ALIGN Working in partnership with HS2

Incident Report: Crossing of the River Misbourne by the Chiltern Tunnel.

1MC05-ALJ-EV-REP-CS02_CL04-000228

Revision	Author	Reviewed by	Approved by	Date approved	Reason for revision
C01	[redacted]			08/07/2022	First Issue

Security classification: OFFICIAL

Handling Instructions: None

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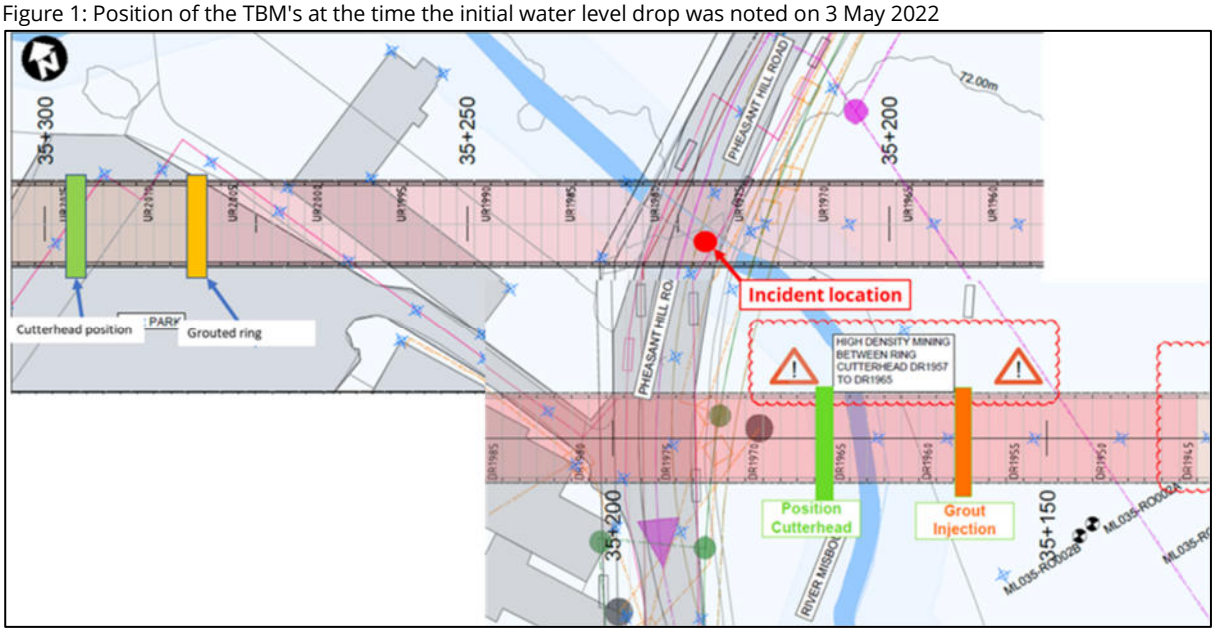
1 Background

1.1.1 On the 29th April 2022, the Chiltern Tunnel entered within 20m of the River Misbourne (defined as the crossing location). The uptrack TBM, Florence, entered the 20m buffer around the river on the evening of 29 April 2022 and undercut the river itself on 1 May 2022, while the downtrack TBM, Cecelia, undercut the river during the afternoon of 3 May 2022.

1.1.2 Routine monitoring of the water levels within the river undertaken by Align identified a sudden drop of 13mm in water level on 3 May 2022 of unknown cause. A surface walk-over was conducted at the crossing point and found no visible issue, and as the water levels appeared stable it was assumed the drop was related to an instrumentation error at the monitoring location. A technical site visit carried out the next morning (4 May 2022) to check the instrumentation identified a depression in the channel of the River Misbourne beneath the Pheasant Hill bridge (the bridge). This was considered to potentially be an area of subsidence. However, as no pre-condition survey had been carried out due to the limited access beneath the bridge, it could not be determined whether the area of subsidence was related to the TBM operations. Conservatively, it was therefore assumed that this may have been a result of the tunnel passing beneath (or in close proximity) to the river during this time and may account for the drop in recorded water level.

1.1.3 The depression was infilled on 6 May 2022 by placement of 7 bags of clay pellets and around 0.3m3 of chalk gravel, with further work carried out on 9 May 2022 consisting of an additional 0.1m3 of chalk gravel being added, followed by levelling out of the depression with silt from the riverbed itself. Thereafter, 2 further drops in water level were identified with no observable cause related to the TBM passage. The position of the TBMs at the time of the initial drop in water level are presented in Figure 1.

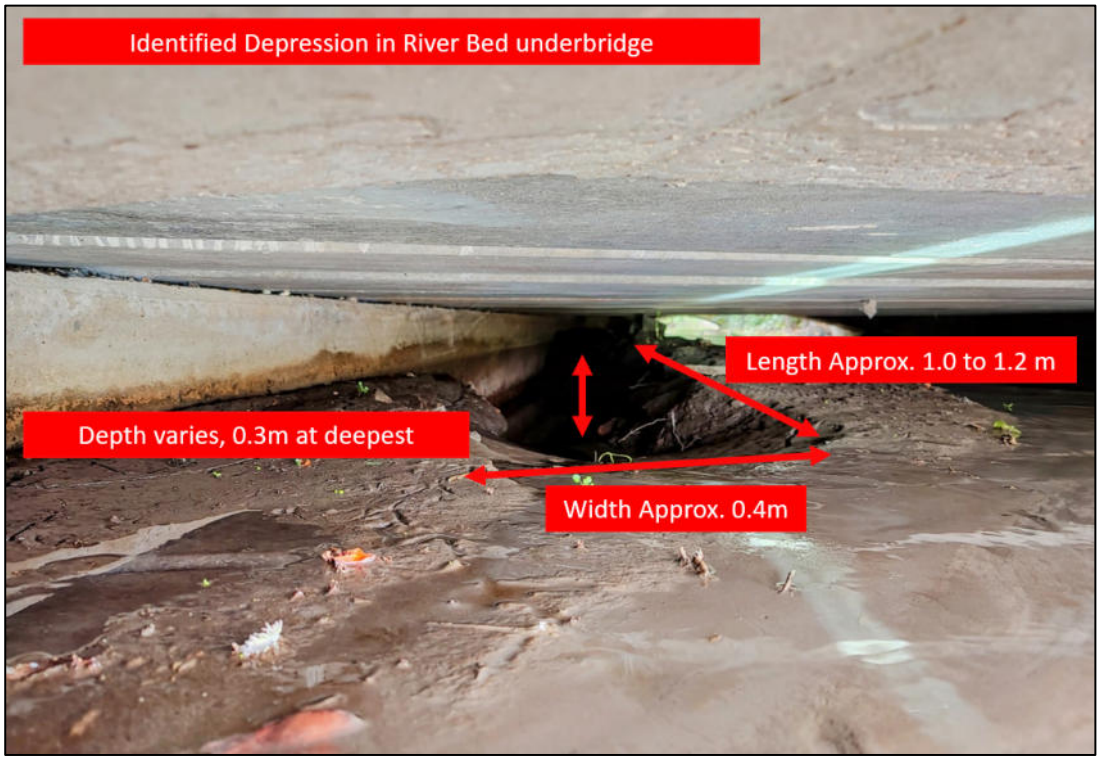
Figure 1: Position of the TBM's at the time the initial water level drop was noted on 3 May 2022



Pheasant Hill Bridge Depression:

1.1.4 The depression identified under the bridge is shown below in Figure 2. Due to the apex of the culvert being only about 0.4m above the riverbed, it was impossible to accurately gauge the dimensions of the feature, but it was estimated to be approximately 1.2m x 0.4m across, with a variable depth of up to 0.3m.

Figure 2 Photograph of the depression identified in the Misbourne Channel beneath Pheasant Hill Bridge (looking north-west)



1.1.5 A drainage camera was inserted into the depression but the footage was unclear and did not provide any further information.

1.1.6 The riverbed under the bridge is heavily silted with fine material. The section of riverbed immediately upstream of the bridge has silt deposits approximately 0.3m deep in places. Downstream of the bridge, the riverbed is made up of larger stones and coarser material.

Site Investigation

1.1.7 An investigation of the upstream river was conducted during May 2022. The land directly upstream of the crossing point (see Figure 3) is agricultural and used for grazing with cattle and sheep known to have direct access to the river approximately 175m upstream of the bridge. Further upstream, the river meanders through fields, with brush and trees on either side of the bank. Approximately 580m upstream the Misbourne is crossed by Mill Lane through a ford.

1.1.8 At Mill Lane the river is diverted from its natural path by an historical water mill, now a residential property. Within the property, [redacted] This channel of the stream then disappears into a farm compound area, where Align have not been able to gain access to survey. Thereafter, it re-joins the natural streambed within the wooded area.

