1MC05

Options for mitigation of the effects of shaft construction on groundwater

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1 Purpose

1.1.1 This technical note has been prepared by Align, on behalf of HS2, to provide information to the Environment Agency and Affinity Water as part of the obligations that HS2 has to these organisations under the High Speed Rail (London – West Midlands) Act 2017[1]. The objective of this report is to provide detailed information regarding the possible environmental effects of shaft construction and where necessary, appropriate mitigation. These are necessary to meet the requirements of the HS2 Technical Standards[2] [3] [4]that support the Environmental Minimum Requirements along with the undertakings and assurances provided by HS2 to a number of stakeholders.

2 Scope

2.1.1 An assurance is required that where the predicted effects of the Proposed Scheme on groundwater flows, levels and quality, have been assessed as significant adverse, a strategy to manage the risk will be agreed with the Environment Agency. The ES[5] identified significant adverse effects to Affinity Water abstractions from the potential for migration of turbid water during construction (i.e. temporary effects) to the following abstractions: TH011 ([redacted] TH171 ([redacted] and TH181 ([redacted] Potential effects of the construction of Chesham Road shaft on the [redacted] abstraction were not included in the ES as the design at that time had a shorter tunnel and there was not a shaft at Chesham Road.

2.1.2 The potential effects of shaft construction are reviewed in this technical report in light of the current, more detailed design, to determine if they remain significant and if that is the case, what mitigation is required. In addition, some non-significant effects are also reviewed to check that the level of significance remains unchanged with the more detailed design information that is now available. Furthermore, the effect of Chesham Road shaft, which was not included in the ES, is also considered.

2.1.3 This technical note has been prepared to outline the options for mitigating the effects of shaft construction on Affinity Water abstractions. It forms part of a series of documents that form the groundwater management strategy[6] to support the discharge of undertaking and assurance 49. This technical note details:

- shaft construction activities that could affect groundwater movement and/or quality;
- potential effects of shaft construction on Affinity Water abstractions;
- identified risks;

[1] UK Government, 2017, High Speed Rail (London – West Midlands) Act 2017, Chapter 7, HMSO
[2] HS2, Technical Standard Groundwater Protection, Document no.: HS2-HS2-EV-STD-000-000010
[3] HS2, Technical Standard Water resources and flood risk consents and approvals, Document no.: HS2-HS2-EV-STD-000-000015
[4] HS2, Technical Standard Water Resources and Flood Risk Monitoring Strategy, Document no.: HS2-(HS2-EV-STD-000-000029
[5] HS2, November 2013, London-West Midlands Environmental Statement, Volume 2 | Community Forum Area report, CFA8 | The Chalfonts and Amersham
[6] Align, 2018, Groundwater Management Strategy, Document No.: 1MC05-ALJ-EV-NOT-C001-600012

- options for mitigation of the effects; and
- proposed approach to managing mitigation.

Proposed monitoring is not included in detail in this report as it detailed in a separate document[7].

3 Definitions and abbreviations

Abbreviations	Definitions
d-wall	Diaphragm wall
ES	Environmental Statement
mAOD	Metres above Ordnance Datum
PWS	Public Water Supply
SPZ	Source Protection Zone
TBM	Tunnel Boring Machine

4 Proposed shaft construction activities

4.1 All shafts

4.1.1 This assessment includes construction of ventilation shafts at the following five locations (from south to north):

- Chalfont St Peter;
- Chalfont St Giles;
- Amersham;
- Little Missenden; and
- Chesham Road.

4.1.2 Although referred to as "ventilation" shafts throughout this report, the shafts also serve another purpose, being for intervention (such as fire-fighting or train evacuation) in the event of an emergency. The Chesham Road shaft is not required for ventilation purposes due to its proximity to the North Portal, but it is required for intervention and for pressure relief for the downline. This notwithstanding, for simplicity it is referred to as a ventilation shaft in this report.

[7] Align, 2018, Section C1 Monitoring position statement, Document no.: 1MC05-ALJ-EV-NOT-C001-600011

4.1.3 The construction of all of the shafts will follow the same generic approach, but there are specific characteristics relevant only at some shafts, with the Chesham Road shaft being of a similar size but different design to the other shafts. The generic design and construction information is therefore provided in this section, with specifics at each shaft in the following sections. The generic approach will be:

- Construction of a compound including offices, generator, fuel storage, steel reinforcement cage storage and bentonite mixing plant / bentonite pools / bentonite de-sander.
- Installation of piling platform and diaphragm wall guide walls.
- Grouting of the top c.15m of ground in a ring at the location of each shaft in order to fill any dissolution cavities and / or fractures.
- Construction of a diaphragm wall (d-wall) of between 1 and 1.5m thick, to form a watertight outer to the shaft. Each diaphragm wall would consist of a series of individual panels that would be excavated to depth using a wire line cutter and then filled with concrete prior to excavation of the next panel. At some shafts all of the panels would be the same width, whilst at others they would be different widths, alternating between wide and narrow panels as the d-wall is constructed. Bentonite would be used within each panel excavation to act as a support fluid and as a cutting medium to aid recovery of cuttings. Once the panel reaches full depth the bentonite would be displaced by concrete pumped into the excavated panel area and would be collected and treated / disposed off-site.
- Construction of a grout plug (fissure grouting) at the base of the shaft. Potentially these plugs could be up to some 12m thick, to limit upward groundwater movement. As Chesham Road shaft would be above the water table there would not be a requirement for a grout plug, whilst at Chalfont St Peter shaft the need for a grout plug would depend on the findings of the additional GI.
- Ground treatment (grouting) at the base of all shafts at the locations where the TBM will break through in order to limit the potential for groundwater inflow. The proposal is to try to reduce the ground permeability to 10^{-6} m/s.
- Pumping of groundwater from beneath the grouted base plug (where present) to reduce the upward pressure head of groundwater, with discharge to groundwater recharge boreholes a suitable distance from the shaft. The number and location of the pressure reduction boreholes has not been determined as this will form part of detailed construction design once the ground investigation, including pumping tests, is complete. The pressure reduction will only be required during construction.
- Excavation of material from within the completed d-wall, with localised pumping to remove water from the saturated soil / rock and incident rainwater. The volume of water likely to be removed will be relatively low as the d-wall and grout plug will prevent any significant groundwater influx and the shaft would be dewatered slowly

as construction progresses. Rainwater accumulation will be limited due to the relatively small size of the shafts. At this stage the required treatment and exact discharge location for the water has not been confirmed, but the preference is for recharge of abstracted water back to ground in the area of the shaft.

- Construction of a thick reinforced concrete base slab at the base of the shaft (i.e. above the grout plug) with localised ground treatment where the TBM is to breakthrough the edge of the shafts.
- Ground treatment in the area where adit construction is required. The ground treatment would likely be fissure grouting to reduce ground permeability to prevent water ingress during adit construction.
- Mining of the adit after the TBMs have passed through the shaft.
- Installation of secondary lining in the shaft.
- Removal of the capping beam, which would be installed to provide stability during shaft construction.
- Construction of the shaft head house.
- Internal fit out.

4.1.4 An indicative work sequence for Chalfont St Peter shaft is provided in Appendix 1. These drawings are provided to give an indication of the possible construction techniques and sequences and are indicative rather than definitive.

4.1.5 At the time of writing some shaft designs are further developed than others and so more detail is provided at these locations.

4.1.6 It is likely that construction activities would take place at two shafts at the same time.

4.2 Chalfont St Peter, Chalfont St Giles, Amersham and Little Missenden

4.2.1 These four shafts will all be constructed to the same design an internal diameter of 17.8m and an external diameter of 20.2m, with the shafts constructed so that the two rail tunnels intersect the sides of each shaft. At Chalfont St Giles, Amersham and Little Missenden it is likely that some localised pressure relief (dewatering) will be required beneath the grouted base plug to reduce the potential for uplift of the concrete base slab during construction. Once the concrete base slab is in place and fully cured water removal would cease. Until the additional ground investigation and associated pumping tests are completed it is not known what abstraction rates are likely to be required, nor what the discharge route for the abstracted water will be (options are to discharge to the River Misbourne or to recharge back to ground a distance from the shaft). A grout plug (fissure grouting) may be required at the base of the at Chalfont St Peter shaft to limit upward groundwater movement, although the need for this would depend on the findings of the additional GI (the existing GI does not indicate a need for a plug).

4.2.2 Ground level at Chalfont St Peter shaft is at about 102mAOD whilst the low rail level will be about 39mAOD. The base of the shaft will extend beneath this to incorporate the full thickness of the concrete base slab, although the design of this has not yet been completed. The shaft will extend below the water table and the diaphragm walls would be extended significantly below tunnel level to reduce groundwater inflows during dewatering (see indicative drawings in Appendix 1). The diaphragm wall at this location could take around 18 weeks to construct, although this depends on ground conditions, the number of rigs used and working hours.

