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with particular reference to :-

Initial Assessment of Principal Issues: Section 7: Flood Risk, groundwater protection and land contamination

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Executive Summary

Extremely challenging bedrock conditions have been identified along the line of the proposed A303 Stonehenge tunnel.

Ground investigation data obtained by Highways England, at all stages of the proposed tunnelling under the Stonehenge World Heritage Site, have produced details of very poor rock and groundwater conditions.

Unless ground stabilisation techniques, such as a bentonite shield-based Tunnel Boring Machine and/or grouting of fractured bedrock are used, there is a high risk of tunnel face collapse, void migration, and potential sinkhole creation upwards from the tunnel crown. To obviate these concerns, it is envisaged that there will be a significant uptake of bentonite slurry/grout into the highly fractured zones of the Chalk along the line of the tunnel. This will be necessary to maintain tunnel stability, especially on the tunnel shoulders and crown.

Dependant on the grout composition, additives and the latency of residual liquids, this could also present threats to long-term groundwater quality. Shield tunnelling methods using slurry, bentonite-based grouts, grout additives and grout penetration into strata surrounding tunnels are discussed in Chapter 12 of "Clay Materials used in Construction".[1]

Closed face TBM systems (with bentonite slurry on a full-face tunnelling machine), combined with the possible necessity of grouting from surface with groundwater control by dewatering methods are most likely to be used. This will be required in the Stonehenge Bottom area, at cross-passage locations, (at high groundwater level periods during construction) and will create a permanent, extensive, diversionary feature to the current groundwater flow system.

A cut-off, or "Groundwater Dam" would thus be created.

Such a feature is highly likely to have significant long-term detrimental effects on local and possibly regional groundwater resources, abstractions and groundwater quality.

Such changes in groundwater flow directions and leaching potential (especially from sub-crops of highly phosphatic Chalk) could derogate existing groundwater systems, abstractions and eventual surface discharges. The River Avon is a Special Area of Conservation (SAC) with a specific nutrient management plan to combat concerns of existing high levels of phosphorus.

The Environment Agency and Stonehenge Alliance have expressed profound concerns about the present inadequacy, in both detail and extent, in reports on groundwater testing, monitoring and modelling by Highways England's consultants (the AMW Consortium – Aecom/Mace/WSP Consultants).

Finally, the Stonehenge Alliance continues to have concerns about vibration during tunnelling causing damage to archaeological features along the tunnel line.

Observations on geological, geotechnical and hydrogeological information, as made available by Highways England to the Stonehenge Alliance.

The following areas, data availability, reports (or lack of reporting), and supporting information (or lack of availability of same), are brought to the attention of The Planning Inspector, Wendy McKay, as a response to her letter of 4th March 2019 requesting input into the Inspectorate's Initial Assessment of Principal Issues (IAPI), with particular emphasis on Section 7: Flood Risk, groundwater protection and land contamination, and concentrating on matters relating to geological, geotechnical and hydrogeological information.

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1. Borehole Data, Drillhole logs, Rock Quality and associated Site Investigation information

1.1 Borehole data (and associated groundwater data) from recent investigations (undertaken during 2018 and to the present date) have not been made publicly available by Highways England (HE).

1.2 The Preliminary Sources Study Report, by the Arup Atkins Joint Venture (Report No. HE551506-AA-HGT-SWI-RP-CX-000004 P05, S3 - dated 22/12/16) is the most comprehensive recent report defining Rock Quality conditions especially along the tunnel line. (See below.)

1.3 A key reference on the White Chalk sequence encountered along the proposed tunnel line is that published in September 2017 by Mortimore et al. (R.N. Mortimore, et al., "Stonehenge—a unique Late Cretaceous phosphatic Chalk geology: implications for sea level, climate and tectonics and impact on engineering and archaeology", *Proc. Geol. Assoc.* (2017).

1.4 This reference describes only the borehole data from the initial (2003/4) 2.1 km. tunnel proposal and does not detail the poor Rock Quality conditions (low/less than 10 RQD values) that were encountered in more recent boreholes.