1.1.9 Residents from Mill Lane reported that during periods of high flow, [redacted] They also reported noticing sudden changes in water level having occurred periodically over a number of years and suggested that [redacted]

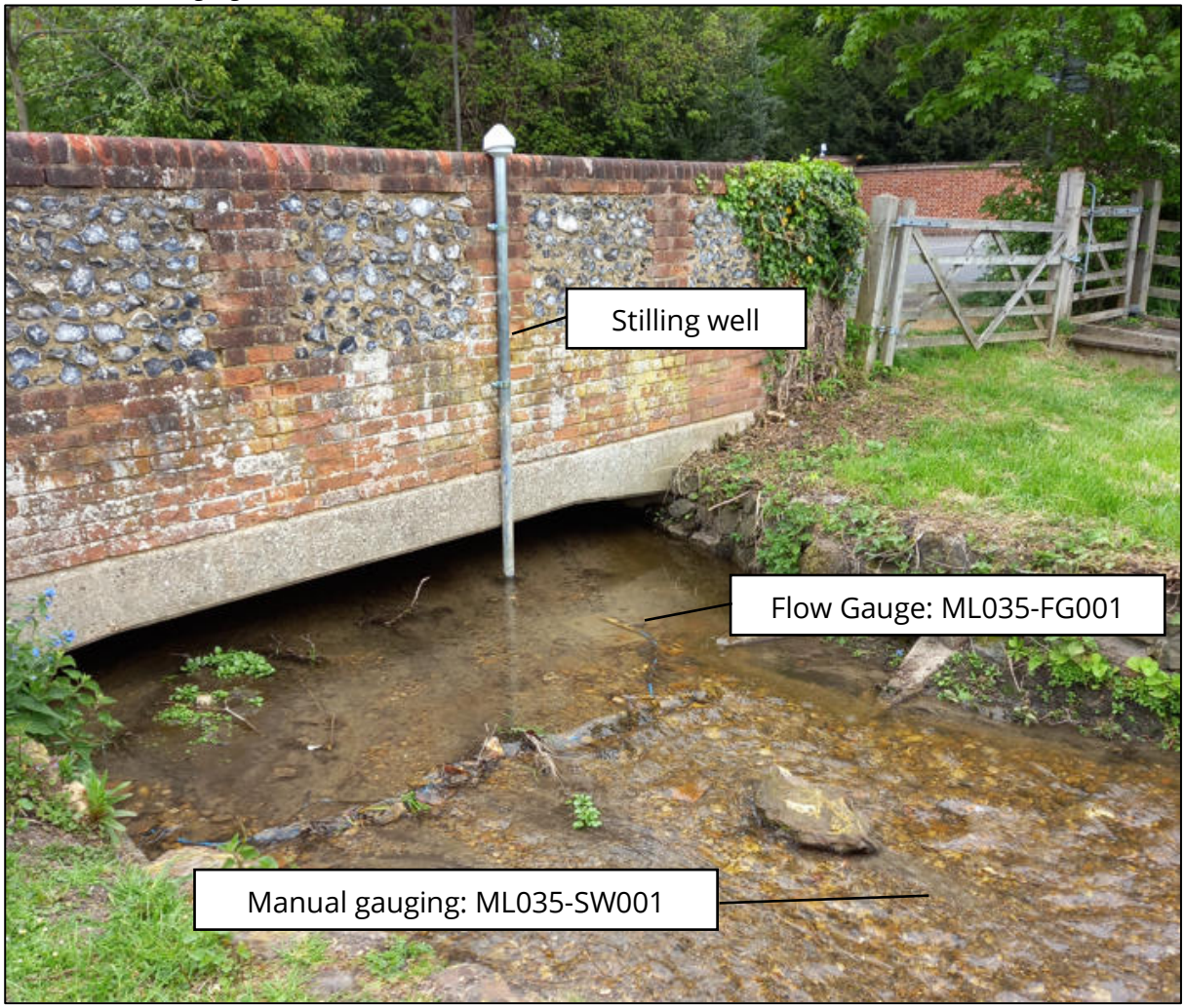
Figure 3: Site layout showing locations of water monitoring points and TBM crossing location

2 Water Level Monitoring Data

Align River Level Data

2.1.1 Water level data from the River Misbourne is recorded by Align at 2 separate installations at Chalfont St Giles (Figure 3). The first is a stilling well installed on the downstream side of the bridge, and the second a Nivus flow gauge (from which water level is calculated) installed in the riverbed about 1m downstream of the bridge (Figure 4).

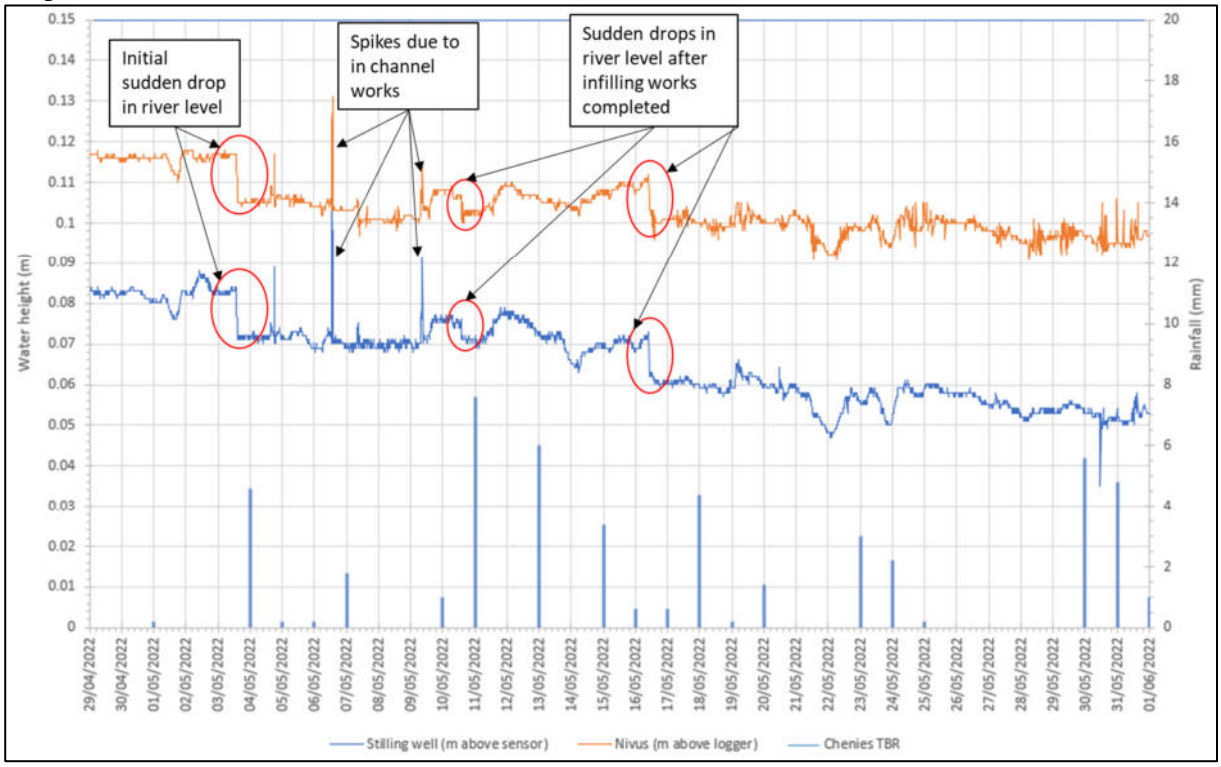
Figure 4: Photograph of monitoring points ML035-SW001 (stilling well installation and manual flow gauging point) and ML035-FG001 (flow gauge installation)



2.1.2 Due to equipment malfunctions and availability delays for replacements, reliable data is only available from February 2022 onwards, with data covering the period of TBM transit beneath the River Misbourne shown in Figure 5.

2.1.3 Although there is a difference in the recorded water levels in both of these instruments (likely due to a difference in the recorded reference level of the installations), there is good correlation between the two in terms of timing and magnitude of water level changes.

Figure 5: River water level data collected from flow gauge and stilling well installations directly below Pheasant Hill Bridge, with rainfall from Chenies Station.



2.1.4 The upgradient TBM Florence arrived within 20m of the River Misbourne on the evening of 29 April 2022 (around 17:00) and began passing directly beneath the Misbourne during the early morning of 1 May 2022 and by 11:30, the cutterhead had moved beyond the bridge area. The downgradient TBM, Cecilia, arrived within 20m of the river on the afternoon of the 2 May 2022 and undercut the river during the early afternoon of the 3 May 2022.

2.1.5 The drop in water level which initially prompted the investigation was detected on 3 May 2022 between 13:30 and 14:45 (see Figure 5). At this time, TBM Florence had moved 76m beyond the incident location and TBM Cecilia was directly beneath the River Misbourne but circa 20m downstream of the bridge.

2.1.6 The drop in water level was recorded as 13mm and occurred over the course of 75 minutes. Water levels after this point remained relatively stable, with a short-term spike recorded on 4 May 2022 linked to rainfall and two further short term spikes on 6 May 2022 and 9 May 2022 which were linked to intervention works (see Figure 5).

2.1.7 After the intervention works on 9 May 2022, river levels rose slightly, before a further two sudden drops in water level were observed on 10 May 2022 and 16 May 2022 of 4mm and 11mm respectively. Water levels trended downwards over the rest of the month, in line with the expected seasonal

decline, with river levels having dropped by about 0.05m by the end of May 2022.

2.1.8 Review of the wider dataset collected by Align at Pheasant Hill Bridge (Figure 6 shows that sudden drops in water level occurred both before and after the arrival of the TBM, with the various occurrences summarised in Table 1.

