.82 (SWC-CFA13-04) 67.79 (SWC-CFA13-08) 58.88 (SWC-CFA13-09)	The main channel of the Padbury Brook will be crossed by the route three times due to the meandering nature of the river. It will be crossed by the route north of Twyford, at the Twyford Viaduct (SWC-CFA13-04), and twice to the north-east of Godington by the Godington East Viaduct (SWC-CFA13-08) and Godington West Viaduct (SWC-CFA13-09). The Padbury Brook is deemed to be heavily modified because of hydromorphological pressures in the areas. It flows to the east and then north at Steeple Claydon before joining the River Great Ouse ear Buckingham.
05	Unnamed drain	An unnamed drain running parallel to Padbury Brook close to SWC-CFA13-04 (SWC-CFA13-05).	Ordinary watercourse	No status class shown in RBMP, assumed status from the Padbury Brook: Moderate	No status class shown in RBMP, assumed status from the Padbury Brook: Good potential	Moderate	0.00001	0.61	The drain joins the Padbury brook north of the route, near Three Bridge Mill.
P11	Three ponds	Three isolated ponds at Cowley Farm	N/A	N/A	N/A	Low	N/A	N/A	The ponds are not connected to any other surface water features in the catchment.

ID*	Water Feature	Location description	Watercourse classification	WFD water body and current overall status	WFD RBMP 2027 status objective	Receptor value	Q95 (m^3/s)	Catchment area at crossing (km^2)	Notes
		and approximately 700 m north of the route (CFA13-P11).							
06	Unnamed drain	An unnamed drain (tributary of Padbury Brook) flowing south and will be crossed by the route near Twyford (SWC-CFA13-06).	Ordinary watercourse	No status class shown in RBMP, assumed status from the Padbury Brook: Moderate	No status class shown in RBMP, assumed status from the Padbury Brook: Good potential	Moderate	0.0003	0.61	This drain joins another drain south of the route, and eventually the Padbury Brook north of the route, near Three Mill Bridge.
07	Unnamed drain	An unnamed drain (tributary of Padbury Brook) flowing south-west. It will be crossed by the route to the east of Godington (SWC-CFA13-07).	Ordinary watercourse	No status class shown in RBMP, assumed status from the Padbury Brook: Moderate	No status class shown in RBMP, assumed status from the Padbury Brook: Good potential	Moderate	0.00001	0.5	The drain joins another drain south of the route and eventually the Padbury Brook north of the route, near Three Mill Bridge.

ID*	Water Feature	Location description	Watercourse classification	WFD water body and current overall status	WFD RBMP 2027 status objective	Receptor value	Q95 (m^3/s)	Catchment area at crossing (km^2)	Notes
E01	Unnamed drain	An unnamed drain at Moat Farm.	Ordinary watercourse	No status class shown in RBMP, assumed status from the Padbury Brook: Moderate	No status class shown in RBMP, assumed status from the Padbury Brook: Good potential	Moderate	N/A	N/A	The drain connects to the Padbury Brook to the north-east of Moat Farm.
P12	Pond	Approximately 40 m south of the route between Padbury Brook and the disused railway (SWC-CFA13-P12).	N/A	N/A	N/A	Low	N/A	N/A	The pond is not connected to any other surface water features in the catchment.
10	Unnamed drain	An unnamed drain flowing east and crossed by the route, north-east of Godington	Ordinary watercourse	No status class shown in RBMP, assumed status from the Padbury Brook: Moderate	No status class shown in RBMP, assumed status from the Padbury Brook:	Moderate	0.00002	0.5	The drains join the Padbury Brook north of the route, to the east of Godington.

ID*	Water Feature	Location description	Watercourse classification	WFD water body and current overall status	WFD RBMP 2027 status objective	Receptor value	Q95 (m^3/s)	Catchment area at crossing (km^2)	Notes
		(SWC-CFA13-10).			Good potential				
P13	Two ponds	Two field ponds at approximately 800 m and 950 m west of the route, near Moat Farm (CFA13-P13).	N/A	N/A	N/A	Low	N/A	N/A	The ponds are not connected to any other surface water features in the catchment.
P14	Moat	An unnamed moat approximately 750 m west of the route, on Moat Farm (CFA13-P14).	N/A	N/A	N/A	Moderate	N/A	N/A	The moat is situated immediately south of Padbury Brook and includes a pond.
E02	Lake	An unnamed lake approximately 750 m west of the route near Moat Farm (CFA13-P14).	N/A	N/A	N/A	Moderate	N/A	N/A	The lake is situated between two channels of the Padbury Brook. The lake does not appear to be connected two either channel.
E03	Lake	An unnamed lake	N/A	N/A	N/A	Moderate	N/A	N/A	The lake has a drain running along the western edge and does not appear to be

ID*	Water Feature	Location description	Watercourse classification	WFD water body and current overall status	WFD RBMP 2027 status objective	Receptor value	Q95 (m^3/s)	Catchment area at crossing (km^2)	Notes
		approximately 400 m north of Moat Farm and immediately west of the former Great Central Main Line railway (200 m west of the route).							connected to the tributary of the Padbury Brook.
E04	Unnamed drain	Located approximately 750 m west of the route flowing to the south through Barton Grounds Farm and Watergate Farm	Ordinary watercourse	No status class shown in RBMP, assumed status from the Padbury Brook: Moderate	No status class shown in RBMP, assumed status from the Padbury Brook: Good potential	Moderate	N/A	N/A	The drain eventually joins the Padbury Brook near Godington.
P15	Two ponds	Two isolated ponds approximately 65 m and 195 m east of the route on	N/A	N/A	N/A	Low	N/A	N/A	The ponds are not connected to any other surface water features in the catchment.

ID*	Water Feature	Location description	Watercourse classification	WFD water body and current overall status	WFD RBMP 2027 status objective	Receptor value	Q95 (m^3/s)	Catchment area at crossing (km^2)	Notes
		Rosehill Farm (CFA13-P15).							
P16	Two ponds	Two isolated field ponds approximately 100 m east of the route near the Hermitage and Chetwode (CFA13-P16).	N/A	N/A	N/A	Low	N/A	N/A	The ponds are not connected to any other surface water features in the catchment.
P17	Two moats	Two unnamed moats approximately 100 m and 200 m east of the route in Chetwode (CFA13-P17).	N/A	N/A	N/A	Low	N/A	N/A	Unnamed moats (potentially dry). Not connected to any other surface water features in the catchment.
P18	Pond and unnamed drain	A pond and drain approximately 270 m east of the route in Chetwode (CFA13-P18).	Ordinary watercourse	No status class shown in RBMP, assumed status from the Padbury Brook: Moderate	No status class shown in RBMP, assumed status from the Padbury Brook:	Moderate	N/A	N/A	The outflow from the pond is linked to a tributary of the Padbury Brook via a drain flowing eastwards.

ID*	Water Feature	Location description	Watercourse classification	WFD water body and current overall status	WFD RBMP 2027 status objective	Receptor value	Q95 (m^3/s)	Catchment area at crossing (km^2)	Notes
					Good potential				
P19	Two moats	Chetwode Moats approximately 650 m east of the route (CFA13-P19).	Ordinary watercourse	No status class shown in RBMP, assumed status from the Padbury Brook: Moderate	No status class shown in RBMP, assumed status from the Padbury Brook: Good potential	Moderate	N/A	N/A	Assumed to be connected to a drain to the west of the moats. The drain flows to the Padbury Brook.
P20	Pond	An isolated pond approximately 470 m west of the route on Barton Hill Farm (CFA13-P20).	N/A	N/A	N/A	Low	N/A	N/A	The pond is not connected to any other surface water features in the catchment.
E05	Unnamed drain	The drain flows west from Barton Hartshorn and will be crossed by the route at SWC-CFA13-	Ordinary watercourse.	No status class shown in RBMP, assumed status from the Padbury Brook:	No status class shown in RBMP, assumed status from the Padbury Brook:	Moderate	0.002	3.18	Tributary of Padbury Brook drain flowing west from Barton Hartshorn.

ID*	Water Feature	Location description	Watercourse classification	WFD water body and current overall status	WFD RBMP 2027 status objective	Receptor value	Q95 (m^3/s)	Catchment area at crossing (km^2)	Notes
		11 and by an access road at SWC-CFA13-22.		Moderate	Good potential				
P21	Two ponds	Two field ponds approximately 550m and 800m east of the route, near Barton Hartshorn (CFA13-P21).	N/A	N/A	N/A	Low	N/A	N/A	The ponds do not appear to be in connectivity with any other surface water features in the catchment.
11 22	Unnamed drain	Unnamed drain, tributary of the Padbury Brook (SWC-CFA13-11 and SWC-CFA13-22)	Ordinary watercourse	No status class shown in RBMP, assumed status from the Padbury Brook: Moderate	No status class shown in RBMP, assumed status from the Padbury Brook: Good potential	Moderate	N/A	N/A	The drain would be diverted and culverted under the proposed Scheme and a proposed access road.
P22	Three ponds	Three field ponds within 50-250m west of the route, to	N/A	N/A	N/A	Low	N/A	N/A	There is no evidence to suggest these ponds are in connectivity with a drain that runs adjacent to the ponds and therefore do not appear to be in connectivity with any

ID*	Water Feature	Location description	Watercourse classification	WFD water body and current overall status	WFD RBMP 2027 status objective	Receptor value	Q95 (m^3/s)	Catchment area at crossing (km^2)	Notes
		the north of Barton Hill Farm (CFA13-P22).							other surface water features in the catchment.
E06	Unnamed drain	The drain runs south along the CFA13/CFA14 boundary near Home Farm.	Ordinary watercourse	No status class shown in RBMP, assumed status from the Padbury Brook: Moderate	No status class shown in RBMP, assumed status from the Padbury Brook: Good potential	Moderate	N/A	N/A	The rote will cross the watercourse un CFA14 and as such it is not assessed here further. The drain eventually flows into the Padbury Brook near Godington.
Features not included in the Environmental Statement									
A01	Unnamed pond	Pond located at the upstream extent of a small tributary of the Padbury Brook (A03).	N/A	N/A	N/A	Low	N/A	N/A	The pond is located 250 m southwest of the proposed Scheme and flows into A03.
A02	Unnamed pond	Pond located at the upstream extent of a	N/A	N/A	N/A	Low	N/A	N/A	The pond is located 750 m southwest of the proposed Scheme and flows into A03.

ID*	Water Feature	Location description	Watercourse classification	WFD water body and current overall status	WFD RBMP 2027 status objective	Receptor value	Q95 (m^3/s)	Catchment area at crossing (km^2)	Notes
		small tributary of the Padbury Brook (A03).							
A03	Unnamed drain	Unnamed tributary of the Padbury Brook located south of the Twyford Viaduct, which flows into the Padbury Brook over 2 km downstream of the Twyford Viaduct.	Ordinary watercourse	No status class shown in RBMP, assumed status from the Padbury Brook: Moderate	No status class shown in RBMP, assumed status from the Padbury Brook: Good potential	Moderate	N/A	N/A	The watercourse flows northwards towards and is culverted beneath the proposed Scheme, approximately 700 m east of the Twyford Viaduct and connects to the Padbury Brook over 2 km downstream of the Twyford Viaduct.
A04	Unnamed drain	Unnamed tributary of the Padbury Brook located north of the proposed Scheme.	Ordinary watercourse	No status class shown in RBMP, assumed status from the Padbury Brook: Moderate	No status class shown in RBMP, assumed status from the Padbury Brook: Good potential	Moderate	N/A	N/A	The watercourse flows southwards and connects to the Padbury Brook between the Godington East and Godington West viaducts.

ID*	Water Feature	Location description	Watercourse classification	WFD water body and current overall status	WFD RBMP 2027 status objective	Receptor value	Q95 (m^3/s)	Catchment area at crossing (km^2)	Notes
A05	Unnamed pond	Unnamed pond located on the right bank of the Padbury Brook.	N/A	N/A	N/A	Low	N/A	N/A	The pond is located less than 100 m west of the Godington West Viaduct on the right bank of the Padbury Brook.
A06	Unnamed drain	Unnamed tributary of the Padbury Brook located downstream of the Barton Hartshorn Embankment.	Ordinary watercourse	No status class shown in RBMP, assumed status from the Padbury Brook: Moderate	No status class shown in RBMP, assumed status from the Padbury Brook: Good potential	Moderate	N/A	N/A	The watercourse flows eastwards and connects to the Tributary of Padbury Brook 900 m southwest of the Barton Hartshorn Embankment.
A07	Unnamed pond	Pond located on the left bank of the Tributary of Padbury Brook.	N/A	N/A	N/A	Low	N/A	N/A	Small pond on the left bank of the Tributary of Padbury Brook located approximately 400 m south (downstream) of the Barton Hartshorn Embankment.
A08	Unnamed pond	Pond located on the right bank of a minor tributary	N/A	N/A	N/A	Low	N/A	N/A	Small pond on the right bank of the Tributary of Padbury Brook located approximately 200 m north (upstream) of the Barton Hartshorn Embankment.

ID*	Water Feature	Location description	Watercourse classification	WFD water body and current overall status	WFD RBMP 2027 status objective	Receptor value	Q95 (m^3/s)	Catchment area at crossing (km^2)	Notes
		of the Padbury Brook							
A09	Unnamed pond	Pond located at the upstream extent of a minor tributary of the Padbury Brook	N/A	N/A	N/A	Low	N/A	N/A	Small pond located at the upstream extent of a small tributary of Padbury Brook located approximately 600 m northeast (upstream) of the Barton Hartshorn Embankment.

**Surface water feature ID shown in the figure in Appendix A*

3.3.1.2 Undertakings and assurances – surface water

A list of Undertakings and Assurances that relate to groundwater are provided in Table 15 and which includes several aspects that relate to surface water, namely U&A 10807. There are several additional undertakings and assurances specific to surface water which are listed in Table 18.

Table 18: Undertakings and assurances within study area – surface water

Reference	Location	Description
U&A 2220_27	Routewide	1.9.1 No excavations, surfaces water or groundwater may be discharged onto the Trusts property until it can be demonstrated to the reasonable satisfaction of the Trust that it is not contaminated. 1.9.2 Where such material or water is contaminated, any proposed remediation prior to discharge should be approved by the Trust.
U&A 2220_29	Routewide	Any Authorised Works that may adversely impact on the Trust's water supplies (short term or long term) from surface water feeders or groundwater pumps will be mitigated by the Promoter to the reasonable satisfaction of the Trust prior to commencement of such Authorised Works
Assurance 978	Routewide	Flood risk and water consenting. Consenting strategy for the water aspects of works required, including works that have the potential to affect the level, flow, and quality of water bodies.
U&A 1613	Moat Farm Godington OX27 9AF	The nominated undertaker will use reasonable endeavours to reconfigure areas of land identified for replacement floodplain storage on Moat Farm, Godington, to reduce agricultural land take.
U&A 1769	Barton Hill Farm Chetwode Bucks MK18 4BA	The nominated undertaker will use reasonable endeavours to reconfigure areas of land identified for replacement floodplain storage on Barton Hill Farm, Chetwode, to reduce agricultural land take.
U&A 1771	Barton Hill Farm Chetwode Bucks MK18 4BA	The nominated undertaker will use reasonable endeavours to reconfigure areas of land identified for permanent drainage requirements (balancing ponds, land drainage, replacement floodplain storage areas) on the holding to reduce agricultural land take.

3.3.2 Surface water abstractions and discharges

According to the Environmental Statement [20], there is one licensed surface water abstraction within the study area, which is potentially linked to a second licence approximately 1.3 km from the proposed route. The surface water abstractions are identified in Table 19.

No unlicensed surface water abstractions have been identified within 1 km of the route, however there is the potential for unlicensed abstractions to exist that have not been identified, as a license is not required for licenses below 20 m^3 per day.

Table 19: Licensed surface water abstractions

License identifier	Distance and direction from the route	Abstraction source	Maximum annual abstraction quantity (m^3)	Maximum daily abstraction quantity (m^3)	Purpose
SWB4 6/33/02/*S/0125	135 m southwest	Drain	4,550	436	Spray irrigation
SWB3	1,250 m southwest	Tributary of Padbury Brook			Spray irrigation

The Environmental Statement [20] identifies 24 consented surface water discharges within 1km of the route. The surface water discharges are identified in Table 20.

Table 20: Surface water discharge consents

Reference number	Permit identifier	Distance and direction from the route	Discharge type	Receiving watercourse
CFA13WD76	AW1NF184	65 m northeast	Sewage discharge – final/treated effluent	Tributary of Padbury Brook
CFA13WD5	AW1NF514	295 m southwest	Sewage discharge – storm overflow/storm tank	Adjoining watercourse
CFA13WD79	EPRLP3823GJ	145 m southwest	Sewage discharge – final/treated effluent	Tributary of Padbury Brook
CFA13WD77	NPSWQD009917	610 m southwest	Sewage discharge – final/treated effluent	Ditch to Mill Stream
CFA13WD78	PR1NF1675	245 m northeast	Sewage discharge – final/treated effluent	Tributary of Padbury Brook
CFA13WD9	PR1NF1676	25 m northeast	Sewage discharge – final/treated effluent	Tributary of Padbury Brook
CFA13WD10	PR1NF1677	385 m northeast	Sewage discharge – final/treated effluent	Tributary of Padbury Brook
CFA13WD8	PR1NF1678	5 m northeast	Sewage discharge – final/treated effluent	Tributary of Padbury Brook
CFA13WD12	PR1NF1679	375 m northeast	Sewage discharge – final/treated effluent	Tributary of Padbury Brook
CFA13WD11	PR1NF1680	315 m northeast	Sewage discharge – final/treated effluent	Tributary of Padbury Brook
CFA13WD13	PR1NF1787	120 m northeast	Sewage discharge – final/treated effluent	Tributary of Padbury Brook

Reference number	Permit identifier	Distance and direction from the route	Discharge type	Receiving watercourse
CFA13WD33	PRCLF14247	759 m northeast	Sewage discharge – final/treated effluent	Tributary of Padbury Brook
CFA13WD20	PRCNF05213	880 m northeast	Sewage discharge – final/treated effluent	Tributary of Padbury Brook
CFA13WD61	PRCNF05581	739 m northeast	Sewage discharge – final/treated effluent	Tributary of Padbury Brook
CFA13WD7	PRCNF05984	497 m southwest	Sewage discharge – final/treated effluent	Padbury Brook
CFA13WD60	PRCNF14444	529 m southwest	Sewage discharge – final/treated effluent	Padbury Brook
CFA13WD63	PRCNF17003	931 m southwest	Sewage discharge – final/treated effluent	Tributary of Padbury Brook
CFA13WD69	PRCNF17853	181 m northeast	Sewage discharge – final/treated effluent	Tributary of Padbury Brook
CFA13WD70	PRCNF18185	220 m northeast	Sewage discharge – final/treated effluent	Tributary of Padbury Brook
CFA13WD1	PRCNF01228	375 m northeast	Sewage discharge – final/treated effluent	Padbury Brook
CFA13WD21	PRCNF05581	735 m northeast	Sewage discharge – final/treated effluent	Tributary of Padbury Brook

3.3.3 Surface water/groundwater interaction

The Environmental Statement [20] identifies three surface water/groundwater interactions within the study area, which are described in Table 21.