4.2.3 Ground level at Chalfont St Giles shaft is at about 96mAOD whilst the low rail level will be about 59mAOD. The base of the shaft will extend beneath this to incorporate the full thickness of the concrete base slab, although the design of this has not yet been completed. The shaft will extend below the water table and the diaphragm walls would be extended deeper than required for construction in order to reduce groundwater inflow during dewatering (see drawings in Appendix 1). The diaphragm wall could take around 18 weeks to construct depending upon ground conditions, rig numbers and working hours.

4.2.4 Ground level at Amersham shaft is at about 105mAOD, whilst the low rail level will be at about 58mAOD. The base of the shaft will extend beneath this to incorporate the full thickness of the concrete base slab, although the design of this has not yet been completed. The shaft will extend below the water table and the diaphragm walls would be extended deeper than required for construction in order to reduce groundwater inflow during dewatering (see drawings in Appendix 1). The diaphragm wall could take around 18 weeks to construct depending upon ground conditions, rig numbers and working hours.

4.2.5 Ground level at Little Missenden shaft is at about 115mAOD, whilst the low rail level will be at about 77mAOD. The base of the shaft will extend beneath this to incorporate the full thickness of the concrete base slab, although the design of this has not yet been completed. The shaft will extend below the water table and the diaphragm walls would be extended deeper than required for construction in order to reduce groundwater inflow during dewatering (see drawings in Appendix1). The diaphragm wall could take around 18 weeks to construct depending upon ground conditions, rig numbers and working hours.

4.3 Chesham Road Shaft

4.3.1 Chesham Road shaft will be some 14m internal diameter and about 18m external diameter, constructed to full depth in between the two railway tunnels. Chesham Road shaft is above water table and so a grout plug would not be required.

4.3.2 Ground level at Chesham Road shaft is at about 182mAOD whilst the low rail level will be at about 141mAOD. The base of the shaft will extend beneath this to incorporate the full thickness of the concrete base slab, although the design of this has not yet been completed. The base of the shaft will be above the "normal" water table, allowing for "normal" seasonal variations, by of the order of 10 to 15m. In extreme high groundwater level conditions the water table could rise to the base of the shaft but as the shaft and tunnel will be sealed there will not be any water ingress. The diaphragm wall could take around 11 weeks to construct at this location, depending on ground conditions, the number of rigs used and working hours.

5 Aquifer characteristics and data limitations

5.1 Geology

5.1.1 At the location of each shaft superficial material is present as follows:

- Chalfont St Peter – Beaconsfield Gravel (sand and gravel).
- Chalfont St Giles – clay with flints.
- Amersham – none (except topsoil / sub soil) on the north western side, but a narrow band of head (gravel) on the south east side of the site.
- Little Missenden – none (except topsoil / sub soil).
- Chesham Road -clay with flints (clay, silt, sand and gravel).

5.1.2 The superficial material is underlain by chalk, with the following strata outcropping or sub-cropping at each shaft:

- Chalfont St Peter – Seaford Chalk Formation and Lewes Nodular Chalk Formation (undifferentiated).
- Chalfont St Giles – Lewes Nodular Chalk Formation.
- Amersham – Lewes Nodular Chalk Formation.
- Little Missenden – New Pit Chalk Formation.
- Chesham Road -Lewes Nodular Chalk Formation and Seaford Chalk Formation (undifferentiated).

5.1.3 The chalk strata underlying the above are detailed in the ES[5].

5.2 Hydrogeology

5.2.1 The Chalk is classified as a Principal aquifer and used extensively for water supply, with Affinity water taking some 100Ml/d from the aquifer via a series of abstraction boreholes in the Colne and Misbourne valleys, via the [redacted] and [redacted] group licences. There is no alternate supply if the abstraction boreholes have to be shut down. The aquifer also provides baseflow to rivers, including the River Colne and the River Misbourne, the latter a sensitive chalk stream.

5.2.2 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 by groundwater standards. This third element means that the aquifer is sometime described as having triple permeability characteristics.

5.2.3 Typically, the permeability of the Chalk is highest in the valleys and lowest in the interfluve areas. Analysis of data gained from pumping tests on three Affinity Water sources in the River Misbourne valley by MWH[8] indicates transmissivities for the fracture network of 1,100 to 2,700 m^2/d (at [redacted] PWS), 4,700 to 9,500 m^2/d (at [redacted] PWS) and 6,400 m^2/d (at [redacted] 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 (although there have been no tracer tests to corroborate this).

5.2.4 All of the large groundwater abstractions have groundwater source protection zones (SPZ) defined for them. 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 (zone 2) - defined by a 400 day travel time from a point below the water table.
- Total catchment area (zone 3) - defined as the area around a source within which all groundwater recharge is presumed to be discharged at the source.

5.2.5 The SPZs have been established by modelling and are based on the data available at that time, and licensed (not actual) abstraction rates. These zones are best estimates and in heterogeneous aquifers such as the Chalk are indicative rather than definitive. The inner and outer zones could be greater in extent and are likely to 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. SPZs should therefore be used with a degree of caution and in this assessment are treated as indicative rather than definitive.

5.2.6 The current groundwater models are regional models and could be updated to provide a model that is more specific to each shaft and it could draw on the additional ground investigation boreholes that have been drilled since the model was prepared and on additional monitoring data. However, as the key risks to sensitive receptors are related to the potential for encountering solutionally enlarged voids, which cannot be accurately predicted by the model, there would be limited benefit in such modelling. This assessment therefore relies on a conceptual understanding of the aquifer and potential flow paths.

[8] MWH, November 2016, Desk Study Assessment of Turbidity Risk at Three Affinity Water Sites

6 Potential effects on the water environment

6.1 Effects predicted in the ES

6.1.1 As noted in section 2 of this technical note, the only significant adverse effects of the shafts on groundwater identified in the ES[5] were to Affinity Water abstractions at [redacted] and [redacted] No significant effects were identified to other PWS, nor to other abstractions in the area. This section re-evaluates this assessment based on more detailed information.

6.1.2 In addition, although the ES states that "Any migration of turbid groundwater to surface water is likely to be a slow process allowing natural attenuation within the chalk, and dilution, to reduce turbidity to levels that are unlikely to significantly affect surface water quality", potential effects on the River Misbourne are also re-assessed.

6.2 Construction of Chalfont St Peter shaft

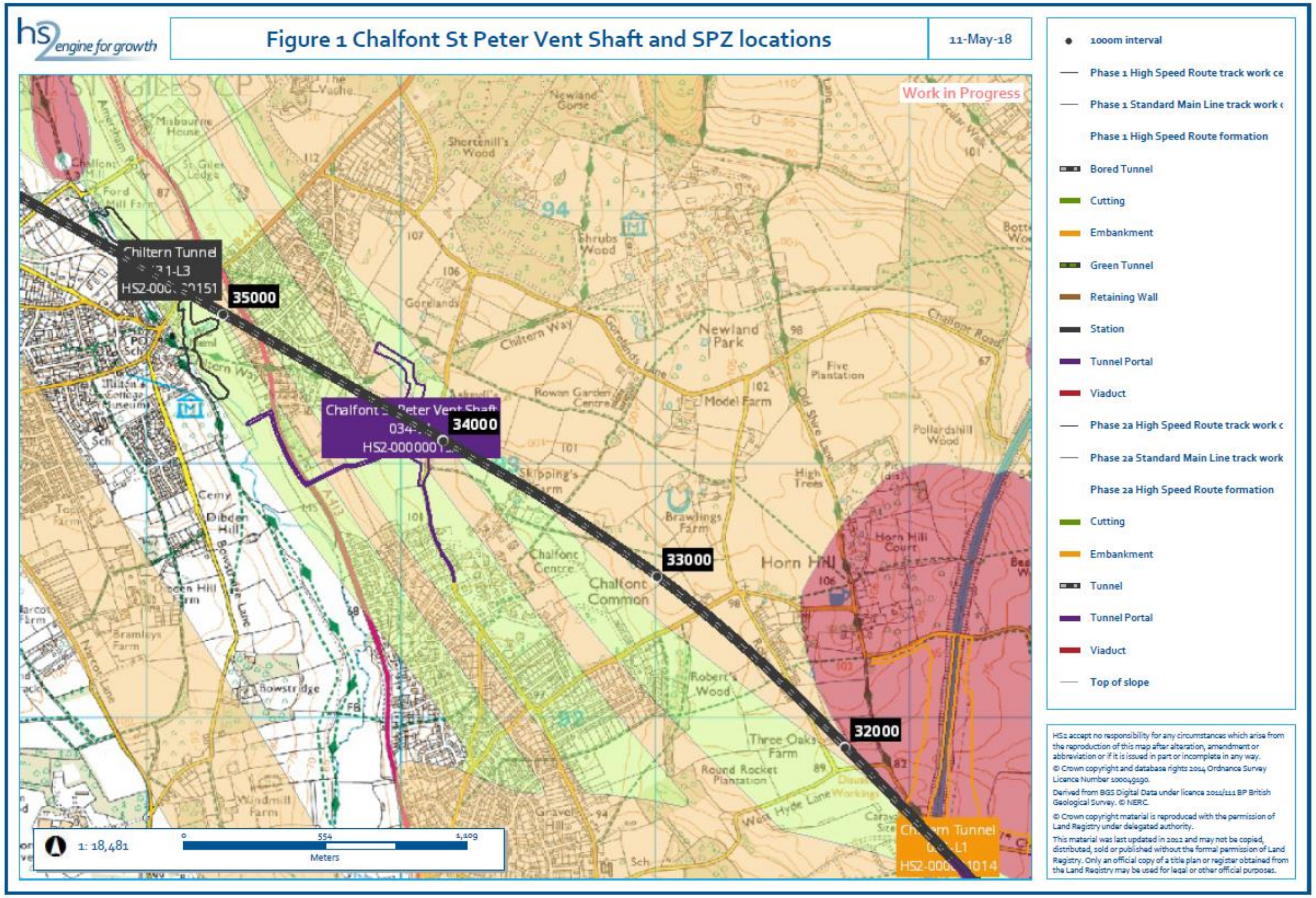
6.2.1 The closest PWS to the shaft is at [redacted] approximately [redacted] to the [redacted] in the Misbourne Valley. Chalfont St Peter vent shaft is located down the regional hydraulic gradient of [redacted] PWS. There is therefore little potential for this PWS to be affected by shaft construction.

