DEEPENING OF TORR QUARRY: ASSESSING THE HYDROGEOLOGICAL IMPACTS

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Abstract

Torr is a rail linked limestone quarry in the Mendip Hills which extracts up to 6 million tonnes of rock per annum, predominantly from beneath the water table. The depth of the quarry will be increased by 115m to 3m AOD releasing 115Mt of saleable reserves in the process. This will require further and prolonged dewatering of a principal aquifer that provides baseflow to rivers and is used locally for abstraction. SKM has completed a hydrogeological impact assessment as part of an Environmental Impact Assessment in support of a planning application which has recently been approved by Somerset County Council subject to a S106 agreement. Planning consent for deepening the quarry was granted in August 2012.

The limestone at Torr is heterogeneous due to the presence of joints, faulting, neptunian dykes and karstification. These, and the surrounding geological units, have resulted in a complex hydrogeological scenario in which permeability can range over many orders of magnitude; from very high flow through conduits and well connected fractures and fissures through to areas of rock with no appreciable permeability and limited groundwater movement. This paper outlines the approach taken to assess the potential impact on local abstractions and the groundwater resource itself. A conceptual hydrogeological model for the aquifer is presented and the method used for the impact assessment is discussed along with the monitoring requirements and options for mitigation of impacts.

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Introduction

Aggregate Industries extract Carboniferous Limestone at Torr Quarry, which is located at the eastern extent of the Mendip Hills, in southern England between the towns of Shepton Mallet and Frome (Figure 1). There has been a quarry (originally known as Merehead Quarry) at this location since the 19th Century, although it is only in the last 50 years that the volume of rock extracted has become substantial; currently some 4 to 5 million tonnes per annum. Some three quarters of this rock is now moved by rail as the site has had a dedicated mineral line since 1971 that joins the site to the UK's rail network.

The quarry was originally restricted to above water table operations, but in 1986 planning permission was granted for working just below the winter water table (at c.147m AOD) with subsequent permissions extending the lateral quarry area. In 2000, permission was granted to deepen the site to 115m AOD, over 30m below the water table. Commensurate with this was an agreed monitoring regime and an extensive water management system that included the construction of the 425 Million Litres Wellington Farm augmentation reservoir to the south of the quarry (Figure 1).

In 2010, a planning application was made to further deepen the quarry by seven c.16m levels down to +3m AOD. As this was wholly below the water table there was the potential for impacting the water environment and so a hydrogeological impact assessment was completed as part of the EIA (Environmental Impact Assessment) in support of the planning application. This paper details the scope and findings of the assessment and the methods used.

Site Setting

Torr Quarry lies in the Mendip Hills to the east of Beacon Hill which rises to an elevation of 285m AOD and then falls gently over 1.5km to c.180 to 220m AOD at the western edge of the quarry.

The Mendip Hills comprise four en echelon periclines which form a mature karstified upstanding plateau in the west, but in the east around Torr Quarry, the relief is lower and the limestone is less well karstified. The periclines have cores comprising Devonian Old Red Sandstone and Silurian volcanics, overlain by the Carboniferous Limestone, the lowest unit of which comprise mudstones with interbedded limestones which form the Lower Limestone Shales (Figures 2 and 3). The Carboniferous Limestone at Torr, which is over 600m thick and dips at 30° to 40° to the south, comprises massive and well bedded, fine to coarse grained

