A417 Missing Link

Preliminary Environmental Information Report

Chapter 13 Road Drainage and the Water Environment - Appendices

28 September 2020

Contents

A417 Missing Link

Preliminary Environmental Information Report

Appendix 13.1
Water Legislative and Policy Framework

28 September 2020

Table of Contents

1 Water legislation and policy framework

1.1 European legislation

Water Framework Directive (WFD) 2000/60/EC

1.1.1 The WFD provides a framework for the protection of inland surface waters (rivers and lakes), transitional waters (estuaries), coastal waters and groundwater. The WFD requires European Union (EU) Member States to establish river basin districts (RBDs), and to prepare, implement and review a River Basin Management Plan (RBMP) for each RBD every six years. The current period from 2015-21 is cycle 2 of these RBMPs.

Groundwater Daughter Directive (GDD) 2006/118/EC

1.1.2 A Daughter Directive of the WFD, the GDD establishes a regime which sets groundwater quality standards and introduces measures to prevent or limit inputs of pollutants into groundwater – clarifying some objectives of the WFD. Amended by Directive 2014/80/EU to clarify groundwater information to be provided to the European Commission. EU Member States must provide information on groundwater bodies classified as being at risk and threshold values for the respective pollutants and indicators established.

Floods Directive 2007/60/EC

1.1.3 The Floods Directive 2007/60/EC requires EU Member States to: assess if watercourses and coastlines are at risk from flooding; map flood extents, assets and humans at risk in these areas; and to take adequate and coordinated measures to reduce this flood risk. The Directive requires that flood risk management plans be prepared, implemented and reviewed every six years for each RBD, in coordination with RBMPs prepared under the WFD.

Habitats Directive 92/43/EEC and Birds Directive 2009/147/EC

1.1.4 The Habitats Directive 92/43/EEC and Birds Directive 2009/147/EC ensure the conservation of a range of rare or threatened species. They establish the EU wide Natura 2000 ecological network of protected areas to safeguard against potentially damaging developments.

Priority Substances Directive 2013/39/EU

1.1.5 The Priority Substances Directive 2013/39/EU amends WFD 2000/60/EC and the Environmental Quality Standards Directive (2008/105/EC) by updating the list of priority substances that would apply to WFD assessment.

Urban Wastewater Treatment Directive 91/271/EEC (as amended) (UWWT Directive (consolidated))

1.1.6 The Urban Wastewater Treatment_Directive 91/271/EEC (as amended) concerns the collection, treatment and discharge of urban waste water and the treatment and discharge of waste water from certain industrial sectors. The objective of the Directive is to protect the environment from the adverse effects of the above-mentioned waste water discharges.

1.2 National legislation

Environmental Protection Act 1990

1.2.1 The Environmental Protection Act 1990 makes provision to control pollution arising from industrial and other processes for waste management.

Land Drainage Act 1991 (as amended)

1.2.2 The Land Drainage Act 1991 requires that a watercourse be maintained by its owner. The Act provides functions to internal drainage boards and local authorities to manage watercourses and provide consenting powers for proposed works to watercourses associated with development.

Water Resources Act (England and Wales) 1991 (as amended in 2009)

1.2.3 The Water Resources Act 1991 (as amended in 2009) sets out the responsibilities of the Environment Agency (EA) in relation to water pollution, resource management, flood defence, fisheries and navigation.

Environment Act 1995

1.2.4 The Environment Act 1995 sets new standards for environmental management, such as requiring national strategies for air quality and waste. It also deals with the establishment of the EA.

Water Act 2003

1.2.5 The Water Act 2003 amends the Water Resources Act 1991 and the Water Industry Act 1991 to make provision with respect to compensation under section 61 of the Water Resources Act 1991.

Water Resources (Abstraction and Impounding) Regulations 2006

1.2.6 The Water Resources (Abstraction and Impounding) Regulations 2006 contain provisions relating to the licensing of abstraction and impounding of water in England and Wales in the light of amendments made by the Water Act 2003 to the Water Resources Act 1991. The 2006 regulations have been updated by the Water Abstraction and Impounding (Exemptions) Regulations 2017.

The Water Abstraction and Impounding (Exemptions) Regulations 2017

1.2.7 The Water Abstraction and Impounding (Exemptions) Regulations 2017 contain circumstances where water abstractions and impounding works are exempt from licensing requirements.

Flood Risk Regulations 2009

1.2.8 The Flood Risk Regulations 2009 transpose the EC Floods Directive (2008/60/EC) on the assessment and management of flood risk into domestic law in England and Wales and implement its provisions. The regulations designate a Local Lead Flood Authority (LLFA) and impose duties on the EA and LLFAs to prepare a number of documents including:

- preliminary flood risk assessments;
- flood risk and flood hazard maps; and
- flood risk management plans.

The Water Supply (Water Quality) Regulations 2018

1.2.9 The Water Supply (Water Quality) Regulations 2018 provide the framework for drinking water quality in England in respect of public supplies provided by water companies and licensed water suppliers. The Drinking Water Inspectorate, acting on behalf of the Secretary of State, enforces the legislation.

Flood and Water Management Act 2010

1.2.10 The Flood and Water Management Act 2010 gives the EA a strategic overview of the management of flood and coastal erosion risk in England. In accordance with the Government's Response to the Pitt Review, it also gives upper tier local authorities in England responsibility for preparing and putting in place strategies for managing flood risk from groundwater, surface water and ordinary watercourses in their areas.

The Environmental Damage (Prevention and Remediation) (England) Regulations 2015

1.2.11 These regulations are based on the 'polluter pays' principle and impose obligations on operators of economic activities requiring them to prevent, limit or remediate environmental damage. They apply to damage to protected species, natural habitats, sites of Special Scientific Interest (SSSI), water and land and implement directive 2004/35/EC, on environmental liability.

The Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015

1.2.12 The WFD Directions present the updated environmental standards to be used in the second cycle of the WFD (2000/60/EC) river basin management planning process in England and Wales. Environmental standards help assess risks to ecological quality of the water environment.

The Groundwater (Water Framework Directive) (England) Direction 2016

1.2.13 The direction sets out instructions to the EA on obligations to protect groundwater, including requirements to monitor and set thresholds for pollutants, add new pollutants to the monitoring list and change the information reported to the European Commission.

The Environmental Permitting Regulations 2016 (SI 2010/675) (as amended in 2018 and 2019)

1.2.14 The Environmental Permitting (England and Wales) Regulations (SI 2010/675) were amended in order to extend the requirement for an environmental permit to flood risk activities, in addition to polluting activities included under the previous regulations. The permitting requirements for flood risk activities allow the EA (as regulator for England) to concentrate on higher risk activities. The 2010 regulations revoked the 2009 Groundwater Regulations, which originally implemented the Groundwater Directive.

The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017

1.2.15 The WFD has been transposed into the Water Environment (Water Framework Directive) (England and Wales) Regulations 2017. WFD is delivered in England

and Wales through a framework of River Basin Management Plans (RBMPs). England and Wales are divided into 11 River Basin Districts (RBDs), each comprising smaller management units known as water bodies, including all river, lake, groundwater, coastal and transitional waters located within that RBD.

1.3 National policy

National Policy Statement for National Networks (NPSNN)

1.3.1 The NPSNN sets out the need and governmental policies for nationally significant rail and road projects for England. Sections 5.90 to 5.115 set out how flood risk impacts should be considered, whilst sections 5.219 to 5.231 cover the assessment of impacts to water quality and resources.

The National Planning Policy Framework 2019 (NPPF)

1.3.2 The NPPF provides a framework within which local people and their accountable councils can produce their own distinctive local and neighbourhood plans. Section 14, titled “Meeting the challenge of climate change, flooding and coastal change” relates to flooding. The policy states that development should be directed away from areas at highest risk of flooding (both existing and predicted), however, where necessary, the development must be safe, for the lifetime of the development, without increasing flood risk elsewhere.

1.4 Regional policy

Cycle 2 RBMPs 2015-2021

1.4.1 The proposed scheme spans the boundary between two RBDs, the Severn and the Thames. These plans provide a framework for protecting and enhancing the benefits provided by the water environment. They also inform decisions on land use planning. Cycle 3 RBMPs are currently being prepared for introduction in 2021.

Flood Risk Management Plans (FRMPs) 2015-2021

1.4.2 The proposed scheme spans the boundary between two RBDs, the Severn and the Thames. The FRMPs set out how organisations, stakeholders and communities will work together to manage flood risk.

1.5 Local policy, strategy and evidence

Gloucestershire Local Flood Risk Management Strategy 2014

1.5.1 Gloucestershire Local Flood Risk Management Strategy 2014 sets out how Gloucestershire County Council and its partner authorities intend to work together to manage flood risk. This strategy is supported by a live action plan which is reported on annually. This Local Flood Risk Management Strategy has been adopted to guide the development of policy and programmes across Gloucestershire County Council’s operations and in its work with other organisations, communities and stakeholders.

Level 1 Strategic Flood Risk Assessment (SFRA) for Gloucestershire 2008

1.5.2 A tool for planning authorities to identify and evaluate flood risk in their area with the aim of directing development to the areas of lowest risk of flooding valid until 2026.

Gloucestershire SuDS Design and Maintenance Guide 2015

1.5.3 The guide sets out Gloucestershire LLFA’s approach to sustainable drainage and aims to aid developers incorporate Sustainable Drainage Systems (SuDS) into their plans. Gloucestershire County Council takes a proactive approach to encourage the use of SuDS for the management of surface water.

Gloucestershire County Council: Flood Risk Assessment Guidance Note (March 2015)

1.5.4 The guidance note is for Local Planning Authorities on Development and Flood Risk. The note details the main flood risk that should be considered and how climate change should be accounted for. The approach to management of surface water is detailed including description of how SuDS can manage surface water run-off. Further considerations detailed include disposal to public sewer, designing for exceedance and developments that are part of a larger proposal.

Cotswold District Local Plan (2011-2031)

1.5.5 The local plan sets out a number of policies with respect to the built, natural and historic environment, placing emphasis on promotion the protection, conservation and enhancement of the natural environment. Policy EN1 seeks to improve “water quality where feasible”. Policy EN4 directly links with the Cotswolds AONB Management Plan (2013-2018) and highlights the special qualities of the Cotswolds including river valleys forming headwaters of the Thames.

1.5.6 Development will not be permitted if it results in unacceptable risk to the natural environment including pollution of surface, or groundwater sources (Policy EN15). This policy also places requirements on the landowner/developer to undertake necessary remedial works on affected sites.

1.5.7 Policy EN14 – Managing Flood Risk: The policy states that development must avoid areas at risk of flooding in accordance with a risk-based sequential approach that takes account of all flooding sources. Minimising flood risk and providing resilience will be achieved by applying the sequential test, outlined in the section entitled ‘Flood Risk and Coastal Change’ of the Planning Practice Guidance; or requiring a SFRA. In addition, the design of development should account for flood risk management and climate change with SuDS. Developers could be required to fund flood management and/or mitigation measures and maintenance.

1.5.8 Policy INF8 – Water Management Infrastructure: The policy states that proposals should consider the impact on off-site water and wastewater infrastructure and make improvements where required. Additionally, proposals should not result in the deterioration of water quality and demand management measures should be implemented. SuDS should be incorporated where appropriate and pollution of groundwater sources should be avoided. The policy specifies further requirements for proposals in Source Protection Zone (SPZ) 1.

Gloucester, Cheltenham and Tewkesbury, Joint Core Strategy 2011-2031

1.5.9 The Joint Core Strategy (JCS) is a partnership between Gloucester City Council, Cheltenham Borough Council, and Tewkesbury Borough Council. It presents a joint and coordinated strategic development plan up for 2011 to 2031 for the three authorities. It was adopted in December 2017. The plan strives for conservation, management and enhancement of the natural environment, and to maximise the opportunities to use land to manage flood water. Policy SD14: Health and Environmental Quality states that a new development must not result in unacceptable levels of water pollution with respect to national and EU limit values.

1.5.10 Policy INF2 - Flood Risk Management states development must accord with the sequential approach and increase risk of safety to occupier, community or wider environment. For strategic sites, the cumulative impact of development on flood risk in relation to existing settlements, communities and allocated sites must be assessed and mitigated. The policy sets out the requirements to reduce the risk of flooding and provide resilience to flooding while accounting for climate change.

Tewkesbury Borough Plan 2011-2031, Draft policies and site options for public consultation (Feb 2015)

1.5.11 Consultation of the proposed draft policies closed in October 2018, however no final document has been published. The Tewkesbury Borough Plan, section K Landscape, Biodiversity and Nature, Policy ENV3 is aligned with the NPPF and the JCS with respect to protection of designated sites.

1.5.12 Section J – Flooding states that development proposals will be relying on NPPF Framework paragraphs 100, 101, 102, 103 and 104. The Joint Core Strategy – Policy INF3 should also be adhered to.

Cotswolds Area of Outstanding Natural Beauty (AONB) Management Plan 2018-2023

1.5.13 Sets out the vision, outcomes and policies for the management of the Cotswolds AONB in order to conserve and enhance the natural beauty of the Cotswolds AONB and increase the understanding and enjoyment of the special qualities of the AONB.

1.5.14 Policy CC6 – Water states water resources should be carefully managed and conserved to: improve water quality, ensure adequate aquifer recharge, ensure adequate river flows, and contribute to natural flood management systems and including sustainable drainage.

Tewkesbury Borough Council Flood and Water Management Supplementary Planning Document 2019

1.5.15 The document provides guidance for new developments to manage water environment and flood risk, including key objectives and a description of the documents required to accompany planning applications.

1.6 Guidance

1.6.1 The assessment methodology is based upon DMRB, volume 11, section 2, part 4, LA 104 Environmental assessment and monitoring, revision 1 (July 2019) ("LA 104") and LA 113.

1.6.2 Due reference has been made to GOV.UK guidance for preventing pollution[1], working on or near water[2] and for managing water on land[3].

1.6.3 CIRIA guidance used for the assessment includes:

- Control of Water Pollution from Construction Sites – Guide to Good Practice (SP156);
- Control of Water Pollution from Construction Sites – Guidance for Consultants and Contractors (C532);
- Control of Water Pollution from Linear Construction Projects – Technical Guidance (C648);
- Control of Water Pollution from Linear Construction Projects – Site guide (C649);
- Environmental good practice on site (C692);
- Groundwater control: design and practice (second edition) (C750);
- The SuDS Manual (C753); and
- Guidance on the construction of SuDS (C768).

References

[1] Environment Agency (2019). Pollution prevention for businesses [Online]. Available at: https://www.gov.uk/guidance/pollution-prevention-for-businesses (Accessed 11/11/2019).
[2] Environment Agency (2019). Check if you need permission to do work on a river, flood defence or sea defence [Online]. Available at: https://www.gov.uk/permission-work-on-river-flood-sea-defence (Accessed 11/11/2019).
[3] Environment Agency (2015). Manage water on land: guidance for land managers [Online]. Available at: https://www.gov.uk/guidance/manage-water-on-land-guidance-for-land-managers (Accessed 11/11/2019).

A417 Missing Link

Preliminary Environmental Information Report

Appendix 13.2
WFD Baseline Conditions

28 September 2020

Table of Contents

Table of Tables

1 Introduction

1.1 Background

1.1.1 The European Union (EU) Water Framework Directive (WFD) 2000/60/EC[1] was transposed into United Kingdom (UK) law in 2004 and establishes a framework for water policy. The WFD is based on a number of key relevant objectives including:

- preventing deterioration of the WFD status of waters;
- protecting, enhancing and restoring all bodies of surface water and groundwater;
- progressively reducing discharges of priority substances and ceasing, or phasing discharges, of priority hazardous substances for surface waters;
- ensuring progressive reduction of groundwater pollution;
- mitigating the effects of floods and droughts; and
- ensuring sufficient supply of water.

1.1.2 Under the WFD, all schemes with the potential to impact upon WFD-designated waterbodies must be assessed to ensure:

- no deterioration of the current status or potential status of any WFD quality elements; and
- no prevention of future attainment of the 'good' status or potential objectives of any WFD quality elements.

1.2 Purpose

1.2.1 The purpose of this report is to:

- provide details on baseline conditions of WFD-designated waterbodies that have the potential to be impacted by the proposed scheme.

2 Methodology

2.1 Guidance

2.1.1 This report has followed guidance[2,3] produced by The Planning Inspectorate (PINS), the Environment Agency (EA) and the Department for Environment, Food and Rural Affairs (DEFRA) to:

- document the baseline condition of the water environment that may be impacted by the proposed works and identify potential receptors;
- screen the proposed activities for impact pathways to WFD quality elements.

2.1.2 The following steps will be conducted within the WFD assessment which will accompany the ES submission at a later date:

- scope out potential risks to WFD quality elements from the activities screened into the assessment; and
- carry out a detailed assessment where activities have been identified as posing a risk to the current status or future potential of WFD quality elements.

2.1.3 Unlike in estuarine or coastal environments, there is no specific or prescribed format or process to follow for fluvial or groundwater WFD compliance assessments. This absence of prescribed approach promotes flexibility to applicants and enables them to undertake a proportionate approach.

2.2 Stage 1: screening

2.2.1 This stage has considered whether the scheme has impact pathways to WFD waterbodies. Where impact pathways have been considered possible, the proposed zone of influence has been established based on the scheme baseline.

Scheme baseline

2.2.2 Scheme components and activities that have the potential to permanently affect surface water and/or groundwater bodies, and that therefore have the potential to impact on WFD status, have been identified. This has included the identification of all relevant embedded mitigation measures within the scheme construction strategy and design.

2.2.3 Potential impacts may result from the activities required to construct the scheme (e.g. temporary dewatering), or as a result of the scheme's design (e.g. watercourse crossings / realignments) and operation (e.g. road drainage).

2.2.4 The components of a road scheme are typically repeatable along its length and have therefore been categorised into generic component types (e.g. culverts, outfalls, cuttings, watercourse realignments) with regards to their likely impacts on surface waterbodies and/or groundwater bodies.

2.3 Stage 2: scoping

2.3.1 An EIA scoping opinion was provided by PINS which included a response relating to WFD assessment from the EA. This response has been considered and included, where appropriate, in this report.

2.3.2 The EA was consulted on the scope of the monitoring being undertaken, as well as key effects of the scheme and mitigation. The EA will be consulted on future risk assessments for activities that may impede groundwater flow by impermeable barriers, such as piling, ground improvement works and foundations, as per their request.

2.4 Stage 3: impact assessment

2.4.1 This will be conducted at a later date to accompany the ES submission.

2.4.2 The objective of the impact assessment is to establish the nature and anticipated magnitude of the effects of relevant scheme components on the WFD quality elements of the surface water and groundwater bodies affected by the scheme. These effects are to be considered in terms of the potential for deterioration of current status and/or the prevention of status objectives.

2.4.3 The EA provides guidance on the definition of no deterioration[4]. Necessary measures must be taken to prevent deterioration from one waterbody status class to a lower one. Furthermore, according to a recent EU Court of Justice ruling[5], within-class deterioration should also be considered as an overall deterioration of the waterbody status.

2.4.4 The approach to the impact assessment suggested by the PINS guidance[2] will be used. The approach includes the following steps:

- a description of the scheme and the aspects of the development considered within the scope of the WFD assessment;
- identification of waterbodies that are potentially affected (directly or indirectly) or could be at risk as a result of the scheme (the zone of influence);
- the baseline characteristics of the waterbodies concerned;
- the methods used to determine and quantify the scale of WFD impacts (described in each topic specific appendix);
- an assessment of the risk of deterioration, as an Article 4.7 derogation may be required where is a there is a risk the scheme will prevent the achievement of good status or result in deterioration in status (further details in Annex A, section 3.6);
- an explanation of any mitigation required and how its delivery is secured; and
- an explanation of any enhancements and/or positive contributions to the River Basin Management Plan (RBMP) objectives proposed and how their delivery would be secured.

Waterbody baseline

2.4.5 This will be established by identifying the WFD surface water and groundwater bodies potentially affected by the scheme and identifying their baseline condition, using a combination of desktop assessment and, where possible, field surveys.

2.4.6 The desktop assessment will collate and review the waterbody status and status objectives information for the relevant WFD waterbodies based on EA data (2016 Cycle 2 Waterbody Status Classification data). This data is considered to provide the current best estimate of status and the formal baseline against which the EA will assess compliance with the ‘no deterioration’ objective in 2017.

2.4.7 The following datasets will also be used to further establish the nature and existing condition of those watercourses located within WFD waterbodies that are affected by the scheme:

- observations from a site walkovers;
- observations from water features survey (March 2018 to April 2019);
- EA Catchment Data Explorer[6];
- EA Water Quality Archive[7];
- Natural England MAGIC[8];
- Ordnance Survey (OS) mapping (including topography);
- British Geological Survey (BGS) mapping[9];
- Severn and Thames RBMP (2015);
- A417 Missing Link EIA Scoping Report;
- A417 Missing Link Preliminary Environmental Impact Report;
- A417 Missing Link Preliminary Groundwater Report 2019[10];
- Water quality assessment;
- Spillage risk assessment;
- Hydromorphological assessment;
- Hydrogeological impact assessment;
- Groundwater dependant terrestrial ecosystems assessment;
- Aquatic invertebrate survey report; and
- Fish habitat report.

2.4.8 Potential groundwater dependent terrestrial ecosystems (GWDTEs) will be identified from statutory environmental designations in the study area and spring features will be identified from issues labelled on the OS maps. Licensed and unlicensed groundwater abstraction details will be sought from the EA or the relevant local authority.

2.4.9 The geomorphology baseline conditions were identified during a site walkover and details are outlined in Appendix 13.3 of the PEI Report. A visual inspection during a site visit is an appropriate method for undertaking a geomorphology survey to inform this level of assessment.

2.4.10 To establish a baseline condition, aquatic invertebrate surveys and fish habitat mapping will be conducted for watercourses that are considered to potentially be modified by the scheme.

2.4.11 Groundwater monitoring is ongoing across the scheme and has informed current reporting. Details are presented in Appendix 13.4 of the PEI Report.

3 Screening

3.1 Scheme components

3.1.1 This report has considered all 'scheme components' that have the potential to permanently affect surface waterbodies and groundwater bodies, and therefore have the potential to impact on WFD status. All proposed scheme components have been assessed individually before the combined effect on quality element status is considered.

3.1.2 Linear infrastructure projects, such as roads, typically have generic scheme components that are repeated across the length of the scheme. A total of six such scheme components have been identified that may directly or indirectly affect surface waterbodies along the proposed alignment. These include:

- culverts (detailed in Table 3-1);
- watercourse realignments (detailed in Table 3-1);
- road drainage basins (detailed in Table 3-1);
- road drainage outfalls (detailed in Table 3-1);
- embankments; and
- cuttings.

