A303 Amesbury to Berwick Down

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Deadline 3
8.23 – Implications of 2018 Ground Investigations to the Groundwater Risk Assessment

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Implications of 2018 Ground Investigations to the Groundwater Risk Assessment Groundwater Risk Assessment

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1 Introduction

1.1.1 The groundwater aspects of the Environmental Statement (ES) comprised a Groundwater Risk Assessment (GRA) appendix (Highways England, October 2018. A303 Amesbury to Berwick Down TR010025. 6.3 Environmental Statement Appendices. Appendix 11.4 Groundwater Risk Assessment [APP-282]) which drew on findings from groundwater model scenarios presented in its Annex 1.

1.1.2 Concurrent with the development of the ES, additional ground investigations were conducted between June and September 2018 to provide more localised data for design purposes. The investigations consisted of geotechnical boreholes drilled along the tunnel alignment. At locations in Stonehenge Bottom valley and on the interfluves west (Stonehenge Down) and east (Coneybury Hill) of Stonehenge Bottom valley, new boreholes were drilled and pumping tests were undertaken.

1.1.3 The results and interpretation of the pumping tests are presented in the Stonehenge Area Pumping Test 2018 Interpretative Report (HE551506-AMW-EWE-SW-GN-000-ZZ-RP-EN-0001 [AS-016]).

1.1.4 This report provides the formal assessment of the findings of the site investigations and pumping tests with regard to the assumptions made in the GRA.

2 Previous Findings

2.1 Reports and Information Available

2.1.1 Geological information in previous site investigation reports was reviewed in order to evaluate whether there was evidence for the presence of preferential flow horizons within the Chalk strata. Information reviewed from all previous site investigation reports consisted of lithological interpretations; geotechnical log CIRIA grading (reflecting fracture frequency and openness); geophysical tests identifying flow horizons; and, packer tests calculating hydraulic conductivity in discrete vertical bands.

2.1.2 Those reports with relevant information were:

- WJ Groundwater Ltd, 2003. A303 Stonehenge Improvements. Pumping Test Factual Report. A303 Stonehenge Improvements. Balfour Beatty Major Projects.
- Mott MacDonald, 2001. A303 Stonehenge Geotechnical Interpretative Report for the Preliminary Investigation and Phase 1 of Main Ground Investigation.
- Pelorus, 2004. A303 Stonehenge Improvement Factual Report on Geophysical Investigation.
- Halcrow-Gifford, 2005. A303 Stonehenge Improvement. Geophysical Field Trials: Interpretative Report.
- Halcrow-Gifford, 2003. Phase 1A Supplementary Ground Investigation for A303 Stonehenge Improvement.
- Halcrow-Gifford, 2004. A303 Stonehenge Improvement. Geotechnical baseline for Tunnel Design.

2.2 Phosphatic Chalk

2.2.1 Previous investigations logged the presence of Phosphatic Chalk. In terms of permeability, the description of this unit includes that it may have conduits for enhanced flows in ‘voidage’ areas but these may be infilled by low permeability silt.

2.2.2 The Phosphatic Chalk was described as a poorly sorted gravelly material, lending itself to a lower permeability gravel compared to a well sorted deposit. That is, poorly sorted deposits mean that different sized particles are able to fit inside the gaps left between larger particles, thus reducing or closing the pore space through which groundwater could flow. In a well sorted deposit, all the particles are of similar shape and size which means that the pore spaces between them remain open, facilitating groundwater flow.

2.2.3 Therefore there is no strong evidence that the Phosphatic Chalk could form a preferential flow horizon. The presence of voids may enhance groundwater flow while silty infill and poorly sorted gravelly infill may reduce the local permeability. While Balfour Beatty-Costain-Halcrow Gifford (2006) described voids being observed, the geological description indicates that open voids are not likely to be laterally extensive or connected to form a significant flow horizon.

2.3 CIRIA Grading

2.3.1 CIRIA grading does not follow a pattern with depth or spatially along the alignment. Gradings are mostly B or C meaning fractures greater than 3 mm aperture or less than 3mm aperture respectively, and 2 or 3 (e.g. B2 to C3); meaning fractures are at close or medium spacing, 60-200mm and 200-600mm apart. There are some intervals of A grading, meaning closed or tight fractures that may indicate layers of lower permeability, but these are not persistent between boreholes

2.3.2 Overall the Chalk rock mass to a depth of approximately 50m aOD appears relatively uniform in the sense that it is a series of mostly C3, C2, B3, B2 types with occasional A3 types, and rarely other grades, with no clear stratification of fracture spacing or aperture. Therefore there is no evidence for a laterally extensive high permeability horizon based on the CIRIA grading in the Chalk across the tunnel alignment.

2.4 Packer Testing

2.4.1 Packer testing involves isolating intervals of a borehole and pumping water into the aquifer and enables a calculation of the permeability in that horizon only. A series of packer tests are available across much of the vertical profile in the numerous boreholes constructed along the alignment. The packer tests results have been considered in understanding the nature of the aquifer in the area but the design of the packer tests has not been reviewed.

2.4.2 The packer tests show no clear pattern with higher and lower hydraulic conductivity zones interspersed vertically and not repeated laterally. These results do not align clearly with the CIRIA grading, that is higher hydraulic conductivity and lower hydraulic conductivity test results do not neatly align with a high frequency open fracture rock type for a high hydraulic conductivity calculation, or with a closed fracture, wide fracture spacing rock type for a low hydraulic conductivity.

2.5 Downhole Geophysics

2.5.1 Geophysical tests are available for several boreholes extending to the proposed elevation of the tunnel including caliper, flow velocity, gamma, salinity and temperature surveys.

2.5.2 Most of these traces show little variation over the vertical profile with anomalies generally seen as small bumps covering a short vertical extent. These are inferred to not be significant flow horizons compared with the larger caliper anomalies which are inferred to be potential preferential flow horizons. However it is not confirmed that such fractures are significant flow conduits.

2.5.3 In the Stonehenge Bottom valley area flow velocity tests during the pumping tests in boreholes W137 and W148 recorded a significant increase in flow between 69 and 73m aOD. The most marked change is in Stonehenge Bottom valley (W148), with a more gradual increase on the interfluve test (W137). In the interpretation it was considered that the bulk of the flow in the pumping tests was coming from this horizon.

