A417 Missing Link

Preliminary Environmental Information Report

Chapter 13 Road Drainage and the Water Environment

28 September 2020

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13.1 Introduction

13.1.1 This chapter of the Preliminary Environmental Information (PEI) report sets out the preliminary assessment of potential impacts on the water environment that may arise from the A417 Missing Link (the proposed scheme). For the purposes of this chapter, the water environment is considered to comprise:

- surface water features within the study area;
- groundwater contained within aquifer units that underlie the study area;
- other water bodies or water dependent features that may potentially be affected; and
- the aspects of potable water supply that directly depend on water resources (e.g. private wells).

13.1.2 The chapter describes the baseline conditions of the existing water environment in the study area and the methodology used to assess potential impacts during the construction and operational phases of the proposed scheme, before presenting the preliminary results of these assessments and any further mitigation measures or monitoring deemed necessary.

13.1.3 The assessment considers the potential effects on the quality and quantity of surface and ground waters, geomorphology and flood risk that may result from construction activities, operational road drainage and accidental spillages.

13.1.4 The Water Framework Directive (WFD) compliance assessment, Hydrogeological Impact Assessment (HIA) and Flood Risk Assessment (FRA) will be reported within the Environmental Statement (ES) (and presented as appendices) which will accompany the DCO application.

13.1.5 Associated effects on ecology (including aquatic ecology) are considered in Chapter 8 Biodiversity, although ecological proxy indicators of water quality may be considered in assessment of effects in the Road Drainage and the water environment ES Chapter. Effects on ground conditions and water quality arising from existing land contamination are considered in Chapter 9 Geology and soils.

13.2 Competent expert

13.2.1 The Road Drainage and Water Environment Chapter lead and technical reviewer of the surface water components of the PEI report Chapter and its appendices is a water environment specialist holding an MSc in Catchment Dynamics and Management (University of Leeds). They are a Chartered Water and Environmental Manager (C.WEM), Chartered Scientist (CSci), Chartered Environmentalist (CEnv) and are a Practitioner Member of the Institute of Environmental Management and Assessment (IEMA).

13.2.2 The technical reviewer of the groundwater components of the PEI report Chapter and relevant associated appendices is a specialist in limestone hydrogeology, with 21 years’ experience as a hydrogeologist. They hold a PhD in hydrogeology (University of Huddersfield) and an MSc in engineering geology (University of Durham) and are a member of the International Association of Hydrogeologists.

13.2.3 Full details are provided in Appendix 1.2 Competent expert evidence.

13.3 Legislative and policy framework

Legislation

13.3.1 A list of the relevant legislation and policy considered is provided in the following sections.

13.3.2 Full details of relevant European, national and local legislation, policy and strategy have been provided in Appendix 13.1 Water legislative and policy framework.

European legislation

- *The EU Water Framework Directive* (WFD) 2000/60/EC
- *Groundwater Directive* (GWD) 2006/118/EC
- *The EU Floods Directive* 2007/60/EC
- *The Habitats Directive* 92/43/EEC and *The Birds Directive* 2009/147/EC
- *Priority Substances Directive* 2013/39/EU
- *Urban Wastewater Treatment Directive* 91/271/EEC (as amended) (UWWT Directive (consolidated))

National legislation

- *Environmental Protection Act 1990*
- *Land Drainage Act 1991* (as amended)
- *Water Resources Act* (England and Wales) *1991* (as amended in 2009)
- *Environment Act 1995*
- *Water Act 2003*
- *The Water Resources (Abstraction and Impounding) Regulations 2006*
- *The Water Abstraction and Impounding (Exemptions) Regulations 2017*
- *The Flood Risk Regulations 2009*
- *The Water Supply (Water Quality) Regulations 2018*
- *Flood and Water Management Act 2010*
- *The Environmental Damage (Prevention and Remediation) (England) Regulations 2015*
- *The Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015*
- *The Environmental Permitting (England and Wales) Regulations 2016* (SI 2010/675) (as amended in 2018 and 2019)
- *The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017*

National policy

- *National policy statement for national networks* (2014) (NPSNN)
- *National Planning Policy Framework* (2019) (NPPF)
- *The Groundwater (Water Framework Directive) (England) Direction 2016*

Regional policy

- Cycle 2 River Basin Management Plans (RBMPs) 2015-2021
- Flood Risk Management Plans (FRMPs) 2015-2021

Local policy, strategy and evidence

- *Gloucestershire Local Flood Risk Management Strategy* (2014)
- *Level 1 Strategic Flood Risk Assessment* (SFRA) for Gloucestershire (2008)
- *Gloucestershire SuDS Design and Maintenance Guide* (2015)
- Gloucestershire County Council: Flood Risk Assessment Guidance Note (March 2015)
- Cotswold District Local Plan (2011-2031)
- *Gloucester, Cheltenham and Tewkesbury, Joint Core Strategy 2011-2031*
- *Tewkesbury Borough Plan 2011-2031* (2020)
- *Cotswolds Area of Outstanding Natural Beauty (AONB) Management Plan 2018-2023*
- Tewkesbury Borough Council *Flood and Water Management Supplementary Planning Document* (2019)

13.4 Assessment methodology

13.4.1 The assessment methodology currently being follow for the ES conforms to the standards of LA 104 *Environmental assessment and monitoring* and LA 113 *Road drainage and the water environment*. LA 104 and LA 113 provide a methodology and criteria for assessing the impact of a proposed road scheme on the water environment. This standard methodology comprises the following steps:

- Identification of potential water receptors within the study area (as defined in Section 13.6), based on the features outlined in Table 13-1, as per Table 3.69 of LA 113.
- Assessment of the potential importance, value and sensitivity of each of these receptors, shown in Table 13-2, as per Table 3.70 of LA 113.
- Assessment of the potential magnitude of any construction or operation impact on the receptor, shown in Table 13-3, as per Table 3.71 of LA 113.
- Assessment of the overall significance of any effects on receptors due to impacts, shown in Table 13-4, as per Table 3.8.1 of LA 104. The significance of effect is determined by a combination of the identified importance/sensitivity of the receptor with the estimated magnitude of the effect. For the purpose of this assessment, values of moderate adverse and above have been defined as significant potential effects.

13.4.2 Specific methods required by LA 113, which only have relevance to particular construction or operation impacts, are detailed in the following sections.

13.4.3 The methodology for groundwater assessment will incorporate the Environment Agency (EA) guidance for Dewatering Abstractions (SC040020 SR1[1] and SR2[2]).

Table 13-1 Attributes and indicators of quality for water features (adapted from Table 3.69 in LA 113)

Feature	Attribute	Indicator of quality	Possible measure
Watercourse	Water supply/ quality	Amount used for water supply (potable) Amount used for water supply (industrial/ agricultural) Chemical water quality	Location and number of abstraction points Volume abstracted daily WFD chemical status
	Dilution and removal of waste products	Presence of surface water discharges Effluent discharges	Daily volume of discharge (treated/untreated)
	Recreation	Access to river Use of river for recreation	Length of river used for recreation (fishing, water sports) Number of clubs
	Value to economy	Value of use of river	Length of river used for recreation commercially Number of people employed Length of river bank developed Length of river fished commercially
	Conveyance of flow	Presence of watercourses	Number and size of watercourses, natural, artificial or heavily modified water body Number of watercourses artificially managed to control flow/levels
	Biodiversity	Biological water quality	Fisheries quality
		Fisheries quality	Fish status, as defined in the WFD
Floodplain	Conveyance of flow	Presence of floodplain Flood flows	Developed area within extent of floodplain affected, as determined from hydraulic modelling Flood risk Mean annual flood
Groundwater	Water supply/ quality	Amount used for water supply Amount used for water supply (industrial/agricultural)	WFD groundwater quantitative and chemical status Catchment abstraction management Strategy (CAMS) status Location and number of abstraction points Volume abstracted daily and use (potable most important) Location and grade of Source Protection Zone (SPZ)
	Soakaway	Presence of soakaways or other discharges to the ground	Location, type and number of discharge points. Daily volume discharged
	Vulnerability	Groundwater vulnerability	Classification of aquifer vulnerability
	Economic value	Extent of use for abstractions	Number of people employed, cost of alternatives

Feature	Attribute	Indicator of quality	Possible measure
	Conveyance of flow	Presence of groundwater supported watercourses Potential for groundwater flooding Groundwater interception by road structures or drainage	Changes to groundwater recharge, levels or flows Number and size of watercourses fed by baseflow
	Biodiversity	Presence of Groundwater-dependent terrestrial ecosystems (GWDTE)	Changes to groundwater recharge, levels or flows. Status or classification of wetland including GWDTE under WFD

Table 13-2 Estimating the importance of water environment attributes (taken from Table 3.70 in LA 113)

Importance	Criteria	Attribute	
Very High	Nationally significant attribute of high importance	Surface water	Watercourse having a WFD classification shown in a RBMP and Q_{95} ≥1.0 m^3/s Site protected/designated under EC or UK legislation (SAC, SPA, SSSI, Ramsar site, salmonid water)/Species protected by EC legislation Ecology and Nature Conservation
		Groundwater	Principal aquifer providing a regionally important resource and/or supporting a site protected under EC and UK legislation Ecology and Nature Conservation Groundwater locally supports GWDTE SPZ1
		Flood risk	Essential infrastructure or highly vulnerable development
High	Locally significant attribute of high importance	Surface water	Watercourse having a WFD classification shown in a RBMP and Q_{95} <1.0m^3/s Species protected under EC or UK legislation Ecology and Nature Conservation
		Groundwater	Principal aquifer providing locally important resource or supporting a river ecosystem Groundwater supports a GWDTE SPZ2
		Flood risk	More vulnerable development
Medium	Of moderate quality and rarity	Surface water	Watercourses not having a WFD classification shown in a RBMP and Q_{95} >0.001m^3/s
		Groundwater	Aquifer providing water for agricultural or industrial use with limited connection to surface water SPZ3
		Flood risk	Less vulnerable development
Low	Lower quality	Surface water	Watercourses not having a WFD classification shown in a RBMP and Q_{95} ≤0.001m^3/s
		Groundwater	Unproductive strata
		Flood risk	Water compatible development

Table 13-3 Estimating the magnitude of an impact on an attribute (taken from Table 3.71 of LA 113)

Importance	Criteria	Attribute	
Major adverse	Results in loss of attribute and/or quality and integrity of the attribute	Surface water	Failure of both acute-soluble and chronic-sediment related pollutants in Highways England's Water Risk Assessment Tool (HEWRAT) and compliance failure with Environmental Quality Standards (EQS) values Calculated risk of pollution from a spillage ≥2% annually (spillage assessment) Loss or extensive change to a fishery Loss of regionally important public water supply Loss or extensive change to a designated nature conservation site Reduction in water body WFD classification
		Groundwater	Loss of, or extensive change to, an aquifer Loss of regionally important water supply Potential high risk of pollution to groundwater from routine runoff - risk score >250 (Groundwater quality and runoff assessment) Calculated risk of pollution from spillages ≥2% annually (spillage assessment) Loss of, or extensive change to GWDTE or baseflow contribution to protected surface water bodies Reduction in water body WFD classification Loss or significant damage to major structures through subsidence or similar effects
		Flood risk	Increase in peak flood level (>100mm)
Moderate adverse	Results in effect on integrity of attribute, or loss of part of attribute	Surface water	Failure of both acute-soluble and chronic-sediment related pollutants in HEWRAT but compliance with EQS values Calculated risk of pollution from spillages ≥1% annually and <2 % annually Partial loss in productivity of a fishery Degradation of regionally important public water supply or loss of major commercial/industrial/agricultural supplies Contribution to reduction in water body WFD classification
		Groundwater	Partial loss or change to an aquifer Degradation of regionally important public water supply or loss of significant commercial/ industrial/ agricultural supplies Potential medium risk of pollution to groundwater from routine runoff - risk score 150-250 Calculated risk of pollution from spillages ≥1% annually and <2 % annually Partial loss of the integrity of GWDTE Contribution to reduction in water body WFD classification Damage to major structures through subsidence or similar effects or loss of minor structures

Importance	Criteria	Attribute	
		Flood risk	Increase in peak flood level (>50mm)
Minor adverse	Results in some measurable change in attributes, quality or vulnerability	Surface water	Failure of either acute soluble or chronic sediment related pollutants in HEWRAT Calculated risk of pollution from spillages ≥0.5% annually and < 1% annually Minor effects on water supplies
		Groundwater	Potential low risk of pollution to groundwater from routine runoff - risk score <150 Calculated risk of pollution from spillages ≥0.5% annually and <1%annually Minor effects on an aquifer, GWDTEs, abstractions and structures
		Flood risk	Increase in peak flood level (>10mm)
Negligible	Results in effect on attribute, but of insufficient magnitude to affect the use or integrity	The proposed project is unlikely to affect the integrity of the water environment.	
		Surface water	No risk identified by HEWRAT (pass both acute-soluble and chronic-sediment related pollutants) Risk of pollution from spillages <0.5%
		Groundwater	No measurable impact upon an aquifer and/or groundwater receptors and risk of pollution from spillages <0.5%
		Flood risk	Negligible change to peak flood level (≤ +/- 10mm)
Minor beneficial	Results in some beneficial effect on attribute or a reduced risk of negative effect occurring	Surface water	HEWRAT assessment of either acute soluble or chronic-sediment related pollutants becomes pass from an existing site where the baseline was of ‘fail’ condition Calculated reduction in existing spillage risk by 50% or more (when existing spillage risk is <1% annually)
		Groundwater	Calculated reduction in existing spillage risk by 50% or more to an aquifer (when existing spillage risk <1% annually) Reduction of groundwater hazards to existing structures Reductions in waterlogging and groundwater flooding
		Flood risk	Creation of flood storage and decrease in peak flood level (>10mm)
Moderate beneficial	Results in moderate improvement of attribute quality	Surface water	HEWRAT assessment of both acute-soluble and chronic-sediment related pollutants becomes pass from an existing site where the baseline was of ‘fail’ condition Calculated reduction in existing spillage by 50% or more (when existing spillage risk >1% annually) Contribution to improvement in water body WFD classification
		Groundwater	Calculated reduction in existing spillage risk by 50% or more (when existing spillage risk is >1% annually) Contribution to improvement in water body WFD classification

Importance	Criteria	Attribute	
			Improvement in water body Catchment Abstraction Management Strategy (CAMS) (or equivalent) classification Support to significant improvements in damaged GWDTE
		Flood risk	Creation of flood storage and decrease in peak flood level1 (>50mm)
Major beneficial	Results in major improvement of attribute quality	Surface water	Removal of existing polluting discharge or removing the likelihood of polluting discharges occurring to a watercourse. Improvement in water body WFD classification
		Groundwater	Removal of existing polluting discharge to an aquifer or removing the likelihood of polluting discharges occurring Recharge of an aquifer. Improvement in water body WFD classification
		Flood risk	Creation of flood storage and decrease in peak flood level (>100mm)
No change		No loss or alteration of characteristics, features or elements; no observable impact in either direction	

Table 13-4 Significance matrix (taken from Table 3.8.1 of LA 104)

		Magnitude of impact (degree of change)				
		No change	**Negligible**	**Minor**	**Moderate**	**Major**
Environmental value (sensitivity)	**Very high**	Neutral	Slight	Moderate or large	Large or very large	Very large
	High	Neutral	Slight	Slight or moderate	Moderate or large	Large or very large
	Medium	Neutral	Neutral or slight	Slight	Moderate	Moderate or large
	Low	Neutral	Neutral or slight	Neutral or slight	Slight	Slight or moderate
	Negligible	Neutral	Neutral	Neutral or slight	Neutral or slight	Slight

Construction impacts

13.4.4 LA 113 recommends that an assessment of construction impacts should use the advice given in Construction Industry Research and Information Association (CIRIA) Report C648 *Control of Water Pollution from Linear Construction Projects*[3] on potential impacts arising during the construction phase and the assessment and mitigation of these risks.

13.4.5 The potential impacts of construction on surface water or sediment runoff, water quality, flood risk and groundwater quality or level have been assessed based on the proposed construction methods and sequencing. Where construction methods have not been available, standard construction practices have been assumed. Cumulative impacts as a result of construction phasing have also been assessed.

13.4.6 Outline measures to reduce construction impacts will be included in an Environmental Management Plan (EMP). These measures will be secured by the DCO application through the imposition of a requirement and these measures are therefore relied on for the purposes of this assessment. For the purposes of the impact assessment it is assumed that they will be implemented correctly. These measures will also be reported in the Register of Environmental Actions and Commitments in the EMP, to be submitted with the ES as part of the DCO application.

13.4.7 The potential impacts of construction on hydrogeology will be evaluated as part of a HIA, by consideration of the proposed construction activities in the context of a baseline conceptual model of the hydrogeological regime. The HIA will be prepared as an appendix to ES Chapter 13 Road Drainage and the water environment and will be submitted as part of the DCO application.

Operational impacts

13.4.8 The assessment of potential impacts during operation will cover the following key aspects of the water environment:

- WFD compliance;
- Flood risk;
- Routine runoff and surface water quality;
- Hydromorphological assessment;
- Spillage and water quality;
- Groundwater level and flow;
- Groundwater quality and routine runoff; and
- Groundwater-dependent terrestrial ecosystems (GWDTEs).

<u>WFD compliance assessment</u>

13.4.9 A WFD compliance assessment for the proposed scheme will be conducted in support of the ES and will be included as an appendix to ES Chapter 13 Road drainage and the water environment, with reference to the Planning Inspectorate (PINS) Advice Note 18 *The Water Framework Directive*[4].

13.4.10 The WFD quality and quantity elements identified through scoping as being at potential risk of impact from the proposed scheme will be assessed in the WFD compliance assessment.

13.4.11 The WFD compliance assessment will identify how the proposed scheme has the potential to affect each of the water bodies' quality/quantity elements and if this results in non-compliance with the WFD. The results of the other assessments in ES Chapter 13 Road drainage and the water environment will be used to inform the WFD compliance assessment, where considered applicable.

13.4.12 For water bodies that have the potential to be impacted by the proposed scheme, the effect of the proposed scheme on any mitigation measures identified within the relevant RBMP will be assessed.

<u>Flood risk</u>

13.4.13 A standalone FRA for the proposed scheme will be conducted as an appendix to ES Chapter 13 Road drainage and the water environment.

13.4.14 This will include the details of the methodology used to assess the risk of flooding from pluvial, fluvial and groundwater sources as a result of the proposed scheme. This follows an approach agreed with Highways England (as the Highway Authority), Gloucestershire County Council (GCC) (as the Lead Local Flood Authority (LLFA)) and the EA (as Lead Authority for main rivers).

