Groundwater Assessment for Construction Tasks – Tunnel and Cross Passages

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1 Scope

1.1.1 This report has been prepared to assess the effects of construction and operation of the Chiltern Tunnel and associated cross passages on the groundwater environment. The report includes:

- formulation of a conceptual hydrogeological model for the length of the tunnel;
- identification of construction activities that could affect groundwater movement or quality;
- effects of addition of liquids other than clean water to aquifers as part of construction;
- effects of operation (i.e. the presence of the structures);
- monitoring requirements; and
- stakeholder consultation completed or underway.

1.1.2 The purpose of the report is not to repeat the information provided in the Environmental Statement[1], but to build on that and to provide more detailed information regarding design, construction and operation proposals that were not available at the time that the Environmental Statement was being prepared. Where there are no changes from the method / approach outlined in the Environmental Statement, only a cursory assessment is included in this report. This report should be read in conjunction with the Environmental Statement.

2 Client objectives

2.1.1 The client objectives are to meet the requirements of the HS2 Technical Standards that support the Environmental Minimum Requirements.

3 Technical Standards

3.1.1 The Technical Standards of relevance to this hydrogeological assessment include:

- Technical Standard – groundwater Protection, HS2-HS2-EV-STD-000-000010.
- Technical Standard - Water Framework Directive Compliance Process (HS2-HS2-EV-STD-000-000012).
- Technical Standard - Water resources and flood risk consents and approvals, HS2-HS2-EV-STD-000-000015.
- Technical Standard - Water Resources Strategy (HS2-HS2-EV-STD-000-000016).

[1] HS2, 2013, London – West Midlands Environmental Statement, Volume 5, Technical Appendices, CFA8 The Chalfonts and Amersham, Water

- Technical Standard – Civil Engineering Instrumentation and Monitoring, HS2-HS2-CV-STD-000-000004.

3.1.2 Although separate documentation has been prepared as part of the Water Framework Directive Compliance Process, some of the requirements are also included in this assessment.

3.1.3 In addition, HS2's Impacts of Tunnels in the UK[2] document has been reviewed during the writing of this report and where relevant, the information has been included in this assessment. This document details the mechanisms associated with ground movement and settlement during tunnelling and describes recent case histories of building rail tunnels in the UK. It reports on impacts that these works have had on people and infrastructure and describes measures that can be implemented to mitigate perceptible noise and vibration.

4 Conceptual site model

4.1 Site location and setting

4.1.1 The Chiltern Tunnel is a 16km long structure that will carry HS2 beneath the M25 and part of the Chilterns Area of Outstanding Natural Beauty (AONB), as shown in Figure 1. The tunnel entrance is formed by the South Portal, located immediately east of the M25 between West Hyde and Chalfont St Peter. The tunnel is orientated in a north-westerly direction between Amersham and Little Missenden before emerging at the North Portal located north-east of Great Missenden.

4.1.2 Ground level is approximately 55mAOD at the South Portal and approximately 190mAOD at the North Portal, with topography along the line of the tunnel varying between 35mAOD and 165mAOD as the tunnel passes beneath a series of valleys and interfluves.

4.1.3 The Chiltern Tunnel crosses beneath the River Misbourne at two locations; the southern crossing is located just east of Chalfont St Giles and the northern crossing is located between Amersham and Little Missenden.

4.1.4 Five shafts (Chalfont St Peter, Chalfont St Giles, Amersham, Little Missenden and Chesham Road) are located along the length of the tunnel to provide ventilation and emergency escape/access. The hydrogeological impact of construction of these shafts is assessed in a separate report: Groundwater assessment for construction tasks - Shafts.

[2] HS2, 2013, Impacts of Tunnels in the UK

Figure 1: Map of Chiltern tunnel showing source protection zones

4.2 Geology and hydrogeology characteristics

4.2.1 The area is predominantly underlain by Cretaceous chalk of the White Chalk Subgroup and the Grey Chalk Subgroup. Two distinct areas of the Lambeth Group are present where the tunnel passes south of Amersham and these strata comprise clay, silt and sand with minor limestone bands.

4.2.2 British Geological Survey (BGS) geological mapping indicates that superficial deposits along the length of the tunnel consist of the Gerrards Cross Gravel and Beaconsfield Gravel in the area between the M25 and the A413; alluvium is present where the tunnel passes beneath the River Misbourne and can comprise clay, peat, silt, sand and gravel; and the Clay with Flints Formation is present in a small area south-west of Amersham and also in the area between Hyde Heath and the North Portal. Borehole logs indicate that a thin layer of superficial deposits of various lithologies is likely to be present across almost the entire length of the tunnel, predominantly Head and the Clay with Flints Formation.

4.2.3 The tunnel passes through the Seaford Chalk Formation, the Lewes Nodular Chalk Formation, the New Pit Chalk Formation and the Holywell Nodular Chalk Formation of the White Chalk Subgroup, along with the Zig Zag Chalk Formation of the Grey Chalk Subgroup. Superficial deposits will only be directly intercepted by the tunnel at the two portal locations, with clay associated with the Beaconsfield Gravel present near the South Portal, and just prior to emergence at the North Portal the tunnel will pass through approximately 200m of the Clay with Flints Formation.

4.2.4 Ground Investigation (GI) data along the line of the tunnel indicates that the tunnel will predominantly pass through the Lewes Nodular Chalk Formation between the M25 and Amersham Shaft, with a 1km section at the South Portal bored within the Seaford Chalk Formation. From Amersham Shaft onwards, the tunnel is predominantly bored within the New Pit Chalk Formation, apart from a 1km section that encounters an anticline where the tunnel passes through the underlying Holywell Nodular Chalk Formation and the Zig Zag Chalk Formation. A geological cross section for the tunnel route is presented in Appendix C.

4.2.5 Faulting is predicted at various locations along the line of the tunnel and is typically associated with the valley of the River Misbourne or dry valleys, and are likely to result in heavily disturbed, high permeability chalk. Additional ground investigation is ongoing to better understand the nature of faulting along the tunnel alignment, particularly at the shaft locations.

4.2.6 A dissolution feature was identified near Little Missenden Shaft at approximately 80mAOD and is present at the same depth as the tunnel at this location. Dissolution features between the Chesham Road Shaft and the North Portal are present at approximately 135mAOD to 155mAOD, though this is below the depth of the tunnel at these locations. Another possible dissolution feature was identified at Chalfont St Giles shaft at an elevation of approximately 70mAOD which is the same depth as the tunnel at this location. There will be other dissolution features encountered during tunnelling but which have not been identified by GI.

4.2.7 The Chalk is classified as a Principal aquifer and is extensively used for groundwater abstraction, including a significant quantity of water for public supply. The Lambeth Group, the various gravel formations and the alluvium are classified as Secondary A aquifers, but they are not widely used for water supply in this area. The Clay with Flints Formation is classified as an Unproductive stratum and does not contain sufficient water to be usable for supply.

4.2.8 The Chalk aquifer that the tunnel passes through is within the Water Framework Directive (WFD) Mid Chilterns Chalk water body, which has a total area of 730km^2. Impacts on groundwater from a WFD groundwater body perspective are summarised in the Section C1 - Updated WFD Compliance Assessment[3] and are not explicitly discussed below to avoid duplication with that report.

4.2.9 The Chalk aquifer is a dual permeability aquifer which is characterised by very low flow rates through the rock matrix and much higher rates of flow through fissures. In some areas these fissures are enlarged by solutional weathering which can result in extremely fast flow rates. The Chalk is heterogeneous with the principal mechanism for groundwater flow to occur through a dendritic network of interconnected fractures and solution enlarged voids rather than extensive voids or karst conduits.

4.2.10 Geophysical data available from different boreholes within the Chalk of the Colne Valley indicates the presence of three distinct fissure bands at 14-16m below ground level (bgl), 26-32m bgl, and 48-52m bgl. The information available does not indicate whether these flow horizons are present over a wide lateral area, or how connected they are, but they will act as principal flow zones where they exist.

4.2.11 The majority of groundwater movement is likely to be in the top 50m of the saturated zone of the Chalk aquifer and there is expected to be layering in the aquifer with some horizons more permeable than others. This layering is caused by the presence of numerous marl bands in the Chalk, particularly in the New Pit Chalk, and there are distinct lithostratigraphic horizons such as the Chalk Rock.

[3] Align 2019, Section C1 - Updated Water Framework Directive Compliance Assessment, 2019, Document no.: 1MC05-ALJ-EV-REP-CS01_CL01-100082

4.2.12 Permeability is typically highest in the valleys and lowest in the interfluve areas. Available in-situ permeability estimates obtained from existing GI positions along the route indicate a range of values between 4.8 x10^{-5} m/d and 0.95 m/d with a median of 2.5 x 10^{-2} m/d. However, the permeability tests are not thought to have been undertaken in any highly fractured zones and are not representative of the high flow zones in the river valleys.

4.2.13 Data collected by the British Geological Survey[4 5] (BGS) indicates that transmissivity in the major valleys (Thames and the Colne) in the Chalk in the Chilterns is high, typically in the range 1500 to 3000m^2/d. The BGS cite leakage into the Chalk from rivers and overlying sands and gravels as being part of the reason for the high transmissivity values in these valleys. The BGS also note that in some areas the presence of putty chalk can locally reduce permeability.

4.2.14 Analysis of data gained from pumping tests on three Affinity Water sources in the River Misbourne valley by MWH[67] indicates transmissivities for the fracture network of 1,100 to 2,700 m^2/d (at Amersham PWS), 4,700 to 9,500 m^2/d (at Chalfont St Giles PWS) and 6,400 m^2/d (at Northmoor PWS). MWH suggest that the tests indicated the presence of a "karstic system" in the valley floor and which had substantially greater transmissivity, estimated to be in excess of 40,000m^2/d.

4.2.15 Groundwater movement is generally in a north-west to south-east direction (see Figure 9 in Section 6 of this report), albeit that the direction is likely to be different in the immediate vicinity of the Affinity Water abstractions, and locally in the vicinity of major river valleys and locally at some dry valleys. The tunnel is largely located beneath the interfluve between the Misbourne and Colne valleys or beneath the valley of the River Misbourne. Given the location of the tunnel and the regional and local hydraulic gradients, no effects are anticipated from the tunnel and cross passages on the River Chess and no changes to cross catchment flows from the Misbourne to the Chess are anticipated.

4.2.16 Groundwater levels along the line of the tunnel vary from circa 42mAOD at the South Portal to circa 148mAOD near the North Portal (there will also be seasonal variations around these levels). The tunnel is expected to be constructed below the water table from Chalfont St Peter to Little Missenden (a distance of approximately 11km).

[4] Shand, P., Tyler-Whittle R., Bersien T., Peach D.W., Lawrence A.R. and Lewis H.O., 2003. BGS Baseline Report Series: 6. The Chalk of the Colne and Lee River Catchments. Environment Agency Technical Report NC/99/74/6 and BGS commissioned report CR/03/69N.Environment Agency.
[5] British Geological Survey, 1997, The physical properties of major aquifers in England and Wales, Hydrogeology Group Technical Report WD/97/34, Environment Agency R&D Publication 8.
[6] MWH, 2017, Desk Study Assessment of Turbidity Risk at West Hyde.
[7] MWH, November 2016, Desk Study Assessment of Turbidity Risk at Three Affinity Water Sites, Ref: 41523805

4.2.17 The annual fluctuation in groundwater level in the valley of the River Misbourne is in the order of 5-7m in an annual cycle, based upon hydrograph data from 17 boreholes over the period 1993 to 2013. In the interfluves the fluctuation is larger, being in the order of 10-15m over an annual cycle. In close proximity to the abstraction wells this could increase to 20 to 30m, depending on the pumping regime. A summary of available groundwater level information is provided in Table 1 with selected groundwater level data along the line of the tunnel presented in Figures 2, 3 and 4. Anticipated maximum groundwater levels along the line of the tunnel were estimated[8] as 76mAOD at Chalfont St Peter shaft, 88mAOD at Chalfont St Giles shaft, 96mAOD at Amersham shaft, 108mAOD at Little Missenden shaft and 140mAOD at Chesham Road shaft.

4.2.18 Areas potentially at risk from groundwater flooding have been identified in the vicinity of the tunnel, primarily within the valley of the River Misbourne[9] but dry valley features at Chalfont St Giles, Amersham and Little Missenden shafts have also been identified as potential areas of groundwater emergence. However, it must be recognised that this was based on a national level assessment and therefore provides relatively coarse information.

[8] Align, 2019, Methodology for estimating the 120yr + climate change groundwater levels along the Chiltern tunnel, Document no: 1MC05-ALJ-EN-NOT-CS02_CL04-410020
[9] Jacobs, 2018, Chiltern and South Bucks Strategic Flood Risk Assessment (Level 1)

Table 1: Summary of water level information along the line of the Chiltern tunnel