Table 21: Surface water/ groundwater interactions

Location description	Distance and direction from the route	Formation	Elevation	Comments
Spring approximately 200m southwest of Rosehill Farm, Chetwode	180 m northeast	Glaciofluvial Deposits	96 m aOD	Contributes to flows to a surface water abstraction 150 m to the south
Issues approximately 300m southwest of Garden Cottage, Barton Hartshorn	350 m northeast	Glaciofluvial Deposits and/or Kellaway Formation	106 m aOD	Feeds a tributary of the Padbury Brook

Location description	Distance and direction from the route	Formation	Elevation	Comments
Springs approximately 350 m north of Manor Farm, Barton Hartshorn	800 m northeast	Glaciofluvial Deposits and/or Kellaway Formation	110 m aOD	Feeds a tributary of the Padbury Brook

In addition to the interactions above, the Padbury Brook is likely to be in hydraulic connectivity to the RTD.

3.3.4 Surface water sensitivity

The status of the water features, in terms of the Water Framework Directive, are outline in Table 17. This section considers ecological and hydrological designations in the vicinity of the Scheme in the study area that influence the overall sensitivity of each waterbody.

There are three water dependent habitats within 1 km of the Scheme in this location, which are outlined in Table 22. There are no other ecologically sensitive or protected areas within 1 km of the Scheme.

Table 22: Description of water dependent habitats

Name and location	Distance and direction from the route	Designation	Comments
Field A Cowley Farm Local Wildlife Site (LWS), approximately 100m southwest of Cowley Farm	400 m north of the proposed Scheme	LWS	Damp unimproved grassland
Field B Cowley Farm Biological Notification Site (BNS), approximately 300m southwest of Cowley Farm	200 m north of the proposed Scheme	BNS	The southern corner of the field contains a pocket of damp grassland
Barton Hartshorn Railway Wood LWS, approximately 500m southwest of Barton Hartshorn	Within the construction boundary to the north of the Scheme	LWS	Designated for its remnant fen, wet woodland, and wet grassland habitats

Drinking water safeguard zones area designated areas in which the use of certain substances must be carefully managed to prevent the pollution of raw water sources that are used to provide drinking water. In this location, the Scheme is within drinking water safeguarding zone (surface water) (ID: SWSGZ1012_Anglian), which is at risk from pesticides [32].

The study area is within a designated Nitrate Vulnerable Zone (NVZ) for surface water (ID: 391, Great Ouse). NVZs are areas designated as being at risk from agricultural nitrate pollution. The surface water NVZ relates to the Padbury Brook in this area [32].

3.4 Study area conceptual model

3.4.1 Key features

The key features of the study area conceptual model are summarised in Table 23 below. Groundwater flow within the OXC is expected to be negligible.

The extent of aquifer connectivity and vertical hydraulic continuity across the underlying GOG is not fully known in this area although it is expected that some continuity exists across these GOG formations and this is assumed to be the case for the purpose of this study. Groundwater recharge to the GOG formations is from the north where, due to the southern dip of the strata, these units occur at shallower depths.

The GOG is likely to be confined by the overlying OXC and potentially by the KLB; pressure heads of the order of 20 m could be expected. The GI data records confined groundwater levels to near surface, however no data indicates that artesian conditions will occur, but these conditions remain a possibility, especially where overburden is removed for construction purposes.

Table 23: Key features of the study area conceptual model

Route	Between ch. 82+300 to ch. 87+200 and includes 10 mainline assets consisting of 2 cuttings, 5 embankments and 3 viaducts. The study area includes 3 overbridges, 3 mainline culverts, 18 balancing ponds (no infiltration basins).
Study area	The study area lies within the catchment of Padbury Brook comprising gently undulating topography.
Water features	There are 14 unlicensed and licensed abstractions throughout the study area. No Environment Agency published Source Protection Zones or GWDTEs are present within the study area.

Stratum	Occurrence	Thickness	Aquifer status	Groundwater levels	Interaction with assets
Superficial deposits					
ALV	Present across low ground in the central and southern portions of the study area	Up to 2 m	Secondary A Aquifer	It is likely that localised areas of perched groundwater exist within the superficial.	Barton Hartshorn Embankment, Chetwode Embankment, Godington West Viaduct, Godington East Viaduct, Godington West Embankment, Godington East Embankment, Cowley Embankment and Twyford viaduct
RTD	Present across low ground in the central and southern portions of the study area	Up to 2 m	Secondary A Aquifer	RTD deposits can be expected to be in hydraulic continuity with adjacent Padbury Brook.	Chetwode Embankment, Godington West Viaduct, Godington East Viaduct, Godington West Embankment, Godington East Embankment, and Cowley Embankment
TILMP	Present across higher ground in the central and northern portions of the study area	Up to 10 m	Secondary A Aquifer	It is likely that localised areas of perched groundwater exist within the superficial.	Barton Hartshorn Embankment, Chetwode Cutting and Chetwode Embankment
GFDMP	Present across higher ground in the central and northern portions of the study area	Up to 10 m	Secondary A Aquifer	It is likely that localised areas of perched groundwater exist within the superficial.	Barton Hartshorn Embankment, Chetwode Cutting
Bedrock					

Stratum	Occurrence	Thickness	Aquifer status	Groundwater levels	Interaction with assets
OXC	Directly underlies assets in the central and southern portions of study area. Absent from the northern portion	0 – 10 m+	Unproductive strata	Shallow perched groundwater may be present.	Twyford Cutting, Chetwode Cutting, Chetwode Embankment, piling at Twyford Viaduct, Godington East Viaduct, and Godington West Viaduct. Piling at PBI/5A Acc. Overbridge, Footpath CHW/18 Acc. Overbridge and School End Overbridge.
KLB	Present in the central and southern portions of study area dipping gently to the south. Absent from the northern portion.	0 – 7 m	Secondary A Aquifer	Extent of saturation unknown.	Piling at Twyford Viaduct, Godington East Viaduct, and Godington West Viaduct. Piling at Footpath CHW/18 Acc. Overbridge
CB	Present throughout the study area; shallower in the north and gently dipping to the south	0 – 4 m	Secondary A Aquifer	Fully saturated	Barton Hartshorn Embankment. Piling at Twyford, Godington East, and Godington East Viaducts. Piling at Footpath CHW/18 Acc. Overbridge
FMB	Present throughout the study area; shallower in the north and gently dipping to the south	2 – 5 m	Secondary A Aquifer	Fully saturated	Piling at Twyford, Godington East, and Godington East Viaducts
WHL	Present throughout the study area; shallower in the north and gently dipping to the south	10 m+	Principal Aquifer	Fully saturated	Piling at Twyford, Godington East, and Godington East Viaducts

4 Design and water related interdependencies

4.1 Introduction

4.1.1 Identification of asset and water feature interdependencies

The following section establishes where hydrological, hydrogeological and design related interdependencies occur for mainline and offline assets and structures, based on the available data presented in Section 3 and design information supplied (Section 1.4). It identifies where there is potential for conflict/impacts with respect to surface water and groundwater flow and surface water and groundwater quality that may result from the design and long-term operation of the route within the immediate vicinity of the study area.

4.1.1.1 Mainline assets

Groundwater levels in relation to each mainline asset, together with details of potential conflict/impacts of the Scheme on surface water are summarised in Table 24.

Table 24: Summary of groundwater data collected from ground investigation boreholes and potential conflicts/impacts on surface waters in relation to each mainline asset

Mainline Asset	Groundwater levels in relation to asset	Surface water features located within an approximate 1km buffer of the asset
Twyford Viaduct	Maximum recorded groundwater level in this asset area is 83.19 m aOD at ML082-CR410, screened in the OXC to KLB and representing a confined groundwater level which will be encountered by piling only. Piling is planned to depths up to 58.5 m aOD, giving a pressure head of approximately 24.5 m. Artesian conditions are not indicated by the monitoring points at this asset. Groundwater levels recorded within the OXC and superficial deposits reflect localised shallow perched groundwater only.	Located in Flood Zone 3, equivalent to an annual chance of flooding of greater than 1 in 100 (1%) [30]. Therefore, the Scheme could impact flood risk due to factors such as a loss of floodplain storage. The Scheme is located on viaduct at this location, which would minimise the potential loss of floodplain storage. Short watercourse diversions/realignments, including a diversion of the Padbury Brook and a tributary to the north, would be implemented to realign the channels to flow perpendicularly under the viaduct. This may impact the hydromorphology of the affected reaches. For further flood risk information or for information on the watercourse diversions, refer to the Padbury Brook Addendum to FLAR [36].
Cowley Embankment	The highest groundwater level recorded within the asset area is at ML082-CP016 is 83.27 m aOD, screened across the RTD and OXC. This is perched groundwater which is expected to be discrete and discontinuous. No impact on the superficial deposits is anticipated due to the limited saturation, low permeability of, and lack of dependency on this deposit for water supply/ water dependant habitats in the vicinity of the asset. The maximum excavation depth is 3m bgl and is not expected to intercept the water table in this area.	The embankment intercepts a tributary of the Padbury Brook. The watercourse will be diverted to flow along the embankment and re-join the Padbury Brook immediately downstream of the Twyford Viaduct. This may impact the hydromorphology of the affected reaches. Mostly located in Flood Zone 1, equivalent to an annual chance of flooding of less than 1 in 1,000 (0.1%). However, the south-eastern extent of the embankment, in proximity to the Twyford Viaduct and the Padbury Brook, is located in Flood Zone 3, equivalent to an annual chance of flooding of greater than 1 in 100 (1%) [30]. Therefore, the embankment could impact flood risk due to factors such as a loss of floodplain storage. For further flood risk information or for information on the watercourse diversions, refer to the Padbury Brook Addendum to FLAR [36].
Twyford Cutting	The highest groundwater level recorded within the asset area (at ML082-RC012) is 89.20 m aOD recorded within the OXC likely to reflect localised shallow perched groundwater and/or seepages into the standpipe from the surrounding OXC. The maximum excavation depth is 7m bgl and is expected to intercept saturated OXC by up to approximately 6 m.	The Twyford Cutting is located in Flood Zone 1, equivalent to an annual chance of flooding of less than 1 in 1,000 (0.1%) [30]. Therefore, there is a low risk of flooding to this asset. The Twyford Cutting crosses the drainage catchment of the Padbury Brook and its tributaries and, therefore, has the potential to impact the natural drainage regime of these watercourses. A land drainage ditch is proposed along the eastern edge of this asset to intercept surface water flows and discharging into the tributaries of Padbury Brook. This may alter the natural drainage regime of the area, in terms of runoff discharge locations and rates.
Godington East Embankment	The highest groundwater level recorded within the asset area is at ML083-CR003 is 83.30 m aOD, screened in the WHL and representing a confined groundwater level with the potentiometric water level recorded within the RTD/Alluvium. The maximum excavation depth is 3 m bgl and is therefore not going to intercept the confined WHL aquifer, therefore this groundwater will not be encountered at the asset.	The Godington East Embankment is partially located in Flood Zone 3, equivalent to an annual chance of flooding of greater than 1 in 100 (1%). The embankment intercepts a watercourse, which is proposed to be culverted beneath the embankment, via the Godington East Culvert. Therefore, the Scheme could impact flood risk due to factors such as a loss of floodplain storage and altered conveyance capacity at the culvert. For further flood risk information or for information on the watercourse diversions, refer to the Padbury Brook Addendum to FLAR [36].
Godington East Viaduct	Maximum recorded groundwater level in this asset area is 85.91 m aOD at ML084-CR408, screened across the CB and FMB and representing a confined groundwater level with the potentiometric level recorded within the alluvium. Piling is planned to depths up to 68.06 m aOD, to within the top of the WHL, pressure head of up to approximately 18 m could be encountered.	Located in Flood Zone 3, equivalent to an annual chance of flooding of greater than 1 in 100 (1%) [30]. Therefore, the Scheme could impact flood risk due to factors such as a loss of floodplain storage. A short watercourse diversion of the Padbury Brook would be implemented to realign the channels to flow perpendicularly under the viaduct. This may impact the hydromorphology of the affected reaches. For further flood risk information or for information on the watercourse diversions, refer to the Padbury Brook Addendum to FLAR [36].
Godington West Embankment	The highest groundwater level recorded within the asset area is 83.33 m aOD at ML084-CR005, screened across the FMB and WHL and representing a confined groundwater level with potentiometric level recorded within the OXC. The maximum excavation depth is 1 m bgl and is therefore unable to intercept the confined WHL aquifer, therefore this groundwater will not be encountered at the asset. Perched groundwater in the superficial deposits at this asset are expected to be discrete and discontinuous. No impact on the superficial deposits is anticipated due to the limited saturation, low permeability of, and lack of dependency on this deposit for water supply/ water dependant habitats in the vicinity of the asset.	The Godington West Embankment is located in Flood Zone 3, equivalent to an annual chance of flooding of greater than 1 in 100 (1%), and Flood Zone 2, equivalent to an annual chance of flooding of between 1 in 1,000 and 1 in 100 (0.1-1%) [30]. Therefore, the Scheme could impact flood risk due to factors such as a loss of floodplain storage. For further flood risk information, refer to the Padbury Brook Addendum to FLAR [36].
Godington West Viaduct	Maximum recorded groundwater level in this asset area is 85.93 m aOD at ML084-CR008, screened in the RLD and representing a confined groundwater level with potentiometric level recorded within the OXC and overlying alluvium. Piling is planned to depths up to 65.91 m aOD to within the WHL, a maximum pressure head of up to approximately 20 m could be encountered.	Located in Flood Zone 3, equivalent to an annual chance of flooding of greater than 1 in 100 (1%) [30]. Therefore, the Scheme could impact flood risk due to factors such as a loss of floodplain storage. A short watercourse diversion of the Padbury Brook would be implemented to realign the channels to flow perpendicularly under the viaduct. This may impact the hydromorphology of the affected reach. For further flood risk information or for information on the watercourse diversions, refer to the Padbury Brook Addendum to FLAR [36].

Mainline Asset	Groundwater levels in relation to asset	Surface water features located within an approximate 1km buffer of the asset
Chetwode Embankment	Maximum recorded groundwater level in this asset area is 87.78 m aOD at ML084-CP441, screened in the OXC likely reflecting localised shallow perched groundwater only. The maximum recorded groundwater level at ML084-CP021, screened in the OXC and underlying KLB, is 87.14 m aOD. This may represent a confined groundwater level within the KLB. The maximum excavate and replace depth is 3 m bgl and is not expected to intercept the KLB/GOG aquifer in this area. Perched groundwater in the superficial deposits at this asset are expected to be discrete and discontinuous. No impact on the superficial deposits is anticipated due to the limited saturation, low permeability of, and lack of dependency on this deposit for water supply/ water dependant habitats in the vicinity of the asset.	Most of the Chetwode Embankment is located within Flood Zone 1, equivalent to an annual chance of flooding of less than 1 in 1,000 (0.1%). The south-eastern extent of the Chetwode Embankment, in proximity to the Godington West Viaduct and the Padbury Brook, is located within Flood Zone 3, equivalent to an annual chance of flooding of greater than 1 in 100 (1%) [30]. Therefore, the Scheme could impact flood risk due to factors such as a loss of floodplain storage. The embankment intercepts one surface water flow pathway, a minor tributary of the Padbury Brook to the north, which is proposed to be culverted beneath the embankment, via the Godington West Culvert. The embankment may cause changes in surface water flow routing and loss of floodplain storage. For further flood risk information or for information on the watercourse diversions, refer to the Padbury Brook Addendum to FLAR [36].
Chetwode Cutting	Maximum recorded groundwater level in this asset area is 103.40 m aOD at ML086-CP413, screened in the till and glaciofluvial deposits. This is perched groundwater which is expected to be discrete and discontinuous. No impact on the superficial deposits is anticipated due to the limited saturation, low permeability of, and lack of dependency on this deposit for water supply/ water dependant habitats in the vicinity of the asset. The maximum groundwater level recorded at ML086-CR014 is 97.51 m aOD. This borehole is screened across the KLB and CB and is therefore likely to represent a confined groundwater level with potentiometric level recorded within the overlying OXC. The maximum cutting depth is 7.8 m bgl and therefore may intercept some perched groundwater in the glaciofluvial deposits, but will not intercept the underlying GOG aquifer.	The Chetwode Cutting is located in Flood Zone 1, equivalent to an annual chance of flooding of less than 1 in 1,000 (0.1%) [30]. Therefore, there is a low risk of flooding to this asset. The cutting has the potential to alter catchment runoff characteristics, for example intercept flows within the cutting or associated drainage network with the runoff being discharged to watercourses at different locations and rates, with respect to existing conditions.
Barton Hartshorn Embankment	Maximum recorded groundwater level in this asset area is 102.51 m aOD at ML086-CR401, screened in the till. This is perched groundwater which is expected to be discrete and discontinuous. No impact on the superficial deposits is anticipated due to the limited saturation, low permeability of, and lack of dependency on this deposit for water supply/ water dependant habitats in the vicinity of the asset. The maximum groundwater level recorded at ML086-CR007 is 99.08 m aOD. This borehole is screened across the CB to WHL and is therefore likely to represent a confined groundwater level with potentiometric level recorded within the overlying alluvium The maximum excavate and replace depth is 3 m bgl and is expected to intersect the CB. It is assumed that the CB is in hydraulic continuity with the underlying GOG units, therefore this may result in groundwater inflows from the confined GOG aquifer in this area during excavation.	The south-east and north-west extents of the Barton Hartshorn Embankment are located within Flood Zone 1, equivalent to an annual chance of flooding of less than 1 in 1,000 (0.1%). The centre of the Embankment, in proximity to the tributary of the Padbury Brook, is located within Flood Zone 3, equivalent to an annual chance of flooding of greater than 1 in 100 (1%) [30]. Therefore, the Scheme could impact flood risk due to factors such as a loss of floodplain storage.