13.4.15 The FRA will use the latest published climate change allowances.

Routine runoff and surface water quality

13.4.16 An assessment of the potential impacts of routine runoff on surface water quality will be undertaken using the Highways England Water Risk Assessment Tool (HEWRAT), to determine whether the risk is acceptable, as an appendix to ES Chapter 13 Road drainage and the water environment.

13.4.17 The assessment will be conducted at locations where the route of the proposed scheme physically interacts with watercourses (for example proposed culverts or realignments) or where sediment loading from the proposed drainage system may occur.

13.4.18 The modelling of the surface waters is proposed to include:

- MicroDrainage hydrological modelling - to provide a measure of pipe size[5] and attenuation;
- TUFLOW modelling to identify areas susceptible to surface water flow paths/flooding; and
- modelling of the rainfall return period events with allowance for climate change.

13.4.19 These models will be used to design suitable drainage systems and mitigation measures, including the design of channel diversions.

Groundwater quality and routine runoff

13.4.20 An assessment of groundwater quality and routine runoff will be undertaken as an appendix to ES Chapter 13 Road drainage and the water environment. This will use Appendix C *Groundwater quality and run off* of LA 113, which provides a methodology to determine the risk of impact on groundwater quality from routine runoff. The method is based on the 'source-pathway-receptor' pollutant linkage principle.

13.4.21 For there to be a risk of impact to groundwater quality, a source, pathway and receptor all must be present to create a pollutant linkage or create a linkage based on natural processes. In the context of road drainage, the source is the road runoff with any pollutants it contains. The pathways are the processes which may modify the pollutants during transmission through the discharge system and unsaturated zone. The receptor is the groundwater resources.

Hydromorphological assessment

13.4.22 A hydromorphological assessment will be undertaken to determine whether the degree of hydromorphological change is acceptable and will presented as an appendix to ES Chapter 13 Road drainage and the water environment.

13.4.23 The appropriate, methods of assessment to measure hydromorphological change will be determined by a competent expert on a site-specific basis. Appendix E *Hydromorphological assessment* of LA 113 will be followed.

13.4.24 A qualitative assessment, including River Habitat Surveys and fluvial audits, of possible impacts on the hydromorphology of watercourses will be undertaken based on a suitably qualified geomorphologist's understanding of the potential for impacts to the flow dynamics and sediment transport processes and the subsequent effects that this might have on the ecological potential of the water feature.

13.4.25 The assessment will be made using professional judgement and experience of working within similar watercourses and is focussed on locations where the route of the proposed scheme physically interacts with watercourses (for example proposed culverts or realignments) or where sediment loading from the proposed drainage system may occur.

Accidental Spillage

13.4.26 An accidental spillage assessment will be undertaken using Appendix D *Spillage assessment* from LA 113 and presented as an appendix to the ES. Using the spillage assessment method, for the risk of a serious pollution incident to be acceptable the calculated annual probability of such an incident shall not be greater than 1%. Where spillage has the potential to affect a Site of Special Scientific Interest (SSSI), Source Protection Zone (SPZ), protected area, drinking water supply or commercial activity abstracting from the watercourse, for the risk of a serious pollution incident to be acceptable the calculated annual probability shall not be greater than 0.5%.

13.4.27 The risk is assessed initially without any mitigation measures. Where mitigation measures are needed to reduce the probability, a reduction factor is applied, depending on the type of mitigation used.

Groundwater

13.4.28 An assessment will be undertaken following the procedures set out in Appendix A *Groundwater levels and flow* of LA 113, which follows a stepped approach.

- Step 1 - Establish regional groundwater body status.
- Step 2 - Develop a conceptual model for the surrounding area.
- Step 3 - Based on the conceptual model, identify all potential features which are susceptible to groundwater level and flow impacts.

13.4.29 The assessment of potential effects resulting from the proposed scheme operation considers the interaction of the baseline conditions presented in the hydrogeological conceptual model with the proposed scheme, particularly focusing on specific elements of the proposed scheme (detailed in Chapter 2 The Project) as follows:

- Crickley Hill embankment and tributary to Norman's Brook diversion;
- ground stabilisation measures;
- Air Balloon cutting (including structures such as the Cotswold Way crossing);
- Shab Hill junction (embankments and structures); and
- cuttings and structures between Shab Hill junction and Cowley junction.

13.4.30 Information from the water features survey has been incorporated into a conceptual model of the proposed scheme to identify key features that pose a risk to groundwater resources.

13.4.31 A HIA will be prepared to evaluate the quantitative impacts of the proposed scheme on selected groundwater receptors before and after mitigation.

13.4.32 For there to be a risk of impact to groundwater quality, a source, pathway and receptor all have to be present to create a pollutant linkage or create a linkage based on natural processes. In the context of this chapter, pollutant sources comprise the drainage water that would be discharged at the outfalls of the proposed drainage system, and the receptors are defined as controlled water bodies, including the groundwater that underlies the proposed scheme. In the case of natural processes, sources include recharge, pathways include flow paths through the aquifer and residence times, and receptors are defined as the aquifer or surface expressions of groundwater such as springs.

13.4.33 The source-pathway-receptor model can also be applied to water resources and water features that are sensitive to groundwater levels and flow. In this context sources include abstraction and recharge points, which may be for dewatering or drainage purposes, that are artificially altering groundwater level and flows. The pathway is the hydraulic connection between the water resource that is being changed and features up or down gradient, so this could include the aquifer that connects the two. The receptors are groundwater bodies and groundwater-dependent features.

Groundwater-dependent terrestrial ecosystems

13.4.34 An assessment will be undertaken in an appendix to the ES following the procedures set out in Appendix B *Groundwater-dependent terrestrial ecosystems* of LA 113, which follows a stepped, risk-based approach which depends upon establishing linkages between potential impacts from the proposed scheme on the hydrological and hydrogeological regime and the GWDTEs.

13.4.35 The site-specific conceptual hydrogeological model will provide an overview of the interactions between groundwater and surface water and will identify potential linkages between potential impacts from the proposed scheme (during construction or operation) and GWDTEs. Groundwater flow paths, groundwater levels and the proximity of GWDTEs will be taken into account in the model, included in the HIA. Should the assessment identify likely significant effects then detailed modelling should be undertaken in accordance with DMRB.

Consultation

13.4.36 A number of stakeholders have been consulted to gather baseline data and inform the assessment. The consultees and the reasons for consultation with them (specific to this chapter) are described below.

13.4.37 A scoping opinion was provided by PINS which included responses relating to road drainage and the water environment from the EA, Cotswolds Conservation Board, Cowley and Birdlip Parish Council and GCC. These responses have been considered and included, where appropriate, in this Chapter.

13.4.38 The EA has been consulted on the scope of the monitoring to be undertaken, as well as key effects of the proposed scheme and mitigation. The EA will be consulted on future risk assessments for activities that may impede groundwater flow and quality, via the construction of impermeable barriers, and activities such as piling, ground improvement works and foundations, as per their request.

13.4.39 It has been acknowledged by the EA that full numerical modelling of the groundwater system is beyond the scope of this assessment given the complexities of the hydrogeological regime in the study area. The HIA will instead focus on developing conceptual models around selected design elements of the proposed scheme to understand the hydrogeological regime, following the standard set out in Appendix A *Groundwater levels and flow* of LA 113.

13.4.40 Discussions with the EA have highlighted the need for flexibility regarding the monitoring data available from the current Phase 2A ground investigations. This flexibility encompasses the spatial distribution and temporal duration of monitoring data and the relative risk of design elements to the water environment given the preliminary monitoring results.

13.4.41 GCC, Stroud District Council and Cotswold District Council were consulted during Stage 2 ‘Option selection’ to obtain baseline data including local and unlicensed abstractions.

13.4.42 GCC will continue to be consulted in their capacity as LLFA with regards to the assessment of flood risk, crossing of ordinary watercourses and road drainage.

13.4.43 Thames Water and Severn Trent Water will be consulted during the development of the ES regarding the locations of water and wastewater utilities.

13.4.44 The record of consultation will be recorded in the Statement of Common Ground, which will accompany the DCO application.

13.5 Assessment assumptions and limitations

13.5.1 Assessment of the road drainage and the water environment aspects of the proposed scheme is being carried out in accordance with LA 113, and supplementary methods (as explained in previous sections) for potential impacts not covered in LA 113.

13.5.2 For the assessment of construction impacts, where construction methods and sequencing are not available, current standard construction practices are assumed.

13.5.3 Assessment of the groundwater aspects of the proposed scheme is being carried out in accordance with the LA 113 standard and EA guidance for dewatering abstractions (SC040020/SR1) and groundwater abstractions (SC040020/SR2).

13.5.4 The drainage design is currently at an outline stage and will be finalised later in the design process.

13.5.5 The field works of the intrusive ground investigations to determine the site-specific ground conditions have now been completed however groundwater monitoring are currently ongoing, due for completion in mid-2021. Conceptual models will be refined with the new information received to inform the hydrogeological impact assessments in the ES. It is considered that for the majority of the monitoring locations at least 11-12 months of monitoring data will be available for these assessments.

13.5.6 It is acknowledged that uncertainty is inherent to this type of assessment, in particular with respect to the assessment of interaction between surface water and groundwater. The ongoing data collection will greatly enhance understanding of current and future conditions and will be reported on in the ES.

13.5.7 Every effort has been made to ensure that the findings of the available surveys present as accurate an interpretation as possible of the baseline conceptual model of the water environment within the study area.

13.5.8 The final environmental design may be amended during detailed design prior to construction. However, the assessment of potential effects has taken account of the ‘worst case’ scenarios and mitigation measures are included within the proposed scheme design accordingly.

13.5.9 This chapter includes the information reasonably required to assess the likely significant environmental effects. A precautionary valuation of the baseline that represents a ‘reasonable worst-case’ is provided, i.e. one that is precautionary, but it is reasonable to assume could occur, rather than an extreme scenario that is unlikely. This approach has been utilised to assign precautionary valuations to surface water and groundwater receptors based on the best available information.

13.5.10 Where reasonable worst-case valuations are necessary, they have been made based on the information available. This has included consideration of any available field or desk study data and published research literature relevant to the study area. The degree of precaution built into the assessment is linked to the level of confidence in the existing data upon which the assessment is based.

13.5.11 The findings presented in this chapter represent those available at the time writing and data collected to end of May 2020.

13.5.12 Further topic-specific limitations and assumptions associated with the proposed scheme are discussed in the following sections.

Surface water

13.5.13 The baseline conditions have been derived from both desk-based and field studies. Additional baseline data collection and monitoring are ongoing.

Groundwater

13.5.14 The understanding of the hydrogeological regime of the proposed scheme and its study area is currently limited to published reports, groundwater monitoring (for January to May 2020) from the ground investigations (detailed in Chapter 9 Geology and Soils) and water features survey (completed between April 2018 to March 2019). The water features survey and groundwater monitoring are still on-going, and the methodology is currently being refined based on the initial survey results. As additional information is received the conceptual models and assessment will be refined and tailored based on ground conditions encountered and existing information.

13.5.15 It has been acknowledged by the EA that full numerical modelling of the groundwater system is beyond the scope of this assessment given the complexities of the hydrogeological regime in the study area. It is unlikely a three-dimensional numerical model will be sufficiently detailed or robust enough to accurately represent the processes occurring within the study area and how they may be affected by the proposed scheme. Analytical and two-dimensional conceptual models will be developed for key assessment areas, which will be tailored for structural and geotechnical design assessments, following the standard set out in Appendix A *Groundwater levels and flow* of LA 113.

13.5.16 The LA 113 Appendix C *Groundwater quality and run off* assessment results in a significance of effect that is relevant to the specific locale of the point of discharge, which is not relevant to the wider groundwater body due to dilution effects. Supplementary risk assessment is proposed to assess this situation if it arises which may include an RDP 20 and/or ConSim methodology (depending on complexity and site-specific characteristics) for the derivation of remedial targets for soil and groundwater to protect water resources.

13.6 Study area

13.6.1 The study area is based on the 'source-pathway-receptor' pollutant linkage principle and is shown on Figure 13.1.

13.6.2 For direct effects on surface waters, the study area includes the geographical extent of the full scope of the works and all surface water features within 0.6 miles (1km), where features have hydrological connectivity to the proposed scheme.

13.6.3 For groundwater, the study area includes the geographical extent of the full scope of the works and all groundwater features within 0.6 miles (1km) of the proposed scheme.

13.6.4 The Planning Inspectorate's *Scoping Opinion*[6] and meetings with the EA highlighted the need to extend the study area beyond a 0.6 mile (1km) buffer.

Extension of the study area beyond the 1km buffer was considered necessary to capture potential impacts to receptors beyond the standard study area by the EA. This was considered particularly important where dewatering is likely to impact receptors upstream and downstream of the study area where underlying geology may result in groundwater connectivity across a wider area. Consequently, a risk-based approach has been taken to the extension of the study area based on assessment of impact pathways and has been kept under review as the understanding of complex interactions has evolved. Following review, tributaries to the River Churn and the headwaters to the River Churn, up to 1.1 miles (1.8km) north of the proposed scheme, were included in the study area due to their local significance.

13.7 Baseline conditions

Current baseline

Baseline methodology

13.7.1 The baseline describes the existing condition of surface waters, groundwater and flood risk within the study area. The value of each water feature identified has been determined based on the attributes and indicators of quality listed in Table 3.69 of LA 113 and shown in Table 13-1.

13.7.2 The following data sources were used to compile the baseline conditions:

- A417 Missing Link EIA Scoping Report (May 2019);
- observations from water features survey;
- observations from site walkover surveys;
- EA Catchment Data Explorer[7];
- Severn and Thames River Basin Management Plans (2015);
- existing highway drainage plans;
- National River Flow Archive[8];
- Natural England, MAGIC[9];
- Ordnance Survey (OS) mapping (including topography);
- British Geological Survey (BGS) mapping[10];
- Envirocheck report;
- information from historic and recent ground investigations including; groundwater levels monitoring and sampling;
- EA flood risk mapping[11];
- EA Water Quality Archive[12];
- topographic surveys;
- water feature report;
- rainfall intensity data;
- National Vegetation Classification (NVC) woodland report;
- Level 1 Flood Risk Assessment of Norman's Brook area; and
- Preliminary Groundwater Report[13]

Site investigations and surveys

13.7.3 Several site investigations and surveys have been completed for the proposed scheme including walkover surveys, a survey of water features, geotechnical ground investigation and a surface water tracer test.

Walkover surveys

13.7.4 Walkover surveys of the study area were undertaken by the water environment team and associated specialists on 11 June 2019, 28 June 2019, 6 August 2019, 8 August 2019, 28 October 2019 and 29 October 2019. The visits focused on building upon knowledge within the water features survey to gain a good overall understanding of the hydrological and hydrogeological regime of the study area.

13.7.5 The weather conditions for the visits varied and seasonal changes in the water environment was evident, with summer visits showing springs generally producing low volumes of water resulting in watercourses having low flow and levels, and winter visits showing springs producing higher volumes of water resulting in watercourses having higher levels and flows.

Water features survey

13.7.6 A water features survey was completed between April 2018 and March 2019, which included five rounds of surveys[14]. The surveys were conducted within the study area and at some locations beyond the study area as it was developed prior to option 30 becoming the preferred alignment. It is anticipated that locations outside the study area were identified due to their potential hydraulic connectivity to features within the study area that may be impacted.

13.7.7 Three hundred and ten surface water and groundwater features were surveyed, including, but not limited to, watercourses, groundwater springs, wet flushes (boggy ground), seepages, road drainage pipes, ponds and groundwater abstractions. Most locations were only visited once during the survey period. Forty-five sites were selected for flow gauge monitoring of watercourses and some groundwater springs, with the majority of these features being gauged twice[15].

13.7.8 The water features within the study area demonstrate that a number of surface water features rely on groundwater sources from the Great Oolite Group and Inferior Oolite Group aquifers, superficial and perched aquifers and their separation with less permeable Lias Group mudstones and the Fullers Earth Formation mudstone.

13.7.9 Spring discharges, wet flushes (boggy ground) and seepages, are mainly found on the escarpment slope but also within the Upper Cotswold Plateau valleys where some valleys are seasonally dry and others have perennial and ephemeral spring flows which can also support wetland environments, including Bushley Muzzard SSSI. This SSSI is an area of marshland that has the potential to be impacted by changes in groundwater levels/quality and drainage related to the proposed scheme.

Ground investigations

13.7.10 Details regarding historical ground investigations are included in Chapter 9 Geology and soils. Although information obtained through these investigations has been used to inform the conceptual ground model for the proposed scheme, these investigations primarily focused on geotechnical aspects.

13.7.11 Recent ground investigations and monitoring were specific to the proposed scheme. The details are presented in Chapter 9 Geology and soils. The following sections provides a summary of hydrogeological aspects of these investigations.

Phase 1 Ground Investigations 2019

13.7.12 The Phase 1 ground investigation was completed between January and February 2019[16]. The scope of works included eight boreholes with standpipe installations in each specifically targeting key hydrogeological elements to support the conceptual model of the proposed scheme options. Groundwater level data loggers were installed in three locations: DS/RC 406, DS/RC 408 and DS/RC

419. To compensate for the total pressure recorded by the water level loggers for barometric pressure, a dedicated barometric logger was installed in the headworks of DS/RC 408.

13.7.13 It should be noted that Phase 1 boreholes were constructed when option 12 was still under consideration and are spatially distributed to incorporate option 12 and option 30 (the proposed scheme). Details on the alternative options are provided in Chapter 3 Assessment of alternatives.

13.7.14 The boreholes were positioned in four locations, where at each location two boreholes were drilled approximately 10m apart, monitoring different aquifer units in relation to the geological faulting. Groundwater monitoring commenced on completion of the installations, between January and February 2019. Groundwater level monitoring using data loggers commenced in March 2019 and the data gathering is currently on-going. A summary of the Phase 1 ground investigation monitoring results is presented in Appendix 13.4 Hydrogeological baseline conditions.

Phase 2A Ground Investigations 2019 - 2020

13.7.15 The Phase 2A ground investigations commenced in April 2019. The field works have now been completed with the post-field works 12-months monitoring currently ongoing, which is programmed to be completed in mid-2021. Section 13.5 sets out the approach to the incomplete data and the precautionary approach adopted for the assessments.