Location	Ground Level	Easting	Northing	Number Dry Readings	Number WL Readings	Lowest Level	Average Level	Highest Level	Geology	Response Zone Top	Response Zone Base	Response Zone Top	Response Zone Base	First Reading Date	Last Reading Date
	m AOD	m	m		-	m AOD	m AOD	m AOD	-	m bgl	mbgl	m AOD	m AOD	-	-
ML031-CR002	86.42	502004.22	191691.60	0	8	43.92	45.27	44.40	CHALK	25.00	45.00	61.42	41.42	12/10/2016	27/10/2017
ML031-CR003	83.69	501961.50	191764.24	0	8	44.27	44.54	44.72	CHALK	24.80	45.00	58.89	38.69	12/10/2016	27/10/2017
ML031-CR004	80.45	501915.45	191864.58	0	10	44.37	44.83	45.27	CHALK	30.00	45.00	50.45	35.45	12/10/2016	27/10/2017
ML031-CR005	76.39	502182.74	191359.94	0	10	42.95	43.43	43.83	CHALK	29.80	40.00	46.59	36.39	12/10/2016	27/10/2017
ML031-CR008	77.08	502148.08	191356.80	0	8	43.18	43.75	44.11	CHALK	14.90	35.00	62.18	42.08	12/10/2016	27/10/2017
ML031-CR009	78.88	502207.58	191671.00	5	0	DRY	DRY	DRY	CHALK	20.30	30.30	58.58	48.58	21/10/2016	26/05/2017
ML031-CR013	75.80	502245.59	191441.56	0	10	42.60	43.10	43.51	CHALK	15.00	35.00	60.80	40.80	16/09/2016	27/10/2017
ML031-CR014	68.18	502289.69	191268.27	0	11	41.20	42.52	43.03	CHALK	13.50	30.00	54.68	38.18	16/09/2016	27/10/2017
ML031-CR015	72.01	502333.54	191372.52	0	13	41.91	42.41	42.84	CHALK	15.00	30.00	57.01	42.01	16/09/2016	27/10/2017
ML031-CR017	77.51	502102.16	191020.47	7	1	47.10	47.10	47.10	CHALK	9.50	30.70	68.01	46.81	14/10/2016	27/10/2017
ML031-CR019	66.14	502479.31	191255.05	10	0	DRY	DRY	DRY	CHALK	13.00	15.00	53.14	51.14	22/09/2016	27/10/2017
ML032-CR001	93.07	501148.53	192426.97	0	8	52.57	53.40	54.28	CHALK	27.00	50.00	66.07	43.07	08/02/2017	24/10/2017
ML032-RC001	87.16	501761.29	191929.49	0	9	45.40	46.16	46.63	CHALK	23.50	64.02	63.66	23.14	30/11/2016	24/10/2017
ML032-RC004	94.27	501608.91	191986.38	0	8	50.57	51.02	51.34	CHALK	28.00	64.01	66.27	30.26	08/02/2017	24/10/2017
ML032-RC006	99.44	501450.85	192155.04	0	8	51.25	51.77	52.29	CHALK	33.50	54.00	65.94	45.44	10/11/2016	24/10/2017
ML032-RC009	99.99	501327.84	192333.19	0	9	51.94	52.88	53.35	CHALK	49.50	64.03	50.49	35.96	17/11/2016	24/10/2017
ML032-RC013	97.50	501037.91	192580.99	1	8	52.36	53.40	54.41	CHALK	42.50	52.50	55.00	45.00	15/12/2016	24/10/2017
ML032-RC014	98.58	501568.53	192113.17	3	6	50.15	51.32	55.33	CHALK	37.80	57.80	60.78	40.78	12/12/2016	24/10/2017
ML033-CR001	97.91	500561.26	192895.67	0	7	56.25	57.20	58.10	CHALK	41.00	63.00	56.91	34.91	08/02/2017	29/09/2017
ML033-RC004	92.49	500859.64	192643.13	0	6	52.97	53.87	54.80	CHALK	35.50	55.50	56.99	36.99	07/04/2017	24/10/2017
ML033-RC006	95.85	500731.94	192825.37	1	8	54.35	55.39	56.13	CHALK	44.00	54.00	51.85	41.85	06/12/2016	29/09/2017
ML033-RC009a	99.24	500360.85	192948.85	0	6	58.53	59.74	62.49	CHALK	47.50	57.50	51.74	41.74	07/04/2017	24/10/2017
ML033-RC010	100.02	500220.96	193095.51	0	2	60.80	61.01	61.22	CHALK	54.00	64.00	46.02	36.02	24/11/2016	30/11/2016
ML034-CR001	102.38	500115.25	193166.78	0	13	59.70	61.28	63.48	CHALK	52.00	75.00	50.38	27.38	18/08/2016	10/01/2018
ML034-CR002	100.88	500049.04	193123.29	0	12	59.91	61.05	62.46	CHALK	47.50	88.00	53.38	12.88	20/12/2016	10/01/2018
ML034-CR002	100.88	500049.04	193123.29	0	13	59.87	61.10	62.41	CHALK	38.00	42.00	62.88	58.88	12/12/2016	10/01/2018
ML034-RC007	100.79	499890.51	193226.26	0	14	60.19	61.85	64.43	CHALK	52.00	63.00	48.79	37.79	16/08/2016	10/01/2018
ML034-RC009	100.32	499733.41	193326.47	0	12	60.45	61.83	63.20	CHALK	52.00	63.00	48.32	37.32	08/12/2016	10/01/2018
ML034-RO001	102.23	500121.38	193163.25	0	13	59.21	60.85	62.17	CHALK	74.50	80.00	27.73	22.23	12/12/2016	10/01/2018
ML035-CR003	71.34	499035.82	193721.10	0	13	60.98	63.31	65.36	CHALK	13.50	34.50	57.84	36.84	07/11/2016	10/01/2018
ML035-CR004	72.15	498913.63	193849.98	0	12	61.70	63.56	65.79	CHALK	18.00	28.00	54.15	44.15	07/11/2016	10/01/2018
ML035-CR004	72.15	498913.63	193849.98	8	2	65.68	66.12	66.55	CHALK	0.50	6.00	71.65	66.15	07/11/2016	10/01/2018
ML035-RC012	79.45	498739.32	193950.72	0	13	62.60	64.07	66.13	CHALK	19.00	40.25	60.45	39.20	07/11/2016	10/01/2018
ML035-RC013	85.82	498602.06	194083.53	0	10	63.29	64.53	65.87	CHALK	14.50	61.50	71.32	24.32	12/01/2017	10/01/2018
ML035-RC016	72.86	499287.56	193572.49	0	13	61.75	63.25	67.21	CHALK	21.00	31.50	51.86	41.36	01/01/2017	10/01/2018
ML035-RO001	76.00	498653.96	194211.88	0	10	63.43	64.54	66.02	A_CHALK	4.50	50.00	71.50	26.00	10/01/2017	10/01/2018
ML035-RO002a	70.95	499179.42	193641.03	0	11	61.94	63.08	64.41	CHALK	6.00	16.00	64.95	54.95	01/02/2017	10/01/2018
ML035-RO003a	70.69	499196.52	193633.70	8	1	64.85	64.85	64.85	A_CHALK	3.00	6.00	67.69	64.69	31/01/2017	10/01/2018

Location	Ground Level	Easting	Northing	Number Dry Readings	Number WL Readings	Lowest Level	Average Level	Highest Level	Geology	Response Zone Top	Response Zone Base	Response Zone Top	Response Zone Base	First Reading Date	Last Reading Date
	m AOD	m	m		-	m AOD	m AOD	m AOD	-	m bgl	mbgl	m AOD	m AOD	-	-
ML036-RC006	113.62	498095.26	194328.18	0	14	65.12	66.82	68.39	CHALK	55.00	68.00	58.62	45.62	07/11/2016	10/01/2018
ML036-RC009	120.91	497933.20	194413.63	0	14	66.01	67.75	69.36	CHALK	56.00	66.00	64.91	54.91	07/11/2016	10/01/2018
ML036-RC010	126.51	497813.94	194487.88	0	14	67.28	68.64	70.04	CHALK	56.00	77.00	70.51	49.51	12/12/2016	10/01/2018
ML036-RC012	110.20	497625.80	194535.79	0	15	68.52	71.73	82.82	CHALK	41.50	52.50	68.70	57.70	07/11/2016	10/01/2018
ML037-RC001	103.63	497551.06	194606.99	0	14	68.35	70.87	72.15	CHALK	29.50	46.50	74.13	57.13	27/10/2016	10/01/2018
ML037-RC003	100.40	497375.39	194688.19	0	15	57.04	72.13	74.18	CHALK	28.00	39.00	72.40	61.40	07/11/2016	10/01/2018
ML037-RC009	99.59	497264.70	194829.69	0	10	73.51	74.22	75.52	CHALK	22.00	43.00	77.59	56.59	13/03/2017	11/01/2018
ML037-RC012	97.32	497195.27	194793.67	0	10	70.97	73.08	75.01	A_CHALK	23.00	37.00	74.32	60.32	13/03/2017	11/01/2018
ML037-RC014	118.24	497018.09	195002.42	0	11	74.31	74.99	76.38	CHALK	37.50	65.50	80.74	52.74	13/03/2017	11/01/2018
ML037-RC016	122.32	496803.71	195097.18	0	5	77.57	77.94	78.41	CHALK	41.00	55.00	81.32	67.32	29/09/2016	08/01/2018
ML037-RC019	94.15	497336.12	194774.65	0	12	72.11	73.78	75.05	CHALK	17.50	37.50	76.65	56.65	25/11/2016	10/01/2018
ML038-RC002	115.35	496708.84	195255.82	0	5	79.06	79.27	79.51	CHALK	29.50	55.50	85.85	59.85	27/10/2016	08/01/2018
ML038-RC004	120.86	496559.95	195405.46	0	5	79.75	80.65	82.70	CHALK	43.00	53.50	77.86	67.36	10/10/2016	08/01/2018
ML038-RC006	129.76	496356.68	195514.53	0	5	81.73	82.04	82.24	CHALK	46.50	67.50	83.26	62.26	27/10/2016	08/01/2018
ML038-RC009	145.26	496304.47	195646.94	0	5	82.09	82.27	82.63	CHALK	68.00	78.00	77.26	67.26	20/12/2016	08/01/2018
ML038-RC010a	142.36	496042.33	195702.55	0	5	80.94	81.21	81.48	CHALK	64.00	84.00	78.36	58.36	20/12/2016	08/01/2018
ML039-RC002	158.76	496039.44	195934.98	3	2	86.70	98.65	110.60	CHALK	53.50	73.00	105.26	85.76	27/10/2016	08/01/2018
ML039-RC002	158.76	496039.44	195934.98	0	5	81.80	82.02	82.46	CHALK	83.00	94.00	75.76	64.76	27/10/2016	08/01/2018
ML039-RC004	163.56	495883.39	196106.50	0	8	86.49	87.22	88.56	CHALK	82.50	103.50	81.06	60.06	27/10/2016	11/01/2018
ML039-RC006	144.69	495719.54	196184.27	0	12	85.37	88.06	89.30	CHALK	70.50	81.50	74.19	63.19	04/10/2016	11/01/2018
ML039-RC008a	135.86	495672.65	196336.25	0	13	87.24	88.65	89.94	CHALK	50.00	80.50	85.86	55.36	27/10/2016	11/01/2018
ML039-RC010	136.07	495475.74	196451.62	0	13	87.71	88.69	89.60	CHALK	65.00	75.00	71.07	61.07	04/10/2016	11/01/2018
ML039-RC015	101.44	495354.83	196594.64	0	13	88.12	89.11	89.87	CHALK	31.00	41.00	70.44	60.44	03/10/2016	11/01/2018
ML039-RO002	103.09	495888.01	196904.95	0	11	86.28	87.43	88.22	CHALK	27.00	70.00	76.09	33.09	10/01/2017	10/01/2018
ML040-RC006	112.86	495267.06	196763.18	0	7	88.71	89.49	90.21	CHALK	43.00	53.00	69.86	59.86	22/12/2016	11/01/2018
ML040-RC008	134.00	495092.03	196869.46	0	8	89.58	90.37	91.06	CHALK	63.00	73.00	71.00	61.00	22/12/2016	11/01/2018
ML040-RC009	140.24	495004.83	197049.32	0	7	90.66	91.09	91.73	CHALK	69.50	80.50	70.74	59.74	22/12/2016	11/01/2018
ML040-RC012	131.21	494940.27	197246.55	0	7	90.71	91.44	92.01	CHALK	54.50	75.50	76.71	55.71	22/12/2016	11/01/2018
ML040-RO006	128.16	495232.65	197079.84	0	13	89.64	90.50	91.33	A_CHALK	24.50	45.50	103.66	82.66	07/11/2016	11/01/2018
ML040-RO007	104.83	494962.15	197480.62	0	7	91.02	91.67	92.26	CHALK	10.00	50.00	94.83	54.83	22/12/2016	11/01/2018
ML041-RC002	110.75	494517.15	197467.76	0	8	91.36	92.11	92.90	CHALK	42.50	63.50	68.25	47.25	22/12/2016	11/01/2018
ML041-RC005	113.43	494337.55	197662.19	0	6	93.73	94.16	94.61	CHALK	36.00	47.00	77.43	66.43	22/12/2016	11/01/2018
ML041-RC007	116.93	494280.95	197733.77	0	14	96.08	96.99	97.63	CHALK	5.00	60.00	111.93	56.93	16/08/2016	11/01/2018
ML041-RC010	107.69	494226.35	197892.23	0	13	97.24	98.24	98.79	CHALK	27.00	39.00	80.69	68.69	16/08/2016	11/01/2018
ML041-RC012	106.37	494061.11	197996.77	0	13	98.67	98.96	99.40	CHALK	5.00	25.00	101.37	81.37	16/08/2016	11/01/2018
ML041-RC015	142.42	494632.07	197322.50	0	7	91.40	92.04	92.70	CHALK	68.00	78.00	74.42	64.42	22/12/2016	11/01/2018
ML041-RO001	103.04	494478.20	197791.55	0	12	95.64	95.95	96.24	A_CHALK	5.00	30.20	98.04	72.84	13/01/2017	11/01/2018
ML042-CR001a	100.64	493836.10	198221.89	0	13	99.03	99.24	99.52	CHALK	20.00	31.00	80.64	69.64	03/10/2016	11/01/2018
ML042-CR001a	100.64	493836.10	198221.89	0	13	99.07	99.23	99.44	ALV	0.80	6.00	99.84	94.64	03/10/2016	11/01/2018
ML042-CR003	100.22	493822.05	198374.45	0	10	99.18	99.47	99.75	CHALK	14.90	35.10	85.32	65.12	07/11/2016	10/01/2018
ML042-RC002	101.11	493937.85	198118.39	0	14	98.95	99.29	99.79	CHALK	20.00	30.00	81.11	71.11	24/08/2016	11/01/2018
ML042-RC010	104.65	493635.32	198499.09	0	6	95.39	99.71	100.95	CHALK	23.00	33.00	81.65	71.65	16/01/2017	08/01/2018
ML042-RC013	106.28	493521.83	198543.14	0	5	101.13	101.19	101.28	CHALK	17.00	37.00	89.28	69.28	16/01/2017	08/01/2018
ML042-RC014	111.37	493449.10	198739.66	0	13	95.97	100.89	101.74	A_CHALK	22.50	33.00	88.87	78.37	08/12/2016	09/01/2018
ML042-RC020	117.26	493393.43	198809.27	0	13	101.19	101.53	101.98	CHALK	23.00	55.00	94.26	62.26	08/12/2016	09/01/2018
ML042-RC021	116.72	493328.76	198800.32	0	13	101.32	101.69	102.16	CHALK	50.00	65.00	66.72	51.72	12/01/2017	09/01/2018
ML042-RO001	117.82	493399.47	198814.85	0	13	101.74	102.12	102.56	CHALK	21.50	42.00	96.32	75.82	20/01/2017	09/01/2018
ML042-RO004	100.81	493866.85	198354.95	0	9	99.07	99.28	99.51	HEAD	1.00	3.00	99.81	97.81	07/11/2016	10/01/2018

Location	Ground Level	Easting	Northing	Number Dry Readings	Number WL Readings	Lowest Level	Average Level	Highest Level	Geology	Response Zone Top	Response Zone Base	Response Zone Top	Response Zone Base	First Reading Date	Last Reading Date
	m AOD	m	m		-	m AOD	m AOD	m AOD	-	m bgl	mbgl	m AOD	m AOD	-	-
ML043-RC004	131.41	493221.20	198983.21	0	14	101.68	102.16	103.35	CHALK	30.00	40.00	101.41	91.41	08/12/2016	09/01/2018
ML043-RC007	130.68	493129.41	199047.51	0	10	102.26	102.88	103.58	CHALK	32.50	43.00	98.18	87.68	12/01/2017	09/01/2018
ML043-RC009	135.34	492896.39	199300.93	0	14	103.30	103.96	105.44	CHALK	32.00	42.00	103.34	93.34	22/12/2016	09/01/2018
ML043-RC011	144.29	492776.06	199392.50	1	13	103.33	104.31	106.02	CHALK	25.00	45.00	119.29	99.29	01/11/2016	09/01/2018
ML043-RO003	118.91	492622.19	199193.87	0	8	103.56	104.06	104.72	CHALK	9.00	19.00	109.91	99.91	31/01/2017	09/01/2018
ML044-RC004	159.86	492561.31	199712.32	12	0	DRY	DRY	DRY	CHALK	31.00	51.00	128.86	108.86	21/12/2016	09/01/2018
ML044-RC006	163.91	492414.95	199774.01	0	13	105.82	106.39	107.01	CHALK	51.00	61.00	112.91	102.91	27/01/2017	09/01/2018
ML044-RC007	163.91	492279.97	200017.54	0	13	106.67	107.40	108.16	CHALK	45.00	75.00	118.91	88.91	10/01/2017	09/01/2018
ML044-RC016	149.32	491988.29	200099.39	0	9	107.32	108.12	108.90	CHALK	24.00	55.00	125.32	94.32	27/01/2017	09/01/2018
ML044-RC021	152.50	492602.39	199559.41	11	0	DRY	DRY	DRY	CHALK	25.00	35.00	127.50	117.50	22/12/2016	09/01/2018
ML045-RC025	164.36	491964.88	200309.39	0	13	107.89	109.72	112.08	CHALK	38.00	65.00	126.36	99.36	09/01/2017	09/01/2018
ML045-RC026	170.14	491849.43	200488.88	0	13	108.14	110.23	114.28	CHALK	38.00	65.00	132.14	105.14	20/01/2017	09/01/2018
ML045-RC027	155.28	491667.58	200660.36	12	0	DRY	DRY	DRY	CHALK	23.00	33.00	132.28	122.28	08/12/2016	09/01/2018
ML045-RC028	166.24	491543.45	200733.20	13	0	DRY	DRY	DRY	CHALK	23.00	43.00	143.24	123.24	08/12/2016	09/01/2018
ML045-RC029	175.62	491478.64	200872.92	11	0	DRY	DRY	DRY	CHALK	30.00	55.60	145.62	120.02	10/01/2017	09/01/2018
ML046-RC025	181.07	491253.82	201161.78	7	4	115.87	119.34	126.54	CHALK	54.50	65.00	126.57	116.07	10/01/2017	09/01/2018
ML046-RC026	182.28	491200.99	201184.50	8	1	122.83	122.83	122.83	CHALK	24.00	60.00	158.28	122.28	01/02/2017	09/01/2018
ML046-RC028	185.17	490934.68	201384.91	12	0	DRY	DRY	DRY	CHALK	21.50	50.70	163.67	134.47	21/12/2016	09/01/2018
ML046-RC030	190.08	490731.93	201713.39	0	14	147.02	147.21	147.58	CHALK	20.00	45.00	170.08	145.08	10/01/2017	08/01/2018