1.5 Following a written request from the Stonehenge Alliance in October 2017 for the release of additional site investigation and borehole data, a reply was received, with reports from 2002 and 2003 (by R.N. Mortimore) on some core logging from that period. A report "The Geotechnical Preliminary Sources Study Report (2016)" was also forwarded to the Alliance by post.

1.6 The letter of reply, headed "*Environmental Information Regulations request: A303 Stonehenge*" dated 1st November 2017 from Derek Parody, Project Director for A303 Stonehenge Major Projects Complex Infrastructure Programme for Highways England, concluded:

"Finally, I can confirm that we do hold some remaining information that is relevant to your request but regret to inform you of my decision not to disclose this at the current time. This data is based on a partial first phase geotechnical investigation that has not yet been completed, and comprises borehole logs, environmental testing data and water table monitoring.

As the data we currently hold is incomplete, the information you have requested is being withheld in reliance on the exemption in regulation(s) 12(4)(d) of the Environmental Information Regulations 2004.

In applying this exemption we have had to balance the public interest in withholding the information against the public interest in disclosure. The key public interest factors in favour of disclosure included that it could support organisational transparency, that it could generate a limited public understanding of the geology and hydrology of the local area, and that it could enable the public to understand how and what evaluations are done during the current stages of scheme's development.

However, the key public interest factors against disclosure were that unprocessed and invalidated data is not in a format that could be readily understood or interpreted by the public, and that the data is still in the process of being collected and could therefore be misleading if used to form an assessment, which could create confusion when an assessment of the full set of data is published in the future. Further factors were that releasing the requested data could adversely impact the next stage of engagement when evaluation of the complete data is published, and that in its incomplete form, the information requested could be misrepresented in order to undermine the decision-making process. We will be publishing this data once it has been validated, confirmed as accurate, and the investigations are completed."

1.7 Following a further request for updates on site investigation data, and especially borehole logging results (in particular from the 2017 SI drilling campaign by Structural Soils for HE) (Reference: letter from Dr K. Fielden of Stonehenge Alliance (SA) to Mr. Derek Parody of Highways England dated 11 February 2017), a special access code to the 2017 Site Investigation report on the British Geological Survey database was received by SA on 9th March 2018. This permitted downloading of the 2017 Site Investigation records of the drilling of 27 boreholes and the excavation of 26 trial pits, with associated permeability tests, carried out during the first few months of 2017 for Highways England.

1.8 Stonehenge Alliance is aware that an extensive programme of further site investigation work has been carried out for Highways England during 2018 and 2019, up to the present. Additional boreholes have been drilled, data and records of groundwater investigation information have been collected, and ground information retrieved since the spring of 2017. Therefore a considerable amount of such work has been continued in 2018 and 2019, with as yet unpublished results. Stonehenge Alliance is not aware of any further ground investigation data releases by HE since the Structural Soils report, dated December 2017. In addition, even this data set is still not generally available and is defined on the Public Record as "Commercial-in-Confidence" on the British Geological Survey (BGS) GeoIndex website. (https://www.bgs.ac.uk/geoindex/ and see recommendations, below).

1.9. Drilling methods using a triple-liner rotary core drilling system were developed in Severn Trent Water Authority's "Nitrates in Groundwater" program in Nottinghamshire in the mid 1970s. As part of that Research programme, Soil Mechanics Ltd. in conjunction with Severn Trent hydrogeologists developed the now widely used Mylar plastic inner liner core barrel system that was used to successfully recover much of the poor quality Chalk bedrock in both phases of the Stonehenge tunnel project. [2](Lucas and Reeves, 1980)

2. Geotechnical Aspects of tunnel construction and legacy concerns of proposed works

2.1 "Structureless Chalk" of the White Chalk stratigraphic group (of the Newhaven Chalk Formation) has been widely reported, generally at shallow (i.e. up to 5 metres) depths along the line of the proposed road and tunnel route. In addition, poor quality rock (RQD ratings of 20 or less) can be identified deeper in many boreholes.
From both the original (2004) Stonehenge tunnel route, and the more recently drilled boreholes, highly fractured weak, poor quality chalk zones (CIRIA Rating Group C: discontinuity spacing less than 200mm; RQDs of 20 or less) are present commonly at shallow depths i.e. 0 to 10m BGL.