13.7.16 The initial scope of Phase 2A included 80 boreholes, however due to land access issues ten boreholes have not been completed. Out of the completed boreholes 47 have been equipped with standpipe installations. All of the boreholes are targeting a specific aspect of the design, with 11 boreholes (so called 'series 400' boreholes) specifically targeting key hydrogeological elements to support the conceptual model of the proposed scheme. Barometric loggers have been installed at Crickley Hill in the headworks of CP 223 and at Stockwell-Nettleton in the headworks of DS/RC 220.

13.7.17 Groundwater level monitoring was scheduled to commence on completion of each installation and is on-going. A summary of the Phase 2A ground investigation monitoring results is presented in Appendix 13.4 Hydrogeological baseline conditions.

13.7.18 The Phase 2A scope included nine packer tests. To date no packer tests have been completed due to insufficient depth of the saturated zone. Instead, permeability testing will be undertaken. The results will be incorporated into the assessments undertaken at the ES stage.

13.7.19 The baseline conditions in this PEI report consider data collected up until end of May 2020. The baseline conditions underpinning the hydrogeological impact assessments in the ES will comprise:

- 21 months of groundwater monitoring data from the Phase 1 boreholes, where monitoring commenced in February 2019;
- 10-13 months of data from the Phase 2A boreholes (series 400), the majority of which were installed between September and December 2019; and
- 6-21 months of data from Phase 2A boreholes (other than series 400 boreholes equipped with installations). The length of monitoring period is dependent on installation date. The longest monitoring period would be

obtained from areas in the western end of the proposed scheme, from the early stages of the investigation.

Future ground investigations

13.7.20 Future ground investigations will be undertaken. It is envisaged that the scope of these further investigations will include installation of further groundwater monitoring locations followed by groundwater quality and level monitoring, and additional permeability and infiltration testing. Data obtained from these investigations will supplement baseline information utilised to undertake detailed design and complete further detailed hydrogeological impact assessments, if required (e.g. as part of an abstraction licence application).

Tracer test

13.7.21 A tracer test was conducted to the watercourse located along the southern toe of Crickley Hill, below the existing road, using tracer dye on 6 March 2019[17]. The test was completed to ascertain where the watercourse flowed to. The tracer confirmed that the tributary is hydraulically connected to Norman's Brook rather than Horsbere Brook as indicated in WFD water body delineation, via a culvert network.

Designated sites

13.7.22 Bushley Muzzard SSSI is a species-rich wet grassland supplied by local springs and seepages. It is located 310m downgradient of the southern end of the existing A417 roundabout, south of Birdlip Quarry.

13.7.23 Crickley Hill and Barrow Wake SSSI is designated for woodland and calcareous grassland habitats. It is located adjacent to the existing A417 on Crickley Hill and at Barrow Wake. Springs supplying the tributary of Norman's Brook are within the protected area downgradient and south of Barrows Wake.

13.7.24 Cotswold Commons and Beechwoods SSSI and Cotswold Beechwoods Special Area of Conservation (SAC), located 270m west and downslope of the B4070, includes areas of vegetation dependent on springs and seepage from high groundwater levels. These areas of vegetation are associated with some nationally rare invertebrate species. These protected areas extend from the south-east of Birdlip to High Brotheridge and include springs supplying Horsbere Brook.

13.7.25 Witcombe Reservoirs, at the foot of the escarpment, is primarily supplied by spring-fed watercourses. It discharges to Horsbere Brook. There are a number of small ponds in the area that may be partially groundwater-dependent or fed by springs.

Surface water

13.7.26 The Cotswold escarpment forms a surface water divide between the River Severn catchment and the River Thames catchment (to the east and south-east of the divide respectively). To the west of the divide, the land drains to the River Severn and its tributaries, including Norman's Brook, Horsbere Brook and the River Frome. To the east and south-east, the land drains to the River Churn, a tributary of the Thames.

13.7.27 Horsbere Brook, Norman's Brook, the River Frome and the River Churn are classed by the EA as ordinary watercourses within the study area and are shown on Figure 13.1. Minor watercourses that are tributaries of these named streams have also been included in the assessment and grouped where required.

13.7.28 Six surface water flow locations have been identified for ongoing monitoring, commencing in July 2020. These are a mixture of continuous (gauged) sites and spot (monthly) measurements. Data will be reported on as part of the ES.

Surface water WFD catchments

13.7.29 The EA's Catchment Data Explorer and Figure 13.3 show that the WFD surface water bodies in the Severn Vale Management Catchment include:

- Norman's Brook – source to confluence Hatherley Brook (No. GB109054032780), within the Cheltenham Hatherley and Norman's Brook Operational Catchment;
- Horsbere Brook – source to confluence River Severn (No. GB109054032760), within the Gloucester Tributary Operational Catchment; and
- River Frome – source to Ebley Mill (No. GB109054032470), within the Frome and Cam Operational Catchment.

13.7.30 The WFD surface water body in the Gloucestershire and the Vale Management Catchment is the Churn – source to Perrots Brook (No. GB106039029810), within the Thames Upper Operational Catchment.

13.7.31 The Cycle 2 (2016) status for these surface water bodies are as follows:

- Norman's Brook – source to confluence Hatherley Brook: Ecological status of 'Poor', chemical status of 'Good', and overall status of 'Poor';
- Horsbere Brook – source to confluence River Severn: Ecological status of 'Moderate', chemical status of 'Good', and overall status of 'Moderate';
- Frome – source to Ebley Mill: Ecological status of 'Good', chemical status of 'Good', and overall status of 'Good'; and
- Churn – source to Perrots Brook: Ecological status of 'Moderate', chemical status of 'Good', and overall status of 'Moderate'.

13.7.32 As outlined in Section 13.7.26, the WFD surface water body for Norman's Brook is inaccurate, and WFD surface water classifications do not extend to the tributaries of Horsbere Brook, Norman's Brook and the River Churn within the study area of the proposed scheme.

Water quality

13.7.33 There are ten relevant EA Water Quality sampling points as shown on the EA's online Water Quality Archive[18]. A review of EA monitoring locations noted water quality sampling has been undertaken at various private and public wastewater treatment plants in the area. There are no routine river water quality sampling locations on the watercourses of interest.

13.7.34 Water quality at ten locations within Bushley Muzzard SSSI was monitored during four rounds between October and December 2018, following events of both low and high precipitation and a variation in flows[19].

13.7.35 Average pH readings of 8.06 were recorded across the monitoring period at all sites, with a range between 7.96 and 8.25 showing the watercourses to be slightly alkaline – consistent with the geological setting. Following high levels of precipitation, pH was typically higher at the majority of locations.

13.7.36 Conductivity ranged between 660µS/cm and 740µS/cm, with higher results after prolonged periods of rainfall. All values were considered to be relatively high for freshwater watercourses, indicating a potential high dependency upon precipitation. Similarly, phosphates and nitrates recorded noticeably higher values following prolonged rainfall, with average results across all locations of approximately 8mg/L following prolonged rainfall and approximately 3mg/L following low or no rainfall.

13.7.37 Six surface water quality sampling locations have been identified for ongoing monitoring, commencing in July 2020. Parameters sampled include environmental indicators to identify the specific local characteristics of the water and pollutants typically associated with road runoff. Data will be reported on as part of the ES.

13.7.38 In addition, rain gauge measurement is being undertaken to identify local relationships between rainfall, groundwater characteristics and surface water response, to understand the local hydro-geological and hydrological system.

Flood risk

Fluvial flood risk

13.7.39 The proposed scheme alignment is located entirely in Flood Zone 1[12], which is defined as having a risk of flooding from fluvial and tidal sources of less than 1 in 1,000 (0.1%) in any year, and as a result is defined as being at ‘low’ risk.

13.7.40 The proposed scheme is located within 0.6 miles (1km) of Flood Zones 2 and 3 for the River Frome and Horsbere Brook at the eastern and western extents of the proposed scheme respectively[20].

13.7.41 Existing flood risk from EA mapping is shown on Figure 13.2.

Pluvial flooding

13.7.42 Sections of the proposed scheme alignment are indicated on the EA mapping to be at risk of pluvial flooding (from surface water sources)[12]. The mapping does not distinguish between areas at risk of flooding purely from surface water runoff (specifically during heavy rainfall events) and areas at risk from small watercourses that are too small to be included on fluvial flood risk mapping.

13.7.43 At the Birdlip junction, the proposed scheme crosses an area of ‘high’ surface water flood risk[21] that appears to coincide with the head of a dry valley and may be associated with an ephemeral watercourse or springs within the valley. An area of ‘low’ surface water flood risk is recorded to the north-east of the proposed scheme at the A436 and Ullenwood Manor Road crossroads and is associated with a tributary of the River Churn. An area of ‘low’ to ‘medium’ surface water flood risk is identified to the north of the proposed scheme area near Crickley Hill Country Park access road. Areas of ‘low’ to ‘high’ surface water flood risk coincide with Norman’s Brook tributary flowing down Crickley Hill, to the south of the existing road. The level of surface water flood risk increases to ‘high’ towards Crickley Hill Farm.

Groundwater flooding

13.7.44 The BGS Groundwater Susceptibility dataset[22] indicates there is the potential for groundwater flooding to occur to the west of Crickley Hill and at Nettleton Bottom, in the River Frome headwater valley. Along Crickley Hill and up to the Severn/Thames catchment divide, and in the southern extent of study area, there is a limited potential for groundwater flooding to occur. Existing groundwater flooding susceptibility is shown on Figure 13.7.

Groundwater

Aquifers

13.7.45 Full details of geological conditions are presented in Chapter 9 Geology and soils. A summary of the geology is provided within the following sections, with a focus on the hydrogeological interaction.

13.7.46 The hydrogeology of the Cotswolds is influenced by the complex relationship between aquifers, aquitards, periglacial geomorphology and surface water - groundwater interactions. An idealised model of the regional hydrogeological processes is presented in Plate 13-1. In the study area, 'head' deposits cover the Lias Group formations. A summary of the aquifers in the study area is presented in Table 13-5.

13.7.47 Local hydrogeological conditions are shown on a series of conceptual models (refer to Figure 13.8) and detailed descriptions are presented in Appendix 13.4 Hydrogeological baseline conditions.

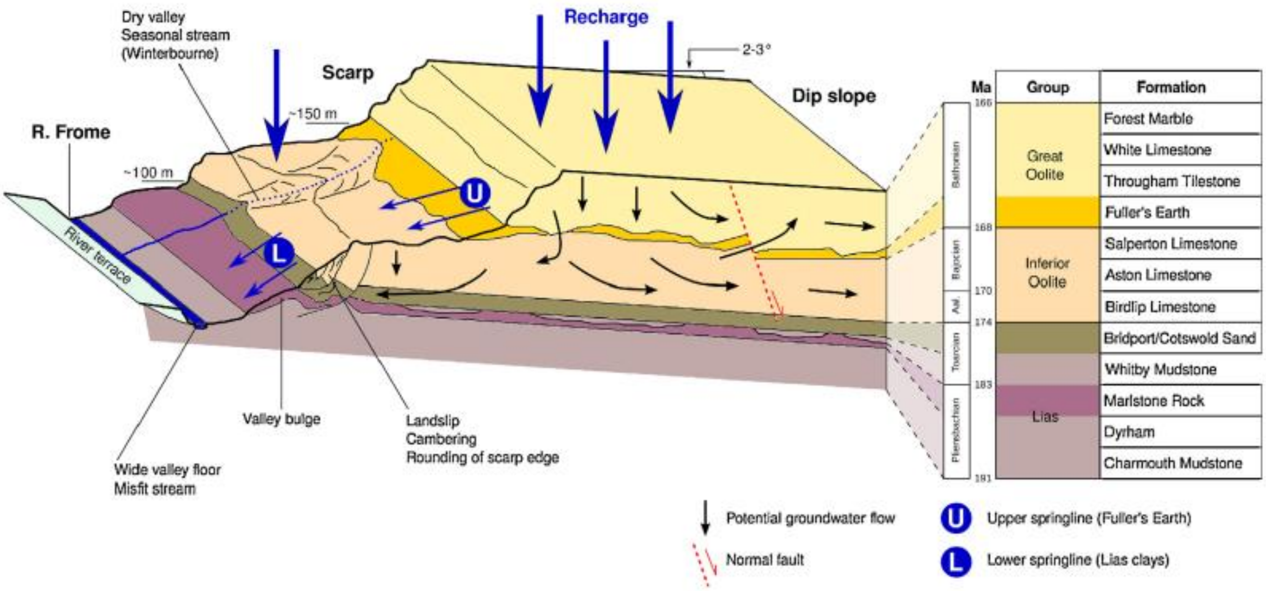

Plate 13-1 Conceptual model of the groundwater regime in the mid Cotswolds[23]

Table 13-5 Summary of aquifers in the study area

Age	Group	Formation	EA designation	Description	Thickness	Hydrogeological properties
Quaternary	-	Cheltenham Sand and Gravel	Secondary A aquifer	Fine to medium grained sand, seams of limestone gravel.	0m to 2m	Groundwater flow through relatively high permeability, intergranular matrix.
		Superficial deposits including alluvium, and head deposits	Alluvium – Secondary A aquifer Head deposits – no aquifer designation	Largely cohesive material with non-cohesive lenses.	0m to 23m	Variable hydraulic conductivity. Groundwater flow through intergranular matrix.
Middle Jurassic	Great Oolite (168-165Ma)	White Limestone	Principal aquifer	Limestone aquifer with clay beds.	10m to 20m	Fractured with enhanced dissolution features, particularly closer to escarpment/valleys and the ground surface. Degree of fracturing decrease with depth. Groundwater flow through secondary and some tertiary porosity features. At depth transitions to interbedded calcareous sandstone, variably oolitic limestone and calcareous mudstone and siltstone with Low effective vertical hydraulic conductivity, but high effective horizontal hydraulic conductivity due to interbedding.
		Hampen		Sandy and ooidal limestone aquifer with clay and marl beds.		
		Fuller's Earth	Unproductive aquifer	Mudstone aquitard with limestone beds.	0m to 15m	Relatively low permeability. Leakage through faulting and fractures connecting Great Oolite with Inferior Oolite. Potential to form a spring line with overlying Great Oolite limestones.
	Inferior Oolite (175-168Ma)	Salperton Limestone	Principal aquifer	Shelly, ooidal limestone aquifer.	0m to 40m	Fissured with cambering, gull and enhanced dissolution features, particularly closer to escarpment/valleys and the ground surface. Degree of fracturing decrease with depth. Groundwater flow through secondary and tertiary porosity features.
		Aston Limestone		Shelly, sandy limestone aquifer.		
		Birdlip Limestone		Ooidal, sometimes sandy, limestone aquifer with sandy clay layers.		

Age	Group	Formation	EA designation	Description	Thickness	Hydrogeological properties
Lower Jurassic	Lias Group (200-175Ma)	Bridport Sand Formation	Secondary (Undifferentiated) aquifer	Sandy mudstone and fine-grained sandstone – minor aquifer.	0m to 10m	Discontinuous presence within the study area. In hydraulic connection with base of Inferior Oolite, where present. Groundwater flow predominately in secondary porosity features and a minor component of flow though primary porosity of the rock mass.
		Whitby Mudstone Formation (WMF)		Mudstone aquitard with limestone beds at base.	12m to 98m[24]	Relatively low permeability. Potential to form a spring line with overlying limestones and Bridport Sand.
		Marlstone Rock Formation (within the WMF)		Ferruginous, ooidal limestone and sandstone – minor aquifer.	0m to 5m[25]	Heavily jointed closer to escarpment and valleys. Can locally form a spring line. Groundwater flow predominantly in secondary porosity features and a minor component of flow though primary porosity of the rock mass. Recharged via leakage from overlying formations.
		Dyrham Formation		Silty mudstone and siltstone aquitard.	15m to 54m[26]	Relatively impermeable.
		Charmouth Mudstone Formation		Mudstone aquitard with thin beds and nodules of limestone.	120m to 284m[27]	Relatively impermeable.

13.7.48 The extent of mapped superficial deposits is limited within the study area, as shown on Figure 9.3 of Chapter 9 Geology and soils. Cheltenham Sand and Gravel superficial deposits are present at the western end of the proposed scheme, while alluvium, comprising clay, silt sand and gravel, is mapped on the northern side of Bushley Muzzard SSSI. Both superficial deposits are designated by the EA as Secondary A aquifers indicating they are "*permeable layers capable of supporting water supplies at a local rather than a strategic scale, and in some cases forming an important source of base flow to rivers"*[28].

13.7.49 Mass movement deposits, referred to as 'head' deposits in this assessment, are mapped across the Cotswold escarpment, the Churn Valley (near Shab Hill Farm) and the Frome Valley (near Stockwell-Nettleton Bottom). These deposits typically comprise a random assortment of the underlying parent geology within a matrix of largely cohesive material, but the nature of these deposits can vary. The head deposits are not an EA designated aquifer, however groundwater within this deposit supports many of the groundwater-surface water interaction features on the Cotswolds escarpment and valleys in the region.

13.7.50 Groundwater flow through the superficial deposit aquifer is dominated by intergranular flow. The variable nature of the material may allow for perching of groundwater within coarse grained zones above the local groundwater table.

13.7.51 Preferential flow paths within the superficial deposits are anticipated to have developed along coarse grained inclusions and connected lenses derived from alluvial processes and coarse parent material within the head deposits. These more permeable zones are anticipated to promote the emergence of some groundwater springs within the Crickley Hill area. Flow paths may also be present along landslide structural features such as failure planes or tension cracks.

13.7.52 The superficial deposits are unconfined however clays may cause some local confinement of water bearing, coarse grained lenses. Groundwater levels are likely to be relatively variable and shallow within the superficial deposit aquifer.

13.7.53 Jurassic-aged bedrock formations comprising Great Oolite Group, the Inferior Oolite Group and the Lias Group underlie the study area. Further details on underlying geology are described in Chapter 9 Geology and soils and shown on Figure 9.3.

13.7.54 In the study area, the Great Oolite limestones are unconfined and groundwater perches above the basal Fuller's Earth Formation. This perched groundwater promotes the development of groundwater springs along the boundary of the limestones over mudstone.

13.7.55 Limestone has characteristic triple permeability and porosity. The primary (matrix) porosity and permeability is typically low but the secondary and tertiary porosity and permeability provide increasingly permeable pathways, so that the aquifer can provide a local high permeabilities even though the aquifer as a whole has relatively low storage capacity.