Table 3-1 Design features of relevance to the water environment

Watercourse	Approximate chainage (m)	WFD Waterbodies (SW: surface water, GW: groundwater)	Description
Tributary of Norman's Brook	0+100	SW: Horsbere Bk – source to conf with R Severn GW: Severn Vale – Secondary Combined	Piped outfall to stream culvert
Tributary of Norman's Brook	0+500	SW: River Churn GW: Severn Vale – Secondary Combined and Severn Vale and Severn Vale – Jurassic Limestone Cotswold Edge South	Piped outfall to stream culvert via Dog Lane
Tributary of Norman's Brook	0+550	SW: Horsbere Bk – source to conf with R Severn	Replacement and realignment of stream culvert

Watercourse	Approximate chainage (m)	WFD Waterbodies (SW: surface water, GW: groundwater)	Description
		GW: Severn Vale – Secondary Combined	
N/a	1+300 to 2+055	SW: Horsbere Bk – source to conf with R Severn River Churn GW: Severn Vale – Jurassic Limestone Cotswold Edge South	Cold Slad Link Retaining Wall/Realignment/loss of watercourse
Tributary of Norman's Brook	1+550	SW: River Churn GW: Severn Vale – Jurassic Limestone Cotswold Edge South	Stepped basins between A417 and private access with outfall to stream
N/a	1+650 to 2+900	SW: River Churn GW: Severn Vale – Jurassic Limestone Cotswold Edge South Burford Jurassic	Air Balloon Cutting
N/a	2+100 to 2+300	SW: River Churn GW: Burford Jurassic	Stepped basins
Dry valley – flowing to unnamed tributary of River Churn 1	2+150	SW: River Churn GW: Burford Jurassic	Drainage basins with overflow to dry valley
Unnamed land drainage ditch	3+100	SW: River Churn GW: Burford Jurassic	Land drainage culvert
N/a	3+200	SW: River Churn GW: Burford Jurassic	Drainage basin
N/a	3+200	SW: River Churn GW: Burford Jurassic	B4070 Cutting
N/a	3+200 to 4+700	SW: River Churn River Frome GW: Burford Jurassic	Stockton to Nettleton Cuttings
Dry valley – flowing to unnamed tributary of River Churn 2	3+900	SW: River Churn GW: Burford Jurassic	Drainage basin with overflow to dry valley
Dry valley – flowing to unnamed tributary of River Frome	4+600	SW: River Frome GW: Severn Vale – Jurassic Limestone Cotswold Edge South	Drainage basin with overflow to dry valley via culvert under farm access
Unnamed land drainage ditch	4+750	SW: River Frome GW: Severn Vale – Jurassic Limestone Cotswold Edge South	Land drainage culvert
Unnamed land drainage ditch	4+750	SW: River Frome GW: Severn Vale – Jurassic Limestone Cotswold Edge South	Land drainage culvert
N/a	5+250	SW: River Frome	Cowley Junction East Cutting

Watercourse	Approximate chainage (m)	WFD Waterbodies (SW: surface water, GW: groundwater)	Description
		GW: Severn Vale – Jurassic Limestone Cotswold Edge South	
Unnamed land drainage ditch	5+300	SW: River Frome GW: Severn Vale – Jurassic Limestone Cotswold Edge South	Land drainage culvert
Tributary of the River Frome	5+500	SW: River Frome GW: Severn Vale – Jurassic Limestone Cotswold Edge South	New outfall or upgrade to existing HE

3.2 Construction activities

Table 3-2 Screening of proposed construction activities for risks to WFD quality elements

Proposed activity	Screen in/out	Justification
Temporary dewatering to enable construction (e.g. for cuttings)	In	The construction of cuttings has the potential to temporarily lower groundwater levels which may impact on nearby receptors that are reliant upon groundwater. The activity therefore has the potential to impact upon WFD quality elements and all WFD water and groundwater bodies have been screened into assessment for this activity.
Temporary loss of a section of the tributary of Norman's Brook to enable embankment widening	In	The widening of the existing road embankment and the new access road at Crickley Hill Tractors are anticipated to require the watercourse to be re-routed between Ch 0+500m and Ch 1+600m during construction of these scheme elements. Following construction, the watercourse will flow along a new alignment around the southern edge of the widened embankment. The impact of this permanent modification is considered under Operational Activities. The loss of approximately 1.1km of watercourse may result in impacts to WFD quality elements of the Norman's Brook - source to confluence Hatherley Brook waterbody. This activity is screened into the assessment.
Works in or near to watercourses (e.g. construction of culverts and drainage outfalls)	Out	In-channel works would be undertaken to install new culverts, drainage outfalls and to realign Crickley Stream. The temporary nature of these works and the construction mitigations described in the EMP minimises the potential for permanent impacts upon WFD quality elements. All WFD waterbodies have been screened out of the assessment for this activity.
Temporary discharge of site runoff to surface waters and groundwaters	Out	Measures considered to be standard industry practice will be adopted during construction to ensure that runoff discharged from the site is of acceptable quality and is discharged in a manner that does not impact upon geomorphology or hydrology of local watercourse. Above standard construction practices to be implemented are detailed in the EMP. With these measures in place no permanent impacts on the current status or status objectives of WFD quality elements are expected as a result of this activity. All WFD waterbodies have been screened out of the assessment for this activity.

Proposed activity	Screen in/out	Justification
Sediment mobilisation from site run-off	Out	Construction activities increase the risk of pollutants entering the wider water environment from spillages from vehicles/plant, concrete wash-waters and sediment mobilisation. These risks would be present over the length of the construction sequence, with high-risk periods during topsoil stripping and works in or near to watercourses. The risk of sediment mobilisation remains until vegetation is established (at least one growing season). The EMP details how water and sediment would be managed across the scheme and include provisions to minimise the likelihood of runoff, provide containment of spillage and capture or treat wastewaters where necessary. These mitigation measures are intended to prevent permanent impacts upon WFD surface water or groundwater quality elements as a result of this activity. All WFD waterbodies have been screened out of the assessment for this activity.
Accidental spillage of pollutants (e.g. fuel leakage from storage or plant)	Out	Measures considered to be standard practice, which are detailed in the EMP, will be adopted during construction to ensure that if an accidental spillage occurs it will be contained and disposed of appropriately. With these measures in place no permanent impacts on the current status or status objectives of WFD quality elements are expected as a result of this activity. All the WFD waterbodies have been screened out of the assessment for this activity.

3.3 Operational activities

Table 3-3 Screening of proposed operational activities for risks to WFD quality elements

Proposed activity	Screen in/out	Explanation
Permanent changes to groundwater levels or flows as a result of new cuttings, embankments or road drainage	In	The cuttings included in the scheme design (listed in Table 3-1) may cause local changes to groundwater levels. The significant areas of cuttings for the scheme extend across all WFD groundwaters bodies including 'Severn Vale – Secondary Combined', 'Severn Vale – Jurassic Limestone Cotswold Edge South' and Burford Jurassic. There is a potential for this activity to result in impacts to WFD quality elements. All WFD groundwaterbodies have been screened into assessment for this activity.
Permanent changes to surface water flow regimes as a result of new cuttings, embankments or road drainage	In	The new cuttings included in the scheme design (listed in Table 3-1) may cause local changes to groundwater drainage which is likely to result in changes to the flow regimes of minor watercourses in the scheme study area. The significant areas of cuttings for the scheme are in 'River Frome – source to Ebley Mill', and 'River Churn – source to Perrots Brook' and 'Norman's Brook – source to confluence Hatherley Brook' catchment. There is a potential for this activity to result in impacts to WFD quality elements. 'River Frome – source to Ebley Mill', 'River Churn – source to Perrots Brook' and 'Norman's Brook – source to confluence Hatherley Brook' WFD waterbodies have been screened into assessment for this activity. The 'Horsbere Bk – source to confluence with the River Severn' WFD waterbody is screened out of assessment for this activity.
Discharge of routine runoff to surface waters or groundwater from	In	Runoff from the carriageway will pass through the road drainage system prior to its discharge to local watercourses and land ditches at greenfield runoff rates.

Proposed activity	Screen in/out	Explanation
the road drainage system		There is potential for this runoff to degrade water quality in waters that receive runoff from the scheme. There is potential for this runoff to impact water quality in the following waterbodies, which are all screened in to the assessment: Surface waters: - 'River Frome – source to Ebley Mill', - 'River Churn – source to Perrots Brook' and - 'Norman's Brook – source to confluence Hatherley Brook' Groundwaters: - 'Severn Vale – Secondary Combined', - 'Severn Vale – Jurassic Limestone Cotswold Edge South' - 'Burford Jurassic'
Accidental spillage of pollutants (e.g. fuel spills)	In	The road drainage system would provide a level of buffering and an opportunity for containment between impermeable areas (where a spillage is most likely to occur) and the wider water environment. Despite this there is potential for accidental spillage to result in a degradation in the quality of waters receiving runoff from the Scheme. There is potential for spillage to impact water quality in the following waterbodies, which are all screened in to the assessment: Surface waters: - 'River Frome – source to Ebley Mill', - 'River Churn – source to Perrots Brook' and - 'Norman's Brook – source to confluence Hatherley Brook' Groundwaters: - 'Severn Vale – Secondary Combined', - 'Severn Vale – Jurassic Limestone Cotswold Edge South' 'Burford Jurassic'
New in-channel structures (e.g. culverts or drainage outfalls)	In	The new in-channel structures would consist of new culverts and drainage outfalls as listed in Table 3-1. New structures within a watercourse can alter local channel cross section and induce local bank or bed erosion, as well as reduce the available natural habitat area. There is potential for impacts to hydromorphology and subsequent effects upon biological quality elements in the following waterbodies, which are all screened in to the assessment: Surface waters: - 'River Frome – source to Ebley Mill', - 'River Churn – source to Perrots Brook' and - 'Norman's Brook – source to confluence Hatherley Brook'
Realignment of tributary of Norman's Brook	In	The realignment of the tributary of Norman's Brook (within the 'Norman's Brook – source to confluence Hatherley Brook' WFD waterbody as identified by the tracer test) has the potential to impact sediment regime, channel morphology and natural fluvial processes. The realignment has result in a change to sediment supply, rate of sediment transfer downstream and depositional zones. The new channel could also lack morphological diversity. Natural fluvial processes could be impacted causing an increase in erosion and/or deposition which can have feedback effects including reduction in channel stability. There is a potential for this activity to impact WFD quality elements and therefore the tributary of Norman's Brook within the WFD waterbody

Proposed activity	Screen in/out	Explanation
		‘Norman’s Brook – source to confluence Hatherley Brook’ has been screened into assessment for this activity.

3.4 Zone of influence

3.4.1 The screening of the scheme components has noted activities that have the potential to impact upon quality elements of WFD surface water and groundwater bodies. The following WFD waterbodies are deemed to be within the potential zone of influence of the scheme:

Surface waterbodies (Figure 13.3):

- Horsbere Brook – source to confluence with the River Severn;
- Norman’s Brook – source to confluence Hatherley Brook;
- River Churn – source to Perrots Brook; and
- River Frome – source to Ebley Mill.

Groundwater bodies (Figure 13.4):

- Severn Vale – Secondary Combined;
- Severn Vale – Jurassic Limestone Cotswold Edge South; and
- Burford Jurassic.

4 Scoping

4.1.1 The scope of the detailed assessment is based upon the activities identified as potentially posing a risk to WFD quality elements in the screening assessment. The study area extends to the waterbodies within the zone of influence.

4.1.2 An EIA scoping opinion was provided by PINS which included a response relating to WFD assessment from the EA. This response has been considered and included, where appropriate, in this assessment.

5 Baseline

5.1 WFD surface waterbodies

5.1.1 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). To the west of the divide, the land within the scheme 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 within the scheme drains to the River Churn, a tributary of the Thames.

5.1.2 Horsbere Brook, Norman’s Brook, the River Frome and the River Churn are ordinary watercourses within the study area.

5.1.3 The scheme is predominantly situated in the wider Severn River Basin District (RBD), with a small area to the east located with the Thames RBD.

5.1.4 The following WFD waterbodies shown in Table 5-1 are relevant to the scheme or hydrologically connected.

5.1.5 The status, failing elements and designations of these watercourses are summarised in Table 5-1.

Horsbere Brook - source to confluence with the River Severn[11]

5.1.6 Horsbere Brook (GB109054032760) is classified as a ‘river’ located within the Severn RBD. This river is formally designated as a ‘heavily modified waterbody’ (HMWB).

5.1.7 The river achieved ‘Moderate’ overall waterbody status in 2016 and has no future objective.

5.1.8 The waterbody received an ‘Moderate’ overall status due to ‘Poor’ ecological status as a result of failing biological quality elements, specifically due to fish.

5.1.9 The reasons for not achieving ‘Good’ status are a result of physical modifications including barriers causing ecological discontinuity.

5.1.10 The EA Catchment Data Explorer depicts the ‘Horsbere Brook source to confluence with the River Severn’ catchment boundary as extending to the north of the A417. The EA also depicts the catchment as encompassing a tributary of Horsbere Brook that borders a stretch of the scheme to the north. However, tracer testing has indicated that the tributary flows to the north and extends out of the ‘Horsbere Brook source to confluence with the River Severn’ catchment, as shown in Figure 13.1. Therefore, this tributary should be considered part of the Norman’s Brook source to confluence Hatherley Brook catchment. The Horsbere Brook catchment would only be connected to the scheme during period of extreme flow, when flow in the tributary of Norman’s Brook exceeds the capacity of the culvert beneath the A417 and backs up to a level where it flows via overland flow westwards along the southern edge of the A417 into Horsbere Brook.

Norman’s Brook - source to confluence Hatherley Brook[12]

5.1.11 Norman’s Brook (GB109054032780) is formally designated as a ‘river’ located within the Severn RBD. Norman’s Brook has not been designated as an artificial or heavily modified river.

5.1.12 The river achieved ‘Poor’ overall waterbody status in 2016 and has no future objective.

5.1.13 The waterbody received an overall ‘Poor’ status due to a ‘Poor’ ecological status as a result of failing biological quality elements, specifically due to macrophytes and phytobenthos combined.

5.1.14 The reasons for not achieving ‘Good’ status have been attributed to diffuse and point pollution related to poor livestock management and sewage discharge, respectively.

5.1.15 As detailed above, a tributary of Norman’s Brook is located within the site boundary and adjacent to the scheme, the watercourse flows along the northern section of the scheme. This tributary is incorrectly shown as being part of the Horsbere Brook catchment on EA Catchment Data Explorer mapping. A second tributary is located to the north of the Crickley Hill and Barrow Wake SSSI, approximately 650m from the scheme, as shown in Figure 13.1.

River Churn - source to Perrots Brook[13]

5.1.16 The River Churn (GB106039029810) is classified as a ‘river’ and is located within the Thames Severn RBD. The River Churn has not been designated as an artificial or heavily modified river.

5.1.17 The river achieved ‘Moderate’ overall waterbody status in 2016 and has an objective of ‘Good’ by 2027.

5.1.18 The waterbody received an overall ‘Moderate’ status due to ‘Moderate’ ecological status as a result of ‘moderate’ biological quality elements. Specifically, due to macrophytes and phytobenthos combined and fish.

5.1.19 The reasons for not achieving ‘Good’ status in relation to macrophytes and phytobenthos combined have been attributed to suspect data and groundwater abstractions. Reasons for not achieving ‘Good’ status in relation to fish have been attributed to poor livestock management.

5.1.20 The nearest tributary of the River Churn to the scheme is located approximately 50m from the scheme, as shown in Figure 13.2.

River Frome – source to Ebley Mill[14]

5.1.21 The River Frome (GB109054032470) is formally designated as ‘river’ and is located within the Severn RBD. The River Frome has not been designated as an artificial or heavily modified river.

5.1.22 The river achieved ‘Good’ overall waterbody status in 2016 and has no future objective set.

5.1.23 The nearest tributary of the River Frome is located approximately 260m from the scheme, as shown in Figure 13.2.

5.2 WFD groundwater bodies

5.2.1 The scheme is located across three WFD groundwater bodies: Severn Vale – Secondary Combine; Severn Vale – Jurassic Limestone Cotswold Edge South; and Burford Jurassic.

Severn Vale – Secondary Combined[15]

5.2.2 The Severn Vale – Secondary Combined groundwater body (GB40902G204900) has a groundwater area of 120,678 Ha. The groundwater area extends across Wales and England from the east of Chepstow up to Great Malvern, encompassing Gloucester and most of Cheltenham. The groundwater body is located to the far most western extent of the scheme, as shown in Figure 13.4.

5.2.3 The groundwater body received a ‘Good’ status in 2016 and has no future objective set.

Severn Vale – Jurassic Limestone Cotswold Edge South[16]

5.2.4 Severn Vale - Jurassic Limestone Cotswold Edge South groundwater body (GB40901G305700) has a groundwater area of 23,910Ha. The groundwater area extends up through Nailsworth, Stroud and Whiteway. The groundwater body is located to the east of the Severn Vale – Secondary Combined groundwater body, as shown in Figure 13.4.

5.2.5 The groundwater body received a ‘Good’ status in 2016 and has no future objective set.

Burford Jurassic[17]

5.2.6 Burford Jurassic groundwater body (GB40601G600400) has a groundwater area of 90,062 Ha. The groundwater area extends from Cirencester up through the Cotswolds to Snowshill. The groundwater body is located to the far most eastern extent of the scheme and to the east of the Severn Vale – Jurassic Limestone Cotswold Edge South groundwater body, as shown in Figure 13.4.

5.2.7 The groundwater body received a ‘Poor’ status in 2016 and has an objective of ‘Good’ by 2027.

5.3 Hydrogeology

5.3.1 The hydrogeological baseline is described in Appendix 13.4.

5.4 Hydromorphology

5.4.1 The hydromorphological baseline is described in Appendix 13.3.

5.5 Aquatic ecology

5.5.1 The aquatic invertebrate baseline is described in Appendix 8.22.

5.5.2 The fish habitat baseline is described in Appendix 8.23.

5.5.3 Tufa deposits have been identified along the tributary of Norman’s Brook between Ch 1+000m and Ch 1+150m. The ecological importance of these deposits has not yet known. Tufa Habitat Surveys have been conducted to establish whether any protected communities or species are present and is presented within the Chapter 8 Biodiversity.

5.6 Protected areas and designations

5.6.1 Under the WFD, ‘Protected Areas’ are defined as areas requiring special protection because of their sensitivity to pollution or due to their particular economic, social or environmental importance. These areas are waterbodies or parts of them:

- used for the abstraction of water intended for human consumption (Drinking Water Protected Area (DrWPA);
- supporting economically significant shellfish or freshwater fish stocks (Freshwater Fish Water; Shellfish Water);
- where a large number of people are expected to bathe (Bathing Water);
- supporting habitats or species of international biodiversity conservation importance (such as a Special Area of Conservation (SAC) or Special Protection Area (SPA)); and/or
- sensitive to nutrient enrichment (such as a Nitrate Vulnerable Zone (NVZ) or Urban Waste Water Treatment Directive (UWWTD) sensitive zone).

5.6.2 The specific environmental designations, measures and actions for these protected areas have been established under previous European Directives, which set out the requirements to ensure the protection of the area’s water environment or protection of wildlife that is directly dependant on that water environment. Where a WFD waterbody falls within or forms all or part of one of these designated predicted areas, the waterbody is subject to additional environmental objectives (and associated monitoring regimes, risk assessments, and regulations) in accordance with the relevant, previous Directive(s).

DrWPA

5.6.3 The nearest DrWPA is the Shropshire, Herefordshire, Worcestershire and Gloucestershire (GB70910509) which is located approximately 9.2km from the scheme.

SAC

5.6.4 The Cotswold Beechwoods SAC is located 270m west and downslope of the B4070, includes areas of vegetation dependent on high groundwater levels that are associated with some nationally rare invertebrate species. These protected areas extend from the south-east of Birdlip to High Brotheridge, and includes springs supplying Horsbere Brook.

5.6.5 The Severn Estuary SAC is located 9km west of the scheme and is hydrologically connected to the scheme via Norman's Brook.

SPA

5.6.6 There are no SPAs that are hydrologically connected to the scheme.

NVZ

5.6.7 The eastern extent of the scheme is located within 'Hatherley Bk – conf Norman's Bk to conf R Severn' Surface Water NVZ under the 2017 designation.

UWWTD

5.6.8 The scheme is not located within an UWWTD sensitive area.

Aquifers

<u>Aquifer designation - bedrock</u>

5.6.9 The majority of the scheme is located upon a Principal Aquifer, except the north western part of the scheme. The aquifer designations are shown on Figure 13.6 of the ES.

5.6.10 More comprehensive details on hydrogeology are included in Appendix 13.4.

<u>Aquifer designation – superficial deposits</u>

5.6.11 The north western extent of the scheme is located within the Secondary Aquifer. There are no other superficial deposits located along the scheme extent. The aquifer designations are shown on Figure 13.6.

5.6.12 More comprehensive details on hydrogeology are included in Appendix 13.4.

5.7 Summary

5.7.1 The WFD surface waterbodies and groundwater bodies that are hydrologically connected to the scheme are shown in Table 5-1 and Table 5-2 of this report, respectively.

Table 5-1 Summary of WFD surface waterbodies in the study area

WFD waterbody	Horsbere Brook – source to confluence with the River Severn	Norman's Brook – source to confluence Hatherley Brook	River Churn – source to Perrots Brook	River Frome – source to Ebley Mill
ID	GB109054032760	GB109054032780	GB106039029810	GB109054032470
Type of Waterbody	River	River	River	River
Area (km^2)	13.04	3.91	16.94	27.73
HMWB/AWB	Heavily Modified	Not designated as HMWB/AWB	Not designated as HMWB/AWB	Not designated as HMWB/AWB
Overall Status	Moderate	Poor	Moderate	Good
Objective	No objective	No objective	Good by 2027	No objective
Chemical Status	Good	Good	Good	Good
Ecological Status	Moderate	Poor	Moderate	Good
Driver of failure to achieve 'good' status	Fish	Macrophytes and Phytobenthos	Macrophytes and Phytobenthos Fish	N/A
Reasons for not achieving 'good' status	Physical modification of barriers causing ecological discontinuity	Poor livestock management (diffuse pollution) Sewage discharge (point source)	Poor livestock management (diffuse pollution) Groundwater abstraction	N/A

Table 5-2 Summary of WFD groundwater bodies in the study area

WFD groundwater body	Severn Vale – secondary combined	Severn Vale – Jurassic Limestone Cotswold Edge South	Burford Jurassic
ID	GB40902G204900	GB40901G305700	GB40601G600400
Type of Waterbody	Groundwater	Groundwater	Groundwater
Area (km^2)	1,206.78	239.10	900.62
Overall Status	Good	Good	Poor
Objective	No objective set	No objective set	Good by 2027
Chemical Status	Good	Good	Poor
Quantitative Status	Good	Good	Good
Driver of failure to achieve 'good' status	N/A	N/A	Chemical DrWPA General chemical test
Reasons for not achieving 'good' status	N/A	N/A	Poor nutrient management (diffuse source) Private sewage treatment (point source)

Glossary

Key Term	Definition
Hydromorphological	Water flow, sediment composition and movement, continuity (In rivers) and the structure of physical habitat.
Hydrological regime	The variations in the state and characteristics of a waterbody which ae regularly repeated in time and space and which pas through phases e.g. seasonal.
Drinking Water Protected Area (DrWPA)	For definition see Safeguard Zones (surface water).
Nitrate Vulnerable Zones (NVZs)	Nitrate Vulnerable Zones (NVZs) are areas designated as being at risk from agricultural nitrate pollution. They include about 55% of land in England.
Phytobenthos	Benthic organisms that are plants or algae.
Safeguard Zones (surface water)	Catchment areas upstream of ‘at risk’ DrWPAs that influence the water quality in the immediate DrWPA are being delineated by the EA and water companies. The ‘at risk’ DrWPAs and Safeguard Zones are where action to address water contamination will be targeted, so that extra treatment by water companies can be avoided. All Safeguard Zones have yet to be fully delineated, or those that are almost complete may be subject to refinement.