Table 1: Summary of water level drops recorded in Align river level monitoring data

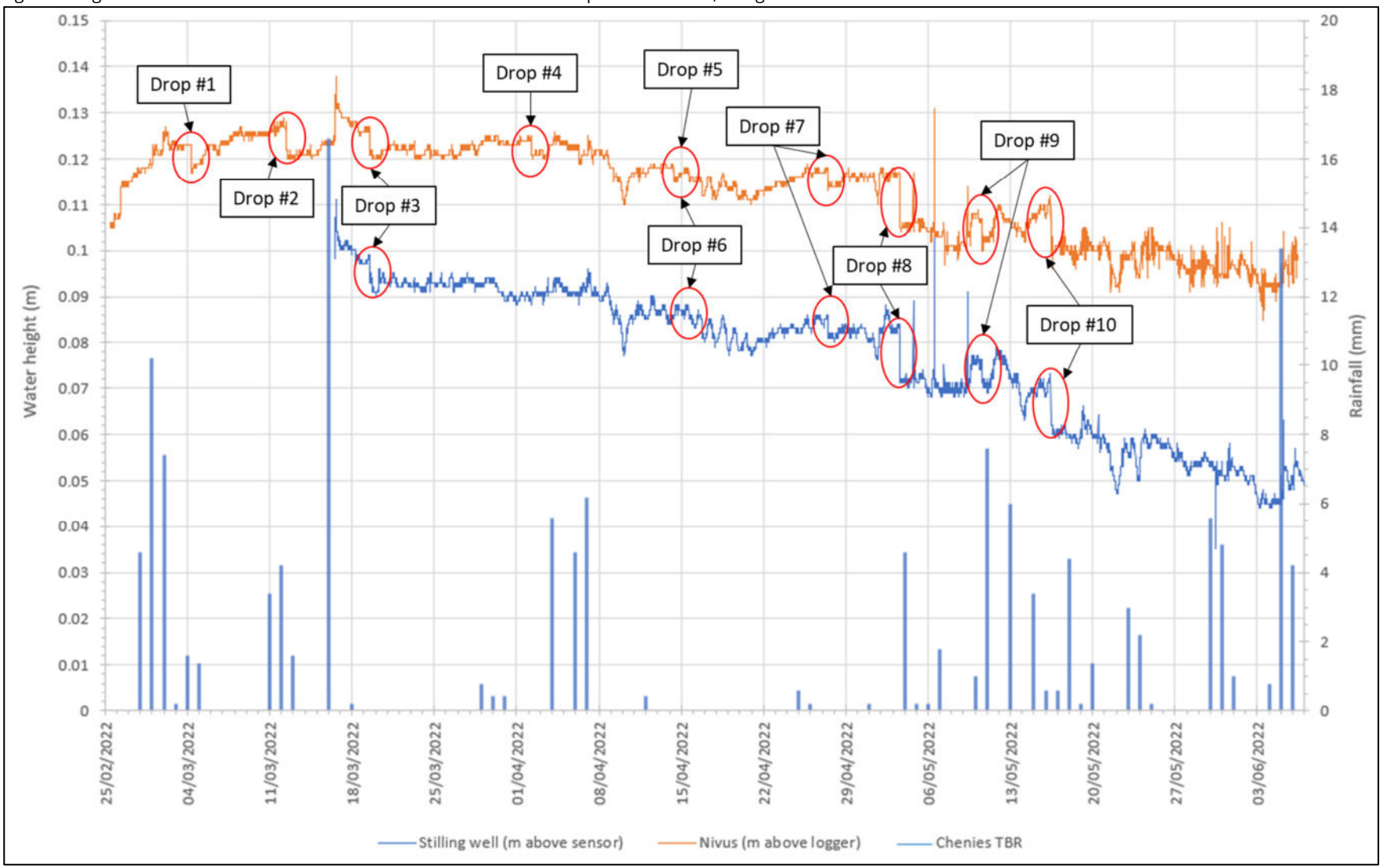
Water level drop	Date	Magnitude	Duration	Stilling well	Nivus flow gauge
Drop #1	04/03/2022	4mm	30 mins	N	Y
Drop #2	12/03/2022	6mm	30 mins	N	Y
Drop #3	19/03/2022	5mm	45 mins	Y	Y
Drop #4	02/04/2022	3mm	30 mins	N	Y
Drop #5	14/04/2022	4mm	60 mins	N	Y
Drop #6	16/04/2022	4mm	60 mins	Y	Y
Drop #7	27/04/2022	5mm	30 mins	Y	Y
Drop #8	03/05/2022	13mm	75 mins	Y	Y
Drop #9	10/05/2022	4mm	15 mins	Y	Y
Drop #10	16/05/2022	11mm	30 mins	Y	Y

2.1.9 The drops in river level were typically of the order of 3 – 6mm and occurred over 30 – 60 minutes. The drop in level recorded on 3 May 2022 (as the TBMs were in the vicinity of the River Misbourne) was double this magnitude at 13mm, although a similar magnitude drop was recorded on 16 May 2022 when the TBMs had passed well beyond the crossing location.

2.1.10 The drops in river level were generally but not always present in data from both monitoring points, although, at the time of two of these events (4 and 12 March 2022) the stilling well was not operational.

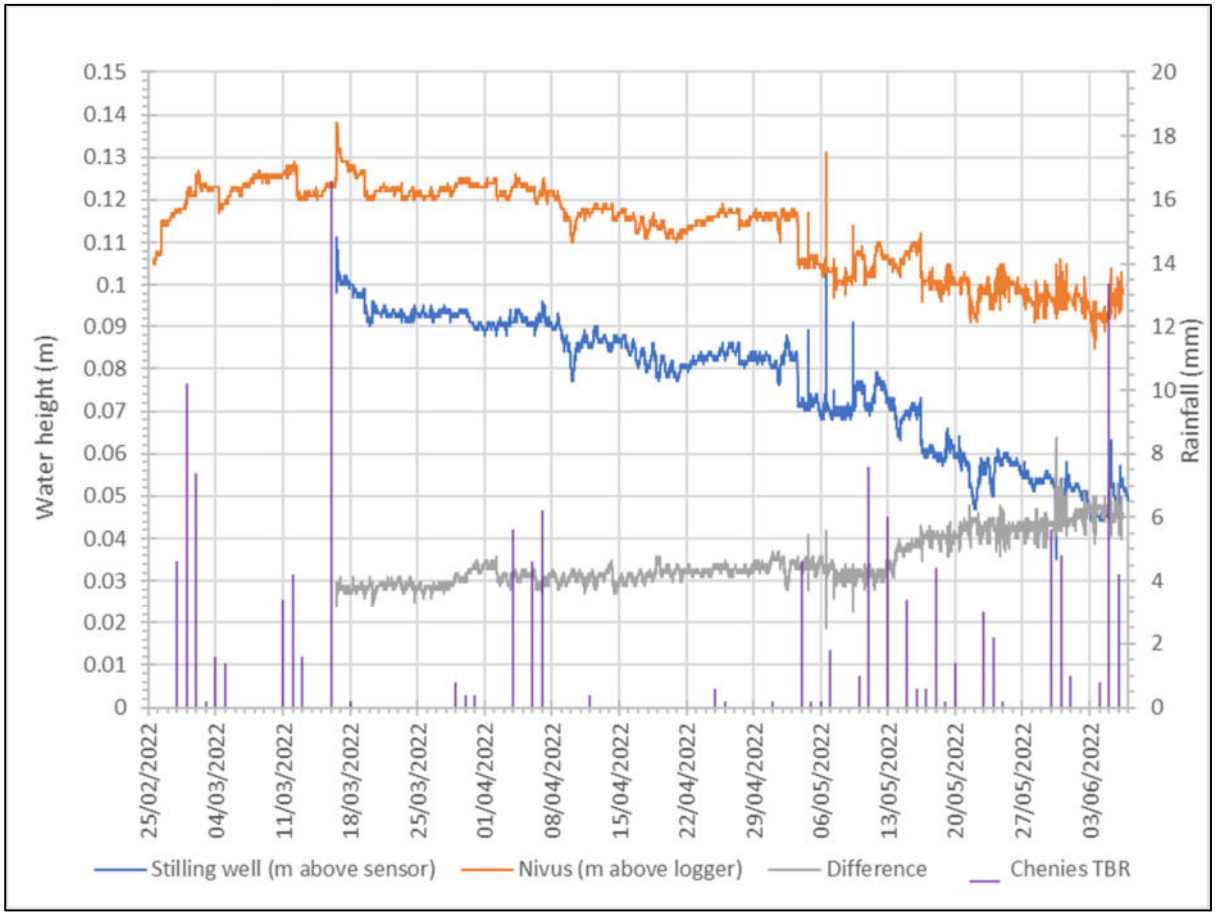
2.1.11 A clear daily fluctuation in water level is observed in both sets of data, although it is not continuous through the data set, with periods of relatively steady water levels also recorded. These fluctuations do not coincide with rainfall events (shown on the Figure 6 below on the secondary axis).

Figure 6: Align river level dataset with identified occurrences of sudden drops in water level, along with rainfall.



2.1.12 The accuracy of the flow gauge decreases once less than 10cm of water is present in the river channel. From 16 May 2022 onwards, the water level recorded by the Nivus was consistently below the required 10cm of water. This is the likely cause of the increasing divergence observed between the two data sets from this point onwards (Figure 7) although this is after the TBMs have crossed beneath the River Misbourne.