6.2.2 Chalfont St Peter shaft is on the boundary of SPZ 2 and 3 (Figure 1) for the [redacted] / [redacted] abstractions, both of which are located in the Colne Valley. The shaft location is some [redacted] of the [redacted] PWS, which is the closest down gradient public abstraction. Work completed for Affinity Water by MWH[9] suggests that the Colne Valley has a well-developed "karstic" flow system along it with the water from the [redacted] abstraction coming from a combination of flow along this route, from radial flow in the area surrounding the three boreholes, and from leakage through the terrace gravels that overlie the Chalk in the Colne Valley.

6.2.3 The shaft location is at about 102mAOD on the interfluve between the River Misbourne and River Colne valleys, and is much closer to the Misbourne than the Colne valley. Chalk permeability in interfluve areas is typically substantially less than in the valleys[10]. There is no obvious dry valley system shown on topographic maps from the area of the shaft towards either river valley, suggesting that there will not be a significant/rapid flow path from the shaft in any direction. The potential for significant or rapid water movement from the area of the shaft to [redacted] PWS is therefore low to very low.

[9] MWH, July 2017, Desk Study Assessment of Turbidity Risk at [redacted]
[10] 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.

Figure 1 Chalfont St Peter Vent Shaft and SPZ Locations

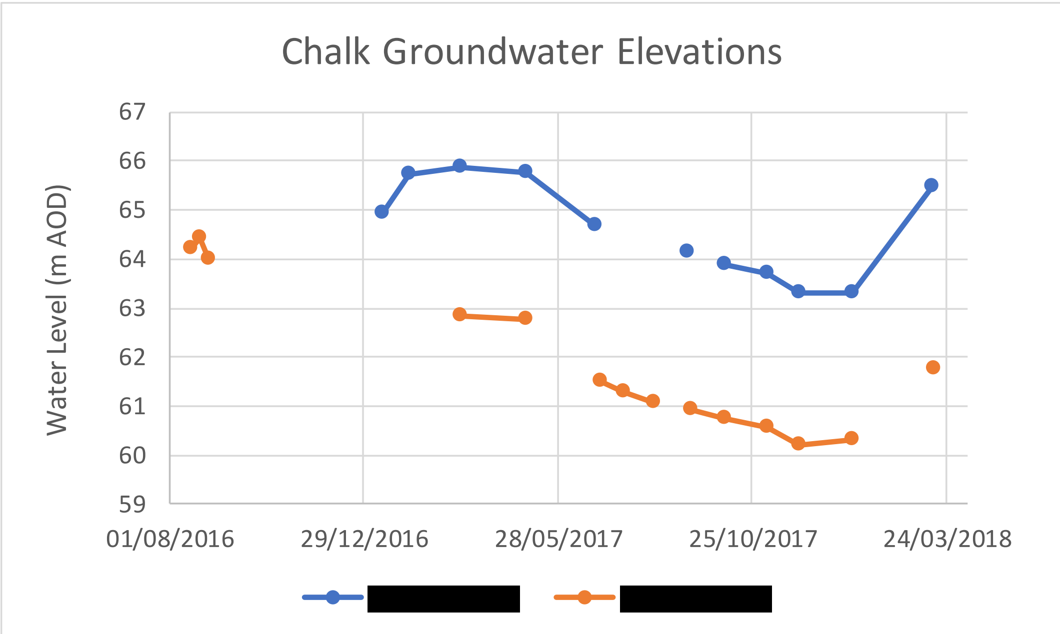


6.2.4 Based on the above assessment the risk from shaft construction to the [redacted] PWS or the [redacted] PWS is very low.

6.2.5 In the period August 2016 to March 2018 the groundwater elevation in the vicinity of the shaft location (as measured at borehole [redacted] which is about [redacted] of the shaft location) ranged between 60.2 and 64.4m AOD (Figure 2). This is within the Lewes Nodular Chalk Formation, some 22m above the junction with the New Pit Chalk Formation. The peak water level was measured in August 2016 and the low in November 2017. This equates to between 40.6 and 36.6m below ground level. This is likely to be below the level of the channel of River Misbourne at this location which is thought to be at an elevation of between 65 and 70mAOD. The Misbourne is often dry in this area due to river losses to ground, although it can flow on occasion so there could be some surface water / groundwater interaction, albeit very limited. The risk from shaft construction to the River Misbourne in this area, is therefore very low.

6.2.6 For comparison Figure 2 also shows the groundwater elevation in the Chalk at borehole [redacted] which is just over [redacted] of [redacted] abstraction and just under [redacted] of the tunnel alignment. This clearly shows that water levels at the shaft location are consistently lower than those close to the abstraction boreholes.

Figure 2 Water levels in the Chalk in the vicinity of the location for Chalfont St Peter Shaft



6.2.7 There are no known active private groundwater abstractions in the immediate vicinity of the vent shaft. However, there is one possible abstraction (designated CFA8-GWUA01 in the ES[5]), which is [redacted] of Chalfont St Peter vent shaft, but there are no details in the Environmental Statement and the EA does not have a record of a de-regulated abstraction in that area but it appears to be around [redacted]). The EA does have a record of a different de-regulated abstraction in the area which is not thought to be in use. It is former licence 28/39/28/0521 at SU 991 936 – by the River Misbourne in Chalfont St Giles. Its use was 'public administration for make-up or top-up water' so possibly it was used to top up the adjacent pond. This is just about [redacted] of Chalfont St Peter vent shaft. The potential for any effects on groundwater abstractions from construction of the shaft is therefore very low.

6.3 Construction of Chalfont St Giles shaft

6.3.1 Chalfont St Giles shaft is within SPZ2 for [redacted] PWS (TH028 in the ES[5]) (Figure 3). The SPZ for this abstraction is a very long and narrow zone and the shaft location is over 7km up gradient of the abstraction borehole so the risk to this abstraction borehole is very low. In addition, the SPZ does appear unrealistic in terms of its shape.

6.3.2 The shaft location is approximately [redacted] of [redacted] PWS, but is not shown as lying within the SPZ for that supply, largely due to topography. The shaft location is on the valley side at about 97mAOD, whilst the abstraction borehole is located in the base of the valley adjacent to the River Misbourne at about 75mAOD.