2.5.4 The conclusion from the geophysical information is that there may be preferential groundwater flow in a zone from 69-73m aOD that is active in Stonehenge Bottom valley, valley side and near-interfluve areas only, with the fracture network created in the dry valley environment extending only a limited distance outside the valley area.

2.5.5 The 69-73m aOD horizon correlates with the zone of water table fluctuation where the aquifer is desaturated and re-saturated seasonally, it is within the average low and high water levels, and therefore it is plausible hydrogeologically that the flow velocity test reflects a zone of fracturing and enhanced flow.

2.6 Pumping Tests

2.6.1 Pumping tests were conducted on two boreholes close to the route alignment in 2002 (winter) and 2004 (summer)– borehole W148 in Stonehenge Bottom valley and borehole W137 about 650 m west of Stonehenge Bottom at Stonehenge Down interfluve (WJ Groundwater, 2003 and 2004).

2.6.2 Groundwater levels at W148 and W137 were 76.0m aOD and 80.0m aOD respectively at the start of the pumping test on W148 on 4 December 2002. The groundwater level at both boreholes was approximately 66.0m aOD for the September 2004 test. Transmissivities of 1,430 - 2,650m2/d for the dry valley, and 400 – 850m2/d in the interfluve are quoted, with the lower values reported in the summer.

2.6.3 In both tests the transmissivity at W148 was about three times that measured in W137. This supports the concept that the transmissivity of the Chalk aquifer is typically greater beneath dry valleys compared to interfluve zones where enhanced development of fissuring within the Chalk beneath dry valleys results in preferential groundwater flow zones.

2.6.4 Falling head tests in investigation boreholes in the Coneybury Hill area showed lower hydraulic conductivities, where previous studies (Balfour Beatty-Costain-Halcrow Gifford, 2006) inferred that this interfluve was an effective barrier to groundwater flow between Stonehenge Bottom and the River Avon.

2.6.5 Each pumping test yielded a range of transmissivities from the data from the observation boreholes which were generally up to 200m away, indicating that there was spatial heterogeneity in the aquifer.

3 2018 Investigation Findings

3.1 Packer Tests

3.1.1 Successful packer tests were conducted on boreholes R619 in Stonehenge Bottom valley, approximately 50m west of W148; and R607 on the Stonehenge Down interfluve, approximately 150m east of W137.

3.1.2 In R619 intervals tested were below 40m aOD where high permeability was noted as pressure could not be maintained in the borehole. Tests were not conducted across the full profile to compare different elevations but this result indicates that preferential flow horizons are not confined to the 69-73m aOD interval.

3.1.3 In R607 the 66-70m aOD section was tested as well as at greater depth. This horizon has higher permeability than deeper horizons with water lost faster than it could be measured. Below 66-70m aOD, testing found variable permeability with no clear vertical trend, some deeper zones have a higher permeability than upper zones. The permeability values were low when there were no caliper anomalies but the size of the caliper anomaly does not correlate with the permeability measured.

3.1.4 Borehole R624 on Coneybury Hill also recorded high permeability values where test pressure could not be maintained due to water loss to the aquifer from 58-65m aOD. Tests at other depths were not conducted. This indicates that the aquifer at Coneybury Hill can accommodate flow, while previous studies (Balfour Beatty-Costain-Halcrow Gifford, 2006) suggested that it may act as a low permeability barrier to groundwater flow.

3.2 Downhole Geophysics

Fracture Sets

3.2.1 Caliper, downhole camera, and electrical conductivity logging was conducted in the new boreholes along the tunnel alignment.

3.2.2 The logs do not show a consistent fracture set running east west from the 69-73m aOD that was identified in the previous pumping tests' (W148 & W137) flow velocity logs. There are various fractures situated above and below this horizon indicating that there may be groundwater flow paths across a large vertical profile.

3.2.3 Along the east-west alignment a caliper anomaly in the 69-73m aOD range appears to be present in borehole R618 40m west of W148, but not in borehole R620 40m west of R618. Then further west there is a caliper anomaly in the 69-73m aOD range in borehole R615 but not in borehole R613 continuing west. It is then again present further west in boreholes R612 and R609, but not in W601, approximately 140m east of W137. Boreholes R607 and R608 approximately 100m east of W137 contain caliper anomalies in the 69-73m aOD range, and borehole R602 approximately 100m east of W137 contains a caliper anomaly at 69.5m aOD only.

3.2.4 The boreholes with a similar vertical extent (in the order of 4m) of caliper anomaly to W148 are R618 (approximately 40m west of W148) with a caliper anomaly from 67-70.5m aOD, and R615 (approximately 200m west of W148) with a caliper anomaly from 69-73m aOD. All other boreholes with an anomaly in this range tend to be in part of the 69-73m aOD only (e.g. 1-2m in extent). Note at these sites anomalies are also present at other elevations outside this range.