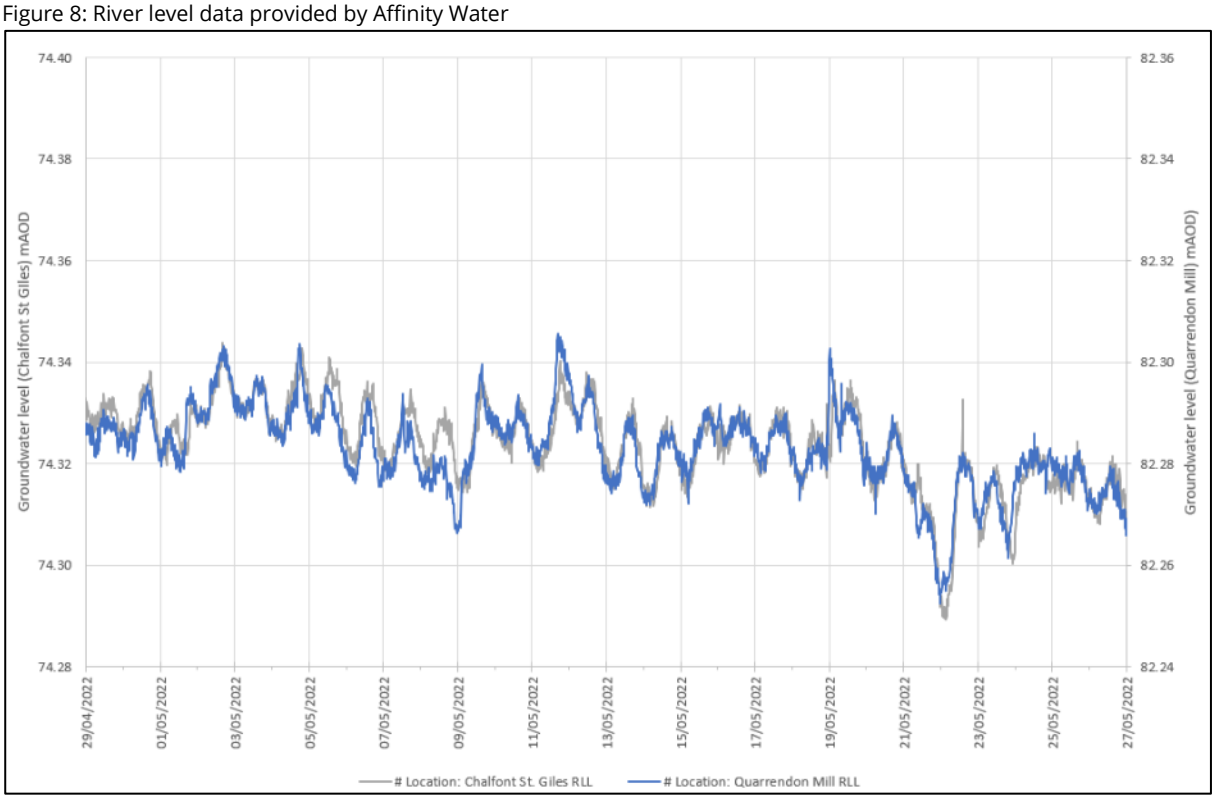
Figure 7: Calculated water level in the River Misbourne recorded by flow gauge (Nivus) and stilling well, with divergence between the two data sets plotted



Additional River Level Data

2.1.13 In addition to the two water level monitoring locations operated by Align, data from river monitoring locations located up and down stream of the TBM crossing point have been obtained from Affinity Water and assessed. These river level monitoring points are Quarrendon Mill, located circa 3km up gradient of the TBM crossing point and Chalfont St Giles which is located circa 60m down gradient of the TBM crossing point (see Figure 3). Data covering the period of the TBM crossing is shown in Figure 8 and shows that the response in river level was very similar at both locations.

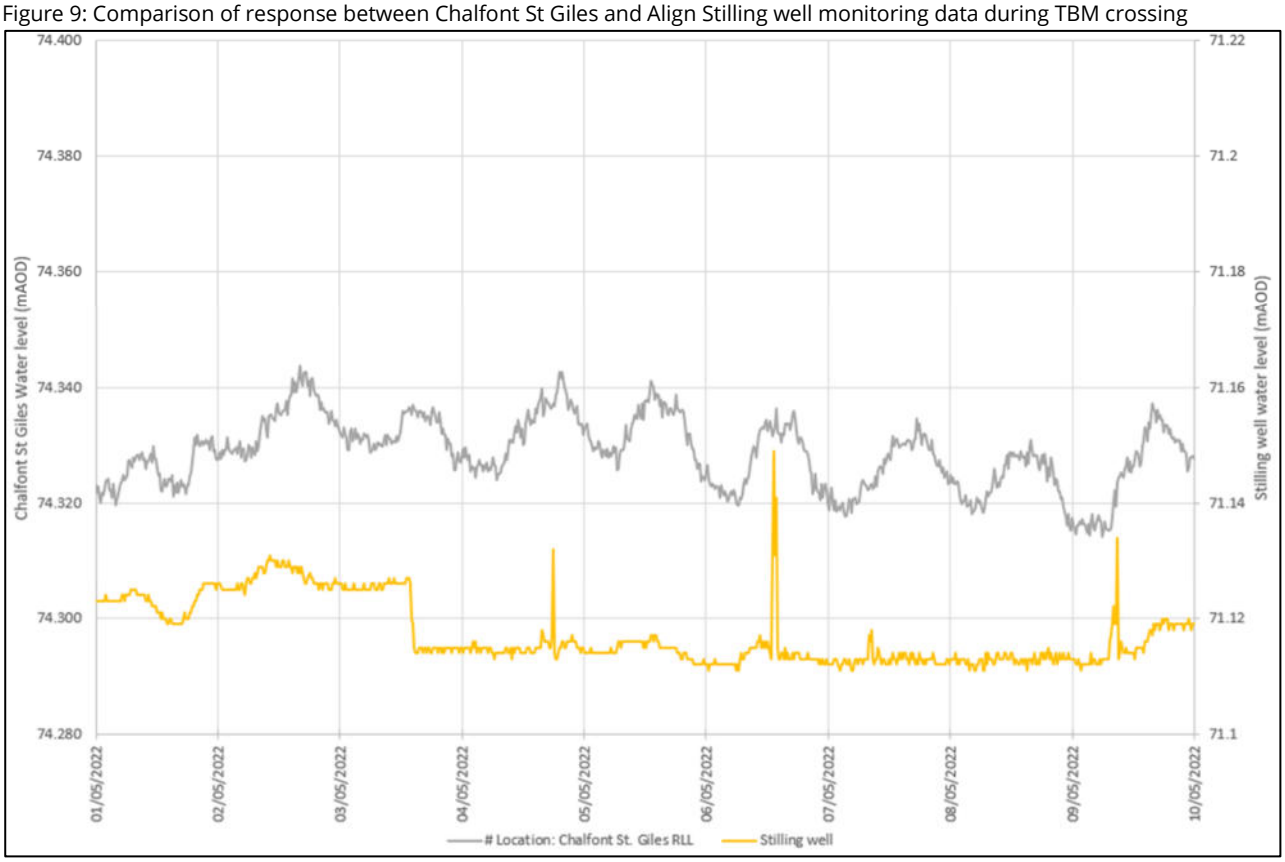
Figure 8: River level data provided by Affinity Water



Data plotted on separate y-axes due to the off-set in absolute water level

2.1.14 The same diurnal fluctuations recorded in the Align data are evident in this data. However, there is no indication of a sudden step change in river level recorded in the Chalfont St Giles monitoring data during or after the transit of the river by the TBMs (Figure 9), as was indicated in the Align data.

Figure 9: Comparison of response between Chalfont St Giles and Align Stilling well monitoring data during TBM crossing