References

[1] European Commission (2017) The EU Water Framework Directive – integrated river basin management for Europe. Available at: http://ec.europa.eu/environment/water/water-framework/index_en.html (Accessed 11/02/2020).
[2] The Planning Inspectorate (2017) Advice Note 18: The Water Framework Directive [Online]. Available at: (June 2017). Available at: https://infrastructure.planninginspectorate.gov.uk/wp-content/uploads/2017/06/advice_note_18.pdf (Accessed 11/02/2020).
[3] EA & DEFRA (2009). WFD Expert Assessment of Flood Management Impacts. Joint EA & DEFRA Flood and Coastal Erosion Risk Management R&D Programme. R&D Technical Report FD2609/TR.
[4] UK Technical Advisory Group (2006). Prevent Deterioration of Status [Online]. Available at: https://www.wfduk.org/sites/default/files/Media/Setting%20objectives%20in%20the%20water%20environment/Prevent%20deterioration%20of%20status_Draft_010506.pdf. (Accessed 11/02/2020).
[5] Court of Justice of European Union (2015). The obligations laid down by the Water Framework Directive concerning enhancement and prevention of deterioration apply to individual projects such as the deepening of a navigable river, Press Release No 74/15 [Online]. Available at: https://curia.europa.eu/jcms/upload/docs/application/pdf/2015-07/cp150074en.pdf (Accessed 11/02/2020).
[6] Environment Agency (2019). Catchment Data Explorer [Online]. Available at: http://environment.data.gov.uk/catchment-planning/ (Accessed 11/02/2020).
[7] Environment Agency (2019). Water Quality Archive [Online]. Available at: https://environment.data.gov.uk/water-quality/view/sampling-point/TH-PUTE0282 (Accessed 11/02/2020).
[8] DEFRA (2019). MAGIC, Interactive mapping at your fingertips [Online]. Available at: http://www.magic.gov.uk/ (Accessed 11/02/2020).
[9] British Geological Society (2019). Geology of Britain viewer [Online]. Available at: http://mapapps.bgs.ac.uk/geologyofbritain/home.html (Accessed 11/02/2020).
[10] Mott MacDonald Sweco Joint Venture (2019). Preliminary Groundwater Report, Doc No. HE551505-MMSJV-HGT-000-RP-CE-00004
[11] Environment Agency (2019). Catchment Data Explorer, Horsbere Bk - source to conf R Severn Overview [Online]. Available at: https://environment.data.gov.uk/catchment-planning/WaterBody/GB109054032760 (Accessed 11/02/2020).
[12] Environment Agency (2019). Catchment Data Explorer [Online]. Available at: https://environment.data.gov.uk/catchment-planning/WaterBody/GB109054032780 (Accessed 11/02/2020).
[13] Environment Agency (2019). Catchment Data Explorer, Normans Bk - source to conf Hatherley Bk Overview [Online]. Available at: https://environment.data.gov.uk/catchment-planning/WaterBody/GB106039029810 (Accessed 11/02/2020).
[14] Environment Agency (2019). Catchment Data Explorer, Frome - source to Ebley Mill Overview [Online]. Available at: https://environment.data.gov.uk/catchment-planning/WaterBody/GB109054032470 (Accessed 11/02/2020).
[15] Environment Agency (2019). Catchment Data Explorer, Severn Vale - Secondary Combined Overview [Online]. Available at: https://environment.data.gov.uk/catchment-planning/WaterBody/GB40902G204900 (Accessed 11/02/2020).
[16] Environment Agency (2019). Catchment Data Explorer, Severn Vale - Jurassic Limestone Cotswold Edge South Overview [Online]. Available at: https://environment.data.gov.uk/catchment-planning/WaterBody/GB40901G305700 (Accessed 11/02/2020).
[17] Environment Agency (2019). Catchment Data Explorer, Burford Jurassic Overview [Online]. Available at: https://environment.data.gov.uk/catchment-planning/WaterBody/GB40601G600400 (Accessed 11/02/2020).

A417 Missing Link

Preliminary Environmental Information Report

Appendix 13.3
Hydromorphology Baseline Conditions

28 September 2020

Table of Contents

Table of Figures

Table of Tables

No table of figures entries found.

1 Introduction

1.1 Purpose

1.1.1 This document describes the hydromorphological baseline for the proposed scheme and outlines the likely potential impacts upon hydromorphology. This informs Chapter 13 Road Drainage and Water Environment and Appendix 13.2 WFD compliance assessment of the PEI Report.

2 Methodology

2.1 Study area

2.1.1 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 1km, where features have hydrological connectivity to the scheme.

2.1.2 For groundwater, the study area includes the geographical extent of the full scope of the works and groundwater features within 1km of the scheme.

2.1.3 The following surface watercourses, shown on Figure 13.1 of the PEI Report, have been deemed to be within the study area of the assessment:

- Norman's Brook– source to confluence Hatherley Brook (No. GB109054032780) waterbody. A tracer test was undertaken in March 2019 finding that the watercourse flowing alongside the A417 at Crickley Hill was a tributary of Norman's Brook, rather than Horsbere Brook;
- River Churn – source to Perrots Brook (No. GB106039029810) waterbody (Unnamed tributaries of River Churn 1 and 2); and
- River Frome – source to Ebley Mill (No. GB109054032470) waterbody.

2.2 Desk study

2.2.1 A desk study to collate and review available hydromorphology information has been conducted for watercourses that may be impacted by the scheme.

2.2.2 The desktop assessment has collated and reviewed the status and objectives information for hydromorphological quality elements of the relevant Water Framework Directive (WFD) waterbodies based on Environment Agency (EA) data (2016 Cycle 2 Waterbody Status Classification data).

2.2.3 The following sources have also been used to further establish the existing conditions of the hydromorphology of watercourses within the study area:

- EA Catchment Data Explorer[1];
- Ordnance Survey (OS) mapping (including topography);
- observations from water features survey (March 2018 to April 2019);
- Severn and Thames River Basin Management Plans (2015);
- Preliminary Groundwater Report 2019[2]; and
- Appendix 13.4 Hydrogeological baseline conditions.

2.3 Site survey

2.3.1 A walkover survey of the watercourses potentially impacted by the scheme was undertaken by a geomorphologist on the 28th and 29th October 2019. The survey collected information on the form of the channels, the flow types and the characteristics of the riparian zone for up to 1km from the scheme boundary. The surveys were undertaken following a weekend of heavy rainfall and flows were high.

2.3.2 Spot flow gauging was undertaken at 47 locations during four monitoring periods between April 2018 and March 2019 (during Stage 2 of the scheme). This has provided an initial characterisation of the range of flows within the watercourses of interest.

2.4 Impact Assessment

2.4.1 Potential impacts upon hydromorphology will be assessed at a catchment level for the ES chapter. The assessment will consider potential impacts upon the following:

- flow processes;
- sediment movement;
- boundary conditions (channel bed and banks);
- riparian zones;
- floodplains;
- downstream and catchment-channel connectivity;
- the general form and function of the channel and near-channel zones; and
- the setting of the watercourse within the wider catchment.

2.4.2 Where significant potential impacts are identified, mitigation measures will be proposed, where possible. Mitigation may take the form of requirements to minimise the effect of the construction activities or requirements to incorporate into the detailed design of the scheme.

Construction impacts

2.4.3 LA 113 recommends that construction impacts are considered using the source – pathway – receptor approach and defers specific guidance of highway construction impacts to CIRIA 648 Control of Water Pollution from Linear Construction Projects.

2.4.4 The potential impacts of construction on hydromorphology will be assessed based on the planned construction methods and sequencing. Where construction methods are not available, standard construction practices will be assumed.

2.4.5 Where measures to reduce construction impacts are considered standard practice they will be included in the EMP, which will be produced and submitted as part of the DCO application. Measures beyond standard practice are typically considered to be mitigation.

Operational impacts

2.4.6 A qualitative assessment of possible impacts on the hydromorphology of watercourses will be undertaken based on a 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 (where relevant).

2.4.7 The assessment will be made using professional judgement and experience and focussed on locations where the proposed route physically interacts with watercourses (for example proposed culverts or realignments) or where discharges from the road drainage system may occur.

3 Baseline hydromorphology

3.1 Introduction

3.1.1 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). 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.

3.1.2 Norman's Brook, the River Frome and the River Churn are classed by the EA as ordinary watercourses within the study area.

3.2 Tributary of Norman's Brook

3.2.1 The unnamed tributary of Norman's Brook flows westwards along the southern edge of the existing A417 embankment at Crickley Hill. The watercourse emerges from a pipe to the north of Crickley Hill Tractors, at approximately National Grid Reference (NGR) SO 93057 15871, and flows down the relatively steep, wooded valley.

3.2.2 The watercourse is fed by several springs that emerge at various elevations from the complex geology in this area. Many of these features are ephemeral.

3.2.3 Spot flow gauging undertaken along the watercourse recorded flows up to 0.013m^3/s, with evidence of flow losses (assumed to the underlying aquifer), principally around Ch 0+900m^3.

3.2.4 The watercourse is approximately 1m wide and is characterised by runs and cascade flow types. The dominant bed material is fine gravel, with coarse gravel, cobbles, sand and clay also present. The banks are densely wooded and composed of cohesive material with limited evidence of erosion, principally by geotechnical failure.

3.2.5 A representative photo of the watercourse is shown in Figure 3-1.

Figure 3-1 Representative photo of characteristics of tributary of Norman's Brook

3.2.6 The watercourse enters a buried culvert via a 2.5m high concrete weir at Ch 1+200m, before re-emerging 50m downstream. Potential tufa formations have been identified immediately downstream of this from Ch 1+150m to Ch 1+000m.

3.2.7 Tufa is formed when carbonate is precipitated out of alkaline water and is present here as a series of cascades. It appears that at least some of the tufa cascades have formed over existing concrete weir structures at this location (Figure 3-2), where carbonate precipitation is induced by the increased air-water interaction created by the turbulent flow. There are seven cascades in total, each around 2.5m wide.

Figure 3-2 Tufa cascades along the Tributary of Norman's Brook

3.2.8 Further information on the hydrogeological setting for the carbonate deposits is presented in Appendix 13.7.

3.2.9 The watercourse is culverted from Ch 0+700m to 0+800m.

3.2.10 The watercourse enters a culvert beneath the existing A417 at Ch 0+600m (Figure 3-3). Due to uncertainties about the flow direction of the culvert, a tracer test has been carried out to establish where the watercourse emerges[4]. This has found that it emerges along Bentham Lane (NGR: SO 91337 16344) and flows north-westwards into Norman's Brook, rather than Horsbere Brook as shown on WFD mapping.

Figure 3-3 Existing culvert entrance under A417 - Tributary of Norman's Brook

3.2.11 The watercourse is therefore assumed to be part of the Norman's Brook - source to confluence Hatherley Brook (GB109054032780) waterbody. The waterbody has an overall status of 'Poor' and a hydromorphological supporting elements status of 'Supports Good'.

3.3 Tributary of River Churn 1

3.3.1 The unnamed tributary of the River Churn 1 flows eastwards away from the scheme. The watercourse is first recorded where it crosses beneath the A436 to the south-east of Ullenwood Manor Golf Course.

3.3.2 The road drainage discharged into this catchment would only flow directly into the watercourse during periods when the catchment was saturated and overland flow processes were active.

3.3.3 The watercourse has been straightened and flows through rough pasture and woodland, with some evidence of poaching (Figure 3-4). The watercourse if approximately 2m wide with flow types of runs and glides and a gravel bed.

Figure 3-4 Representative photo of characteristics of Tributary of River Churn 1

3.3.4 Spot flow gauging of the watercourse was undertaken four times from April 2018 to March 2019 at NGR SO 94711 16460. Flows were too low to be recorded in April 2018, July 2018 and February 2018 but were recorded as 0.04m^3/s in March 20193.

3.3.5 The watercourse is within the River Churn - source to Perrots Brook (GB106039029810) waterbody. It has an overall status of ‘Moderate’ and a hydromorphological supporting elements status of ‘Supports Good’.

3.4 Tributary of River Churn 2

3.4.1 The unnamed tributary of the River Churn 2 is a dry valley feature which is crossed by the scheme at the head of the valley between Ch 3+100m and 3+300m. A watercourse is not present in the valley bottom until approximately 1.2km downstream of the scheme at NGR SO 95380 15473.

3.4.2 The dry valley may experience episodical surface water flows during periods of high groundwater levels but is otherwise a relict landscape feature formed by past periglacial processes.

3.4.3 The watercourse is ponded and flows eastwards through along a dense wooded field boundary towards the River Churn (Figure 3-5).

Figure 3-5 Representative photo of characteristics of Tributary of River Churn 2

3.4.4 Spot flow gauging of the watercourse was undertaken four times from April 2018 to March 2019 at NGR SO964155. Flows ranged from dry (July 2018) to 0.07m^3/s (April 2018)3.

3.4.5 The watercourse is within the River Churn - source to Perrots Brook (GB106039029810) waterbody. It has an overall status of ‘Moderate’ and a hydromorphological supporting elements status of ‘Supports Good’.

3.5 River Frome

3.5.1 The River Frome and its unnamed tributaries emerge to the south of the eastern end of the scheme, near Nettleton. The catchment is fed by a series of springs that emerge at the boundary of the Great Oolite limestones over Fuller’s Earth mudstone.

3.5.2 The watercourses in this catchment are not directly modified by the scheme but would receive discharges from the road drainage network.

3.5.3 The tributary which flows southwards from Nettleton is within a piped culvert from the existing A417 until it emerges as shown on OS mapping. The watercourse has been overdeepened and has approximately 1.5m high banks (Figure 3-6).

Figure 3-6 Representative photo of characteristics of Tributary of River Frome at Nettleton

3.5.4 The Nettleton tributary joins the main arm of the River Frome at the southern end of Bushley Muzzard SSSI. A 1m high concrete weir forms a densely vegetated ponded area at this location.

3.5.5 Downstream of this the watercourse flows through woodland and has a relatively natural form, made up of runs with small cascade sections, typically formed by outcrops of clay hardpan material. The riverbed level appears to be controlled by the erosion resistant clay with sections dominated by fine gravel.

3.5.6 Another small tributary enters in this section which would receive flow from the road drainage system.

3.5.7 Approximately 700m downstream of the scheme area, the watercourse has been impounded to form a series of ponds through Brimpsfield Park. The impounding structures are large concrete weirs which appear to restrict coarse sediment transport downstream.

References

[1] Environment Agency (2019). Catchment Data Explorer [Online]. Available at: http://environment.data.gov.uk/catchment-planning/ (Accessed 02/08/2020).
[2] Mott MacDonald Sweco JV (2019). Preliminary Groundwater Report, Doc No. HE551505-MMSJV-HGT-000-RP-CE-00004
[3] Mott MacDonald Sweco JV (2019). A417 “Missing Link” Road Scheme, A417 Stream Flow Gauging Report, Document Reference HE551505-MMSJV-EWE-000-SU-LV-00007
[4] Mott MacDonald Sweco JV (2019). A417 “Missing Link” Road Scheme, A417 Tracer Test, Document Reference HE551505-MMSJV-EWE-000-RP-LX-00003

A417 Missing Link

Preliminary Environmental Information Report

Appendix 13.4
Hydrogeological Baseline Conditions

28 September 2020

Table of Contents

Table of Figures

Table of Tables

1 Introduction

1.1 Purpose of this document

1.1.1 The purpose of this document is to present the hydrogeological baseline conditions based on the groundwater monitoring programme for the A417 Missing Link (the scheme). This baseline conditions report will underpin Hydrogeological Impact Assessments (HIA) that will be undertaken for the Environmental Statement.

2 Methodology

2.1 Overview

2.1.1 The Cotswold region is an area of valued geological and environmental interest and importance. To understand the environmental risks of the scheme in the context of groundwater, a desktop study and review of ground investigation data was completed to understand the groundwater regime and the potential impact of proposed design elements.

2.1.2 The geological setting and ground conditions along the proposed scheme are presented in Chapter 9, Geology and Soils.

2.2 Ground investigations

2.2.1 Details of the completed intrusive ground investigations are presented in Chapter 9 Geology and Soils. The following sections focus on the hydrogeological aspects of these investigations.

Phase 1 ground investigation

2.2.2 The Phase 1 ground investigation was completed by Geotechnical Engineering Ltd between January and February 2019[i]. The scope of works included eight boreholes with standpipe installations in each and water level loggers were installed within four of these. The boreholes were positioned in four locations, where two boreholes were drilled approximately 10m apart in each location to monitor different aquifers. The locations targeted for monitoring include National Star College (DS/RC 408 and OH 407), Air Balloon public house (DS/RC 406 and OH 405), Barrow Wake (DS/RC 419 and DS/RC 404) and Roman Road (DS/RC 415 and OH 406). To compensate 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. A summary of the Phase 1 monitoring installations is presented in Appendix B.

2.2.3 Groundwater monitoring of the eight Phase 1 boreholes commenced in February 2019 and is currently on-going. The locations are scheduled to provide continuous logging data and dip meter measurements on a monthly basis. Due to contractual issues, dip meter measurements were not taken between June 2019 and August 2019. For this baseline conditions report, diver logger data is only available up until end of May 2020. Additional monitoring data received after this point will be included in the ES.

Phase 2A ground investigation

2.2.4 The Phase 2A ground investigation included the installation of 52 groundwater monitoring boreholes, where the proposed in-situ testing and monitoring of these boreholes included:

- 14 water level loggers for continuous groundwater level monitoring;
- 8 packer tests; and
- 7 permeability tests.

2.2.5 The Phase 2A ground investigation has been completed, however due to restrictions by land access agreements with private land owners, five installations have not been completed. The monitoring installation coverage to date is concentrated in land parcels where access has been granted. At the time of writing, a total of 47 monitoring locations will be included in this baseline conditions review to support the Environmental Statement (ES) groundwater conceptual model.

2.2.6 Monitoring of the Phase 2A boreholes constructed early in the ground investigation programmed commenced at the end of May 2019. Currently the available groundwater monitoring data comprises dip meter and water level loggers.

2.3 Baseline conditions scope

2.3.1 The locations of groundwater monitoring installations used to inform this baseline conditions review are presented in Figure A-1 in Appendix A of this document. Monitoring data received up until the 31 May 2020 has been considered in this review. The available factual data is presented in the factual reports, enclosed in Appendix 9.4 of the PEI report, relating to investigated land parcels as follows:

- Land parcel ref. 1077;
- Land parcel ref. 987;
- Land parcel ref. 948;
- Land parcel ref. 1059;
- Land parcel ref. 1118;
- Land parcel ref. 992;
- Land parcel ref.1106;
- Land parcel ref. 1098; and
- Land parcel ref. 1245.

2.3.2 Barometric loggers have been installed during the Phase 2A investigation at Crickley Hill in the headworks of CP 223 and at Stockwell-Nettleton in the headworks of DS/RC 220.

2.3.3 Daily rainfall data has been acquired for the Ebsworth rainfall gauge (461800) from the Environment Agency. The gauge is located approximately 6.7 km south-west of the scheme. The dataset for this gauge is incomplete however, and rainfall between the 18th October 2019 and 16th November 2019 is missing. A complete dataset will be available in a future edition of this review.

2.4 Regional water resources

Catchment Abstraction Management Strategy (CAMS)

2.4.1 The scheme is located within three CAMS areas as designated by the EA. These are listed below and presented in Figure 13.10 of the PEI report:

- The Severn Corridor[ii] – up to approximately CH2+100, west of the groundwater divide;
- The Cotswolds[iii] – between approximately CH2+100 and CH3+800, east of the groundwater divide; and
- The Severn Vale[iv] – from approximately CH3+800, west of the groundwater divide.

2.4.2 The availability of water for abstraction within the catchments is presented in Table 1.

Table 1 CAMS water resource availability summary

Flow type	Severn corridor	Cotswolds	Severn Vale
Q95 (lowest)	Limited water available	Water not available	Limited water available
Q70	Water available	Water not available	Limited water available
Q50	Water available	Water not available	Limited water available
Q30 (highest)	Water available	Restricted water available	Limited water available

EA designations

2.4.3 Aquifers within the study area that have been designated by the EA are listed below and presented in Figure 13.6 of the PEI report.

2.4.4 The Cheltenham Sand and Gravel and alluvial deposits are designated by the EA as Secondary A aquifers. This designation indicates the aquifers 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'[v].

2.4.5 The Great Oolite Group (excluding the Fuller's Earth Formation) and Inferior Oolite Group are designated as 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"[vi].

2.4.6 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"[vii].

2.4.7 In the study area, the 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[viii], the Bridport Sand Formation is considered a minor aquifer. However, the site-specific information in this report is based upon SI 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 info.

2.4.8 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*"[ix].

Water Framework Directive (WFD)

2.4.9 The 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[x]. 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[xi]. A summary of the WFD groundwater bodies is presented in Table 2 and Figure 13.4 of the PEI report.

2.4.10 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 2.

2.4.11 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, Normans Brook and their tributaries.

2.4.12 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.

2.4.13 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 scheme.

2.4.14 The Thames catchment includes 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.

2.4.15 The overall 2016 status of both the Jurassic Limestone Cotswolds Edge South and Secondary Combined groundwater bodies is good, however the Burford Jurassic is poor.

Table 2 Summary of WFD groundwater bodies[xii]

	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.

3 Baseline setting

3.1 Regional geology

Superficial deposits

3.1.1 Superficial deposits are located in discrete areas relative to the scheme including, the Cotswold escarpment (west of the escarpment crest), the Churn Valley (near Shab Hill Farm) and the Frome Valley (near Stockwell-Nettleton) (Figure 9.3 of the PEI report).

3.1.2 The superficial deposits comprise of[xiii,xiv]:

- mass movement deposits – landslide deposits, cohesive material derived from limestone and mudstone parent materials;
- alluvial deposits - clay, silt, sand and gravel; and
- Cheltenham sand and gravel - sand, quartzose, fine to medium grained, generally unbedded, with seams of poorly sorted predominantly limestone gravel, especially in the lower part.

3.1.3 For the purposes of this project 'head' is being used as a general term for transported slope material derived from the underlying bedrock and transported to its current position as a result of a range of slope processes, including landslides, hillwash, and soil creep. Locally these deposits may also contain lenses of peat or organic material. Therefore, mapped mass movement deposits are encapsulated in 'head' deposits.

3.1.4 ‘Head’ deposits underlie the scheme on Crickley Hill and the valley at Shab Hill Junction which feeds into the River Churn. These deposits are also present in the valleys that feed into the River Frome, west of the scheme’s southern end. For the purposes of this project any deposits related to slope processes are referred to as head deposits.

3.1.5 Alluvial deposits are present west of the scheme’s southern end, in the valley that forms part of the River Frome’s headwaters.

3.1.6 Cheltenham Sand and Gravel underlie the western end of the scheme and extend towards the north west.

Bedrock geology

3.1.7 The scheme is underlain by three bedrock geological groups (Figure 1)[xv]. Structurally these bedrock units generally dip between 2º and 5º towards the east and south-east. The bedrock groups include, from youngest to oldest:

- Great Oolite Group – Jurassic aged limestones and basal mudstone;
- Inferior Oolite Group – Jurassic aged limestones; and
- Lias Group – Triassic aged mudstones with limestone beds.

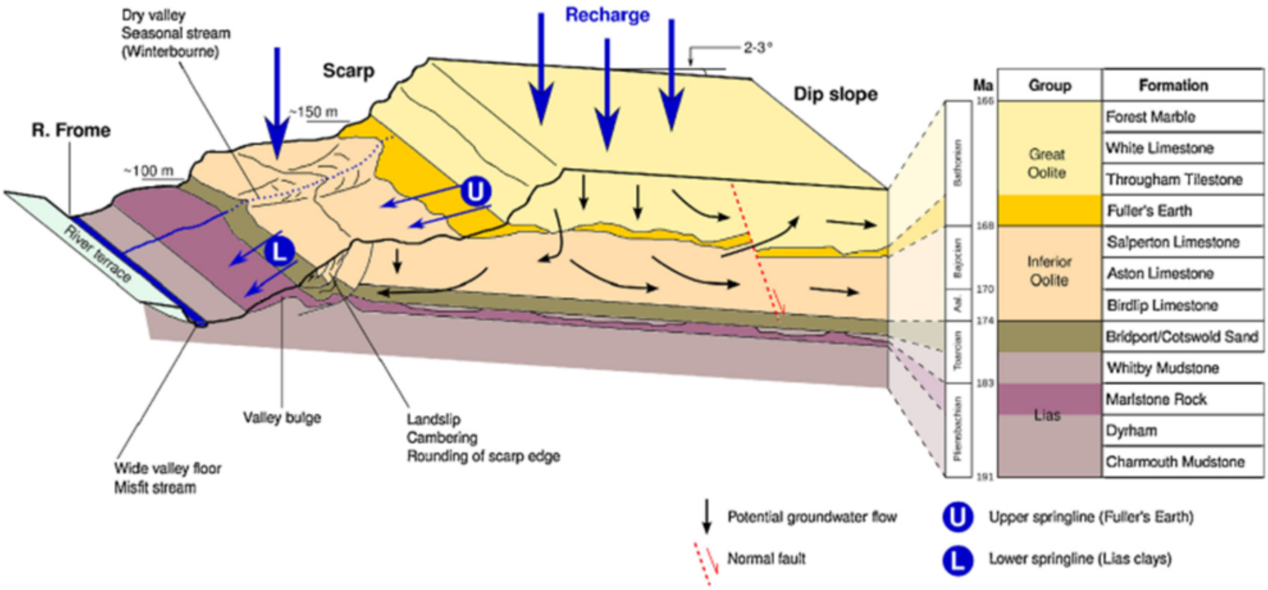


Figure 1 Idealised conceptual model of the hydrogeological processes in the mid-Cotswold area[xvi]

3.1.8 The Great Oolite Group includes White Limestone Formation, the Hampen Formation and Fuller’s Earth Formation. Both the White Limestone and Hampen Formations are described as limestones with clay beds, where the Hampen is differentiated by its sandy and ooidal matrix. The Fuller’s Earth Formation is a grey mudstone with limestone beds at the base of the Great Oolite Group. The Great Oolite Group underlies the scheme south of Shab Hill (Figure 9.3 of the PEI report).