Figure 2: Groundwater levels in the chalk along the length of the Chiltern tunnel (Chalfont St Giles to Amersham)

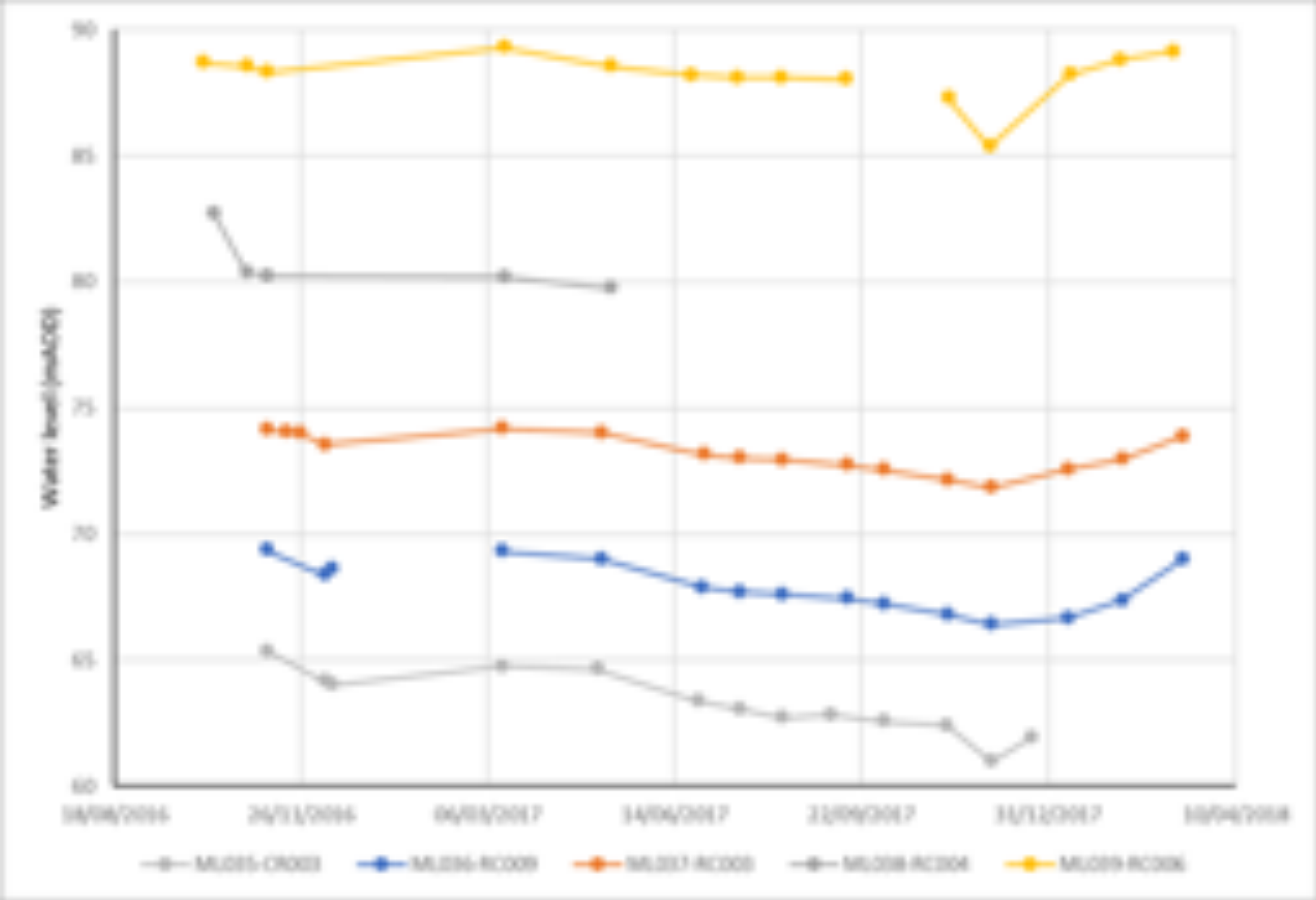


Figure 3: Groundwater levels in the chalk along the length of the Chiltern tunnel (Amersham to Little Missenden)

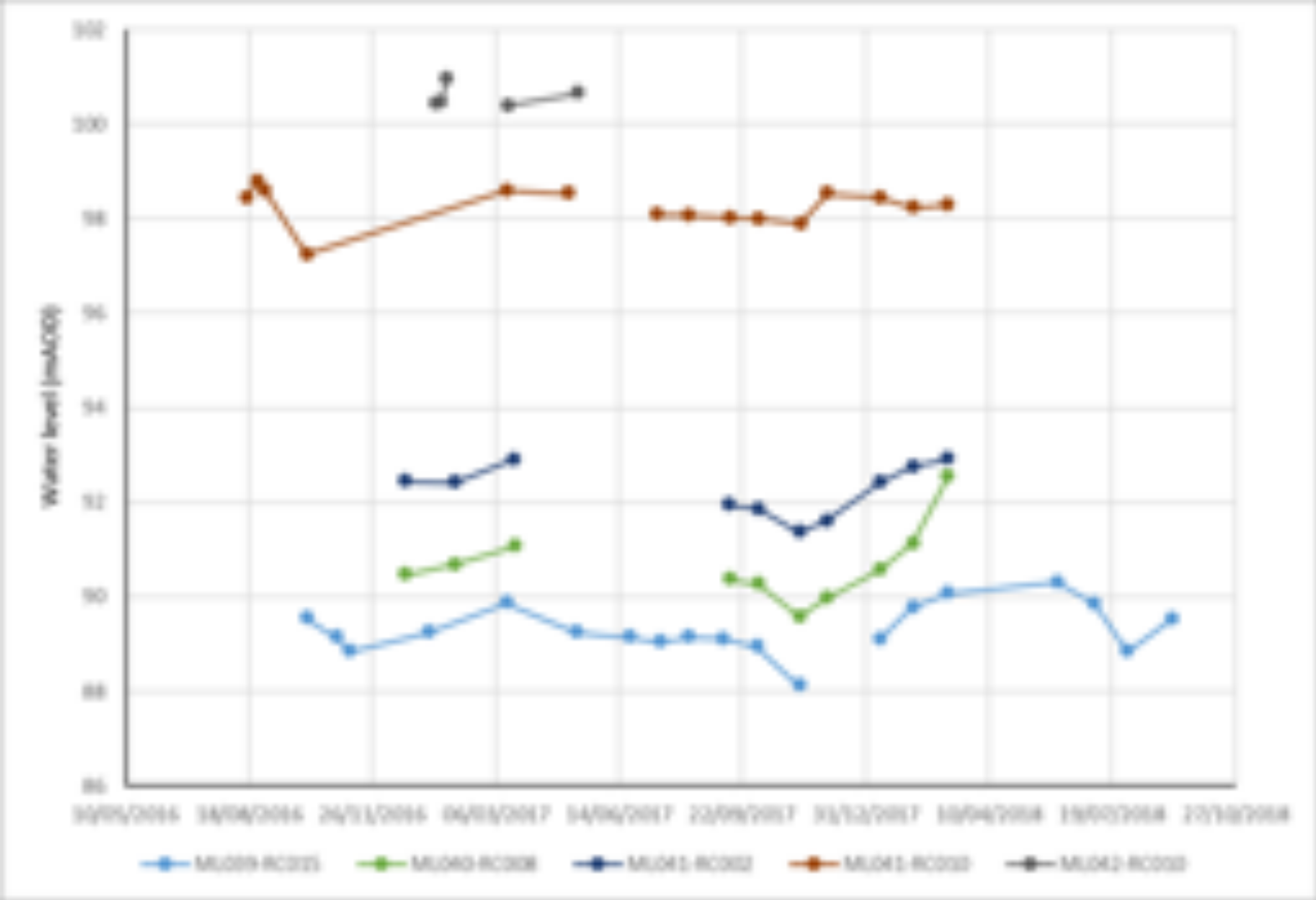
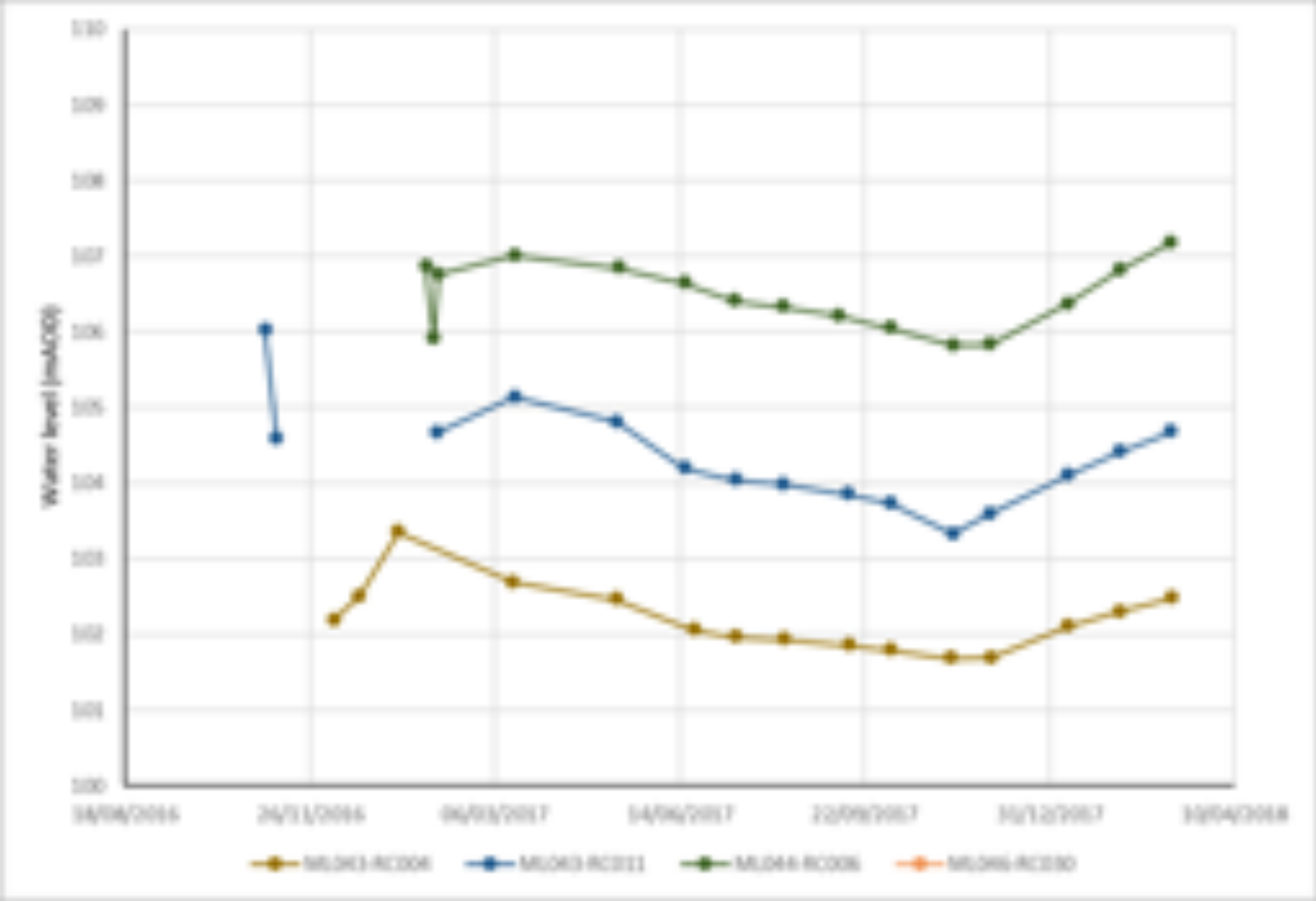


Figure 4: Groundwater levels in the chalk along the length of the Chiltern tunnel (Little Missenden to North Portal)



4.3 Groundwater abstractions

Affinity Water PWS

4.3.1 In this area, Affinity Water is licenced to take 88Ml/d from the Chalk aquifer as part of the Blackford Group licence (which includes 9 abstraction wells) and 12Ml/d as part of the Great Missenden Group licence (which includes 3 abstractions), although not all are operational. These values are average values and short term peak abstraction could exceed this. The wells in closest proximity to the tunnel, West Hyde, Chalfont St Giles and Amersham, abstract up to 32Ml/d. If the abstraction wells have to be shut down there is no alternative water supply.

4.3.2 All of the large public water supply groundwater abstractions have groundwater source protection zones (SPZ) defined for them (Figure 1). These comprise three zones:

- inner zone (zone 1) - defined as the 50 day travel time from any point below the water table to the source;
- outer zone - defined by a 400 day travel time from a point below the water table; and
- total catchment area - defined as the area around a source within which all groundwater recharge is presumed to be discharged at the source.

4.3.3 The SPZs are defined by modelling and are based on best available data at the time of modelling and licensed rather than actual abstraction rates. These zones are best estimates and in heterogeneous aquifers such as the Chalk should be taken as indicative rather than definitive. The inner and outer zones could be greater in extent and may be a slightly different shape where there are preferential flow zones. All modelling is dependent upon the available data and where this is limited there is quite a bit of interpolation. Furthermore, the model used is a single layer model and so takes no account of any vertical variations in permeability. SPZs should therefore be used with a degree of caution. Given the heterogeneous nature of the aquifer and the available hydrogeological data further groundwater modelling would be unlikely to increase the certainty of the hydrogeological environment and in particular groundwater flow paths from proposed structures. Additional computer modelling has therefore not been undertaken.

4.3.4 The tunnel route passes in close proximity to a number of Public Water Supply boreholes, including West Hyde which is 0.9km to the north-east of the above ground route, increasing to 1.3km to the east of the tunnel portal. However, at this location the tunnel would be above the water level and would not likely penetrate the water table until it is over 2km to the north-west of West Hyde PWS. Chalfont St Giles PWS is some 200m to the north-east of the tunnel route, Amersham PWS is 1km to the north-east and Great Missenden is 1.2km to the south-west of the tunnel route.

4.3.5 The tunnel is located within SPZ1, SPZ2 and SPZ3 for the West Hyde and Amersham abstractions, as well as passing through SPZ2 and SPZ3 for a supply near Gerrards Cross. Approximately 5% of the tunnel length is located within SPZ1, 50% in SPZ2 and 30% in SPZ3. The Gerrards Cross PWS is over 7km from the tunnel and is not considered further. As the only water treatment employed by Affinity Water prior to distribution is application of UV there are concerns that the tunnelling could affect the quality of water being put into supply.