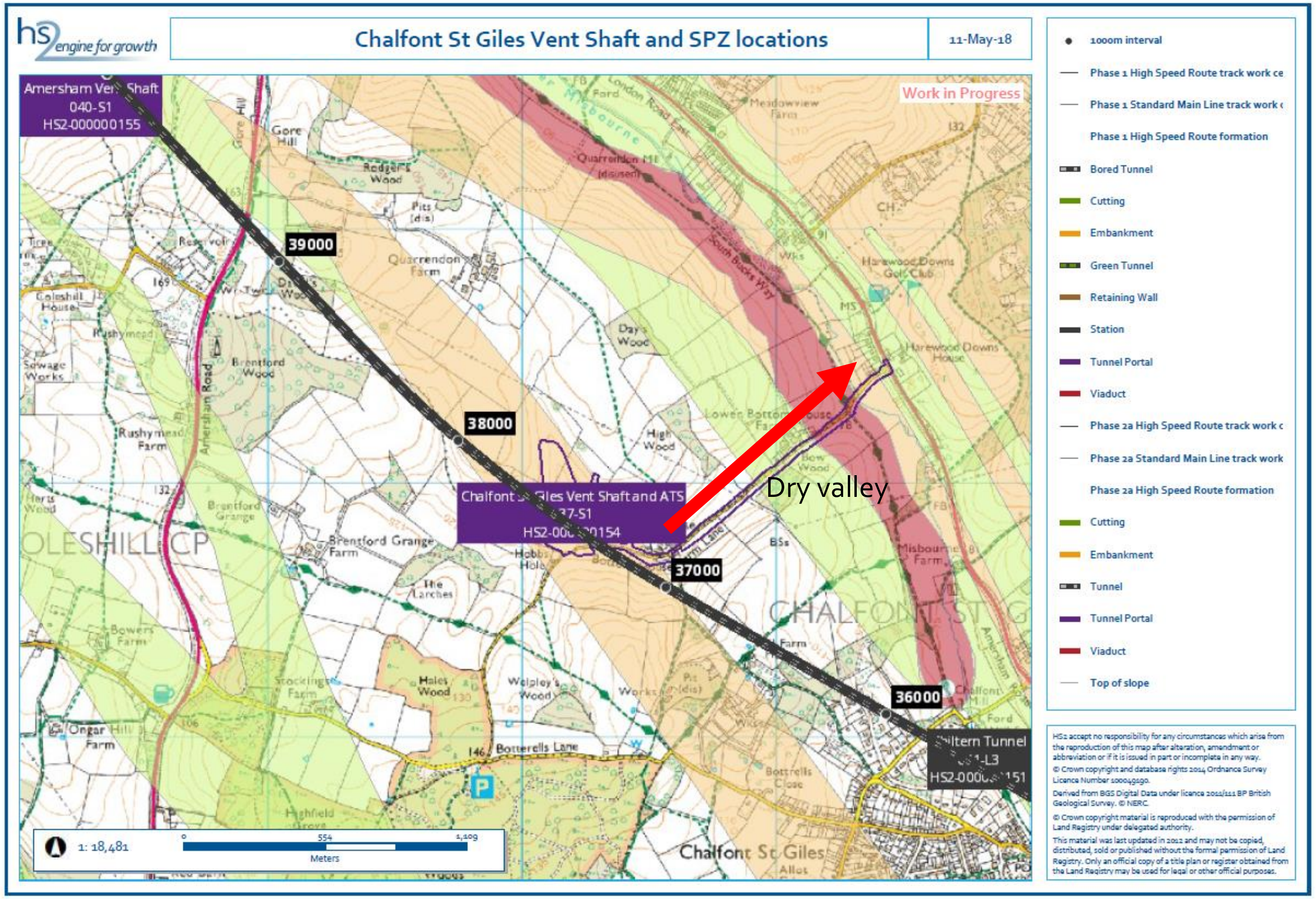
6.3.3 MWH[8] suggest that there is a "karst flow system" along the valley of the River Misbourne and that the [redacted] PWS is well connected to this system. MWH suggest that there is a "linear zone with solution widened fractures in the pre-existing fracture network" along the Misbourne valley at this 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.

6.3.4 The shaft is to be located 1.2km to the south west of the River Misbourne towards the upper end of a dry valley that trends to the north east towards the valley of the River Misbourne (Figure 3) and it is likely that this forms a preferential flow path to that valley. Any effects on water quality would likely be transmitted along this route and to the Misbourne valley where the groundwater would flow into the "karst flow system" referred to by MWH[8]. The flow path length from the shaft location to the PWS is some 2.5km. 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.

6.3.5 It is therefore possible that some groundwater from the vicinity of [redacted] shaft could flow towards the [redacted] PWS, but if it does, it would be a very small proportion of the total volume of water abstracted and is unlikely to be connected by a direct rapid flow path. However, once the water enters the valley of the Misbourne the flow path will be rapid. There is therefore some potential for turbidity from shaft construction to affect [redacted] PWS, but the risk is assessed as low.

6.3.6 There are no known private abstractions within 1km of the vent shaft.

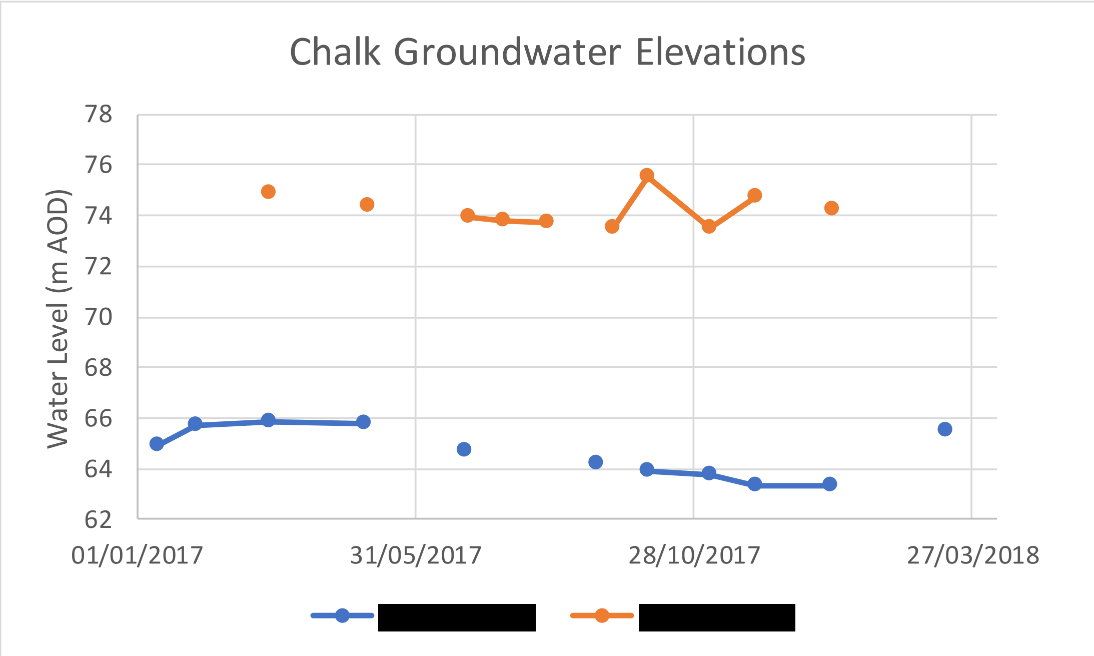
Figure 3 Chalfont St Giles Vent Shaft and SPZ locations



6.3.7 The groundwater elevation at borehole [redacted], which is very close to the shaft location was measured in 2017 and early 2018 at between 73.5 and 75.5m AOD (Figure 4), which is 26.1 to 24.1m below ground level. This water level is within the Lewes Nodular Chalk, some 13m above the junction with the New Pit Chalk Formation. This is likely to be just below the River Misbourne at this location which is thought to be at an elevation of between 75 and 80mAOD. The river in this stretch varies from flowing or dry depending on groundwater levels so there is some potential for groundwater / surface water interaction, albeit the river is dry for most of the year so that influence is likely to be limited. If there is any interaction it will most likely be via diffuse recharge through alluvium in the bed of the river and this will provide filtration of any turbidity. The risk from shaft construction to the River Misbourne is therefore low.

6.3.8 For comparison Figure 4 also shows the groundwater elevation in the Chalk at borehole [redacted] which is just over 100m to the south west of [redacted] abstraction and just under [redacted] of the tunnel alignment. As noted above, [redacted] PWS is located in the [redacted] the River Misbourne with the rest water level at about 70mAOD (i.e. lower than the water level at the shaft).

Figure 4 Water levels in the Chalk in the vicinity of Chalfont St Giles shaft



6.4 Construction of Amersham shaft

6.4.1 The Amersham vent shaft location is within SPZ3 for the Gerrards Cross (TH028 in the ES) PWS, although it is over 10km up gradient of the abstraction due to the long narrow nature of the SPZ (which as stated above appears unrealistic in shape) (Figure 5). There is therefore no risk to this abstraction from construction of the shaft. The shaft location is just over [redacted] of the [redacted] PWS, but is not shown as lying within the SPZ for that supply, although as stated in section 5.2, the extent and shape of SPZs are not being relied upon in this assessment as being an accurate reflection of where the water is derived from.