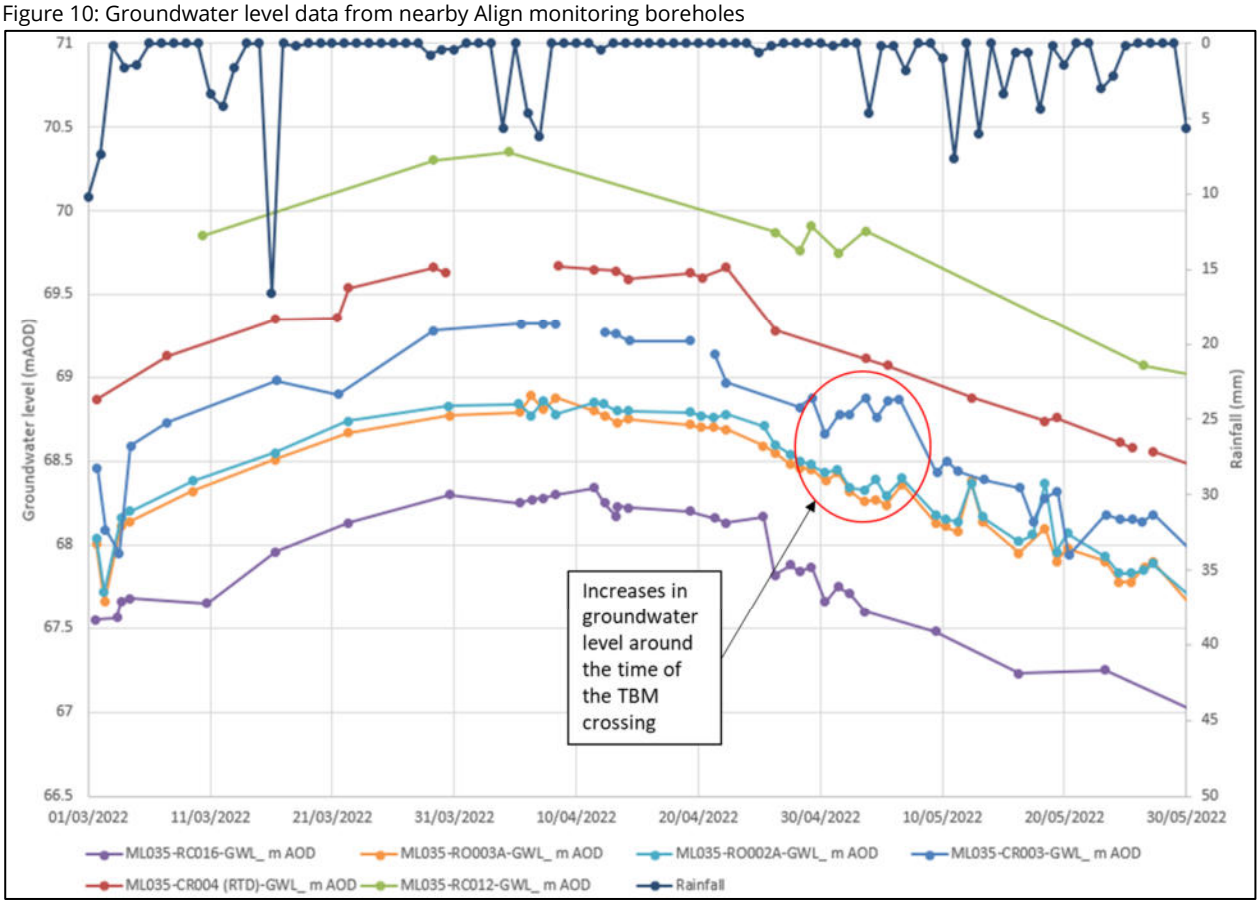


Groundwater Level Data

2.1.15 Groundwater level data from the nearby Align monitoring boreholes are presented in Figure 10 with their locations presented in Figure 3. These data show the groundwater level peak to have occurred some time in early April 2022 with water levels slowly decreasing from that point for the remaining monitoring period. At the time of the TBM crossing (between 30 April and 9 May 2022) groundwater levels in locations nearest to the river (ML035-RO002A, ML035-RO003A and ML035-CR003) were circa 68.5mAOD, some 5.5 - 6m below the water level in the river as reported by the Chalfont St Giles river level station (circa 74.3 m AOD).

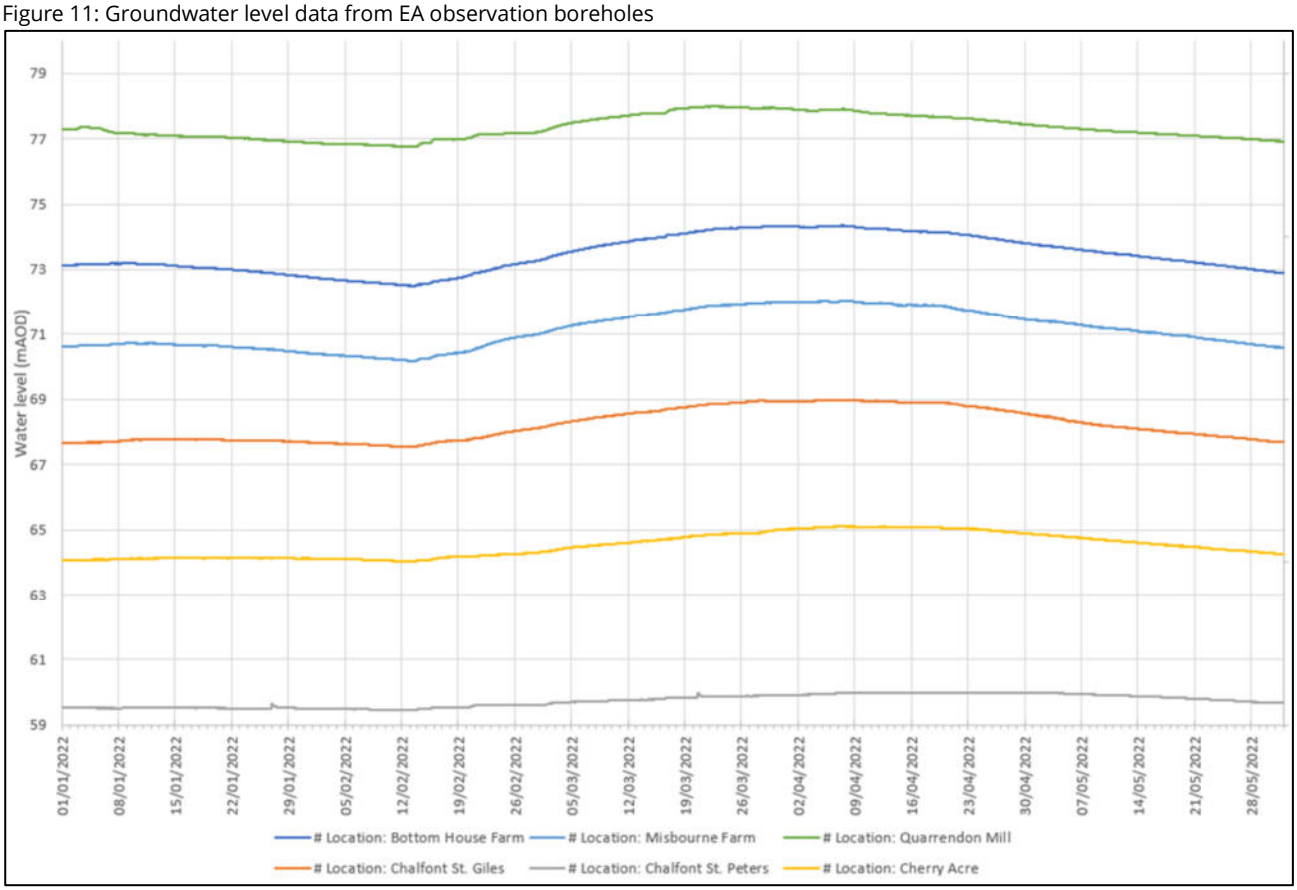
2.1.16 Some minor increases in water level are recorded in ML035-RO002A and ML035-RO003A (located circa 50m and 65m down gradient of the TBM crossing point respectively) around the time of the TBM crossing. A similar response is recorded over this time period in ML035-CR003 and ML035-RC012 which are located circa 130m and 500m up gradient of the TBM crossing point.

Figure 10: Groundwater level data from nearby Align monitoring boreholes



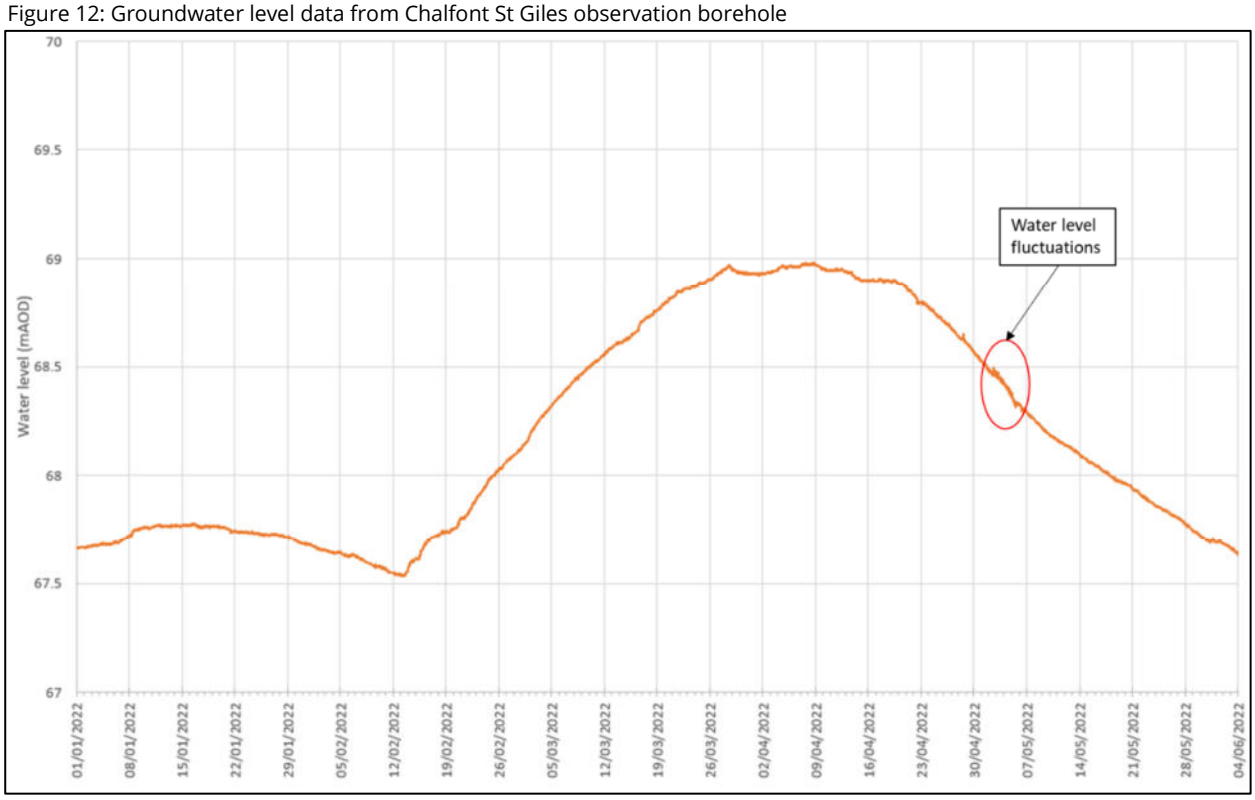
2.1.17 In addition, groundwater level data from nearby EA observation boreholes have been reviewed and are presented in Figure 11. The tunnel crown is at circa 53m AOD at the tunnel crossing point.