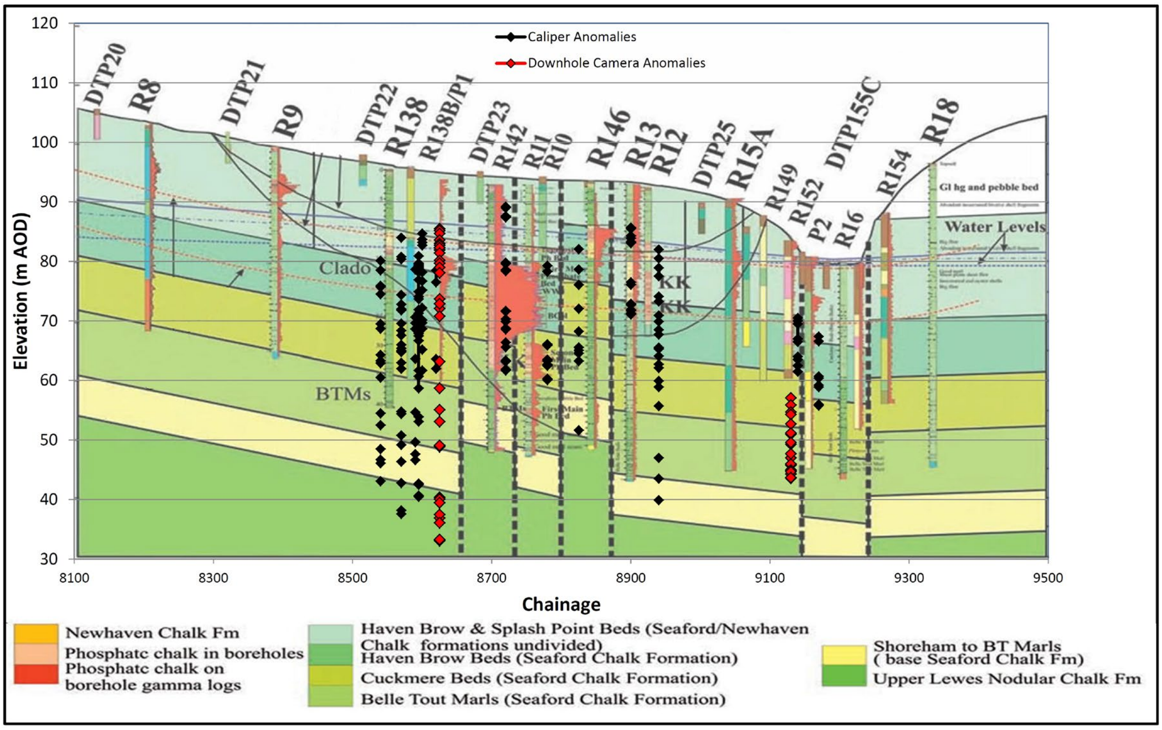
3.2.5 The downhole camera found that fracturing in the 69-73m aOD range is absent in W601 and W617, situated in Stonehenge Down and Stonehenge Bottom valley respectively. It is present at 69m aOD in W623 on Coneybury Hill. Numerous fractures are identified in the downhole camera logs above and below the 69-73m aOD range.

3.2.6 These results tend to support that a fracture zone is present in Stonehenge Bottom valley in line with W148 results, but that this new density of data indicates it is not persistent in an east west band from valley to valley side and interfluve at Stonehenge Down, being less prominent even on the western side of Stonehenge Bottom valley compared to the east near W148. It is also not vertically persistent with most locations with anomalies between 69-73m aOD containing 1-2m of fracturing.

3.2.7 The caliper and downhole camera logs indicate that fracture sets are not concentrated in a particular part of the aquifer profile, and there is no obvious pattern of increasing fracture frequency with elevation.

3.2.8 Figure 1 shows the position of the fracture anomalies against the stratigraphic profile from Mortimore (2012).

Figure 1 Fracture Locations Inferred from Caliper and Downhole Camera Logs



3.2.9 A table of the location and depth of caliper anomalies is included at Appendix 1. A table of the location and depth of fractures identified in the downhole camera log is included at Appendix 2.

Stratigraphic Horizons

3.2.10 The inferred elevations of the Chalk Rock and Whitway Rock (if present) have been added to the geological section (Mortimore, 2012) to show the context of the tunnel alignment. The geological section from 2012 does not extend to sufficient depth as it was based on the ground investigation boreholes. The section has been extended to the top of the Lewes Nodular Chalk in order to map the possible location of the Chalk Rock.

3.2.11 The Chalk Rock elevation has been inferred based on geological mapping and cross sections produced in the area as part of the Bourne and Nine Mile Study (EA, 2001, EA, 2004). This study identified the Lewes Nodular Chalk having a consistent thickness of approximately 35m and the Chalk Rock was mapped as being approximately 10m above the base of the Lewes Nodular Chalk.

3.2.12 The Whitway Rock is another potential flow horizon found within the Seaford Chalk. However this unit has not been identified from previous ground investigations in this area (Mortimore, 2012). The British Geological Survey also indicated (as part of discussions for the Bourne and Nine Mile Study) that this hard rock horizon may disappear lithologically moving southwards to the edge of the basin that formed the hard rock bands. If this is also the case to the west then the Whitway Rock may not be present in the study area.

3.2.13 The range within which the Whitway Rock would be anticipated in the geological sequence is given in Figure 2. If present, the Whitway Rock would be above the tunnel elevation zone and typical water table elevations across parts of the tunnel alignment. Fracture mapping from the ground investigation boreholes indicates the presence of fractures in this zone, though fractures are also present above and below this zone. This suggests groundwater flow may not be constrained to flow through a limited fracture horizon.

3.2.14 The inferred elevation of the Chalk Rock has been added to the geological sections along the tunnel alignment from Mortimore (2012) to compare with the tunnel elevation. This shows that the inferred elevation of the Chalk Rock is likely to be at significant depth below the tunnel (Figure 2). The Whitway Rock has also been added to the section (although not proven in this area) to indicate where it may be situated if present, based on being mapped at 28m to 36m above the base of the Seaford Chalk in the Bourne and Nine Mile Study (EA, 2001, EA, 2004).

3.2.15 Stratigraphic mapping placed the Stonehenge area chalks into the overall Chalk stratigraphy at an elevation above the Chalk Rock (Figure 3), entirely within the Seaford Chalk and Newhaven Chalk (Mortimore, 2017).

3.2.16 Therefore it is considered that the fracture sets and potential flow horizons identified in the ground investigations do not represent known important flow horizons such as the Chalk Rock. These fractures are located in the postulated area of the Whitway Rock but it is not known if this hard ground is present. Fractures are present over a large vertical extent and not restricted to specific horizons.