However, such conditions have also been encountered mostly along the western section of the proposed tunnel line at greater depths (e.g. up to 26.92 metres in BH R503B, and 19.00 metres in BH R507A).
The results of unconfined compression tests (quoted by the Arup-Atkins Joint Venture report for Highways England, December 2016) gave intact compressive rock strengths mostly between 1 and 3MPa with an average of 2MPa, corresponding to the description of a 'very weak' rock.
The poorest quality White Chalk in the Stonehenge area has been identified commonly and linked to the "dry valleys" (or combes) such as the Stonehenge Bottom valley.

2.2 In addition to surprisingly weak rock, the occurrence of a previously unknown (pre-2000) sub-crop of highly phosphatic Chalk (i.e. very weak Chalk rock altered and enriched with phosphate) has been identified mostly in the western half of the tunnel route. These are the thickest such deposits identified so far in the UK (Mortimore et al. 2017). These materials are thought to have been deposited in scoured marine channels ("cuvettes") in an organic rich environment on the Late Cretaceous sea bed floor. Although laboratory leaching tests carried out for HE have not identified any groundwater contamination risks, it remains a concern that changes in groundwater flow patterns caused by the proposed tunnel construction, and/or changes in groundwater quality and chemistry may cause long term concerns (also see below, Section 4, Groundwater). Disposal of tunnel spoil is likely to cause problems and concerns of induced phosphate contamination, especially when the status of the River Avon as a Special Area of Conservation (SAC), with existing unacceptable elevated levels of phosphate, is considered. Natural England in conjunction with Wiltshire County Council have implemented the River Avon Phosphate Management Plan (published in February 2016) to drastically reduce phosphate levels in the river.
Similar materials to this Phosphatic Chalk are mined in Northern France for use in fertilisers and the chemical industry.

2.3 As a consequence of the above information on the occurrence of poor quality rock along the line of the proposed tunnel, and the relatively shallow depth of the middle portion of the tunnel route in the Stonehenge Bottom area, it has been proposed by HE that a "slurry shield" method of closed-faced tunnelling would be the most likely tunnelling method to be adopted.
This depends on a full-face tunnel boring machine (TBM) with a bentonite-mud based slurry forming external additional long-term grout support to the strata surrounding the tunnel face and sides.

Therefore on completion of each tunnel drive (two circa 2.9km long drives of 13m diameter approx.), an annulus of unpredictable extent will surround the pathway excavated by the TBMs, outside the tunnel lining. If overbreak occurs at the tunnel crown or wall failure at the flanks, due to the highly fractured nature of the Chalk, surface based grouting from a network alignment of new additional grout injection boreholes may be necessary.
This introduced impermeable barrier to the natural (i.e. pre-tunnel) groundwater flow (generally southwards towards the River Avon), gives great cause for concern for long term effects on groundwater movement (see below, Section 4: Hydrological and Hydrogeological Concerns).

2.4 Additional ground stability concerns exist, also due to the very poor quality rock especially at the western portal. Here a short 300 metre section of cut-and-cover "tunnel" is planned before the TBM drive eastwards starts. A shorter (approx. 80 metres) length of cut-and-cover tunnel section is proposed at the western portal site. These are both probably planned due to the weak rock conditions at shallow depths as the tunnel bores meet the present land surface levels, as well as to accommodate environmental and visual concerns.