6.4.2 The [redacted] PWS is within [redacted]. MWH[8] indicate that there is "…strong anisotropy with high transmissivity aligned along the valley. Within the valley 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". MWH consider that this system is well connected to the [redacted] PWS. If this is the case, the water abstracted at [redacted] will be predominantly from along the valley of the River Misbourne, both upstream and downstream of the boreholes.

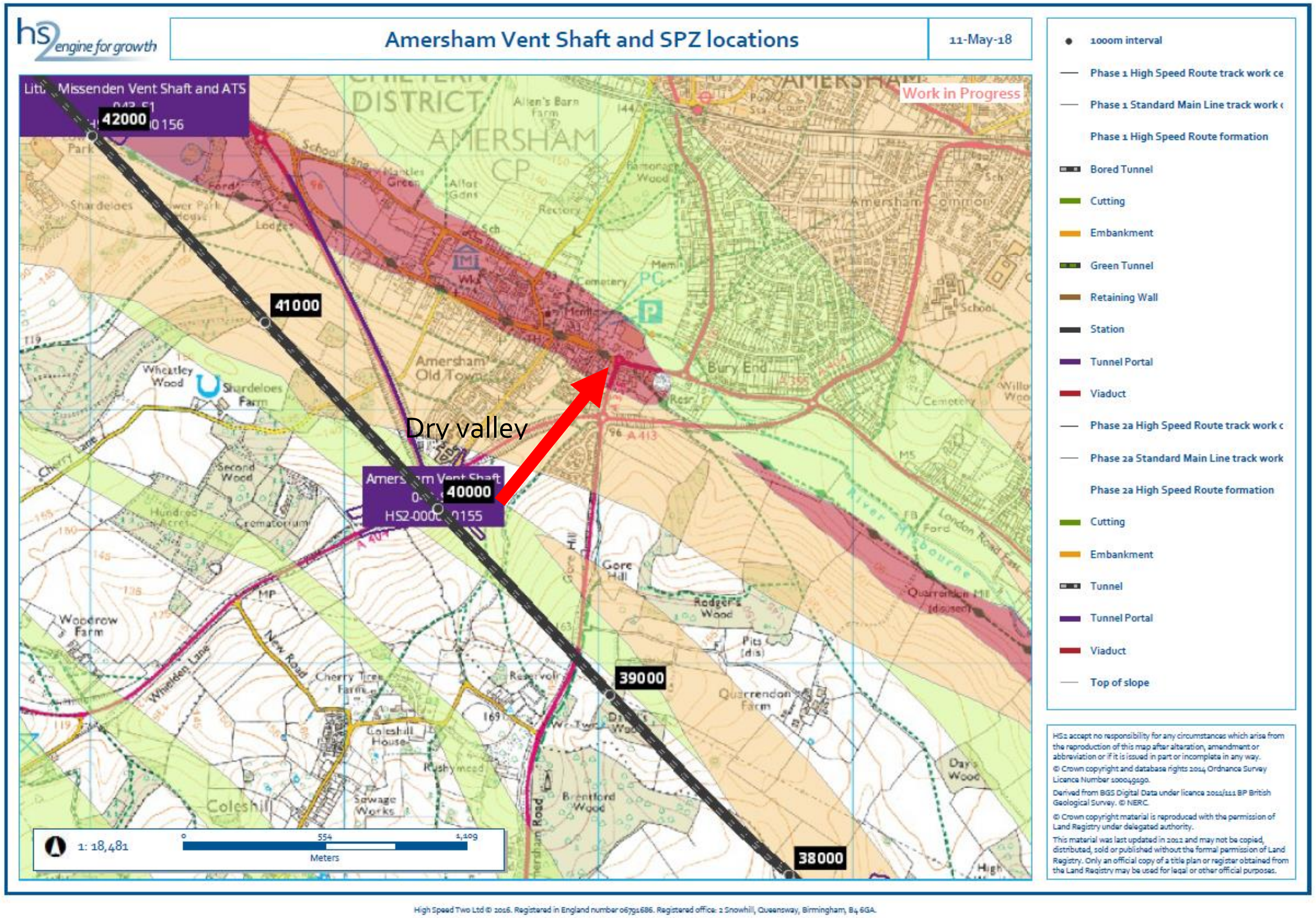
6.4.3 The [redacted] PWS is [redacted] of the shaft location and so are across rather than directly down gradient of the shaft. The PWS is at an elevation of about 90mAOD, whilst the location for the vent shaft is at about 105mAOD, part way along a dry valley that trends north east to the valley of the River Misbourne. It is likely that, as is the case elsewhere in the chalk[10], the dry valley forms a preferential groundwater flow path. It is therefore possible that some groundwater from the vicinity of the Amersham shaft could flow towards the [redacted] PWS, via the dry valley, and then via any preferential flow system present in the valley. If water does move via this route it is likely that only a very small proportion of the total volume of water abstracted comes from this source as the majority will be from along the valley, particularly if the abstraction is supported by a conduit. The distance from shaft to borehole, excluding tortuosity, would be about 1.5km. Due to this distance and the potential presence of a preferential flow path, the risk from turbidity generated during shaft construction to the [redacted] is considered to be moderate.

6.4.4 There is one licensed groundwater abstraction approximately 900 metres north north east of [redacted] vent shaft on the northern side of the River Misbourne (licence no. 28/39/28/0109, [redacted] Prints Ltd. (now known as [redacted] Fabrics), The Maltings, School Lane, [redacted] HP7 0ES) and which is identified in the ES[5]. The abstraction is located within the SPZ1 for the [redacted]. The borehole is thought to be 32m deep and the water is used as process water for textiles and the daily abstraction limit is small at only 44m^3/d. 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. As the location is upstream of where the north east trending dry valley enters the Misbourne valley, and as the abstracted volume is very small, the potential for shaft construction to have a significant effect on the supply is low. However, there is some uncertainty in this effect due to the presence and effect of the [redacted], as the [redacted] Prints borehole is within the zone of influence of the [redacted].

6.4.5 There are also two private unlicensed abstractions within 1 km of [redacted] vent shaft – referred to as CFA8-GWUA02 and CFA8-GWUA03 in the ES[5]. There is limited detail in the Environmental Statement regarding these sources. The owners of one borehole (CFA8-GWUA03), at Shardloes Farm, contacted HS2 and provided a drilling log. This indicates that 40m of drift was encountered overlying chalk and that the water level in the chalk was some 60m below ground level. The water is used for supply to the house, equestrian centre, stables and paddock and is located to the west of [redacted] at SU94823 96998. This supply is up hydraulic gradient of the shaft location and is not located in an area where a flow path between the shaft and the supply would be expected. The risk to this supply from shaft construction is therefore low, but this assertion would be checked during the pumping test at the location of [redacted] shaft.

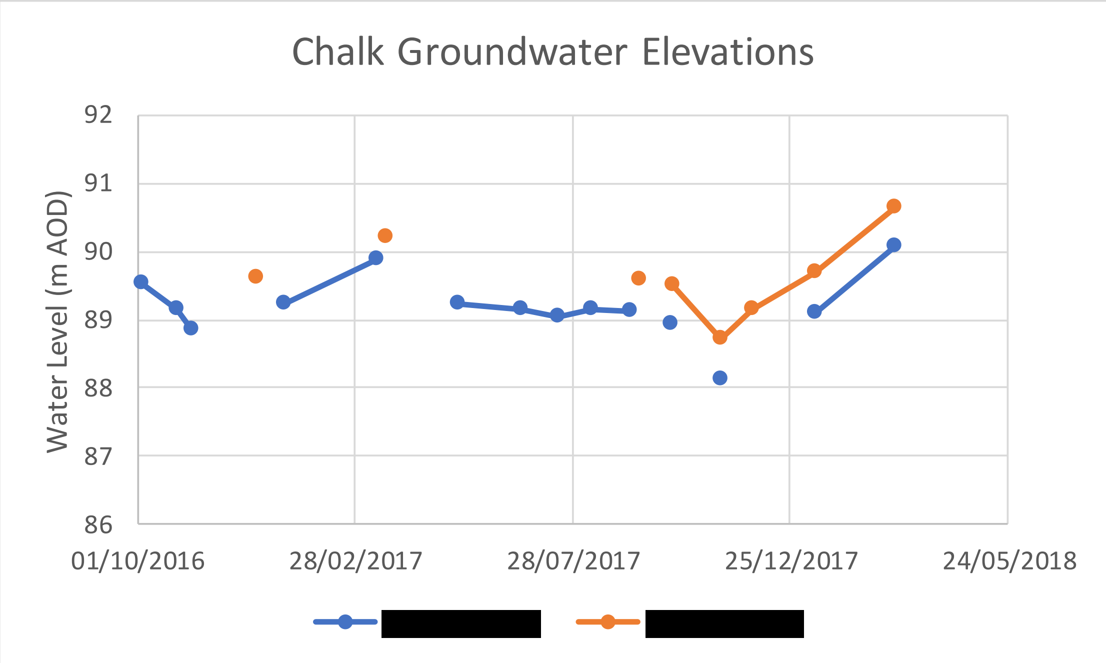
6.4.6 The second abstraction is at [redacted] some 800m to the south of [redacted] vent shaft location, at SU 95265 95960. The land here is at 170mAOD and is across rather than directly down gradient of the vent shaft location. [redacted] is on the interfluve and aquifer permeability is expected to be relatively low with no direct flow path to the vent shaft. The risk to this supply from shaft construction is therefore low, but this assertion would be checked during the pumping test at the location of [redacted] shaft.