4.3.6 The West Hyde abstraction comprises three boreholes within the valley of the River Colne, with two of the boreholes drilled to an elevation of approximately -35mAOD with the third drilled to -21mAOD. Two of the boreholes have slotted casing installed for almost all of their length, with one of the deeper boreholes open hole from 13mAOD to -35mAOD. Rest water level is at about 40mAOD. At its nearest point, tunnel invert level is approximately 55mAOD and is located on the interfluve between the valleys of the River Colne and River Misbourne. The Chalk in the abstraction boreholes is described as initially even with just a few discontinuities but becomes more nodular with an irregular surface below -10mAOD. Affinity Water does not hold any detailed information regarding preferential inflow horizons to the abstraction boreholes, nor any details regarding stratigraphy (this applies to all of the boreholes listed below).

4.3.7 The Chalfont St Giles supply is located to the north-east of Chalfont St Giles and consists of two boreholes adjacent to the River Misbourne drilled to depths of approximately 91m (-17mAOD) and are open hole from about 60mAOD. Local geology includes approximately 4m of superficial deposits overlying the Chalk. Rest water level is approximately 4.3m to 5.7m below ground level (about 70mAOD). The tunnel invert level is at approximately 45mAOD at its nearest point to the abstraction, located on the edge of the valley of the River Misbourne. The chalk in the abstraction wells is blocky and well fissured, with evidence of minor historical collapse in one of the boreholes.

4.3.8 The Amersham abstraction constitutes two production boreholes with two disused boreholes also identified on-site. Information is only available for one of the production boreholes and indicates that it was originally drilled to a depth of 79.4m and penetrated 7.5m of superficial deposits before encountering chalk. The borehole experienced partial collapse in 1931 resulting in infill to a depth of 65.5m (25mAOD), but CCTV surveys have found the chalk to be in good condition, clean, well fissured and stable with no evidence of recent collapse. Rest water level was recorded as 2.9m below ground level (about 84mAOD). Tunnel invert level at its closest approach to the abstraction is approximately 58mAOD.

4.3.9 The Great Missenden abstraction is comprised of two boreholes, drilled to 27m and 45m below ground level (approximately 88mAOD and 70mAOD respectively). Both boreholes have plain steel casing in the upper part of the boreholes (16m in borehole 1 and 24m in borehole 2) and are open hole below this depth. The chalk in borehole 1 is very fractured and uneven between 16mbgl and 20mbgl with many significant horizontal discontinuities recorded. Below this the lithology changes and the chalk is more even and massive, with fewer discontinuities, although several open fissures and a "huge cavity" were recorded between 20mbgl and 27mbgl. Borehole 2 has few cavities and only minor horizontal features. Below 36mbgl the chalk is even and massive with no significant fissures or fractures.

Private licensed and unlicensed abstractions (1km zone around the tunnel)

Two licensed private abstractions and four unlicensed private abstractions have been identified within 1km of the tunnel route and are shown on Figure 1. A summary of their recorded uses and locations relative to the tunnel route are summarised in Table 2.

Table 2: Private licensed and unlicensed abstractions within 1km of the tunnel

Abstraction ID in the ES [5]	Location	Distance from Tunnel	Recorded use
CFA08-GWUA01	Dibden Hill Farm	700m south-west	Not listed in Tech Appendix
CFA08-GWUA02	Coleshill House	530m south-west	Assumed to be Domestic
CFA08-GWUA03	Shardloes Farm	140m south-west	Farm use, unknown
28/39/28/0109	Amersham Prints Ltd	700m north-east	Textiles and leather, process water
28/39/28/0198	Little Missenden	700m south-west	remedial river/wetland support, top up water
CFA09-GWUA02	Wheatsheaf Cottage	730m north-east	Single Domestic
Hill Farm GSHP	Hill Farm	110m south-east	Ground source Heat Pump system

4.4 Surface water interactions

The River Misbourne is a chalk fed stream, which is in hydraulic connection with groundwater in the Chalk aquifer. However, in dry conditions, the groundwater level can be several metres below the base of the river in mid catchment (around 10m lower in the reach between Amersham and Chalfont St Peter). As a result, the River Misbourne tends to lose water to groundwater in these stretches through seepage downwards to the Chalk aquifer and can dry out completely in reaches between Amersham and Chalfont St Peter.

There are no permanently flowing tributaries to the River Misbourne along the route of the tunnel. There are a number of lakes and ponds along the line of the River Misbourne, but these appear to be "online" lakes which are essentially extensions of the River Misbourne. The largest is Shardloes lake, an artificial online lake controlled by a downstream weir, located approximately 2km west of Amersham.

5 Design and construction proposals

5.1 Tunnel overview

5.1.1 The Chiltern Tunnel will extend for 16km. The tunnel elevation will vary along its length, ranging from approximately 55mAOD at the South Portal, increasing to 190mAOD at the North Portal, with a minimum elevation of approximately 35mAOD in the vicinity of the Chalfont St Peter ventilation shaft.

5.1.2 The Chiltern Tunnel will consist of a twin bore tunnel with each tunnel having an internal diameter of 9.1m and an external diameter of 10.6m.. Forty cross passages, required to provide a means of escape from one tunnel to the other in the event of an incident, will be constructed along the length of the tunnel, with a typical spacing of 500m.

5.1.3 The two tunnels will be constructed simultaneously by means of two Tunnel Boring Machines (TBMs) and will be progressed from the South Portal to the North Portal. The first TBM will start before the second with a 200-300m distance between the two TBMs during operation.

5.1.4 Construction of the tunnel and cross passages will continue for a period of approximately 3 years and so it will not be possible to avoid construction activities during Affinity Water's peak demand period.

5.2 Tunnel boring machine selection

5.2.1 In very simple terms TBMs comprise a cutterhead that forms part of a tunnelling shield, with the latter being a protective structure / system that prevents collapse of the tunnel walls until the lining can be placed. Three shield types are generally recognised, an open face shield, a slurry shield and an earth pressure balance (EPB) shield, with each type of shield being best suited to particular ground conditions. In changeable ground conditions no single type of shield can efficiently and effectively bore through all strata.

5.2.2 An open face shield TBM only provides lateral support to the tunnel with the face being open for access and inspection. They are not suitable for use below the water table and so are not considered further in this assessment.

5.2.3 In the case of an EPB TBM, the high water inflows that are anticipated in the chalk would be detrimental to the efficient operation of the TBM, specifically with regard to building up the paste in the chamber behind the cutting face. The ground conditions would require the addition of chemical conditioning agents (foam and polymers) for stabilising the excavation face and managing these potential high water inflows in the highly fractured zones that are anticipated. The use of large quantities of such chemical conditioning agents, even if they are "environmental/bio-degradable compatible", would be of concern in a sensitive aquifer such as the chalk. In addition, with the tunnel below the water table, the spoil coming out from the EPB TBM would have a high water content (c.50%), requiring significant additional treatment of the spoil and a large temporary storage space in order for it to be suitable for future landscaping.

5.2.4 A large portion (c.30%) of the tunnel drive is above the water table. As the use of slurry potentially has negative environmental impacts, there will be challenges creating a cake at the cutting face in fractured ground. This is not a problem for an EPB TBM but is problematic for a slurry TBM. In addition, there are several 'low cover' areas along the route, most particularly at the M25 crossing where the tunnel crown is roughly one diameter of the TBM below the M25 (i.e. approx. 10-11m). Using a Slurry TBM, these areas would lead to high risks in slurry blow-outs at the surface given the potentially karstic nature of the ground and thin cover. A final concern with a slurry TBM is the potential for loss of slurry through fissures leading to confinement pressure loss at the cutting face and possible slurry circulation in the vicinity of pumping areas, contaminating the groundwater.

5.2.5 In recent years multi-mode TBMs have been developed that can switch between these shield systems, either by halting the TBM and changing TBM modules in the tunnel or by constructing more complex machines that allow tunnelling mode to be changed in a relatively short space of time in the tunnel with only short stoppages in operation.

5.2.6 The TBM selected for Section C1 is manufactured by Herrenknecht who have developed the Variable Density TBM. This highly complex multi-mode TBM uses earth pressure balance and slurry supported modes in a single machine such that different tunnelling modes can be selected in the tunnel without the need for stopping and changing components. This ability to change boring method will be particularly beneficial in the strata being bored to form the Chiltern tunnel, which includes a mix of unconsolidated drift materials, weathered chalk, chalk rock, hard bands, flints, and most critically from a hydrogeological perspective, fractures, fissures and voids, some of which could be large. This type of TBM has been successfully used in karstic situations in Kuala Lumpur, and for other purpose in Cairo and Hong Kong.

5.2.7 The TBM uses a screw conveyor system (see Figure 5) to remove the spoils from the excavation chamber to the slurry circuit. A slurryfier box at the end of the screw conveyor makes it possible to drive the TBM with a hydraulic slurry circuit in slurry mode. As a slurry TBM the Variable density TBM maintains the confinement pressure to the face through a regulated bubble chamber, the injection ratio of slurry to the excavation chamber allows a quick regulation of the density into the chamber in order to reduce the potential for loss of slurry to any fractures or fissures. At large voids the slurry circuit can be switched off and the TBM operate in high density mode with the screw still being able to transfer the spoils to the slurryfierbox. In addition, the variable density TBM allows the rock crusher to be relocated to the exit of the screw inside the slurryfier box which means that maintenance of the crusher can be done at atmospheric pressure at any time (i.e. specialist equipment and techniques are not required).

Figure 5: Indicative schematic for a variable density TBM

5.2.8 The pressure at the cutting face is continuously monitored via a series of earth pressure sensors. In addition, the cutterhead integrating instrumentation monitoring using the 'MOBYDIC' system comprises an arrangement of sensors that are integrated into the cutter discs and which transmit real-time data to the TBM control room. These sensors constantly measure loads, rotation speed(s) and temperatures applied on discs and can produce "ground interpretation" for the TBM pilot in real time. This allows the detection of cavities and measures to be implemented if and when necessary. The MOBYDIC system is also useful when flint bands are encountered as it allows adjustment of the TBM parameters and better planning of maintenance requirements, allowing these to be undertaken at appropriate locations.

5.2.9 The cutting face is normally maintained under a slight positive overpressure of a minimum of 0.1bar (equivalent to a 1m head of water) so there will not be any water make by the machine, but also so that there are not substantial losses of rock slurry to the aquifer. This pressure is automatically changed as hydrogeological conditions at the cutting face change.

5.2.10 Regular maintenance on the TBMs will be required, typically with up to 3 hours of maintenance per day, although this will largely be within the TBM. There will be programmed shutdowns as the cutters and tools are worn down and need replacement. The rate of wearing will be strongly influenced by the number of flint bands that are penetrated by the TBMs. These will be undertaken by specially trained technicians at the cutting face where they will work at normal atmospheric pressure, although some will be completed using compressed air if required.

5.2.11 There are therefore significant advantages from a management, operation and environmental perspective for using a variable density TBM. This type of TBM also provides other benefits, including those associated with slurry pumping and separation of the spoils for landscaping as outlined below.

5.3 Slurry pumping

5.3.1 As noted above, as the TBM cuts the rock at the working face the cuttings will be mixed with light slurry to form a thick slurry which will be pumped along pipes within the TBM (Figure 5) and out of the tunnel to a treatment plant at the South Portal where the slurry will be de-sanded and the fines particles pressed to form filter cake for placement. Following treatment regenerated slurry will be then returned to the TBM via a second pipe with fresh top up water added when required.

5.3.2 The typical sizing of a slurry circuit to cope with a 60mm/min of TBM Advance speed with a cutting diameter of 10.265m is to:

- have a flow in the slurry circuit of 2 300m^3/h;
- use slurry pumps of 1 100Kw; and
- have pipes with a diameter of 500mm.

5.3.3 Due to the length of the tunnels (2no. of 16km length), the slurry circuit would normally require a large number of slurry pumps to enable the hydraulic transportation of the rock cuttings from the TBM to the STP, and a substantial power consumption and water to feed these pumps. Align's supplier is proposing a new concept which will drastically reduce the cost and water requirements for slurry movement. The concept consists of:

- Keeping the feed line from the STP to the TBM continuously sending regenerated slurry to be processed by the STP.
- Adding a second line from the STP to TBM in order to send recycled water to the slurryfier box and/or excavation chamber to control the density in the return line. This will enable a lower flow return to the STP.

- Automatically adjusting the feed line and recycled water pumps to maintain the density of the return line with regard to the TBM advance speed, with secondary dilution undertaken at the STP.

5.3.4 This new concept allows better control of the return and feed line densities with regard to the TBM advance speed and markedly reduces energy and water consumption compared to the standard approach. This is only possible with a Variable Density TBM as the mix of slurry and water is carried out in the slurryfier box. This results in the following changes:

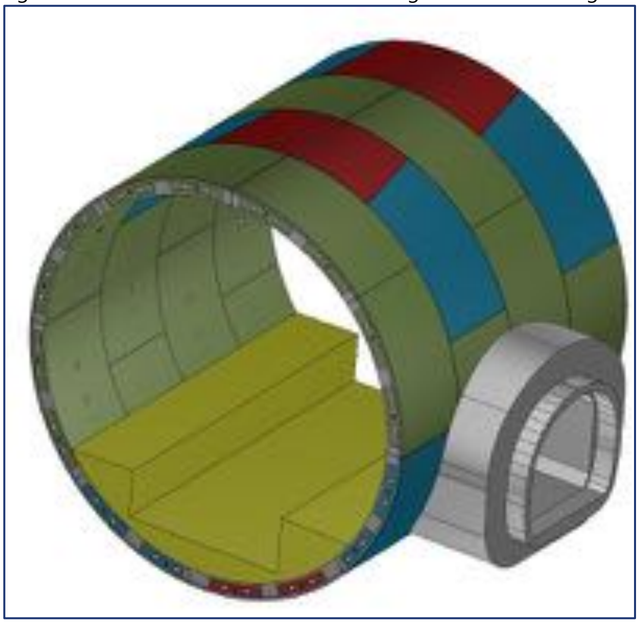
- Flow of the slurry circuit is reduced to 1 250m^3/h and the flow of recycled water is 400m^3/h.
- Slurry pumps are smaller than would otherwise be the case (now at 700Kw each).
- The number of pumps is decreased and the pipe diameter can be reduced to 400/350mm, allowing less water to be used for flushing.

5.4 Tunnel lining

5.4.1 The concrete tunnel lining segments are placed by the TBM behind the cutting face so that a lined tunnel is created behind each TBM. The TBMs will bore the tunnel and the segmental steel fibre reinforced pre-cast concrete segments will be installed as the TBMs progress along the tunnels. The segments will fit together to form rings that comprise the tunnel lining (Figure 6). The concrete lining segments will be pre-cast at the South Portal compound and transported into the tunnel on multi-service vehicles.

5.4.2 The tunnel lining is designed to resist loads throughout the life of the structure, to form the required internal tunnel profile and to limit leakage of groundwater into the tunnel. Grout will be injected into the annulus between the installed pre-cast concrete segments and the bored tunnel to seal any void and prevent formation of any preferential flow paths along the line of the tunnel. The grout will be injected under pressure and the injected volume will be continuously monitored with the pressure limited to minimise the potential for losses into the aquifer.