Figure 2 Chalk Stratigraphy with Tunnel and Chalk Rock Elevations (adapted from Mortimore (2012))

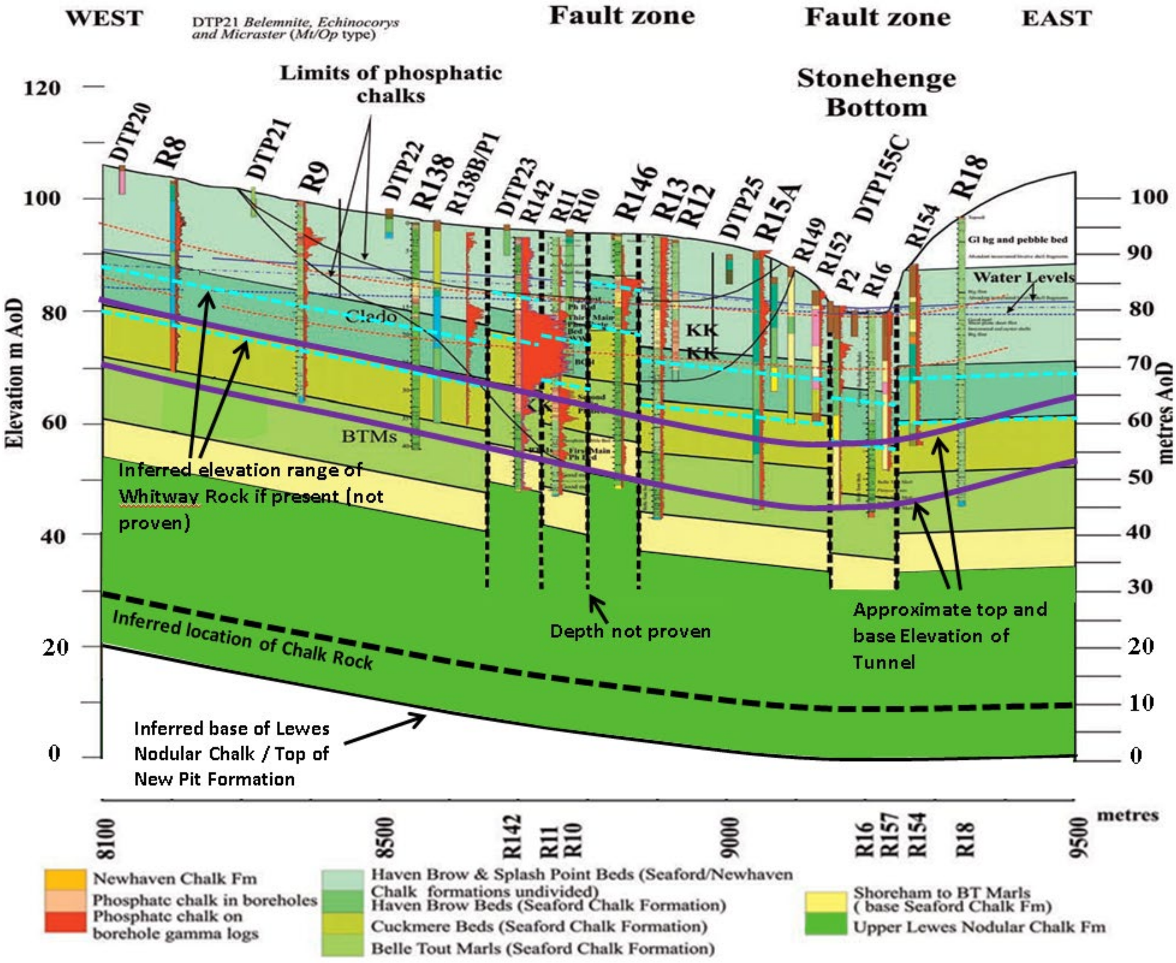
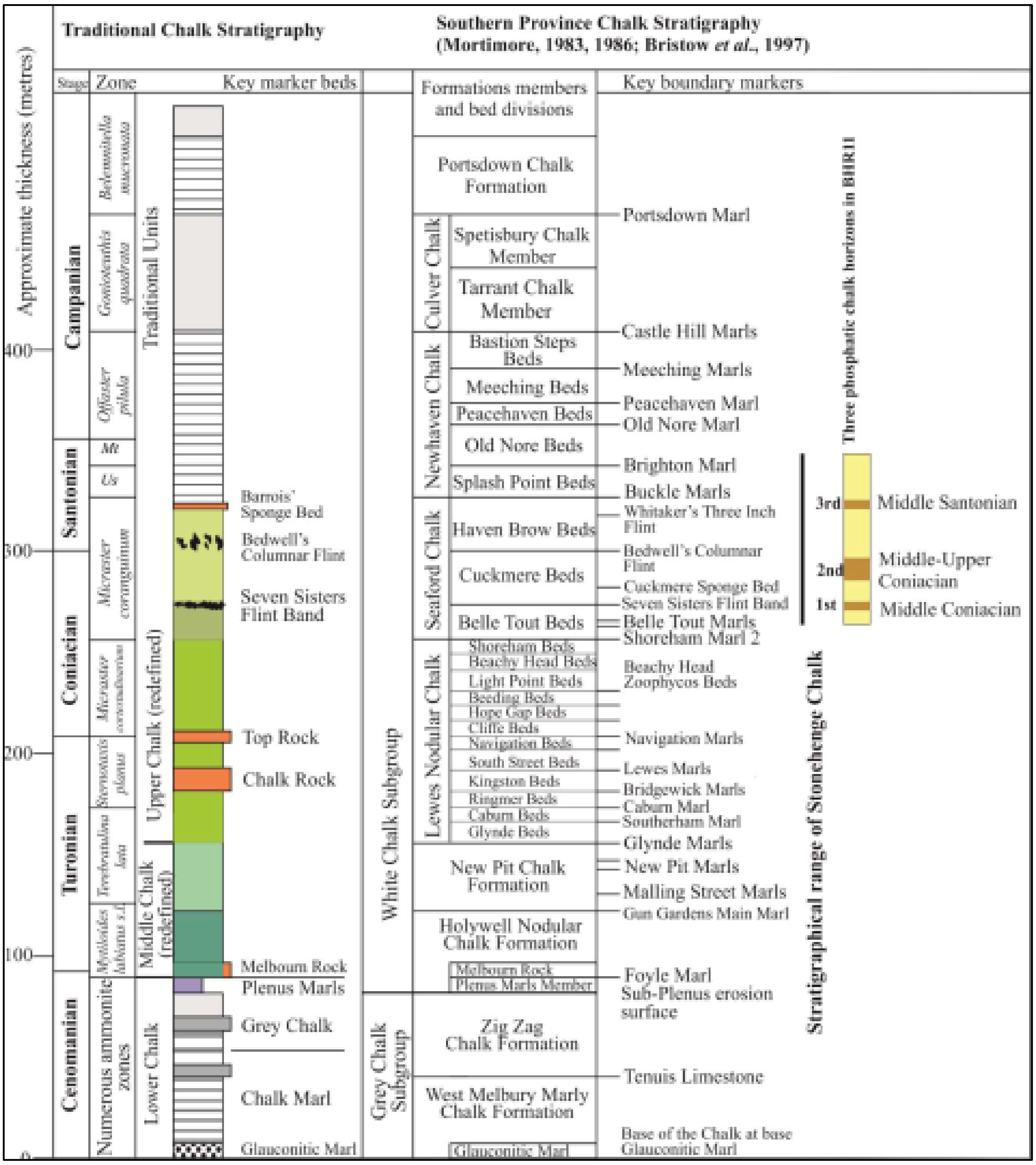