13.7.56 Secondary porosity features include joints and bedding planes within the rock mass, which are anticipated to decrease in frequency with depth and away from valley features. Tertiary porosity features include secondary porosity features which have been solutionally enlarged and may be present to a limited extent in the Great Oolite Limestones on the Upper Cotswold Plateau where there are fewer cambering processes occurring.

13.7.57 Where the Great Oolite limestone formations transition to the Fuller's Earth Formation, limestones are likely to be interbedded by mudstones with the frequency and thickness of mudstone beds increasing with depth. As a result, the effective horizontal hydraulic conductivity of the transition zone is dominated by limestone beds. The vertical conductivity of the transition zone is anticipated to be limited by the hydraulic conductivity of the mudstone.

13.7.58 Limestones within the transition zone are anticipated to be recharged via leakage through the overlying interbedded mudstone. It is uncertain how laterally extensive the interbeds are, however it is possible that limestone beds are near surface and may be directly recharged rainfall.

13.7.59 The Fuller's Earth Formation is a grey mudstone with limestone beds which acts as an aquitard at the base of the Great Oolite Group. Regional conceptual models for the Cotswolds suggest that the Fuller's Earth Formation may not be laterally continuous, which may facilitate local hydraulic continuity between the Great Oolite Group and Inferior Oolite Group limestones.

13.7.60 The Inferior Oolite limestone aquifer forms the plateau of the Cotswold escarpment and extends south-east from the escarpment (shown on Figure 13.5). The aquifer is largely unconfined, however in the southern portion of the Proposed scheme it is partially confined by the Fuller's Earth Formation mudstone aquitard. The Inferior Oolite Group features deeply incised valleys which have a strong effect on the piezometric surface within the group[29].

13.7.61 Assessment of the fractures encountered during borehole drilling show orange-brown staining indicative of weathering and groundwater flow within the Salperton Limestone Formation and the Aston Limestone Formation[30]. The degree of staining decreased with depth in the Aston Limestone Formation, suggesting more limited groundwater movement through the rock mass[31].

13.7.62 Is it possible that some of the fissures and gulls along the escarpment are groundwater flow paths that may feed groundwater springs at the Inferior Oolite limestone and Lias Group boundary or groundwater springs emerging from the 'head' deposits.

13.7.63 The Great Oolite (excluding the Fuller's Earth Formation) and Inferior Oolite are classified as a Principal Aquifers, described as *"permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers*"[32]. The Fuller's Earth Formation is classified by the EA as an Unproductive Aquifer associated with "*low permeability [and] negligible significance for water supply or river base flow*"[33]. Aquifer designations are shown on Figure 13.6.

13.7.64 The Whitby Mudstone formation, Dyrham formation and Charmouth mudstone formation are the thicker formations within the Lias Group and are the prime influence for the group's hydraulic properties. Largely comprising mudstone and silty mudstone, the formations have relatively low permeabilities and function as aquitards.

13.7.65 The Bridport Sand and Marlstone Rock formations are relatively thinner geological units that influence more localised groundwater processes.

13.7.66 It is considered that the Bridport Sand Formation at the top of the Lias Group is hydraulically connected with the base of the Inferior Oolite Group aquifer and is recharged via these overlying limestones. Groundwater flow through the formation is likely to be dominated by secondary porosity features including bedding planes and joints, and a secondary component of flow through the rock matrix.

13.7.67 The Marlstone Rock Formation is very heavily jointed as a result of the cambering process but is more massive at depth[34]. The cambering processes will be more pronounced closer to the edge of the escarpment, and therefore anticipated to be very heavily jointed, with widened discontinuities at shallower depths and closer to the escarpment edge. Relatively higher hydraulic conductivity within the Marlstone Rock, relative to the overlying Whitby mudstone formation, may promote leakage from the mudstones and locally form a spring-line.

13.7.68 In the study area, BGS present the stratigraphy encompassing the upper parts of the Lias Group and the lower parts of the Inferior Oolite Formation as the 'Lias Group and Inferior Oolite (undifferentiated)'. Owing to this stratigraphy being combined, the Lias Group and Inferior Oolite (undifferentiated) is designated by the EA as a Principal aquifer. Based on descriptions of the Lias Group[35], the Bridport Sand Formation is considered a Minor aquifer. However, the site-specific information in this report is based upon Site Investigation data from this project, thereby this provides a higher resolution to the EA mapping in the site area. As such the properties of the aquifers in this area are based on site specific information.

13.7.69 In the study area the Charmouth Mudstone Formation is classified by the EA as a Secondary (undifferentiated) aquifer, described as *"both minor and non-aquifer in different locations due to the variable characteristics of the rock types"*.

13.7.70 Structurally the bedrock groups dip between 2º and 5º towards the east and south-east and are intersected by inferred faults in the region. It is considered that faulting throughout the region are providing flow paths for groundwater, particularly between the Great Oolite Group and Inferior Oolite Group. The location of the faults is shown on Figure 9.3 of Chapter 9 Geology and soils.

13.7.71 Cambering and gulls are prevalent within the Inferior Oolite Group that are underlain by the Lias Group due to cambering processes along the Cotswold escarpment. Less cambering and gulls are anticipated further away from the escarpment, at the proposed scheme sections located on the Upper Cotswold Plateau. The effects of cambering are anticipated to be less frequent in the Great Oolite Group at the southern portion of the proposed scheme, where there is an interbedded transition from limestone to mudstone.

Groundwater WFD catchments

13.7.72 The proposed scheme is located over two river basin districts: the Severn to the west and the Thames to the east. The topographical catchment boundary along the Upper Cotswolds Plateau generally correlates to the groundwater divide between the Severn and Thames catchments[36]. These river basin districts are divided into three WFD groundwater bodies, where two are within the Severn Vale catchment and one is within the Thames catchment[37]. A summary of the WFD groundwater bodies is presented in Table 13-6.

13.7.73 The superficial deposit aquifers are not specifically designated as WFD groundwater bodies. However, it is anticipated they are hydraulically connected to the relevant underlying designated WFD groundwater bodies presented in Table 13-6.

13.7.74 The Severn Vale catchment is divided into the Severn Vale - Jurassic Limestone Cotswold Edge South (ID GB40901G305700) and the Severn Vale - Secondary

Combined (ID GB40902G204900) groundwater bodies. These groundwater bodies locally drain towards the west into the River Frome, Norman's Brook and their tributaries.

13.7.75 The Severn Vale - Jurassic Limestone Cotswold Edge South groundwater body generally correlates to areas of the Great Oolite Group, Inferior Oolite Group and Upper Lias Group, west of the groundwater divide.

13.7.76 The Severn Vale - Secondary Combined groundwater body includes areas underlain by the Charmouth Mudstone Formation at the base of the Lias Group at the western end of the proposed scheme.

13.7.77 The Thames catchment in the study area comprises solely of the Burford Jurassic WFD groundwater body (ID GB40601G600400). The Burford Jurassic groundwater body generally correlates to the Great Oolite Group and the Inferior Oolite Group limestones that drain towards the south-east where the Inferior Oolite is confined by the Fuller's Earth Formation. The aquifers locally feed into the River Churn and its tributaries in the south-east.

13.7.78 The 'Current overall status' (2016) of both the Jurassic Limestone Cotswolds Edge South and Secondary Combined groundwater bodies is classified as 'Good', however the Burford Jurassic is classified as 'Poor'.

Table 13-6 Summary of WFD groundwater bodies

Groundwater body name	Burford Jurassic	Severn Vale – Jurassic Limestone Cotswolds Edge South	Severn Vale – Secondary Combined
Groundwater body ID	GB40601G600400	GB40901G305700	GB40902G204900
Operational catchment	Burford Jurassic	Severn Vale – Jurassic Limestone Cotswolds Edge South	Severn Vale – Secondary Combined
Management catchment	Thames GW	Severn England GW	Severn England GW
River basin district	Thames	Severn	Severn
Current overall status	Poor (2016)	Good (2016)	Good (2016)
Current quantitative status	Good (2016)	Good (2016)	Good (2016)
Current chemical status	Poor (2016) – poor nutrient management (diffuse sources) and private sewage treatments (point sources)	Good (2016)	Good (2016)
Quantitative objective	Good by 2015	Good by 2015	Good by 2015
Chemical objective	Good by 2027	Good by 2015	Good by 2015
Protected area	Drinking water protected area and nitrates directive.	Drinking water protected area and nitrates directive.	Drinking water protected area and nitrates directive.

13.7.79 The proposed scheme alignment is underlain by Principal Aquifers with a current WFD status of 'Good' and 'Poor' and a Secondary (undifferentiated) Aquifer with a status of ‘Good’, shown in Table 13-6. The majority of the extent of the proposed scheme alignment is not located within a SPZ, however east of Stockwell the proposed scheme runs adjacent to an SPZ3 for the Baunton abstraction. A summary of the geological aquifers and how they align with the WFD groundwater bodies is presented in Table 13-7.

Table 13-7 Underlying aquifer characteristics

Name	WFD groundwater body	Key characteristics
Superficial deposits - Secondary A aquifer	Not assessed as a WFD groundwater body by the EA	Aquifer may be a source of baseflow to tributaries feeding into tributaries of the River Frome or the Bushley Muzzard SSSI.
Lias Group - Secondary (undifferentiated) aquifer	Severn Vale – Secondary Combined	Springs issuing from the contact of the Lias Group and Inferior Oolite supply the River Frome.
Inferior Oolite - Principal aquifer	Severn Vale – Jurassic Limestone Cotswolds Edge South	Aquifer supports the Crickley Hill and Barrow Wake SSSI, springs, river headwaters including Norman’s Brook, public water supply and private water abstractions.
Great Oolite - Principal aquifer	Burford Jurassic	Aquifer providing private water supply and local public water supply where the study area is within the SPZ3. Supports Bushley Muzzard SSSI, springs and headwaters of rivers, including the River Churn, within the catchment.

Hydraulic conductivity

13.7.80 Groundwater flow through the limestones is dominated by secondary (fracture) porosity pathways and tertiary (karstic) porosity features, so the aquifer may locally have a high permeability but overall have low storage capacity. Bedding planes and stress relief joints in conjunction with cambering processes are expected to form many of the secondary porosity features of the limestone. The frequency of secondary porosity features within the rock mass, is likely to be higher closer to the Cotswold escarpment. Karstic enhancement and enlargement of these features by dissolution creates tertiary porosity features, with variable degrees and types of infill that will affect the hydraulic conductivity.

13.7.81 Interpretation of borehole data obtained from the limited Phase 1 ground investigation scope suggests sub-vertical fracturing in the Great Oolite Group is restricted to thin limestone beds[38]. Interpretation of fractures within the Inferior Oolite are typically sub-horizontal with some open, sub-vertical fractures and a decrease of likely groundwater stained fractures with depth in the Aston Limestone Formation[39]. It needs to be noted that the Phase 1 ground investigation was of a limited scope and the data obtained from the currently on-going Phase 2A investigations, when available, will be examined to derive a more detailed understanding of the hydraulic properties of the bedrock underlying the proposed scheme and the preliminary assessments will be validated. For the purpose of this assessment and in line with the precautionary approach, conservative values have been adopted.

13.7.82 The mass movement processes on the escarpment edge have implications on groundwater flows and specifically with development of karst processes. Fissures within limestones present in the region are likely to have developed due to destressing of the rock mass in conjunction with movement within the underlying mudstones that facilitated the formation of camber and gull features. The fracture frequency is expected to be higher in rock mass closer to the ground surface and the escarpment. Fissures may be enhanced by dissolution, particularly close to the ground surface, where rainfall recharge percolates into the aquifer and the aquifer is exposed to repeated wetting and drying cycles.

13.7.83 During the construction of the Birdlip bypass a number of larger fissures (0.3m wide and up to 17m depth) within the Inferior Oolite limestones were treated with lean mix concrete or a mixture of rock fill and concrete, in the case of smaller fissures at the formation level of the Barrow Wake Cutting[40]. Locally the hydraulic conductivity of the Inferior Oolite around the Birdlip bypass is expected to be lower where these fissures have been treated.

13.7.84 The Fuller’s Earth Formation and Lias Group mudstones are low permeability formations where leakage through the formation is via faulting within the region. Generally, they are considered to have a very low rate of hydraulic conductivity.

13.7.85 Aquifer testing was conducted during the Phase 1 ground investigation to estimate the hydraulic conductivity (K) of selected bedrock formations. A combination of constant head and rising head tests were used depending upon saturated aquifer thickness[41]. A summary of the Phase 1 field testing results is presented in Table 13-8.

Table 13-8 Summary of field-testing results[42]

Location	Test interval	Test lithology	K (m/s)
OH416	3.0 – 5.0mbgl 283.85 – 281.85mAOD	Weathered Fuller’s Earth Formation – Great Oolite	$2x10^{-7}$
DS/RC404	23.0 – 34.0mbgl 246.0 – 235.0mAOD	Birdlip limestone - Inferior Oolite	$4.6x10^{-5}$ to $7.2x10^{-5}$
DS/RC406	20.5 – 35.0mbgl 218.15 – 203.65mAOD	Birdlip limestone - Inferior Oolite	$2x10^{-6}$
OH405	11.0 – 18.0mbgl 228.5 – 221.5mAOD	Inferior Oolite	$5.7x10^{-5}$
OH407	6.0 – 15.5mbgl 225.75 – 216.25mAOD	Inferior Oolite	$4.2x10^{-5}$ to $7.0x10^{-5}$
DS/RC419	36.0 – 42.0mbgl 232.9 – 226.9mAOD	Bridport sand – Lias Group	$3.2x10^{-6}$
DS/RC408	20.0 – 24.0mbgl 212.5 – 208.5mAOD	Bridport sand – Lias Group	$1.1x10^{-5}$

13.7.86 The proposed hydraulic parameters are based on a combination of field tests and published data are presented in Table 13-9 and are considered preliminary.

Table 13-9 Proposed hydraulic parameters

Unit	Description	K, minimum (m/s)	K, maximum (m/s)
Engineered fill	Granular, gravelly sand	$5.0x10^{-5}$	$5.0x10^{-4}$
Alluvium	Clay, sandy clay	$1.0x10^{-8}$	$1.0x10^{-6}$
Head deposits	Clay, sand/gravel bands	$1.0x10^{-8}$	$1.0x10^{-4}$
Cheltenham sand and gravel	Sand and gravel	$1.0x10^{-4}$	$1.0x10^{-2}$
Great Oolite	Fractured limestone	$2.0x10^{-6}$	$2.0x10^{-4}$
	Fractured mudstone	$2.0x10^{-8}$	$2.0x10^{-7}$
Inferior Oolite	Fractured limestone	$1.0x10^{-6}$	$1.0x10^{-4}$

Unit	Description	K, minimum (m/s)	K, maximum (m/s)
	Massive limestone	$3.0x10^{-11}$	$3.0x10^{-9}$
Lias Group	Bridport Sand	$1.0x10^{-7}$	$1.0x10^{-5}$
	Mudstone	$1.0x10^{-11}$	$1.0x10^{-7}$

Groundwater levels

13.7.87 A groundwater monitoring network has been progressively installed across the proposed scheme as part of the wider ground investigation programme. A total of 48 monitoring locations have been installed and are distributed along the proposed scheme alignment with some locations further away from the proposed scheme to inform the regional understanding of the aquifers, landslip hazard risk in Crickley Hill and potential impacts to environmentally sensitive sites like the Bushley Muzzard SSSI.

13.7.88 Within the Crickley Hill area there are 18 monitoring locations within the head deposits and 5 monitoring locations within the Lias Group mudstones. Due to the large topographical relief of the escarpment there is a large range in groundwater levels recorded between each monitoring location, however, some general trends are observed. Monitoring within the head deposits indicates there are shallower or perched groundwater flows which are generally less than 4 mbgl and generally vary by less than 2.0 m. Deeper monitoring installations indicate there are water bearing units deeper within the head deposits that may have limited connection to shallower groundwater flows. Some of these deeper locations demonstrated confined or semi-confined conditions. The groundwater levels recorded in deeper monitoring installations showed a larger variation in groundwater levels, up to 3.0 m, in response to rainfall and distinctly higher levels during winter relative to summer. The increase in groundwater levels of the deeper monitoring locations was typically gradual and did not rapidly respond to rainfall. Monitoring within the Lias Group mudstones showed some degree of seasonality to groundwater levels, however this was only apparent in two boreholes, CP 223 and CP 204(d).

13.7.89 Near Air Balloon, there are 8 monitoring locations within Inferior Oolite Group limestones and 1 location within the Bridport Sands Formation. The recorded groundwater levels are relatively deep below ground level between 26.1 and 31.9 mbgl. The monitoring locations showed variable responses to rainfall input where DS/RC 406, within the Birdlip Limestone Formation, showed groundwater levels responding rapidly to winter rainfall and varied between 207.6 and 210.8 mAOD, but limited to no response over summer months when groundwater levels are lower. The Bridport Sand Formation showed a delayed and muted response to winter rainfall, where the groundwater level gradually rose from 210.4 to 211.2 mAOD over the winter months

13.7.90 Within Shab Hill Junction there are 2 monitoring locations within Inferior Oolite Group limestone and 1 monitoring location within Great Oolite Group limestone. The monitoring location, OH 413 within the Great Oolite Group limestone extends to the top of the Fuller’s Earth Formation, however it has consistently dipped ‘dry’. The location of OH 413, is close to the Shab Hill Barn fault, away from the dry valley feature in this area, so it is unlikely to be representative of the conditions in the dry valley. Within the Inferior Oolite Group Limestone, monitoring at DS/RC 315, showed an overall large range of groundwater levels. From the commencement of monitoring in late October to late November the groundwater level rose from 198.2 to 203.7 mAOD. Between late November 2019 and late

March 2020, groundwater levels remained high, typically between 201.4 and 203.7 mAOD and showed a delayed response to rainfall.

13.7.91 The cuttings south of Shab-Hill, between Stockwell and Nettleton, include 4 monitoring locations within Great Oolite Group limestone and 2 monitoring locations within Inferior Oolite Group limestone. Variable magnitudes of groundwater level variance and response to rainfall were observed across the monitoring locations. Within the Great Oolite Group limestones, DS/RC 218 demonstrated the highest degree of response to rainfall events. Over the winter period groundwater levels were recorded between 279.5 and 281.7 mAOD in response to rainfall events, however there is a gradual decline in levels by 4.3 m from late February to mid-April as conditions become drier. Monitoring within the Inferior Oolite Group limestones is overlain by the Great Oolite Group, including its basal mudstone the Fuller's Earth Formation. Groundwater levels recorded in the Inferior Oolite Group are significantly lower than the Great Oolite Group, indicating limited connected between the aquifers.