Figure 5 Amersham Vent Shaft and SPZ locations



6.4.7 The groundwater elevation in the vicinity of the shaft was measured in 2017/2018 to vary between 88.1 and 90.7m AOD (Figure 6). The groundwater elevations to the immediate south east of the shaft were measured in borehole [redacted] and are lower (down gradient) than those in borehole [redacted] which is just over 100m to the north of the shaft location. The depth to groundwater in the borehole closest to the shaft ([redacted]) was between 13.3 and 11.4m below ground level in 2017/2018. The borehole was drilled rotary open hole to 20m below ground level (c. 81m AOD) so it is not possible to confirm the strata at this depth.

Figure 6 Water levels in the Chalk at Amersham vent shaft location



6.4.8 The groundwater elevation at the shaft location is likely to be at about the same elevation as the River Misbourne at this location which is thought to be at about 90mAOD so the two will likely be in hydraulic continuity during wetter periods. During dry periods the water table will likely be below river bed level.

6.4.9 Affinity Water has indicated that the river reach from Amersham downstream to Chalfont St Giles loses water to ground, with an estimated 20% loss in flow. Upstream of Amersham the river gains in flow which supports the above assessment regarding the river and groundwater being in hydraulic continuity. This, combined with the potential presence of a preferential groundwater flow path beneath the dry valley that trends north eastwards from the shaft location, means that there is potential for below water table shaft construction activities to affect the River Misbourne. However, the volume of water that will be moving along this flow path and enter the River Misbourne is likely to be very low in comparison to the volume already in the river (assuming it is flowing). Furthermore, there are no known discrete outflows points (springs or risings) into the river and the river is located on a layer of alluvium which will provide some filtering of water from the chalk before it enters the river as a diffuse inflow. In addition, through parts of Amersham Old Town the river is culverted. In addition, the river is far less effected by low concentrations of turbidity than the PWS. The level of risk to the water quality in the river is therefore assessed as low and additional mitigation is not required.

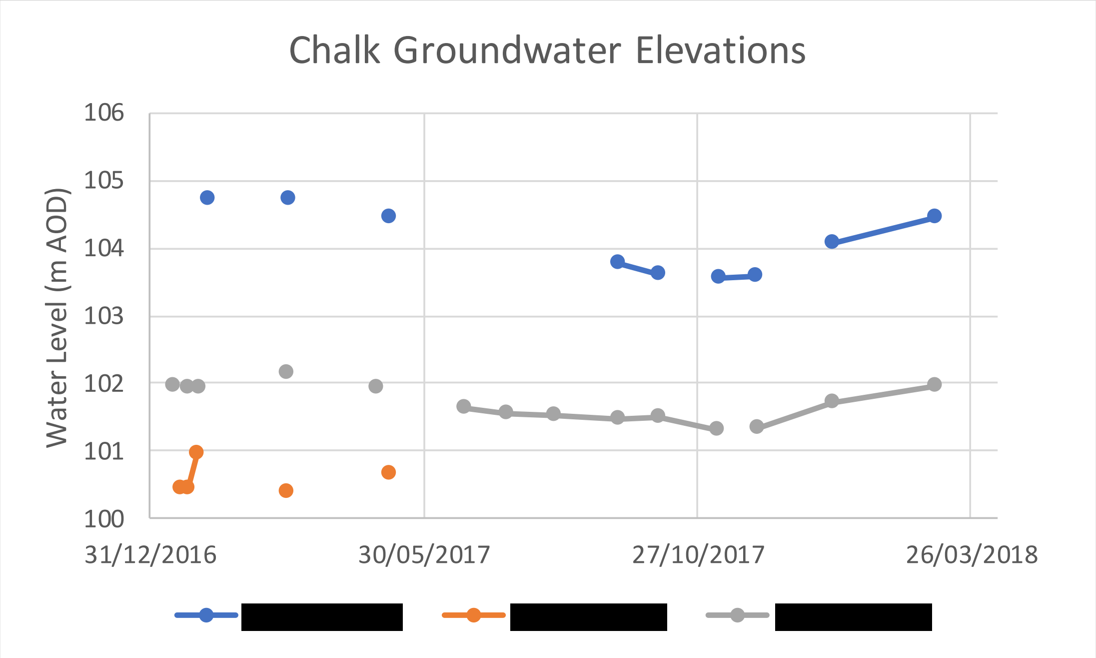
6.5 Construction of Little Missenden shaft

6.5.1 Little Missenden shaft is in the valley of the River Misbourne and is about [redacted] from [redacted] PWS, but is not shown as lying within the SPZ for that supply and it is down gradient from the abstraction so does not represent a risk to it (Figure 8). The shaft location is within the SPZ2 for the [redacted] PWS which is some [redacted] away. It is likely that there is a high flow zone along the River Misbourne Valley towards the [redacted] PWS (as noted above, from MWH[8]). Due to the distance, and as the shaft is on the river valley side, albeit on the lower slopes, the risk from shaft construction to the PWS is low to moderate.

6.5.2 The groundwater elevation at the shaft location has been measured in borehole [redacted] since late 2016 and the results are shown in Figure 7 (note: the water level in other boreholes at the shaft location are shown in Figure 8 in the shaft hydrogeological report[11], but these are omitted here for clarity and they show the same fluctuations at a similar elevation). This data shows that the water table has very limited changes, fluctuating between 101.3 and 102.0 in the monitoring period, equivalent to 15.4 to 14.8m below ground level. The groundwater elevation to the south east of the shaft towards the River Misbourne in borehole [redacted] is slightly lower at around 100.5 to 101.0m AOD (albeit over a more limited monitoring period), whilst that in borehole [redacted] some [redacted] was higher ranging from 103.6 to 104.7m AOD. The confirms the general hydraulic gradient from north west to south east in this area. There are no monitoring boreholes in close proximity to the [redacted] PWS, although the rest water level is likely to be at about 110m AOD based on approximate ground elevation and rest water information from CCTV surveys.