Figure 3 Chalk Stratigraphy and Stonehenge chalks (from Mortimore (2017))



3.3 Electrical Conductivity

3.3.1 Electrical conductivity was measured down hole in boreholes R620, W601, and R613. These are located in Stonehenge Bottom valley, in Stonehenge Down near W137, and an intermediate location respectively.

3.3.2 Little variation in electrical conductivity was recorded so no prominent inflow horizons could be detected.

3.4 Pumping Tests

3.4.1 Three pumping tests were conducted in June and July 2018. At pumped well W617 in Stonehenge Bottom valley, approximately 75m west of W148, which is at the western margin of the dry valley compared to the previous test on the eastern side of the dry valley.

3.4.2 At pumped well W623 on Coneybury Hill, the test was to confirm whether or not the conclusion from previous investigations that this interfluve is a low permeability area potentially impeding groundwater flow to the River Avon is valid.

3.4.3 Pumped well W601 on Stonehenge Down was approximately 100m east of W137 where the previous Stonehenge Down pumping test was conducted.

Coneybury Hill

3.4.4 Six observation boreholes were drilled around the Coneybury Hill pumped well W623, at distances from 7.7m to 102.6m from the pumped well. Drawdown at these observation boreholes at the end of the 7 day pumping test reached a maximum of approximately 2.2m, and were relatively stable at this point without any significant ongoing declining trend.

3.4.5 Calculated transmissivities from each of the observation boreholes ranged between 388m2/d and 615m2/d. However the transmissivity calculated from borehole R628 was 1617m2/d, potentially indicating a recharge barrier, higher transmissivity, or high flow zone to the east. The distance drawdown analysis also gave a higher result of 928m2/d.

3.4.6 Storage coefficients ranged from 0.0002 to 0.0074. The high value of 0.0074 corresponds to the location of high transmissivity at borehole RX628.

Stonehenge Down

3.4.7 Seven observation boreholes were drilled around the Stonehenge Down pumped well W601, at distances from 17m to 93m from the pumped well. Drawdown at these observation boreholes at the end of the 7 day pumping test were approximately 2-3m, and were relatively stable at this point without any significant ongoing declining trend.

3.4.8 In addition to the seven observation boreholes in the W601 cluster, it was noted that the effect of the pumping test was detected in two of the catchment observation boreholes RX509 and PX506, located 1200m north west and 450m south west respectively from W601. The drawdown was approximately 0.2m and 0.5m respectively.

3.4.9 Calculated transmissivity values from each of the observation boreholes ranged between 336m2/d and 531m2/d with borehole RX509, located 1200m north west of W601 giving a result of 1085m2/d.

3.4.10 Storage coefficients ranged from 0.0021 to 0.0072. The 0.0072 value was in borehole R609 located near the pumped well. Other high values were also calculated in observation wells nearest the pumped well (R607-0.0052, R602-0.0052). Higher and lower storage coefficients do not correlate with the transmissivity values which showed little variation.

Stonehenge Bottom

3.4.11 Seven observation boreholes were drilled around the Stonehenge Down pumped well W617, at distances from 10m to approximately 150m from the pumped well.

Drawdowns at these observation boreholes at the end of the 7 day pumping test were all similar at approximately 0.5m. Levels were relatively stable at this point without any significant ongoing declining trend.

3.4.12 The exception was borehole R620 where the recorded drawdown was approximately 1.3m. This observation borehole is closest to the pumped well (10m south) so would be expected to have the greatest drawdown.

3.4.13 Calculated transmissivity values from each of the observation boreholes typically ranged between 293m2/d and 778m2/d with the data from borehole R619, located 35m east of W617 giving a result of 1253m2/d. R619 is nearest W148 and is therefore a consistent result with the previous pumping test at W148 where higher values were recorded, and where downhole geophysics found evidence of a higher flow horizon.

3.4.14 Storage coefficients ranged from 0.0018 to 0.0875.

4 Discussion

4.1.1 From the three pumping tests carried out in 2018, the results indicate a large degree of heterogeneity in different directions from the pumped wells in each of the interfluve and valley locations.

4.1.2 Stonehenge Bottom valley yielded transmissivity values that are approximately 50% higher than at Stonehenge Down, compared to the previous pumping tests where the transmissivity in Stonehenge Bottom valley was approximately three times that at Stonehenge Down. The groundwater levels at the start of each test were very similar, within 2m.

4.1.3 However the analysis from the observation borehole in Stonehenge Bottom valley nearest the previous test at W148 gives a similar transmissivity value.

4.1.4 The interpretation of this information is that the high transmissivity in Stonehenge Bottom valley is actually located on the eastern side of the valley and reduces on the western side of the valley. This correlates with the downhole geophysics where the borehole in the centre of the valley (R618) has a caliper anomaly in the 69-73m aOD range while boreholes on the western side of the valley (R620) did not.

4.1.5 All test results from observation boreholes on Stonehenge Down were similar to the previous test at W137.

4.1.6 The transmissivity values calculated at Coneybury Hill on average do not indicate that this interfluve is a lower permeability block of Chalk compared to Stonehenge Down to the west, based on previous studies (Balfour Beatty-Costain-Halcrow Gifford, 2006) from falling head and packer tests. This understanding also formed an assumption in AAJV (2016). The more easterly observation borehole (RX628) indicated an area of high transmissivity that may be a discrete flow horizon.