2.5 Proposals to use rock slope stabilisation techniques (dowels, meshing, and presumably deeper rock anchors and soil nailing) will undoubtedly be required at both portals and probably in all the proposed cuttings.
These features and techniques are normally only specified in detail on and during excavation which is likely to cause major concerns during construction. Slope failures in portal areas and cuttings may involve the acquisition of additional land adjacent to the alignment.

2.6 During a TBM drive, especially in poor quality (i.e. weak) rock, there is the possibility for vibration caused by the tunnelling process. This may cause induced fracture migration and settlement in overlying strata transmitted upwards from the tunnel crown and shoulders through overlying, progressively weak strata, towards the surface. In the extreme, subsidence could migrate to surface levels.
Settlement of badly fractured rock zones and possible migration through existing voids and fracture zones may cause overbreak at the tunnel crown which could migrate to surface, forming "sinkholes". Compaction and consolidation of structureless and weak chalk rock could occur, with possible compaction of deeper soils up towards the ground surface.

2.7 Grout migration from the TBM systems in excess of the predicted expected uptake of grout to the surrounding rock may indicate the presence of unidentified voids, shafts or other historic "workings". This could lead to extensive permanent areas of Chalk with lowered permeability (essentially forming a "groundwater dam" or cut-off structure).

2.8 The potential loss of fissures, fractures, void spaces, burial features, galleries, tunnels and shafts, at present undiscovered and unidentified (such as the recognised Wilsford Shaft), either by grout injection, settlement or the combined effects of both processes, could lead to the permanent loss of potentially important archaeological features. (See Surface Geophysical Surveys, below).

2.9 Similar detrimental effects of subsidence/settlement and grout migration may also cause problems in land drainage and surface/shallow subsurface drainage systems, in addition to more profound effects on groundwater catchment-scale systems.

2.10 Despite reassurances of HE that "*effects on heritage assets positioned above the tunnel would be managed through the placement and operation of tunnel movement monitoring stations during construction works*" (DCO APP-195 6.3 Environmental Statement Appendix 6.1-

Heritage Impact Assessment- Section 9.2.7), concerns exist that damage could well be caused by vibrations from the tunnelling process.
Potential damage to the long barrow nearest to Stonehenge, just to the east of the western portal, 250m north of Normanton Gorse (NHLE no. 1008953) is specifically mentioned (ibid. Section 9.2.8).

2.11 Concerns of the effects of ground vibrations, especially with respect to the stone structures of Stonehenge itself, at a 200m horizontal distance from the tunnel route, is also highlighted by HE in DCO APP-047 6.1 Environmental Statement Chapter 9- Sections 9.3.13 and 14.

The greatest threat from tunnelling activities however, along the proposed route, is to such unidentified "heritage features" at depth above the tunnel crown. A thorough engineering geophysical campaign along the proposed tunnel route to the full depth of potentially disturbed ground would identify any such features. (See next section).

3. Geophysical Data

3.1 Extensive use of down-hole wireline geophysical logging has been used in most deep boreholes drilled for Highways England at all stages of the A303 project, both for the initial (2004) alignment and the recent (2018) reconfigured scheme. This is to be applauded as a relatively unusual, but significantly useful development in UK site investigations.
Specific targets have been identifying the phosphatic zones (using Natural Gamma, density and electrical logs), together with optical televiewer and borehole caliper logs to attempt characterisation of heavily fractured zones.

3.2 The use of surface geophysical survey investigations to assess rock properties especially, along the line of the proposed route has, however, been sparse, if not completely absent. (See recommendations below.) Identification of weak rock zones, weathering levels, and even poor RQD horizons is now possible using appropriate surface geophysical survey techniques, equipment and interpretive methods.

3.3 No linear deep-seeking surface geophysical survey work (e.g. using inter-alia, engineering seismics, gravity, electro-magnetics, resistivity or ground probing radar techniques) has been carried out (to the knowledge of the Stonehenge Alliance and its local supporters and sources), apart from at the western (and probably also the eastern) portal sites.
Even the existence of this data is uncertain (although GPR systems have been seen in use on the Western portal area), as neither Highways England nor its contractors have yet published any reports or information on such activities.