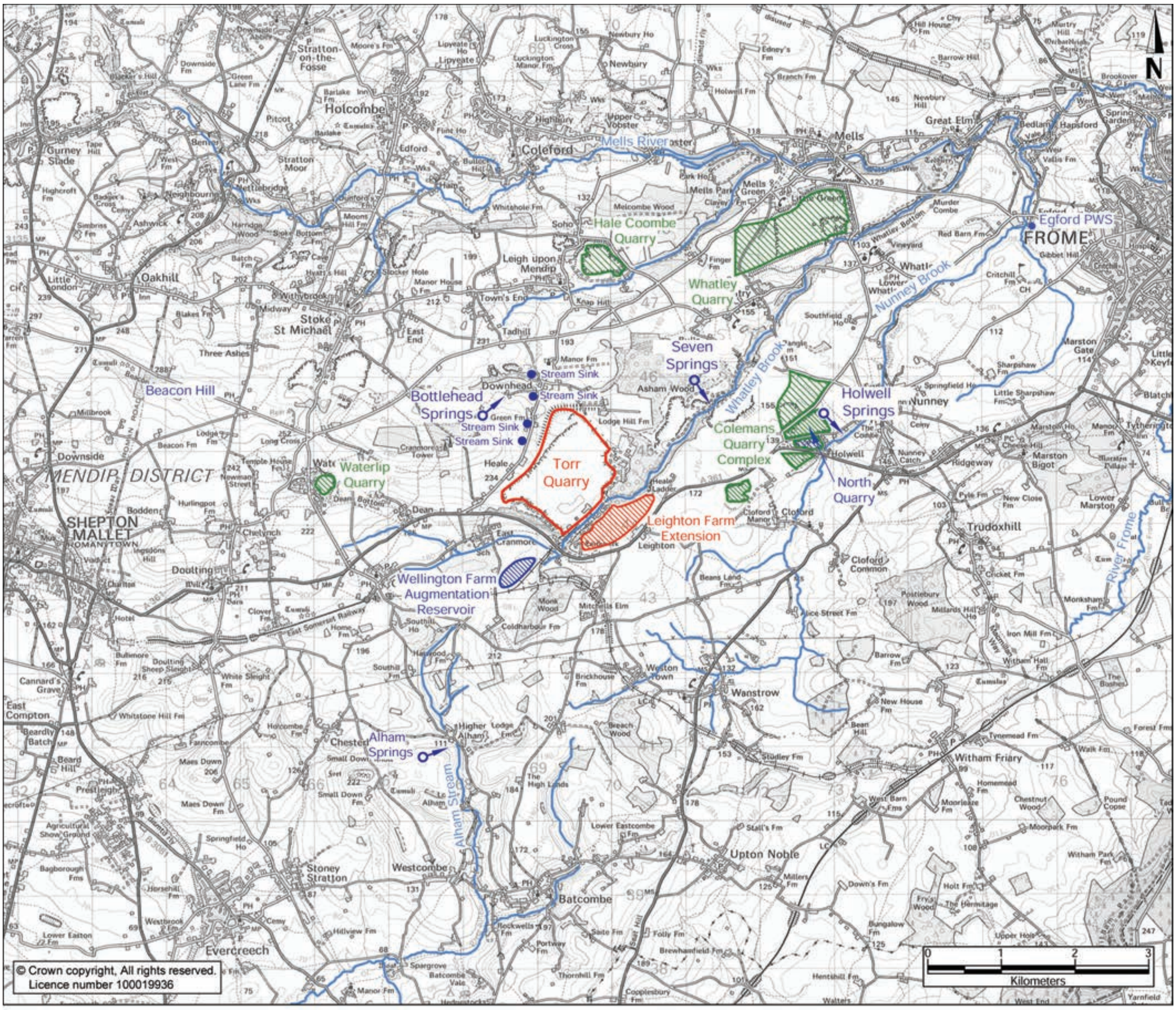

Figure 1. *Site location map showing local features, specifically; local quarries, watercourses, a reservoir, springs and stream sinks and Egford PWS (Public Water Supply) borehole.*

limestones of low primary porosity. To the east of Torr the limestones are unconformably overlain by the Jurassic Inferior Oolite, a massive, fissured coarse bioclastic and ooidal limestone some 15m thick. This is in hydraulic continuity with the Carboniferous Limestone and dips very gently to the east. To the south the limestones are dominantly overlain by Jurassic clays, whilst to the west and north they are underlain by the Old Red Sandstone which forms the core of the Beacon Hill pericline, the eastern most of the Mendip periclines. On the northern side of the pericline the limestones outcrop again, although the strata dip more steeply than at Torr. This limestone is extracted at several locations including Whatley and Halecombe quarries (Figure 1).

There are a number of faults around the quarry (Figure 2), three of which play an important role in the hydrogeology of the area:

- To the west is the Downhead Fault;
- To the south west is the Cranmore Fault; and
- To the south east is the Leighton Fault.

Conceptual Hydrogeological Model

Recharge

The majority of the recharge to the aquifer comprises dispersed rainfall over the limestone outcrop, with annual rainfall totals being some 1,100mm, of which some 550mm is effective rainfall (i.e. after evapotranspiration over grass), although these values do vary quite markedly with more rainfall over the higher ground to the west of the quarry, than to the east.