Based on information presented in Table 24 above the potential interference on the groundwater and surface water environments associated with the mainline assets are as follows:

a. Interception of confined groundwater by piling is expected at Twyford Viaduct, Godington East and Godington West Viaducts. Pressure heads up to approximately 20 m could be expected; available site data does not indicate that artesian conditions will occur, but this remains a possibility;
b. Interception of saturated clay at Twyford Cutting and Chetwode Cutting;
c. Potential interception of perched groundwater through excavate and replace works at Cowley Embankment, Godington East Embankment, Godington West Embankment and Chetwode Embankment;
d. Potential interception of confined groundwater from the GOG aquifer through excavate and replace works at Barton Harthorn Embankment where excavation extends to the CB bedrock;
e. Potential impact on fluvial flood risk for those areas of the scheme that are located in high flood risk areas due to factors such as the loss of floodplain storage, culverting of watercourses and changes to flow pathways;
f. Changes in the hydromorphological regime of watercourses and waterbodies in the study area due to watercourse diversions/realignments; and
g. Interception of surface water flows potentially altering catchment runoff characteristics with respect to existing conditions.

4.1.1.2 Offline assets and structures

The groundwater levels and surface water features in relation to each offline asset are summarised in Table 25 below. The long section (Figure 5a-d) shows groundwater levels and maximum depths of the planned overbridge piling.

Table 25: Summary of groundwater data collected from ground investigation boreholes and summary of potential impacts to surface water features in relation to each offline feature

Asset type	Asset Identification	Legacy ID	Asset Name	Groundwater levels in relation to asset	Surface water features in relation to asset
Overbridge	HS2-000001320	083-S1	PBI/5A accommodation overbridge	Piling intercepts potentially saturated strata by up to approximately 9 m within OXC and KLB	These assets do not impact surface water features and they are located in Flood Zone 1 (low flood risk).
	HS2-000001321	085-S3	Footpath CHW/18 accommodation overbridge	Piling intercepts OXC, KLB, CB, FMB and WHL. A potentiometric head of the order 10 m can be expected when encountering the GOG.	
	HS2-000001322	086-S2	School end overbridge	No groundwater intercept expected	
Culvert	HS2-000001430	083-S4	Godington East Culvert	No groundwater intercept expected	This asset is designed to accommodate river flows for the tributary of Padbury Brook for the 1 in 100 year (1%) plus 40% climate change). Channel realignment of the tributary of Padbury Brook is required at this area. Therefore, there is a potential impact on hydromorphology.
	HS2-000001431	084-S4	Godington West Culvert	Saturated strata intercept of up to 2 m within OXC	This asset is designed to accommodate river flows for the tributary of Padbury Brook for the 1 in 100 year (1%) plus 40% climate change). Channel realignment of the tributary of Padbury Brook is required in this area.
	HS2-000001432	087-S3	Barton Hartshorn Culvert	Groundwater intercept of up to 2 m within ALV and CB.	This asset is designed to accommodate river flows for the tributary of Padbury Brook for the 1 in 100 year (1%) plus 40% climate change). Channel realignment of the tributary of Padbury Brook is required in this area.
Flood compensation area	FCA_34 FCA_36 FCA_37 FCA_38 FCA_39	None	None	-	Positive impact as designed to manage flood risk and mitigate any adverse impacts of the proposed scheme on flooding.
Watercourse realignment	-	-	-	-	Potential impact on hydromorphology, water quality and habitats.

4.2 Assessment of identified effects

4.2.1 Introduction

Based on the asset and water feature interdependencies identified in Section 4.1.1, the potential design related hydrological and hydrogeological effects that could occur within the study area include:

- Changes in groundwater levels and flows;
- Impacts on aquifer interconnection;
- Deterioration in groundwater quality;
- Changes in hydromorphology and flood risk; and
- Deterioration in surface water quality.

General impacts on designated sites and water interests are also recognised. These are considered in the following assessment.

4.2.2 Changes in groundwater levels and flows

4.2.2.1 Mainline assets

Cuttings

The Twyford Cutting and Chetwode Cutting are both shown to potentially intercept saturated clay by up to approximately 7 m and 6 m, respectively. The Chetwode Cutting is expected to involve excavation through the overlying TLMP and GFMP into the underlying OXC. The Twyford Cutting is largely into the OXC. Ground investigation works in both cutting areas area have established that ground conditions are clay dominated and low permeability. As such no significant groundwater flow is anticipated and no special drainage measures are envisaged; no overall impact on the groundwater water environment is anticipated.

Embankments

In relation to Cowley Embankment, Godington East Embankment, Godington West Embankment and Chetwode Embankment, excavate and replace is planned across the embankments but is not expected to intercept the regional groundwater level.

Confined groundwater levels in the WHL are recorded at the same elevation as the alluvium at Barton Hartshorn Embankment. As the excavation depth at Barton Hartshorn Embankment is expected to intersect the underlying CB, which is assumed to be in hydraulic continuity with the underlying GOG units, groundwater inflows may be possible at this location during excavation. The design of the replacement fill (density and thickness) will need to take account of the potential hydrostatic pressure and potential for uplift.

Viaducts

The planned piling depths at Twyford Viaduct, Godington East Viaduct and Godington West Viaduct are expected to intersect confined groundwater within the GOG. Although this report does not address the construction phase of works, it is highlighted that the piling process is likely to intercept confined groundwater under pressure heads of up to 10 m+. The available data does not indicate that artesian conditions will occur, but this should be considered a possibility. The planned piling structures are individual bored piles that do not create a complete cut-off. Only minor modifications to groundwater flow behaviour is therefore expected as groundwater will naturally divert around these structures.

The associated risk is considered minimal and mitigation measures are not considered necessary. No impact on the identified groundwater features is anticipated. The viaduct piling is being addressed in separate Piling Risk Assessments (PRAs), in progress at the time of writing:

- PB-03 – Twyford Viaduct (1MC06-CEK-EV-REP-CS06_CL10-000087); and
- PB-04 – Godington West Viaduct & Godington East Viaduct (1MC06-CEK-EV-REP-CS06_CL10-000088).

4.2.2.2 Offline assets and structures

The review presented in Section 2 indicates that the piling structures relating to the three overbridges within the asset area intersect the OXC and underlying formations. At overbridge HS2-000001321 a pressure head of the order 10 m+ can be expected when encountering the GOG formations underlying the KLB and will need to be appropriately managed. A potential long-term risk is to alter the groundwater flow behaviour in direct proximity to the pile structures. Because the structures are individual bored piles that do not create a complete cut-off, risks to groundwater flow behaviour is minimal and mitigation measures are not considered necessary on this basis. The impacts from this asset are considered negligible. A separate piling risk assessments is currently being undertaken: PB-05 - Restricted Byway PBI/5A Accommodation Overbridge (1MC06-CEK-EV-REP-CS06_CL10-000086).

Two culverts have been identified to have potential to intercept groundwater (Barton Hartshorn Culvert and Godington Culvert West) which may cause problems during construction due to inundation of excavations. This risk relates to temporary works which is outside of the DJV scope of works. The culverts may also act as barriers to shallow groundwater flow, or act as conduits for flow should the surrounding backfill material around the culverts provide preferential low pathways. However, the excavations are expected to be into low permeability ALV and OXC; any effects are expected to be limited to the area surrounding the culvert, and as no abstractions or groundwater features are located in the vicinity of the culverts hence no operational impacts are expected, or mitigation required.

One retaining wall is planned within the study area. No design details are available at the time of writing; however, any associated works are expected to be less than 2 m depth and are not expected to impact on groundwater environment.

4.2.3 Groundwater quality

4.2.3.1 Mainline assets

The geo-environmental assessment for ch. 80+100 and ch. 88+000, [Aylesbury Link and Dismantled Great Central Railway Geo-Environmental Assessment Report] [21] identified a Moderate/Low risk to groundwater. Mitigation measures are outlined in the geo-environmental assessment.

For the mainline assets included in this HAR report, none of the LQ 13-07 impacts are relevant as the route of the former railway is remote to the HS2 route. The only relevant mitigation recommended is the appropriate management of seepages/groundwater ingress into cuttings and excavations in line with legal requirements.

The planned piling structures at Twyford Viaduct, Godington East Viaduct, Godington West Viaduct and the three overbridges poses a potential contamination risk associated with leakage into the surrounding groundwater from the degradation of concrete materials used for the piling structures.

As the planned piling will intersect the five formations (OXC, KLB, CB, FMB, WHL) identified across the study area. The hydraulic continuity between these formations and aquifer units across the study area is not fully understood. The piling process has potential to connect aquifer units which may not be in natural hydraulic continuity across the study area during construction. Piling may increase the contamination risk to the deeper aquifer units where a downward hydraulic gradient exists. Where deeper units are confined (e.g. WHL), piling may create upgradient flow paths between the units. These risks are assessed in the PRAs mentioned in Section 4.2.2.2.

4.2.3.2 Offline assets and structures

No risks to groundwater have been identified from the offline assets.

4.2.4 Changes in hydromorphology and flood risk

4.2.4.1 Offline assets

The route will cross tributaries of the Padbury Brook at the Godington West Culvert, Godington East Culvert, and the Barton Hartshorn Culvert. The culverts would convey the design flow, the 1 in 100-year flow plus an allowance for climate change, and maintain 1 m freeboard to track level during the 1,000-year flood event. As such, it is considered that the culverts would have a neutral impact on flow and water levels and, therefore, no significant impact.

Short watercourse diversions/realignments would be implemented at the Godington East Culvert, the Godington West Culvert and the Barton Hartshorn Culvert. These short (less than 20m) watercourse diversions/realignments are required at the culvert inlets and outlets to realign the existing channels with the culverts. The diversions/realignments would be limited to the minimum length required and would be designed to replicate the existing channel profiles and morphological characteristics where possible. As such, it is considered that the diversions would be unlikely to result in a significant impact on channel capacity, including during extreme and low flow/baseline events. However, as this is a key driver in the assessed Amber risk of deterioration for the WFD water body further studies may be required during the detailed design stage to confirm there are no negative impacts on the hydromorphology of the affected watercourses and no risk to the water body as a whole.

Where flow pathways are intercepted by the proposed Scheme, the drainage ditch network, which runs parallel to the proposed Scheme, would reconnect these watercourses back into the Padbury Brook and its tributaries. Drainage ditches and attenuation ponds have been designed to accommodate the 1-in-100 year plus a 40% allowance for climate change flood event. Following fluvial modelling, as outlined in the Padbury Brook Addendum to FLAR [36] and the Tributary of the Padbury Brook Addendum to FLAR [37], it is considered that there would be no significant impacts on flood risk from the proposed offline assets.

The surface water land drainage strategy will have been designed to intercept and convey overland flow to watercourses. It is assumed that the potential impact that the embankments and cuttings may have on the existing land drainage regime i.e. the interception of natural drainage catchments, will have been addressed within the strategy so that there would be no significant impacts on flows in the Padbury Brook and its tributaries.

4.2.4.2 Mainline assets

The Padbury Brook is classed as a heavily modified watercourse and is impacted by an existing flow restriction from the Great Central Mainline railway. This existing restriction to flow means that Padbury Brook has a wide floodplain, where floodwaters back-up behind the existing railway. Those areas of the Scheme that are located within the floodplain have the potential to result in an increased flood risk. There are sections of embankments included in the proposed Scheme that are located in areas of Flood Zone 2 and Flood Zone 3 and, therefore, would reduce the available flood storage volume of the floodplain. Five FCAs are proposed to provide equivalent compensation flood storage. The FCAs are hydraulic connected to the watercourse crossings and areas of lost floodplain and provide sufficient storage to eliminate any losses of floodplain.

Watercourse modelling has been undertaken to test the design of the proposed Scheme, including testing the watercourse crossing designs, function of FCAs and the overall flooding extents [36]. The watercourse modelling has identified no significant impacts (changes in flood extents or water levels) from the proposed Scheme. Further details can be found in the Padbury Brook Addendum to the FLAR [36] and the Tributary of the Padbury Brook Addendum to the FLAR [37].

The Scheme would require the realignment/diversion of several watercourses and hence there is the potential to have a negative impact on the hydromorphology of the affected reaches. Cowley Embankment would extend across a tributary of the Padbury Brook, with the crossing located less than 200m north of the Twyford Viaduct. This watercourse will be realigned to flow parallel to the embankment and would tie into its original course immediately downstream of the Twyford Viaduct. At the Twyford Viaduct and Godington East Viaduct short watercourse diversions are proposed so that the watercourses flow perpendicular to the viaduct, which would maintain access to the piers. At the Twyford Viaduct, a small tributary will be crossed and a 17 m diversion of this watercourse is required to realign it to flow beneath the viaduct. At the Godington West Viaduct, a pier is proposed in the channel, therefore a short watercourse diversion is required to realign the watercourse around the pier and to flow perpendicular to the viaduct. The watercourse diversion will be designed to replicate existing channel geometry where appropriate and the channel will tie back into the existing channels; however a minor impact on the channel hydromorphology, including water level and flow is predicted [36].

The diversions/realignments would be limited to the minimum length required and would be designed to replicate the existing channel profiles and morphological characteristics where possible. As such, it is considered that the diversions would be unlikely to result in a significant impact on channel capacity, including during extreme and low flow/baseline events. However, further studies may be required during the detailed design stage to further mitigate any negative impacts on the hydromorphology of the affected watercourses and to realise opportunities for channel enhancement where appropriate to improve the aquatic environment. For more details on the watercourse diversions, including impacts to flood risk and water levels, refer to the Padbury Brook Addendum to FLAR [36] and the Tributary of the Padbury Brook Addendum to FLAR [37].

The Padbury Brook WFD water body has been assessed as Amber risk of deterioration due to cumulative potential minor impacts which may lead to impacts on a water body scale.

4.2.5 Surface water quality

4.2.5.1 Mainline assets

Track drainage has been accepted by the EA as being of rainwater quality during normal situations and therefore the impact on receiving waters would be negligible. There would be a potential risk to receiving water quality in the unlikely event of an accidental spillage, however, this risk would be mitigated through drainage design and adherence to technical standards.

4.2.5.2 Offline assets

Land drainage has been accepted by the EA as being of rainwater quality during normal situations and, therefore, the impact on receiving waters would be negligible. However, highway drainage may contain contaminants and, therefore, would have the potential to impact receiving water quality.

There are no highway drainage discharges within the study reach, as such, no risks to surface water quality have been identified from the offline assets.

4.3 Summary of associated effects

4.3.1 Groundwater

The review of baseline hydrogeological conditions within the study area has identified that the area is underlain by Secondary and Unproductive Strata and one Principal Aquifer (WHL) at depth which is at its shallowest in the north of the study area (approximately 12m depth). Assessment of the potential effects from the proposed design of mainline and offline assets and structures are summarised as follows:

1. Where superficial and shallow formation deposits are dissected by cuttings or shallow excavate and replace, interception of localised groundwater is expected. Where the superficial deposits (Alluvium, Glaciofluvial deposits, Till, RTD) and OXC are excavated, any groundwater inflows will be restricted to more permeable horizons and lenses, which are likely to be limited and discontinuous and only requiring minor slope drainage provision. No special drainage or mitigation measures are envisaged. The proposed cuttings are not expected to cause any significant changes in aquifer groundwater conditions although possible shrinkage/desiccation effects could be expected;
2. Confined groundwater inflows may occur during excavation at Barton Hartshorn Embankment where excavation depths intersect the CB bedrock;
3. Piling is expected to intercept confined groundwater within the GOG, and the piling design/methodology should take account of these expected conditions. Artesian conditions are not expected based on the available data, but control measures should be available to manage artesian flows should they be encountered during piling;

4. Bored pile structures associated with the three viaducts and three overbridges will intersect the water table and extend into the WHL but are expected to result in negligible barrier effects to groundwater flow; and
5. Piling could create hydraulic connections between aquifer units which are hydraulically separated and/or confined which could impact on groundwater resource and groundwater quality during construction. A potential contamination risk exists associated with leakage into the surrounding groundwater from the long-term degradation of concrete materials used for the piling structures. This is addressed in Section 5.
6. The geo-environmental assessment for ch. 80+100 and ch. 88+000, [Aylesbury Link and Dismantled Great Central Railway Geo-Environmental Assessment Report] [21] identified a Moderate/Low risk to groundwater.
7. For the mainline assets included in this HAR report, none of the LQ 13-07 impacts are relevant as the route of the former railway is remote to the HS2 route. The only relevant mitigation recommended is the appropriate management of seepages/groundwater ingress into cuttings and excavations in line with legal requirements.

4.3.2 Surface water

The review of baseline surface water conditions within the study area and assessment of the associated effects from the proposed design of mainline and offline assets and structures can be summarised as follows:

1. The track crosses the Padbury Brook and its tributaries several times along this study reach and embanked sections of track are located within the floodplain. Therefore, there is the potential for the Scheme to result in an increased flood risk. However, detailed flood modelling has shown that the proposed design, which includes the provision of a number of FCAs and culverted sections, would not significantly impact flows or water levels and the asset passes HS2 Technical Standards for Flood Risk;
2. The embankments and cuttings introduced in the proposed Scheme intercept the natural drainage catchments of the Padbury Brook and its tributaries and, therefore, there is a potential to impact the flow regime in these watercourses. However, it is assumed that this would have been addressed as part of the land drainage strategy and addressed to ensure that there would be no significant impact on the flow conditions in these watercourses;
3. The watercourse diversions/realignments that are proposed at several locations would impact the hydromorphology of the affected reaches. However, it is understood that the diversions/realignments would be designed to replicate the existing channel profiles and morphological characteristics where possible and, therefore, it is considered there would be no significant impacts on an individual basis however the Padbury Brook WFD water body has been assessed as Amber risk of deterioration due to cumulative impacts. Further studies may be required alongside ongoing liaison with the Environment Agency during the detailed design stage to confirm this and additional mitigation measures may need to be included to prevent deterioration; and
4. There are no highway drainage discharges within the current study area and, given that track and land drainage are considered to be of rainwater quality, significant impacts to surface water quality are not expected.