3.1.9 The Inferior Oolite Group includes the Salperton Limestone Formation, the Aston Limestone Formation and the Birdlip Limestone Formation. The formations are differentiated by their matrix compositions where the Salperton Limestone Formation is shelly and ooidal, the Aston Limestone Formation is shelly and sandy, and the Birdlip Limestone ooidal, sometimes sandy with sandy clay lenses. The Inferior Oolite Group is underlain by the Lias Group mudstones and the surface boundary between these units is near the crest of the Cotswolds escarpment. The Inferior Oolite Group underlies the scheme from the crest of the Cotswold Escarpment to the northern side of the Shab Hill fault (Figure 9.3 of the PEI report).

3.1.10 The Lias Group in the Cotswolds area comprises the Worcester Basin Formations. The Worcester Basin includes the Bridport Sand Formation, the Whitby Mudstone Formation, the Marlstone Rock Formation, the Dyrham Formation and the Charmouth Mudstone Formation.

3.1.11 The Whitby Mudstone Formation, Dyrham Formation and Charmouth mudstone Formation are the thicker formations within the Lias Group. Largely comprising mudstone and silty mudstone the formations are relatively impermeable. The Whitby Formation does however include limestone beds at the base over the more permeable Marlstone Rock Formation.

3.1.12 The Bridport Sand Formation is described as a sandy mudstone and fine-grained sandstone. The Marlstone Rock Formation is described as sandy, shell-fragmental and ooidal ferruginous limestone interbedded with ferruginous calcareous sandstone, and generally subordinate ferruginous mudstone beds.

3.1.13 The Lias Group is overlain by other geological units in the area of the scheme, but it does influence the geological and hydrogeological processes in the area. On the western side of the Cotswold escarpment the Lias Group is covered by a mantle of head deposits and at the western end of the scheme by localised Cheltenham Sand and Gravel (Figure 9.3 of the PEI report). To the east of the escarpment, the Lias Group is overlain by Inferior Oolite limestone.

Structural geology

3.1.14 The geological faults in the region that the scheme is likely to intersect are the Shab Hill fault, the Shab Hill barn fault and Stockwell farm fault. The faults typically strike north-west to south-east.

3.1.15 Review of the geomorphological evidence for faults near Air Balloon suggest the position of the Shab Hill barn fault may be 170m north-east of the inferred location[xvii] on the existing geological map[xviii]. Additionally, the Shab Hill fault has not been conclusively identified in the review and based on this information the fault has been inferred to have an offset of less than 5m[xix]. The revised position will be adopted for the ES and is presented on Figure 9.3 of the PEI report.

3.1.16 The location of the Stockwell farm fault has also been revised based on geomorphological evidence and geophysical resistivity testing conducted where the fault is anticipated to intersect the scheme[xx]. The location of this fault has also been revised approximately 30 to 40m north of the existing geological mapped location and is presented in on Figure 9.3 of the PEI report.

3.1.17 The geological setting in conjunction with Quaternary glacial and interglacial processes has facilitated a number of processes, which create the geomorphological setting of the Cotswold region. The Cotswold escarpment is a pronounced feature in the region, which formed from mechanical stress relief in the rock mass during the Quaternary.

3.1.18 It is likely that cambering, valley-bulging, and both rotational and translational landslides occurred during the transitional periods in the Quaternary, facilitated by lateral stress relief during valley erosion and reduced effective stresses caused by increased pore water pressure initiated by the melting of ground-ice, as illustrated in Figure 2. Evidence of mass movement, such as landslides, cambering, gulls, and solifluction (soil creep due to freeze-thaw activity) are present along the Cotswold escarpment at Crickley Hill.

3.1.19 These mechanically derived geological features within limestone formations have the potential to be solutionally enlarged and be in the process of developing karst features. Karst features observed near the Crickley Hill escarpment include a dry valley, infilled gull-caves, rockfall/scree and carbonate mineralisation ('dogtooth spar') on the sides of open voids[xxi].

3.1.20 Away from the escarpment there are few karst features (dry valley at Shab Hill). On the plateau, where there is a more gradual, interbedded transition from limestone to mudstone in the Great Oolite Group, there is less pronounced mechanical processes of stress-relief and glacial/interglacial effects. Self & Boycott (2004) identified in the Stroud area that the tributaries of the River Frome have incised deeply through the Fuller's Earth Formation and into the Great Oolite Limestonesbut no gull caves are known[xxii]. This is likely to be similar to the area of Great Oolite Group at the southern end of the scheme.

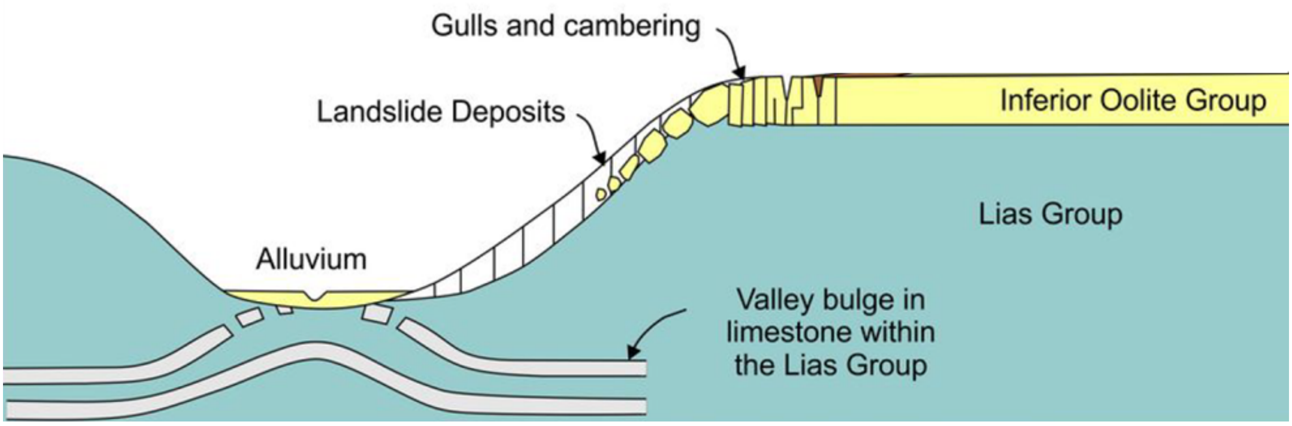


Figure 2 **Schematic illustration of cambering, valley bulging and landslides (modified from Farrant et al., 2014)**

3.2 Regional hydrogeology

3.2.1 The hydrogeology of the Cotswold 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 Figure 1. In the scheme area, 'head' deposits cover the Lias Group formations.

Superficial deposits

3.2.2 The superficial deposits comprise alluvial deposits, head deposits and the Cheltenham Sand and Gravel in discrete areas beneath and around the scheme. While the superficial deposits are not continuous over the scheme, the groundwater regime is anticipated to be similar locally. 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.

3.2.3 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.

3.2.4 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.

3.2.5 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.

Great Oolite Group-limestone formations

3.2.6 Limestones within the Great Oolite Group are considered the main water bearing formations that allow for groundwater movement in this geological group. In the scheme 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.

3.2.7 Groundwater flow through the limestones is dominated by secondary porosity, so the aquifer has a high rate of transmissivity but low storage capacity. 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.

3.2.8 Where the Great Oolite limestone formations vertically 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.

3.2.9 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 by rainfall.

3.2.10 For the ES, the transition zone will be included within the Great Oolite limestone aquifer as the hydraulic properties in relation to the proposed cuttings in the same area are likely to be dominated by the limestone beds.

Great Oolite Group – Fullers Earth formation

3.2.11 The Fuller's Earth Formation is a grey mudstone with limestone beds, which is the basal formation of the Great Oolite Group.

3.2.12 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.

For the purposes of these conceptual models local to the scheme, the Fuller's Earth Formation aquitard is assumed to be laterally continuous below the Great Oolite Group limestones and therefore considered an aquitard at the base of the Great Oolite Group. This assumption is based on the presence of Fuller's Earth Formation in the surface geology surrounding the Great Oolite Group limestones, and the relatively local extent of the Great Oolite Group in the study area.

Inferior Oolite Group

3.2.13 The Inferior Oolite limestone aquifer forms the crest of the Cotswold escarpment and extends south-east from the escarpment (Figure 9.3 of the PEI report). The aquifer is largely unconfined, however in the southern portion of the 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[xxiii].

3.2.14 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.

3.2.15 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.

Lias Group

3.2.16 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.

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

3.2.18 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. Groundwater flow through the Bridport Sand 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.

3.2.19 The Marlstone Rock Formation is greatly affected by cambering and therefore is very heavily jointed, but more massive at depth[xxiv]. 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 Formation, relative to the overlying Whitby Mudstone Formation, may promote leakage from the mudstones and locally form a spring-line.

Groundwater quality

3.2.20 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 (NVZ)[xxv]. 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[xxvi].

3.2.21 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 scheme at Crickley Hill) as an NVZ[xxvii].

3.2.22 Bicarbonate rich groundwater is expected to be the dominant water type in the region given the presence of limestone[xxviii]. 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. A schematic showing the conceptualisation of the Cotswold Plateau is shown in Figure 3, and described below.

3.2.23 Groundwater close to recharge areas are typically oxidising and strongly pH buffered with calcium and bicarbonate (HCO_3^-) as dominant dissolved ions[xxix]. Recharge areas are particularly susceptible to high nitrate concentrations from agricultural pollution. This is anticipated to be most reflective of unconfined waters the scheme may encounter.

3.2.24 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[xxx]. The process of ion exchange causes dissolved calcium ions in the groundwater to attach or 'adsorp' onto the rock surface and, in exchange, sodium ions come off the rock surface and into the groundwater.

3.2.25 In more confined groundwaters, dissolved oxygen is reduced or absent, with conditions becoming more reducing, which is evidenced by redox-sensitive elements[xxxi]. Lower nitrate levels can suggest that denitrification may be occurring[xxxii], 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.

3.2.26 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[xxxiii].

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

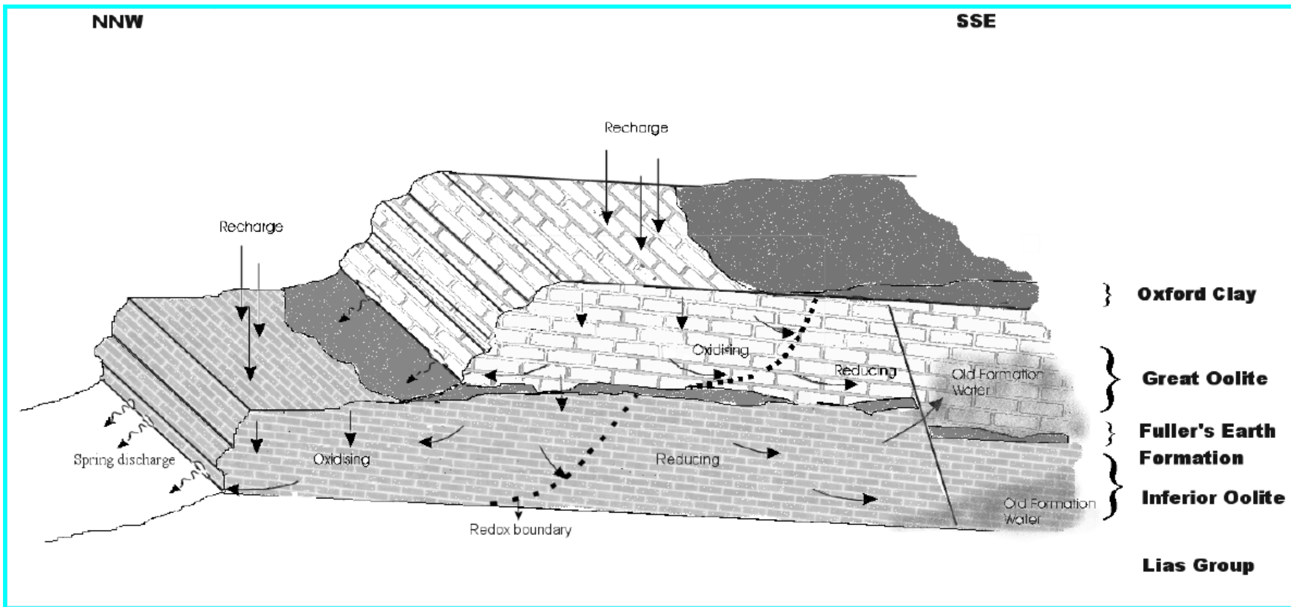


Figure 3 Conceptual model of redox conditions within the Cotswolds[xxxv]

Rainfall and recharge

3.2.28 Rainfall and potential evapotranspiration vary over the Thames catchment area with rainfall being higher in the west and also increasing with topography[xxxvi] - both correlating to the location of the scheme in the catchment. The mean annual rainfall in the area is 805mm and estimated recharge is 370mm per annum[xxxvii]. The amount of recharge can be wide ranging, as Morgan-Jones and Eggboro (1981) noted in the hydraulic years of 1975 and 1976 where recharge was 100mm and 630mm respectively.

3.2.29 The superficial deposit aquifers are recharged by a variety of mechanisms including rainfall infiltration, run off 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.

3.2.30 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.

3.2.31 Recharge of the Inferior Oolite limestone in the scheme area is from rainfall where exposed. 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[xxxviii].

3.2.32 The future baseline conditions 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.

3.2.33 The future baseline conditions are likely to reduce the amount of recharge to the groundwater aquifers which may have impacts upon groundwater dependent features near the scheme and cause some perennial features to become seasonal. 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.

3.2.34 Rainfall data for the Ebsworth monitoring station approximately 5.4km south-west of the scheme is presented in Appendix C. Data received is for the period of 1 January 2009 to June 2020. Note, data is missing from the 18th October 2019 until the 16th November 2019 and will be included in the HIA prepared for the Environmental Statement.

Abstractions

3.2.35 The Baunton public water supply abstraction (approximately 12km south-east of the scheme) and associated source protection zone (SPZ) is located within the Thames groundwater catchment. The Baunton abstraction takes groundwater from the Inferior Oolite aquifer and its associated SPZ3 (corresponding to the total catchment area) is intersected by part of the scheme near Stockwell.

3.2.36 Land east of Stockwell, and extending south along the scheme, is located within SPZ3. The southern end of the scheme is approximately 2.8km from SPZ2 and 3.4km from SPZ1 in the south-east (Figure A-1 in Appendix A of this document).

3.2.37 There are no further recorded licensed abstractions known within 1km of the scheme.

3.2.38 The Water Feature Survey identified 16 potentially unlicensed abstractions, boreholes and wells near the scheme[xxxix]. 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. The locations of these are presented on Figure 13.5 of the PEI report.

Consented discharge

3.2.39 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 scheme[xl]. 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 scheme. The consented discharge locations are presented on Figure 13.5 of the PEI report.

3.2.40 These consented groundwater discharges are existing potential point sources of pollution to the underlying aquifers.

Table 3 Consented groundwater discharge licences within 1km of the 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) (incl. farm house)	Underground strata	Active	Sewage discharges – final / treated effluent - not water company
Hardings barn	Domestic property (single) (incl. farm house)	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

Surface water

3.2.41 The scheme is located within two surface water catchments: the Severn River catchment (21,000km^2) and the Thames River catchment (16,200km^2). In the scheme area, the catchment divide is set back from the Cotswold escarpment where the Severn catchment is located to the west and the Thames catchment is to the east. As a result, the scheme interacts with the headwaters of these respective surface water catchments, in the form of localised tributaries.

3.2.42 The Severn River discharges in the Bristol Channel and the Thames discharges into the North Sea. Surface water resources near scheme are managed by the Severn River Basin District River Basin Management Plan[xli] and the Thames River Basin District River Basin Management Plans[xlii].

3.2.43 The surface water catchments and watercourses are presented on Figure 13.5 of the PEI report.

3.3 Local geology

3.3.1 The review of the local geology is based on published geology and past ground investigation information and preliminary interpretation of available Phase 2A borehole records. Visual representation of the conceptual models as described below is shown on Figure 13.8 of the PEI report.

CH0+000 to 0+500, Crickley Hill approach

3.3.2 Along the scheme alignment, the existing ground profile at the Crickley Hill approach gently rises from approximately 96mAOD to 114mAOD. The ground conditions comprise Cheltenham Sand and Gravel, thickening towards the west, underlain by Charmouth Mudstone Formation bedrock.

2.5.3 A summary of the materials and strata thickness anticipated are presented in Table 4.

Table 4 Summary of ground conditions between CH0+000 to 0+500, Crickley Hill approach

Stratum	Typical description	Approximate thickness (m)
Cheltenham Sand and Gravel	Firm to very stiff mottled brown silty clay with frequent fine to coarse ooidal limestone gravel.	1 - 2
Charmouth Mudstone Formation (Lias Group)	Grey thin- to medium-bedded silty mudstone with occasional shell fragments. Weathered mudstone recovered as stiff to very stiff grey fissured silty clay.	Not proven

CH0+500 to 1+700, Crickley Hill escarpment

3.3.3 The existing ground profile along the scheme alignment at Crickley Hill rises from approximately 114mAOD to 212mAOD, generally following the low point in the embayment adjacent to the tributary of Normans Brook.

3.3.4 The ground conditions on the escarpment are dominated by head deposits, which are highly variable in their composition and thickness. The head deposits are generally anticipated to be thinner at the crest of the escarpment and thicken towards the scheme. However due to the variety of landslipping processes occurring across the escarpment, the thickness of head is quite variable across the escarpment.

3.3.5 Overlying the head deposits are areas of localised made ground at Crickley Hill tractors and some localised alluvium is expected along the tributary of Normans Brook.

3.3.6 The mantle of head deposits over the escarpment is underlain by the Lias Group. The top of the Lias Group in this area dips towards the tributary of Normans Brook.

3.3.7 The revised position of the Shab Hill Barn fault intersects the scheme at CH1+600, striking in a north-west to south-east direction.

3.3.8 A summary of the materials and strata thickness anticipated are presented in Table 5.

Table 5 Summary of ground conditions between CH0+500 to 1+700, Crickley Hill escarpment

Stratum	Typical description	Approximate thickness (m)
Made Ground	Encountered at Crickley Hill Tractors only (Ch1+400 to Ch1+600). Brown fine and medium sand / firm sandy clay. Gravel is fine to coarse limestone, mudstone, sandstone, brick, bituminous material, concrete.	1 - 3
Alluvium	Not encountered in recent ground investigation, but mentioned in previous report (Hutchinson, 1991). Organic silt/clayey sand.	< 2
Head	Variable in composition, comprising: Loose to medium dense clayey gravel or very soft to firm slightly gravelly clay/clayey silt. Gravel is fine to coarse oolitic limestone. Locally contains peat or organic material.	1 - 23
Lias Group (undifferentiated)	Very weak dark grey mudstone /siltstone. Contains thin beds (<1.5m) of weak to strong grey limestone. Weathered mudstone recovered as stiff to very stiff dark grey slightly sandy silty clay; weathered siltstone recovered as very stiff dark grey sandy clayey silt.	Not proven

CH1+700 to CH2+800, Air Balloon

3.3.9 Within the Air Balloon cutting section, the existing ground cuts into the crest of the Inferior Oolite limestone, rising from approximately 212mAOD to 228mAOD between CH1+700 and CH1+1+900. From CH1+900 the existing ground level becomes less steep on the Upper Cotswold Plateau, which includes rolling hills up to 274mAOD.

3.3.10 The ground conditions include some small localised areas of made ground, underlain by Inferior Oolite limestone up to approximately 35m depth. The Inferior Oolite is anticipated to be thinner towards the escarpment, particularly within the existing A417 cutting near the transition to Lias Group bedrock.

3.3.11 The Bridport Sand Formation is a laterally discontinuous layer that occurs in the region. It is not shown on geological maps within the site area, but has been described in the adjacent published 1:50,000 scale geological map of Cirencester as a sandy mudstone with fine-grained sandstone, up to 10m in thickness. Preliminary interpretations of recent ground investigation information suggest the Bridport Sand Formation is locally present, and may interdigitate with the underlying Whitby Mudstone Formation. The Bridport Sand Formation is captured within the undifferentiated Inferior Oolite Group in Table 6.

3.3.12 The Shab Hill barn fault intersects the scheme at CH1+925, striking in a north-west to south-east direction.

3.3.13 A summary of the materials and strata thickness anticipated are presented in Table 6.

Table 6 Summary of ground conditions between CH1+700 to CH2+800, Air Balloon

Stratum	Typical description	Approximate thickness (m)
Made Ground	Encountered at Air Balloon car park only. Tarmacadam / slightly sandy clayey fine to coarse limestone gravel (fill).	< 1
Inferior Oolite Group (undifferentiated)	Thin- to medium-bedded grey very weak to medium strong highly fractured oolitic limestone with shell fragments with irregular orange-stained voids. Weathered limestone recovered as soft to stiff sandy gravelly clay / slightly sandy clayey fine to coarse limestone gravel with high limestone cobble content.	20 - 35
Lias Group (undifferentiated)	Extremely weak mudstone/siltstone with thin (<1.5m) limestone beds, locally stained reddish brown. Weathered mudstone/siltstone recovered as very stiff fissured thinly laminated dark grey clay or silt.	Not proven

CH2+800 to CH3+500, Shab Hill

3.3.14 The Shab Hill area is within the Upper Cotswold Plateau area, with low gradient rolling hills between approximately 274mAOD to 280mAOD. The plateau is intersected by an incised, dry valley at CH3+140 which travels in a generally easterly direction. The steep valley sides are up to approximately 30m high at the eastern side of the proposed Shab Hill Junction and the valley continues to deepen towards the headwaters of the River Churn.

3.3.15 The scheme is intersected by the Shab Hill fault at CH3+000 and the Shab Hill Barn fault at CH3+500, both striking in a north-west to south-east direction.

3.3.16 North of the Shab Hill fault the scheme is underlain by Inferior Oolite limestones. Between the two faults the scheme is underlain by undifferentiated Great Oolite limestones transitioning into Fuller’s Earth Formation over Inferior Oolite limestone from approximately 20m depth below ground.