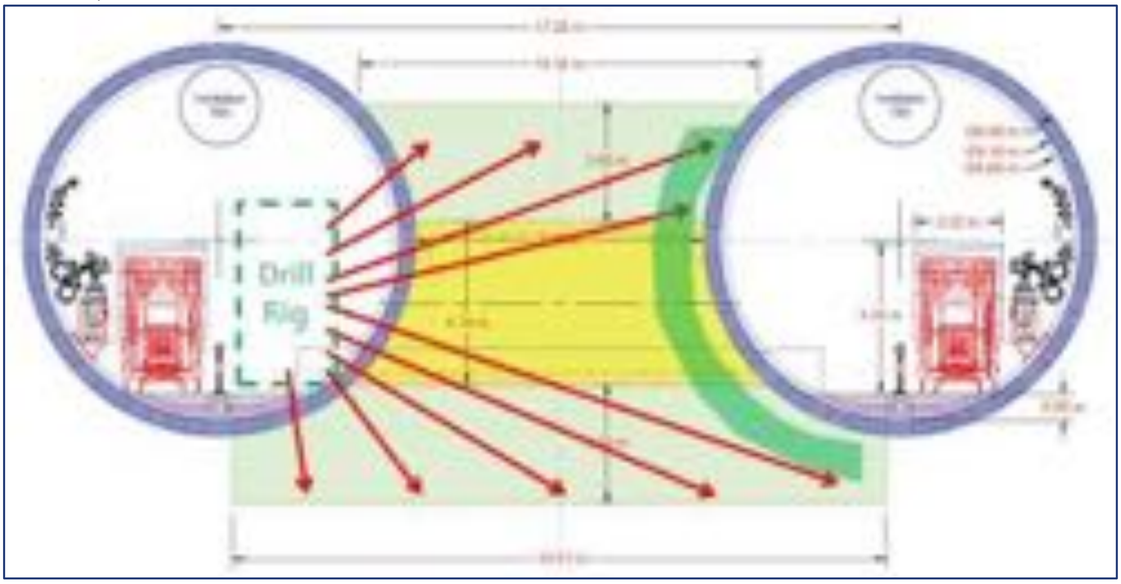
Figure 6: Indicative schematic section through a tunnel showing concrete segments and cross passage junction



5.5 Cross passages

5.5.1 Cross passages will be constructed following on after installation of the tunnel lining. The Cross Passage excavation is likely to be constructed using light plant through the sidewall of the tunnel. The requirement for ground improvement and groundwater control will be ascertained through systematic probing at each Cross Passage before construction begins. Pre-support of the excavations may comprise break-out spiles, systematic spiles or a pipe arch, and groundwater control may include grout injection around the location designated for each Cross Passage to prevent groundwater inflow during construction (Figure 7). Controls on the volume and pressure of grout injected will be put in place to ensure that large volumes of grout are not lost to the aquifer. Should large voids be encountered then amendment to the grout mix will be implemented to increase viscosity and ensure fissures are sealed.

Figure 7: Indicative schematic section showing grout injection for cross-passage construction (all dimensions are indicative)



6 Potential effects on the groundwater environment

6.1 Tunnel construction versus cross passages

6.1.1 The effects of the tunnels are likely to be greater than the cross passages because: (i) they are continuous linear features; (ii) they will occupy a much larger volume of the aquifer; (iii) they will be continuous in terms of construction; (iv) comprise two large tunnels; and, (v) the cross passages will only be around 4m in diameter compared to the 10m diameter for the tunnels. The effect of the cross passages is therefore likely to be masked to a large degree by that of the tunnels. The effects of the cross passage construction are considered to be broadly similar to the tunnels, just much smaller and with a shorter construction period for each passage (c. 2 to 3 months) and so they are not considered separately in the following assessment. The only exception relates to the pre-construction grouting as this could have a localised effect on any fissures or voids.

6.2 Groundwater quality

6.2.1 There is the potential for the tunnel and cross passages to affect groundwater quality in the Chalk aquifer via a number of activities outlined below. Where practicable the design and working methods have been selected to limit the potential effects. These potential effects are all associated with construction and so have a limited duration. No long term effects on groundwater quality associated with the operation of the railway have been identified.

Chalk turbidity

6.2.2 Chalk generally comprises coccoliths, foraminifera and other shell debris, cemented together to lesser or greater degrees. The coccoliths are particularly small being several µm across. Any construction work can result in disintegration of the chalk mass into these fine particles which, when the work is below or close to the water table, has the potential to induce chalk turbidity. Due to their small size these particles do not settle quickly and can rapidly migrate through fissures in the aquifer. There may be significant increases in turbidity in the aquifer local to construction activities, but these will have very limited overall effect on the Chalk aquifer and will be of short duration. At the aquifer scale no significant effects are anticipated.

6.2.3 The Affinity Water abstractions are close to the line of the tunnel and have very low limits on turbidity as it can limit the effectiveness of UV water treatment. Limits on turbidity are set at 1 NTU (Water Quality Regulations, 2016) but as a precaution Affinity Water take boreholes out of supply at 0.8 NTU. Private water supplies are also present in close proximity to the tunnel and may similarly be negatively impacted if turbidity levels in abstracted water increases as a result of tunnel construction.

6.2.4 Of particular concern for turbidity migration will be the two locations where the tunnel will pass beneath the River Misbourne as the river valley is known to be a high flow zone and it is also where the Chalfont St Giles, Amersham and Great Missenden PWS are located.

6.2.5 There is little information on the migration of chalk turbidity through chalk aquifers to abstraction boreholes during construction activities. However, it is an issue that is known to Affinity Water (who have some data on this) and there have been instances during HS2 ground investigations when turbidity has increased at an abstraction borehole due to below water table construction work. Research has been completed on the migration of natural turbidity through karstic systems, including the effects of this on potable water supplies, but these turbidity events are due to movement of turbid water into natural sinkholes rather than from below ground construction activity.

6.2.6 In addition to chalk turbidity, there are other sources of natural turbidity which could be enhanced or altered by construction of the tunnels and cross passages. These sources include sediment that could be washed into fissures from surface water runoff. This sediment can be washed through the groundwater system into the aquifer and to Affinity Water abstractions, to natural discharge points, or it can become deposited in fissures in the chalk and remobilised at a later date, particularly if there are changes to groundwater flow rate and direction of groundwater movement such as those caused by the tunnels.

Cement / grout

6.2.7 Cement / grout tends to be highly alkaline and can pollute water supplies if it gets into them with pH of 10 to 12 not being uncommon. Drinking water has a pH limit of 9.5. There is a risk that migration of cement or grout (e.g. from the tunnel annular space or from ground improvement at the cross passages) could impact water quality in the Chalk, although their viscosity limits their potential to move within the aquifer, provided they're not released into rapidly flowing, turbulent water. That is unlikely to be the case in the majority of the Chalk aquifer as although rapid flow paths are known, they are not ubiquitous.

6.2.8 The risk of cement or grout migration can be mitigated to a degree by careful use and, ensuring that quick setting material is used and where necessary the cement or grout is thickened to reduce its potential to flow. It is planned to use grout with a gel time of 12 seconds and a cure time of 30minutes for injection into the tunnel annulus, and cure time of 40 minutes for grout used during construction of the cross passages. The rapid gel time is to be achieved by the addition of sodium silicate just prior to the grout's injection into the tunnel annulus. Sodium silicate is non-toxic but is an alkaline substance (pH=11 in bulk form) and so could result in alterations to pH in line with the effects of cement grout. However, it will be used in lower volumes than the grout (5-10% of the total grout volume) and so is expected to have less impact on water quality than the grout. The rapid gel time of the grout means it is expected to flow only briefly to fill up any voids in the immediate vicinity of the tunnel but will not flow far through any fractures as it cures.

6.2.9 There is limited potential for migration if the materials are appropriately managed with maximum take volumes established to control the injection of materials and those that are pumped underground are quick setting. There is of course the risk that cementitious materials are unknowingly pumped into fissures, but with a high level of monitoring this potential can be reduced.

Drilling slurry

6.2.10 Drilling slurry is generated at the TBM cutting face due to the mixing of rock cuttings and water which is required to effectively remove cuttings from the face. The slurry is comprised of water and suspended fines of rock material (dominantly chalk) that could induce elevated turbidity in groundwater. The TBM balances the pressure of the slurry at the cutting face against the pressure of groundwater and the system reacts quickly to changes in pressure head so that there is no significant inflow of groundwater or significant outflow of slurry. The vast majority of the slurry is removed from the cutting face through the TBM and is pumped backed to the surface for treatment. However, there is a risk that some slurry will be lost, especially where large fissures / solutionally enlarged voids are encountered.

Lubricants and hydraulic fluids used in the TBM

6.2.11 The following section assesses the nature of the lubricants to be used in the TBM and considers their hazardous nature as stated on the safety data sheets (i.e. according to EC1272/2008 as amended). No information is provided on the safety data sheets regarding the detailed chemical composition of the lubricants so the manufacturers were contacted to check the substances present and particularly to identify any listed by the WFD UK TAG as being hazardous[10].

6.2.12 The legislative position regarding the definition of whether a substance is hazardous[11] is discussed in Appendix A as the situation is relatively complex, particularly as the substances in question here are essential greases used for safe and cost effective equipment operation rather than liquid discharges .

6.2.13 Based on the assessment presented in Appendix A, it is not considered that use of a grease in the TBM, even where it contains a substance defined in the UK TAG list as hazardous, would be in breach of the Environmental Permitting Regulations (Groundwater Activities) as the greases are not being "discharged" in the sense conveyed in the Regulations. Not using the greases would result in significantly higher operational costs and more maintenance work. This notwithstanding, the use of greases for the TBM in the aquifer is considered in terms of whether they are soluble and so the assessment below indicates where there are hazardous substances in the greases.

HBW grease

6.2.14 At the cutting face of the TBM a number of lubricants are used to protect the main drive and drive seal. The primary substance is Condat HBW which is injected into the labyrinth of the main drive seal which is then in direct contact with the spoil in the excavation chamber. It is an exclusion grease used to stop the soil from entering the main drive seals. The rate of use is likely to be of the order of 1.1m^3/km, with the lubricant primarily lost to the spoil, but some may also be lost to the tunnel walls.

6.2.15 The Safety Data Sheet for HBW, which is included in Appendix B, indicates that the lubricant is not hazardous, is a solid paste, is insoluble in water and is "stable and non-reactive under normal conditions of use". It is not classified as an environmental hazard and has a relative density of 1.2 and so would sink in water. Based on this information, it

[10] http://www.wfduk.org/resources/groundwater-hazardous-substances-standards

is unlikely that the lubricant would become dissolved in water at a measurable or significant concentration and almost all of it will adhere to rock cuttings. If the TBM encounters a void or fissure which slurry is subsequently lost into then any migration of the lubricant would be in solid (paste) form adhering to the rock cuttings.

6.2.16 Condat Groupe, the supplier of the grease, was contacted to determine if HBW contains any hazardous substances as listed by WFD UK TAG. Condat confirmed that it does not contain any substances on the UK TAG list, although it does contain the following substances that are included in Annex I of directive 2006/118/EC (the protection of groundwater against pollution and deterioration). These substances are biocides and a fungicide:

- 1,2-benzisothiazol3(2H)-one (CAS:2634-33-5) at <0.005%.
- 2-methyl 2H-isothiazol-3-one (CAS: 2682-20-4) at <0.005%.
- 2-pyridinethiol,1-oxide, sodium salt (CAS: 3811-73-2) at <0.020%.

6.2.17 As noted above the majority of these substances will be lost to the tunnel spoil. Condat has estimated that the quantity present in the spoil would range between 0.003mg/kg of spoil for the former two substances and 0.013mg/kg of spoil for the latter. As this will effectively be part of the spoil and is defined as "insoluble" in the safety data sheet it is unlikely that there will be any measurable leaching from the material.

6.2.18 No effect on the Chalk aquifer water quality is therefore anticipated. If the rock particles appeared at an Affinity water abstraction they would result in turbidity, and the water would not be put into supply, or it would be removed by the turbidity treatment plant. The risk of this lubricant to drinking water or the environment is therefore extremely low.

GR217 grease and BTG 4602 grease

6.2.19 Options are currently being evaluated regarding which of these greases will be used for lubrication of the drive seal. Whichever is selected, it would come into contact with the rock cuttings and would likely be used at a rate of 2.3m^3/km.

6.2.20 Condat lubricant GR 217 is not hazardous (see MSDS in Appendix B), is a solid paste, is insoluble in water and is stable under normal conditions. It is not classified as an environmental hazard and is immiscible with a relative density of 0.9 and so would float on water. This lubricant is classified as insoluble and so it would not dissolve and migrate in groundwater. As with HBW, if a void is encountered by the TBM any migration of the lubricant would be in solid (paste) form adhering to the rock cuttings, and ultimately degrading (GR 217 is biodegradable). However, the majority of this lubricant will mix with the drilling slurry in the TBM chamber and be removed in the slurry and pumped out to the treatment plant.

6.2.21 Condat Groupe, the supplier of the grease, was contacted to determine if GR217 contains any hazardous substances as listed by WFD UK TAG. Condat confirmed that it contains two listed non-hazardous pollutants and one hazardous substance:

- molybdenum disulphide (CAS 1317-33-5) at <0.5% (non-hazardous).
- diphenylamine (CAS 122-39-4)) at <0.005% (non-hazardous).
- mineral oil at <0.3% (hazardous).

6.2.22 Based on the concentrations of these substances in the grease Condat has estimated that the losses would equate to 0.163, 0.002 and 0.098mg/kg of spoil (respectively), with the majority of losses (estimated as >90%) being to the spoil brought to the surface for treatment. It is unlikely that any measurable amount would be lost to groundwater in the aquifer due to the insoluble nature of the grease and the very limited contact time with groundwater at the cutting face for the majority of the grease. The risk of GR 217 to drinking water or the environment is therefore extremely low.

6.2.23 Condat was contacted regarding the role of the mineral oil in GR217 and they confirmed that it was an essential part of the additives within the formula used to make the grease. It is one of the substances that makes the grease effective in the main seal.

6.2.24 Condat lubricant BTG 4602 is not hazardous, is a solid paste, is insoluble in water and is stable and non-reactive under normal conditions. It is not classified as an environmental hazard and is immiscible with a relative density of 0.96 and so would float on water. This lubricant is classified as insoluble and so it would not dissolve and migrate in groundwater. As with GR 217, if a void is encountered by the TBM any migration of the lubricant would be in solid (paste) form adhering to the rock cuttings. However, the majority of this lubricant will mix with the drilling slurry in the TBM chamber and be removed in the slurry and pumped out to the treatment plant.

6.2.25 Condat Groupe, the supplier of the grease, was contacted to determine if BTG 4602 contains any hazardous substances as listed by WFD UK TAG. Condat confirmed that it contains one non-hazardous pollutant and one hazardous substance:

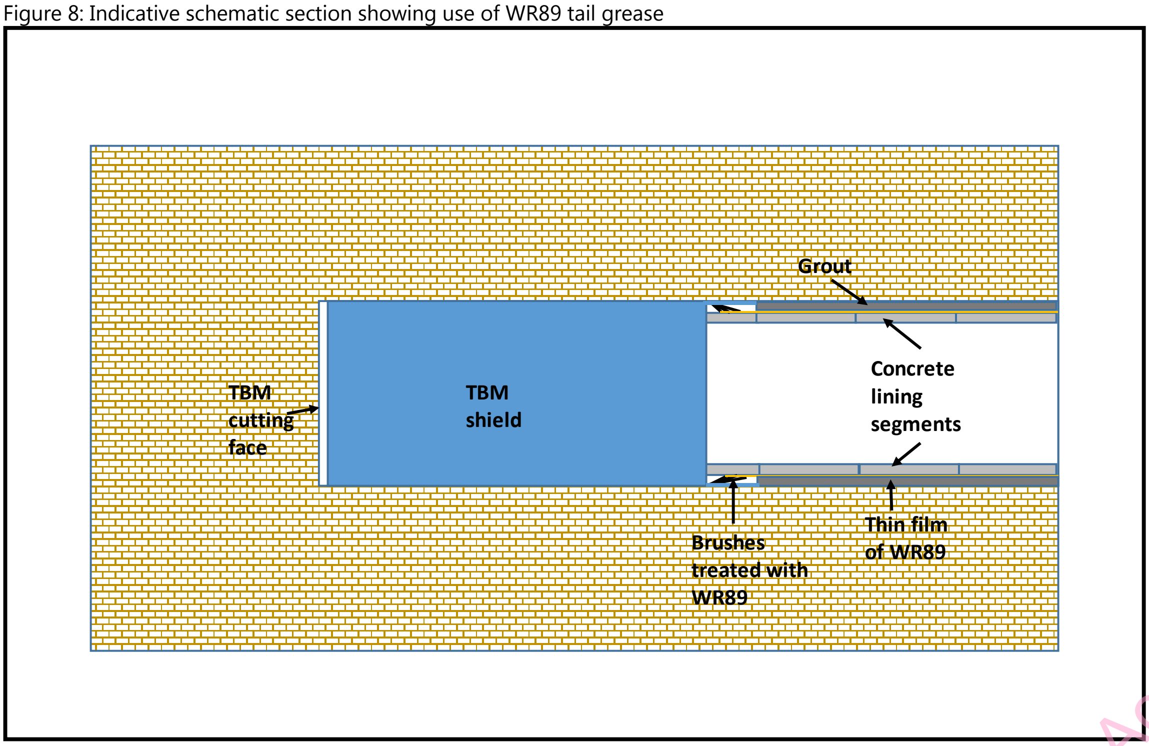
- diphenylamine (CAS 122-39-4)) at <0.004% (non-hazardous).
- mineral oil at <0.3% (hazardous).