5 Detailed design and mitigation requirements

5.1 Introduction

Mitigation is typically required as a part of detailed design to minimise any effects on the water environment and to ensure that the scheme is, where possible, inherently compliant with the objectives of protecting both surface water and groundwater bodies. Where identified in the assessment above, mitigation is described in the following sections.

Groundwater levels and surface water flows are likely to be impacted by climate change through the lifespan of the planned infrastructure. This may result in both groundwater level and/or flow increases and reductions. Inadequate data is currently available to undertake detailed assessment to quantify these potential changes; design works should however include adequate mitigation to allow for such potential long-term variations.

5.2 Mitigation requirements

The groundwater and design related interdependencies outlined in Section 4 detail the requirement for mitigation measures necessary for this section of the route.

5.2.1 Groundwater levels and flows

Some interception of groundwater is expected across the cutting and excavate and replace areas. However, any inflow to the cuttings and excavations are expected to be limited and will likely only require minor slope drainage provision. No impact on the identified groundwater features is anticipated and no special measures are required.

Mitigation measures may be required during excavation at Barton Hartshorn Embankment where excavation depths intersect the CB bedrock. If groundwater is encountered, potential groundwater control techniques can be assessed using CIRIA C750 'Groundwater Control: Design and Practice' guidance [45]. Design of the replacement fill (density and thickness) will also need to be considered to take account of any hydrostatic pressure and potential for uplift.

5.2.2 Groundwater quality

Groundwater quality may be impacted by degradation of concrete materials used in piling structures where groundwater is intercepted, particularly with respect to the WHL Principal Aquifer. Selection of appropriate concrete materials during scheme design will ensure there is no premature degradation of concrete used in construction.

Piling risk assessments will be undertaken and safeguards designed per asset in line with HS2 Code of Construction Practice [46] and Technical Standard for Groundwater Protection [47]. Piling risk assessments are currently being undertaken as follows:

- PB-03 – Twyford Viaduct (1MC06-CEK-EV-REP-CS06_CL10-000087);
- PB-04 - Godington West Viaduct & Godington East Viaduct (1MC06-CEK-EV-REP-CS06_CL10-000088); and
- PB-05 - Restricted Byway PBI/5A Accommodation Overbridge (1MC06-CEK-EV-REP-CS06_CL10-000086).

5.2.3 Aquifer interconnection

Aquifer interconnection may be affected by piling. Piling risk assessments will be required for all piling structures within the study area and best practices adopted to minimise impacts on the water environment including the expected confined conditions within the GOG formations.

5.2.4 Hydromorphology and flood risk

As part of the scheme design there are embedded mitigation measures to manage the risk to surface waters. The following general measures will be in place to manage the impacts to hydromorphology and flood risk:

- The surface water land drainage design strategy is such that, where natural drainage catchments are intercepted by the Scheme, the surface waters would be captured by the drainage network and discharged to the same receiving watercourse as would occur under existing conditions;
- Provision of FCAs to offset any loss of fluvial floodplain resulting from the scheme;
- Provision of replacement storage and surface water attenuation facilities to restrict peak surface water runoff rates to existing greenfield rates; and
- Ensuring watercourse diversions/realignments are designed to replicate existing channel profiles and morphological characteristics where possible and appropriate, and to incorporate additional channel enhancements where appropriate. There should therefore be no net loss of the watercourses due to realignments or by implementing the enhancements and mitigation measures required to avoid deterioration.

5.2.5 Surface water quality

The surface water drainage design adheres to technical standards that have been developed to ensure that there will be negligible impact on surface water quality. Mitigation measures embedded in the drainage design, such as oil interceptors/separators, filter drains and attenuation ponds incorporating impermeable liners, would minimise the risk to water quality in the unlikely event of accidental spillages from the railway and associated infrastructure.

6 Conclusions and recommendations

6.1 Conclusions

This report has defined the baseline hydrological and hydrogeological conditions associated with the HS2 Scheme between Twyford Viaduct and Barton Hartshorn Embankment. The study area includes a series of mainline assets and offline assets and structures that cross/interact with several surface water and groundwater bodies. This report provides a review of that baseline condition and how the Proposed Scheme within the study area may affect those conditions.

The review of baseline hydrogeological conditions within the study area has identified that the area is underlain by Secondary and Unproductive Strata and one Principal Aquifer (WHL) at depth which is at its shallowest in the north of the study area.

Potential design and groundwater related interdependencies have been identified that include the interception of groundwater across cuttings, intersection of confined aquifer conditions and groundwater quality effects associated with piling. This report does not address construction phase works, but it does identify that the piling process is expected to encounter confined groundwater within the GOG formations which may require control measures. This will be addressed in separate piling risk assessments.

The geo-environmental assessment for ch. 80+100 and ch. 88+000, [Aylesbury Link and Dismantled Great Central Railway Geo-Environmental Assessment Report] [21] identified a Moderate/Low risk to groundwater. Mitigation measures are outlined in the geo-environmental assessment. For the mainline assets included in this HAR report, none of the LQ 13-07 impacts are relevant as the route of the former railway is remote to the HS2 route. The only relevant mitigation recommended is the appropriate management of seepages/groundwater ingress into cuttings and excavations in line with legal requirements.

This assessment has identified several surface water features present across the study area that may be subject to design and surface water related dependencies. These include:

1. The track will cut across the natural drainage catchments of the Padbury Brook and several of its tributaries, potentially impacting the flow regime in these watercourses. However, it is understood that the drainage strategy is such that surface waters would be captured by the drainage network and discharged to the same receiving watercourse as would occur under existing conditions, thus mitigating the risk of impacting flows in these watercourses;
2. The proposed Scheme route would cross the Padbury Brook and several of its tributaries along this reach and therefore there is the potential to impact flood risk. However, the design of the viaducts and culverts is such that, with the inclusion of FCAs, no significant impact on flood risk is predicted;
3. Watercourse diversions and realignments that are required at several locations have the potential to impact the channel hydromorphology and aquatic habitats. However, it is understood that watercourse diversions/realignments would be designed to replicate the existing channel profiles and morphological characteristics where possible, therefore, it is considered there would be no significant impact; and
4. Potential for surface water discharges from the track and land drainage systems to impact the water quality of the receiving surface waterbodies. It has been accepted by the Environment Agency that track and land drainage can be assumed to be of rainwater quality, therefore, there would be no significant impact on the receiving waters. Mitigation measures embedded in the drainage design would minimise the risk to water quality in the unlikely event of accidental spillages from the railway and associated infrastructure.

6.2 Recommendations

To address surface water and groundwater and the design related interdependencies identified in this assessment, mitigation and/or further action is proposed. These measures are summarised in Table 26. For completeness, Table 26 includes <u>all</u> assets and shows where no design change or mitigation is anticipated.

Table 26: Summary of potential impacts to groundwater and surface waters and their risks

Operational based interdependencies	Asset/feature	Risk	Mitigation measure
Groundwater levels and flow	Cowley Embankment	Potential interception of perched groundwater during shallow "excavate and replace" works; the excavations are into low permeability superficial strata and underlying geological strata as such no significant risk has been identified.	None required.
	Godington East Embankment		
	Godington West Embankment		
	Chetwode Embankment		
	Barton Hartshorn Embankment		
	Barton Hartshorn Embankment	Potential interception of groundwater from the GOG aquifer where the excavation depth intersects the CB bedrock.	Mitigation measures are required during excavation. This relates to temporary works, outside the scope of this report. Design of the replacement fill (density and thickness) will need to considered to account for hydrostatic pressure and potential for uplift.
	Chetwode Cutting	Interception of saturated clay strata	Some slope drainage (no special measures) required. Geotechnical control measures may be required to control potential desiccation effects.
	Twyford Cutting		
	Godington West Viaduct	Risk of piling affecting aquifer interconnectivity	The associated risk is considered minimal and mitigation measures are not considered necessary. No impact on the identified groundwater features is anticipated.
	Godington East Viaduct		
	Twyford Viaduct		
Groundwater quality	Godington East Viaduct	Risk to surrounding groundwater quality and nearby abstractions related to degradation of piling material. Risk is considered low.	Risks minimised by selection of appropriate concrete materials at design stage. Piling risk assessments will be undertaken and safeguards designed per asset in line with HS2 Code of Construction Practice [46] and Technical Standard for Groundwater Protection [47].
	Godington West Viaduct		
	Twyford Viaduct		
Hydromorphology and flood risk	Cowley Embankment	Potential to increase flood levels and modify existing flow pathways. Potential risk of deterioration (Amber) of the Padbury Brook WFD surface water body due to cumulative minor impacts to hydromorphology (surface water issues only).	No additional mitigation required, following implementation of embedded mitigation measures: The viaducts pass all HS2 Technical Standards with respect to flood risk. Where embankments and viaducts extend into the floodplain, FCAs are provided to provide equivalent storage and ensure no increase in flood risk. Where embankments and cuttings bisect existing surface water flow paths, land drainage is designed so that surface waters would be captured by the drainage network and discharged to the same receiving watercourse as would occur under existing conditions Watercourse diversions to be designed to provide enhancements where appropriate to the satisfaction of the EA. Cumulative impacts of the scheme will be addressed through design of surface watercourses to ameliorate the current risk of deterioration rating for the Padbury Brook WFD water body
	Godington East Embankment		
	Godington East Viaduct		
	Godington West Embankment		
	Godington West Viaduct		
	Chetwode Embankment		
	Chetwode Cutting		
	Barton Hartshorn Embankment		
Surface water quality	All surface waterbodies	Risk to receiving water quality in the event of an accidental spill.	Drainage design should be in accordance with technical standards, therefore, there would be no requirement for further mitigation. Any departure from technical standards should be reviewed by the relevant team.

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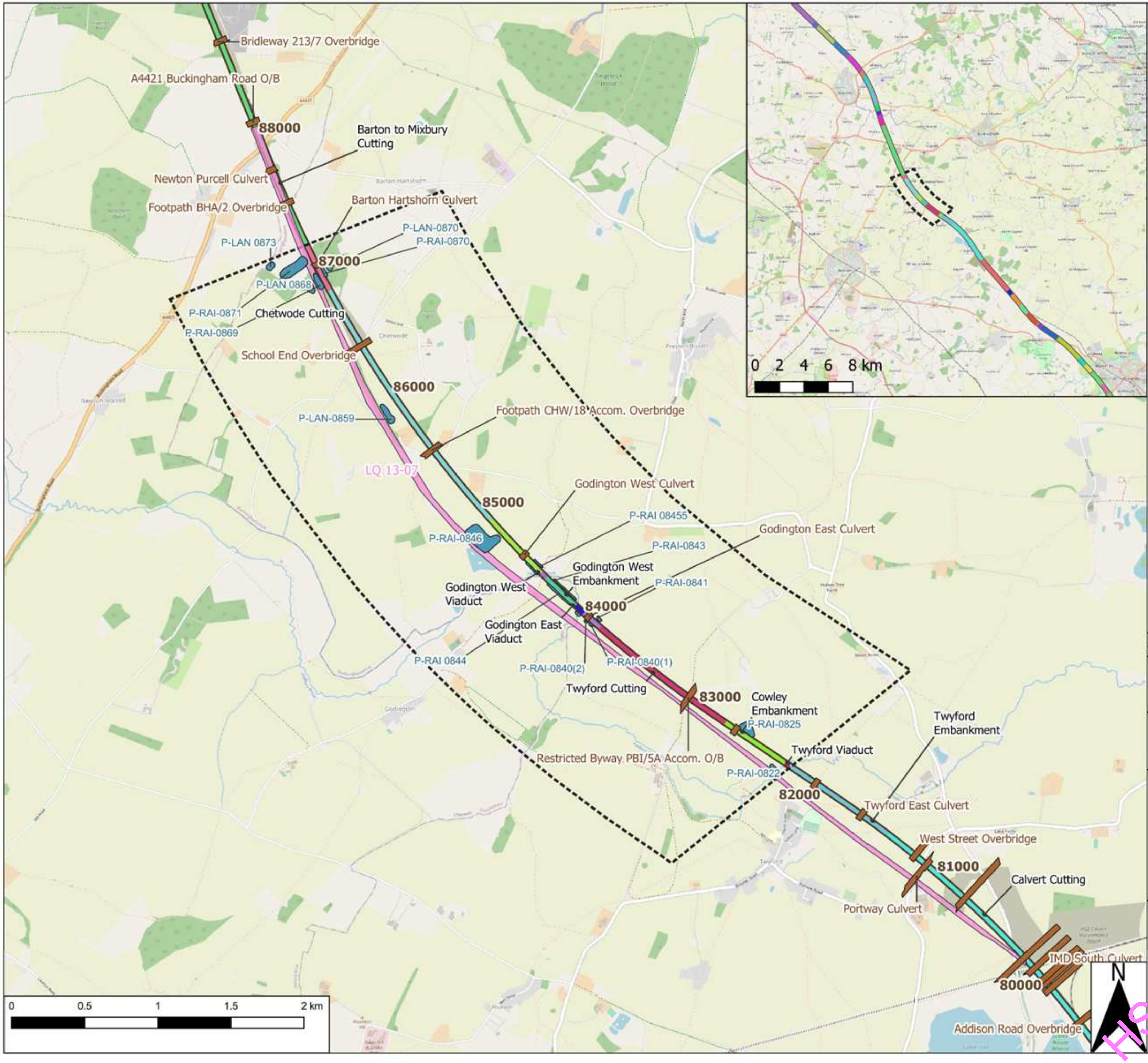
FIGURES



Legend

Assets within study Area

- Twyford Viaduct
- Cowley Embankment
- Twyford Cutting
- Godington East Embankment
- Godington East Viaduct
- Godington West Embankment
- Godington West Viaduct
- Chetwode Embankment
- Chetwode Cutting
- Barton Hartshorn Embankment
- Study Area

Assets outside study area

- Calvert Cutting
- Twyford Embankment
- Barton to Mixbury Cutting

- Land Quality Sites
- Culverts and Overbridges
- Ponds

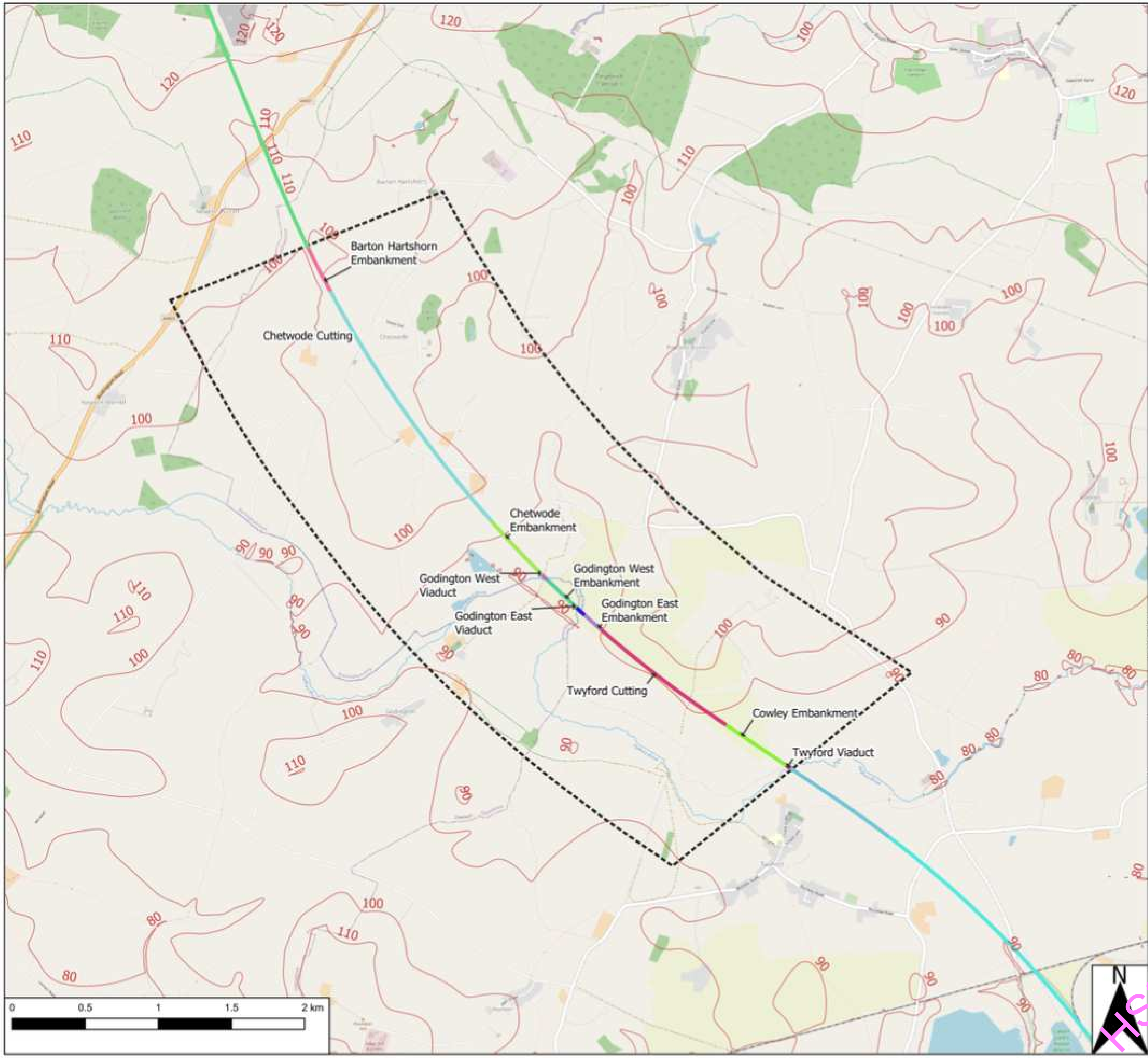
Source: © OpenStreetMap contributors

Main Map Scale - 1:25,000

Figure 1: Site Location Plan

Twyford Viaduct to Barton Hartshorn Embankment

1MC06-CEK_EV-REP-CS06_CL10-000026 Rev.C03



Legend

- Twyford Viaduct
- Cowley Embankment
- Twyford Cutting
- Godington East Embankment
- Godington East Viaduct
- Godington West Embankment
- Godington West Viaduct
- Chetwode Embankment
- Chetwode Cutting
- Barton Hartshorn Embankment
- Study Area
- Topographical Contours (mAOD)