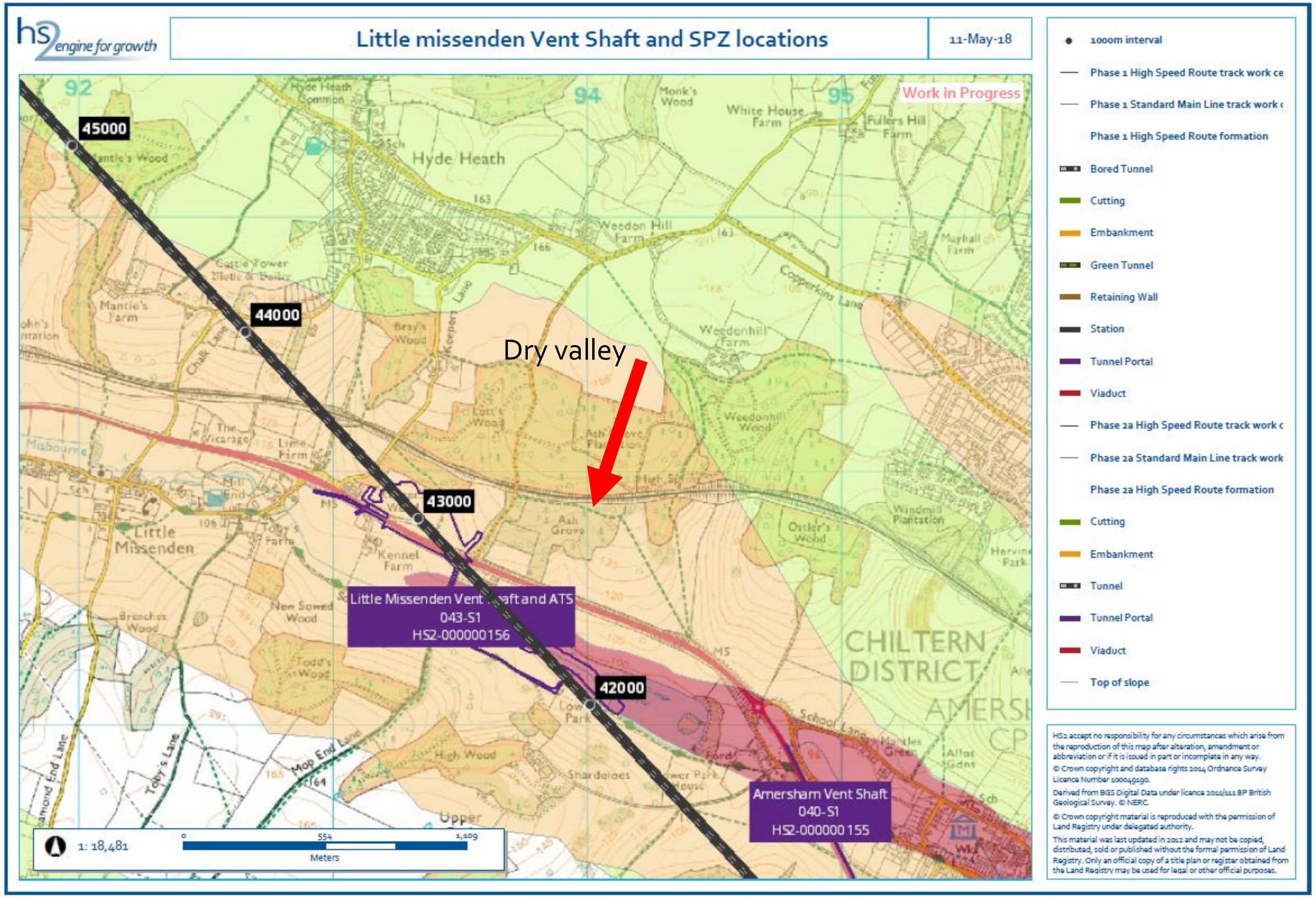
[11] Align, 2019, Groundwater Assessment for Construction Tasks – Shafts, Ref: 1MC05-ALJ-EV-NOT-CS02_CL04-300112

Figure 7 Water levels in the Chalk around Little Missenden vent shaft location



6.5.3 There are no known private abstractions within 1km of the shaft.

Figure 8 Little Missenden Vent Shaft and SPZ locations



6.5.4 The shaft location is just over 300m to the north east of the River Misbourne. The groundwater elevation in the vicinity of the shaft is at about 101 to 102mAOD, which is likely to be at about the same elevation as the River Misbourne at this location which is thought to be at about 102mAOD based on topographic maps. Groundwater and the river are therefore likely to be in hydraulic continuity. As noted above, Affinity Water has indicated that the in the river reach upstream of [redacted] the river gains in flow which supports the above assessment regarding the river and groundwater being in hydraulic continuity.

6.5.5 The shaft location is at the south western end of a dry valley that trends from 160mAOD towards the river (Figure 8). It is possible that this represents a preferential groundwater flow path and that any groundwater migration from the vicinity of the shaft could move quite rapidly towards the River Misbourne. However, the river is underlain by alluvium at this location and any inflow to the river would be diffuse and would represent only a small fraction of the flow in the river. Due to the proximity of the shaft to the river and the presence of the dry valley the risk from shaft construction to turbidity in the River Misbourne is moderate.

6.5.6 It is also possible that any dewatering at the shaft could have an effect on flows in the River Misbourne, although this is highly dependent on the time of year at which such dewatering takes place, its volume, depth and its duration. Until the additional ground investigation is completed we do not have any indication of the volume or duration of any pumping required. Due to proximity of the shaft to the river the risk of a significant effect is low to moderate.

6.6 Construction of Chesham Road shaft

6.6.1 Chesham Road shaft is approximately [redacted] of the [redacted] PWS, but it is not shown as being within the SPZ for that abstraction (Figure 9). The shaft is within SPZ3 for the [redacted] PWS which is some [redacted]. The shaft location is at an elevation of 184mAOD.

6.6.2 Four boreholes were drilled in the vicinity of the shaft location as part of the HS2 ground investigation and they have been monitored since January 2017. Although they are frequently dry, as the shaft is anticipated to be above the water table except in extreme circumstances, this is not a concern for monitoring during construction.

- [redacted] to the south east of the shaft location to a depth of 55m below ground level (125m AOD). This location was dry on 12 of 13 monitoring visits, with the only measured water level being between at 125m AOD.
- [redacted] within the shaft construction area to a depth of 65m below ground level (116m AOD). This location was dry on 7 of 12 monitoring visits, with the measured water levels being between 116 and 127m AOD.
- [redacted] within the shaft construction area to a depth of 60m below ground level (122m AOD). This location was dry on 9 of 10 monitoring visits, with the only measured water level being between at 123m AOD.

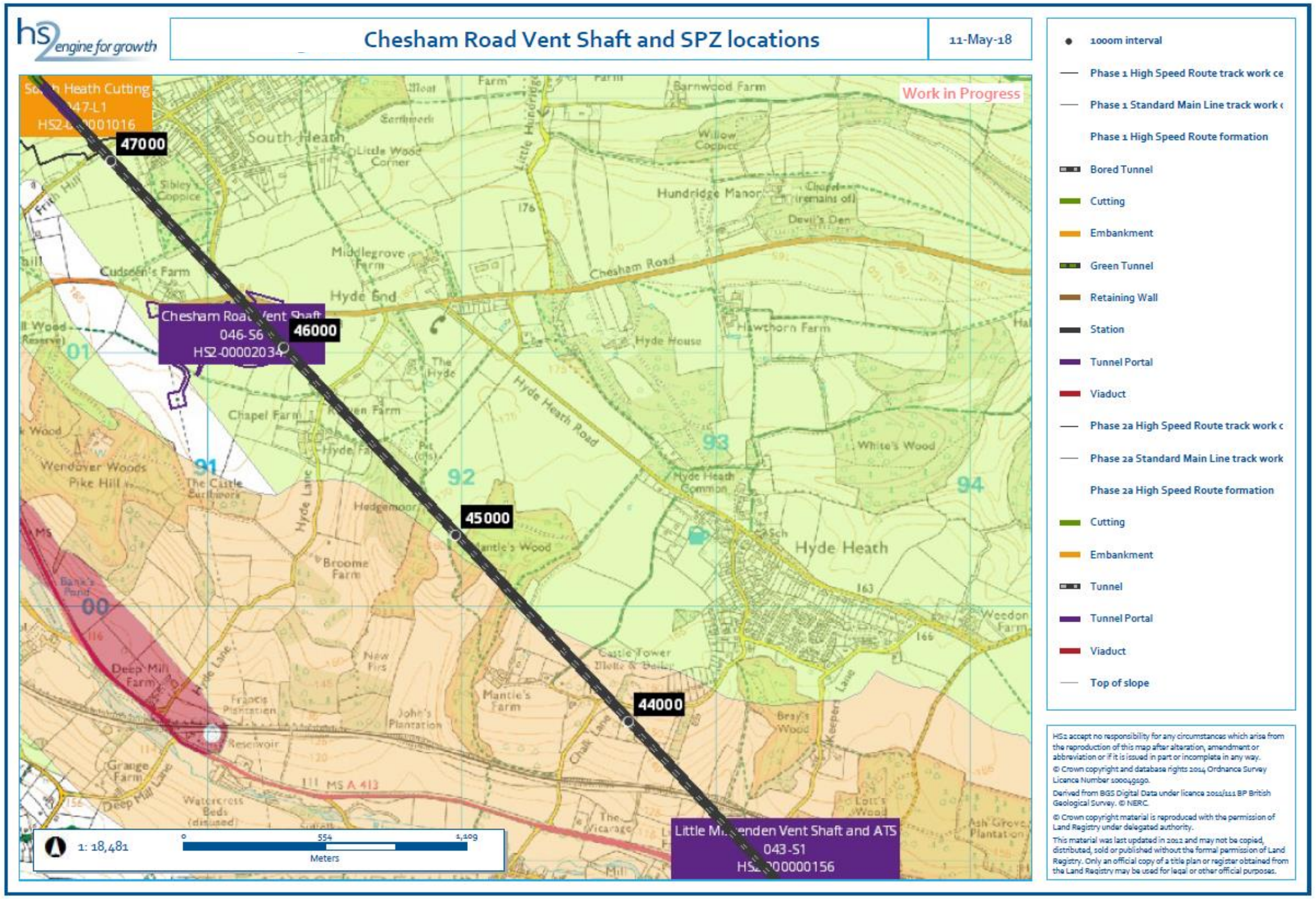
- [redacted] some 300m to the north west of the shaft location to a depth of 51m below ground level (134m AOD). The was dry during all 13 monitoring visits.