6.2.26 Based on the concentrations of these substances in the grease Condat has estimated that the losses would equate to 0.001 and 0.098mg/kg of spoil (respectively), with the majority of losses (>90%) being to the spoil brought to the surface for treatment. It is unlikely that any measurable amount would be lost to groundwater in the aquifer due to the insoluble nature of the grease and the very limited contact time with groundwater at the cutting face for the majority of the grease. The risk of BTG 4602 to drinking water or the environment is therefore extremely low.

WR89 grease

6.2.27 Condat WR89 lubricant, which is a solid, paste like substance, will be injected into the tail skin brushes which surround the outer rear of the TBM shield where the concrete segments are placed (Figure 8). Once lubricated these brushes help to provide a seal at the rear of the TBM shield to limit the potential for ingress of water and fines into the tunnel[11]. It is estimated that the lubricant will be used at a rate of $31m^3/km$. Part of it will come back through the brushes into the tunnel but the majority of the lubricant will form a very thin film (around 1mm thick) on the extrados of the concrete lining. Immediately after the lining is placed, grout is pumped between the lining and the tunnel wall, such that the thin layer of grease is encapsulated and cannot migrate into groundwater. The setting time for the grout is around 30minutes.

Figure 8: Indicative schematic section showing use of WR89 tail grease



6.2.28 The WR89 lubricant is classified as not being hazardous according to the Safety Data Sheet (Appendix B). The constituents have not been assessed against the GWDD/WFD

[11] https://www.condat-lubricants.com/product/sealant-foam-lubricant-tunnel-boring/mastic-sealants-tbm-tail-seal-greases/

list of hazardous substances as it will not be placed in contact with groundwater. In addition it is insoluble and immiscible with water. It is also stated in the Safety Data Sheet that it is stable and non-reactive under "normal conditions of use" and is not classified as an environmental hazard.

6.2.29 The WR89 lubricant will form a thin film on the concrete lining segments which will be encapsulated by the grout and so will not be in contact with groundwater. In particular, it will not be available to move out into any rapid flow paths such as fissures within the chalk rock as the lining will not be in contact with the rock. Thus, although WR89 will be used in relatively large quantities, the potential for any to come into contact and become dissolved in groundwater is extremely limited and there is no potential for movement directly into any fissures / voids encountered.

WR90 grease

6.2.30 In addition to the Condat WR89, Condat WR90 lubricant is injected into the brushes before the TBM starts operating in order to protect the brushes. This is a once only activity and losses of WR90 to the aquifer are not anticipated as the first rings are built in the excavated tunnel above the water table; it will be flushed by the WR89 prior to the end of the tail seal entering the ground. Like WR89, this lubricant is not hazardous, is a solid paste, is insoluble (see Appendix B) and will be encapsulated by the grout injected outside of the tunnel lining system. There is therefore no risk from this lubricant. As this lubricant will not be placed in contact with groundwater it has not been determined if it contains any hazardous substances listed on the GWDD/WFD list.

Emergency SDS

6.2.31 In the event that the tail seals fail due to damage or failure of the brushes then Condat Emergency SDS could be used. This is not part of normal operations and so there is no information on likely rate of use, or even on the likelihood of use. Its purpose would be to limit water inflow to the tunnel from around failed brushes. As with WR89, this material would form a layer on the outside of the lining segments and would be encapsulated by the injected grout.

6.2.32 The Safety Data Sheet for SDS (Appendix B) indicates that the material represents a hazard to health as it is a skin and eye irritant in its bulk form and contains aliphatic acids, salts and calcium hydroxide (an alkaline corrosive). It is a solid (paste), is insoluble and defined as stable and non-reactive under normal conditions of use, but it is toxic to aquatic organisms at low concentrations (EC50 = 0.01 to 0.1 mg/l). However, it would only be used in an emergency and like WR89, would be encapsulated by the grout in the tunnel annular space, and would not migrate into groundwater. For these reasons there is no risk from this lubricant.

Hydraulic oils

6.2.33 The TBM will utilise hydraulic fluids (Condat D46 and D68 – Appendix B) that will be contained in pipework within the machine. The potential for loss would be via a pipe failure with the greatest potential at first start up and during the later stages of operations as parts become worn. At start up the machine would be at ground level and subject to many inspections so any loss to the environment is extremely unlikely. A regular maintenance plan during operation will minimise the potential for failure during operation. As there are no plans for this hydraulic fluid to come into contact with groundwater it has not been determined if it contains any hazardous substances listed on the GWDD/WFD list.

6.2.34 In the event that there is a pipe failure during operation, the operator would shut down hydraulic pumps to restrict losses and the fluid would likely be contained within the TBM and not released to the environment (one of the advantages of the variable density TBM is that there are no hydraulic hoses or components inside the excavation chamber). This fluid would be cleaned up and disposed of in the normal way. In the unlikely event of a release to the environment, the risk would only be significant if a large volume of liquid was lost and it moved into the groundwater regime rather than remaining in the tunnel. If such a loss occurred, its containment would be dealt with by following the accident and incident response plan to remove any significant risk to the environment.

6.2.35 If a significant volume of the hydraulic oil did escape before it could be contained this would enter the slurry on the atmospheric side of the TBM and would be pumped to the slurry treatment plant where it would be treated. It is difficult to envisage a realistic scenario where there would be loss of hydraulic oil to the environment. However, in the extremely unlikely scenario of a loss of hydraulic fluids, as these are low density (0.92) and insoluble (see Appendix B) they would float and would likely be trapped in the upper parts of fissures, within the rock matrix, or would migrate to the surface. Given the extremely low likelihood of this, and the deep intake zones on the Affinity Water abstractions, there is no significant risk to water supplies. In the even more unlikely case of any migration to surface water, the oil would be removed following procedures detailed in the accident and incident response plan. The hydraulic oils represent a chronic risk to aquatic organisms as they contain small amounts (<5%) of phosphorothioic acid and O,O,O-triphenyl ester. Therefore, rapid intervention of any release to the environment would be undertaken.

6.3 Groundwater flow paths

6.3.1 There is the potential for the Chiltern Tunnel and the cross passages, to change flow characteristics in the Chalk aquifer and potentially reduce yields at public and private water supplies in the vicinity of the tunnel. These changes are due to the structures being built and so are considered as permanent effects, with only one potential effect (TBM operation) solely during construction.

TBM operation

6.3.2 During construction of the tunnel, impacts will be limited to very local, minor changes in groundwater level as a result of fluctuations in pressure at the cutting face of the TBM. However, as stated earlier, the pressure at the cutting face will be a minimum of 0.1bar, which is equivalent to 1m head of water. This would not be sufficient to cause a significant change in flow direction or the total flow to the Affinity abstractions, particularly as the location of the head change will be continuously moving as the TBM progresses. Significant increases in head would be required at the cutting face to have a noticeable effect on groundwater levels, and such head increases are not proposed as part of normal TBM operations. It is therefore not considered further in this assessment.

Ground improvement for cross passage construction

6.3.3 There is the potential for the below ground use of cement or grout to block fissure systems. This is of particular concern in the immediate vicinity of the cross passages which could result in a localised change in the rate and direction of groundwater movement. This would be a particular issue in hard karstified limestones where development of single isolated conduits can occur. However, in softer strata such as chalk, development of isolated conduits is far less common, and instead, fracture and fissure networks tend to develop, often along preferential routes, such as in valleys. The potential for complete blockage of a fissure network from grouting prior to cross passage construction is therefore relatively low. As indicated on Figure 7, the zone of grout injection around the cross passages is limited to less than 3m around the cross passages resulting in a cross sectional area being blocked of about 10m (i.e. 4m from the cross passage and 3m on either side from the grout). In addition, any localised blockage caused by the grout injection would lead to a head build up behind the grout such that water would be forced through fissures around the blockage. Any effects are therefore likely to be small scale and localised and have much less effect than the tunnel construction.

6.3.4 The cross passages are much smaller than the tunnels and are not continuous, with each located about 500m apart. There are 40 locations proposed, 38 mined below ground and 1 constructed within each of the North and South Portals. Thus, although their construction will block fissures in the aquifer in their immediate vicinity, their effect will not be spatially extensive.

6.3.5 The blocking of fissures by grouting will therefore result in local changes in flow direction and hydraulic head around the cross passages, but in a well fractured aquifer such as the chalk the water will move through fractures around the outside of the grouted area. As the majority of the tunnel is at depth, dominantly below interfluve areas, any changes in hydraulic head caused by grouting are extremely unlikely to result in groundwater breakout at the surface.

Construction and operation of tunnels and cross passages

6.3.6 During operation, impacts from the tunnel could take the form of local changes to flow routes due to obstruction of preferential flow paths from the presence of the tunnel and cross passages, and/or a reduction in flow through the aquifer due to a reduction in the cross-sectional area of the aquifer available to groundwater flow. These changes are likely to be localised around the tunnels, and as with the cross passages, are unlikely to result in new breakouts of groundwater at the surface. This is assessed below.

6.3.7 Hydraulic heads around the tunnel could change due to the reduction in saturated thickness of the aquifer which reduces the rock available for water migration, or due to any reduction in permeability caused by the tunnel or cross passages (including grouted zones) blocking preferential flow paths. The order of magnitude effect of this can be estimated using Darcy's Law with the following assumptions:

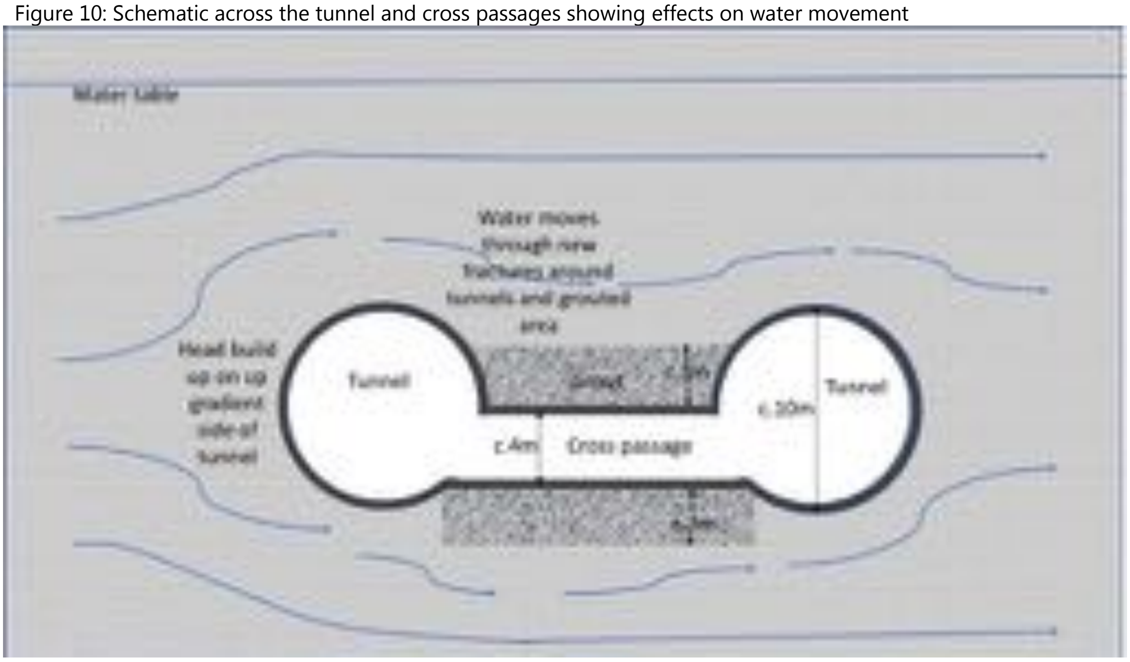
- The tunnels are perpendicular to the direction of groundwater movement. This is not actually the case (see below), but presents a worst case situation.
- The hydraulic gradient is 0.005, which is based on the regional hydraulic gradient across the area as shown in the Environmental Statement[12], an excerpt from which is included in Figure 9. It is recognised that this is at very best indicative (and now somewhat out of date as it was prepared using data from 1976) and that the directions of flow vary greatly, especially around and along valleys, but it provides a useful indication of the likely low water level regional hydraulic gradient.
- The hydraulic conductivity is 10 m/d. This value can vary widely (see discussion in Section 4.2) and is used as a starting point for this assessment.
- The width of the aquifer is 1000m. This varies and the value used here is purely for illustrative purposes.
- The active saturated aquifer thickness is 50m (Section 4.2).

[12] HS2, London-West Midlands Environmental Statement, Volume 5, Technical Appendices, CFA8, The Chalfonts and Amersham

Figure 9: Excerpt from the Environmental Statement showing the regional groundwater flow pattern (October 1976 low groundwater level contours taken from BGS hydrogeological map under copyright). This is provided solely to indicate broad regional direction of groundwater flow during low groundwater conditions

6.3.8 Based on these assumptions, across a distance of 30m (the approximate length of the cross passage and diameter of two tunnels when looked at in cross section – see sketch in Figure 10), the head drop would be about 0.14m without the tunnel present. With the tunnel present, this head drop would increase to 0.17m, assuming that the head is evenly distributed throughout the thickness of the aquifer. This is an insignificant change, although it is at best indicative.

Figure 10: Schematic across the tunnel and cross passages showing effects on water movement



6.3.9 If the hydraulic conductivity was also reduced by the presence of the tunnel, from 10 m/d to 1 m/d, then with a 40m thick aquifer the resultant head drop is estimated to increase by about 2m. This is a large increase, although as the water table is over 10m below ground for the vast majority of the tunnel route, this will not result in any significant changes to the regional hydrogeology.

6.3.10 Where the tunnel is due to pass beneath the River Misbourne the water level is at or just below ground surface, depending upon season and rainfall. A rise in groundwater level could therefore increase flows in the river thereby reducing the water in the aquifer. However, the river valleys are zones of preferential groundwater movement in the chalk which have a high transmissivity, and with the tunnel being approximately 20m below ground level at these locations, the likelihood of a large reduction in transmissivity due to the tunnels and cross passages is relatively low (but uncertain). This notwithstanding, a small change in head is likely and this could result in discharge of groundwater into the river which would reduce groundwater flow along the river valleys. This would be beneficial for the surface water environment as water could enter the River Misbourne, but it could reduce groundwater movement along the valley and so further assessment of the potential effects on each of the Affinity Water sources has been undertaken in Section 7.