Source:
- Contains OS data © Crown copyright and database right 2020
- © OpenStreetMap contributors

Map Scale - 1:25,000

Figure 2: Topography within the study area

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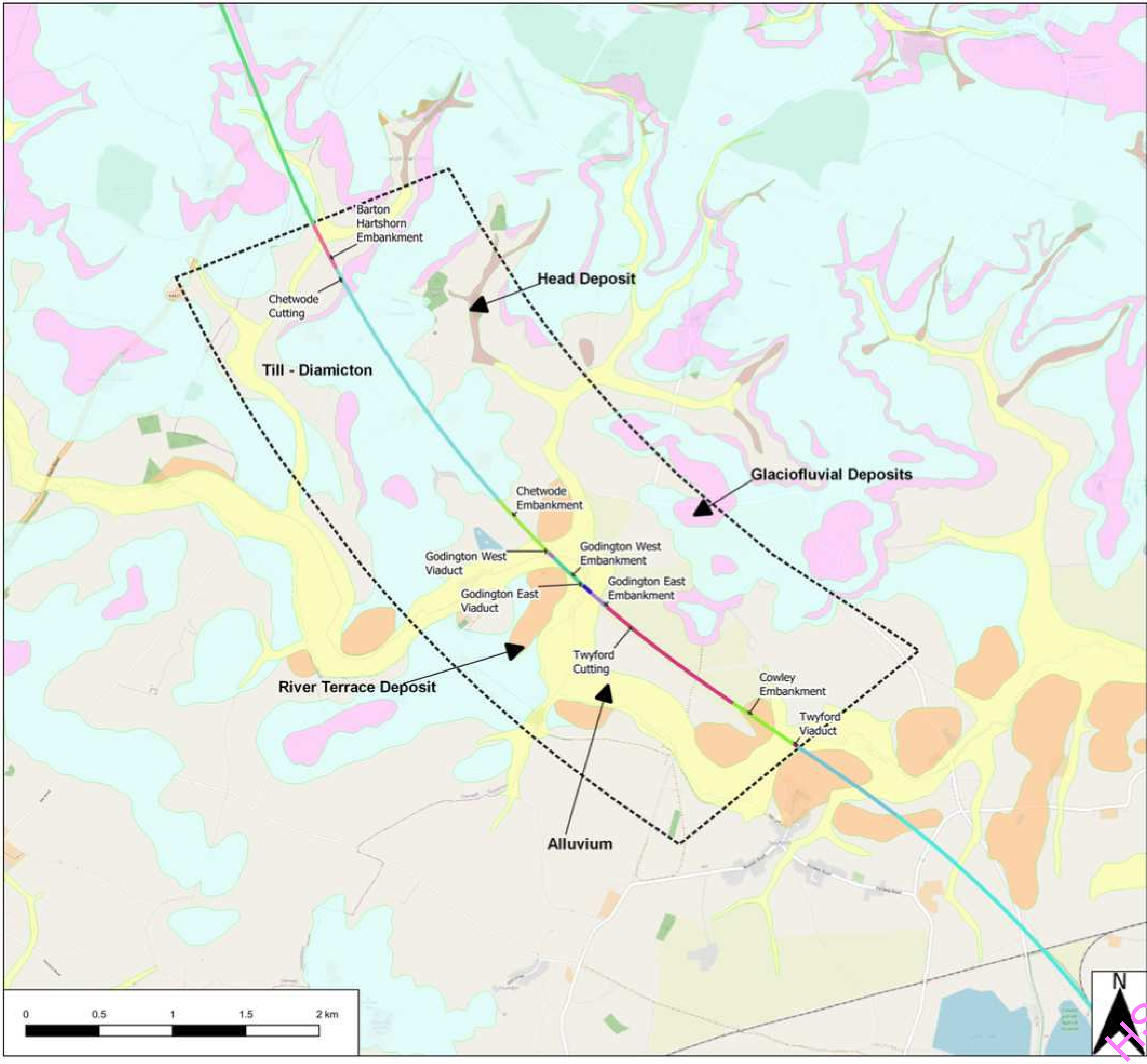

Source:
- Contains British Geological Survey materials © UKRI 2020 (1:50,000 scale superficial deposits)
-© OpenStreetMap contributors

Map Scale - 1:25,000

Figure 3: Superficial Deposit within Study Area

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Rev C03

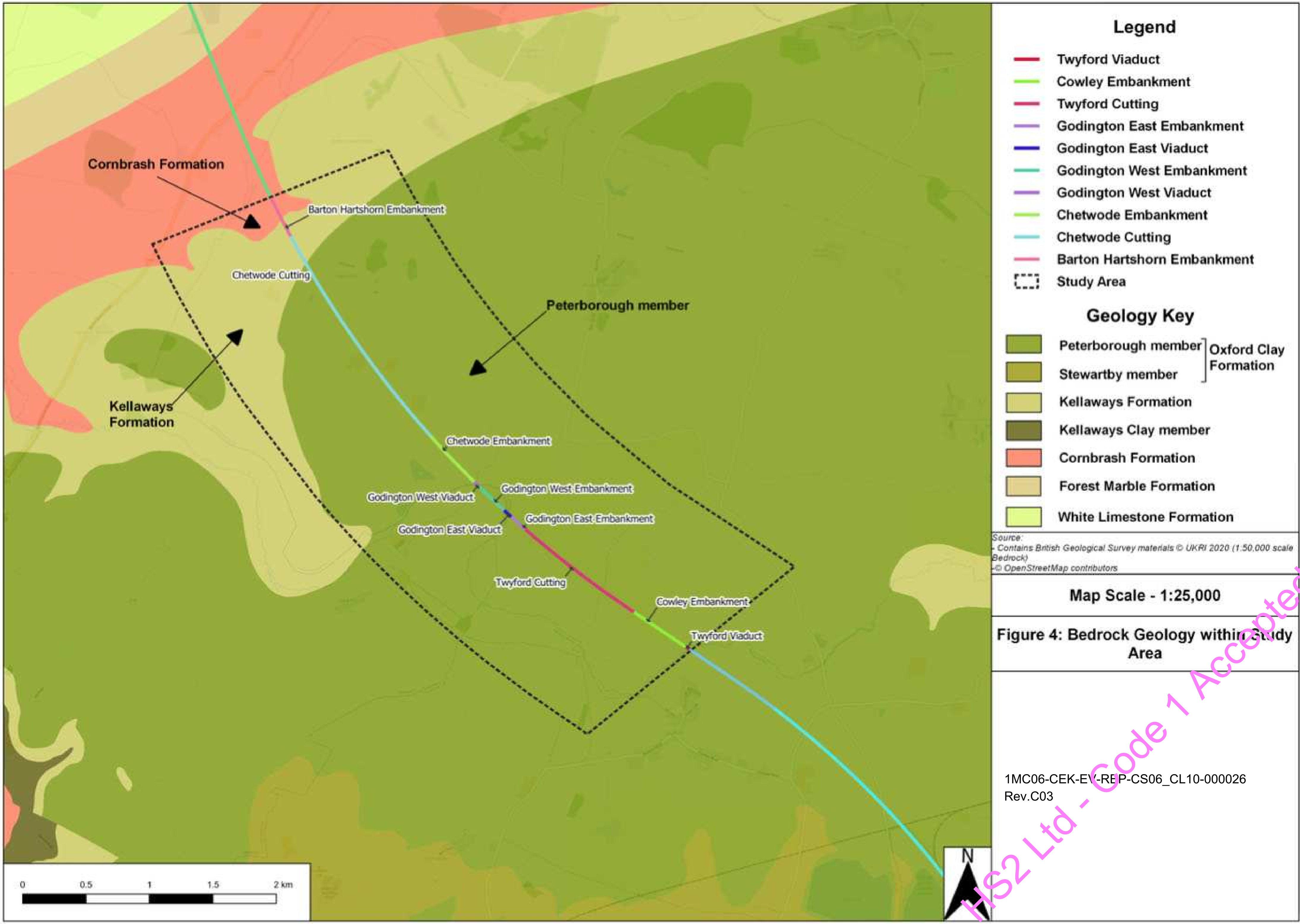

Figure 4: Bedrock Geology within Study Area

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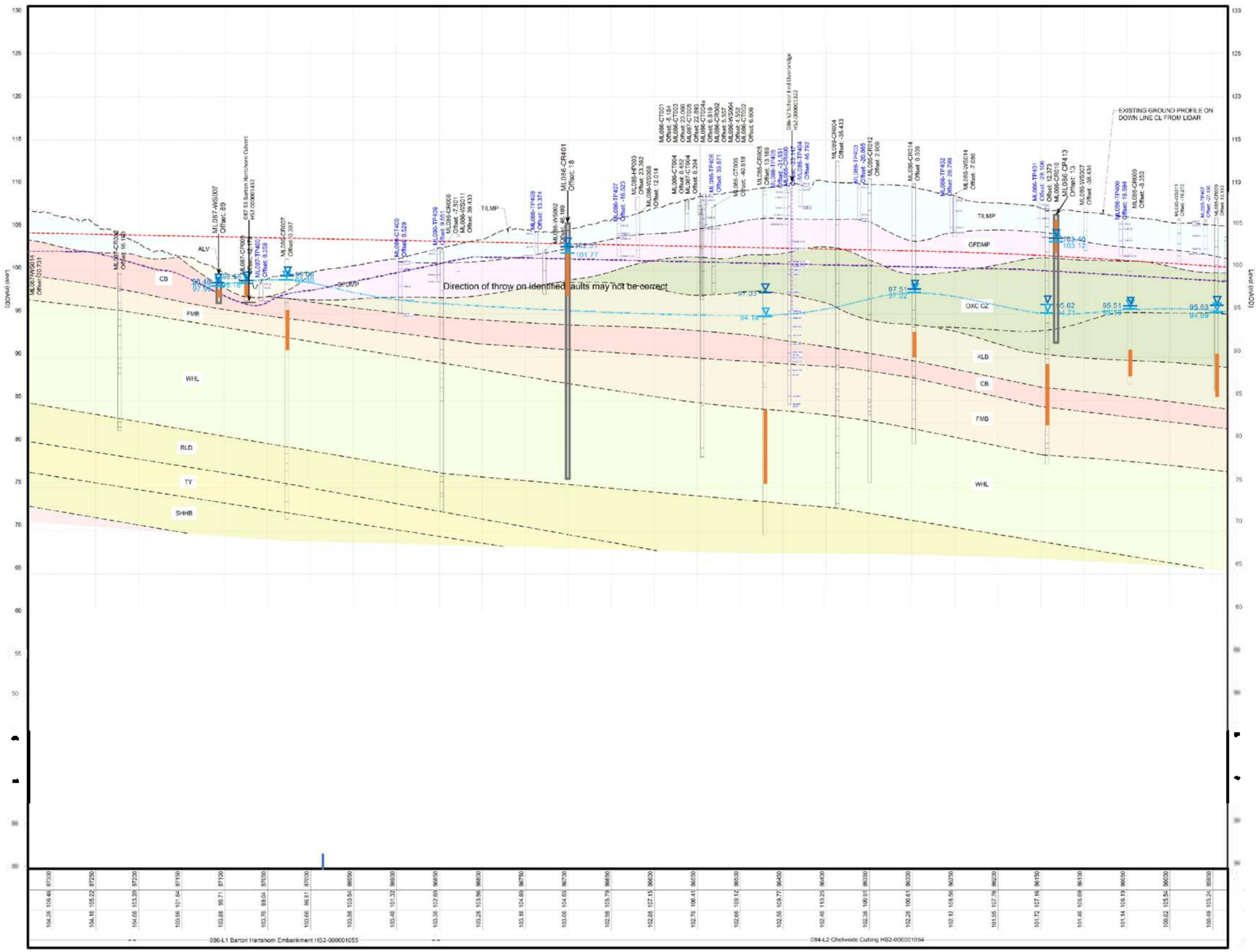

Legend

Maximum recorded groundwater level (m AOD)

Screened interval

Average recorded groundwater level (m AOD)

Proposed rail level

Maximum base of excavation for each asset (where the maximum recorded depth at any one point along the asset is assumed for whole length of the asset)

Inferred potentiometric surface (m AOD)

Maximum piling depths of overbridges

Maximum depth of culvert

Geology Key

ALV	Alluvium
TILLMP	Till, Mid Pleistocene
GFDMP	Glaciofluvial Deposit, Mid Pleistocene
OXC	Oxford Clay Formation
KLB	Kellaways Formation
CB	Cornbrash Formation
FMB	Forest Marble Formation
WHL	White Limestone Formation
RLD	Rutland Formation
TY	Taynton Limestone Formation
SHHB	Sharp's Hill Formation

Note: The inferred potentiometric surface is for the Great Oolite Group formations which for the purpose of this study are assumed to act as one hydraulic unit and are confined by the overlying KLB and OXC. Localised and discontinuous perched groundwater may additionally be present within the superficial deposits and shallow OXC as indicated on individual boreholes where data exists

Figure 5a: Barton Hartshorn Embankment to Chetwode Cutting

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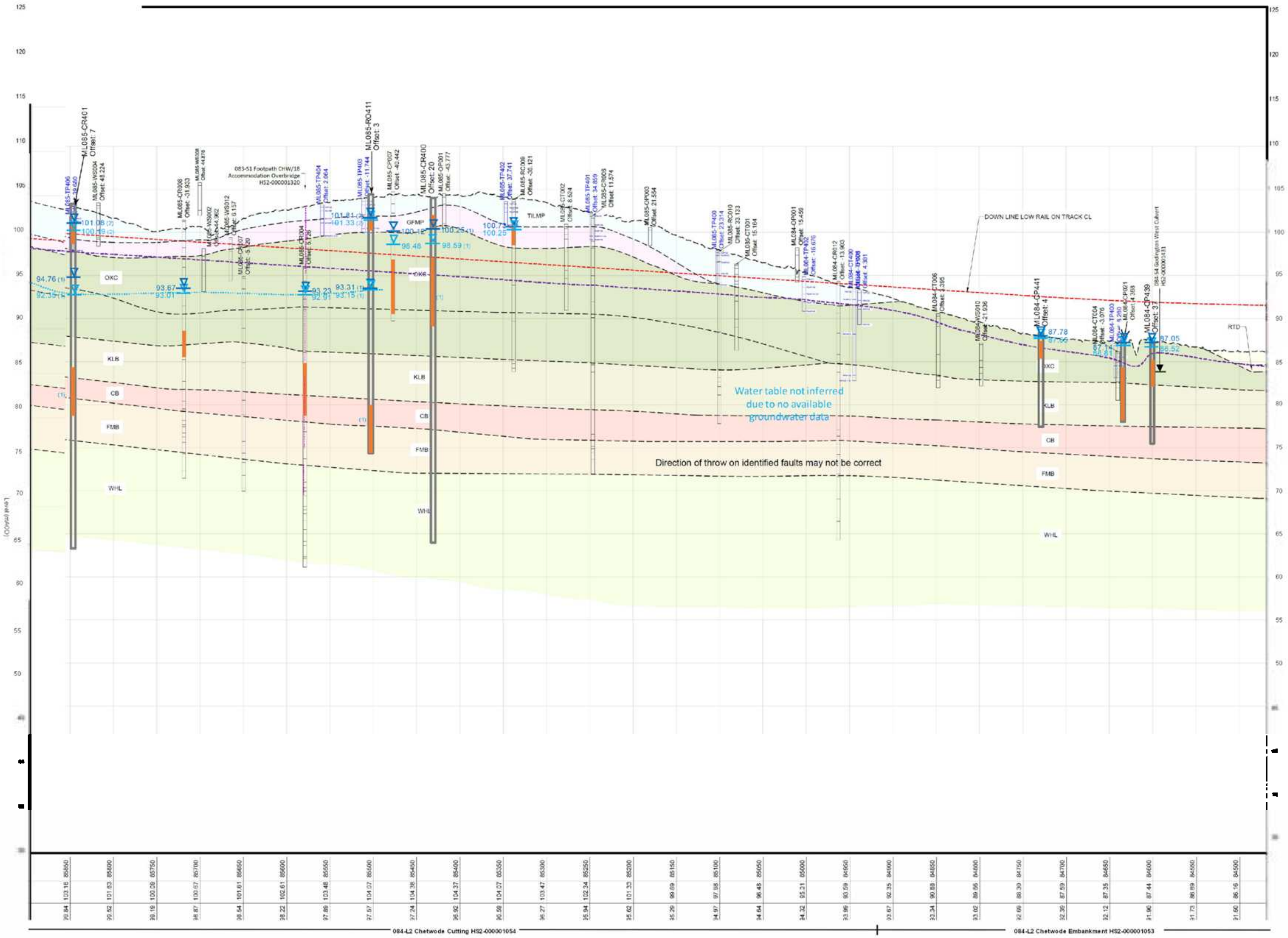