3.3.17 A summary of the materials and strata thickness anticipated are presented in Table 7.

Table 7 Summary of ground conditions between CH2+800 to CH3+500, Shab Hill

Stratum	Typical description	Approximate thickness (m)
Topsoil	Very stiff sandy gravelly clay with rootlets. Gravel is fine to coarse limestone.	0.3
Great Oolite Group (undifferentiated)	Interbedded calcareous sandstone, variably oolitic limestone and calcareous mudstone and siltstone.	10
Fuller’s Earth Formation (Great Oolite Group)	Grey bedded silicate- to lime-mudstone containing fossils, with units of thinly interbedded limestone and sandstone.	10
Inferior Oolite Group (undifferentiated)	Thin- to medium-bedded grey very weak to medium strong highly fractured oolitic limestone with shell fragments with irregular orange-stained voids.	30 - 40
Lias Group (undifferentiated)	Very weak to weak thinly laminated mudstone or calcareous siltstone with frequent laminae of grey silt or siltstone nodules.	Not proven

CH3+500 to CH5+760, Stockwell-Nettleton

3.3.18 In the Stockwell-Nettleton area, the scheme roughly follows the ridgeline of the Upper Cotswold Plateau. The existing topography features rolling hills running in a relatively north-south direction and ranging in elevation from 260mAOD to 286mAOD.

3.3.19 The scheme is underlain by undifferentiated Great Oolite limestone, transitioning to Fuller's Earth Formation. The Great Oolite members is underlain by Inferior Oolite Limestone approximately 65m thick over Lias Group.

3.3.20 A summary of the materials and strata thickness anticipated are presented in Table 8.

Table 8 Summary of ground conditions between CH3+500 to CH5+760, Stockwell-Nettleton

Stratum	Typical description	Approximate thickness (m)
Great Oolite Group (undifferentiated)	Medium strong thinly bedded bioclastic and oolitic limestone with very thin beds of sandy clay or sandstone, stained infilled subvertical fractures and some voids.	10
	Interbedded calcareous sandstone, variably oolitic limestone and calcareous mudstone and siltstone. Mudstone locally weathered to stiff gravelly silty clay.	10
Fuller's Earth Formation (Great Oolite Group)	Grey bedded silicate- to lime-mudstone containing fossils, with units of thinly interbedded limestone and sandstone. Fractures noted to be sub horizontal, occasionally infilled with silty clay, or stained orangish-brown.	10 - 15
Inferior Oolite Group (undifferentiated)	Medium strong thickly bedded bioclastic argillaceous limestone with shell fragments and sub horizontal fractures stained orangish-brown. Voids (up to 80mm) partially infilled with sandy clay noted at depth (78mbgl).	65

4 Groundwater monitoring programme

4.1.1 Groundwater monitoring is being undertaken as part of the Phase 2A investigations. Refer to Chapter 9 Geology and soils for details of the completed intrusive investigations. The scope is presented in Arup Addendum Specification[xliii] . In summary this provides for:

- Weekly monitoring required for duration of Phase 2A fieldwork period.
- Monthly monitoring required for 12 months post Phase 2A field work period.
- Installation of data loggers in selected installations (set to take readings at 15mins intervals) with monthly downloads and dip meter verification at Diver data logger locations required for 12 months post Phase 2A field work period.
- The Contractor may be asked to extend both the monthly monitoring of standpipes and the monthly data logger reading interval beyond the 12 month post fieldwork period, or to amend the frequencies.

4.1.2 The groundwater monitoring boreholes have been selected at locations where specific design elements are proposed or where water receptors have been identified. Together, these locations provide a spatial network of groundwater monitoring across the study area so that hydraulic gradients and directions of flow can be identified. The location of all groundwater monitoring locations is presented in Appendix A.

4.1.3 The design of each monitoring installation is presented in Appendix B.

4.1.4 Monitoring data comprises of manual dips and logger data. The hydrographs for each monitoring well are presented in Appendix C and discussed in Section 5. Logger data provides a high frequency of data recording that allows correlation with rainfall/recharge events and provides a reflection of groundwater responses. The water level data included in this report is draft. Queries on data errors have been flagged for both manual and logger data. These data will be updated in the final data set.

4.1.5 Water quality samples have been collected as part of this programme and the results of these are presented in Appendix D and discussed in Section 6.

4.1.6 Hydraulic testing results from the monitoring wells are included in Appendix E and discussed in Section 7.

5 Groundwater level monitoring results

5.1 Superficial Aquifer - Head deposits, Crickley Hill

Overview

5.1.1 The locations of groundwater monitoring wells are shown in Appendix A. A summary of the response zone strata is presented in Appendix B and the range of observed groundwater levels is presented in Table 9.

5.1.2 The hydrographs for groundwater monitoring within the head deposits of Crickley Hill are presented in Appendix C, Figure C-1 to Figure C-7. Within the Crickley Hill area there are a total of 18 groundwater monitoring locations within the head deposits. Monitoring at these locations has progressively started since the 17th May 2019. The distribution of monitoring locations includes:

- 4 between CH0+500 and CH1+000 in the lower slopes of Crickley Hill
- 10 between CH1+000 and CH1+400 in the mid slopes of Crickley Hill
- 4 between CH1+400 and CH1+700 in the upper slopes of Crickley Hill

Table 9 Summary of groundwater monitoring in superficial head deposits at Crickley Hill

Location	Formation	No. dips	GWL range (average) (mbgl)	GWL range (average) (mAOD)	Observed range (m)
CH0+500 to CH1+000 (southern side of A417) – Lower Crickley Hill					
CP 102	Head deposits - silty clay	20	0.91 - 1.69 (1.17)	125.86 - 126.64 (126.38)	0.78
CP 104A	Head deposits - sand	17	8.54 - 11.5 (9.95)	136.5 - 139.46 (138.05)	2.96
CP 200	Head deposits - sand and gravel	22	1.11 - 3.76 (2.76)	125.94 - 128.59 (126.94)	2.65
CP 202	Head deposits - clay	21	0 - 1 (0.31)	134.7 - 135.7 (135.39)	1.00
CH1+000 to CH1+400 (northern side of A417) – Mid Crickley Hill					
CP 210 (s)	Head deposits/Lias Group (weathered)	21	Dry	Dry	-
CP 211	Head deposits - gravel	19	Dry	Dry	-
CP 215 (s)	Head deposits - clay	23	1.51 - 1.96 (1.78)	184.09 - 184.54 (184.27)	0.45
CP 215 (d)	Head deposits – fissured clay	28	12.85 - 15.38[2] (14.35)	170.67 - 173.2[2] (171.7)	2.53
DS/RC 205	Head deposits - gravelly clay	22	7.05 - 8.9 (8.13)	158.25 - 160.1 (159.02)	1.85
CH1+000 to CH1+400 (southern side of A417) - Mid Crickley Hill					
CP 105	Head deposits - silt and gravel	27	1.97 - 4.55 (3.49)	165.36 - 167.94 (166.42)	2.58
CP 206	Head deposits - clay	N/A[1]	1.74 - 5.31 (3.59)	157.54 - 161.11 (159.26)	3.57
CP 216	Head deposits - gravelly silty clay	N/A[1]	0.19 - 2.33 (1.19)	171.17 - 173.31 (172.31)	2.14
CP 204 (s)	Head deposits - clay	10	Dry	Dry	-
CP 212 (s)	Head deposits - gravel and clay	N/A[1]	7.34 - 11.57 (8.32)	180.03 - 184.26 (183.28)	4.22
CH1+400 to CH1+700 (southern side of A417) - upper Crickley Hill					
CP 106	Head deposits/Lias Group (mudstone)	13	15.67 - 16.19 (15.91)	170.06 - 170.58 (170.34)	0.52
DS/RC 108	Head deposits - sandy silty clay, weathered limestone	27	1.76 - 3.4 (2.31)	190.2 - 191.84 (191.29)	1.64
DS/RC/OH 107	Head deposits - sands and gravels	27	1.95 - 2.77 (2.08)	189.13 - 189.95 (189.82)	0.82

Note: 1. Continuous monitoring data available
2. Groundwater level falls below response zone base

CH0+500 to CH1+000 – Lower Crickley Hill

5.1.3 The groundwater monitoring locations in the lower slopes of Crickley Hill are located on the southern side of the A417 next to Norman's Brook. Within this domain, relatively shallow (< 3 mbgl) groundwater levels were recorded in CP 102, CP 200 and CP 202. Deeper groundwater levels were recorded in CP 104A (average 10 mbgl).

5.1.4 The shallow wells CP 102, CP 200 and CP 202 are located within silty and clayey head deposits. They generally do not show response to individual rainfall events but rather show a gradual seasonal response.

5.1.5 CP 104A monitors the groundwater level within a confined or semi-confined sand layer. The groundwater response at CP 104A also shows a seasonal response, indicating that the sand layer is connected to recharge.

CH1+000 to CH1+400 (northern side of A417) – Mid Crickley Hill

5.1.6 In the mid-slope region of Crickley Hill between CH1+000 and CH1+400, there are five groundwater monitoring locations. Relatively shallow groundwater levels (< 2 mbgl) were recorded in CP 215(s), whilst other shallower response zones in CP 210(s) (2.5 to 5.5 mbgl) and CP 211 (1.1 to 3.3 mbgl) consistently dipped dry. Deeper groundwater levels were recorded in CP 215(d) and DS/RC 205, which may indicate there is limited connection with the shallower, perched groundwater levels.

5.1.7 CP 210(s) and CP211 are both monitoring within shallow, coarse-grained head deposits. The monitoring to date indicates an absence of groundwater within these deposits, however this may be limited by the frequency of recordings and the rate groundwater levels may respond to rainfall.

5.1.8 CP 215 (s) is monitoring within a bed of clay dominated head deposits. The groundwater levels recorded between 13th August 2019 and 1st April are relatively consistent at approximately 184.3 mAOD. A rise in groundwater levels was observed following larger rainfall events in early January 2020 and mid-February 2020, where the groundwater rose by approximately 0.3 m. The maximum groundwater level recorded was 184.5 mAOD on the 20th February 2020.

5.1.9 Greater groundwater fluctuations were recorded in CP 215(d) and DS/RC 205, which are monitoring within clay dominated head deposits at depth. Between August 2019 and early November 2019, the groundwater levels recorded in CP 215(d) are approximately 170.9 mAOD, showing a delayed response to the higher winter rainfalls beginning at the end of September 2019. From the 4th November the groundwater gradually rises, with minor fluctuations, to the maximum level recorded over winter of 173.2 mAOD on the 20th February 2020. The groundwater levels decrease relatively linearly over this time to the final recorded level of 171.8 mAOD on the 31st March 2020. CP 215(d) is monitoring within fissured clays which may eb directly connected to the underlying fractured limestone

5.1.10 DS/RC 205, located further down hill from CP 215(s) showed a much more rapid response to rainfall and thus a larger amplitude in the groundwater levels recorded as the recovery period is also relatively rapid in some cases. From the commencement of monitoring on the 4th October 2019, there is a steady, linear increase in groundwater levels. Following this period, there are rapid fluctuations in groundwater level, up to 1.4 m between readings taken one week apart. The maximum recorded level during winter was 160.1 mAOD on the 20th February 2020, and there is a more gradual decline to the final reading of 158.9 mAOD on the 30th March 2020.

CH1+000 to CH1+400 (southern side of A417) - Mid Crickley Hill

5.1.11 Between CH1+000 and CH1+400 on the southern side of the A417, there are five groundwater monitoring locations. Similar to other areas of Crickley Hill, relatively shallow groundwater levels were recorded (< 4 mbgl) near Norman's Brook over deeper recorded groundwater levels between 7.3 and 11.6 mbgl at CP212 (s), which is located approximately halfway up the Crickley Hill escarpment.

5.1.12 CP 105, CP 206 and CP 216 are located on the southern side of Norman's Brook, where CP 206 and CP 216 have groundwater level loggers installed. CP 206 located further downgradient of CP105 and CP 216 and so the groundwater levels recorded here are relatively lower between 157.5 and 161.1 mAOD. CP216 is located upgradient so groundwater levels are relatively higher, between 171.2 and 173.3 mAOD.

5.1.13 Logger data in CP 206 and CP 216 demonstrates that groundwater levels respond rapidly to recharge events. At both locations there is a steady decline in groundwater levels from the end of March 2020, and it is likely levels have continued to decline over the drier spring and summer months of 2020.

5.1.14 Monitoring within CP105 is limited to manual dips between the 20th May 2019 and the 18th December 2019. Due to the limited amount of measurements at this location the response to rainfall is uncertain at this location, however a seasonal variation is apparent.

5.1.15 CP 204(s) is located mid-way up the Crickley Hill escarpment and has response zone within clay dominated head deposits at approximately 8.5 to 9.9 mbgl. Manual dips taken at this location have been consistently dry.

5.1.16 CP 212(s) is also located mid-way up the Crickley Hill escarpment. It's response zone is located within gravel and clay head deposits. The range in groundwater levels has been recorded indicates a seasonal range of 180.0 to 184.5 mAOD

CH1+400 to CH1+700 (southern side of A417) - upper Crickley Hill

5.1.17 Within the upper slopes of Crickley Hill there are three monitoring locations (CP106, DS/RC108 and DS/RC/OH107) installed into the head deposits located on the southern side of the A417. Groundwater readings are limited to manual dips in this area.

5.1.18 Of the three monitoring installations, CP 106 is the most downgradient and it has a response zone that extends from the head deposits into the underlying Lias Group.. Groundwater levels recorded ranged from 170.1 to 170.6 mAOD (note limited measurements have been recorded at this location, where only two manual dip readings are available over the winter period).

5.1.19 The recorded groundwater levels in DS/RC/OH 107 are relatively consistent at approximately 189.8 mAOD. These levels indicate that the groundwater level is at surface and may contribute to a man-made pond.

5.1.20 Groundwater level records in DS/RC 108 indicate that the well took significant time to stabilise following installation in May 2019. From the 23rd October 2019 to the 23rd January 2020, the groundwater level gradually increases from 191.5 to 191.8 mAOD.

5.2 Great Oolite Group - Limestones

Overview

5.2.1 The locations of groundwater monitoring wells are shown in Appendix A. A summary of the response zone strata is presented in Appendix B and the range of observed groundwater levels is presented in Table 10.

5.2.2 The hydrographs for groundwater monitoring within the Group Oolite Group limestones are presented in Appendix C and Figure C-9. Across the scheme there are 6 monitoring locations within the Great Oolite Group limestones. Monitoring at these locations has progressively started since the 3rd October 2019. The distribution of monitoring locations includes:

- 1 between CH3+000 and CH3+500 at Shab Hill Junction
- 4 between CH3+500 and CH5+000 Stockwell-Nettleton
- 1 near the Bushley Muzzard SSSI

5.2.3 A summary of the response zone strata is presented in Appendix B and the range of observed groundwater levels is presented in Table 10.

Table 10 Summary of groundwater monitoring in Great Oolite Group limestones

Location	Formation	No. dips	GWL range (average) (mbgl)	GWL range (average) (mAOD)	Observed range (m)
CH3+000 to CH3+500 - Shab Hill Junction					
OH 413	Great Oolite (Limestone)	24	Dry	Dry	-
CH3+500 to CH5+000 - Stockwell-Nettleton					
DS/RC 218	Great Oolite (Limestone)	24	1.5 - 8.88 (4.53)	276.77 - 284.15 (281.13)	7.38
DS/RC 220	Great Oolite (Limestone)	N/A[1]	1.11 - 3.28 (1.74)	275.57 - 277.74 (278.26)	2.17
DS/RC 317	Great Oolite (Limestone)	22	1.9 - 3.8 (3.15)	271.2 - 273.1 (271.85)	1.90
DS/RC 401	Great Oolite (Limestone)	17	5.8 - 6.46 (6.33)	266.64 - 267.3 (266.77)	0.66
Bushley Muzzard SSSI					
DS/RC 420	Great Oolite (Limestone)	N/A[1]	1.54 - 3.07 (2.04)	274.03 - 275.56 (273.36)	1.53

Note: 1. Continuous monitoring data available
2. Groundwater level falls below response zone base

CH3+000 to CH3+500 - Shab Hill Junction

5.2.4 OH 413 is located on the northern side of the Shab Hill Barn fault and the response zone extends to 1 metre above the Fullers Earth Formation. The location has consistently dipped dry since monitoring commenced.

CH3+500 to CH5+000 - Stockwell-Nettleton

5.2.5 Between CH3+500 and CH5+000 there are 4 monitoring locations: DS/RC 218, DS/RC 220, DS/RC 317 and DS/RC 401 (from north to south along the scheme). These installations are monitoring within the transition zone of the Great Oolite Group which includes interbedded limestones and mudstones.

5.2.6 Manual dips recorded during the initial monitoring periods for DS/RC 218, DS/RC 317 and DS/RC401 are higher than the levels recorded over the winter period when the highest groundwater levels are anticipated. It is likely these high groundwater levels recorded are recovering post installation and borehole development.

5.2.7 DS/RC 218 shows the greatest variation in groundwater levels between the 22nd October 2019 and the 26th February 2020, where levels were recorded between 279.5 and 281.7 mAOD. The location is responsive to rainfall events, particularly higher intensity events over winter months. From the 26th February 2020 until the final on the 15th April 2020, the groundwater level declines by 4.3 m to 276.8 mAOD. DS/RC 220, shows a similar response pattern to rainfall as DS/RC 218, however at a smaller amplitude. From the commencement of monitoring on the 17th December 2019 until the 23rd March 2020, the groundwater varies between 276.9 and 277.7 mAOD, before steadily declining to 275.6 mAOD on the 26th May 2020.

5.2.8 Smaller variations (< 0.5 m) in groundwater level are recorded in manual dips at DS/RC 317 and DS/RC 401 between January 2020 and April 2020. The groundwater levels in DS/RC 317 over the winter months is generally around 271.1 mAOD and level logger data indicates the location responds rapidly to rainfall events (up to 0.7 m increase in level). DS/RC 401 however doesn’t have a logger installed so it is unclear how it responds to rainfall events. Groundwater levels recorded at DS/RC 401 are relatively consistent around 266.8 mAOD

Bushley Muzzard SSSI

5.2.9 DS/RC 420 is located on the western side of the Bushley Muzzard SSSI and is monitoring within the interbedded limestones and mudstones that likely drain into the SSSI. Manual dips are available for the initial monitoring period at this location from the 10th October 2019 to the 18th December 2019.The variation in groundwater levels recorded during this period was between 274.9 to 275.4 mAOD. The level logger recorded a larger range in groundwater levels from the 18th December 2019, however there were sometimes poor correlations with manual dips taken. The location responds rapidly to rainfall, however the largest variation in groundwater level following a large rainfall event was 0.9 m in mid-February 2020.

5.3 Great Oolite Group – Fuller’s Earth Formation

Overview

5.3.1 There is one groundwater monitoring location within the Fuller’s Earth Formation, located adjacent to Ermin Way (Roman Road), approximately 900 m west of the Bushley Muzzard SSSI The maps showing the locations of these wells are presented in Appendix A, Figure A-1 and the hydrographs for these groundwater monitoring locations are presented in Appendix C, Figure C-10. Monitoring at the location commenced on the 4th February 2019.

5.3.2 Table 11 provides a summary the range of groundwater levels recorded, the number of manual measurements and whether a water level data logger was used. A summary of the response zone interval is presented in Appendix B, Table B-17.

5.3.3 The sections below provide a description of the groundwater level data recorded for each area and provides an interpretation of these fluctuations based on seasonal recharge and responses to rainfall events.

Table 11 Summary of groundwater monitoring in Fuller's Earth Formation

Location	Formation	No. dips	GWL range (average) (mbgl)	GWL range (average) (mAOD)	Observed range (m)
OH 416	Fuller's Earth Formation	N/A[1]	1.44 - 3.34 (2.21)	283.51 - 285.41 (284.64)	1.90

Note: 1. Continuous monitoring data available

Ermin Way

5.3.4 One groundwater monitoring borehole (OH 416) is located adjacent to Ermin Way (Roman Road). The location of the monitoring borehole is presented in Appendix A, Figure A-1. The geology of the response zone is described in Appendix B, Table B-17. In this area the Fuller's Earth Formation is at ground surface.

5.3.5 The groundwater monitoring record for this borehole (Table 11 and hydrograph Appendix C, Figure C-10) shows water levels are perched within the weathered zone of the formation. Water level logger results (March 2019 to May 2020) show there is a 1.9 m seasonal variation in water levels. Leading into winter month there is a sharp rise in water levels, which show little response to rain events over the winter period. Outside of winter months, the water levels are mostly responsive to rain events that last for several days.

5.3.6 Based on the water level data recorded, the Fuller's Earth Formation at Ermin Way (Roman Road) receives direct recharge. The higher water levels recorded are likely controlled by the granular road formation material which overlies the Fullers Earth Formation at the borehole location.

5.3.7 Level logger monitoring within OH 416 commenced in March 2019 and data is available until May 2020, so a complete year of monitoring has been completed. The monitoring indicates groundwater levels at this location respond rapidly to rainfall, however the magnitude of the response is different depending on the antecedent conditions.

5.3.8 From the 21st March 2019 until the 12th June 2019, the groundwater level is trending downwards, albeit with small fluctuations. Following a series of large rainfall events in mid-June 2019, the groundwater level increased from 284.1 to 284.8 mAOD, followed by a steady decline. A similar response was observed in mid-August 2019. Following the commencement of seasonal recharge in late September 2020, the groundwater level rapidly increased by 0.9 m to 284.7 mAOD. Over the winter groundwater levels remained high, up to 285.4 mAOD and fluctuations in levels over this time were relatively minor (<0.2 m). From March 2020, the groundwater levels steadily declined to the final level recorded 283.5 mAOD on the 26th May 2020.

5.4 Inferior Oolite Group

Overview

5.4.1 There are a total of 15 groundwater monitoring locations within the Inferior Oolite Group limestones. The maps showing the locations of these wells are presented in Appendix A, Figure A-1 and the hydrographs for these groundwater monitoring locations are presented in Appendix C, Figure C-11 to Figure C-17. Monitoring at these locations has progressively started since the 5th February 2019. The groundwater monitoring network for the Inferior Oolite Group may be divided into the following specific areas:

- 8 between CH1+700 and CH2+000 at Air Balloon
- 2 near Barrow Wake
- 1 near the proposed B4070
- 2 between CH3+000 and CH3+500 at Shab Hill Junction
- 2 between CH3+500 and CH4+575 at Stockwell-Nettleton

5.4.2 Table 12 provides a summary the range of groundwater levels recorded, the number of manual measurements and whether a water level data logger was used. A summary of the response zone interval is presented in Appendix B, Table B-17.

5.4.3 The sections below provide a description of the groundwater level data recorded for each area and provides an interpretation of these fluctuations based on seasonal recharge and responses to rainfall events.

Table 12 Summary of groundwater monitoring in Inferior Oolite Group

Location	Formation	No. dips	GWL range (average) (mbgl)	GWL range (average) (mAOD)	Observed range (m)
CH1+700 and CH2+000 - Air Balloon					
DS/RC 109	Inferior Oolite (Limestone)	17	Dry	Dry	-
DS/RC 301	Inferior Oolite (Limestone, Bridport Sand)	17	26.13 - 27.75 (26.47)	205.25 - 206.87 (206.53)	1.62
DS/RC 302	Inferior Oolite (Limestone)	26	23.95 – 25.80 (25.20)	208.7 - 210.55 (209.3)	1.85
DS/RC 406	Inferior Oolite (Birdlip Limestone)	N/A[1]	27.77 - 31.94 (30.85)	206.71 - 210.88 (207.8)	4.17
DS/RC 415	Inferior Oolite (Salperton, Aston and Birdlip Limestone Formations)	44	Dry	Dry	-
DS/RC 418	Inferior Oolite (Limestone)	9	55.96 - 56.12 (56.03)	216.13 - 216.29 (216.22)	0.16
OH 405	Inferior Oolite (Limestone)	41	Dry	Dry	-
OH 407	Inferior Oolite (Limestone)	37	Dry	Dry	-
Barrow Wake					
DS/RC 404	Inferior Oolite (Birdlip Limestone)	24	33.28 - 33.42 (33.39)	235.58 - 235.72 (235.61)	0.14
DS/RC/OH 414	Inferior Oolite (Limestone)	24	55.03 - 58.9 (57.03)	215.7 - 219.57 (217.57)	3.87
B4070 realignment					
DS/RC 314	Inferior Oolite (Limestone)	26	14.87 - 15.15 (14.92)	278.05 - 278.13 (278.1)	0.28
CH3+000 to CH3+500 - Shab Hill Junction					
DS/RC 315	Inferior Oolite (Limestone)	24	42.75 - 48.7 (45.04)	198.2 - 204.15 (201.86)	5.95
DS/RC/OH 412	Inferior Oolite (Limestone)	21	26.86 - 28.95 (28.74)	221.35 - 223.44 (221.56)	2.09
CH3+500 to CH4+575 - Stockwell-Nettleton					
DS/RC/OH 400	Inferior Oolite (Limestone)	19	70.72 - 71.8 (71.12)	196.15 - 197.23 (196.83)	1.08
OH 417	Inferior Oolite (Limestone)	25	60.51 - 70.6 (69.18)	205.05 - 215.14 (206.47)	10.09

Note: 1. Continuous monitoring data available

CH1+700 and CH2+000 - Air Balloon

5.4.4 Eight groundwater monitoring boreholes (DS/RC 109, DS/RC 301, DS/RC 302, DS/RC 406, DS/RC 415, DS/RC 418, OH 405, OH 407) are located at Air Balloon. The location of the monitoring boreholes is presented in Appendix A,

Figure A-1. The geology of the response zone is described in Appendix B, Table B-17. In this area the Inferior Oolite Group is at ground surface.