6.3.11 The above assessment assumes that groundwater flow direction is perpendicular to the tunnel alignment, which could be considered the worst case in terms of a regional affect as the tunnel and cross passages act as a barrier to flow across the width of the aquifer. However, along much of the length of the tunnel the regional flow direction is along the line of the tunnels (Figure 9) or sub-perpendicular to the tunnels. In these instances the effect is likely to be less, as the cross sectional area of the tunnels relative to the cross sectional area of the aquifer is less.

6.3.12 Tunnel and cross passage design will ensure that leakage rates into the tunnel will be low; somewhere between 200 and 450m^3/d for both tunnels, the cross passages and the shafts (design work is ongoing to refine these figures). This will therefore not have any noticeable effect on groundwater levels in the long term, although as the volume is greater than 20m^3/d a Schedule 33 approval will be required rather than an abstraction licence (this is due to the water being abstracted from within the HS2 Act limits). Due to the aquifer being closed to new consumptive abstractions this will necessitate recharge of this leakage water back to ground which would require an Environmental Permit. The requirements for pre-treatment prior to recharge to ground are currently being reviewed, but would likely be required to ensure the quality of the recharge water.

6.3.13 Therefore, although the tunnels and cross passages will change flow directions and rates, these will be localised around the tunnels and will not be laterally extensive across the aquifer.

6.4 Abstraction borehole stability

Potentially, vibrations during tunnel construction could lead to borehole collapse if there were any Affinity Water abstractions located within close proximity of the works. However, as the chalk is a soft rock the degree of vibration would be extremely low, and the closest abstraction is at Chalfont St Giles, which is located about 200m from the tunnel. Given this distance, the depth of the tunnels and the low vibration generation by the TBM there is no significant potential for any effect and so this is not considered further. If an effect was identified this would be mitigated under the asset protection agreement between HS2 and Affinity Water, with mitigation options including borehole rehabilitation, lining or re-drilling.

7 Potential impacts on groundwater abstractions

Section 6 of this report assessed affects to the groundwater environment in general, whilst this section considers potential effects at individual abstraction points.

7.1 Affinity Water abstractions

West Hyde abstraction

7.1.1 The Chiltern Tunnel route is located approximately 1.3km away from the West Hyde abstraction and is located obliquely up hydraulic gradient of the supply, on the interfluve between the valleys of the River Colne and River Misbourne at an elevation of approximately 85mAOD (Figure 11).

Figure 11: West Hyde PWS and surrounding area

7.1.2 Desk study of hydraulic pumping test data from the area around the West Hyde abstraction was interpreted by MWH as indicating the presence of a “karst system” aligned along the valley of the River Colne, with the potential for a similar “karst system” extending up along the dry valley at Tilehouse Lane. A radial flow response was observed around the abstraction in early time-drawdown data from which MWH indicated that West Hyde is not directly connected to the “karst system”, but instead a well-developed fracture network is present around the abstraction.

7.1.3 Regional groundwater contours and SPZs indicate that the majority of water will flow to the PWS from the north-west. The presence of the “karst system” may suggest a significant contingent of flow comes from the north, along the line of the Colne valley, but this is not confirmed. Based on this evidence groundwater flow to the West Hyde abstraction is likely to occur from the north and north-west.

7.1.4 The tunnel route runs obliquely along the western edge of the West Hyde SPZ1 (Figure 11) and, inaccuracies of SPZs notwithstanding, is useful in highlighting the tunnels position generally parallel to the likely flow direction, rather than perpendicular to it. This has implications for the likely degree of interference the tunnel and cross passages will have on flow paths within the aquifer.

7.1.5 The tunnel invert level at the point closest to the PWS would be at approximately 55mAOD and groundwater level in this area is approximately 53mAOD. This indicates that the tunnel would be just above the water table at this location, albeit it is recognised that groundwater levels do change. Even with the tunnel above the water table there is still a risk of turbidity migration from the TBM due to chalk slurry, and this will increase as the TBM approaches the water table and particularly if solutionally enlarged voids are encountered that are connected to a rapid flow system.

7.1.6 The tunnel route passes close to the head of a dry valley that trends east towards the valley of the River Colne. These valleys can provide preferential pathways for groundwater flow, but GI data indicates this valley to be infilled with over 20m of clay material, although there is chalk beneath this. At this location the tunnel is expected to be close to, but above, the water table and so any turbidity effects generated by tunnel construction may be partially ameliorated, although a risk is still present.

7.1.7 Based on this evidence there are unlikely to be any significant/rapid flow paths from the tunnel to the Colne Valley, although there is a degree of uncertainty associated with this. The risk to the West Hyde PWS from turbidity is therefore assessed as low, but due to the uncertainty associated with the role that the dry valley at Tilehouse Lane has, this could increase to moderate.

7.1.8 The tunnel is expected to intercept the groundwater table at a location just south of Horn Hill, which is approximately 2.1km away from the West Hyde PWS. At this location the tunnel is likely to be completely beneath the water table. The direction of groundwater movement is along the line of the tunnels. The outside diameter of each tunnel is 10.6m and the cross passages and grouted zone is expected to be between 7 and 10m wide, yielding a cross sectional area of about 30m wide by 10m high, or some 300m^2. Assuming a saturated thickness of 50m and an aquifer width of 1.4km this represents a likely reduction in cross sectional area available to groundwater flow towards the West Hyde PWS of only 0.4%. This is not significant.

7.1.9 At this distance any local changes to groundwater flows as a result of tunnel construction are unlikely to reach the West Hyde PWS and it is therefore concluded that no significant effect on groundwater flow paths will be experienced at the West Hyde PWS.

Chalfont St Giles abstraction

7.1.10 The tunnel route is located approximately 200m to the south-west of the Chalfont St Giles PWS and is located on the western flanks of the Misbourne valley, with ground level up to an elevation of about 100mAOD (Figure 12).

Figure 12: Chalfont St Giles PWS and surrounding area

7.1.11 The Chalfont St Giles supply is thought by MWH to be directly connected to a "karst flow system" aligned along the Misbourne valley with little radial flow occurring to the abstraction. MWH suggest that there is a "linear zone with solution widened fractures in the pre-existing fracture network" along the Misbourne valley at this location, and that this "…has a dominant control on the groundwater flow in the valley…". If this is correct, the dominant source of water to the PWS would be along the valley of the Misbourne from the north. As the tunnel would not intercept this flow system up gradient of the Chalfont St Giles PWS it is unlikely that construction of the tunnel will have any significant impact on groundwater flow paths to the abstraction.

7.1.12 As indicated in Section 6 there is some potential for the tunnel and cross passages to increase groundwater heads on their upgradient side. Chalfont St Giles is some 600m up the valley from the point where the tunnel passes beneath the river at the southern crossing. Thus, any increase in head caused by the tunnel would be beneficial to Affinity Water as it would increase the head in the direction of the abstraction borehole.

7.1.13 Although the SPZ1 is not intercepted by the tunnel route (Figure 12), as noted earlier the SPZs are not considered to be accurate and there is potentially some flow from downgradient of the PWS. However, as MWH suggest that the Chalfont St Giles supply has little radial flow, the volume of water from the vicinity of the tunnel is likely to be very low.

7.1.14 The tunnel invert level at the location nearest the PWS would be approximately 45mAOD and groundwater level in this area is approximately 65mAOD. Tunnel construction could result in the generation of chalk turbidity which would migrate in groundwater. There is no evidence of a dry valley or similar preferential pathway between the tunnel and the abstraction at this location, little radial flow was shown in the pump test data and the tunnel is located downstream of the PWS. The close proximity of the supply means turbidity could reach the abstraction, as pumping induced backflow can occur in karst systems, but the risk of this has been assessed as low.

7.1.15 Two dry valleys are present along the tunnel route up hydraulic gradient along the Misbourne valley. The first trends north-east along the line of a footpath in the vicinity of Hill Farm at tunnel chainage 36,600. The second trends north-east in the vicinity of the Chalfont St Giles Shaft at chainage 37,300. Both valleys are likely to form preferential pathways for groundwater flow into the valley of the River Misbourne, but it is not known how deep these pathways might be, although they could extend down to 50m below the water table based on dominant flow zones elsewhere in the Chalk. The tunnel would pass through this zone. Any effects on water quality could be transmitted along these routes and to the Misbourne valley where the groundwater would flow into the "karst flow system" referred to by MWH. The flow path lengths from the tunnel to the PWS along these dry valleys is some 1.2km and 2.5km respectively. This distance does not account for tortuosity which can be significant in groundwater systems and could increase the distance by one and half or two times.

7.1.16 It is therefore possible that some groundwater could flow from the vicinity of the tunnel towards the Chalfont St Giles PWS, either by "backflow" along the Misbourne valley, or where the tunnel passes close to preferential pathways associated with dry valleys. However, if it does it is likely to be a very minor component of total flow to the abstraction and the majority is not likely to occur along a direct rapid flow path. This means that there would be a degree of dilution and settlement of the turbidity before it reaches the abstraction. Based on this the risk of turbidity from the tunnel impacting the Chalfont St Giles abstraction is assessed as moderate.

Amersham abstraction

7.1.17 MWH's review of available pumping test hydraulic data indicated the presence of "...strong anisotropy with high transmissivity aligned along the valley. Within the valley MWH contend that both the hydraulic and turbidity responses provide strong evidence for a karst conduit that extends for more than 3.7 km both upstream and downstream from the Amersham site". It was interpreted that a well-developed fracture network was present around the Amersham supply, but that the boreholes were not directly connected to the valley conduit, as early time-drawdown data indicated radial flow to the boreholes. Nevertheless, it was considered likely that the PWS would draw the majority of its flow from this "karst conduit".

7.1.18 The tunnel route is approximately 1km south-west of the Amersham PWS at its nearest approach (Figure 13), at which point the ground level is approximately 135mAOD. This is located across hydraulic gradient from the Amersham abstraction (Figure 13), on the edge of a dry valley trending north-east towards the Misbourne valley. It is likely that this valley acts as a preferential pathway for groundwater flow into the Misbourne valley, and that a proportion of flow to the Amersham abstraction could occur along this route. However, this is likely to contribute only a small amount of the total flow to the Amersham PWS, with the vast majority moving down the Misbourne valley through the high transmissivity zones cited by MWH. Any disturbance to groundwater flow pathways within this dry valley would have little impact on total abstraction volume at Amersham PWS.

Figure 13: Amersham PWS and surrounding area

7.1.19 Any water quality effects generated during tunnel construction could travel along this dry valley into the Misbourne valley and thence to the Amersham PWS through the "karst conduit" and fracture network. The distance of this flow path is approximately 1.5km, excluding tortuosity. Based on this the risk from turbidity generated during tunnel construction impacting the PWS is assessed as moderate.

7.1.1 The tunnel would cross beneath the River Misbourne 2.8km north-west of the Amersham PWS. At this location the tunnel is within SPZ1 for the PWS and crosses the high transmissivity horizons that supply the majority of water to the abstraction. The tunnel at this location is at approximately 69-79mAOD and groundwater level is approximately 99mAOD. The current base of the abstraction borehole is at some 25mAOD so the tunnel would pass through the flow zone that supplies the Amersham PWS.

7.1.2 The tunnel crosses roughly perpendicular to the direction of groundwater flow down the valley, and its presence will reduce the cross sectional area available to groundwater movement. The majority of groundwater flow is expected to occur in the upper 50m of the Chalk (although there are flow zones deeper than this) and is supported by existing GI data that indicates chalk in this region of the Misbourne valley is highly fractured down to depths of approximately 50m bgl. The external tunnel diameter is 10.6m, which means the area through which groundwater can flow will be reduced to approximately 39.4m, a reduction of 21%.

7.1.3 Due to the reduction in cross sectional area of the active aquifer there is the potential for the tunnels and cross passages to affect hydraulic heads with an increase in head on the upgradient side of the tunnels and the potential for an increase in the discharge of groundwater to the River Misbourne (see Section 6). There is potential, albeit low, that this could reduce the flow along the valley towards the Amersham abstraction, although if the only driver is a change in aquifer thickness (from say 50m to 40m), the reduction in groundwater flow would be limited, estimated to be about 50m^3/d (Section 6). This assumes that the hydraulic gradient remains unchanged, which would not happen unless groundwater levels are at the surface (i.e. there is already groundwater discharge to surface water).

7.1.4 The estimated reduction in flow along the valley would be from c.230m^3/d without the tunnel to c.180m^3/d with the tunnel (assuming k=10m/d, i=0.0045, valley width=100m, saturated thickness = 50m). This volume would reduce if the hydraulic gradient increased due to groundwater backing up behind the tunnel (e.g. if i=0.005, then Q would only reduce from 230 to 200m^3/d). Clearly these values cannot represent all of the groundwater moving along the valley as the average output from Amersham alone is 7,000m^3/d. However, the estimates do suggest that in percentage terms the potential losses to the abstraction from the blocking effect of the tunnel would be low.

7.1.5 The exception to the above assessment would be if only one flow zone exists in the Misbourne valley and this is completely blocked by the tunnel. At the location of the tunnel crossing point two GI boreholes have been drilled: ML042-CR001 and ML042-RC002, although the former was only drilled to 84mAOD which is just above the tunnel roof. The log from RC002, which was drilled to 51mAOD (about 50m bgl) shows a great deal of weak chalk attributed to the New Pit Chalk Formation, with many cored sections having poor recovery, no recovery or chalk not recovered intact. Where recovery was good, abundant randomly orientated fractures were noted. At 73mAOD, at the approximate midway point of the tunnel, (which is from c.69-79mAOD) the chalk changes to the Holywell Nodular Chalk Formation, but this remains weak with abundant fractures. There is no evidence from the borehole log of any preferential flow zone just at the depth of the tunnel. Beneath the depth of the tunnel the chalk continues to be abundantly fractured with the Melbourn Rock identified at about 61mAOD, well below the tunnel base. Just below 60mAOD the Zig Zag Chalk was encountered.

7.1.6 Any turbidity generated during tunnel construction or mobilised as a result of alterations in flow paths in this area is likely to travel rapidly down the Misbourne valley towards the Amersham abstraction. The PWS is not directly connected to the “karst conduit”, however, and this will permit a degree of attenuation before any turbid water reaches the abstraction. The travel distance will be approximately 2.8km, with tortuosity increasing this by a factor of 1.5 to 2 (solutionally enlarged features and fissures are never straight). It is therefore expected that risks from turbidity generated during tunnel construction at this location to the PWS will be moderate. However, as the TBM will be progressing at about 15 to 20m/d, the duration of any disturbance is likely to be very short lived, albeit that it would happen during two periods as each TBM passed beneath the valley.

Great Missenden abstraction

7.1.7 The tunnel route is located approximately 1.2km north-east of the Great Missenden abstraction, located on interfluve to the north of the Misbourne Valley at an elevation of 160mAOD (Figure 14). The tunnel is located across hydraulic gradient from the abstraction and is not shown as lying within the SPZ for this supply (noting the issues with the accuracy of SPZs discussed in Section 4.3).

Figure 14: Great Missenden PWS and surrounding area

7.1.8 There is a dry valley that trends south from the tunnel route, with a dogleg to the south east part way along it. This dry valley slopes into the Misbourne valley and is likely to act as a preferential pathway for groundwater flow. However, this dry valley enters the Misbourne valley some 700m downgradient of the PWS and so is unlikely to contribute any groundwater flow to the Great Missenden abstraction. Tunnel impacts on groundwater flow paths to the PWS are therefore expected to be low. Likewise, any turbidity generated during tunnel construction is also going to enter the Misbourne valley a significant distance down gradient of the PWS and so risks to the abstraction from turbidity are low.

7.2 Private licensed and unlicensed abstractions

CFA08-GWUA01

7.2.1 CFA08-GWUA01 is located on Interfluve south of Chalfont St Giles, above the valley of the River Misbourne, approximately 700m from the tunnel route. Ground level at this location is approximately 95mAOD, with the tunnel invert level at its nearest point at an elevation of 40mAOD. The abstraction is across hydraulic gradient of the tunnel route and there is no obvious dry valley system connecting the two together so the risk to this supply from tunnel construction is low.