13.7.92 A summary of the proposed scheme elements and anticipated groundwater levels at each element is presented in Table 13-10.

13.7.93 Summaries of the groundwater monitoring results completed to date for each aquifer are presented in Appendix 13.4 Hydrogeological baseline conditions.

Table 13-10 Proposed scheme elements and anticipated groundwater levels

Proposed scheme elements	Chainage (m)	Maximum change in formation level	Minimum monitored groundwater levels (mbgl)	Maximum monitored groundwater levels (mbgl)	Observed ranges in groundwater level (m)	Potential groundwater level relative to foundation
Crickley Hill approach	0+000 to 0+500	-1.5m	No monitoring data available – within an area of potential groundwater flooding			At existing ground level
Crickley Hill embankment widening, diversion of Norman's Brook tributary Stabilisation of landslide deposits at Crickley Hill	0+500 to 1+700	8.0m (Head deposits)	0 – 16.2	125.9 – 191.5	0.4 – 4.2	At existing ground level
Air Balloon cutting	1+700 to 3+000	-32.5m (Inferior Oolite Group)	26.1 – 31.9	205.3 – 210.9	1.7 – 6.1	At existing ground level at approx. CH1+700, otherwise >1m
Shab Hill Junction	3+000 to 3+500	20.1m (Great Oolite Group)	1.5 – 8.9	271.2 – 284.1	1.5 – 7.4	At existing ground level within dry valley
Cuttings south of Shab Hill	3+500 to 5+700	-8.2m	1.4 – 3.8	271.2 – 285.4	1.5 – 1.9	Above cut foundation level

Note: In the '*Maximum change in formation level*' column, negative numbers indicate a cutting and positive numbers indicate fill relative to existing ground level

Springs

13.7.94 Springs and seepages in the region typically correlate to the geological boundary between the Great Oolite Group and the Fuller's Earth Formation and the boundary between the Inferior Oolite Group and the Upper Lias, where more permeable oolitic limestones are underlain by less permeable mudstone units.

13.7.95 Springs also emanate from the colluvial deposits along the Cotswold escarpment where preferential flow paths have developed through more permeable zones of the mixed material. At this stage it is difficult to determine exactly which aquifer each spring is associated with as the unstructured nature of the colluvial material is likely to mask where these springs are discharging from in the underlying bedrock.

13.7.96 Some springs and seepages in the region correlate to bedrock formations, boundaries and structural features including:

- The Great Oolite limestones and the Fuller's Earth mudstone;
- The Inferior Oolite limestone (in spatially limited connection with Bridport; Sand) and Lias Group mudstone;
- The Marlstone Rock Formation; and
- Shab Hill Barn fault.

13.7.97 Many springs in the study area are considered to be seasonal features that dry out in response to lower groundwater levels within the respective source aquifers, or area linked to major fissures or gulls and respond only to rainfall. Morgan-Jones and Eggboro (1981) noted extremes in recharge caused changes in the emergence points of some springs in the Gloucestershire region[43]. A period of low recharge, 100mm, between October 1975 and October 1976 caused some springs to stop flowing[44]. The following year recharge was estimated to be 630mm, which reactivated springs and cause the emergence points to change[45].

13.7.98 Many watercourses in the study area are spring-fed systems with losing and gaining reaches.

13.7.99 The springs identified within the study area are shown on Figure 13.5.

Carbonate deposits

13.7.100 Superficial carbonate precipitates are terrestrial deposits[46] which form a variety of environments and are commonly found in areas with limestone bedrock. Common names for terrestrial carbonate deposits, 'tufa' and 'travertine', are often used interchangeably within karst literature. The naming convention adopted by Ford & Williams (2007) has been applied to this assessment where:

- Tufa refers to grainy deposits accreting to algal filaments, plant stem and roots at springs, along banks of watercourses, lake edges, etc.[47]

13.7.101 Carbonate deposits typically form due to the precipitation of calcium carbonate, when carbon dioxide degasses from supersaturated carbonate waters:

$$Ca^{2+} + 2HCO^{3-} \Leftrightarrow CaCO_3 + CO_2 + H_2$$

13.7.102 Potential tufa formations were identified along the tributary of Norman's Brook during the Water Feature Survey. Based on the geological setting close to the tributary of Norman's Brook it is anticipated that the tufa formations are depositing from groundwater emerging from head deposits derived from limestone parent material. The high permeability of the head deposits allows significant surface area contact with groundwater, which can become hard relatively quickly.

Recharge, such as rainfall precipitation, which is slightly acidic and can dissolve calcium carbonate and other ions is often referred to as 'attacking'[48].

13.7.103 The habitat value of the carbonate deposits is discussed in Chapter 8 Biodiversity. The geological value of tufa deposits is discussed in Chapter 9 Geology and soils

Dry valleys

13.7.104 Dry valleys in limestone terrains are glaciofluvial karst features. Such valleys originally formed by periglacial streams that incised into the limestone bedrock, often creating steep sided gorges and ravines. Subsequently, the streams drained elsewhere, often being lost to ground as losing streams[49]. Dry valleys are relic topographical features, but seasonal streams may flow episodically[50,51].

Abstractions

13.7.105 The majority of the study area is not located within a designated groundwater SPZ. However, the SPZ for the Baunton public water supply abstraction (approximately 12km south-east of the proposed scheme) extends into the study area within the Thames groundwater catchment. The Baunton abstraction, abstracting water from the Inferior Oolite aquifer, intersects part of the proposed scheme where the proposed works in these areas are primarily within the Great Oolite aquifer. The southern end of the proposed scheme is approximately 2.8km from SPZ2 and 3.4km from SPZ1 in the south-east.

13.7.106 The Baunton public water supply is abstracting water from the Inferior Oolite aquifer which is hydraulically separated from the design elements in the SPZ3 by the Fuller's Earth Formation.

13.7.107 There are no further recorded licensed abstractions that are known of within the study area.

13.7.108 The water features survey identified 16 potentially unlicensed abstractions, boreholes and wells within the study area[52]. Many of these features were either not in use or details on their usage and groundwater source were not able to be obtained. Borehole dimensions are currently only available for two locations and it is envisaged that some locations may need to be revisited in the future to obtain further details.

13.7.109 Two unlicensed abstractions identified during the water features survey are used for drinking water supply. The first unlicensed abstraction is a piped spring shared between a private dwelling and Crickley Hill Tractors (both at Grove Farm), which is likely to be sourced from the Inferior Oolite Group. The second unlicensed abstraction is a spring at Bushley Muzzard SSSI to supply Watercombe Farm, which is likely to be sourced from the Great Oolite Group.

13.7.110 Consultations have been undertaken to identify unlicensed abstractions as detailed in Section 13.4.

Consented discharge

13.7.111 To date there have been nine consented discharges of treated sewage or unspecified combined sewage and trade effluent to land and underground strata recorded within 1km of the proposed scheme[53]. Of these, three discharge licenses are still active and are located at Air Balloon Public House, Crickley Hill and the Birdlip wastewater treatment works approximately 1km west of the proposed scheme. A summary of the consented discharges is presented in Table 13-11.

Table 13-11 Consented groundwater discharge licences within 1km of the proposed scheme

Site Name	Site type	Receiving water	License status	Effluent description
Air balloon public house	Food and beverage services	To ground	Revoked	Sewage discharges – final / treated effluent - not water company
Air balloon public house	Wastewater treatment works (not water company)	Underground strata (soakaway)	Active	Sewage & trade combined - unspecified
Air balloon public house	Food and beverage services	Underground strata	Revoked	Sewage & trade combined - unspecified
Air balloon public house	Wastewater treatment works (not water company)	Underground strata (soakaway)	Revoked	Sewage & trade combined - unspecified
Birdlip wastewater treatment works	Wastewater / sewage treatment works (water company)	Groundwater into infiltration system	Active	Sewage discharges – final / treated effluent - water company
Crickley cottages	Domestic property (single) (including farmhouse)	Underground strata	Active	Sewage discharges – final / treated effluent - not water company
Hardings barn	Domestic property (single) (including farmhouse)	Inferior oolite	Revoked	Sewage discharges – final / treated effluent - not water company
Hardings barn	Domestic property (single)	Inferior oolite	Revoked	Sewage discharges – final / treated effluent - not water company
Ullenwood manor	Dentist / hospital / nursing home (medical) / human health	Land	Revoked	Sewage discharges – final / treated effluent - not water company

Environmentally sensitive sites

13.7.112 Two SSSIs are located in the study area: the Crickley Hill and Barrow Wake SSSI in the northern section of the study area, around Air Balloon; and Bushley Muzzard SSSI in the southern half of the study area, near Nettleton Bottom.

13.7.113 Crickley Hill and Barrow Wake SSSI is designated for its calcareous grassland, broadleaved woodland and nationally important rock exposures[54]. During consultation, the EA and Natural England highlighted that beech (*Fagus sylvatica*) woodland at Crickley Hill and Barrow Wake SSSI and Cotswold Beechwoods SAC were considered to be groundwater-dependant, and the risk of lowered groundwater levels would result in stress and damage to the shallow rooted trees. The National Vegetation Classification (NVC) code for beech trees is 'W12', which is not classified as being groundwater-dependant according to relevant guidance[55]. Based on nearby groundwater monitoring data to Crickley Hill and Barrow Wake SSSI, the depth to groundwater is approximately 28mbgl, and it anticipated to result in a relatively deep unsaturated zone below the SSSI, resulting in interaction between groundwater and root systems of beech trees being unlikely. The ecological surveys completed for the proposed scheme did not identify the presence of groundwater-dependent habitats[56]. These habitats are considered to therefore be fed by near-surface flow and precipitation. As a result, these habitats are not considered to be receptors and are not considered further.

13.7.114 Bushley Muzzard SSSI, previously known as Watercombe Marsh, is species-rich wet grassland supplied by localised springs and seepages[57]. It has been identified as supporting a groundwater-dependent habitat. It is located downgradient of the southern end of the proposed scheme. The SSSI is within a valley feature adjacent to the contact between the Great Oolite Group over the Fuller's Earth Formation. Consequently, there are springs associated with the geological contact in this area that contribute to the marshland conditions of the SSSI. These springs support fen-meadow (M22) vegetation, which may be sensitive changes in local groundwater condition[58].

13.7.115 Associated effects on the ecology of groundwater-dependent habitats are considered in Chapter 8 Biodiversity.

Rainfall and recharge

13.7.116 The recharge of the Inferior Oolite and Great Oolite aquifers primarily occurs within the Thames catchment. Rainfall and potential evapotranspiration vary over the Thames catchment area with rainfall being higher in the west and also increasing with topography[59] - both correlating to the location of the proposed scheme in the catchment. The mean annual rainfall in the area is 805mm and estimated recharge is 370mm per annum[60]. However, the amount of recharge is expected to vary as Morgan-Jones and Eggboro (1981) noted in the hydraulic years of 1975 and 1976 where recharge was 100mm and 630mm respectively.

13.7.117 The superficial deposit aquifers are recharged by a variety of mechanisms including rainfall infiltration, runoff from low permeability mudstones and groundwater draining from limestone aquifers higher in the landscape. It is possible that limestone inclusions within mudstone formations and the Marlstone Rock Formation could also be locally, hydraulically linked to the superficial deposit aquifer. In the Churn and Frome valleys, the superficial deposits may be leaking into the underlying Inferior Oolite limestones.

13.7.118 The Great Oolite limestone is recharged directly by rainfall. The underlying Fuller's Earth Formation perches the groundwater table, preventing connection to the underlying Inferior Oolite except where a fault is present. Springs emerging from the Great Oolite limestone and Fuller's Earth Formation boundary have the potential to recharge the Inferior Oolite limestones downgradient.

13.7.119 Recharge of the Inferior Oolite aquifer in the proposed scheme area is from rainfall and leakage from the overlying Great Oolite aquifer via leakage through faults or from runoff over Fullers Earth mudstone. However, Maurice et. al. (2008) suggest leakage from the Great Oolite to the Inferior Oolite may only occur during the wetter months of the year when drainage from the unconfined Great Oolite aquifer reduces the elevation of the water Table such that the saturated zone of the aquifer thins to an extent that transmissivity is greatly reduced[61].

13.7.120 Further information on aquifer recharge is presented in Appendix 13.4 Hydrogeological baseline conditions.

Groundwater quality

13.7.121 Limestone aquifers are particularly vulnerable to contamination, which may originate from point or diffuse sources. In accordance with the Nitrate Pollution

Prevention Regulations 2015, the EA have identified areas at risk of agricultural nitrate pollution and have designated these as Nitrate Vulnerable Zones (NVZs)[62]. Waters are defined within the Nitrates Directive as polluted if they contain, or could contain if preventative action is not taken, nitrate concentrations greater than 50mg/L[63].

13.7.122 The EA has designated the Upper Cotswold Plateau, limestone at the crest of the Cotswold escarpment and the northern side of Crickley Hill (approximately 220m north of the Proposed scheme at Crickley Hill) as an NVZ[64].

13.7.123 Bicarbonate-rich waters are expected to be the dominant water type in the region given the presence of limestone. The geochemistry of waters in carbonate aquifers is particularly affected by residence times and mixing with recharge, older formation water and/or anthropogenic influences. Water types can typically be categorised by source, age and geological conditions including aquifer confinement.

13.7.124 Groundwaters close to recharge areas are typically oxidising and strongly pH-buffered with calcium and bicarbonate ($HCO3^-$) as dominant dissolved ions[65]. Recharge areas are particularly susceptible to high nitrate concentrations from agricultural pollution. This is anticipated to be most reflective of unconfined waters that the proposed scheme may encounter.

13.7.125 Regionally, as groundwater becomes more confined, down gradient of recharge areas, ion-exchange processes occur, with sodium and bicarbonate being the dominant ions in the groundwater[66]. The process of ion exchange causes dissolved calcium ions in the groundwater to attach or ‘absorp’ onto the rock surface and, in exchange, sodium ions come off the rock surface and into the groundwater.

13.7.126 In more confined aquifers, dissolved oxygen is reduced or absent. This leads to more reducing conditions, which is evidenced by redox-sensitive elements[67]. Lower nitrate levels can suggest that denitrification may be occurring[68], however this could also be affected by mixing with old formation waters deep within the aquifer that have low nitrate levels when entering the aquifer.

13.7.127 Mixing with older formation water deeper within the confined aquifer results in a sodium-chloride type groundwater. Isotope analysis suggests a residence time in the order of thousands of years for these waters[69].

13.7.128 Neumman et al. (2003) concluded no significant differences in the chemistry of the Great and Inferior Oolite groundwaters can be observed[70].

13.7.129 During the Phase 1 ground investigation in February 2019, two groundwater samples were taken from the Birdlip Limestone of the Inferior Oolite aquifer (DS/RC 406) and Bridport Sand Formation (DS/RC 419). Sampling from Phase 2A boreholes has progressively been completed since 11 November 2019. A summary of the groundwater quality testing results is detailed in Appendix 13.4 Hydrogeological baseline conditions.

13.7.130 The composition of water samples from each geological formation is relatively similar where bicarbonate waters are the most common. Calcium is the dominant cation however some samples had higher concentrations of potassium and sodium. Samples with higher potassium and sodium concentrations were from the head deposits, Inferior Oolite Group and Lias Group mudstone.

13.7.131 Water samples were typically fresh (<1,560 µS/cm), however some slightly saline to moderately saline waters were sampled from Lias Group mudstones and head deposit samples. The highest EC reading was 5,600 µS/cm in DS/RC 224, located at the crest of the Crickley Hill escarpment where the Inferior Oolite Group and Lias Group mudstone are included in the response zone.

13.7.132 Exceedance of UK Drinking Water Standards occurred in the following samples:

- Sulphate as SO_4^{2-} – 392mg/l in CP 104 (head deposits);
- Nitrite as NO_2 – 1,600µg/l in DS/RC 110 (Inferior Oolite Group), 6,300 to 12,000µg/l in DS/RC 224, 750µg/l in CP 206 (head deposits), 650µg/l in DS/RC 403 (Fuller's Earth Formation);
- Manganese – 27 exceedances primarily from head deposits and Inferior Oolite group samples, where the maximum recorded concentration was 1,300µg/l in CP 206;
- Sodium – 240mg/l in DS/RC 110 (Inferior Oolite Group), 260 to 270mg/l in DS/RC 224 (Lias Group mudstone and Inferior Oolite Group); and
- Arsenic – 10.2µg/l in CP 200 (head deposits).

13.7.133 A review of groundwater quality with respect to published Environmental Quality Standards is presented in Chapter 9 Geology and soils.

Existing road drainage and outfalls

13.7.134 HADDMS[71] identifies five priority outfalls within the study area for the exiting A417 network. Three of these were classed as moderate priority (category C status), one as low priority (category D status) and one as risk addressed. HADDMS notes that the medium priority outfall south of the Air Balloon roundabout and the low priority outfall may be soakaways.

Accidental spillage

13.7.135 Incidents occurring on roads can cause spills of fuels and other potentially polluting substances. These spills can enter the road drainage system and consequently enter surface waters that receive highways drainage. There is also a risk of spills entering groundwater from natural infiltration.

13.7.136 Personal Injury Collision data on the A417 has been collected for five years until the end of April 2018[72]. The data indicates that the number of incidents is equal to the national average although there is a greater casualty rate per collision. As a result, there is potential for fuel spills and other spills of potentially polluting substances.

Future baseline

13.7.137 As set out in Chapter 4 Environmental assessment methodology, the 'Do Minimum' and 'Do Something' scenarios have been set out, with the 'Do Minimum' scenario representing the future baseline with minimal interventions and without new infrastructure. Potential changes to road drainage and water environment receptors in the future would not be noticeable i.e. accidental spillage is unlikely to change and the receptor groups are unlikely to be different to those whose identified in the baseline text above. Therefore, the future baseline would remain the same as set out above.

Assessment of importance

13.7.138 Table 13-12 summarises the assessment of the importance of water environment attributes within the study area in line with Table 13-2, and as per DMRB standards outlined in Section 13.4.