5.4.5 The groundwater monitoring records for DS/RC 301 and DS/RC 418 (Table 4 and hydrograph Appendix C, Figure C-11) show the water level lies near the base of the aquifer unit and that the aquifer is largely drained. Water levels recorded are < 3.5 m above the aquifer base (note that in DS/RC 301 the water level is within the Bridport Sand Formation part of the response zone). Manual dips recorded at DS/RC 418 (January 2020 to March 2020) and DS/RC 418 (November 2019 to March 2020) show the water levels do not respond to rain events.

5.4.6 The groundwater monitoring records for DS/RC 302 and DS/RC 406 (Table 4 and hydrograph Appendix C, Figure C-11) show the water level lies near the base of the aquifer unit and that the aquifer is largely drained. Water levels recorded are < 6 m above the aquifer base. Water level monitoring at DS/RC 302 (February 2020 to March 2020) and DS/RC 406 (February 2019 to May 2020), show the water levels are highly responsive to recharge events. A large seasonal variation (4.2 m) was recorded at DS/RC 406.

5.4.7 Based on the water levels recorded, the Inferior Oolite Group at Air Balloon receives direct recharge. The water levels recorded in this area are influenced by the underlying Bridport Sand Formation, which has a greater storage capacity than the Inferior Oolite Group.

Barrow Wake

5.4.8 Two groundwater monitoring boreholes (DS/RC 404 and DS/RC/OH 414) are located adjacent to the proposed B4070 realignment. The location of the monitoring boreholes is presented in Appendix A, Figure A-1. The geology of the response zone is described in Appendix B, Table B-17. In this area the Inferior Oolite Group is at ground surface.

5.4.9 The groundwater monitoring record for DS/RC 404 (Table 4 and hydrograph Appendix C, Figure C-12) shows the water level lies near the base of the aquifer unit and that the aquifer is largely drained. Water levels recorded are < 2 m above the aquifer base. Manual dip data (January 2019 to February 2020) shows that the water table has minimal seasonal fluctuation (< 0.2m) and that it does not respond to rainfall events. DS/RC 404 was frequently dipped as 'dry' (and these readings have not been presented on Figure C 12.). Monitoring between November 2019 and January 2020 recorded relatively consistent groundwater levels between 235.6 and 235.7 mAOD with very little fluctuation.

5.4.10 The groundwater monitoring record for DS/RC/OH 414 (Table 4 and hydrograph Appendix C, Figure C-13) also shows the water level lies near the base of the aquifer unit and that the aquifer is largely drained. Water levels recorded are < 5.5 m above the aquifer base. Manual dip data (October 2019 to March 2020) shows that the water table has a flashy response to rainfall. Over the winter period, groundwater levels responded rapidly to rainfall inputs where the maximum difference between reading was 215.7 mAOD on the 8^{th} January 2020 and 219.6 mAOD on the 15^{th} January 2020. From late February, the groundwater level appears to decline.

B4070 realignment

5.4.11 One groundwater monitoring borehole (DS/RC 314) is located adjacent to the proposed B4070 realignment. The location of the monitoring borehole is presented in Appendix A, Figure A-1. The geology of the response zone is described in Appendix B, Table B-17. In this area the Inferior Oolite Group is at ground surface.

5.4.12 The groundwater monitoring record for this borehole (Table 4 and hydrograph Appendix C, Figure C-14) shows that the groundwater level lies near the base of the aquifer unit and that the aquifer is largely drained, maintaining only 3m of water above the aquifer base throughout the year. Manual dip data (October 2019 to March 2020) shows that the water table has minimal seasonal fluctuation (< 0.3m) and does not respond to rainfall events.

CH3+000 to CH3+500 - Shab Hill Junction

5.4.13 Two groundwater monitoring boreholes (DS/RC 315 and DS/RC/OH 412) are located at Shab Hill Junction. The location of the monitoring boreholes is presented in Appendix A, Figure A-1. The geology of the response zone is described in Appendix B, Table B-17. In this area the Inferior Oolite Group is overlain by the Great Oolite Group and superficial head deposits. The Great Oolite Group in this area includes the basal Fullers Earth Formation mudstone. Towards the east the Inferior Oolite Group is overlain by superficial head deposits.

5.4.14 The groundwater monitoring record for DS/RC 315 (Table 12 and hydrograph Appendix C, Figure C-15) shows the water level lies near the base of the aquifer unit and that the aquifer is largely drained. Water levels recorded are < 11 m above the aquifer base. The manual dips recorded (October 2019 to April 2020) show a large seasonal variation (approximately 6 m). The water levels gradually rose by 5.5 m from October 2019 to November 2019 and thereafter showed a flashy response to larger rainfall events (> 20 mm/day). Additional monitoring at this location will confirm the water level response to rainfall events during drier antecedent conditions.

5.4.15 The groundwater monitoring record for DS/RC/OH 412 (Table 12 and hydrograph Appendix C, Figure C-16) shows the water level lies near the base of the aquifer unit and that the aquifer is largely drained, maintaining a water level at approximately 28.7 m (221.6 mAOD). The manual dip data (October 2019 to April 2020) shows the groundwater does not respond to rainfall events. However., a 70° incipient fracture logged between 28.8m and 28.9m.

5.4.16 Based on the water level data recorded, the Inferior Oolite Group is unlikely to receive direct recharge. Groundwater in the aquifer is likely to be indirectly recharged by leakage from the overlying superficial head deposits where there is a direct, vertical hydraulic connection between the stratigraphic units. Where the aquifer is overlain by the Great Oolite Group, groundwater may be maintained by steady leakage from the overlying stratigraphic units.

CH3+500 to CH4+575 - Stockwell-Nettleton

5.4.17 Two groundwater monitoring boreholes (OH 417 and DS/RC/OH 400) are located adjacent to the proposed cuttings between Stockwell and Nettleton. The location of the monitoring boreholes is presented in Appendix A, Figure A-1. The geology of the response zone is described in Appendix B, Table B-17. In this area the Inferior Oolite Group is at surface along the valley sides and overlain by the Great Oolite Group along the ridgeline. The Great Oolite Group in this area includes the basal Fullers Earth Formation mudstone.

5.4.18 The groundwater monitoring record for these boreholes (Table 12 and hydrograph Appendix C, Figure C-17) shows the water levels lie close to the base of the aquifer and that the aquifer is largely drained, maintaining < 10 m of water above the aquifer base throughout the year. Manual dips recorded at these locations (October 2019 to April 2020) show a response to larger rainfall events (> 20 mm/day). As monitoring continues at these locations, seasonal variation can be assessed.

5.4.19 On the basis of the water level data recorded, the Inferior Oolite Group between Stockwell and Nettleton is likely to receive direct recharge. Steady leakage from the overlying stratigraphic units may also occur.

5.5 Lias Group – Bridport Sand Formation

Overview

5.5.1 There is a total of 2 groundwater monitoring locations within the Bridport Sand Formation. The maps showing the locations of these wells are presented in Appendix A, Figure A-1 and the hydrographs for these groundwater monitoring locations are presented in Appendix C, Figure C-18 and Figure C-19. Monitoring at these locations has progressively started since the January 2019. The groundwater monitoring network for the Lias Group within Crickley Hill may be divided into the following specific areas:

- 1 at Air Balloon
- 1 at Barrow Wake

5.5.2 Table 13 provides a summary the range of groundwater levels recorded, the number of manual measurements and whether a water level data logger was used. A summary of the response zone interval is presented in Appendix B, Table B-17.

5.5.3 The sections below provide a description of the groundwater level data recorded for each area and provides an interpretation of these fluctuations based on seasonal recharge and responses to rainfall events.

Table 13 Summary of groundwater monitoring in Lias Group – Bridport Sand Formation

Location	Formation	No. dips	GWL range (average) (mbgl)	GWL range (average) (mAOD)	Observed range (m)
Air Balloon					
DS/RC 408	Lias Group (Bridport Sand)	N/A[1]	21.23 - 22.77 (21.82)	209.73 - 211.27 (210.68)	1.54
Barrow Wake					
DS/RC 419	Lias Group (Bridport Sand)	N/A[1]	35.61 - 39.93 (38.00)	228.97 - 233.29 (230.90)	4.32

Note: 1. Continuous monitoring data available

Air Balloon

5.5.4 One groundwater monitoring well (DS/RC 408) is located within the proposed Air Balloon cutting. The location of the monitoring borehole is presented in Appendix A, Figure A-1. The geology of the response zone is described in Appendix B, Table B-17. In this area the Bridport Sand Formation is overlain by weathered

Whitby Mudstone Formation (recovered as fissured clay) and the Inferior Oolite Group.

5.5.5 The groundwater monitoring record for this borehole (Table 13 and hydrograph Figure C-18) shows that the groundwater level lies near the base of the Bridport Sand Formation and the aquifer is largely drained, maintaining up to 3.1 m of water above the aquifer base throughout the year. The level logger data (March 2019 to May 2020) shows that the water table has minimal seasonal variation (< 1.6 m) and that it does not respond to rainfall events. From October 2019 to March 2020, there was a gradual rise in water levels from 210.4 mAOD to 211.2 mAOD.

5.5.6 On the basis of the water level data recorded, the Bridport Sand Formation at the Air Balloon is unlikely to receive direct recharge. Groundwater in the aquifer is likely to be maintained by steady leakage from overlying stratigraphic units.

Barrow Wake

5.5.7 One groundwater monitoring well (DS/RC 419) is located near Barrow Wake. The location of the monitoring borehole is presented in Appendix A, Figure A-1. The geology of the response zone is described in Appendix B, Table B-17. In this area the Bridport Sand Formation has a thin, fractured mudstone bed (0.95 m thick) at the top of the formation which is overlain by the Inferior Oolite Group.

5.5.8 The groundwater monitoring record for this borehole (Table 13 and hydrograph Figure C-19) shows that the groundwater level is highly responsive to rainfall events. The level logger data (January 2019 to May 2020) shows there is a large seasonal variation (up to 4.3 m) between summer and winter conditions. From September 2019 to October 2020 there is a gradual rise in water levels from 228.9 mAOD to 231.3 mAOD. From February 2020 the water levels gradually fall from 233.2mAOD to 229.7 mAOD in May 2020.

5.5.9 Based on the water level data recorded, the Bridport Sand Formation at Barrow Wake is unlikely to receive direct recharge, but has a strong hydraulic connection to the overlying Inferior Oolite Group.

5.6 Lias Group – undifferentiated mudstones

Overview

5.6.1 There is a total of 5 groundwater monitoring locations within the Lias Group undifferentiated mudstones. The maps showing the locations of these wells are presented in Appendix A, Figure A-1 and the hydrographs for these groundwater monitoring locations are presented in Appendix C, Figure C-20 to Figure C-22. Monitoring at these locations has progressively started since May 2019. The groundwater monitoring network for the Lias Group within Crickley Hill may be divided into the following specific areas:

- 4 between CH1+000 and CH1+400 in the mid-slopes of Crickley Hill
- 1 in the upper slopes of Crickley Hill

5.6.2 Table 14 provides a summary the range of groundwater levels recorded, the number of manual measurements and whether a water level data logger was used. A summary of the response zone interval is presented in Appendix B, Table B-17.

5.6.3 The sections below provide a description of the groundwater level data recorded for each area and provides an interpretation of these fluctuations based on seasonal recharge and responses to rainfall events.

Table 14 Summary of groundwater monitoring in Lias Group undifferentiated mudstones

Location	Formation	No. dips	GWL range (average) (mbgl)	GWL range (average) (mAOD)	Observed range (m)
CH1+000 to CH1+400 (northern side of A417) – Mid Crickley Hill					
CP210 (d)	Lias Group (weathered, mudstone)	23	14.45 - 16.40 (15.15)	157.9 - 159.85 (159.15)	1.95
CH1+000 to CH1+400 (southern side of A417) – Mid Crickley Hill					
CP204 (d)	Lias Group (weathered clay)	19	10 - 12.15 (11.01)	166.75 - 168.9 (167.89)	2.15
CP212 (d)	Lias Group (mudstone)	N/A[1]	17.72 - 19.21 (18.05)	172.39- 173.88 (173.55)	1.49
CP223	Lias Group (mudstone/ sandstone)	N/A[1]	19.6 - 23.36[2] (21.0)	156.37[2] - 160.13 (158.92)	3.77
Southern Crest of Crickley Hill					
DS/RC 224	Lias Group (mudstone/ limestone)	N/A[1]	17.34 - 226.85[2] (8.13)	191.2 - 209.51[2] (159.02)	18.32

Note: 1. Continuous monitoring data available
2. Groundwater level falls below response zone base

CH1+000 to CH1+400 (northern side of A417) – Mid Crickley Hill

5.6.4 One groundwater monitoring borehole (CP 210(d)) is located on the northern side of the A417, in the mid-slopes of Crickley Hill. The location of the monitoring borehole is presented in Appendix A, Figure A-1. The geology of the response zone is described in Appendix B, Table B-17. In this area the Lias Group is overlain by superficial head deposits.

5.6.5 The groundwater monitoring record for CP 201(d) (Table 14 and Appendix C, Figure C-20) shows the groundwater level lies within the weathered zone of the Lias Group. The manual dips recoded (October 2019 to March 2020) show the water table fluctuated in response to rainfall and the variation recorded over this time was 1.95m.

5.6.6 On the basis of the water level data recorded, the Lias Group in the mid-slopes of Crickley Hill are likely to receive recharge via leakage from the overlying head deposits.

CH1+000 to CH1+400 (southern side of A417) – Mid Crickley Hill

5.6.7 Three groundwater monitoring boreholes (CP 204(d), CP 212(d) and CP 223) are located on the northern side of the A417, in the mid-slopes of Crickley Hill. The location of the monitoring borehole is presented in Appendix A, Figure A-1. The geology of the response zones are described in Appendix B, Table B-17. In this area the Lias Group is overlain by superficial head deposits.

5.6.8 The groundwater monitoring recorded for CP 204(d) and CP 223 (Table 14 and Appendix C, Figure C-21) shows the groundwater level lies within the Lias Group and does not rise up to the base of the overlying head deposits. The manual dips recorded (August 2019 to March 2020 in CP 204(d) and May 2019 to January 2020 in CP 223) shows the water table has seasonal fluctuation of approximately 2.2 m, which responds to rainfall particularly when antecedent conditions are wetter.

5.6.9 Similarly, the groundwater monitoring recorded for CP 212(d) (Table 14 and Appendix C, Figure C-21) shows the groundwater level lies within the Lias Group and does not rise up to the base of the overlying head deposits. The level logger data recorded (July 2019 to May 2020) shows the water table has a minimum seasonal fluctuation (< 1 m), where low water levels recorded in September 2019 are due to the borehole recovering after sampling. The water levels also indicate the location does not respond to rainfall events.

5.6.10 On the basis of the water level data recorded, the Lias Group in the Crickley Hill area are unlikely to receive direct recharge. Is it likely the groundwater within the mudstones is maintained by steady leakage from the overlying superficial head deposits and stratigraphy within the Lias group that is more weathered or permeable, such as sandstone bedding. The low hydraulic conductivity of the mudstone limits this hydraulic connection. The weathered zones and sandstone beds within the Lias Group likely receive recharge via leakage from the overlying head deposits. The higher hydraulic conductivity of these units relative to the Lias Group mudstones, creates a higher degree of hydraulic connection with the overlying head deposits.

Southern Crest of Crickley Hill

5.6.11 On groundwater monitoring borehole (DS/RC 224) is located near the southern crest of the Crickley Hill escarpment. The location of the monitoring borehole is presented in Appendix A, Figure A-1. The geology of the response zones are described in Appendix B, Table B-17. In this area the Lias Group is overlain by superficial head deposits.

5.6.12 The groundwater monitoring record for this borehole (Table 14 and Appendix C, Figure C-22) has been affected by a slow response in water levels following installation and sampling events. The level logger data (January 2020 to February 2020) shows the water table responds to rainfall events, however seasonal variation is masked by the changes in water level due to sampling.

5.6.13 However, on the basis of the water level data recorded, the Lias Group at the southern crest of Crickley Hill is unlikely to receive direct recharge. Groundwater in the aquifer is likely to be maintained by steady leakage from overlying stratigraphic units or the hydraulic connection of the limestone bed within the response zone to stratigraphic units that receive direct recharge.

5.7 Hydraulic gradient

5.7.1 Within the Crickley Hill area, groundwater flow paths typically following the topographical slopes and generally flow towards surface water features such as the tributary of Normans Brook and the unnamed tributaries that flow into this watercourse. To the south of the Normans Brook tributary the hydraulic gradient is generally towards the north and north west. Conversely, to the north of the Normans Brook tributary the hydraulic gradient is to the south and south west.

5.7.2 The Cotswold escarpment forms a groundwater divide between the River Severn catchment and the River Thames catchment (to the west and south-east of the divide respectively). This divide is set back from the escarpment crest and is likely to cause divergent flow to the west and east within the Inferior Oolite aquifer near Air Balloon. At present there is a lack of groundwater monitoring data to confirm where this divergence is occurring.

5.7.3 Groundwater flow is typically towards the east in the Shab Hill area and south of the Shab Hill barn fault groundwater flow is towards the west. The groundwater divide generally runs along the eastern edge of the Great Oolite limestone exposure in the Stockwell-Nettleton area. As a result, divergent flows to the west and east are expected in the Great Oolite limestone aquifer in this area. Incised valleys in this area are likely to induce local groundwater gradients towards the low points of the valley.

5.7.4 Monitoring within the Great Oolite limestones south of the Stockwell farm fault indicates the hydraulic gradient decreases towards the south.

5.8 Hydraulic relationships between aquifer units

5.8.1 Faults may be providing groundwater flow pathways between the bedrock aquifers in the region. Additionally, the throw induced by the faults vertically offsets the geological formations either side of the fault. It is anticipated that in the Great Oolite limestone aquifer, the Stockwell farm fault and Shab Hill barn fault are facilitating downward leakage into the underlying Inferior Oolite aquifer. As previously discussed, this leakage may be more prominent during wetter periods when there is sufficient saturated zone within the Great Oolite limestone aquifer[xliv].

5.8.2 The Bridport Sand Formation at the top of the Lias Group is assumed to be hydraulically connected to the base of the Inferior Oolite Group aquifer and is recharged via these limestones.

5.8.3 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, however it is unclear whether the two are in direct hydraulic connection as this stage.

6 Groundwater quality

6.1.1 During the Phase 1 ground investigation, groundwater samples were taken from the Birdlip Limestone of the Inferior Oolite aquifer (DS/RC 406) and Bridport Sand Formation (DS/RC 419) on the 14th February 2019. Sampling from Phase 2A boreholes has progressively been completed since the 11th November 2019. A summary of the groundwater quality testing results is presented in Appendix D.

6.1.2 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.

6.1.3 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.

6.1.4 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 NO2 – 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).

7 Aquifer testing

7.1.1 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[xlv]. A summary of the Phase 1 field testing results is presented in Table 15 and test reports are included in Appendix E.

Table 15 Summary of field testing results[xlvi]

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 Formation - Inferior Oolite	$4.6x10^{-5}$ to $7.2x10^{-5}$
DS/RC406	20.5 – 35.0mbgl 218.15 – 203.65mAOD	Birdlip Limestone Formation - 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 Formation – Lias Group	$3.2x10^{-6}$
DS/RC408	20.0 – 24.0mbgl 212.5 – 208.5mAOD	Bridport Sand Formation – Lias Group	$1.1x10^{-5}$

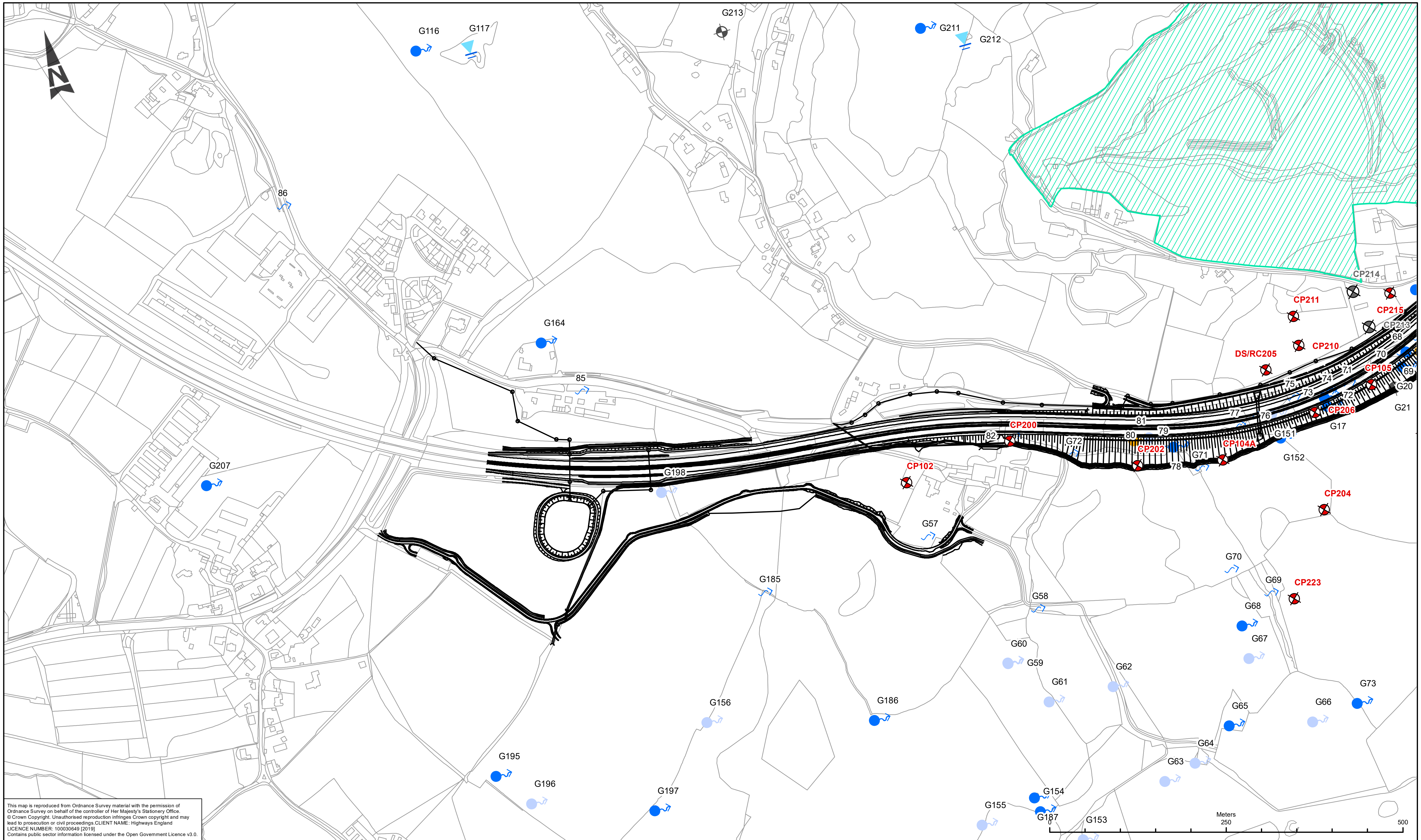
7.1.2 A summary published hydraulic conductivity of the bedrock formations in the Cotswold area is presented in Table 16.