Concentrated recharge to the limestone takes place at a series of discrete stream sinks located along the Downhead Fault (Figure 1). Water emerges from springs in the Old Red Sandstone on Beacon Hill and flows eastwards until it reaches the Carboniferous Limestone where it sinks into a series of swallow holes (locally known as slockers), including Downhead Swallet, Dairyhouse Slocker, Bottlehead Slocker and Heale Slocker.

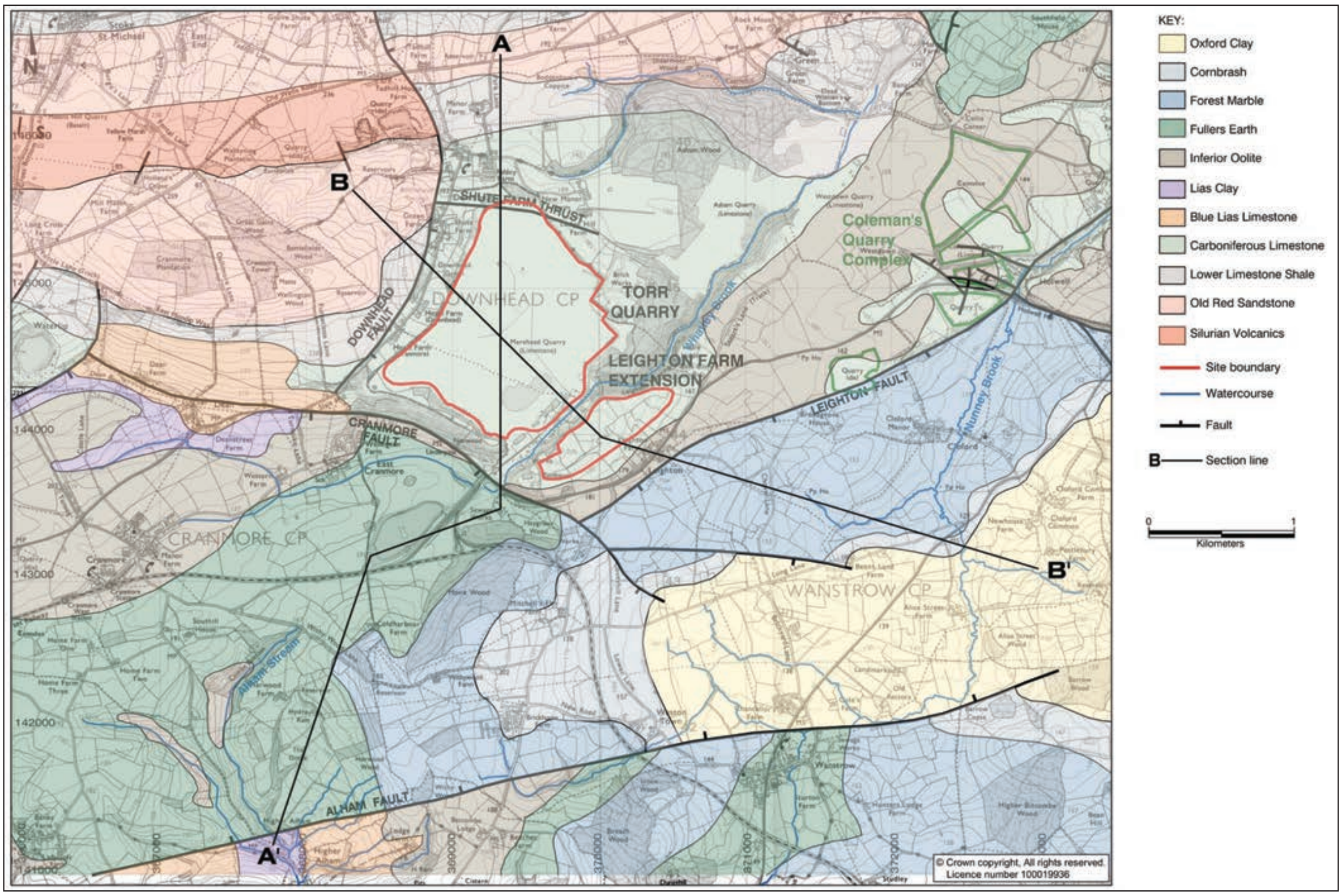

Figure 2. *Geological situation, at and around Torr Quarry (British Geological Survey, 2000).*