Figure 11: Groundwater level data from EA observation boreholes



2.1.18 None of the observation boreholes indicate a significant increase in groundwater level that coincides with the transit of the TBMs. Groundwater levels all show a gradual decline with good agreement in the rate of recession across all locations. There are some slight fluctuations evident in water level readings at the Chalfont St Giles borehole located circa 60m down gradient of the crossing location which correlate with the period of the TBM crossing (see Figure 12) and are not present before or after. Groundwater levels at Chalfont St Giles after the TBMs have crossed the Misbourne behave in a similar way to the other groundwater monitoring locations and continue to gradually decline.

Figure 12: Groundwater level data from Chalfont St Giles observation borehole



3 TBM data

Stability Monitoring

3.1.1 At the time when the incident was noticed, the TBM locations were as per Figure 1. The Upline TBM, Florence, was already 38 rings (76m) past the incident location, and the Downline TBM, Cecilia, was under the River Misbourne, but circa 20m downstream of the bridge.

3.1.2 Several monitoring points and instruments were installed with baseline data available prior to the crossing. Daily readings were taken from these instruments during the crossing period.

3.1.3 The monitoring in that area consisted of:

- 7# levelling points (LP) above each drive for 60m before the river crossing (14# total),
- 4# LPs for the High Street Road Bridge,
- 15# LP for utilities monitoring along High Street Road,
- 16# LP for utilities monitoring across the Coop car park,
- 19# Building levelling points for the Coop and Stone Cottage.

3.1.4 As of 11.00am on 4 May 2022, the readings were as per Figure 13 and Figure 14 below.

3.1.5 Maximum settlement under the upline was 1.06mm at the bridge location, and maximum settlement below the downline was 1.65mm just before the river crossing.

Figure 13: Monitoring conditions of the Bridge, the utilities and TBM alignment as of 4 May 2022

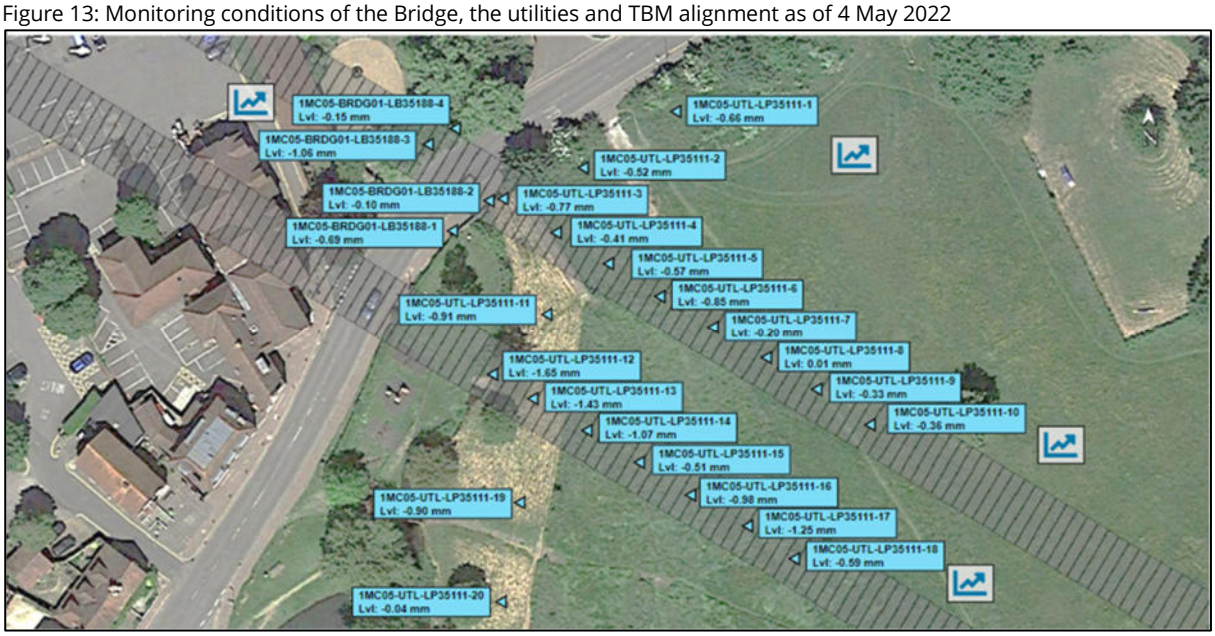
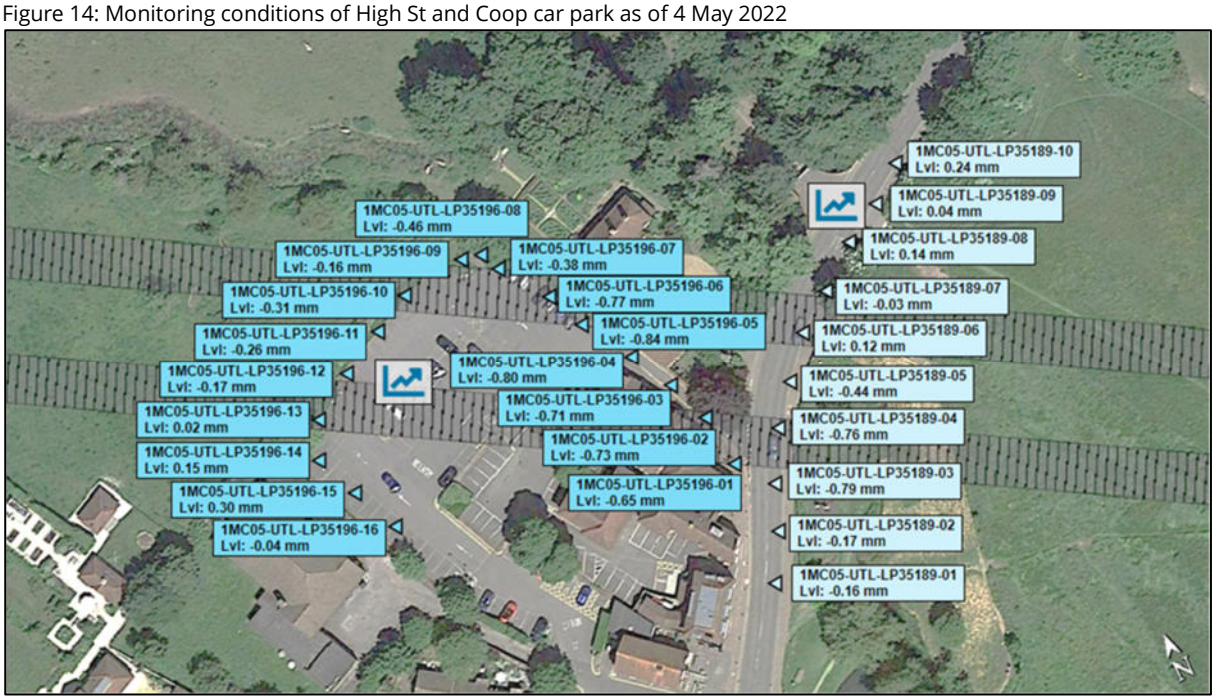


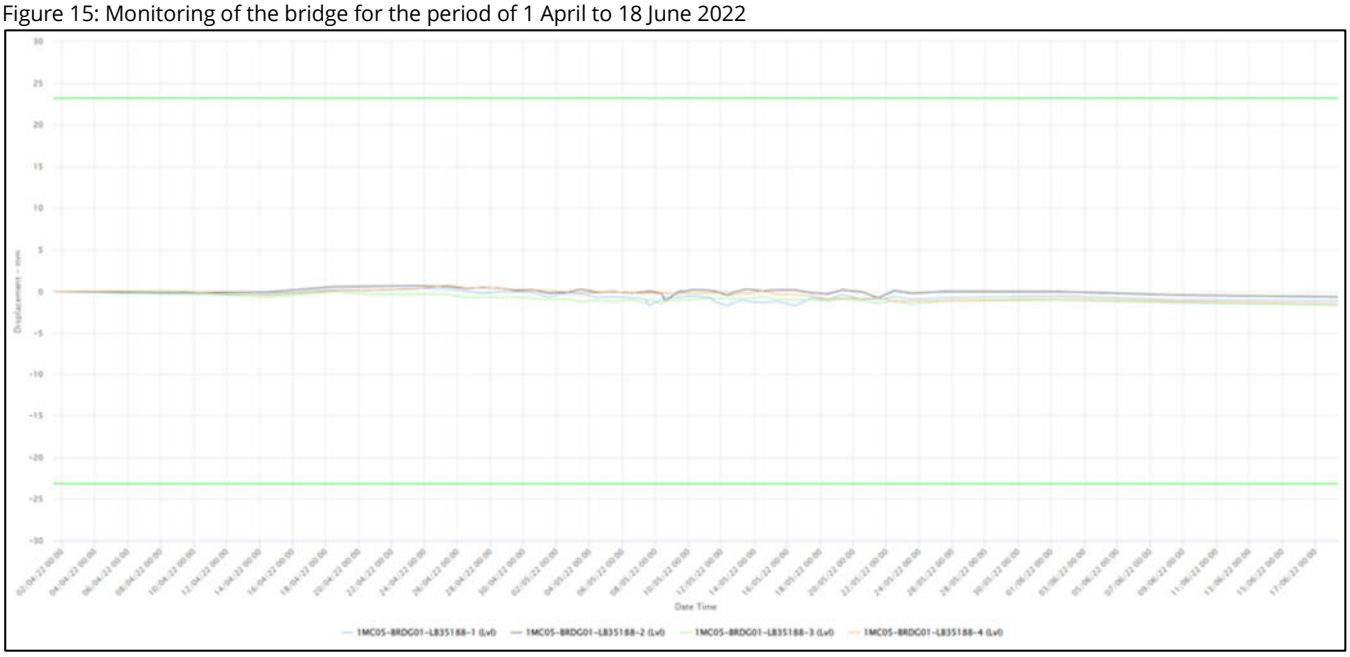
Figure 14: Monitoring conditions of High St and Coop car park as of 4 May 2022



3.1.6 Following the incident, and as a result of the Management Action Team (MAT) meeting held, the monitoring frequency was increased to twice daily for a period of one week. On the basis of no further movement, it was decreased to daily measurements for another 10 days, and then back to the normal monitoring weekly readings.