Table 16 Summary of published hydraulic conductivities for bedrock in the Cotswolds

Parameter	K range (m/s)	K suggested mean (m/s)
Bridport Sand	$8x10^{-8}$ – $4x10^{-6}$	-
Lias Group	$1x10^{-11}$ – $4x10^{-6}$	-
Inferior Oolite limestone	$3x10^{-11}$ – $5.8x10^{-3}$	$1.1x10^{-9}$ and $5.8x10^{-9}$
Fuller's Earth formation	$6.9x10^{-6}$	$2.3x10^{-7}$
Great Oolite limestone	$2.2x10^{-11}$ –$2.2x10^{-5}$	$1.1x10^{-9}$

Appendices

Appendix A Groundwater monitoring locations



LEGEND

PROPOSED GROUNDWATER MONITORING
- BH

PHASE 2A GROUNDWATER MONITORING
- BH

- LAKE
- SEEPAGE
- SPRING
- POTENTIAL TUFA FORMATION
- WATERCOURSE
- SITES OF SPECIAL SCIENTIFIC INTEREST (SSSI)

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE IN THE DESIGN HAZARD LOG)

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
P08	21/09/20	CLIENT COMMENTS ADDRESSED	EB	AL-P	JP	SW

Suitability: S4 | Drawing Status: SUITABLE FOR STAGE APPROVAL

ARUP

Client: highways england

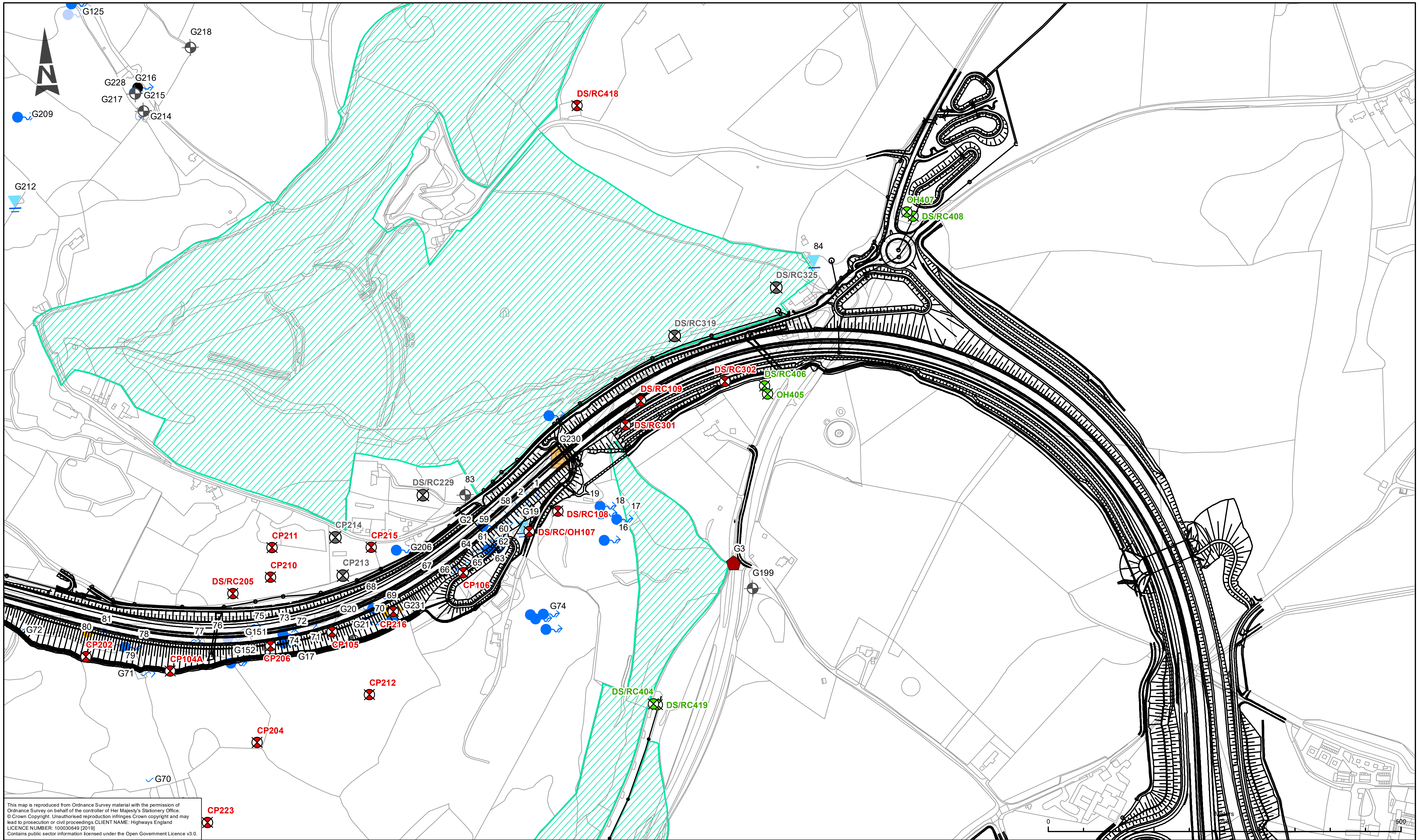
Project Title: A417 MISSING LINK

Drawing Title: FIGURE A-1 GENERAL ARRANGEMENT SHEET 1 OF 6

Scale	By	Checked	Approved	Authorised
1:5,000	EB	AL-P	JP	SW
Original Size	**Date**	**Date**	**Date**	**Date**
A3	21/09/20	21/09/20	21/09/20	21/09/20

Drawing Number: HE PIN | Originator | Volume
HE551505 - ARP - EWE
X_XX_XXXX_X - DR - LE - 000034
Location | Type | Role | Number

Revision: P08



LEGEND

PROPOSED GROUNDWATER MONITORING
- BH

PHASE 1 GROUNDWATER MONITORING
- BH

PHASE 2A GROUNDWATER MONITORING
- BH

- DRAINAGE
- DRY VALLEY
- LAKE
- SEEPAGE
- SPRING
- POTENTIAL TUFA FORMATION
- WASTE TREATEMENT
- WATERCOURSE
- SITES OF SPECIAL SCIENTIFIC INTEREST (SSSI)

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE IN THE DESIGN HAZARD LOG)

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
P08	21/09/20	CLIENT COMMENTS ADDRESSED	EB	AL-P	JP	SW

Suitability: S4
Drawing Status: SUITABLE FOR STAGE APPROVAL

ARUP

Client: highways england

Project Title: A417 MISSING LINK

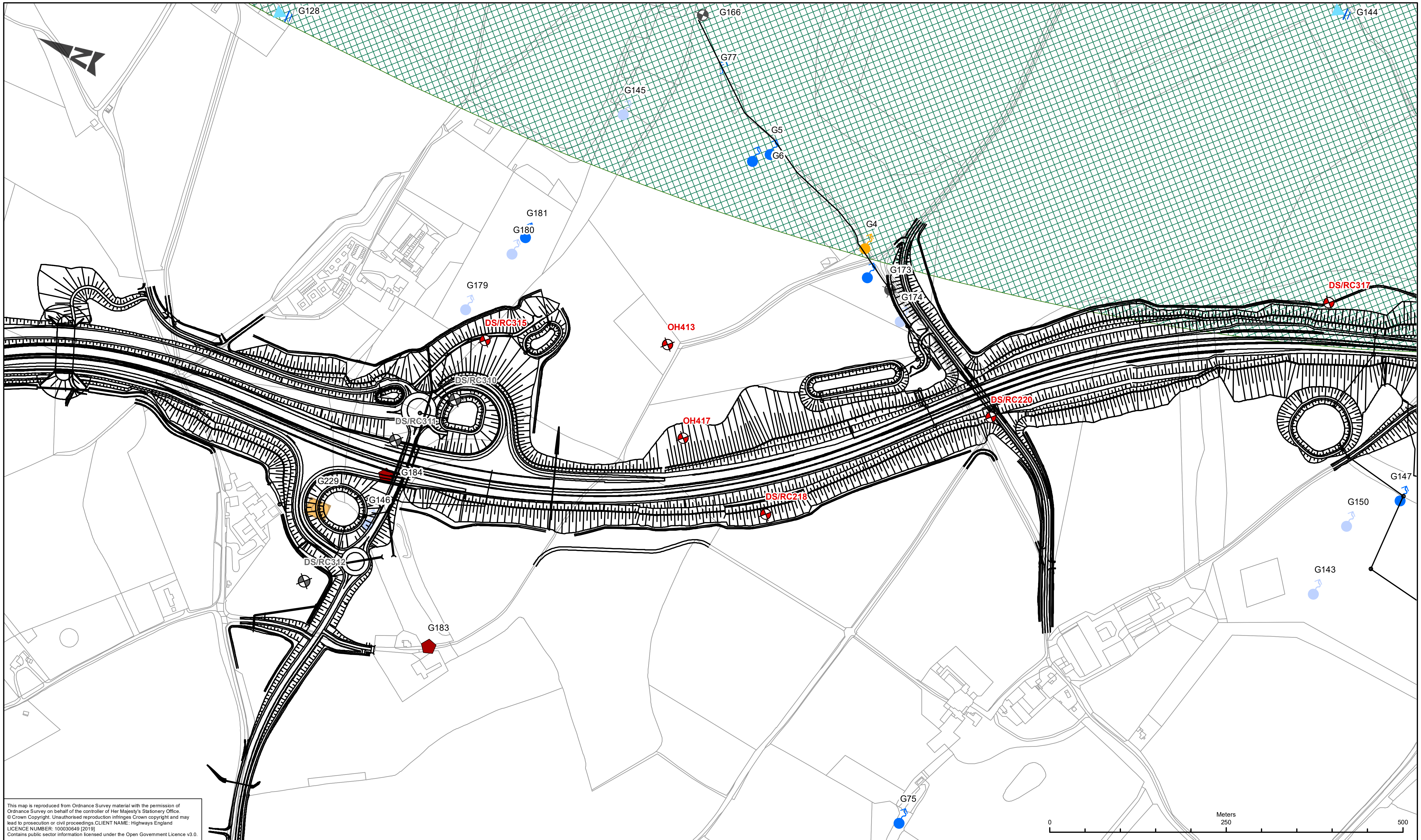
Drawing Title: FIGURE A-1 GENERAL ARRANGEMENT SHEET 2 OF 6

Scale	By	Checked	Approved	Authorised
1:5,000	EB	AL-P	JP	SW

Original Size	Date	Date	Date	Date
A3	21/09/20	21/09/20	21/09/20	21/09/20

Drawing Number: HE PIN | Originator | Volume
HE551505 - ARP - EWE
X_XX_XXXX_X - DR - LE - 000035
Location | Type | Role | Number

Revision: P08



LEGEND

PROPOSED GROUNDWATER MONITORING
- BH

PHASE 2A GROUNDWATER MONITORING
- BH

- DRY VALLEY
- LAKE
- SEEPAGE
- SPRING
- POTENTIAL TUFA FORMATION
- WASTE TREATEMENT
- WATERCOURSE
- SOURCE PROTECTION ZONE 3

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE IN THE DESIGN HAZARD LOG)

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
P08	21/09/20	CLIENT COMMENTS ADDRESSED	EB	AL-P	JP	SW

Suitability: S4
Drawing Status: SUITABLE FOR STAGE APPROVAL

ARUP

Client: highways england

Project Title: A417 MISSING LINK

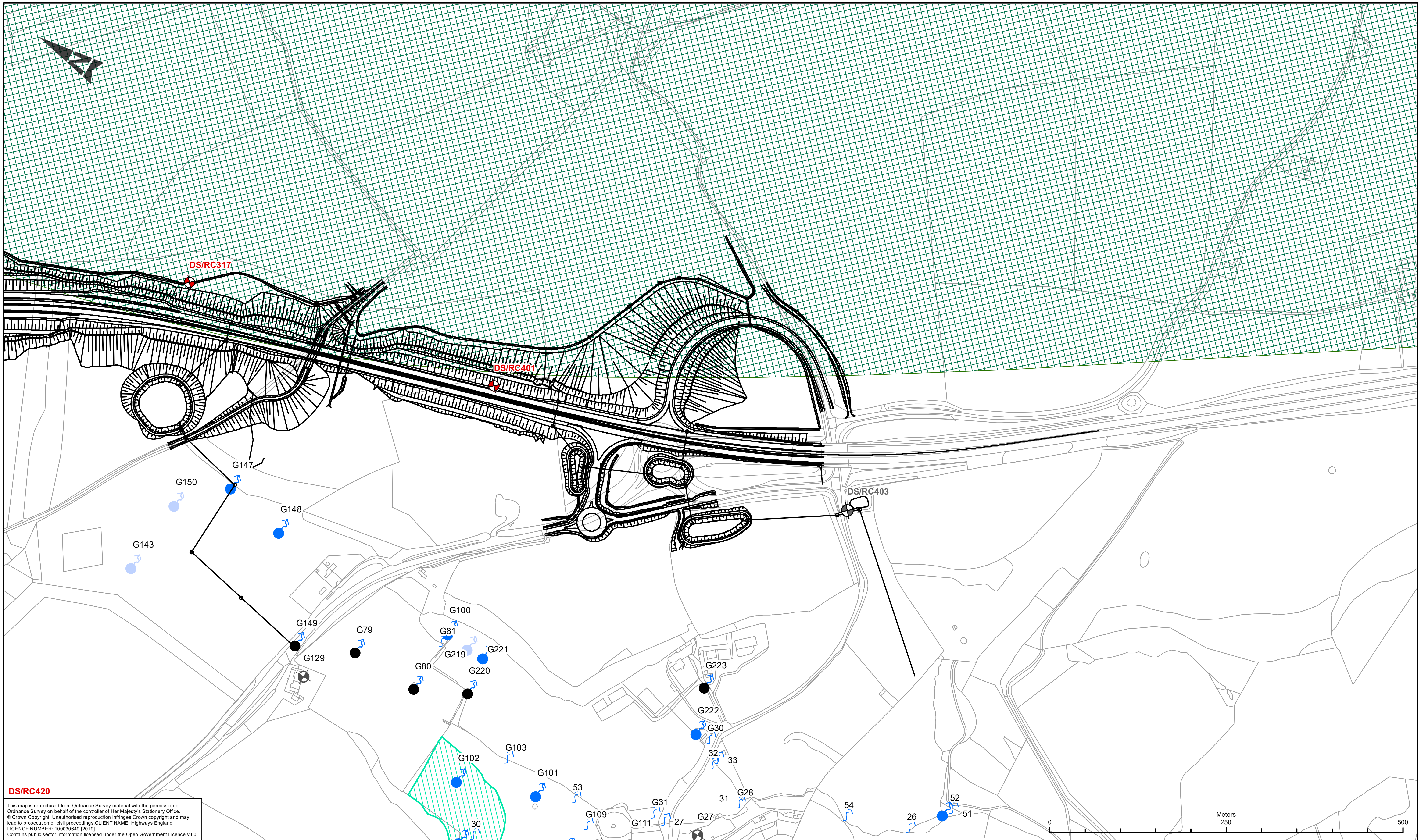
Drawing Title: FIGURE A-1 GENERAL ARRANGEMENT SHEET 3 OF 6

Scale	By	Checked	Approved	Authorised
1:5,000	EB	AL-P	JP	SW

Original Size	Date	Date	Date	Date
A3	21/09/20	21/09/20	21/09/20	21/09/20

Drawing Number: HE PIN | Originator | Volume
HE551505 - ARP - EWE
X_XX_XXXX_X - DR - LE - 000036
Location | Type | Role | Number

Revision: P08



LEGEND

PROPOSED GROUNDWATER MONITORING

BH

PHASE 2A GROUNDWATER MONITORING

BH

DRAINAGE
LAKE
SEEPAGE
SPRING
WATERCOURSE
SOURCE PROTECTION ZONE 3
SITES OF SPECIAL SCIENTIFIC INTEREST (SSSI)

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE IN THE DESIGN HAZARD LOG)

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
P08	21/09/20	CLIENT COMMENTS ADDRESSED	EB	AL-P	JP	SW

Suitability: S4
Drawing Status: SUITABLE FOR STAGE APPROVAL

ARUP

Client: highways england

Project Title: A417 MISSING LINK

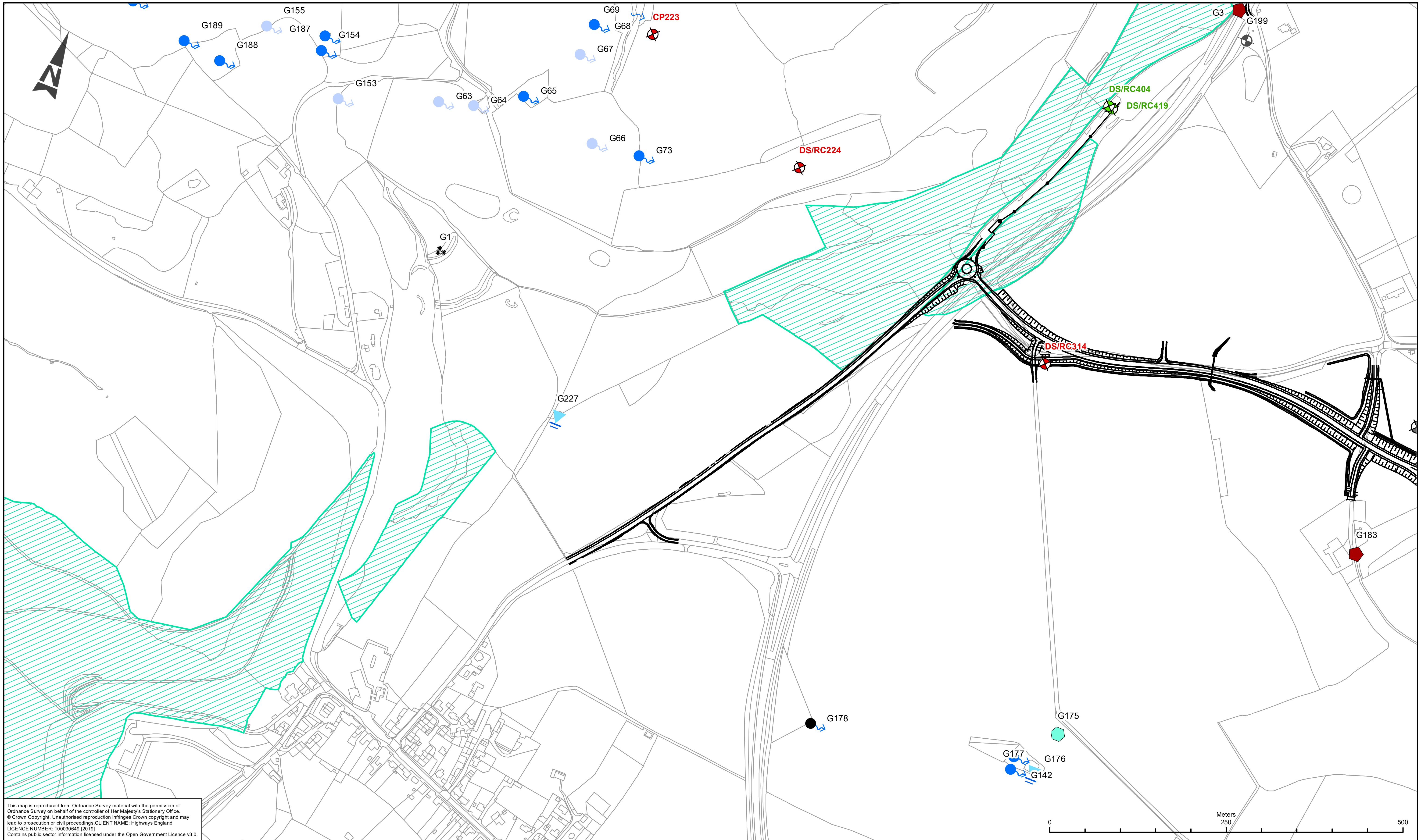
Drawing Title: FIGURE A-1 GENERAL ARRANGEMENT SHEET 4 OF 6

Scale	By	Checked	Approved	Authorised
1:5,000	EB	AL-P	JP	SW

Original Size	Date	Date	Date	Date
A3	21/09/20	21/09/20	21/09/20	21/09/20

Drawing Number: HE PIN | Originator | Volume
HE551505 - ARP - EWE
X_XX_XXXX_X - DR - LE - 000037
Location | Type | Role | Number

Revision: P08



LEGEND

PROPOSED GROUNDWATER MONITORING
- BH

PHASE 1 GROUNDWATER MONITORING
- BH

PHASE 2A GROUNDWATER MONITORING
- BH

- DRAINAGE
- DRY VALLEY
- FLOODED GROUND
- LAKE
- OUTCROP
- SEEPAGE
- SPRING
- WATERCOURSE
- SITES OF SPECIAL SCIENTIFIC INTEREST (SSSI)

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE IN THE DESIGN HAZARD LOG)

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
P08	21/09/20	CLIENT COMMENTS ADDRESSED	EB	AL-P	JP	SW

Suitability	Drawing Status
S4	SUITABLE FOR STAGE APPROVAL

ARUP

Client
highways england

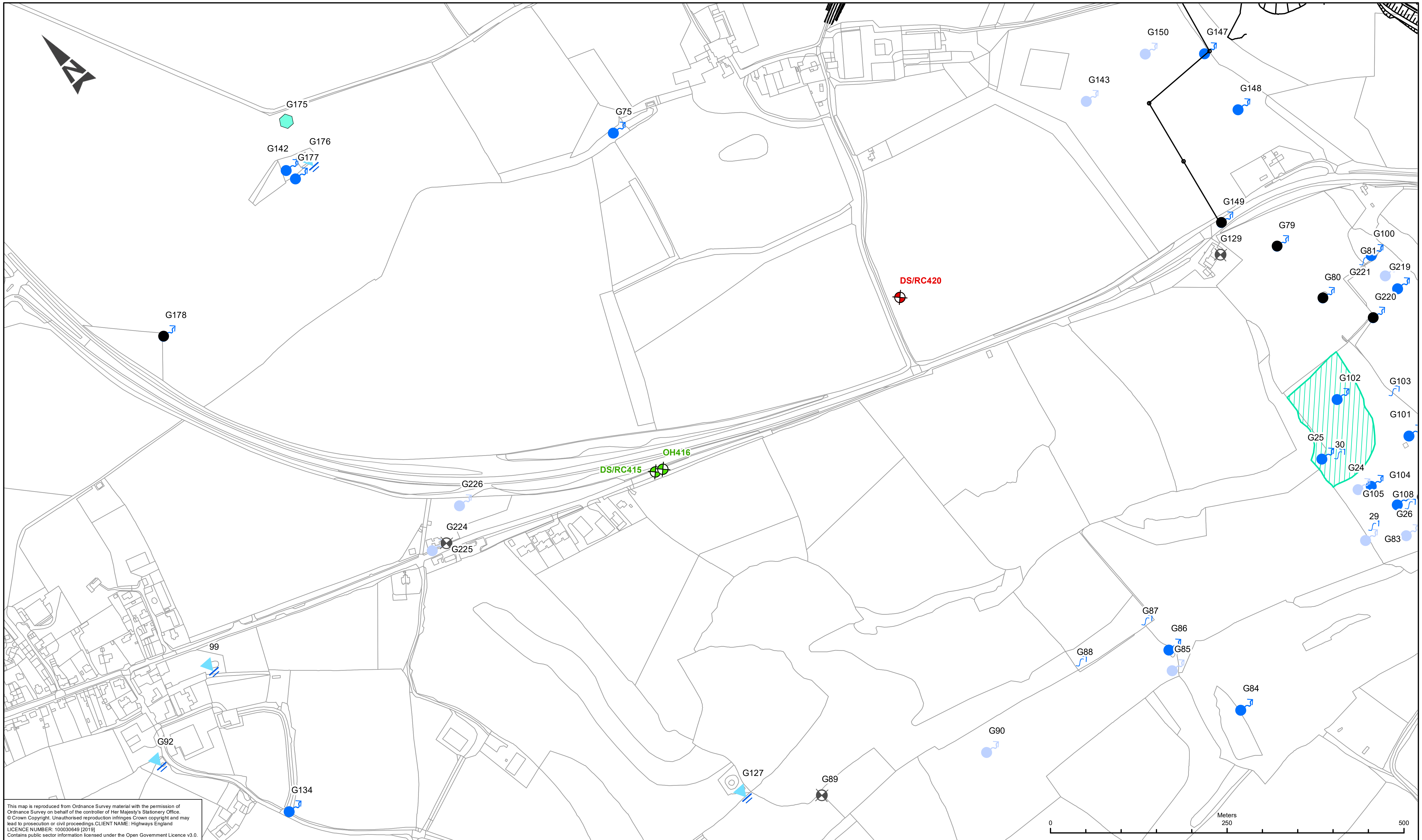
Project Title
A417 MISSING LINK

Drawing Title
FIGURE A-1
GENERAL ARRANGEMENT
SHEET 5 OF 6

Scale	By	Checked	Approved	Authorised
1:5,000	EB	AL-P	JP	SW
Original Size	Date	Date	Date	Date
A3	21/09/20	21/09/20	21/09/20	21/09/20