Table 13-12 Water environment receptors, attributes and importance

Receptor	Attribute/Features	Importance of Receptor	Quality
Surface water			
Tributary of Norman's Brook	Water supply/quantity	Medium	Watercourse not having a WFD classification shown in a RBMP, with 'Good' chemical status
	Conveyance of flow (presence of watercourses)	Medium	Headwater watercourse with flow of Q_{95} >0.001m^3/s
	Biodiversity	High	Potential for species protected under EC or UK legislation Ecology and Nature Conservation
Tributary of Horsbere Brook	Water supply/quantity	Medium	Watercourse not having a WFD classification shown in a RBMP
	Conveyance of flow (presence of watercourses)	Medium	Headwater watercourse with flow of Q_{95} >0.001m^3/s
River Frome and its tributaries	Water supply/quantity	High	WFD classified as 'Good' overall status
	Conveyance of flow (presence of watercourses)	Medium	Headwater watercourse with flow of Q_{95} 0.002m^3/s
Tributary of River Churn	Water supply/quantity	Medium	Watercourse not having a WFD classification shown in a RBMP
	Conveyance of flow (presence of watercourses)	Medium	Headwater watercourse with flow of Q_{95} 0.002m^3/s
Groundwater			
Superficial deposits - Secondary A aquifer	Water supply/quantity	Medium	Secondary aquifer and potential local resource
	Soakaway	Medium	No known discharge via soakaway; unsaturated zone thickness may be not sufficient to allow good infiltration conditions
	Vulnerability	High	Aquifer vulnerability is 'High'/'Medium-high'
	Conveyance of flow	Low	No evidence of providing base flow to a watercourse in study area
	Biodiversity	Low	No GWDTEs supported by this aquifer identified in the study area
Lias Group - Secondary (undifferentiated) aquifer	Water supply/quantity	Low	Secondary aquifer; primarily comprising unproductive strata (mudstone) within the proposed scheme area
	Soakaway	Low	Permeability of strata unlikely to allow good infiltration conditions
	Vulnerability	Medium	Aquifer vulnerability is 'Medium'

Receptor	Attribute/Features	Importance of Receptor	Quality
	Conveyance of flow	Low	No evidence of providing base flow to a watercourse in study area
	Biodiversity	Low	No GWDTEs supported by this aquifer identified in the study area
Inferior Oolite - Principal aquifer	Water supply/quantity	High	Principal aquifer and WFD waterbody; SPZ 3 and local abstraction points
	Soakaway	Very high	A number of discharges via soakaways present within study area; very deep unsaturated zone and bedrock properties allow for good infiltration conditions
	Vulnerability	High	Aquifer vulnerability is ‘High’
	Conveyance of flow	High	Numerous springs forming headwaters of tributary to Norman's Brook and River Frome
	Biodiversity	Low	No GWDTEs supported by this aquifer identified in the study area
Great Oolite - Principal aquifer	Water supply/quantity	High	Principal aquifer and WFD waterbody
	Soakaway	Medium	One known discharge via soakaway; encountered bedrock properties variable; unsaturated zone thickness may be not sufficient to allow good infiltration conditions
	Vulnerability	High	Aquifer vulnerability is ‘High’
	Conveyance of flow	High	Numerous springs forming headwaters of River Frome and River Churn
	Biodiversity	High	Supports Bushley Muzzard SSSI and GWDTE

13.8 Potential impacts

13.8.1 The proposed scheme has the potential to impact the water environment during construction and operation.

13.8.2 The following are the potential impacts considered during the assessment, and are based on consultation with the regulators, the designers and professional judgment.

Construction

13.8.3 During construction, likely significant effects to surface water features and groundwater features could arise from:

- increased pollution risks from mobilised suspended solids and spillage of fuels or other harmful substances e.g. cement that may migrate to surface water and groundwater receptors;
- impacts to the hydromorphological and ecological quality of watercourses associated with works within or in close proximity to watercourses, including physical change to the watercourses and longer-term changes associated with sediment deposition;
- impacts to local land drainage structures, that may alter existing drainage patterns within catchments and provide potential pathways for pollution; and
- impacts on local hydrogeology and groundwater resources, through changes to groundwater levels, flows and quality arising from construction activities,

primarily dewatering, construction of cuttings or shallow earthworks and intrusive investigation works creating new flow paths for groundwater.

13.8.4 Details on potential impacts are provided in the following sections.

Dewatering

13.8.5 Excavation of cuttings may encounter shallow groundwater or intersect the saturated aquifer, particularly in the section south of the proposed Shab Hill junction, where dewatering is likely to be required.

13.8.6 The Air Balloon cutting (Ch 1+700 to 3+100) will initially result in at grade widening of the existing A417 route corridor (up to Ch 1+800) and up to 5m cut below the existing highway level (Ch. 1+800 to 2+000) progressing into up to 12m cut (Ch2+000 to 3+100, maximum at approximately Ch. 2+500). The groundwater level monitoring indicates the groundwater levels up to 210mOD in that part of the Air Balloon cut. The lowest elevation of the proposed scheme in the cut section is 208mOD (at Ch. 1+700) at which point it is over 4m higher than the existing highway. This means that at that location the groundwater levels are already influenced by the existing highway drainage and are below the proposed scheme elevation. The proposed highway is above 210mOD from Ch. 1+720. This means that dewatering may be required on a very limited section of the proposed scheme.

13.8.7 Where works will require groundwater control measures e.g. local groundwater level reduction or removal of the water from the excavation (dewatering), this could locally reduce groundwater levels and divert flow. Discharge of removed groundwater into surface watercourses may impact the quality of the receiving watercourses, primarily through sediment release but also if the removed groundwater is contaminated.

13.8.8 Dewatering zone of influence may extend into the outer area of SPZ3 for the Baunton abstraction. The Baunton abstraction takes water from the Inferior Oolite Group aquifer, however the Stockwell-Nettleton cutting within the Great Oolite Group and dewatering impacts are unlikely to impact the abstraction.

13.8.9 These construction activities may lead to a reduction or cessation of spring flow and baseflow supplying watercourses within the Frome and Churn catchments, as well as adversely impacting on groundwater resources/abstractions.

13.8.10 Dewatering, if required, to allow stabilisation of the landslip material on Crickley Hill could significantly affect flow to springs rising from the escarpment, although the water would be returned to the tributary of Norman's Brook at the toe of the landslip.

13.8.11 A reduction of groundwater levels may cause settlement in soft cohesive deposits.

13.8.12 The impacts resulting from the dewatering works would also translate into impacts during the proposed scheme's operation primarily through operation of the road drainage.

Impacts of construction of cuttings on groundwater flow

13.8.13 Treatment of any voids (e.g. large fissures, gulls) encountered during construction may result in blockage of preferential flow paths within the rock mass. This could impact upon water resource availability for springs and baseflow.

Impact of shallow earthworks on groundwater flow and quality

13.8.14 Dewatering of shallow trenches and voids preparing for construction works can also drawdown the shallow groundwater table should the water table be intercepted. This risk will depend on the time of year as flows and levels will vary in an aquifer of this nature. This water may also be connected to spring systems which feed into local watercourse baseflows. The impact on groundwater resources is however considered to be localised and temporary.

13.8.15 Stockpiling of construction materials and excavated spoil may contaminate or pollute groundwaters if they are not stored correctly. These contaminants and pollutants may include fuels, hazardous substances and suspended solids. This has the potential to impact the water quality of the aquifer, springs, watercourses, abstractions and groundwater-dependent habitats. The flashy response of the limestone aquifers may exacerbate the extent of pollution and make it hard to contain. This is a concern in relation to the Baunton SPZ3.

13.8.16 Introduction of wet concrete and grout into the fissures of the Inferior Oolite Group or as part of soil nailing in the Crickley Hill escarpment landslip area have the potential to impact upon groundwater quality due to its inherently high pH and the potential to migrate. This would impact upon the water quality of the aquifer, springs, watercourse base flows and groundwater-dependent habitats.

13.8.17 Removal of topsoil or hardstanding and exposure of underlying soils to increased rainwater infiltration may result in pollutants leaching into the underlying groundwater.

Intrusive investigation work creating new flow paths

13.8.18 Ground investigation boreholes may create pathways through relatively low permeability formations, such as the Fuller’s Earth, and connect the Great and Inferior Oolite. New flow pathways for pollution may also be created, allowing polluted waters to enter water bodies not previously impacted by pollution. There may be localised impacts upon water quality within the aquifers.

New drainage systems (temporary works)

13.8.19 Construction works may reduce the rate of recharge to aquifers where the water is captured in relative to where it is discharged. This is likely to impact the flow of springs, watercourses, groundwater abstractions and groundwater-dependent habitats, such as Bushley Muzzard SSSI which may be adversely impacted by changes in groundwater levels or quality.

13.8.20 Drainage for construction works may also distribute contaminants and pollutants to other parts of the aquifer and create an accumulation of these substances where soakaway basins are used. Discharges via soakaways could lead to direct pollution of a strategically important aquifer underlying the proposed scheme.

13.8.21 Intensive rainfall may reactivate springs flows to cuttings or in dry valleys leading to drainage system overload and consequently result in flooding.

Works around watercourses

13.8.22 Physical change to watercourses and longer-term changes associated with sediment deposition are likely to have impacts on the hydromorphological and ecological quality of watercourses.

13.8.23 The proposed scheme would involve the realignment of the tributary of Norman’s Brook, which would result in the permanent loss of this hydromorphological feature.

13.8.24 The realignment of the tributary of Norman’s Brook may also result in the loss of geological features including tufa formations, which may also be of ecological importance in the area, and locally change the groundwater regime that feeds springs and baseflow in the vicinity. Potential ecological impacts are assessed in Chapter 8 Biodiversity.

13.8.25 These works would also result in the loss of geomorphological features and habitat niches within the channel, although there may be opportunities to deliver enhancement through the design of the realigned channel.

13.8.26 Working in, on or adjacent to watercourses may affect surface water quality through the accidental discharge of sediments or chemicals, including hydrocarbons. There may also be impacts to channel form through plant movements and operations. All works close to watercourses should be carefully designed and supervised.

Operation

13.8.27 During operation, the likely significant effects to surface water features, groundwater features and flood risk could arise from:

- polluted surface water runoff containing silts and hydrocarbons that may migrate or be discharged to surface water features or groundwater resources via the proposed highway drainage system, including from spillages;
- permanent impact to the hydromorphological and ecological quality of water features associated with works within or in close proximity to water features;
- permanent impacts to catchment hydrology and hydrogeology caused by the introduction of a barrier to natural overland flow e.g. introduction of embankments or below ground structures, and changes to natural catchment dynamics associated with the proposed highway drainage system;
- permanent impacts to catchment hydrology and hydrogeology caused by impact to natural groundwater springs or groundwater flow associated with proposed drainage in road cuttings that could affect baseflow to watercourses and groundwater resources;
- increased rates and volumes of surface water runoff from an increase in impermeable area or changes to the existing drainage regime leading to a potential increase in flood risk;
- increased flood risk to the proposed scheme and to people and property elsewhere caused by crossing of watercourses thus affecting flood flow conveyance;
- change in the rate of recharge of aquifers due to change in ground surface cover and introduction of new drainage systems; and
- reduced dilution and/or dispersion of consented discharges to groundwater and treated sewage effluent due to reduced or redirected groundwater flow paths.

13.8.28 There is limited information regarding the existing road drainage arrangements and water treatment provision. The proposed scheme may provide an opportunity to provide betterment.

13.8.29 Details on selected potential impacts are provided below.

<u>Changes to ground surface cover</u>

13.8.30 New areas of hardstanding and associated drainage systems may increase the rate of runoff and reduce the rate of recharge. This is likely to impact the flow of springs, watercourses, groundwater abstractions and groundwater-dependent habitats.

Impact of cuttings on groundwater flows and flow paths

13.8.31 The Air Balloon cutting may redirect groundwater flows in the Inferior Oolite. This is primarily a concern during and after recharge events (e.g. rainfall) as most of the cutting is expected to be excavated in the unsaturated zone. These temporary groundwater flows during recharge events may be directed to the cutting, which would act as a drainage line in the area and impact upon the water balance between the groundwater catchments. Cutting at the Air Balloon could intercept shallow spring systems and cut off their flow pathways making them dry overtime particularly in the Crickley Hill area.

13.8.32 Cuttings that intercept faults zones which act as a flow barrier, may connect previously disconnected strata and groundwater bodies with dissimilar qualities. New flow paths for pollution may also be created and allow polluted waters to enter water bodies not previously impacted by pollution. However, leakage though relatively low permeability formations via faulting is noted throughout the region, so the impact of any new flow paths that may be created is expected to be not significant on a regional scale. There may be localised impacts upon the water quality within the aquifers.

13.8.33 Cuttings associated with the Shab Hill junction and the road section stretching towards the Cowley junction could impact upon groundwater flows in the Great Oolite aquifers.

13.8.34 The impacts resulting from the cuttings would also translate into impacts during the proposed scheme's construction.

Embankments creating a barrier to flow

13.8.35 Embankments could create a barrier for surface water and springs currently recharging to the surface watercourses and redirection of flows to a different catchment, ultimately reducing catchment areas of the River Churn and the River Frome and changing the flow regime within these surface waters. This may also have consequential effects for aquatic ecology.

13.8.36 Construction of the embankment supporting the road widening along the Crickley Hill would result in the Norman's Brook tributary diversion, potentially into a watercourse elevated in relation to the current watercourse alignment. This may result in springs currently issuing into the watercourse infiltrating the proposed embankment and consequently reducing flows within the watercourse.

13.8.37 The Shab Hill junction is located within a dry valley and a number of ephemeral springs discharge seasonally into this valley, which could impact flows to Coldwell Bottom and the River Churn if they are intercepted by the proposed scheme.

13.8.38 Groundwater infiltrating the embankments may cause instability issues. Precipitation of calcium carbonate from groundwater into any engineering drainage designed to intercept groundwater may result in fouling of the matrix and subsequent reduction in hydraulic conductivity, resulting in potential impacts on stability and localised flooding. This is however unlikely to occur in the buried drainage infrastructure as the precipitation of calcium carbonate is a result of degassing of supersaturated water and is influenced by changes in temperature or flows, which typically occurs when the water emerges at surface. The review of exploratory hole logs did not identify evidence of cementation in coarse materials, which are similar in nature to drainage materials, that might indicate that precipitation of calcium carbonates occurs.

Road drainage in cuttings

13.8.39 The creation of a drain may divert water from one surface water catchment to another (between local surface water catchments within the Severn catchment, and between the Severn and Thames catchments). This interruption of flow may lead to a reduction or loss of water supply to abstractions, springs and watercourses and potential loss of habitat (which may be permanent). The loss of water from one catchment to another, potentially affecting resources availability further down-gradient in the confined aquifers.

13.8.40 A change in the groundwater flow regime and flood flow pathway may impact on receptors (properties and environmental) near to Flood Zones 2 and 3, and Bushley Muzzard SSSI, located just north of Flood Zones 2 and 3 for the River Frome.

13.8.41 Road drainage in cuttings in the section south of the proposed Shab Hill junction may create a localised reduction of groundwater levels, leading to a reduction or cessation of local spring flow. This may result in the depletion of existing watercourses and loss of water supply to groundwater receptors, including springs, watercourses and abstractions.

13.8.42 Road drainage in a cutting at Air Balloon junction may intercept groundwater over a very limited section of the proposed scheme, as detailed in Section 13.8.6, resulting in reduce groundwater flows towards Norman's Brook tributary. This may impact surface water flows in watercourses and have consequential effects for aquatic ecology.

13.8.43 Localised settlement may occur where affected water levels are within shallow cohesive deposits.

Road drainage discharge

13.8.44 Road drainage discharge of routine runoff to outfall, or soakaway if required, may cause a long-term degradation of water quality. Discharge of runoff during accidental spills, or collisions, or with elevated suspended solids concentrations, may have a significant impact on water quality.

13.8.45 The pollution of surface watercourses may result in the pollution of environmental receptors and the potential loss of aquatic habitat. This may, in turn, result in impacts on the amenity and economic value of surface water bodies.

13.8.46 An increase in the rate and volume of surface water runoff to surface watercourses may impact on properties and aquatic environments near to flood zones.

13.8.47 A reduction of recharge to the underlying aquifer may result in a reduction or loss of water supply to abstractions, springs, watercourses, and the potential loss of aquatic habitat (which may be permanent), and GWDTEs, such as Bushley Muzzard SSSI which may be adversely impacted by changes in groundwater levels or quality.

13.8.48 The loss of groundwater flow, due to cuttings and subsurface structures, may reduce the dilution potential of aquifers receiving discharge via soakaway. This may impact on receiving aquatic environments dependent upon groundwater.

Impact of below ground structures on groundwater flow

13.8.49 The proposed scheme comprises structures such as overbridges and underbridges. The conceptual structures foundation design indicates that the proposed structures would be founded on deep piled foundations, usually consisting of individual piles, sometimes constructed in groups of two or more. This kind of foundation would require a pile cap, a shallow concrete structure placed at or near ground level, providing protection to the inserted piles. Such below ground structures may act as barriers to shallow groundwater flow and they may provide more vertical downward pathways for perched/shallow groundwater flow into the deeper aquifer. Contamination migration as a result of the proposed scheme is considered in Chapter 9 Geology and soils.

13.8.50 These underground structures may cause local changes to groundwater flow and mounding of groundwater on the up-gradient side of the structure (raised groundwater levels on the up-gradient side with potentially reduced groundwater levels on the down-gradient side) causing creation or reactivation of springs or even induce groundwater flooding. This could have an impact on springs, watercourses, groundwater-dependent habitats and abstractions, where flow could be reduced or temporarily ceased. Considering the proposed structures as part of the proposed scheme and the extent of the below ground foundation works associated with these structures, these impacts are likely to be localised.

13.8.51 Deep foundations such as piling may create pathways through relatively low permeability formations, such as the Fuller's Earth, and connect the Great and Inferior Oolite aquifers. Deep foundations that intercept faults zones which act as a flow barrier, may connect previously disconnected strata and groundwater bodies with dissimilar qualities. New flow paths for pollution may also be created and allow polluted waters to enter water bodies not previously impacted by pollution. As discussed below, the impact of any new flow paths that may be created is expected to be not significant on a regional scale as leakage via faulting is noted throughout the region. There may be localised impacts upon the water quality within the aquifers.

Alteration of ground elevations

13.8.52 Alteration of ground elevations and changes in surface water flood flow pathways may result in the overloading of drainage systems and/or surface watercourses. This may impact on flood-sensitive receptors near to overloaded systems.

Culverting/structures within watercourses

13.8.53 A change in the flood flow pathway may impact on properties and aquatic environments close to flood zones. In particular, the realignment of the Norman's Brook tributary may result in flooding further upstream and downstream without appropriate mitigation to attenuate flows.