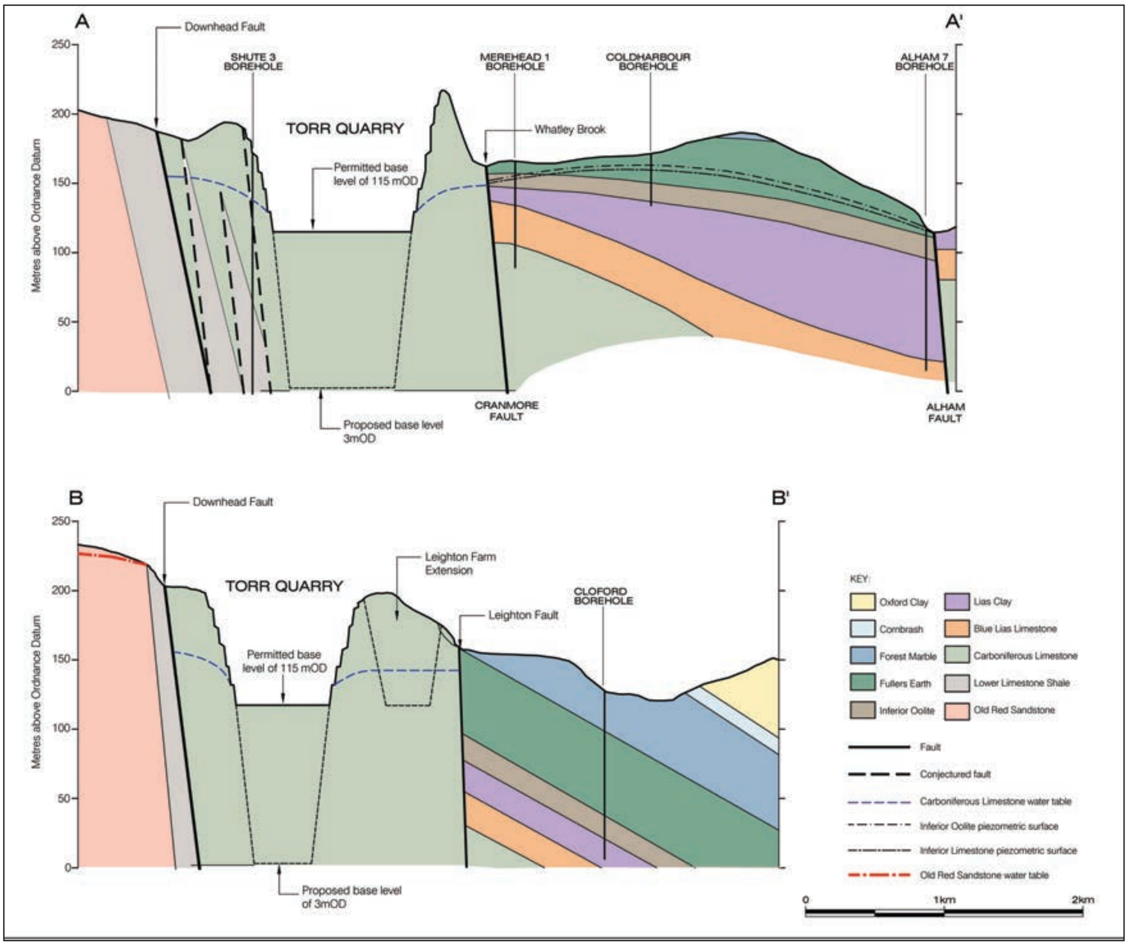

Figure 3. *Geological cross sections through Torr Quarry. Cross section positions shown on Figure 2.*

Flow

The flow mechanism at Torr is variable with the stream sinks largely flowing via well defined conduits to risings at Seven Springs (Figure 1) with groundwater velocities of hundreds to low thousands of metres per day (Smart, Hobbs and Edwards, 1991). The limestone in this part of the Mendips is not well karstified in comparison to that in the west and the dominant flow mechanism through the bulk of the limestone is diffuse flow. The typical hydraulic conductivity is c.0.1 to 1m/d, but ranging over four or five orders of magnitude (excluding the conduits) to provide a heterogeneous aquifer and one in which extremes of permeability can be seen over very short distances (Smart, Edwards and Hobbs, 1991).

The flow characteristics of the limestone vary quite markedly in the vertical plane as well as laterally. Although the hydraulic controls on groundwater discharge are formed by the springs in the area, it is well documented that conduit flow paths in particular can be present well below these discharge points. Active groundwater flow in the Mendip Hills typically occurs in the upper 50m of the aquifer, although in Torr Quarry, borehole drilling in the quarry floor indicated high permeability flow zones beneath this (below a depth of 50m AOD), albeit that these were very localised and only present in one site investigation borehole, confirming the heterogeneous nature of the aquifer at depth.