6.6.3 Groundwater is therefore at about 115 to 130m AOD at the shaft location. It is likely that water levels during very wet years will rise above this, but the potential for them to remain high for long periods of time is limited. As the tunnel and shaft will be sealed there will be no effects associated with the long term operation at the site even if water levels rise to the base of the shaft. Similarly, there will be no effect of the structure on groundwater flow or quality.

6.6.4 The River Misbourne in this area is at about 120mAOD, similar to the groundwater elevation, albeit that the groundwater level could fluctuate quite widely.

6.6.5 Given the above, and the fact that the shaft will not be constructed below the water table, the potential for an effect on any PWS, other abstraction or the River Misbourne is very low.

Figure 9 Chesham Road Vent Shaft and SPZ locations



6.7 Discussion

6.7.1 There is currently limited hydrogeological information at the location for each shaft, and only a small amount of information regarding the abstraction boreholes that are closest to the shafts. However, additional GI is proposed for 2018 / 2019 and this will include borehole drilling at the location of each shaft. The drilling will include rotary coring to a depth of about 70m (possibly more in some cases) and pumping tests at four shaft locations, with the abstracted water recharged to ground at bespoke boreholes. Water levels will be monitored using data loggers throughout the pumping tests. Of specific interest will be any holes that encounter solutionally enlarged voids. This notwithstanding, there is sufficient information available to assess the requirements for mitigation with an appropriate degree of certainty. The hydrogeological risk assessment and need for additional mitigation will be reviewed in light of the findings of the additional GI.

6.7.2 Based on the above assessment the risks to the Chalk aquifer, Affinity Water PWS, other abstractions and to the River Misbourne are summarised in Table 1.

Table 1 Summary of potential effects of shaft construction on groundwater and surface water receptors

Vent Shaft	Chalk Aquifer	PWS	Abstractions	River Misbourne
Chalfont St Peter	Likely localised effect	Very low	Very low	Very low
Chalfont St Giles	Likely localised effect	Low	n/a	Low
Amersham	Likely localised effect	Moderate	Low	Low
Little Missenden	Likely localised effect	Low to moderate	n/a	Moderate
Chesham Road	Very low	Very low	n/a	Very low

6.7.3 Based on this assessment, mitigation for the Chalk aquifer is not required. Mitigation for PWS's is not required during the construction of Chalfont St Peter, Chalfont St Giles, Little Missenden nor Chesham Road vent shafts, although monitoring will be required to confirm that there is no significant effect. This monitoring would be undertaken by Align at a series of monitoring boreholes along Section C1, as detailed in the Monitoring Position Statement[7]. At Amersham vent shaft there is a potential risk to [redacted] PWS from turbidity associated with chalk and potentially bentonite used in the d-walls, particularly if solutionally enlarged voids are encountered during excavation. Mitigation is therefore required.

6.7.4 The only shaft location where there is a risk to the River Misbourne greater than low is Little Missenden (moderate risk). The risks are associated with potential effects on water quality and flow rates. At the other shafts no significant effects are anticipated, although monitoring will be required to confirm this.

7 Mitigation and monitoring

7.1 Amersham Vent Shaft

7.1.1 Although the risks to Amersham vent shaft apply year round, the period of most concern to Affinity Water is the peak demand period between May and September (inclusive) as this is when demand is highest and the resilience in the supply system is lowest. Timing is therefore important in planning the construction works, although this largely applies to construction of the d-wall panels as after these are in place the potential to effect turbidity will be lower, although it could occur during drilling for grouting works outside of the shaft (e.g. at the location where the TBM will break into the shaft). At Amersham the construction of the d-wall could take around 18 weeks (although this is indicative at this stage) so it would be possible to complete all of these works outside of peak demand period, if programme allows.

7.1.2 The risk to the PWS is from turbidity, primarily from chalk, but also from bentonite used to support the d-walls during excavation. There is a potential for turbidity from concrete particles released as the TBM breaks through the shaft to also cause turbidity, but it is unlikely that these particles would migrate far and reach a PWS. Bentonite includes a number of naturally occurring clays with sodium bentonite and calcium bentonite being most widely used in industry. As clays, they have very fine particle sizes and so may not settle quickly and could migrate through fissures in the aquifer, depending upon flow rates and flow type. The bentonite has thixotropic properties such that it gels when left undisturbed but flows when it is agitated. The potential for significant migration in the aquifer is therefore limited, particularly away from rapid flow paths where groundwater flow is laminar.

7.1.3 In order to mitigate the effects of turbidity HS2 is funding the construction of turbidity treatment plants, one of which will be installed at [redacted] PWS. These plants have been designed to treat the anticipated chalk turbidity load based upon modelling work conducted by MWH[8]. These plants have been designed to treat chalk turbidity but will treat bentonite turbidity, although it is acknowledged that the efficiency of the plant will be less for this material. Even so, it is anticipated to be able to treat chalk and bentonite turbidity arising from d-wall construction and so further mitigation is not required.

7.1.4 During construction of the shaft there will be a requirement for groundwater pressure reduction by localised dewatering. Although this will not occur during d-wall construction, it will take place after construction and could act in a similar manner to a scavenger pump, removing turbid water. It is also possible that the abstraction to prevent uplift could be implemented earlier than needed to remove turbid water (i.e. acting as a scavenger well), although this is extremely unlikely to be required. The discharge route for any water removed during construction has not been confirmed, but ideally it would be to ground, but only if it is of a good enough quality, otherwise it might be treated and discharged to surface water, tankered off-site, or discharged to sewer if that is possible. Potential levels of turbidity cannot be predicted at this stage, but after completion of monitoring during the Load Test Piles and the pumping test at [redacted] we will be in a better position to estimate such levels.

7.2 Little Missenden Vent Shaft

7.2.1 The potential effect on water quality in the River Misbourne from shaft construction are associated with turbidity, primarily from chalk. However, as the river is not as sensitive to low levels of turbidity as the PWS, and there are no known discrete outflows points (springs or risings) into the river, groundwater movement to the river would be diffuse and subject to filtration through superficial deposits. This will help to mitigate the effect.

7.2.2 In addition to the above, as at Amersham localised dewatering will be required for pressure reduction beneath the grout plug. This dewatering could be implemented sooner than required if turbidity migration into the River Misbourne became a significant concern, as the dewatering would provide a degree of hydraulic containment (i.e. it would act as a scavenger well) and the water could be treated prior to discharge to remove turbidity. At this stage hydraulic containment is not deemed necessary.

7.2.3 The potential for a reduction in flow in the River Misbourne due to dewatering can be mitigated by either pumping the dewatering water to the Misbourne, or by recharging to ground down gradient of the shaft and up gradient of the Misbourne. The water may require treatment first in order to reduce suspended solids / turbidity but this should be relatively straightforward using standard techniques.

7.2.4 The potential for effects on the River Misbourne will be dependent upon climatic conditions and whether the area is experiencing "drought" conditions as this will affect flows in the river. However, with the mitigation outlined above, there is unlikely to be a significant effect on the river. Any effect that does occur will be reversible and short term as d-wall construction at the Little Missenden vent shaft could take around 18 weeks (although this is indicative at this stage). Effects during winter are likely to be less significant than those during summer.

7.3 Monitoring

7.3.1 Monitoring will be required at a number of locations, including down gradient of all of the shafts to check that the findings of this report are valid, and if not, to allow additional mitigation to be implemented. The monitoring requirements are not detailed in this report as they are included in a separate monitoring position statement[7].

8 Conclusions

8.1.1 The potential effects of shaft construction on groundwater abstractions and surface water quality and flow are unlikely to be significant at Chalfont St Giles, Chalfont St Peter and Chesham Road vent shafts. There is a potential risk to [redacted] PWS from Amersham vent shaft but through monitoring and appropriate mitigation the effect can be reduced to not significant. There is also a potential risk to the River Misbourne at Little Missenden, but again the significance of the effect can be reduced by monitoring and appropriate mitigation. This notwithstanding, an extensive monitoring programme is proposed to check the effects of all shaft construction on groundwater and surface water receptors, and if impacts are identified additional mitigation would be considered.