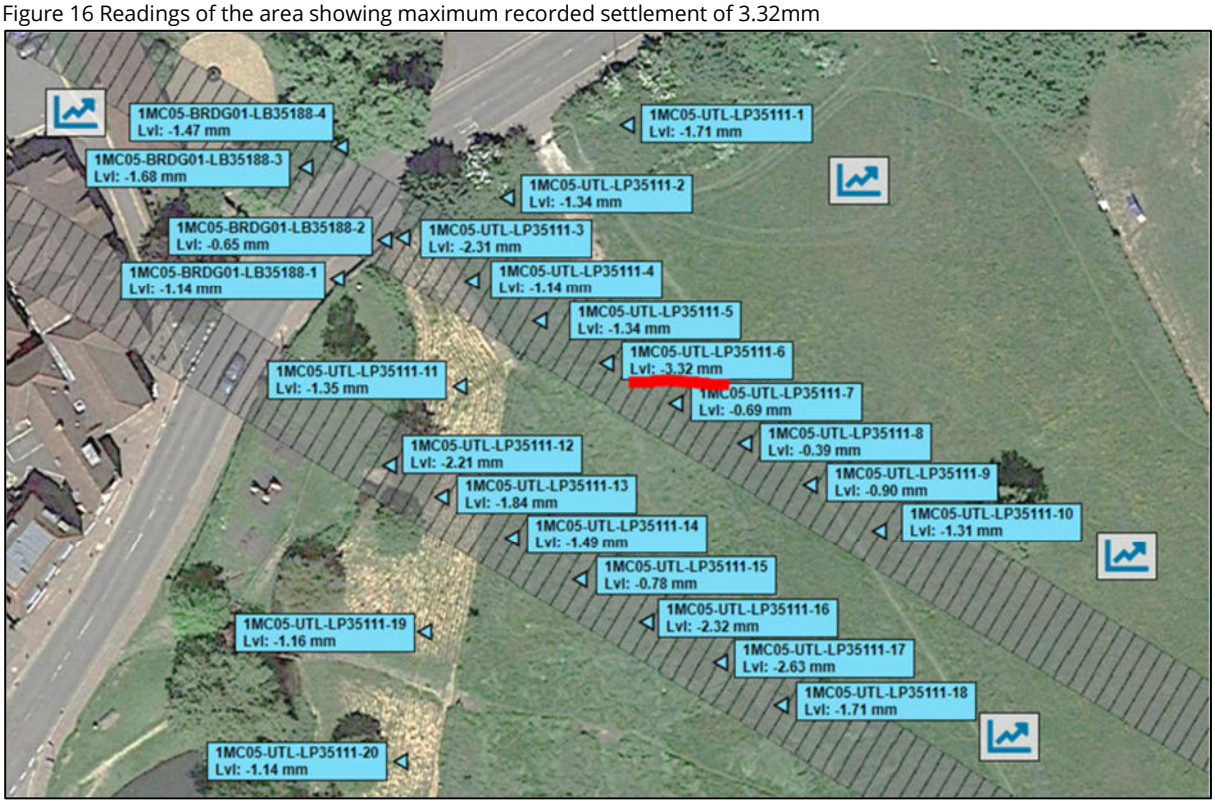
3.1.7 Figure 15 below shows the bridge monitoring for the period from 1 April 2022 to the latest reading to date, 18 June 2022. The readings remain stable and are well within the green monitoring condition (+/- 23mm).

Figure 15: Monitoring of the bridge for the period of 1 April to 18 June 2022



3.1.8 Based on the results, the biggest movement observed throughout the whole area is 3.32mm, above the upline tunnel, approximately 40m downgradient of the incident location.

Figure 16 Readings of the area showing maximum recorded settlement of 3.32mm

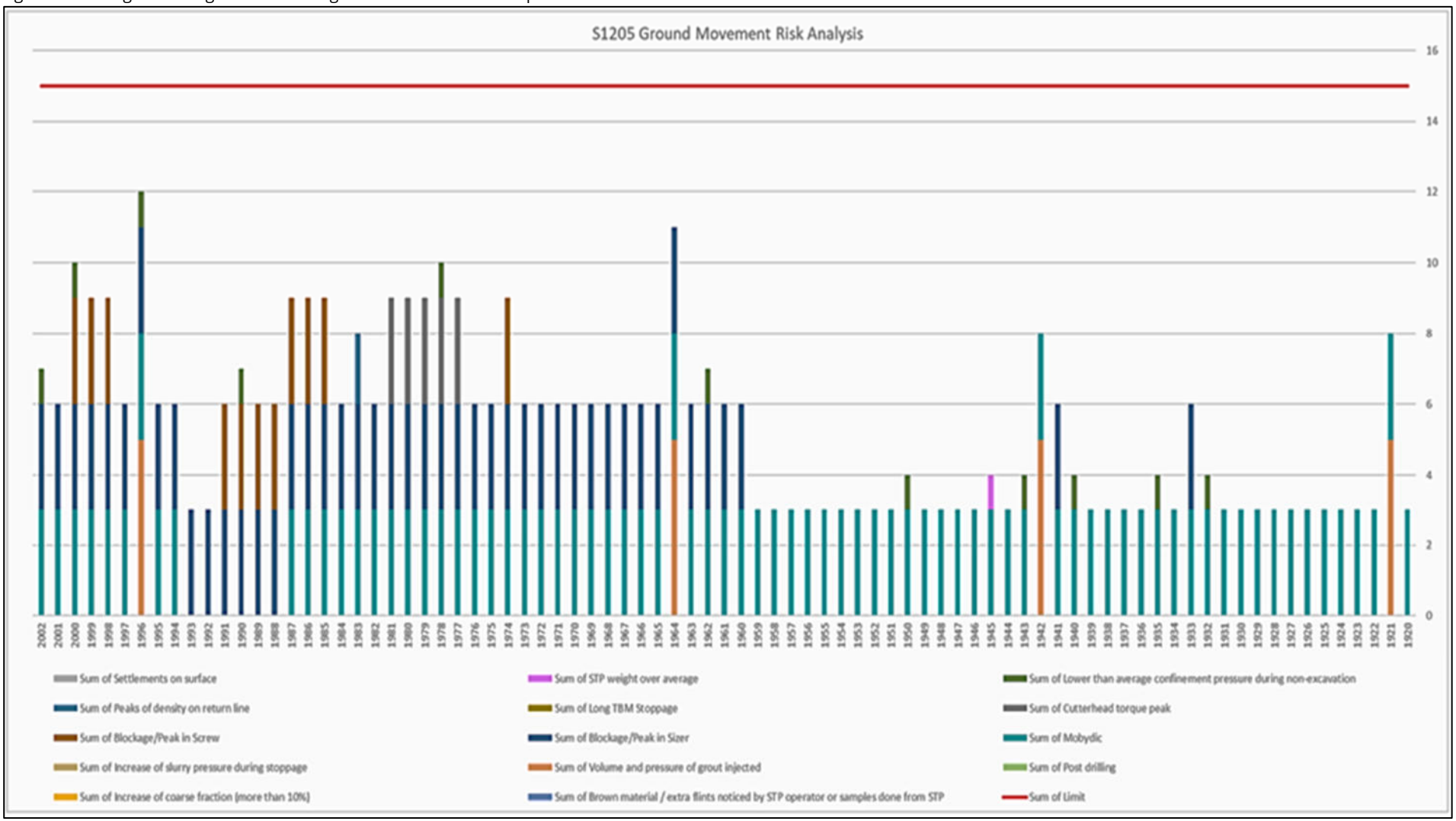


TBM Parameters

3.1.9 As per the current ground movement action plan several TBM parameters have been identified as potentially indicating the crossing of a dissolution feature. They are reviewed daily and each ring is scored according to the breach of the parameter triggers (abnormally high STP weight, poor Mobydic readings, high sizer or screw torque etc.). If a score is >15/49, a MAT meeting is called to decide upon further actions.

3.1.10 Figure 17 below shows the scoring of the rings for the period of interest – the ring being excavated at the time the incident happened is UR1970, so the parameters corresponding to that ring have been considered. The score of that ring is 6/49, so well below the trigger level for concern.