It is likely that the majority of flow in the aquifer at Torr takes place above 100m AOD, with the deep flow zones having little if any connection with surface watercourses. Part of the reason for this assertion is that groundwater movement at Torr is dominantly strike orientated such that there is no driver for deep active groundwater movement. In comparison, in the Central Mendips groundwater movement is down dip which has resulted in deeply looping conduits, such as that explored by cave divers at Wookey Hole.

Hydraulic testing to the east of Torr Quarry at the Colemans complex of quarries (Figure 1) indicated far less heterogeneity in the limestone, with a hydraulic conductivity range (based on a number of single borehole slug tests) from 0.04 to 0.7m/d and no known conduits associated with stream sink to spring connections.

Storage

Groundwater storage capacity in the Carboniferous Limestone is typically low with an effective porosity of c.1% or less, which is associated with solution features such as fractures and fissures. The water can be present in both the saturated and unsaturated zones, although in the unsaturated zone it tends to be limited to the upper part of the strata if there is a well developed epikarst, or sub-cutaneous zone. Where quarries are present, especially sub water table quarries, this storage will have locally been removed.

Although conduits play a very important role in water transmission through the limestone at Torr, they have little relevance for water storage. The total volume of these rapid transmission routes is relatively small in comparison to the aquifer as a whole, however, they may play an important role in recharging water into adjacent fissured rock, especially via the differential head recharge mechanism. This is most likely to occur during periods of heavy rainfall when the head in the conduit increases more quickly than that in the surrounding diffuse flow aquifer resulting in water movement from the conduit to the surrounding aquifer. When the differential head reverses water movement occurs from the diffuse zone to the conduit.

Aquifer classification

An aquifer classification system was devised by Hobbs and Gunn (1998) and subsequently utilised by the Environment Agency (2007) as part of their approach for assessing the hydrogeological impact of quarry dewatering. Based on the above assessment, the aquifer at Torr is likely to fall into Group 4, as an aquifer dominated by diffuse flow, high storage and variable recharge.

Potential Impacts Associated With Quarry Deepening

Deepening the quarry at Torr could extend the zone of groundwater impact beyond that currently observed and could increase the duration of any impact on the water environment. Identification of potential receptors is therefore critical.

Receptors of concern

The receptors of concern include the groundwater resource at and around the quarry, the surface watercourses that are fed by baseflow from the limestone and by discharge from Seven Springs. In addition, there are potential impacts associated with the discharge of water (abstracted for dewatering) to the Whatley Brook, but this paper just focuses on the groundwater assessment.

Groundwater

The Carboniferous Limestone is defined by the Environment Agency as a Principal Aquifer and the groundwater receptors comprise the water resource itself along with licensed and private / domestic abstractions. Although Torr Quarry does not sit within a Source Protection Zone, such a zone is present to the east of the quarry associated with the Egford Public Water Supply (PWS) which is operated by Bristol Water and which is located some 6km to the north east of Torr Quarry (Figure 1). There are two shallow wells associated with the supply, one of which is located on a former spring, and both are in the Inferior Oolite which as noted above, is in hydraulic continuity with the Carboniferous Limestone.

There are a large number of other licensed and private / domestic abstractions in the area which are used for agricultural and domestic uses. Groundwater sources utilised in the vicinity of the quarry are summarised in Table 1. In the case of the Secondary Aquifers (as defined by the Environment Agency), only those within 3km of the quarry are considered, whilst in the Principal Aquifers abstractions present up to some 6km distant have been considered.

Geological Unit	Source	No.	Uses	Max Licensed Rate (ML/annum)
Old Red Sandstone (ORS)	Springs rising from ORS	3	Farming, domestic, fish farm	200
Lower Limestone Shales	Borehole	1	Industrial	< licensing requirement
Carboniferous Limestone	Boreholes and springs	10	Industrial, farming, domestic	17
Inferior Oolite	Wells, borehole	5	Public water supply, farming	2000
Forest Marble	Spring, well	2	Brewing / farming	< licensing requirement
Fullers Earth	Springs	2	Farming, domestic	
Cornbrash	Spring	1	Farming, domestic	

Table 1. *Summary of Strata used for Groundwater Abstractions in the vicinity of Torr Quarry.*

Surface water

The three main watercourses around Torr Quarry and shown on Figure 1 are:

- Whatley Brook which runs immediately adjacent to the south eastern side of the quarry, and which is the receiving watercourse for the quarry dewatering discharge;
- Nunney Brook – to the east of the quarry; and
- Alham Stream – to the south.