13.8.54 An interruption of flow in the watercourse may result in a reduction or loss of water supply to downstream receptors, including abstractions, rivers and wetland, and the potential loss of aquatic habitat (which may be permanent).

13.8.55 Polluted surface water runoff containing silts and hydrocarbons that may migrate or be discharged to surface water features or groundwater resources via the proposed highway drainage system.

Climate change

13.8.56 Chapter 14 Climate follows the methodology set out in LA 114 *Climate* and considers the effects related to climate change as per the requirements of EU

Directive 2014/52 and the 2017 EIA Regulations. The assessment of effects considers the combined impacts of the proposed scheme and potential climate changes on the receiving environment during construction and operation.

13.8.57 Future climate conditions derived from the UK Climate Projections 2018 (UKCP18) indicates that the study area may undergo climatic changes including higher temperatures, increase in heat waves, reduced precipitation in summer and increased precipitation in winter.

13.8.58 Surface water flows are likely to become more variable, with more frequent extremes including wetter winters and drier summers.

13.8.59 Increasing long spells of hot weather and wildfires may result in soils developing water repellence, which may reduce or temporarily impede water infiltration, leading to preferential flow and increased surface runoff.

13.8.60 These conditions are likely to reduce the amount of recharge to the groundwater which may have impacts upon features in the study area and cause some perennial features to become ephemeral. Abstractions, springs, groundwater-fed watercourses, areas of flooded ground and Bushley Muzzard SSSI are likely to be particularly sensitive to these impacts. Groundwater quality is also likely to be affected by a reduction in the flushing of aquifers, which may increase the residence time of groundwater within them.

13.8.61 While the impacts of climate change are likely to affect the water environment, no significant effects are predicted as a result of the incorporation of embedded mitigation in the proposed scheme design, such as climate change allowances in the drainage design identified within the FRA.

13.8.62 Mitigation is outlined and secured by way of commitments within the EMP. The EMP will be secured by a legal requirement in the DCO application, which, once granted, becomes the legal mechanism through which the mitigation is delivered.

13.9 Design, mitigation and enhancement measures

Construction mitigation

13.9.1 The EMP, to be provided as part of the ES, will include measures that are considered standard good practice to be implemented by the construction contractor to reduce the likelihood of impacts, or their magnitude if they were to occur. The EMP will include ground and surface water monitoring plans. Requirements for monitoring will be derived during the detailed design phase.

13.9.2 Works would also be carried out in accordance with any additional permitting requirements, for example Ordinary Watercourse Consent. Land drainage consents will be obtained from the LLFA, and will include information on all works, including temporary works, methodology and permanent design approval. Measures that are non-standard or site-specific are described below and these should be incorporated into the contractor’s construction method statement.

13.9.3 The standard measures to be included in the EMP will be based on the EA’s Pollution Prevention Guidelines (PPGs) (withdrawn in 2015), subsequent guidance on GOV.UK, the relevant CIRIA publications and best practice measures outlined in the PPGs replacement series, Guidance for Pollution Prevention (GPPs).

13.9.4 Examples of standard practice mitigation measures that will be included in the EMP include the provision of spill kits, restricting site traffic to dedicated haul roads and ensuring hard-standing areas are regularly swept and maintained.

13.9.5 Effective delivery of the measures set out in the EMP is to be monitored during the construction phase.

13.9.6 Site-specific measures would include:

- A surface water management system using measures such as temporary silt fencing, cut off ditches, settlement ponds and bunds set up early in the construction period to capture all runoff and prevent ingress of sediments and contaminants into existing drainage ditches where necessary. This would be managed by the EMP in accordance with CIRIA guidelines and the EA's approach to groundwater protection[73] and groundwater protection guidelines[74].
- Water with a higher risk of contamination which requires discharge, including groundwater pumped out of pilings during concrete pouring, would be contained and treated using appropriate measures such as coagulation of sediments, dewatering and pH neutralisation prior to discharge. Such discharges would be regulated via environment permits issued by the EA.
- Areas of exposed sediment deemed at risk of erosion during heavy rainfall or flood inundation should be protected using either temporary measures (e.g. sheeting) or semi-permanent measures (for example coir matting) until vegetation is able to establish on these surfaces.
- Works would be suspended during out-of-bank river flows or during intense rainstorms.
- A water quality monitoring programme prior to and during construction works would be agreed with EA.
- Tracer testing to identify and confirm groundwater flow paths and surface water interactions. It is anticipated additional tracer tests and hydraulic testing may be required to confirm hydraulic connectivity and properties of surface waters and groundwater bodies, define sub-catchments and fill gaps in knowledge following the previous rounds of surveys and monitoring.
- Appropriate sequencing and domaining of works, such as the Norman's Brook tributary realignment, to reduce impacts to surface and groundwater flows to be temporarily diverted downstream of the works area.
- Consideration of local groundwater catchment and flow regimes that may be affected by dewatering design and discharging the abstracted water to the same groundwater catchment and down gradient of the dewatered element.
- Discharge from dewatering activities such as earthworks, works within a floodplain or within eight metres of a watercourse will have a tailored risk assessment, consent and licences from the EA. Dewatering abstractions may also require transfer licenses from the EA.
- Grouting may be required to treat voids encountered during earthworks and ground stabilisation works that may involve soil nailing or soil anchors. It is inherently difficult to prevent grout from entering fissures. Therefore, appropriate grouting methodology to be used to reduce risk to the water environment. This will include limitation of grout volumes, monitoring for pH spikes in monitoring standpipes/surface flows, and specification of polymer grouts should this be required. The results of the tracer tests or any other investigations, where available, to be considered in grouting methodology development.

- A site-specific foundation works risk assessment (FWRA) for the construction of underground structures and ground improvement works.
- Design of underground structures will require drainage provisions to relieve hydrostatic pressure. These would allow for groundwater flow around the structure.
- Review and update of groundwater conceptual model as new, site-specific information is received.
- Review and update of the hydrogeological assessment as new, site-specific information is received.

13.9.7 Following the completion of post-construction groundwater monitoring, observation boreholes may be decommissioned. The decommissioning of the boreholes should be done in such a way that the material placed in the observation well mimics the annulus construction.

Operational embedded mitigation

13.9.8 Operational embedded mitigation is described in detail in Chapter 2 The Project.

Essential mitigation

13.9.9 Essential mitigation to address likely significant effects will be included following completion of the detailed assessment for the ES. Essential mitigation is likely to focus around maintaining groundwater and surface water responses to the greatest extent possible, as outlined in Table 13-13.

Enhancement

13.9.10 Opportunities for enhancing the different aspects of the water environment shall be sought and reported in the ES.

13.9.11 The new Norman's Brook would be designed to cater for the ecological requirements of aquatic species present in Norman's Brook. The barriers (man-made weirs) currently present within Norman's Brook would not be recreated in the new channel, which would be characterised by steep-pool habitat, typical of higher gradient headwater streams. The new channel would improve connectivity of habitat for aquatic species due to the removal of barriers. There may be a further enhancement opportunity around daylighting and restoring Norman's Brook as it runs under the old A417 at the bottom of Crickley Hill.

13.10 Assessment of likely significant effects

13.10.1 The provisional assessment of likely significant effects of the proposed scheme on surface water and groundwater receptors is presented in Table 13-16 and Table 13-17 for construction and operational effects respectively. The assessment is based upon current available information and professional judgement. At this point a precautionary view has been taken, however, these effects could reduce as the EIA progresses.

13.10.2 The proposed scheme will include road drainage that will capture pollutants within road runoff and remove pollutants before the treated runoff is discharged into surface water and groundwater features. The proposed scheme will provide a betterment of the existing road drainage system and hence improve the water quality of receiving surface water and groundwater.

13.10.3 The removal of the existing culverted section under the historic A417 carriageway, to the north of the proposed scheme, and daylighting, restoring and naturalising the channel may also provide an opportunity for potential enhancement.

Construction effects

Surface water

Surface water quantity

13.10.4 The scheme alignment generally traverses the watershed between the River Severn and Thames catchments, to the west and east, respectively. Several springs emerge along the flanks of this watershed boundary, flowing to the west and east and, as such, there are some areas of interaction with cuttings and earthworks associated with the scheme.

13.10.5 Potential impacts include modifications to the hydrology of existing springs or watercourses due to local changes in groundwater flow or levels resulting from cutting, structure or embankment drainage.

13.10.6 Four areas of embankment have been noted to be over existing springs and headwater streams. The location, hydrology and potential impact of each of these are summarised within Table 13-13.The potential magnitude of impact of embankment construction on the tributary of the River Churn is **minor adverse**, as flow regimes would be modified at a local scale, without a significant impact on the wider catchment. Therefore the effect would be **slight adverse** and not significant.

13.10.7 The potential magnitude of impact of embankment construction on the Norman's Brook tributary is **moderate adverse,** as flow regimes would be modified along a significant length of the watercourse, with an effect that would be **moderate adverse** and significant without mitigation. A moderate adverse significance of effect was selected because the change in flow regime would be reversed upon completion of the scheme.

13.10.8 The potential magnitude of impact of embankment construction on the unnamed tributary of River Frome is **moderate adverse,** as flow regimes would be modified close to the headwaters upstream of Bushley Muzzard SSSI, with an effect that would be **moderate adverse** and significant without mitigation. A moderate adverse significance of effect was selected because the change in flow regime would be reduced upon completion of the scheme.

13.10.9 The potential magnitude of impact of structure construction on the features identified in Table 13-13 is **minor adverse**, as flow regimes would be modified at a local scale, without a significant impact on the wider catchments. The effect would be **slight adverse** and not significant.

13.10.10 The assessment of potential effects as a result of the cutting drainage during the construction phase will be completed and presented in the ES.

13.10.11 Detailed assessment of embankments, cuttings and structures will be undertaken during detailed design to establish the likelihood for impacts of the scheme on each feature. Where an impact is established, additional (essential) mitigation would be implemented. With this mitigation in place the magnitude of impact would be reduced to **negligible**, leading to an effect that would be **neutral** and not significant, with the exception of Norman's Brook tributary and the unnamed tributary of the River Frome.

13.10.12 It is anticipated that the construction of the realigned channel of Norman's Brook tributary would impact upon the water levels of the watercourse. Unmitigated, the change in baseflows into Norman’s Brook tributary would result in an effect that is **moderate adverse** and significant. Design of essential mitigation measures through detailed drainage design would retain the recharge of flows in Norman’s Brook tributary and the unnamed tributary of the River Frome. Following this, the magnitude of is considered to be **negligible**. Therefore, the effect would be **slight adverse** and not significant.

Table 13-13 Summary of the springs and headwater streams affected by embankments and structures during construction

Receptor	Importance of receptor	Potential impact	Embedded design/ mitigation	Magnitude of impact	Significance of effect
Embankments					
Springs flowing into Norman's Brook tributary	High	Crickley Hill embankment constructed over route of headwater stream	Mitigation will maintain existing flow regime	Negligible	Slight adverse and not significant
Springs with seasonal flows into upper reaches of unnamed tributary of River Churn	Medium	Shab Hill and Cowley Junction embankments constructed over route of headwater stream			Neutral and not significant
Spring flowing into upper reaches of River Frome	Medium	Stockwell-Nettleton embankment constructed over route of headwater stream			Slight adverse and not significant
Piled Structures					
Springs with seasonal flows into upper reaches of unnamed tributary of River Churn	Medium	Piled foundations related Stockwell-Nettleton overbridge potentially impacting baseflow to the tributary by acting as a partial groundwater barrier	Structure drainage maintains flow directions and existing catchment areas wherever possible. Detailed assessment of groundwater -surface water interaction during detailed design.	Negligible	Neutral and not significant
Spring flowing into upper reaches of River Frome	High	Piled foundations Stockwell-Nettleton overbridge potentially impacting baseflow to the tributary by acting as a partial groundwater barrier			Slight adverse and not significant
Unnamed tributary of Horsbere Brook	Medium	Cuttings related to drainage basins potentially impacting baseflow to the tributary by acting as a partial groundwater barrier			Neutral and not significant

Surface water quality

13.10.13 Four receptors were identified as receiving potential impacts due to pollution during construction. The tributary of Norman's Brook and tributary of River Frome have an importance of **high**, whilst the tributary of the River Churn and tributary of Horsbere Brook have an importance of **medium**.

13.10.14 Following the implementation of mitigation listed in section 13.9, the magnitude of any pollution incident as a consequence of the construction of the scheme is likely to be **negligible**. Therefore, the effect would be **slight adverse** and not significant. A slight adverse significance of effect was selected for receptors of medium importance because effects may be detectable.

Hydromorphology

13.10.15 The widening of the A417 and its embankment through Crickley Hill requires the watercourse to be realigned. The realignment of the watercourse would impact upon channel morphology and may also impact upon hydrology by limiting the ability of the realigned watercourse to receive water from existing springs due to its raised bed level. The Hydromorphology Assessment will identify and assess the potential effects upon hydromorphology.

13.10.16 A potential adverse effect during construction of the scheme is from sediment runoff, which is considered to be suitably mitigated by the measures included in section 13.9

13.10.17 There would also be an adverse effect upon hydromorphology as a result of the temporary loss of Norman's Brook tributary through the construction period. This impact would be localised to the 1.1km section of watercourse from the existing culvert beneath the A417 to the spring at the head of the watercourse. Mitigation of this effect is unlikely to be feasible given the constraints on the construction area. Opportunities for enhancement of the realigned channel will be sought to offset the impact and provide net benefit.

13.10.18 There would also be an adverse effect during construction due to the loss of Norman's Brook tributary. With the sensitivity of the receptor being **high**, and a magnitude of impact of **moderate adverse**, the effect would be **moderate adverse** and significant. As the loss is temporary, a significance of effect for the loss of Norman's Brook tributary during construction is considered to be **moderate adverse**, and significant.

Groundwater

Groundwater levels and flows

13.10.19 A potential effect upon some groundwater features identified along the scheme prior to essential mitigation are presented in Table 13-14.

13.10.20 The assessment of potential impact on groundwater levels resulting from the proposed road drainage intercepting groundwater (i.e. in cuttings) will be completed and presented in the ES.

Table 13-14 Groundwater receptors potentially impacted by introduction of structures and cuttings from the scheme

Receptor	Importance of receptor	Potential impact	Embedded design/mitigation	Magnitude of impact	Significance of effect
Tributary of Norman's Brook springs (G152, G206)	High	Stabilisation measures related to Crickley Hill embankment and the realignment of the Tributary of Norman's Brook are likely to drawdown groundwater levels and permanently impact the springs.	None	Minor adverse	Moderate adverse
Groundwater dependent features at Crickley Hill	High	Construction of the Air Balloon cutting may have an impact on groundwater flow paths, particularly near the Cotswold escarpment where it may intercept fissures and gulls that transport groundwater to groundwater dependent features at Crickley Hill.	None	Minor adverse	Moderate adverse

13.10.21 Given that a change in groundwater level or flow may impact upon identified groundwater dependent features, mitigation is proposed in section 13.9 to reduce this impact to negligible. Therefore the effect would be **neutral** and not significant.

13.10.22 This is with an exception of:

- a potential **moderate adverse** significance of impact on tributary of Norman's Brook springs (G152, G206) from the introduction of stabilisation measures in the Crickley Hill area. Design of stabilisation (essential) mitigation measures will discharge captured groundwater into the realigned tributary therefore maintaining the net water balance within the catchment.
- A potential **moderate adverse** significance of impact on groundwater dependent features at Crickley Hill from intercepting/blocking flow paths as a result of voids treatment. This will require additional (essential) mitigation, which will include development of voids protocol setting out procedures and measures allowing for treatment of voids that will reduce impact on groundwater flows.

13.10.23 Following the essential mitigation, the magnitude of impact is considered to be **negligible**. Therefore, the effect would be **slight adverse** and not significant.

Groundwater quality

13.10.24 Groundwater receptors have been identified by ground investigation, water level monitoring and geophysical surveys to ensure that the location and connectivity with the scheme is understood prior to works. Available baseline information is presented in the Hydrogeological baseline conditions (Appendix 13.4). The importance of groundwater receptors is presented in Table 13-12.

13.10.25 Following the implementation of mitigation set out in Section 13.9, the magnitude of any pollution incident is likely to be **negligible**. Therefore, the effect would be **neutral** and not significant.

GWDTEs

13.10.26 The assessment of effects on GWDTE, particularly Bushley Muzzard SSSI, will be presented in the ES. It will be based upon the outputs from the hydrogeological conceptual model developed for the Hydrogeological Impact Assessment. It will evaluate the drawdown in groundwater levels associated with scheme's cuttings, in particular the Stockwell-Nettleton cuttings.

Accidental spillage

13.10.27 The EMP will accompany the ES and be submitted as part of the DCO application. This will include best practice measures for the storage of hazardous substances, the siting of higher risk activities (e.g. vehicle washdown areas) and the maintenance of plant.

13.10.28 Following the implementation of these practices upon the receptors outlined in Table 13-12, the magnitude of any accidental spillage is likely to be **negligible**. Therefore, the significance of effect would be **neutral** and not significant.

WFD compliance

13.10.29 The WFD Compliance assessment is being undertaken, with the baseline presented as Appendix 13.2.

Flood risk

13.10.30 The risk of flooding to the site during construction of the scheme is considered to be low, although several areas at medium to high risk of pluvial flooding, in particular around Norman's Brook tributary, and groundwater flooding have been identified in the Flood Risk Assessment that will accompany the ES as part of the DCO submission.

13.10.31 The risk of fluvial flooding to or from the site is low, however there are high areas of risk from surface water and groundwater flooding. Several ordinary watercourses cross the route of the scheme, however these are too small to be represented on EA flood mapping. The watercourses typically have constricted valleys and existing topography means the flood risk they pose is low. There are no main rivers crossed by the proposed alignment.

13.10.32 Surface water generated across the site would be managed by construction drainage (including suitably sized temporary settlement and attenuation basins, drainage ditches and culverts). This will be installed early in the construction period as per EMP which would manage surface and groundwater flooding to ensure that flood risk does not increase as a result of the scheme.

13.10.33 Suitable practices, such as the storage of plant and materials outside of flood prone areas, will be included within the EMP to be submitted with the ES as part of the DCO application.

13.10.34 Following the implementation of mitigation outlined in the EMP, the risk posed by flooding to and from the site from construction is considered to be **no change**. Therefore, the effect would be **neutral** and not significant.