Legend

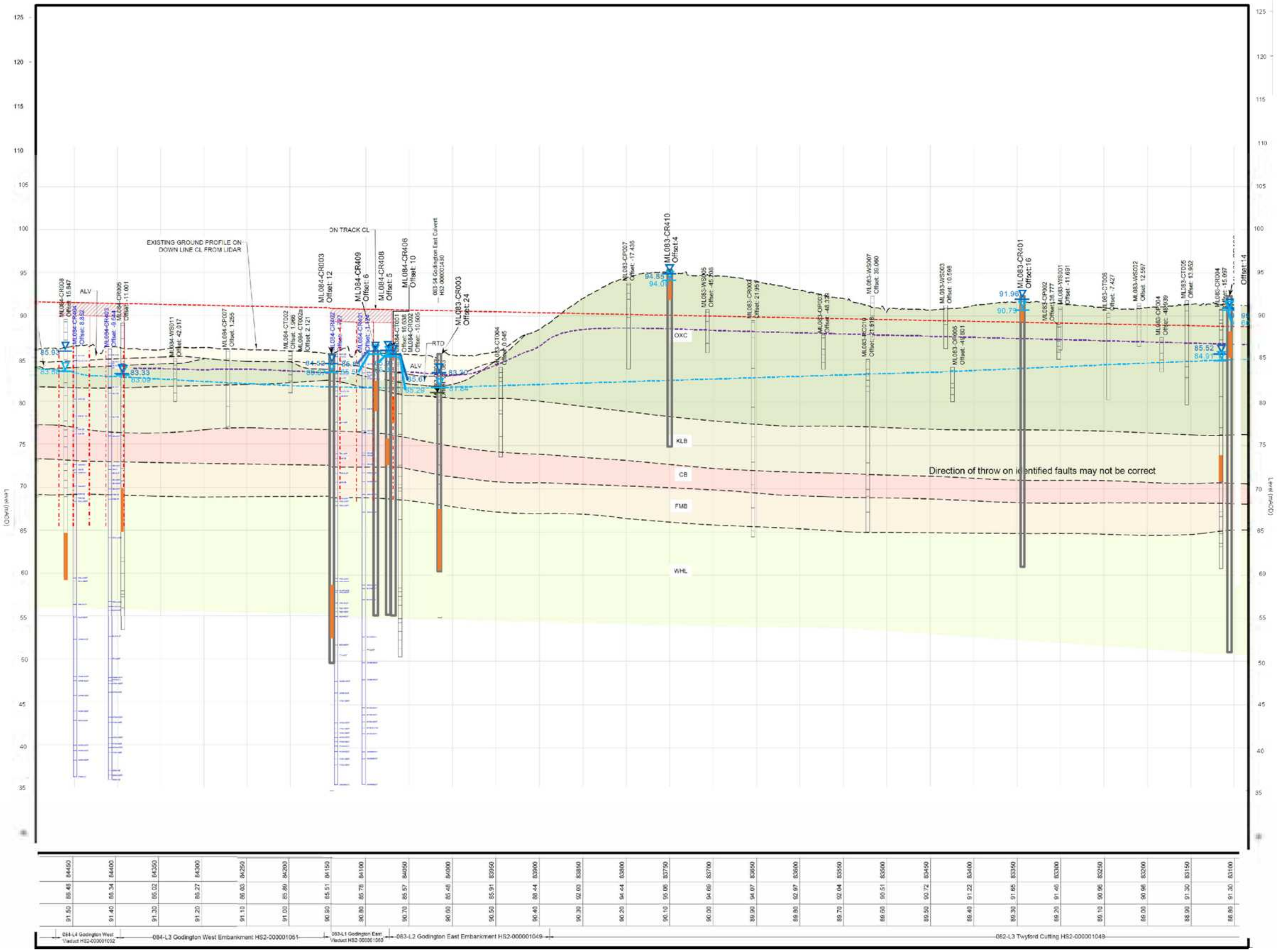
- Maximum recorded groundwater level (m AOD)
- Screened interval
- Average recorded groundwater level (m AOD)
- Proposed rail level
- Maximum base of excavation for each asset (where the maximum recorded depth at any one point along the asset is assumed for whole length of the asset)
- Inferred potentiometric surface (m AOD)
- Maximum piling depths of overbridges
- Maximum depth of culvert

Geology Key

ALV	Alluvium
RTD	River Terrace Deposit
TILLMP	Till, Mid Pleistocene
GFDMP	Glaciofluvial Deposit, Mid Pleistocene
OXC	Oxford Clay Formation
KLB	Kellaways Formation
CB	Cornbrash Formation
FMB	Forest Marble Formation
WHL	White Limestone Formation

Note: The inferred potentiometric surface is for the Great Oolite Group formations which for the purpose of this study are assumed to act as one hydraulic unit and are confined by the overlying KLB and OXC. Localised and discontinuous perched groundwater may ***additionally be present within the superficial deposits and shallow OXC as indicated on individual boreholes where data exists***

Figure 5b: Chetwode Cutting to Chetwode Embankment



Legend

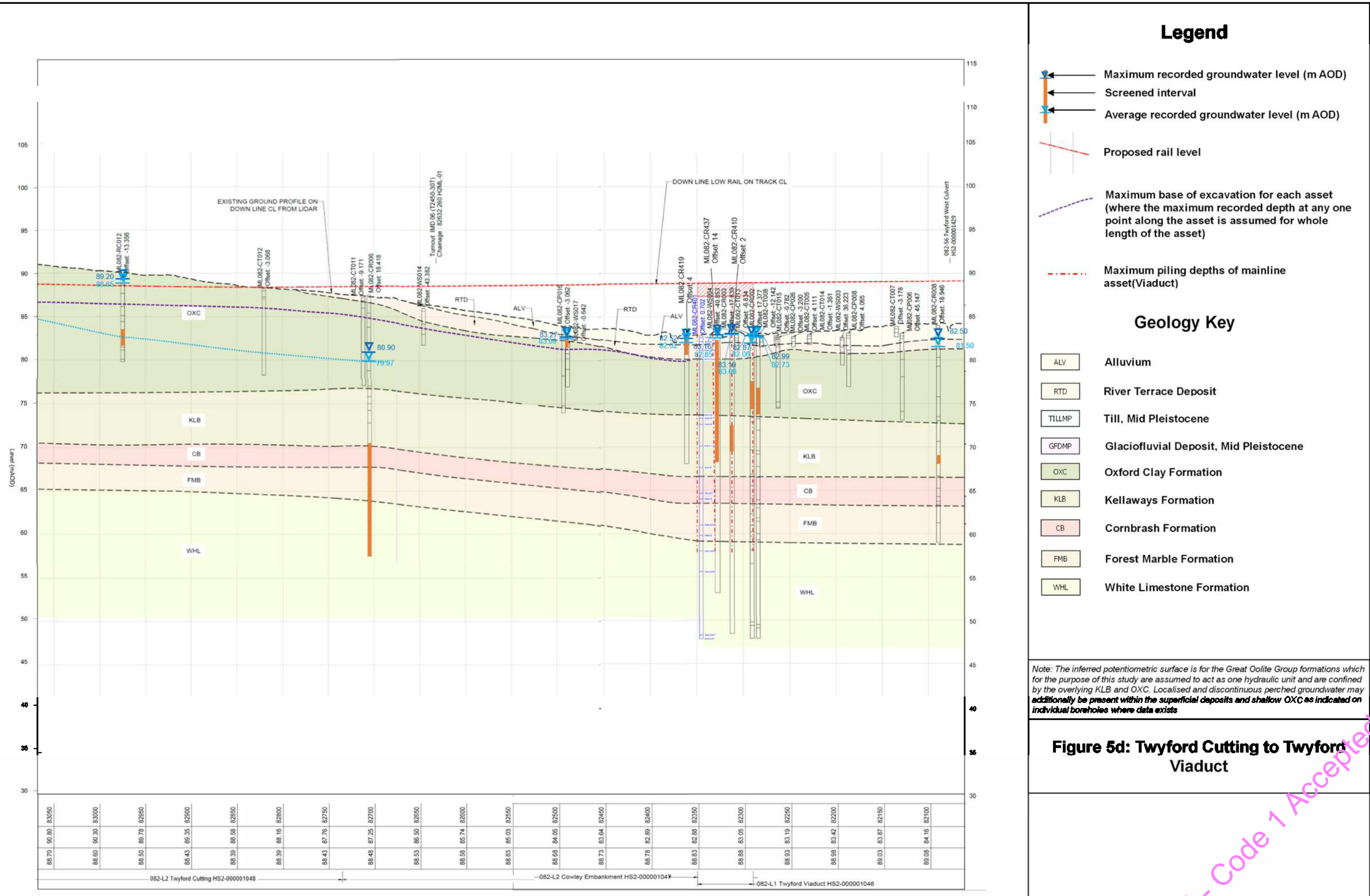
- Maximum recorded groundwater level (m AOD)
- Screened interval
- Average recorded groundwater level (m AOD)
- Proposed rail level
- Maximum base of excavation for each asset (where the maximum recorded depth at any one point along the asset is assumed for whole length of the asset)
- Inferred potentiometric surface (m AOD)
- Maximum piling depths of overbridges
- Maximum piling depths of mainline asset(Viaduct)
- Maximum depth of culvert

Geology Key

ALV	Alluvium
RTD	River Terrace Deposit
TILLMP	Till, Mid Pleistocene
GFDMP	Glaciofluvial Deposit, Mid Pleistocene
OXC	Oxford Clay Formation
KLB	Kellaways Formation
CB	Cornbrash Formation
FMB	Forest Marble Formation
WHL	White Limestone Formation

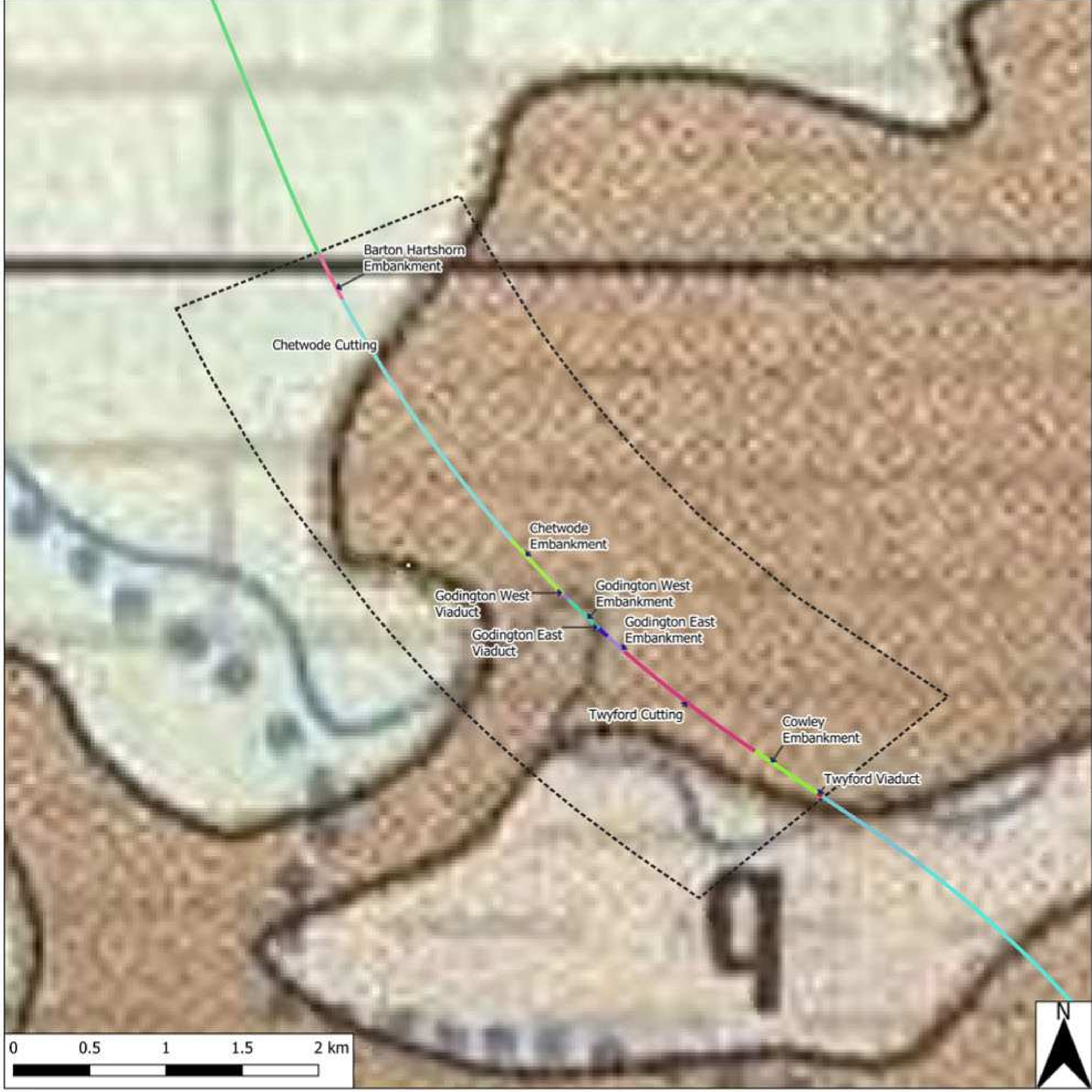
Note: The inferred potentiometric surface is for the Great Oolite Group formations which for the purpose of this study are assumed to act as one hydraulic unit and are confined by the overlying KLB and OXC. Localised and discontinuous perched groundwater may additionally be present within the superficial deposits and shallow OXC as indicated on individual boreholes where data exists

Figure 5c: Godington West Viaduct to Twyford Cutting



Note: The inferred potentiometric surface is for the Great Oolite Group formations which for the purpose of this study are assumed to act as one hydraulic unit and are confined by the overlying KLB and OXC. Localised and discontinuous perched groundwater may additionally be present within the superficial deposits and shallow OXC as indicated on individual boreholes where data exists

Figure 5d: Twyford Cutting to Twyford Viaduct



Legend

- Twyford Viaduct
- Cowley Embankment
- Twyford Cutting
- Godington East Embankment
- Godington East Viaduct
- Godington West Embankment
- Godington West Viaduct
- Chetwode Embankment
- Chetwode Cutting
- Barton Hartshorn Embankment
- Study Area
- Regions underlain by unproductive strata without groundwater except at shallow depth
- Locally important aquifers
- Concealed aquifers,aquifers of limited potential regions without significant groundwater
- Oxford Clay and Kellaways Beds
- Conbrash and Great Oolite of Lincolnshire
- Quarternary: coastal and fluviatile alluvium
- Perennial river or stream
- Hydrometric area boundary

Source: Contains British Geological Survey materials © UKRI [1977]

Scale - 1:25,000

Figure 6: BGS Hydrogeological map, reproduced for the Study Area

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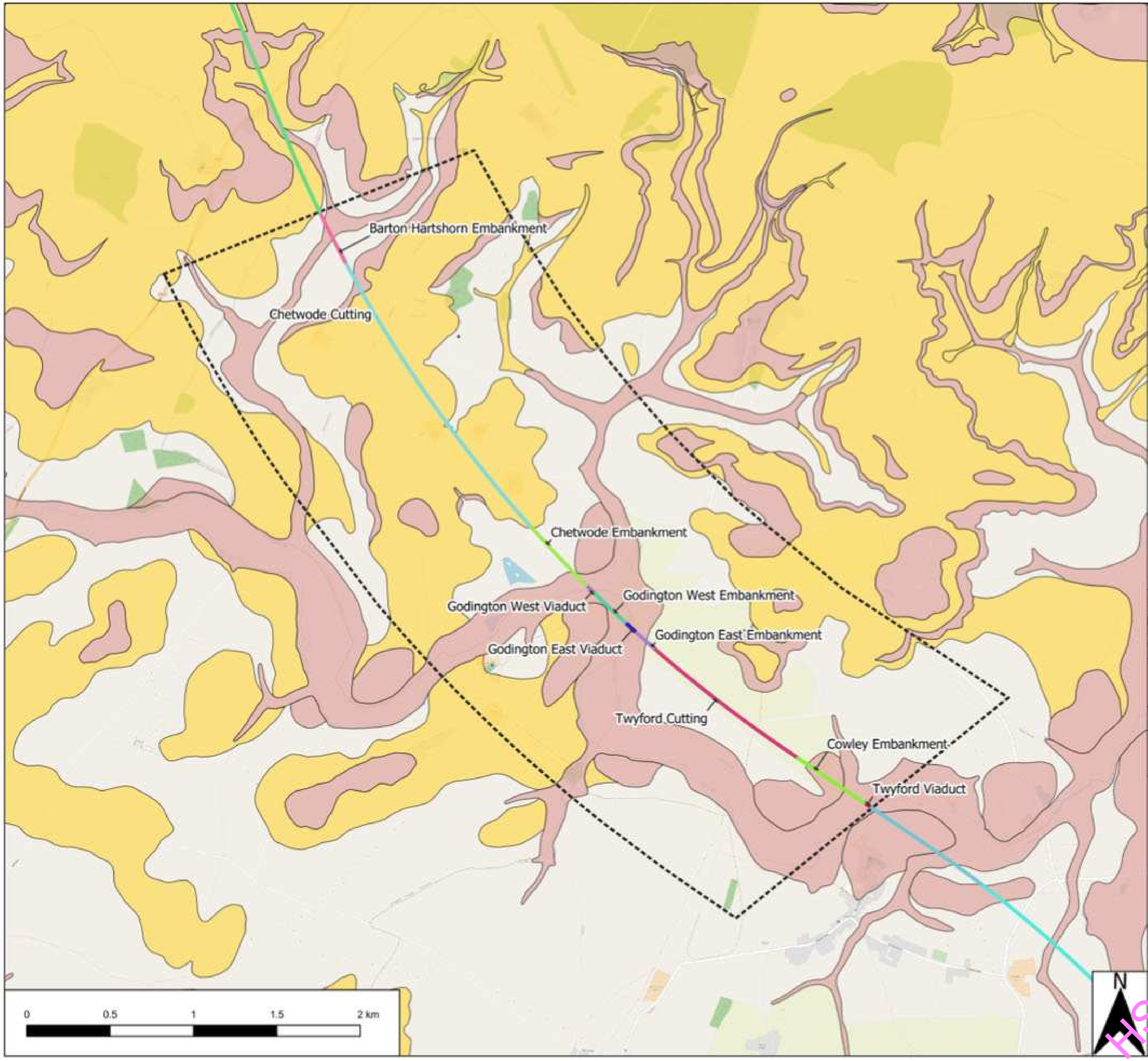

Legend

- Twyford Viaduct
- Cowley Embankment
- Twyford Cutting
- Godington East Embankment
- Godington East Viaduct
- Godington West Embankment
- Godington West Viaduct
- Chetwode Embankment
- Chetwode Cutting
- Barton Hartshorn Embankment
- Study Area

Aquifer Designation - Superficial Deposit

- Secondary (undifferentiated) Aquifer
- Secondary A Aquifer
- Unproductive Strata

Source:
- British Geological Survey "Aquifer Designation Map Superficial Drift" [GIS polygon data for HS2], Scale 1:50,00. Updated 2020 Producer Enviroment Agency (EA), Natural Resources Wales and BGS
- © OpenStreetMap contributors