There are several springs that flow into these watercourses as summarised in Table 2, but there are no groundwater dependent ecosystems with a statutory designation.

Bath hot springs rises from Carboniferous Limestone strata some 40km to the north of the quarry and concerns have been raised that their source is the Mendip Hills and that quarry dewatering could impact the springs, however, no impact has ever been proven and, given the distance of the quarry from the hot springs, and the geological structure, there is negligible likelihood of an impact on the hot springs and so they are not considered as receptors in this paper.

Impact assessment

Impacts to date

Monitoring of a substantial number of boreholes, wells, springs and watercourses around Torr Quarry, along with rainfall at two locations, has been undertaken since the 1980s and this forms a comprehensive baseline database. This information has been used to assess the impact of current dewatering from Torr Quarry upon the Carboniferous Limestone aquifer and upon adjacent rock strata. This monitoring shows a substantial impact on groundwater levels in the Carboniferous Limestone at and immediately adjacent to the quarry, but the zone of impact is relatively limited in lateral extent as summarised in Table 3.

With regard to conduit intersection, at least one concentrated inflow has been encountered in the quarry, but it is not clear if it is a conduit draining from Beacon Hill or a preferential flow zone. The conduit that takes the most flow from the Old Red Sandstone at Beacon Hill and which discharges at Seven Springs is located some distance to the north of the quarry and is unlikely to be intersected by quarry deepening.

Stream augmentation has been required to the Alham and Nunney Brooks, although this has been limited and is also affected by climatic conditions and other quarry discharges.

Geological Unit	Spring	Comments
Old Red Sandstone	Bottlehead Springs (and numerous small unnamed springs)	These form a stream which sinks into the Carboniferous Limestone at Downhead Swallet, and which then flows underground to Seven Springs
Carboniferous Limestone	Seven Springs	discharge directly to Whatley Brook
	Holwell Spring	discharge directly to Nunney Brook
Jurassic strata (mainly Fullers Earth)	Alham Springs and many other springs which feed the River Alham	A group of disparate springs which rise from Jurassic strata and form the headwaters of the River Alham

Table 2. *Springs in the vicinity of Torr Quarry (shown on Figure 1).*

Location	Rock Strata	Current Impact (m drawdown)
Quarry sump	Carboniferous Limestone	>50
West, 200m	Carboniferous Limestone	5
South, 200m	Carboniferous Limestone	10
North East, 500	Carboniferous Limestone	10
East, 1100m	Carboniferous Limestone	5-10
South, 500m	Inferior Oolite	5
South West, 500m	Inferior Oolite	None
South	Blue Lias	5-15

Table 3. *Summary of current (2010) groundwater impacts on strata at and around Torr Quarry.*

Predicted impacts

The hydrogeological assessment of the potential future quarry impacts has indicated the following:

a) Conduit Intersection

The aquifer is most permeable in the upper 50 to 60m below ground level. Although high permeability zones below this are known to be present, they are unlikely to be linked to surface watercourses and there are no spring discharge points thought to be linked to these. Evidence in the quarry indicates that there has been considerable infilling of solution features by Jurassic & Triassic sediments and it is likely that any deep high permeability zones have limited influence on the current hydrogeology.

Conduit intersection at depth is unlikely as the conduits are strike developed and so will tend to be in the upper 50 to 60m of aquifer, not "looping" down dip to depth as occurs elsewhere in the Mendips. The main conduit (Downhead to Seven Springs) is well to north of the quarry; it may be partially captured but not intercepted. There is some evidence of capture of other conduits from dye tracing but these are small and do not impact surface water (Whatley Brook), nor water levels in the Old Red Sandstone.

The potential for conduit intersection resulting in river backflow or extensive lateral dewatering is therefore assessed as very low.

b) Dewatering Rates

Dewatering at Torr Quarry has ranged from 4ML/d in the 1980s to 16ML/d seen in recent years, and these rates have formed the starting point for estimating future dewatering rates. The Dupuit-Forchheimer equation (Environment Agency, 2007) has been used to determine influx from various quarry faces (to take into account of variations of inflow from different directions). It has been suggested that the equation breaks down at quarry faces due to turbulent flow, but it gives an indication which is biased towards the worst case. Packer test data was used to estimate a typical permeability for each bench of the quarry for particular faces, but excluding the high inflow zone identified in one of the test holes. This is because it is anticipated (for reasons outlined above) that this would be uncharacteristic of the aquifer and would lead to overly high estimates of dewatering.