Operational effects

Surface water

Surface water quantity

13.10.35 The effects upon surface water quantity are principally related to new embankments and cuttings and the interactions with existing water features. These potential effects are very similar during construction and operation of the scheme and have been discussed in full in Construction Effects (section 13.10.4 onwards). The significance of effects is therefore considered to be the same as the construction assessment, with the exception of Norman's Brook tributary.

13.10.36 Following detailed design, Norman's Brook tributary will be within a new realigned channel. The design of the realigned channel is anticipated to have similar characteristics to the existing channel. Therefore, the effect would be **slight adverse** and not significant.

Surface water quality

13.10.37 The drainage design of the scheme directs runoff from the mainline carriageway and realigned side roads to 12 outfalls to surface waters.

13.10.38 HEWRAT adopts a tiered approach as follows:

- Step 1: Runoff quality. This predicts concentrations of pollutants in untreated and undiluted highway runoff prior to any treatment and dilution in a water body.
- Step 2: In-river impacts. This predicts concentrations of pollutants after mixing within the receiving water body. At this stage, the ability of the receiving watercourse to disperse sediments is considered and, if sediment is predicted to accumulate, the potential extent of sediment coverage (i.e. the deposition index, DI) is also considered. Step 2 also incorporates two 'tiers' of assessment for sediment accumulation, based on different levels of input parameters. If one or more risks are defined as unacceptable at Tier 1, i.e. 'fail', then a more detailed Tier 2 assessment is undertaken, requiring values for further parameters relating to the physical dimensions of the receiving watercourse.
- Step 3: In-river impacts with mitigation. Steps 1 and 2 assume that the road drainage system incorporates no mitigation measures to reduce the risk. Step 3 includes mitigation in the form of Sustainable Drainage Systems (SuDS), taking into account the risk reduction associated with any existing measures or any proposed new measures.

13.10.39 A cumulative assessment will be undertaken for outfalls within 1km of each other for soluble pollutants and within 100m for sediment. Outfalls only qualified if they were within the same catchment. With embedded mitigation incorporated, all outfalls pass for sediment. All outfalls failed for soluble pollutants. Mitigation is therefore required within the detailed drainage design ensure that the appropriate treatment levels are met.

13.10.40 Effects upon designated areas (e.g. Bushley Muzzard SSSI) downstream of the discharge locations for the proposed drainage network are not anticipated.

Hydromorphology

13.10.41 Three new culverts are proposed within the scheme to enable the proposed highway to cross existing watercourses (Table 13-15). None of these watercourses are designated as main rivers. In addition to these culverts, there will be numerous smaller culverts conveying flows from the cut-off ditches under tracks and private accesses.

13.10.42 Culverts have the potential to effect watercourses by causing local shading, reducing river habitat connectivity and inducing hydromorphological change.

Table 13-15 New culverts proposed as part of the scheme.

Receptor (chainage)	Importance	Description	Embedded design/mitigation	Magnitude of impact	Significance of effect
Norman's Brook tributary (0+530m)	High	0.6m (existing) culvert to account for existing watercourse.	Design mitigation (section 13.9) and the CD 529 Design of outfall and culvert details standard and CIRIA C786 Culvert, Screen and Operation Manual guidance incorporated in the detailed design of the scheme	Negligible	Slight adverse
Dry valley at Shab Hill (3+200m)	Medium	1.2m culvert to account for dry valley.			
Dry valley at Stockwell (4+775m)	Medium	1.2m culvert to account for dry valley.			

13.10.43 New outfalls would be installed to discharge treated carriageway runoff from the drainage system to surface watercourses. The discharges would be limited to the Greenfield Runoff Rate, where infiltration is not possible, and would be located near to the proposed attenuation basins.

13.10.44 New outfall structures within a watercourse can alter local channel cross section and induce local bank or bed erosion, as well as reduce the available natural bank habitat area. These potential effects can be reduced by ensuring that outfall structures are sensitively designed based on the mitigation proposed.

13.10.45 The effects of these structures on WFD quality elements will be discussed in greater detail in the WFD Compliance Assessment that will accompany the ES as part of the DCO submission

13.10.46 Provided the design mitigation (section 13.9) and the CD 529 Design of outfall and culvert details standard and CIRIA C786 Culvert, Screen and Operation Manual guidance is incorporated in the detailed design of the scheme, the magnitude of impact is considered to be negligible. Therefore, the effect would be **slight adverse** and not significant.

Groundwater

Groundwater levels and flows

13.10.47 The effects upon groundwater quantity are principally related to new structures (with associated foundations) and cuttings, and any changes in groundwater levels or flows related to dewatering by the road drainage. These potential effects are very similar during construction and operation of the scheme and are discussed in full in Construction Effects (section 13.11.12 onwards). The assessment of effects from cuttings and associated highway drainage will be presented in the ES.

13.10.48 Given that a change in groundwater level or flow may impact upon identified groundwater dependent features, mitigation is proposed in section 13.9 to reduce this impact to negligible resulting in an overall effect of **neutral to slight adverse** and not significant.

13.10.49 This is with an exception of a potential moderate adverse significance of impact on tributary of Norman's Brook springs (G152, G206) from the introduction of stabilisation measures in the Crickley Hill area. Design of stabilisation measures (essential mitigation) will discharge captured groundwater into the realigned watercourse tributary therefore maintaining the net water balance within the catchment. Considering the high value of the receptor (Norman's Brook) and negligible magnitude of impact, the effect would be **slight adverse** and not significant.

Groundwater quality

13.10.50 An assessment following Appendix C of LA 113, which will consider the impact of infiltration of road runoff to groundwater will conducted for all discharge locations for the scheme and will be presented in the ES.

13.10.51 In accordance with Appendix C of LA 113, should a 'medium' or 'high' risk of impact be indicated, detailed assessment is to be undertaken by a competent expert. The detailed assessment would be undertaken as part of the detailed design, on confirmation of the drainage solution.

13.10.52 Should the detailed assessment indicate that additional mitigation measures are required to reduce the risk to a suitable level, these may include the drainage design to incorporate feasible treatment, or where this is not possible, no infiltration will be permitted. Considering the high value of the receptor (groundwater supply and quality) and impact resulting in no change, the effect would be **neutra**l and not significant.

GWDTEs

13.10.53 The assessment of effects on GWDTE, particularly Bushley Muzzard SSSI, will be presented in the ES. It will be based upon the outputs from the hydrogeological conceptual model developed for the Hydrogeological Impact Assessment. It will evaluate the drawdown in groundwater levels associated with scheme's cuttings, in particular the Stockwell-Nettleton cuttings.

Accidental spillage

13.10.54 Assessment of accidental spillages of polluting substances from roads will be carried out using Appendix D as prescribed in DMRB LA 113 using vehicle numbers from 2039 AADT traffic flows, taken from the scheme's traffic model, to account for future growth.

13.10.55 On all roads, there is a risk that an accidental spillage or vehicle fire may lead to an acute pollution incident. LA 113 states that the pollution risk on any road is linked to the risk of an HGV road traffic accident. Where a spillage does reach a surface watercourse the pollution effect can be severe but is usually of short duration.

13.10.56 The acceptable risk of a pollution incident, as stated in LA 113, is an annual probability of less than 1%, or a return period of 1 in 100 years.

Flood risk

13.10.57 The risk of flooding to the site during operation of the scheme is considered to be low, with very low risk of fluvial flooding. However, areas of medium to high risk of pluvial flooding, in particular around Norman’s Brook tributary, and groundwater flooding have been identified in the Flood Risk Assessment (Volume 6 Document Ref 6.4 Appendix 13.3).

13.10.58 Outputs from preliminary modelling will be presented in the Flood Risk Assessment that will accompany the ES.

13.10.59 Further detailed modelling is required to fully understand the residual flood risk and to include the scheme following design of the realignment of Norman’s Brook tributary and the scheme’s drainage design, to ensure that flood risk does not increase as a result of the scheme. The detailed design of Norman’s Brook tributary and the drainage system in this area, to control peaks to the inlet of the Norman's Brook culvert, will be undertaken to improve the resilience of the area. It is assumed that the scheme will be designed to not cause any detriment to fluvial, surface or groundwater flood risk. Further modelling will be undertaken in the detailed design phase of the scheme.

13.10.60 It is anticipated that the greater standard of flood protection included for the scheme over the existing A417 between Cowley Junction and Witcombe would be a benefit to road users travelling through the area.

Significance of effects

13.10.61 Table 13-16 and Table 13-17 outline the summary of significant effects following the embedded mitigation through design and essential mitigation measures identified to address significant effects, identified in previous sections, for the construction and operation of the scheme, respectively.

Table 13-16 Preliminary Assessment of Effects – Construction

Receptor	Potential Impacts and Effects	Design and Mitigation	Likely Significant Effect?
Surface water	Dewatering during earthworks altering existing drainage patterns within catchments and provide potential pathways for pollution	The contractor will adhere to pollution prevention procedures, to be outlined in the EMP and in accordance with CIRA guidelines. Appropriate risk assessments and consents will be obtained from the EA and a Land Drainage Consent will be obtained from the LLFA for working within 8m of a watercourse.	No
Surface water	Degradation of surface water quality, as work near to watercourses has the potential to discharge site runoff into watercourses. In addition, there is risk of accidental spillage of pollutants (e.g. fuel leakage from the storage of plant). Four receptors were identified as receiving potential impacts due to pollution during construction. The tributary of Norman's Brook and tributary of River Frome have an importance of high, whilst the tributary of the River Churn and tributary of Horsbere Brook have an importance of medium.	Comprehensive temporary construction drainage scheme to trap and remove pollutants before reaching the receiving environment. Following the implementation of mitigation which will be detailed in a Groundwater and Surface Water Management Plan as part of the EMP, the magnitude of any pollution incident as a consequence of the construction of the scheme is likely to be negligible. Therefore, the effect would be slight adverse and not significant. A slight adverse significance of effect was selected for receptors of medium importance because effects may be detectable.	No
Surface water	Potential introduction of sediments, particularly fine particles which could smother fish spawning areas.	Comprehensive runoff control installed at the start of construction to trap sediment. Sediment within sediment traps to be removed periodically, when required to maintain adequate capacity.	No
Surface water	Realignment of tributary of Norman's Brook.	Re-creation of watercourse following detailed design. Details are provided in Chapter 2 The project.	Potentially adverse, given an importance of 'High' and likely 'Moderate adverse' magnitude on account of the watercourse being realigned.
Groundwater	Introduction of new flow paths between aquifers due to ground investigation works allowing groundwater pollutants migration.	Clean drilling technique. Appropriate decommissioning of installations.	No

Receptor	Potential Impacts and Effects	Design and Mitigation	Likely Significant Effect?
Groundwater	Degradation of groundwater quality (including spillage, stockpiles of construction material, earthworks, polluted runoff, temporary drainage, change in ground cover).	The contractor will adhere to pollution prevention procedures, to be outlined in the EMP (i.e. pollution control, groundwater monitoring, as outlined in Section 13.9) and in accordance with CIRA guidelines. Temporary drainage design Groundwater quality monitoring.	No
Groundwater	Pollution of groundwater due to loss of grout/cement from piling operations or ground improvement such as soil nailing/anchoring.	Baseline data collection and update of groundwater conceptual model. FWRA EMP (pollution control, groundwater monitoring, as outlined in Section 13.9) Grouting methodology.	No
Groundwater	Construction activities of embankments, voids treatment, underground structures may affect groundwater flow - redistribution of flow paths and rate; new flow paths; affecting groundwater dependant features, aquifer and surface water recharge.	Baseline data collection an update of groundwater conceptual model. Voids treatment protocol FWRA EMP (as outlined in Section 13.9).	No
Groundwater / Surface water	Construction activities of cuttings, trenches (incl. dewatering) may affect groundwater flow - redistribution of flow paths and rate; new flow paths; affecting groundwater dependant features, aquifer and surface water recharge.	Baseline data collection an update of groundwater conceptual model. Temporary drainage design. EMP (as outlined in Section 13.9).	Assessment to be undertaken in the ES
Groundwater	Intensive rainfall may reactivate spring flow to cuttings or in dry valleys leading to flooding.	Temporary drainage design.	No
Groundwater	Change in runoff and aquifer recharge rates due to temporary drainage networks.	Baseline data collection and update of groundwater conceptual model.	No

Table 13-17 Preliminary Assessment of Effects – Operation

Receptor	Potential Impacts and Effects	Design and Mitigation	Likely Significant Effects?
Surface water	Excavation of the cutting through Shab Hill and the top of Crickley Hill may act as a pathway that diverts surface water between catchments (between sub catchments of the Severn catchment, and between Severn and Thames catchments).	Drainage design to maintain existing catchments water balance.	No
Surface water	Road drainage could introduce contaminants or increase concentrations of contaminants to watercourses.	Comprehensive SuDS scheme to remove pollutants before reaching the environment and provide habitat and amenity benefits.	No
Surface water	Changes to flow regime as a result of changes to groundwater-surface water interactions.	Cutting or structure drainage maintains flow directions and existing catchment areas wherever possible. Mitigation for effects associated with embankments will be detailed in the EMP will maintain existing flow regime Detailed assessment of groundwater-surface water interaction during detailed design.	No
Surface water	Changes to aquatic habitats and associated niches through changes to flow regime as a result of changes to groundwater-surface water interactions:	The potential magnitude of impact of cuttings and structures on the features identified in is **minor adverse**, as flow regimes would be modified at a local scale, without a significant impact on the wider catchments. The effect would be **slight adverse** and not significant	No
Surface water	Creation of diverse habitat niches and sediment and flow regimes within realigned channel.	Delivered through design.	No
Surface water	Introduction of artificial structures into the water environment (especially culverts).	Effective mitigation to be introduced at detailed design.	No
Surface water	Potential introduction of sediments, particularly fine particles which could smother fish spawning areas.	Comprehensive SuDS scheme to trap sediment and provide habitat and amenity benefits.	No
Groundwater	Introduction of new flow paths between aquifers or recharge of aquifers due to cuttings intercepting flow	Baseline data collection and update of groundwater conceptual model.	No

Receptor	Potential Impacts and Effects	Design and Mitigation	Likely Significant Effects?
	paths, fault zones and/or piling also allowing groundwater pollutants migration.	Drainage design FWRA.	
Groundwater	Change in groundwater resource due to highway drainage.	Baseline data collection and update of groundwater conceptual model. Drainage design.	Assessment to be undertaken in the ES
Groundwater	Embankments and/or underground structures may affect groundwater flows and recharge rate; new flow paths; affecting aquifer and surface water catchment and recharge.	Baseline data collection an update of groundwater conceptual model. Design to include drainage solution to allow groundwater infiltration/flow. Structures design.	No
Groundwater	Drainage in cuttings may result in permanent lowering of groundwater levels and impacting groundwater resources/ dependent features incl. springs, abstraction points, Bushley Muzzard SSSI.	Baseline data collection and update of groundwater conceptual model. Drainage design.	Assessment to be undertaken in the ES
Groundwater	Drainage aspects of ground improvement works for colluvium stabilisation, and/ or road drainage resulting in partial or total loss of springs.	Baseline data collection and update of groundwater conceptual model. FWRA. Drainage design.	No
Groundwater	Intensive rainfall may reactivate springs to cuttings and drainage system being overwhelmed leading to flooding.	Drainage design to consider groundwater flows.	No
Groundwater	Intensive rainfall may reactivate springs flows in dry valleys buried by embankments drainage system being overwhelmed leading to flooding and potential instability issues.	Embankments design to allow for groundwater infiltration.	No
Groundwater	Precipitation of calcium carbonate from groundwater may result in fouling of the drainage layer, resulting in potential impacts on stability also localised flooding.	Collection of baseline data to increase understanding of tufa formation process; Drainage design and maintenance options (also to incorporate long-term maintenance considerations).	No

13.11 Monitoring

13.11.1 A pre-construction (baseline) monitoring strategy has been developed to provide a holistic understanding of all aspects of the water environment in this locality, including the inter-relationships between groundwater and surface water, and particular elements of these including flow regime, water quality, ecology and geomorphology.

13.11.2 The monitoring strategy identifies groups of representative features to monitor, particularly watercourses, groundwater springs and groundwater boreholes.

13.11.3 Monitoring will be conducted pre and during construction of the proposed scheme in catchments where impacts have been identified.

13.11.4 The duration of monitoring is intended to be sufficient to provide baseline data and allow comparison between the baseline and subsequent monitoring during the construction and operation of the project.

13.11.5 Water (surface and ground) monitoring of parameters would be conducted across the proposed scheme at appropriate locations to detect any changes in the water environment from the construction phase, and to determine locations for additional new mitigation or maintenance of existing mitigation measures.

13.11.6 Water monitoring of the following groups of parameters (selected to capture construction and operational risks), will be undertaken as a minimum, with results plotted against appropriate trigger values, based upon WFD status and baseline monitoring results:

- laboratory testing for hydrocarbons, suspended solids and heavy metals;
- in-situ testing of physio-chemical parameters, such as pH, electrical connectivity, dissolved oxygen and turbidity and suspended solids; and
- streamflow, where impacts to hydromorphology have been identified.

13.11.7 Where significant adverse environmental effects are reported for a scheme, projects shall undertake monitoring in accordance with LA 104. Further details of monitoring will be agreed with Highways England and will be summarised in the Environmental Statement.

13.12 Summary

13.12.1 This road drainage and water environment chapter of this PEI report describes the existing conditions associated with the water environment within the study area and provides an assessment of the potential effects on surface water, groundwater and flood risk that may result from the proposed scheme.

13.12.2 A stand-alone FRA and a WFD compliance assessment will be appended to the ES. It is considered that there is potential for the proposed scheme to have significant effects on the water environment, as a result of the highly sensitive nature of the receiving environment.

13.12.3 A summary of the preliminary likely significant effects of the proposed scheme is presented below. This is based upon currently available information and professional judgement. However, these effects could change as the EIA progresses.

Preliminary construction assessment

- Adverse effect on surface water - realignment of tributary of Norman’s Brook.

Preliminary operation assessment

- No operational significant effects are anticipated.

Further Work

13.12.4 The WFD compliance assessment, HIA and FRA will be reported within the ES which will accompany the DCO application.

13.12.5 Collection of baseline data is currently on-going and additional information will be incorporated into the conceptual groundwater model and further assessments when it becomes available. It is anticipated that this will provide clarity on the likely significant effects upon water environment receptors.

13.12.6 In addition, work is continuing on the water quality assessment (using the HEWRAT tool), the hydromorphology assessment, the spillage risk assessment, the hydrological impact assessment and the groundwater dependent terrestrial ecosystem assessment. These will be reported on in the ES.

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