Map Scale - 1:22,000

Figure 7: Aquifer Designation of Superficial Deposit in relation to Study Area

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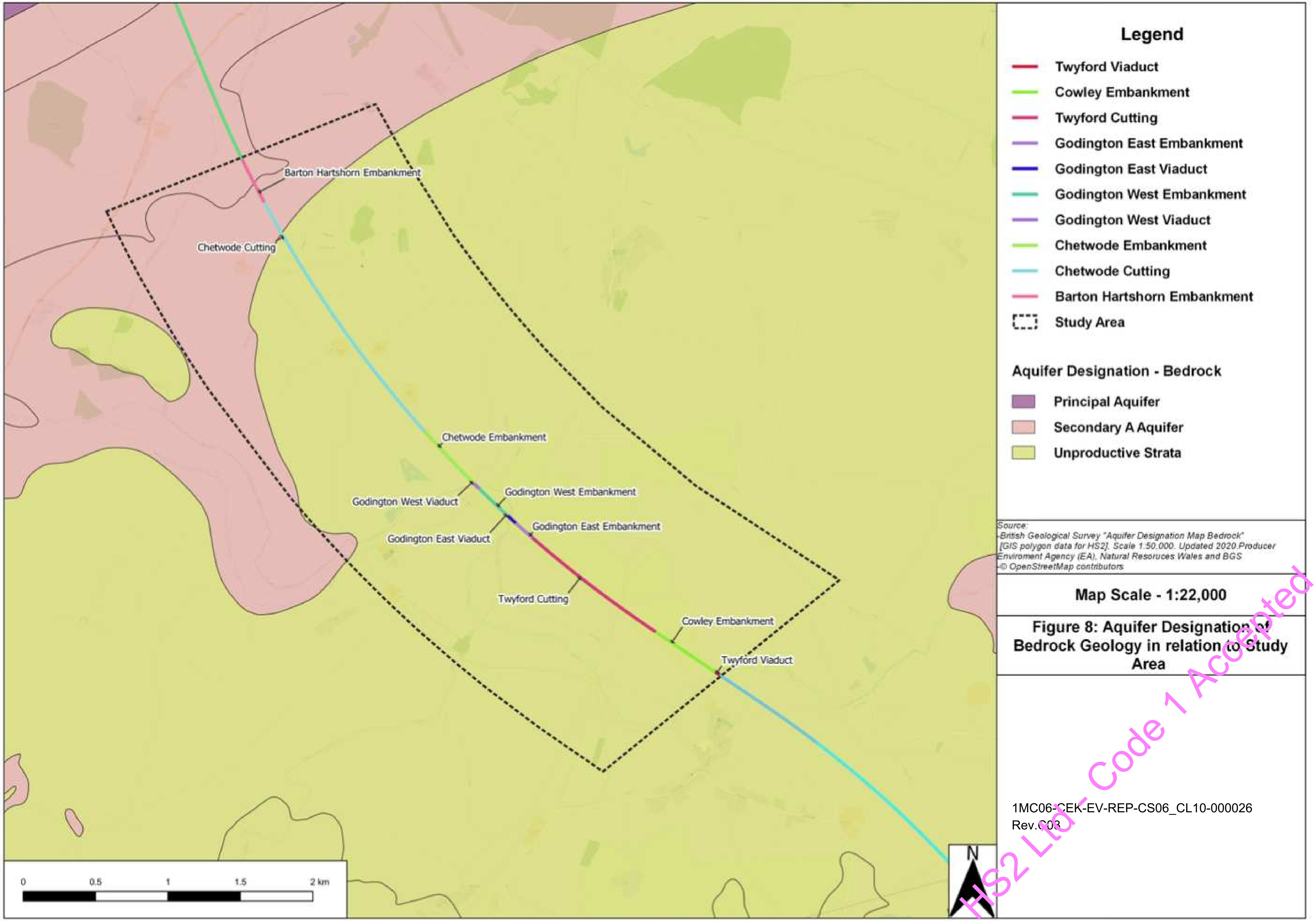

Figure 8: Aquifer Designation of Bedrock Geology in relation to Study Area

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Rev.C03

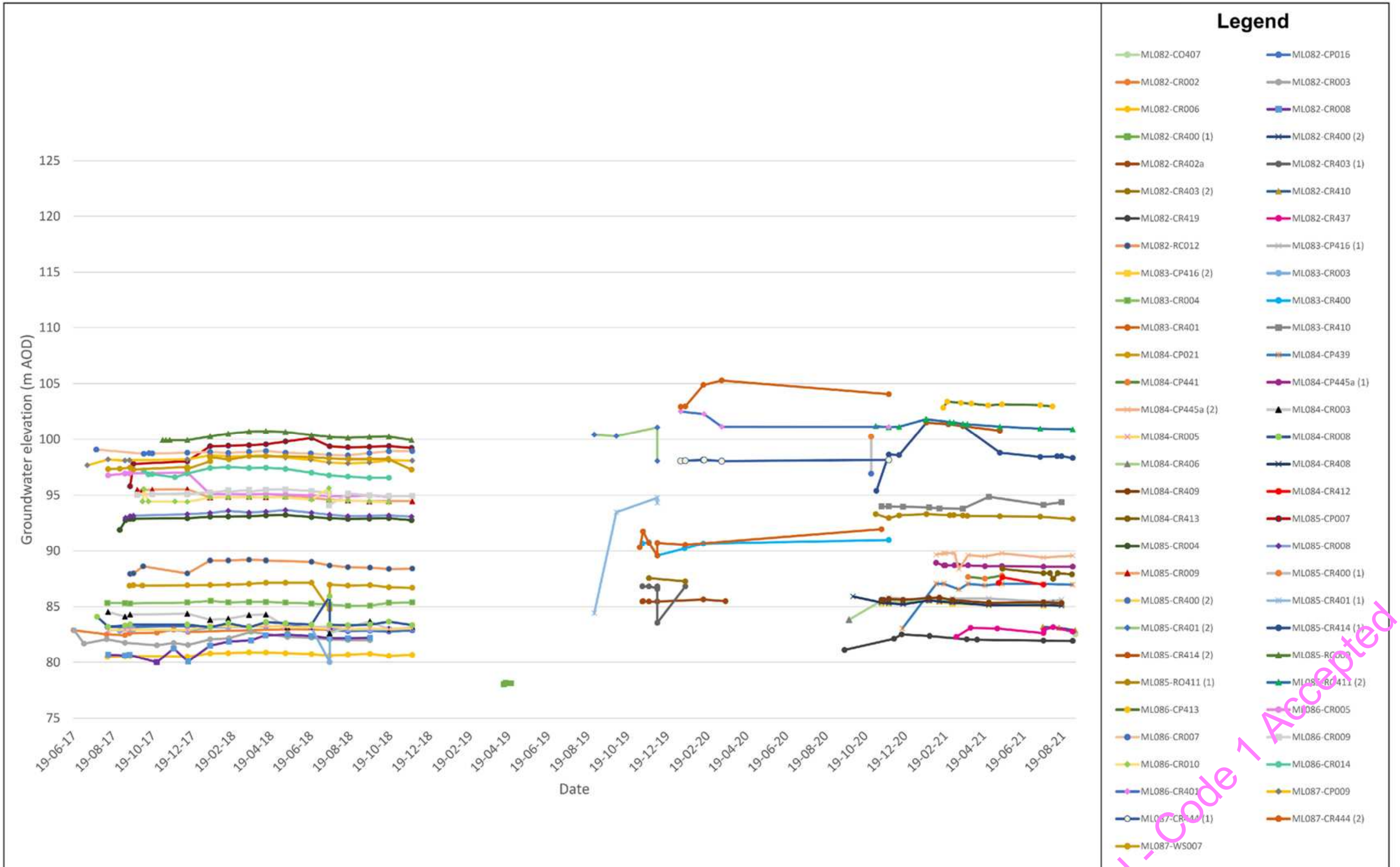


Figure 9a - Hydrograph of groundwater levels in HS2 observation boreholes (all locations)

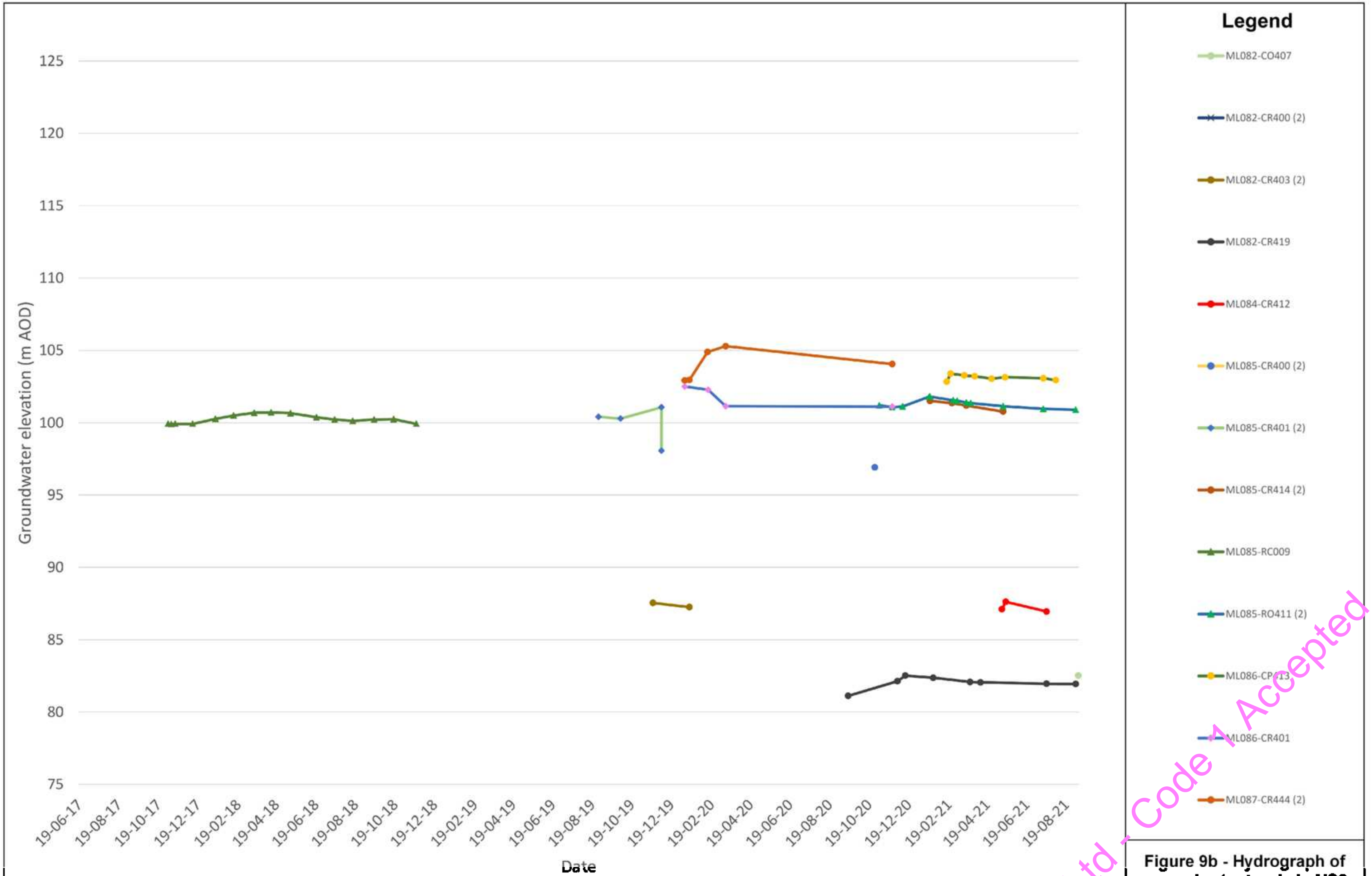


Figure 9b - Hydrograph of groundwater levels in HS2 observation boreholes screened in superficial deposits

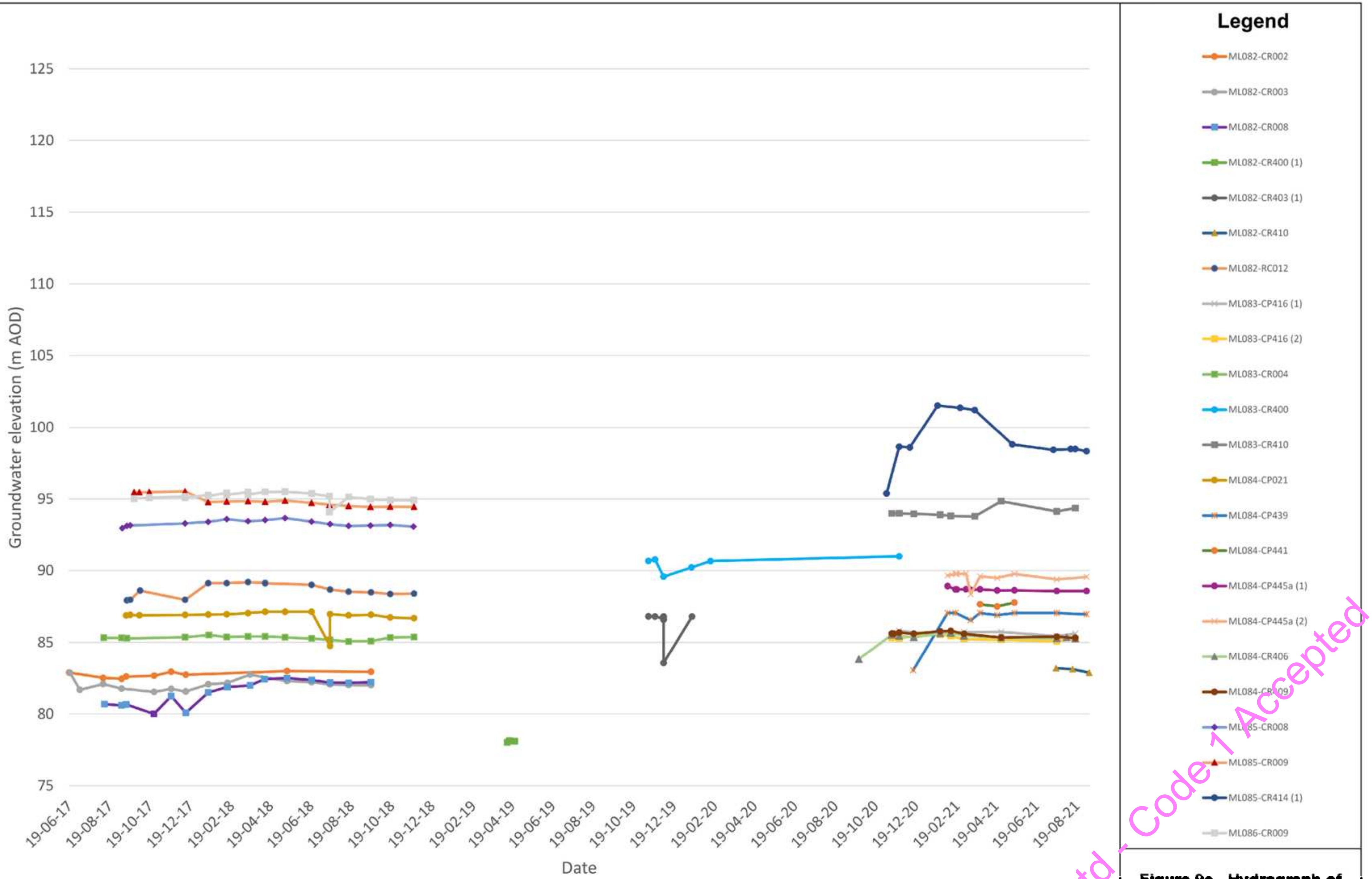


Figure 9c - Hydrograph of groundwater levels in HS2 observation boreholes screened in OXC and KLB