4.1.7 Storage coefficients derived from the pumping tests were highest in Stonehenge Bottom valley and, as noted for transmissivity, the highest value is on the easternmost side of the valley. On the interfluves, the average of the calculated storage coefficients from the observations boreholes was lower on Stonehenge Down compared to Coneybury Hill, while the lowest value was calculated from an observation borehole on Coneybury Hill.

4.1.8 Calculated storage coefficients are highly variable, ranging across two orders of magnitude, but within the same general range as the previous pumping tests. The exception is Stonehenge Down where the highest values calculated in W137 are two orders of magnitude higher than the results in W601.

4.1.9 The Stonehenge Down pumping test was conducted where the Phosphatic Chalk ‘cuvette’ deposits have been mapped. The conceptual understanding of these deposits from previous authors (Balfour Beatty-Costain-Halcrow Gifford, 2006) was uncertain, they may be conduits for enhanced flows in ‘voidage’ areas but equally these may be voids infilled by low permeability silt.

4.1.10 The 2018 pumping test findings indicate that there is no significant difference in transmissivity at Stonehenge Down W601 compared to the previous results of the W137 test 100m to the west of the Phosphatic Chalk deposits. However the lower storage values in W601 may indicate a lower storage coefficient in the Phosphatic Chalk deposits.

4.1.11 The drawdowns measured in the observation boreholes in each pumping test were less than 2m (approximately 2000 m^3/d was being abstracted during the tests on the interfluves and 500m^3/d in Stonehenge Bottom valley). The drawdowns recorded in each pumping test were very similar to those in the 2002 and 2004 pumping tests.

5 Implications for Groundwater Risk Assessment

5.1 Groundwater Model setup

Hydraulic Conductivity Zones

5.1.1 A groundwater model is used to evaluate the effects of the scheme on groundwater.

5.1.2 The A303 groundwater model was based on the Wessex Basin regional groundwater flow model. It was modified to improve the fit between peak modelled and observed groundwater levels. The change in hydraulic conductivity with saturated thickness (VKD) was amended, preventing the VKD gradient from increasing hydraulic conductivity with rising groundwater level because this led to transmissivity values significantly higher than those calculated from the 2002 and 2004 pumping tests, at Stonehenge Down in particular. In the Wessex Basin model this had the effect of subduing the water table rise in winter to levels significantly below those measured at observation boreholes along the tunnel alignment, as well as at Berwick Down OBH.

5.1.3 The geophysical caliper logs indicate that fracture sets are not concentrated in a particular part of the aquifer profile, and there is no obvious pattern of increasing fracture frequency with elevation to suggest uniform VKD exists in this block of Chalk.

5.1.4 The Chalk Rock has been mapped across the study area but not identified in ground investigation boreholes. This is because the Chalk Rock is interpreted to be significantly below the depth of the ground investigation boreholes, and hence below the design depth of the tunnel. The Whitway Rock has not been mapped in the study area. Therefore these hardgrounds, understood to be major flow horizons, are not known to be present within the depth profile of the tunnel.

5.1.5 It is considered more likely that groundwater flows in discrete fracture sets in a stratified system rather than uniformly increasing flow with elevation. This is acknowledged in the Wessex Basin study (EA, 2011). VKD was used as a means to allow higher transmissivities in valleys compared to the interfluves rather than to reflect specific observation of VKD-like properties.

5.1.6 However the pumping test results do show a difference in transmissivity between summer and winter groundwater levels that would require a larger hydraulic conductivity than the ‘base K’ combined with the water level difference to achieve the transmissivity difference.

5.1.7 The Wessex Basin model VKD setup did not match these variations in transmissivity and, as the focus was in matching peak groundwater levels for groundwater flood risk, this was achieved in the A303 model using the ‘base K’ where variations to VKD were not made.

5.1.8 The A303 model setup at low groundwater levels produced river flows that were still well calibrated. This may have been due to higher Chalk storage parameters than calculated in the recent pumping tests. The 2002 and 2004 pumping tests did not give reliable storage coefficient values so no changes were made to the A303 model.

5.1.9 The change to using the 'base K' meant that the measured transmissivity values in Stonehenge Bottom valley were not replicated in the model. Accordingly, an additional lateral zone of hydraulic conductivity was created to produce a valley transmissivity approximately three times higher than the interfluve transmissivity as calculated in the 2002 and 2004 pumping tests.

5.1.10 The 2018 pumping test gave very similar results for the Stonehenge Down interfluve, and therefore the model representation remains appropriate.

5.1.11 The 2018 pumping test on Coneybury Hill gave similar transmissivity values to those on Stonehenge Down, with the exception of the easternmost monitoring point with higher values.

5.1.12 The groundwater model treated both interfluves in the same way as per the Wessex Basin model setup. Falling head tests in previous studies (Balfour Beatty-Costain-Halcrow Gifford, 2006) had suggested that Coneybury Hill may be a low permeability area though falling head tests do not stress the aquifer sufficiently to give confidence in assigning aquifer properties at any distance from the well.

5.1.13 The pumping test on Coneybury Hill confirms that the aquifer properties of the two interfluves are not significantly different at a regional scale and therefore the current model setup is appropriate for this understanding.

5.1.14 The Stonehenge Bottom pumping test at W617 gave lower values than the summer 2004 pumping tests at W148, conducted at very similar groundwater levels. The average result was only approximately one third higher than the Stonehenge Down results, compared to being three times higher in the 2004 tests.

5.1.15 The calculated transmissivity from the Stonehenge Bottom (W617) pumping test at the observation borehole nearest W148 gave a very similar result to that at W148 in 2004. However the transmissivity values at the borehole on the western side of the dry valley were significantly lower.

5.1.16 The 2018 geophysical survey results were available at numerous boreholes in between the 2002 and 2004 test sites at W148 and W137 where evidence of a high flow horizon was identified. This showed that these horizons are not laterally continuous across the valley and valley sides, being notable near W148 but not on the western side of the valley. This supports the pumping test results in W148 described above.

5.1.17 The model contains a higher hydraulic conductivity zone in the valley and this is supported by the 2018 data.

5.1.18 While the transmissivity on the interfluves is generally similar the storage coefficients are different, with Stonehenge Down averaging 0.004 and Coneybury Hill averaging 0.002. Therefore the western interfluve has approximately twice the storage as the eastern interfluve.