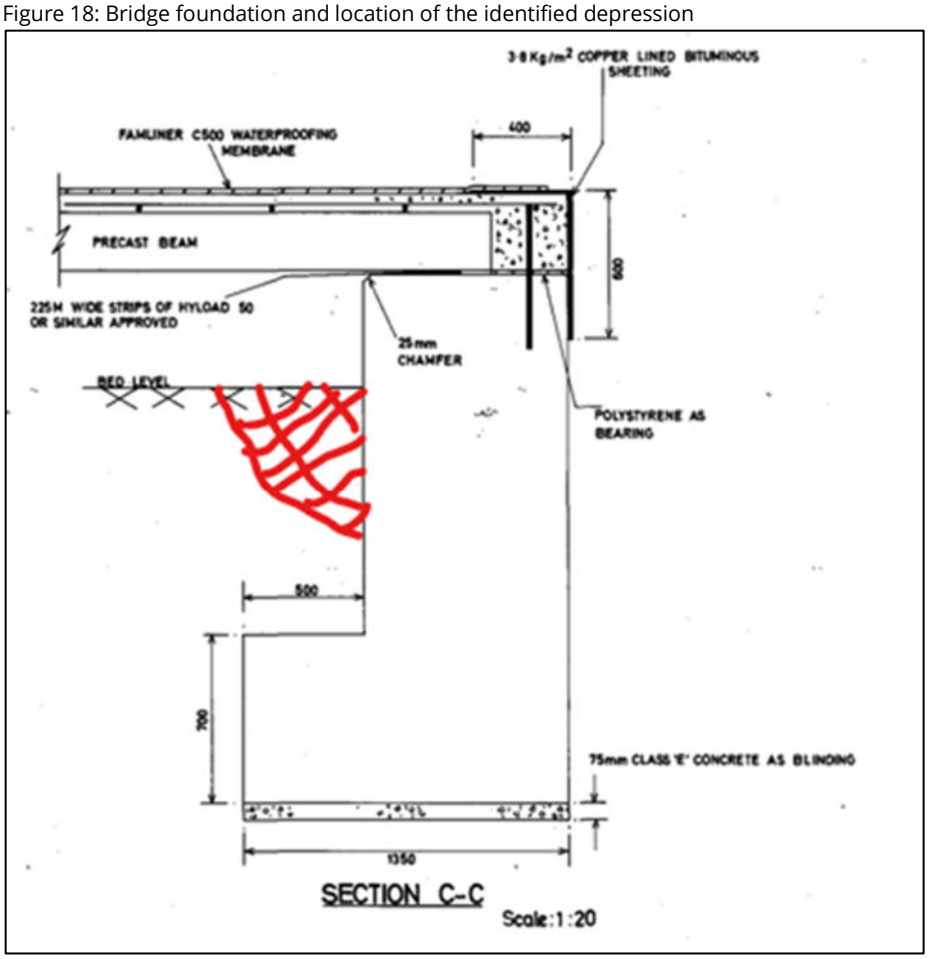
Figure 17 Scoring of the rings based on the ground movement action plan



3.1.11 In this ground movement analysis, the grouting is also considered. For that ring, the grouting has been particularly good as there is a difference of <0.5% between the theoretical and the actual volume of grout, with a target pressure achieved. This means no indication of remaining voids in the ground after the passing of the TBMs.

3.1.12 Of particular interetst is the shape of the bridge foundation, as presented Figure 18 below.

Figure 18: Bridge foundation and location of the identified depression



**Red hatched area indicates approximate location of depression (not to scale)*

3.1.13 The foundation of the bridge is in an “L” shape, with the depression that has been identified above the horizontal bar of the “L”. The location of the depression is therefore difficult to link to the TBM activity given that the foundation would offer protection against deep rooted subsidence.

3.1.14 Due to its location, the depression under this small bridge could easily have been missed during the pre-construction period, so there is a distinct possibility that it was pre-existing prior to the passing of the TBMs.

4 Discussion

4.1.1 The water level data obtained by Align (Figure 5 and Figure 6) does show that a sudden drop in river level occurred around the time of the TBM crossing with evidence of a slight increase in river level after the intervention works were completed. The timing of the drop in water level does not exactly tie in with the transit of the TBMs as Florence had already passed circa 70m beyond the river at the time of the drop in river level and Cecilia was down gradient of the position. While the water level drop of 3 May 2022 was double the magnitude of drops that occurred before the TBM crossing, the river level never recovered to the same height again and a similar magnitude drop was recorded on 16 May 2022, with levels dropping below those recorded during the incident. Based upon this observation it seems unlikely that the depression is regulating levels to a particular elevation within the riverbed.

4.1.2 In addition, sudden drops in river level occurring over a similarly short time frame of circa 30 – 75 minutes were recorded in the weeks before and after the TBMs had crossed the river (though generally of a smaller magnitude). This indicates that this response was evident before the transit of the TBMs beneath the River Misbourne and is not connected to TBM activity.

4.1.3 The daily fluctuations present in both the Align and Affinity Water data are recorded in locations over 3k from each other and indicate a wide scale effect within the aquifer. Literature review indicates that this is likely to be principally attributable to changes in evapotranspiration and air temperature, with a potential link to temperature dependent viscosity changes and associated changes in hydraulic conductivity within the hyporheic zone[1].

4.1.4 The river level data provided by Affinity Water (Figure 8) was in good agreement both up and down stream of the TBM crossing point over the entire period of interest and there was no indication of a sudden change in the river level or hydraulic characteristics of the river post TBM transit, as was picked up by the Align

[1] Marciniak, M. and Szczucińska, A., 2016. Determination of diurnal water level fluctuations in headwaters. Hydrology Research, Volume 47, Issue 4

monitoring data. This indicates that no change in river behaviour has occurred between the two locations either during or after the crossing by the TBMs.

4.1.5 The groundwater level data obtained from both the Align and EA observation monitoring points show no evidence for losses from the river having occurred. No significant increase in groundwater levels in close proximity to the TBM crossing point were detected. Small oscillations in water level did occur over this time period but were observed in locations both up and down stream of the TBM crossing point. Given that the monitoring points are spread over a relatively wide area it would seem unlikely to be caused by localised river leakage induced by TBM activity and instead it suggests the observed increases represent more widespread responses to rainfall.

4.1.6 Most of the data assessed indicates that no significant change in river or groundwater levels occurred during or immediately after the crossing by the TBMs. This is in contrast to the data collected by Align which indicates repeated sudden drops occurring both before, during and after the passage of the TBMs. The Align data does not pick up all of the flow peaks present in the data provided by Affinity Water and may point to inaccuracies in the readings, but the fact that the trace from both Align instruments agree so well with each other over the period of the TBM crossing would seem to indicate that these were genuine events. It could be that the effect detected in these instruments is very local to the TBM crossing point i.e. the sudden drops in water level occur in a stretch between the Quarrendon Mill and Chalfont St Giles river level gauges. Localised factors downstream of the bridge mean that these drops in recorded river levels coincide with times when groundwater is generally receding. It could be that as groundwater levels decline in this area inactivation of baseflow pathways result in these sudden drops in river level.

4.1.7 However, this is not corroborated by the data from the Chalfont St Giles monitoring station and given that this is located only circa 60m down gradient of the Align monitoring locations it would seem unlikely that a drop in river level would be detected by the Align monitoring but then dissipate before reaching the Chalfont St Giles station. No springs or point discharges into the Misbourne are known that could provide an inflow that would mask the drops in level recorded by Align and groundwater levels in the vicinity of the TBM crossing point remained below the base of the river over this time period, preventing baseflow contributions. The reason for this is unclear. Taking the river level data from Affinity Water at face value no difference in river levels up and down stream of the TBM crossing location have been observed and therefore any changes that occurred are attenuated long before water reaches the downstream gauge.

4.1.8 The data obtained from the structural and TBM monitoring installations show no evidence of a settlement event having occurred, with minimal ground movement being recorded and no evidence of a void or solution feature having been encountered.

4.1.9 TBM performance throughout the whole area has been particularly good as:

- The tunnel only has 17-20m of cover
- The ground conditions expected and encountered were not particularly good due to the fact it is in a valley,
- The maximum movement recorded is 3.32mm when the expected movements were more in the range of 20 to 30mm.
- No indication of a void or solution feature having been encountered based on the grout take information.

4.1.10 Following the above, there is no evidence of any abnormality neither in the TBM data nor the Instrumentation and monitoring data that could link the depression identified to the TBMs activities.

5 Conclusion

5.1.1 Review of the available data indicates that:

- No evidence of ground collapse was detected by the seismic monitoring devices with minimal ground movement having occurred in the vicinity of the Pheasant Hill bridge.
- No evidence of solution features (which are often linked with subsidence events) were detected as the TBM passed beneath the River Misbourne.
- There was no evidence of significant groundwater level changes in the vicinity of the TBM crossing location that could indicate leakage from the river has occurred.
- No evidence of a sustained change in the hydraulics or river level response down gradient of the TBM crossing location was identified.

5.1.2 The recorded sudden drop in river level is likely to be either anomalous readings collected by Align or local effects within the river that are not linked to TBM operation. The data do not indicate that a sustained change in river flow characteristics has occurred to the River Misbourne as a result of the TBM crossings.

5.1.3 Monitoring of river level will continue at the location of the TBM crossing to confirm that no lasting impact to the River Misbourne has occurred, with an additional up gradient monitoring location due for installation over the summer.