3.4 In addition, since an incomplete picture is currently held by both archaeologists and Highways England of a full inventory of shallow and deeper sub-surface archaeological features along the route of the proposed new A303 alignment, damage to any such as-yet to be discovered features by any ground disturbance caused by tunnelling and excavation damage remains a significant threat.

4. Hydrological and Hydrogeological Concerns

4.1 The creation of what would effectively be a "groundwater cut-off dam", at depths of up to 40 metres below ground level, with grout invasion potentially penetrating some distance from the tunnel bores, will considerably affect long-term groundwater conditions.

4.2 Effects on regional and local groundwater flow paths, as well as knock-on detrimental effects on groundwater quality, are of much concern to existing riparian groundwater users, as well as public supply boreholes to the east towards Amesbury.

4.3 Considerable efforts have apparently been targeted by HE and their contractors to specific locations of groundwater concern during 2018. Groundwater observation piezometers have been installed and a series of pumping tests (with attendant observation boreholes close to a pumped well) have been carried out.
Locations, information, groundwater data and results of this have not been released or published by HE, apart from those from the two sites investigated earlier in the winter period, November/December 2002 and a summer test in September 2006. (Arup Atkins 2016).

4.4 The main results derived from these tests were that transmissivity values in Stonehenge Bottom are very high (a value of 2,650m3/d implying an average permeability of about 100m/d or 1.2 x 10-3m/s) but are less than a third of this value some 650m to the west (Arup Atkins Joint Venture Report, 2016).
This is consistent with the general observation that borehole yields in the chalk are higher in the valleys than the interfluves.

4.5 Maps showing predicted (and in some locations measured and plotted) groundwater flow paths have been published by Mortimore et al., 2017, and in the December 2016 Arup Atkins Joint Venture Report, "Preliminary Sources Study Report HAGDMS No. 29300" (Figure 5-10, page 24, after Halcrow Gifford report, 2006).

4.6 Detailed hydrological and groundwater modelling of the area has to some extent (it is believed by the Stonehenge Alliance) been carried out by consultants for Highways England (HE).
However in a letter to the Planning Inspectorate A303 (Stonehenge) Improvement Scheme Team, Mr. Barry Smith, Team Leader-Sustainable Places-EA Wessex Area, warned that
"*. . . submission of evidence in relation to Groundwater Modelling and Flood Risk Assessment (FRA) should be required prior to the application for any Development Consent Order (DCO)*." And "*To date there is still outstanding work on these matters being undertaken on behalf of Highways England (the applicant)."*

He concludes the letter thus: ***"Please note that at the point of submission of the relevant representations we do not have any agreed deadlines for the submission of this work outstanding work to support the DCO submission (sic). Therefore you may wish to liaise with the applicant on this matter to discuss the proposed timetabling of this application".***

Recent publications of a number of draft versions of reports on this groundwater monitoring and modelling work have been placed on the Planning Inspectorate website by Highways England.
This work is incomplete, inadequately if not in some areas completely unreferenced (with respect to the primary sources of ground investigation data) and is totally inadequate to properly address concerns about future adverse groundwater conditions caused by tunnelling.

4.7 Absence of any significant authoritative and comprehensive groundwater (and associated hydrological) modelling of the area affected by the proposed tunnel and associated groundworks presents an enormous gap in the assessment of both short and long term effects, especially from the tunnel construction (as outlined above).

Short term (i.e. only one or two years or less of complete season groundwater records) groundwater information on trends in "normal" as well as recent drought conditions are totally inadequate for robust long-term groundwater modelling.

4.8 Both short and long term effects on the quantity and quality of local and regional groundwater systems by the tunnel and new road construction also cause concerns. Changes in principal flow pathways (especially for example in locations such as Stonehenge Bottom) could significantly alter groundwater chemistry and hence leaching potential, especially in the areas of high phosphatic chalk.