5.1.19 This difference is not represented in the model. These values are lower than typical unconfined Chalk and represent a semi-confined condition. The modelled storage value was 0.015 across both interfluves. From the western margins of the tunnel to the River Till, the model has another storage zone with a value of 0.005.

5.1.20 Therefore the model has an appropriate storage value in the western part of the Stonehenge Down interfluve but across the eastern part of Stonehenge Down and Coneybury Hill interfluve the model value could be too high.

5.1.21 In Stonehenge Bottom valley the storage is significantly higher and representative of typical unconfined chalk, with an average value of 0.02. The modelled value was 0.015. Therefore the modelled value in Stonehenge Bottom valley is a reasonable storage estimate.

Representation of Tunnel

5.1.22 The tunnel is represented in the model by changing the hydraulic conductivity by the vertical extent of the tunnel below the water table compared to a 50m notional saturated aquifer thickness. As the tunnel declined from surface to its low point the reduction in hydraulic conductivity was generally from 10-30%.

5.1.23 A preferential flow horizon from 69-73m aOD was represented by overriding the calculation using the change in saturated thickness above, by assuming a large proportion of flow was in this zone. Where the tunnel crossed this zone the reduction in hydraulic conductivity was 80%.

5.1.24 This assumed that the preferential flow horizon was continuous across Stonehenge Bottom valley. Geophysical data and the Stonehenge Bottom valley pumping test indicate that the inferred preferential flow horizon is laterally discontinuous and in the valley itself most likely a feature only of the eastern side of the valley.

5.1.25 Furthermore the geophysical caliper logs indicated numerous fracture sets at various elevations that suggest flow may not be concentrated in the 69-73m aOD range. Packer testing also identified higher permeability chalk below 40m aOD.

5.1.26 Therefore it is likely that the model is over-estimating the degree of flow impedance caused by the tunnel.

5.2 Effect on Model Predictions and the ES

5.2.1 The modelled transmissivity values on the interfluves approximate the average of the range of values calculated during the 2018 and earlier pumping tests.

5.2.2 Aquifer storage derived from the 2018 pumping tests is lower than the values used in parts of the model. The effect of lower storage, along with the range of pumping test derived transmissivities, would be expected to arrive at a similar calibration to the existing model.

5.2.3 It was concluded that the modelling in support of the GRA does provide a suitable simulation of the groundwater conditions in the Chalk aquifer at the regional scale. Nevertheless, additional model runs would add confidence that a wider range of aquifer properties have been sensitivity tested. The description and findings of additional confirmatory model runs are reported in the report on Supplementary Groundwater Model Runs to Annex 1 Numerical Model Report (HE551506-AMW-EWE-SW-GN-000-ZZ-RP-WR-0103).

6 References

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Appendix 1 Caliper Anomalies

W601	R602	R606	R607	R608
14.5-16.5 (76.5-78.5 maOD)	8 (84.693 mAOD)	14.8 (80.113 mAOD)	10 (83.994 mAOD)	16 (78.653 mAOD)
29.5-31 (62-63.6 maOD)	9 (83.693 mAOD)	16.4 (78.513 mAOD)	13.2 (80.794 mAOD)	24 (70.653 mAOD)
	9.5-10 (83.193-82.693 mAOD)	19 (75.913 mAOD)	13.6 (80.394 mAOD)	25 (69.653 mAOD)
	14.5 (78.193 mAOD)	19.2-20.4 (75.713-74.513 mAOD)	19.6 (74.394 mAOD)	26 (68.653 mAOD)
	16 (76.693 mAOD)	25.4 (69.513 mAOD)	21.2 (72.794 mAOD)	31 (63.653 mAOD)
	17.5 (75.193 mAOD)	26.2 (68.713 mAOD)	22-22.2 (71.994-71.794 mAOD)	40 (54.653 mAOD)
	20.5 (72.193 mAOD)	30.6 (64.313 mAOD)	24.4 (69.594 mAOD)	45 (49.653 mAOD)
	22.5 (70.193 mAOD)	31.6 (63.313 mAOD)	25.6 (68.394 mAOD)	47-48 (47.653-46.653 mAOD)
	2324 (69.693-68.693 mAOD)	32 (62.913 mAOD)	26.4 (67.594 mAOD)	
	27.5 (65.193 mAOD)	34.4 (60.513 mAOD)	28 (65.994 mAOD)	
	31 (61.693 mAOD)	40.4 (54.513 mAOD)	28.6-29 (65.394-64.994 mAOD)	
		42.4 (52.513 mAOD)	29.2 (64.794 mAOD)	
		46.4 (48.513 mAOD)	31 (62.994 mAOD)	
		48.2 (46.713 mAOD)	32 (61.994 mAOD)	
		48.8 (46.113 mAOD)	39.2-39.6 (54.794-54.394 mAOD)	
		51.8 (43.113 mAOD)	43.2 (50.794 mAOD)	
			44.8 (49.194 mAOD)	
			47.6 (46.394 mAOD)	
			51.2 (42.794 mAOD)	
			55.8 (38.194 mAOD)	
			56.4 (37.594 mAOD)	