CFA08-GWUA02

7.2.2 CFA08-GWUA02 is located on interfluve south of Amersham at an elevation of approximately 170mAOD, at a distance of approximately 530m from the tunnel route. The tunnel invert level at its nearest is at an elevation of 60mAOD so it is unlikely that the abstraction would extend to a similar depth within the aquifer. The abstraction is across hydraulic gradient of the tunnel route and there is no obvious dry valley system between this position and the tunnel. Therefore, the risk to the supply from tunnel construction is low.

28/39/28/0198

7.2.3 Abstraction 28/39/28/0198 is located alongside the River Misbourne at Little Missenden approximately 700m from the tunnel route on the valley side of the River Misbourne at an elevation of approximately 125mAOD. The tunnel invert level at its nearest is at an elevation of 115mAOD, with maximum recorded groundwater level in this area at 114mAOD. There is a dry valley trending south and south-east from the tunnel route towards the Misbourne valley, but this enters the Misbourne some 800m down gradient of the abstraction and so any water quality issues are unlikely to be transmitted to this private supply. No impacts on groundwater flow paths are expected at this abstraction.

CFA09-GWUA02

7.2.4 CFA09-GWUA02 is located on the interfluve south-east of South Heath, approximately 730m from the tunnel route at an elevation of 175mAOD. The tunnel invert level at its nearest is at an elevation of 130mAOD, in the order of 20m above the local groundwater table. Therefore, the risk to supply from tunnel construction is very low.

28/39/28/0109

7.2.5 Abstraction 28/39/28/0109 is located in Amersham Old Town and is licensed to abstract up to 44m^3/d water for processing textiles. It is located on the north bank of the River Misbourne at an elevation of approximately 95mAOD, and is located within the SPZ1 / 2 for the Amersham PWS. The tunnel route is some 700m to the south-west and the tunnel has an invert level at an elevation of about 60mAOD. BGS records indicate the borehole to be approximately 32m deep and given its location in the valley of the Misbourne, and its small abstraction volume it will dominantly take water from the north-west, along preferential flow paths beneath the river. The same dry valley as noted in Section 7.1.16 could act as a preferential pathway between the tunnel and the Misbourne valley, although as it enters the Misbourne valley some 360m down gradient of the abstraction it is unlikely to impact the supply.

7.2.6 The tunnel route crosses the Misbourne valley approximately 1.7km to the north-west of the abstraction. As noted above, preferential flow paths aligned along the Misbourne valley are likely to rapidly transmit any turbidity generated during tunnel construction down the valley towards this abstraction. It is unclear whether the abstraction is directly connected to these preferential flow paths or whether a fracture network around the supply connects it to the valley “karst conduit”. The latter scenario would allow a degree of attenuation of the turbidity to occur, but a direct connection would provide little attenuation. As the source is small and is not used for potable purposes it is far less sensitive to increases in turbidity than the PWS. The proximity of the tunnel and the potential for a rapid linkage to the supply means risk to this abstraction from turbidity generated during tunnel construction is moderate. This would be a relatively short lived impact, however, as turbidity will only be generated during construction and tunnelling will only occur in the valley for a period of roughly 10 to 15days.

7.2.7 As the abstraction volume from this abstraction is small, and the tunnel is located approximately 1.7km away, any changes to groundwater flow paths due to construction activities are not likely to reach this abstraction and consequently the potential for a significant impact on groundwater flow is low.

CFA08-GWUA03

7.2.8 CFA08-GWUA03 is located south-west of Amersham and circa approximately 145m south-west of the tunnel route at an elevation of circa 145mAOD. Drilling logs indicate that 40m of superficial deposits are present above the Chalk at this location and that the supply extends to a depth of 109mbgl (approximately 36mAOD) with screen installed from 42mbgl to 109mbgl (103mAOD to 36mAOD). The tunnel invert level at its nearest to the supply is at an elevation of 60mAOD and abstraction volumes are unknown. The abstraction is located on interfluve, across hydraulic gradient from the tunnel with no obvious dry valley linking the tunnel to the supply.

7.2.9 Despite the proximity of the supply to the tunnel there is limited potential for hydraulic connection between the two and so risks from turbidity and alterations to groundwater flow paths are low.

Hill Farm Ground Source Heat Pump (GSHP)

7.2.10 Hill Farm GSHP is understood to be a ground source heat system comprised of two boreholes, although it is unknown if this an open loop or closed loop system. The boreholes are located north-west of Chalfont St Giles, approximately 110m south-east of the tunnel route at an elevation of circa 135mAOD. Borehole depth is estimated to be 30 to 40m, (although this is not confirmed) located on interfluve across hydraulic gradient from the tunnel with no obvious dry valley linking the tunnel to the receptor.

7.2.11 A closed loop system would not be impacted by the construction of the tunnel. If this is an open loop system it is likely that most of the water feeding this abstraction would be from the north-west, parallel to the tunnel, with only a relatively small proportion from the vicinity of the tunnel location. Despite its proximity there is unlikely to be a significant interaction between the tunnel and the receptor and so risks from turbidity and alterations to groundwater flow paths are low.

8 Potential impacts on surface water

8.1.1 Below ground construction associated with the Chiltern Tunnel and cross passages could lead to the following effects on the River Misbourne:

- potential enhanced leakage from the River Misbourne to groundwater by induced fractures, washout of infilled voids or other changes to flow paths caused by tunnelling activities, including settlement;
- potential reduction in baseflow during operation as a result of disturbance to groundwater flow paths caused by the construction of the tunnel;
- potential contamination by chalk turbidity which could migrate within groundwater which subsequently discharges at the River Misbourne; and/or
- an increase in flows at the tunnel crossing points due to increases in hydraulic heads up gradient of the tunnels (as assessed in Sections 6 and 7).

8.1.2 Settlement resulting from construction of the tunnels is predicted to be in the range 10 to 30mm. This could potentially result in limited opening up of some fractures in competent chalk above the tunnels, but as the valley of the River Misbourne is already a well fractured high flow zone, this is unlikely to alter flow rates or change pathways. The competent chalk is overlain by weathered chalk which is likely to behave similar to a clay and so is not likely to result in a significant increase in openings. In addition, the weathered chalk is overlain by alluvium which is likely to be a mixture of clay, silt, sand and gravel. Any settlement in this is unlikely to change flow rates. Given the relatively limited extent of the section of the tunnel beneath the river crossings, the depth of the tunnel at these locations (some 15 to 20m below the River Misbourne) and the presence of superficial deposits beneath the riverbed, it is considered unlikely that tunnelling activity will result in a significant increase in leakage from the River Misbourne. No mitigation is therefore required with regard to the effects of settlement on surface water.

8.1.3 There is no evidence for springs within the Misbourne valley forming a potential source for the river and groundwater levels in the upper catchment are broadly similar to the river level, indicating a degree of connection between groundwater and the River Misbourne. It is therefore considered that baseflow to the Misbourne is diffuse and occurs up through superficial deposits into the river over a relatively long stretch of the upper catchment.

8.1.4 Baseflow primarily occurs in the upper reach of the Misbourne, with the middle reaches between Shardeloes Lake and Chalfont St Peter typically losing water to the underlying aquifer. The northern crossing (Figure 14) is therefore the area most at risk of experiencing reductions in baseflow as a result of tunnel construction.

8.1.5 At the northern crossing the tunnel passes beneath the River Misbourne at an oblique angle with tunnel invert level at an elevation of approximately 70mAOD. As discussed in Sections 6 and 7, this is likely to alter local groundwater flow in the immediate vicinity of the tunnel by blocking some of the preferential flow pathways within the Misbourne valley. This could result in more groundwater entering the river, or groundwater flow down the valley could redirect around the tunnel through shallower fracture zones such that total flow down the valley will not be reduced.

8.1.6 Diffuse baseflow would not be affected upstream of the tunnel and baseflow can still occur downstream as total groundwater flow is unlikely to be significantly altered. Baseflow in the vicinity of the northern crossing may be slightly altered but as baseflow occurs over such a long distance it is likely to have an insignificant effect on river flow. The risks of tunnel construction reducing baseflow to the River Misbourne are therefore considered to be low.

8.1.7 Chalk turbidity will be generated by the tunnelling activity and could rapidly reach the River Misbourne due to the proximity of the works and the ease with which chalk particles migrate within groundwater. Turbidity effects caused by tunnelling are likely to be of greatest concern in the vicinity of the northern crossing, due to the gaining nature of the Misbourne in this area. The presence of alluvium beneath the River Misbourne at the northern crossing will provide a degree of filtration, although given the fine particle size of chalk turbidity this may only have a limited effect.

8.1.8 At the northern crossing the top of the tunnel will be approximately 21m below the River Misbourne and there is unlikely to be a vertical gradient directing turbidity straight to the river, although there is some potential for it to appear downstream under some hydrogeological conditions. Tunnel construction is expected to advance at a rate of approximately 15 to 20m per day which means that each TBM will likely be in the Misbourne valley in the order of about 10 to 15 days. Any turbidity effects that do reach the river will therefore be short lived.

8.1.9 Flow volumes in the River Misbourne are likely to be much greater than the volume of baseflow entering the river in the vicinity of the northern crossing and so any turbidity in the baseflow waters will be diluted significantly within the river itself, although flow paths and travel times will be important in the extent to which the dilution is significant. The river Misbourne will have a background level of turbidity, although for the majority of the time this will be very low and the stream will be clear. However, after some local rainfall events, especially those that are high intensity, and due to some agricultural practices such as ploughing fields, turbidity events of a higher magnitude than any potential turbidity generated during tunnelling may occur. The short term effects generated by tunnel construction are therefore considered to pose a low risk to the River Misbourne.

9 Discussion

9.1.1 Based on the above assessment the risks to the Chalk aquifer, secondary aquifers, Affinity Water PWS, other abstractions and the River Misbourne are summarised in Table 3.

Table 3: Summary of potential effects of shaft construction on groundwater and surface water receptors

Receptor	Turbidity risk	Flow path risk	Water quality risk (non-turbidity)
Chalk Principal aquifer	Low at the aquifer scale Moderate to high locally	Low at the aquifer scale Moderate locally	Low
Secondary aquifers	Very low	Very low	Very low

Receptor	Turbidity risk	Flow path risk	Water quality risk (non-turbidity)
Mid Chilterns Chalk WFD water body[13]	Very low at the water body scale	Very low at the water body scale	Very low at the water body scale
West Hyde PWS	Low to moderate	Low	Very low
Chalftont St Giles PWS	Moderate	Low	Very low
Amersham PWS	Moderate	Low	Very low
Great Missenden PWS	Low	Low	Very low
CFA08-GWUA01	Low	Low	Very low
CFA08-GWUA02	Very low	Very low	Very low
CFA08-GWUA03	Low	Low	Very low
28/39/28/0109	Moderate	Low	Very low
28/39/28/0198	Very low	Very low	Very low
CFA09-GWUA02	Low	Low	Very low
Hill Farm GSHP	Low	Low	Very low
River Misbourne	Low	Low	Very low

9.1.2 Based on this assessment mitigation for the Chalk aquifer and secondary aquifers is not required. Mitigation at PWS's is not required during tunnel construction at West Hyde and Great Missenden, although monitoring will be required to confirm no significant effects are taking place. This notwithstanding, HS2 has agreed to install a turbidity treatment plant at West Hyde PWS, but this was driven principally by the potential impact from the original design for the South Portal that included piling below the water table, and the uncertainties regarding the groundwater flow paths. At Chalfont St Giles and Amersham there is a potential risk from chalk turbidity generated during tunnelling activities and mitigation is therefore required.

9.1.3 In addition, the licensed abstraction 28/39/28/0109, located near Amersham, could potentially be impacted by turbidity from tunnel construction and may require mitigation.

9.1.4 No significant effects are expected on the River Misbourne, although there is uncertainty and monitoring will be required to check this.

[13] See Align, 2019, Section C1 - Updated Water Framework Directive Compliance Assessment, Document no: 1MC05-ALJ-EV-REP-CS01_CL01-100082

10 Proposed mitigation and monitoring

10.1.1 Mitigation of chalk turbidity will take the form of treatment at the public supply abstractions along the route of the tunnel (Chalfont St Giles and Amersham) and Affinity Water is having an appropriate treatment solution designed and installed. Avoidance of Affinity Water's peak demand period is not feasible given the 3-year duration of the tunnelling works. The type of TBM has been selected specifically to minimise the potential effects on the groundwater environment.

10.1.2 Monitoring of groundwater levels and turbidity will be undertaken at locations as indicated in the monitoring position statement and management and control processes for the operation of the TBMs will be agreed between Align, HS2 and Affinity Water to manage turbidity risk at Affinity abstractions.

10.1.3 If there is a significant effect at licensed abstraction 28/39/28/0109, it may be necessary to provide a temporary alternative supply during the period when tunnelling is occurring at the northern crossing in the Misbourne valley. This could take the form of mains water (either a temporary main, or paying for additional water use if a main is already present on site) or use of tankers depending upon the volume of water required and the quality required. This is only likely to be required for a period of 10 to 15 days for each TBM. Groundwater level and quality at the supply will be monitored before and after the tunnel crosses the Misbourne valley near Little Missenden to ensure that no other impacts are evident outside of the timeframe expected.

10.1.4 Monitoring of river flows and water quality within the River Misbourne will be required to check if any significant impacts are experienced as a result of construction activities. If there is a significant negative effect then localised stream lining may be necessary. It is also possible that there may be a beneficial effect.

10.1.5 Monitoring during construction will be undertaken by Align, with baseline data having been collected by HS2. If monitoring reveals any significant effects are taking place as a result of tunnel construction at any of the receptors further mitigation may be required. This could modify the approach to construction of some of the cross passages and could also mean changes in how TBM2 is operated if effects are identified from TBM1.

10.1.6 Detailed monitoring requirements are presented in the monitoring position statement.

11 Consent requirements

11.1.1 The HS2 Technical Standard "Water resources and flood risk consents and approvals" (HS2-HS2-EV-STD-000-000015) requires consents to be obtained under Schedule 33 (Protective Provisions) of the HS2 Act for:

- below groundwater construction activities; and
- use or application of chemicals, additives or lubricants to works below the groundwater table.

11.1.2 Construction of the tunnel will include use of lubricants as well as concrete/grout and will therefore require a consent for these activities. As the activities are in a Principal aquifer and in some cases within SPZ1, the level of consent specified in the Technical Standard is "detailed".

11.1.3 The construction for the tunnel will therefore require application for a consent. This hydrogeological assessment provides supporting information for the consent application with regard to the hydrogeological setting and the proposed construction activities and potential effects on groundwater.

12 Stakeholder liaison

12.1 Environment Agency

12.1.1 As the regulator of the water environment in England the Environment Agency was a statutory consultee for the Environmental Statement. In addition, discussions have been held on a number of occasions regarding the potential effect on the water environment and the need to demonstrate environmental compliance for the scheme.

12.2 Affinity Water

12.2.1 The approach to tunnelling and TBM selection has been discussed with Affinity Water on several occasions during 2017 and 2018 in order to understand their key concerns and to discuss the proposed approach to the works. Consideration of multiple effects on abstractions from construction of the shafts and the tunnel at the same time has also been considered. This document takes into account Affinity Water concerns and opinions.

13 Next Steps

13.1.1 The operators of the licensed abstraction 28/39/28/0109 will be contacted for additional details in order to properly assess the likelihood of any impacts upon their water supply.

13.1.2 Further liaison will be undertaken with the Environment Agency regarding consent applications for construction, and in particular the supporting evidence and any mitigation required.

13.1.3 Further discussions with Affinity Water regarding the potential effects of the tunnel on PWS.