The groundwater influx was calculated for each bench and added to the effective rainfall over the quarry area to estimate the likely water influx, and therefore the likely dewatering rates that will be required in the future. The results are summarised in Table 4 along with measured dewatering rates during recent quarrying of Benches E and F. It must be noted that dewatering of each bench will not be a simple operation; dewatering may be required at multiple locations on different benches, and so the estimates are at best indicative. The methods used are steady state at the end of each complete quarry bench and assume no major conduit intersection that would cause backflow from Whatley Brook, and do not account for variations in climatic conditions from the average. Short term high volume pumping will be needed to accommodate sump construction and is also excluded.

c) Extent of the Zone of Impact

The extent of the zone of impact (i.e. where the reduction in water level or flow could be significant) has been estimated by a combination of qualitative and quantitative means as follows:

- Western direction: zone will extend to Downhead fault with some dewatering of the Old Red Sandstone, but this will be limited based on the very steep hydraulic gradient that exists across the fault;
- Northern direction: zone will extend to the Lower Limestone Shales, but no further as the permeability of the shales is very low (although some high permeability zones have developed but they are only local in extent);
- Eastern direction: zone will extend from 0.5km, possibly as far as 2km once the quarry reaches maximum depth (assuming steady state). At a distance of just greater than 2km is the Coleman's complex of quarries, also owned by Aggregate Industries and where sub water table working has previously taken place. Within this complex is the flooded North Quarry which has a water storage capacity of 500 to 750ML depending upon the season. Water in the quarry would recharge groundwater in the limestone if the zone of depression extended as far as this location and would provide mitigation against impacts extending further east (most critically towards the public water supply wells at Egford);
- Southern Direction: to the south east drawdown is limited by the Leighton Fault and Jurassic clays /

Bench and floor level (m AOD)	Average annual measured dewatering (ML/d)	Calculated average groundwater inflow to quarry (ML/d)	Effective rainfall over 1.6km^2 of quarry (ML/d)	Total estimated dewatering volume (ML/d)
E Bench 131	13.2	9.8	3.8	14
F Bench 115	14.8	10.5	3.8	14
G Bench 99		13.2	3.8	17
H Bench 83		16.0	3.8	20
I Bench 67		17.2	3.8	21
J Bench 51		18.2	3.8	22
K Bench 35		20.7	3.8	25
L Bench 19		22.5	3.8	26
M Bench 3		24.2	3.8	28

Table 4. *Recent and predicted dewatering rates at Torr Quarry.*

mudstones. To the south is the most significant uncertainty due to hydraulic continuity between the Carboniferous Limestone and the Blue Lias / Inferior Oolite aquifers. This could influence flow from springs to the River Alham (see the section below that discusses augmentation).

d) Impact Upon Water Supplies

Following the above estimate of the impact of quarry deepening on the water resource, specific receptors located in various quadrants around the quarry were assessed to determine what individual impacts could occur. This assessment confirmed that:

- Water supplies on the Old Red Sandstone, Lower Limestone Shales, Fuller's Earth Rock and Forest Marble are not at risk from dewatering due to their small size and limited connectivity to the Carboniferous Limestone;
- Water supplies from the Inferior Oolite to the south of the quarry are at minimal risk due to the geological structure in this area;
- Sources at risk in the Carboniferous Limestone include:
  - Waterlip Quarry: a flooded quarry to the west of Torr (Figure 1) used for submersible equipment testing. Annual fluctuations / changes in climate will have more effect on water levels than dewatering at Torr due to the limited connectivity between the two quarries (as evidenced by boreholes between the two locations);
  - Leighton Farm abstraction borehole: the base of the borehole is substantially below the current low water level and the additional likely drawdown due to dewatering and an impact on abstraction is not anticipated;
  - Westdown Farm Borehole: previously deepened due to the impact from Coleman's Quarry, although the cessation of dewatering and flooding of North Quarry will limit any future impact from Torr;
- Sources potentially at risk in the Blue Lias Limestone include Talbot Farm Borehole, although this is effectively redundant as the farmhouse is on mains supply;
- Sources at risk in the Inferior Oolite to east; the main supply of concern is the Egford public water supply. Torr Quarry is outside of the groundwater source protection zone set by the Environment Agency, but there are still some concerns from Bristol Water regarding the potential impact on the supply. Monitoring of the Carboniferous Limestone between Torr and Egford shows a relatively low permeability / homogeneous aquifer. Monitoring to date shows no impact this far east and flooding of North Quarry will mitigate any effects.