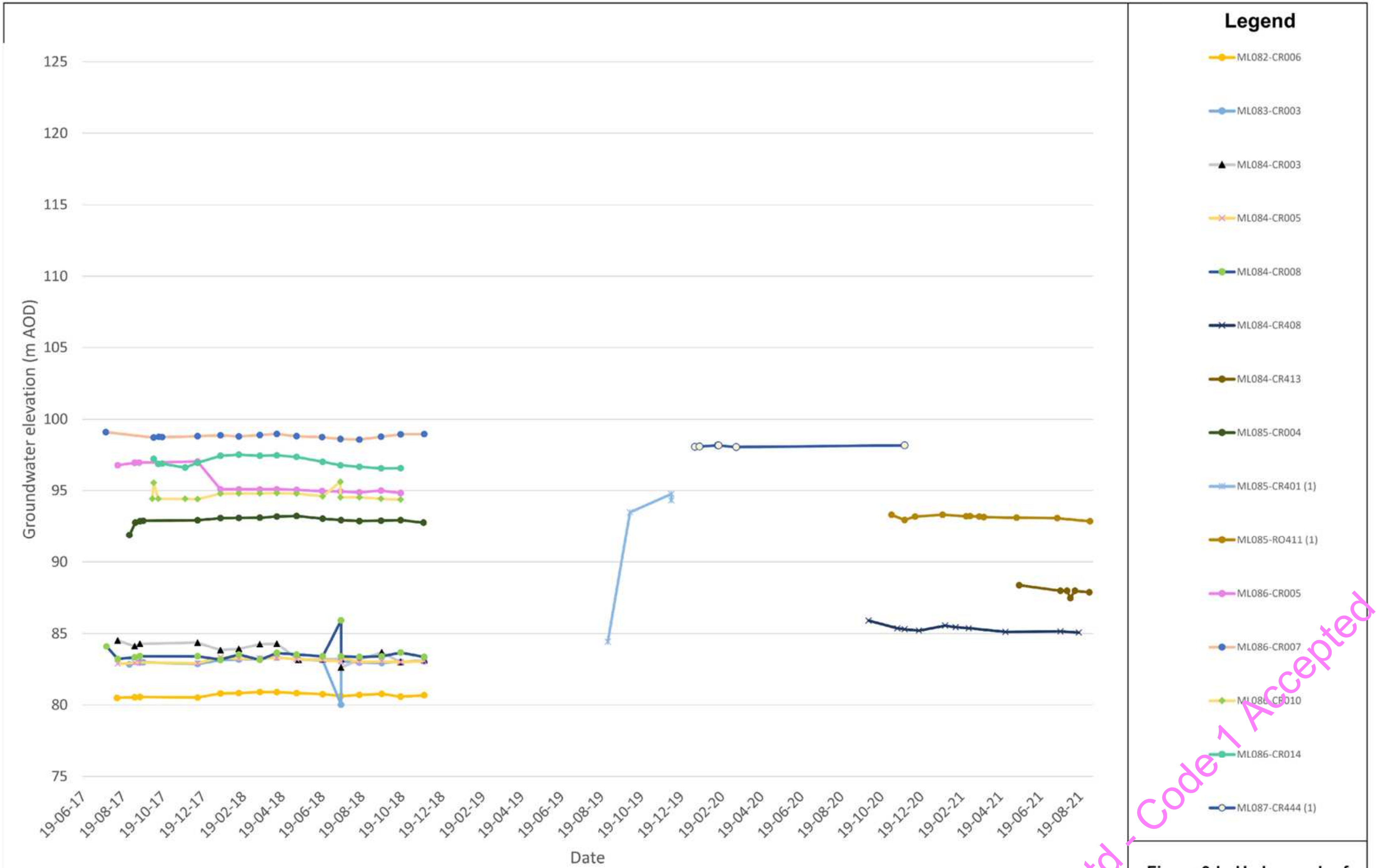
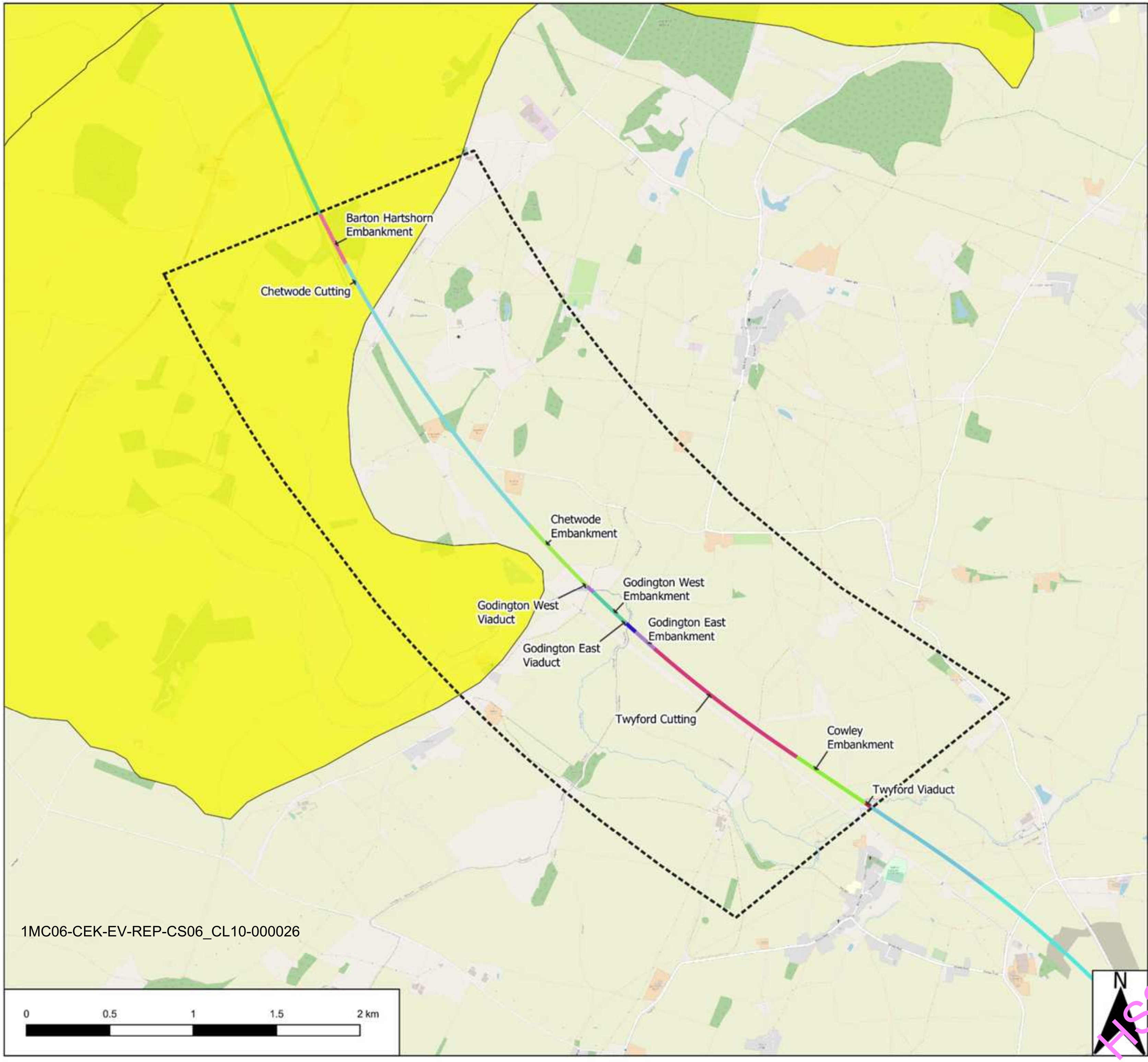


Figure 9d - Hydrograph of groundwater levels in HS2 observation boreholes screened in GOG



Legend

- Twyford Viaduct
- Cowley Embankment
- Twyford Cutting
- Godington East Embankment
- Godington East Viaduct
- Godington West Embankment
- Godington West Viaduct
- Chetwode Embankment
- Chetwode Cutting
- Barton Hartshorn Embankment
- Study Area

Water Framework Directive Bodies

- Upper Bedford Ouse Oolite Principal Secondary (Yellow)

Source: © OpenStreetMap contributors

Map Scale - 1:22,000

Figure 10: Water Framework Directive groundwater bodies in relation to Study Area

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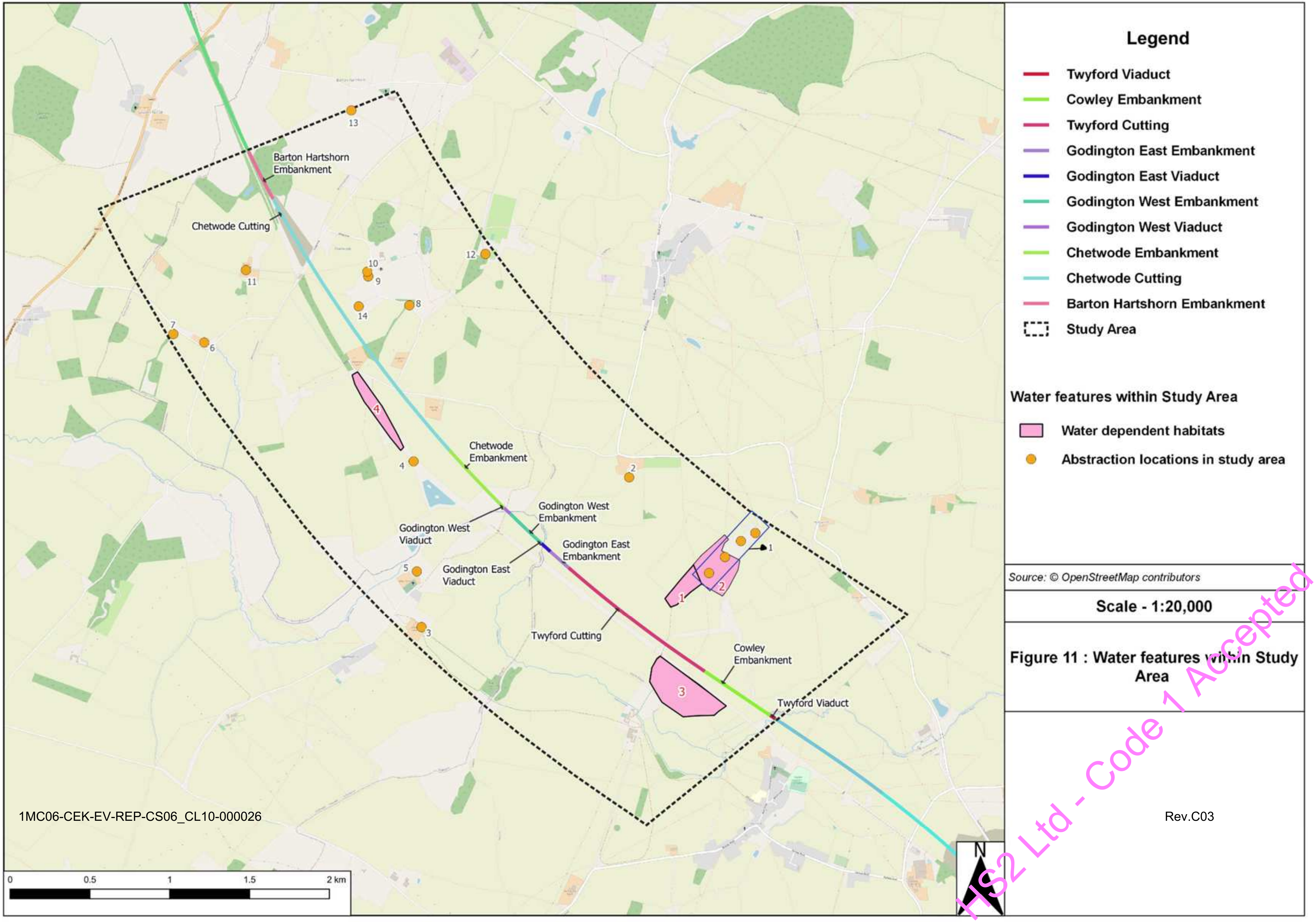

Figure 11 : Water features within Study Area

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Legend

- Twyford Viaduct
- Cowley Embankment
- Twyford Cutting
- Godington East Embankment
- Godington East Viaduct
- Godington West Embankment
- Godington West Viaduct
- Chetwode Embankment
- Chetwode Cutting
- Barton Hartshorn Embankment
- Study Area

Water Framework Directive Bodies

- GB105033038210 - Padbury Brook

Source: © OpenStreetMap contributors

Scale - 1:22,000

Figure 12: Water Framework Directive Surface water bodies in relation to study area

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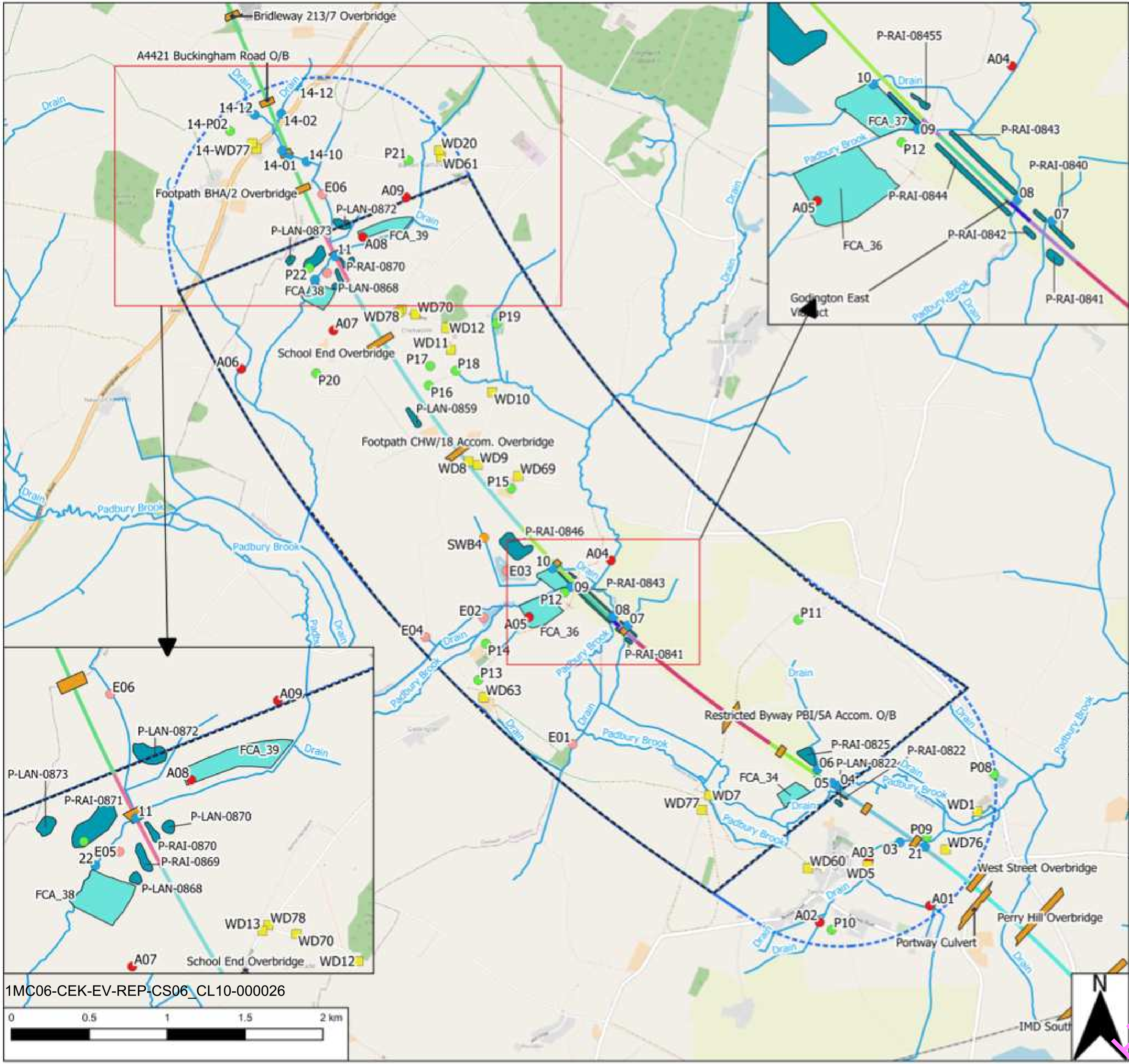
APPENDIX A

Surface Water Features Drawing

Number of Pages: 01



1MC06-CEK-EV-REP-CS06_CL10-000026

Appendix A

Legend

- Twyford Viaduct
- Cowley Embankment
- Twyford Cutting
- Godington East Embankment
- Godington East Viaduct
- Godington West Embankment
- Godington West Viaduct
- Chetwode Embankment
- Chetwode Cutting
- Barton Hartshorn Embankment
- Study Area
- HS2 Assets
- 1km buffer from end of study area assets

Surface Water Features

- Abstraction
- Discharge
- Non-ES
- Non-Mapbook
- Pond
- Watercourse

Flood and Drainage Storage

- Attenuation Pond
- Flood Compensation Area (FCA)

Note: Watercourses and ponds are labelled by their IDs from the Environmental Statement, however the "SWC-CFA" has been removed to improve the clarity in labelling. Water features referred to in the Environmental Statement but not shown in the respective map book (Non-Mapbook) are labelled in this figures as "EXX". Water features not included in Enviromental Statement (Non-ES) are labelled "AXX".

Source: © OpenStreetMap contributors

Map Scale - 1:24,000

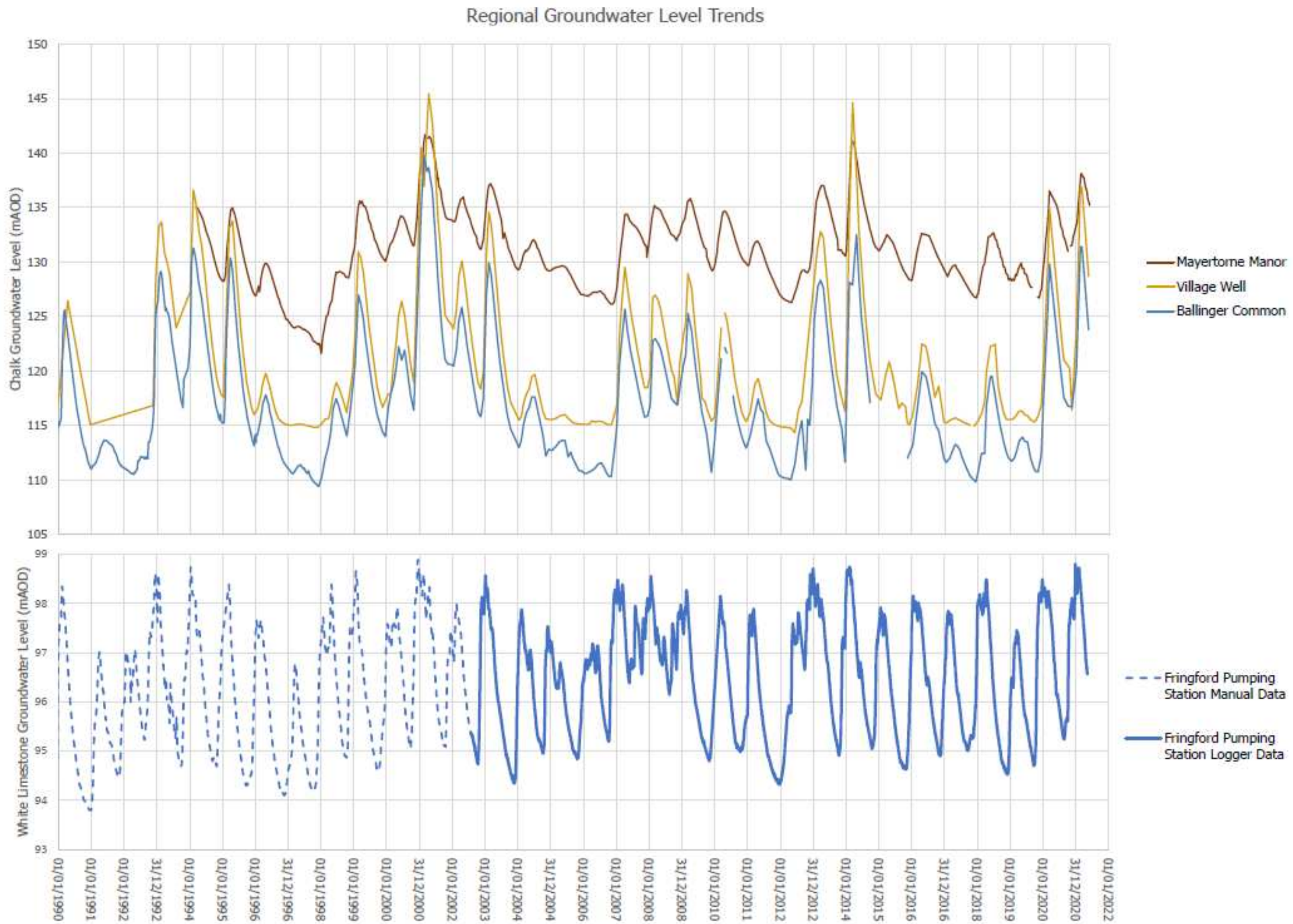
Surface water features

Rev.C03

APPENDIX B

Regional Groundwater Level Trends

Number of Pages: 01



Graph taken from GWP Report Document No.21052