R609	**R612**	**R613**	**R614**	**R615**
12.2-12.4 (78.2-78.4 maOD)	4-4.2 (89-89.2 maOD)	14.4-15.4 (78.3-79.3 maOD)	11 (82.068 maOD)	5.8-6 (85.5-85.7 maOD)
12.8-14.0 (79.7-80.9 maOD)	5.6-5.8 (87.4-87.6 maOD)	27.6-27.8 (65.9-66.1 maOD)	14.4 (78.668 maOD)	7.2-7.6 (83.9-84.3 maOD)
14.2-14.4 (78.9-79.1 maOD)	13.4-13.6 (79.6-79.8 maOD)	30.2-30.4 (63.3-63.5 maOD)	17 (76.068 maOD)	8.2-8.4 (83.1-83.3 maOD)
14.6-14.8 (79.3-79.5 maOD)	14.6-14.8 (78.4-78.6 maOD)	31-31.2 (62.5-62.7 maOD)	21 (72.068 maOD)	15-15.4 (76.1-76.5 maOD)
16.8-18.8 (74.9-76.9 maOD)	21.5-21.6 (71.6-71.7 maOD)	33.4-33.6 (60.1-60.3 maOD)	24.8 (68.268 maOD)	18.6-18.8 (72.7-72.9 maOD)
19.6-20 (73.7-74.1 maOD)	22.9-23.3 (69.9-70.3 maOD)		27.5 (65.568 maOD)	19.6-19.8 (71.7-71.9 maOD)
21.8-22.4 (71.3-71.9 maOD)	24.4-24.6 (68.6-68.8 maOD)		28 – 28.5 (65.068-64.568 maOD)	20.2-20.4 (71.1- 71.3 maOD)
23.5-24 (69.7-70.2 maOD)	26.8-27.6 (65.6-66.4 maOD)		29.8 (63.268 maOD)	22.2-22.4 (69.1-69.3 maOD)
25.8-26.2 (67.5-67.9 maOD)	29.8-30 (63.2-63.4 maOD)		41.4 (51.668 maOD)	25.2-25.6 (65.9-66.3 maOD)
27-32 (61.7 - 66.7 maOD)	31.3-31.5 (61.7-61.9 maOD)			27.4-27.6 (63.9-64.1 maOD)
33-35 (58.7-60.7 maOD)	4-4.2 (89-89.2 maOD)			30.4-30.6 (60.9-61.1 maOD)
39.8-40.6 (53.1-53.9 maOD)	5.6-5.8 (87.4-87.6 maOD)			31.4-32 (59.5-60.1 maOD)
51-51.2 (42.5-42.7 maOD)	13.4-13.6 (79.6-79.8 maOD)			34.4-34.6 (56.9-57.1 maOD)
53-53.2 (40.5-40.7 maOD)	14.6-14.8 (78.4-78.6 maOD)			35.6-35.8 (55.7-55.9 maOD)
	21.5-21.6 (71.6-71.7 maOD)			44-44.4 (47.1-47.5 maOD)
	22.9-23.3 (69.9-70.3 maOD)			47.9-48.1 (43.4-43.6 maOD)

R616	**R618**	**R620**		
9.5 (82.023 mAOD)	9-9.5 (70-70.5 maOD)	12.2-13 (66.6-67.4 maOD)		
11 (80.523 mAOD)	10-12.5 (67-69.5 maOD)	18.9-19.2 (60.4-60.7 maOD)		
12.6-14 (78.923 – 77.523 mAOD)	12.5-13 (66.5-67 maOD)	20.4-20.7 (58.9-59.2 maOD)		
17.4 (74.123-73.923 mAOD)	15.5-16 (63.5-64 maOD)	23.6-23.8 (55.8-56.0 maOD)		
20.6 (70.923 – 69.923 mAOD)	17-18 (61.5-62.5 maOD)			
23 (68.523 mAOD)				
23.8 (67.723 mAOD)				
25.6 (65.923 mAOD)				
26 (65.523 mAOD)				
27.4 (64.123 mAOD)				
28.8 (62.723 mAOD)				
29.4 (62.123 mAOD)				
31.6 (59.923 mAOD)				
32.6 (58.923 mAOD)				
35.8 (55.723 mAOD)				
44.5 (47.023 mAOD)				
48 (43.523 mAOD)				
51.6 (39.923 mAOD)				

Appendix 2 Downhole Camera Anomalies

W623	**W601**	**W617**
11.8-12.4m (99.28-99.88 mAOD)	7.6m (85.50 mAOD)	22.5m (57.10 mAOD)
15.2m (96.48 mAOD)	7.9m (85.20 mAOD)	23.7m (55.90 mAOD)
19.7-20.3m (91.38-91.98 mAOD)	8.4m (84.70 mAOD)	24.9m (54.70 mAOD)
23.1-23.3m (88.38-88.58 mAOD)	9.5m (83.60 mAOD)	25.3m (54.30 mAOD)
25.8m (85.88 m AOD)	10.1m (83.00 mAOD)	26.9m (52.70 mAOD)
26.3-27.0m (84.68-85.38 mAOD)	10.4m (82.70 mAOD)	28.4-28.6m (51.00-51.20 mAOD)
27.5-28.3m (83.38-84.18 mAOD)	10.8-11.2m (81.90-82.30 mAOD)	30.0-30.3m (49.30-49.60 mAOD)
30.6m (81.08 mAOD)	11.7m (81.40 mAOD)	31.9-32.6m (47.00-47.70 mAOD)
30.9-32.1m (80.58-80.78 mAOD)	12.9m (80.20 mAOD)	33.6-33.8m (45.80-46.00 mAOD)
33.1-33.7m (77.98-78.58 mAOD)	13.4m (79.70 mAOD)	34.6-34.7m (44.90-45.00 mAOD)
34.3-34.8m (76.88-77.38 mAOD)	14.1m (79.00 mAOD)	34.9-35.3m (44.30-44.70 mAOD)
34.8-35.4m (76.28-76.88 mAOD)	15.0m (78.10 mAOD)	35.9-36.0m (43.60-43.70 mAOD)
38.6m (73.08 mAOD)	19.4m (73.70 mAOD)	
41.8-42.5m (69.18-69.88 mAOD)	20.2-21.0m (72.10-72.90 mAOD)	
44.3-44.8m (66.88-67.38 mAOD)	22.3m (70.80 mAOD)	
48.1-48.7m (62.98-63.58 mAOD)	29.9m (63.20 mAOD)	
51.6m (60.08 mAOD)	34.4m (58.70 mAOD)	
52.2-52.7m (59.98-59.48 mAOD)	38.0m (55.10 mAOD)	
52.8m (58.88 mAOD)	40.0m (53.10 mAOD)	
53.6m (58.08 mAOD)	44.0-44.2m (48.90-49.10 mAOD)	

53.8-54.6m (57.08-57.88 mAOD)	52.7m (40.40 mAOD)	
58.7m (52.98 mAOD)	53.0m (40.10 mAOD)	
60.0-60.2 (51.48-51.68 mAOD)	53.6m (39.50 mAOD)	
	55.6-56.2m (36.90-37.50 mAOD)	
	57.0m (36.10 mAOD)	
	59.8-60.0m (33.10-33.30 mAOD)	

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