e) Stream Augmentation

When sub water table quarrying commenced at Torr Quarry, infrastructure was put in place to allow augmentation of the Whatley Brook, Nunney Brook and Alham Stream should it prove necessary. However, as the dewatering water from the quarry is pumped to the Whatley Brook, augmentation *per se* is not actually required. The augmentation at the other two locations was implemented by pumping water from a sump in the quarry floor to agreed locations, with the augmentation volume set at agreed rates of up 10L/s into the Alham Stream and up to 20L/s into the Nunney Brook. As quarry development progressed it was recognised that the augmentation resulted in over pumping to the streams such that flows were higher than would occur naturally if the quarry was not present. The augmentation requirements were therefore benchmarked against a control stream which helped to provide a more natural regime than had previously been the case. It was recognised that the use of an in-quarry augmentation sump only had a finite life as it compromised quarry operations as the pit deepened and so a 425ML off site reservoir has been constructed to allow augmentation without the need for an in quarry sump.

The impacts of quarry deepening on the need for augmentation are not likely to increase significantly and it is anticipated that the current reservoir will provide sufficient water during the life of the quarry. In addition, with the flooding of North Quarry, which is adjacent to the Nunney Brook, Aggregate Industries have a further source of augmentation water available if required.

f) Quarry Restoration

Post quarrying the excavation will be allowed to flood, although it could be some 20 years before equilibrium is reached (depending upon rainfall) and stream augmentation will be required during this period. Final water levels in the quarry lake will be less than the current situation on the western side of the quarry but similar to natural levels in the east, albeit annual variations will be substantially damped, in and immediately around the quarry. Pre-quarry dewatering water levels were 145 to 170m AOD, post quarry they are likely to be c.145 to 148m AOD.

The higher (i.e. 170m AOD) water levels pre-quarrying were on the western side of the quarry towards the Downhead Fault which is at the contact of the Old Red Sandstone and the Carboniferous Limestone. As this fault has relatively low permeability this long term reduction in water level on the western side of the limestone is unlikely to have a significant effect on water supplies from the Old Red Sandstone.

Monitoring And Mitigation

Aggregate Industries has designed and implemented a comprehensive monitoring scheme to provide baseline information that has been used for the impact assessment outlined above. The monitoring will continue during stone extraction in order to verify the predictions and so that the need for any further mitigation can be identified. The monitoring includes:

- Rainfall at two gauges;
- Water level in 16 water supply boreholes and springs;
- Water level measurement at 22 monitoring boreholes;
- River flows at seven locations using purpose constructed weirs; and
- Water quality monitoring of the Whately Brook, Nunney Brook and Alham Stream.

Mitigating activities include:

- Augmentation of surface water flows as required;
- Provision of alternate water supplies and deepening of water supply wells as required; and
- If the groundwater impacts extend further to the east than currently predicted, then there is also an option of implementing artificial recharge of the limestone aquifer via North Quarry.

Conclusions

A comprehensive impact assessment was completed as part of a proposed increase in the depth of Torr Quarry of over 100m, all of which will be sub water table. A conceptual hydrogeological model was developed and used to complete an impact assessment for the water environment which concluded that:

- It is unlikely that the main conduit linked to Seven Springs would be significantly impacted;
- The dewatering rate at depth is likely to be of the order of 25 to 30ML/d;
- The extent of the zone of impact will be limited in northern and western directions by the geological strata and structure, whilst to the east it could extend to between 0.5 and 2km. To the south there is a greater degree of uncertainty, but localised impacts could occur;
- There will be limited impacts, if any, on existing groundwater supplies around the quarry;
- Augmentation of surface watercourses will be required seasonally, but there is sufficient capacity to accommodate this in the system at the quarry; and
- Post quarry closure it is anticipated that water levels in the east will recover to close to the pre-quarry levels, but in the west they will remain much lower.

A monitoring and mitigation plan is in place to manage these impacts.

Acknowledgements

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