4.9 A major campaign of groundwater resources and groundwater quality modelling, based on a robust, extensive and long time frame database would provide a useful prediction of future consequences of the proposed construction project.

5. Conclusions

5.1 Together with the listed criteria and items under the Examining Authority's Principal Issue 7 (Flood risk, groundwater protection, geology and land contamination) it is considered that all the above observations, with attendant details and relevant reference documents, should be brought to the Panel's attention.

5.2 Key specific issues are therefore:

a). **A requirement for an holistic approach to the now vast collection of ground characterisation data from all stages of the A303 Stonehenge realignments projects.**
Presentation of this information could best be delivered by means of a digitally-based 3-D Ground Modelling system, as undertaken by the British Geological Survey for similar (often urban, sometimes groundwater-related) projects.
There are, however, issues relating to the public access, availability, presentation and digital complexity of such modelling, outputs, and reporting. No doubt the Panel would wish to investigate this complex area of data availability and presentation.

b). **The short and long term effects of the most likely proposed tunnelling method** with special consideration to ground movements caused by tunnelling, grout migration and impermeable barrier creation, as well as groundwater flow and quality change effects that are potentially serious.

c). Consideration of the possibility of emergency measures involving **an extensive surface grouting programme and subsequent effects** for ground stabilisation, and the issues relating to plans for the **stabilisation of slopes and cuttings.**

d). The apparent absence in Highways England documentation of any **Groundwater Modelling output**, data or reports relating to b), as above, especially with respect to effects on groundwater flow (local and regional), groundwater resources and quality.

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01.05.19

Biographic Note:

George Reeves is an independent consultant with more than 40 years post-graduate experience in industry and academia. His research and consultancy interests cover wide areas of geotechnical engineering, including hydrogeology, coastal engineering, tunnelling and minegas/subsidence. Prior to returning to the UK in 1986, he worked for AECL Research Company in Manitoba, Ontario and Ottawa, Canada, as a member of their Deep Geological Disposal Research Area Characterisation team, on AECLs' Underground Research Laboratory near Lac du Bonnet, Manitoba; for AECLs Low Level Waste office, based at AECL Head Office, in Ottawa, and for the Geological Survey/AECL group, also based in Ottawa.

He has worked as a consultant and advisor to BNFL, UKEA, MoD, UK Nirex, CoRWM, DTI and DoE/DEFRA, as well as for Greenpeace and Friends of the Earth, and has also supervised a number of postgraduate research projects with some of these organizations. Dr Reeves represented the Stonehenge Alliance at the 2004 Public Inquiry held in Salisbury as a geoscientific specialist.

George was a member of the DoE/DEFRA Radioactive Waste Advisory Committee (RWMAC) from 1986 to 2004. He has been both an active Council and committee member and has held a number of posts, within the Geological Society, including Editorial Board Member, Quarterly Journal of Engineering Geology and Hydrogeology, and was Chairman and Proceedings Editor of the International Conference on "Geo-Engineering of Hazardous and Radioactive Wastes" in 1997. He is co-author/editor of a number of Specialist Engineering Geology Publications of the Geological Society.

His research area specialisations have included a 20 plus year study of the use of down-hole geophysics in hydrogeological characterization of deep rock excavations for which he was awarded a PhD in 2004 by Newcastle University. He continues to work as an independent consultant for his company, HydroGEOtecH Consultants and has appeared as an expert witness in a number of public inquiries and legal representations.

(For more details see www.hydrogeotech.co.uk)

Additional References:

1. Reeves, G. M., Sims, I. & Cripps, J.C. (Eds). 2006. "Clay Materials Used in Construction". (Chapter 12- Specialized Applications.) Geological Society Special Publication 21: ISBN: 978-1-86239-184-0
2. Lucas, J. L. and Reeves,G. M., "An Investigation into High Nitrate in Groundwater and Land Irrigation of Sewage", *Progress in Water Technology*, Vol. 13, Brighton 1980, pp. 81-88