Drawing Number (HE PIN | Originator | Volume / Location | Type | Role | Number): HE551505 - ARP - EWE X_XX_XXXX_X - DR - LE - 000038

Revison: P08



LEGEND

PHASE 1 GROUNDWATER MONITORING
- BH

PHASE 2A GROUNDWATER MONITORING
- BH

- DRAINAGE
- FLOODED GROUND
- LAKE
- SEEPAGE
- SPRING
- WATERCOURSE
- SITES OF SPECIAL SCIENTIFIC INTEREST (SSSI)

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING SIGNIFICANT RESIDUAL RISKS (REFERENCE SHALL ALSO BE MADE IN THE DESIGN HAZARD LOG)

CONSTRUCTION
NONE

MAINTENANCE / CLEANING
NONE

USE
NONE

DECOMMISSIONING / DEMOLITION
NONE

Rev.	Date	Description	By	Chk'd	App'd	Auth'd
P04	21/09/20	CLIENT COMMENTS ADDRESSED	EB	AL-P	JP	SW

Suitability: S4
Drawing Status: SUITABLE FOR STAGE APPROVAL

ARUP

Client: highways england

Project Title: A417 MISSING LINK

Drawing Title:
FIGURE A-1
GENERAL ARRANGEMENT
SHEET 6 OF 6

Scale	By	Checked	Approved	Authorised
1:5,000	EB	AL-P	JP	SW
Original Size	Date	Date	Date	Date
A3	21/09/20	21/09/20	21/09/20	21/09/20

Drawing Number: HE PIN | Originator | Volume
HE551505 - ARP - EWE
X_XX_XXXX_X - DR - LE - 000040
Location | Type | Role | Number

Revison: P04

Appendix B Standpipe installations

Table B-17 Summary of groundwater monitoring installations used to inform baseline conditions review

Location	Ground investigation	Easting	Northing	Log status	Monitoring zone	Top of hole (mAOD)	Depth of hole (mbgl)	Response zone (mbgl)	Response zone (mAOD)
CP102	Phase 2A GI	392085.8	215732.9	Draft	Head deposits - silty clay	122.60	20.00	3.0 - 5.5	119.6 - 117.1
CP104A	Phase 2A GI	392492.7	215667.7	Draft	Head deposits	148.00	16.76	14.6 – 16.0	133.4 – 132.0
CP105	Phase 2A GI	392764.6	215682.4	Draft	Head deposits - silt and gravel	169.90	30.00	3.0 - 9.5	166.9 - 160.4
CP106	Phase 2A GI	392950.6	215755.8	Draft	Head deposits/Lias Group (mudstone)	186.37	35.50	19.0 – 30.0	167.37 - 156.37
CP200	Phase 2A GI	392242.4	215749.5	Draft	Head deposits - sands and gravels	129.10	14.50	8.5 - 12	120.6 - 117.1
CP202	Phase 2A GI	392329.3	215691.9	Draft	Head deposits - clay	135.50	20.00	3.7 - 5.5	131.8 – 130.0
CP204 (d)	Phase 2A GI	392644	215535	Draft	Lias Group (weathered)	156.10	25.00	12.0 – 14.0	144.1 - 142.1
CP204 (s)	Phase 2A GI	392644	215535	Draft	Head deposits - clay	156.10	25.00	8.5 - 9.9	147.6 - 146.2
CP206	Phase 2A GI	392655.5	215664.1	Draft	Head deposits - clay	162.85	19.70	10.0 – 16.0	152.85 - 146.85
CP210 (d)	Phase 2A GI	392672.9	215768.1	Final	Lias Group (weathered, mudstone)	174.30	25.00	13.0 – 17.0	161.3 - 157.3
CP210 (s)	Phase 2A GI	392672.9	215768.1	Final	Head deposits/Lias Group (weathered)	174.30	25.00	2.5 - 5.5	171.8 - 168.8
CP211	Phase 2A GI	392677	215810	Draft	Head deposits - gravel	183.46	35.00	1.1 - 3.3	182.36 - 180.16
CP212 (d)	Phase 2A GI	392814	215558	Draft	Lias Group (mudstone)	191.60	24.50	18.5 - 24.5	173.1 - 167.1
CP212 (s)	Phase 2A GI	392814	215558	Draft	Head deposits - gravel and clay	191.60	24.50	8.0 – 14.0	183.6 - 177.6
CP215 (d)	Phase 2A GI	392817.6	215797.0	Draft	Head deposits - clay	186.05	25.00	14.5 - 15.5	171.55 - 170.55
CP215 (s)	Phase 2A GI	392817.6	215797.0	Draft	Head deposits - clay	186.05	25.00	2.0 – 3.0	184.05 - 183.05
CP216	Phase 2A GI	215664.1	215664.1	Draft	Head deposits - gravelly silty CLAY	173.49	10.00	2.0 - 7.5	171.49 - 165.99
CP 223	Phase 2A GI	392596.2	215474.1	Draft	Lias group (Mudstone/Sandstone)	179.73	25.50	19 - 22.6	160.73 - 157.13

Location	Ground investigation	Easting	Northing	Log status	Monitoring zone	Top of hole (mAOD)	Depth of hole (mbgl)	Response zone (mbgl)	Response zone (mAOD)
DS/RC 109	Phase 2A GI	393208	215995	Draft	Inferior Oolite (Limestone)	232.99	105.00	2.5 – 20.0	230.49 - 212.99
DS/RC 205	Phase 2A GI	392618.7	215747.4	Draft	Head deposits - gravelly CLAY	167.16	30.00	9.5 - 11.5	157.66 - 155.66
DS/RC 218	Phase 2A GI	394126.1	214739.3	Draft	Great Oolite (Limestone)	285.63	25.00	2 – 15.0	283.63 - 270.63
DS/RC 220	Phase 2A GI	394378.8	214501.2	Draft	Great Oolite (Limestone)	278.87	30.00	3 – 13.0	275.87 - 265.87
DS/RC 301	Phase 2A GI	393184.7	215961.9	Draft	Inferior Oolite (Limestone, Bridport Sand)	234.50	105.3	7.4 - 28.5	227.1 – 206.0
DS/RC 302	Phase 2A GI	393328.6	216017.5	Final	Inferior Oolite (limestone)	234.50	35.20	15.0 – 26.0	219.5 - 208.5
DS/RC 314	Phase 2A GI	393256	215193	Draft	Inferior Oolite (Limestone)	239.10	15.00	2.0 – 15.0	237.1 - 224.1
DS/RC 315	Phase 2A GI	394193.5	215201.4	Draft	Inferior Oolite (Limestone)	246.90	90.00	4.4 - 52.7	242.5 - 194.2
DS/RC 317	Phase 2A GI	394718	214127	Draft	Great Oolite (Limestone)	274.89	30.00	1.0 - 3.8	273.89 - 271.09
DS/RC 401	Phase 2A GI	394822	213684	Final	Great Oolite (Limestone)	273.10	20.00	4.8 - 8.2	268.3 - 264.9
DS/RC 404	Phase 1 GI	393207	215566	Final	Inferior Oolite (Birdlip Limestone)	269.00	100.50	23.0 - 33.5	246 - 235.5
DS/RC 406	Phase 1 GI	393384	216009	Final	Inferior Oolite (Birdlip Limestone)	238.65	60.00	20.5 - 34	218.15 - 204.65
DS/RC 408	Phase 1 GI	393605	216240	Final	Lias Group (Bridport Sand)	232.50	75.20	20.0 - 23.5	212.5 – 209.0
DS/RC 415	Phase 1 GI	393527	213994	Final	Inferior Oolite (Salperton, Aston and Birdlip Limestone Formations)	287.20	51.00	25.5 - 49	261.7 - 238.2
DS/RC 418	Phase 2A GI	393136	216417	Draft	Inferior Oolite (Limestone)	272.13	61.50	27.0 – 58.0	245.13 - 214.13
DS/RC 419	Phase 1 GI	393213	215564	Final	Lias Group (Bridport Sand)	268.90	60.20	36.0 - 41.5	232.9 - 227.4
DS/RC 420	Phase 2A GI	393950	213950	Draft	Great Oolite (Limestone)	277.10	30.00	0.8 - 3.2	276.3 - 273.9
DS/RC /OH 400	Phase 2A GI	394666	213848	Draft	Inferior Oolite (Limestone)	267.95	90.30	13.3 – 76.0	254.65 - 191.95
DS/RC /OH 412	Phase 2A GI	394241	215146	Draft	Inferior Oolite (Limestone)	250.30	30.00	13.2 - 29.5	237.1 - 220.8

Location	Ground investigation	Easting	Northing	Log status	Monitoring zone	Top of hole (mAOD)	Depth of hole (mbgl)	Response zone (mbgl)	Response zone (mAOD)
DS/RC /OH 414	Phase 2A GI	393481.6	215559.1	Draft	Inferior Oolite (Limestone)	274.60	90.00	28.3 - 59.3	246.3 - 215.3
DS/RC/OH 107	Phase 2A GI	393057.2	215838.5	Draft	Head deposits - sands and gravels	191.87	30.20	2.0 - 5.5	189.87 - 186.37
DS/RC 108	Phase 2A GI	393083.1	215863.1	Draft	Head deposits - sandy silty CLAY, weathered limestone	193.55	49.50	8.5 – 16.0	185.05 - 177.55
DS/RC 224	Phase 2A GI	392856.7	215345.9	Draft	Lias group (Mudstone/limestone)	226.87	80.50	49.0 - 70.5	177.87 - 156.37
OH 405	Phase 1 GI	393388	215997	Final	Inferior Oolite Group	239.50	40.00	11.0 – 17.0	228.5 - 222.5
OH 407	Phase 1 GI	393596	216246	Final	Inferior Oolite Group	231.75	55.55	6.0 – 15.0	225.75 - 216.75
OH 413	Phase 2A GI	394291	214962	Draft	Great Oolite (Limestone)	270.67	100.00	2.7 - 15.7	267.97 - 254.97
OH 416	Phase 1 GI	393538	213990	Final	Fuller's Earth Formation	286.85	5.00	3.0 - 4.5	283.85 - 282.35
OH 417	Phase 2A GI	394178	214889	Draft	Inferior Oolite (Limestone)	275.64	90.00	5.5 - 70.9	270.14 - 204.74

Appendix C Groundwater monitoring results

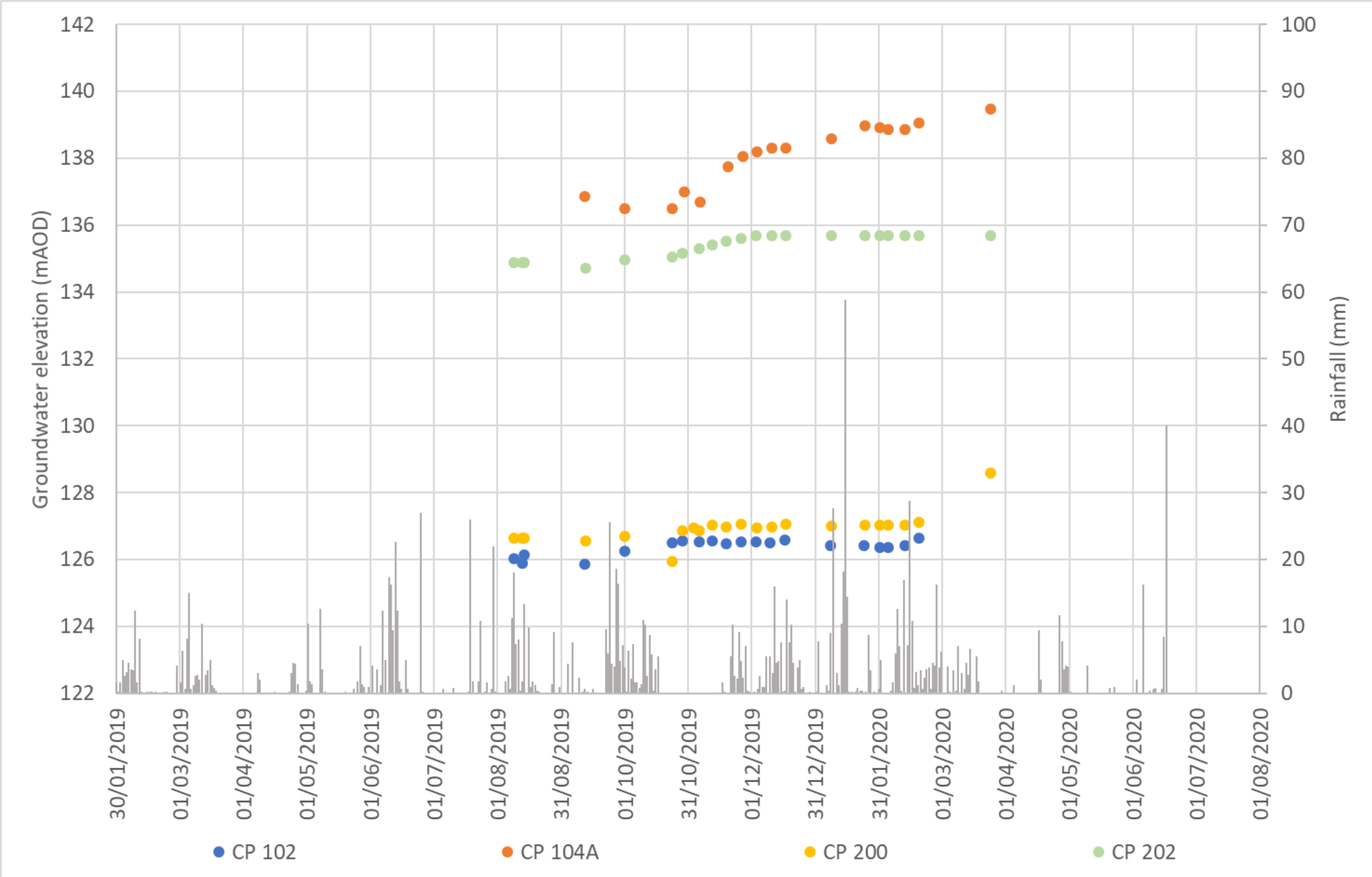


Figure C-1 Head deposits groundwater monitoring – CH0+500 to CH1+000, lower Crickley Hill

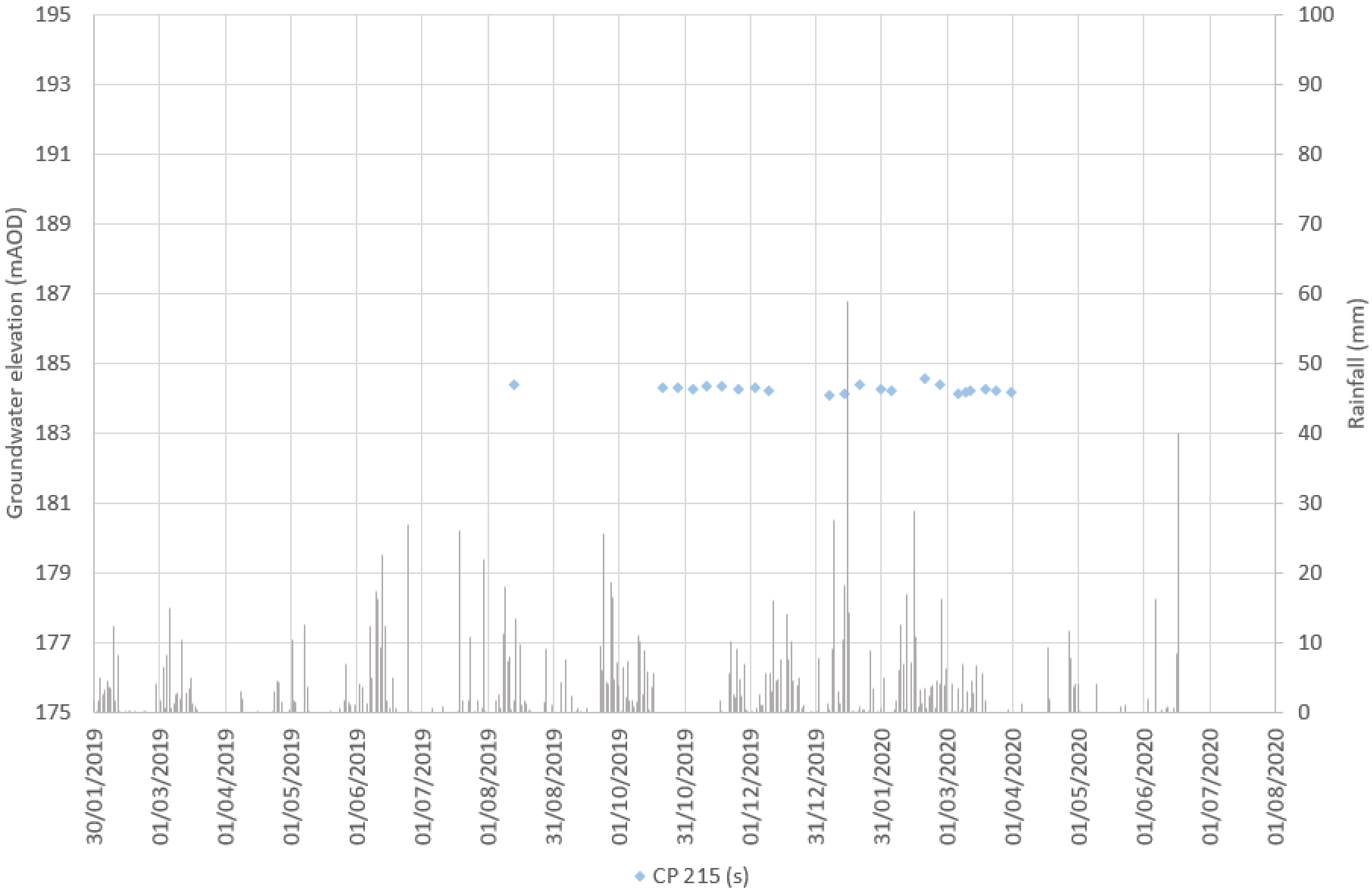


Figure C-2 Head deposits groundwater monitoring – CH1+000 to CH1+400 (northern side of A417), mid Crickley Hill

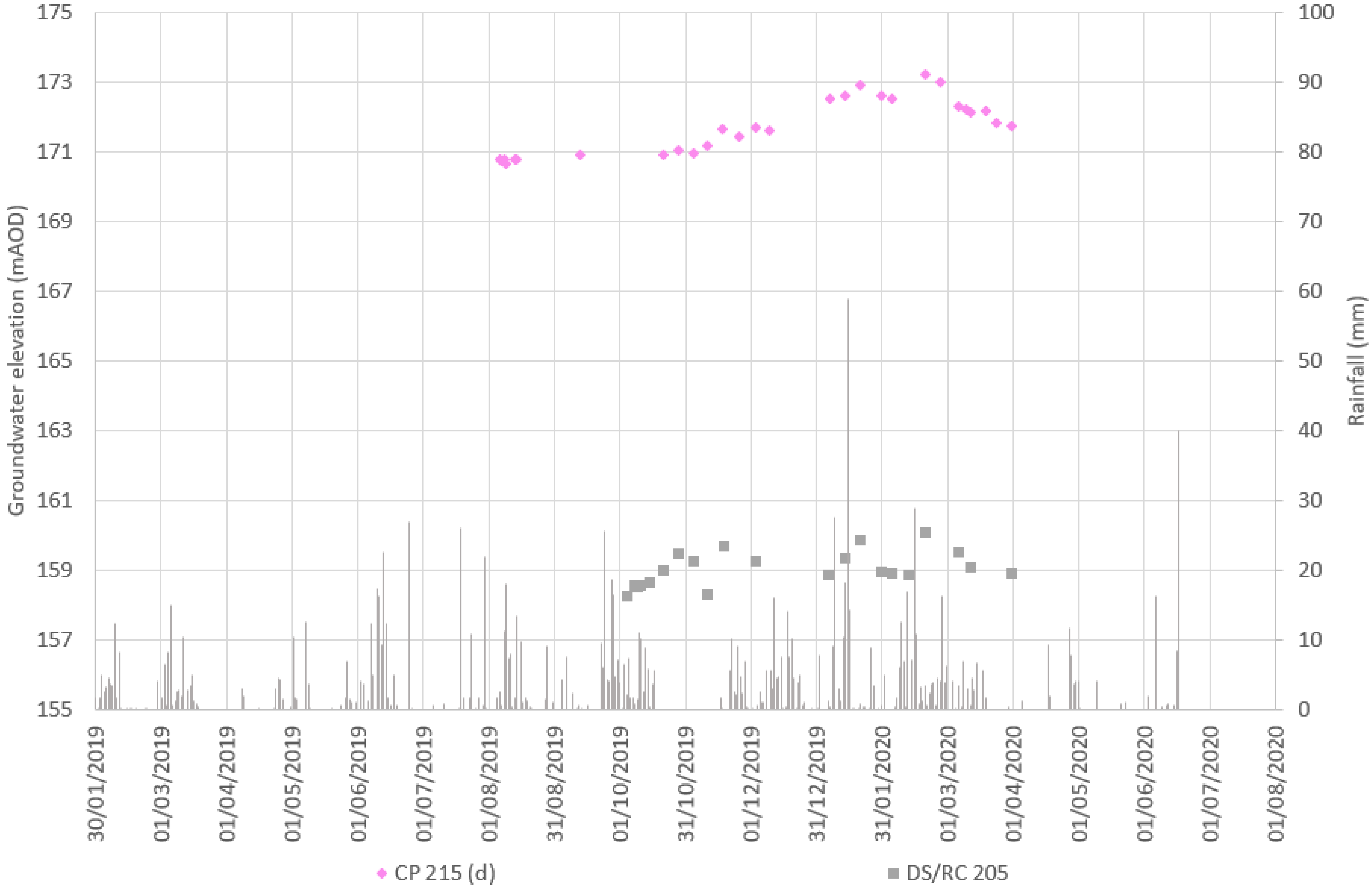


Figure C-3 Head deposits groundwater monitoring – CH1+000 to CH1+400 (northern side of A417), mid Crickley Hill

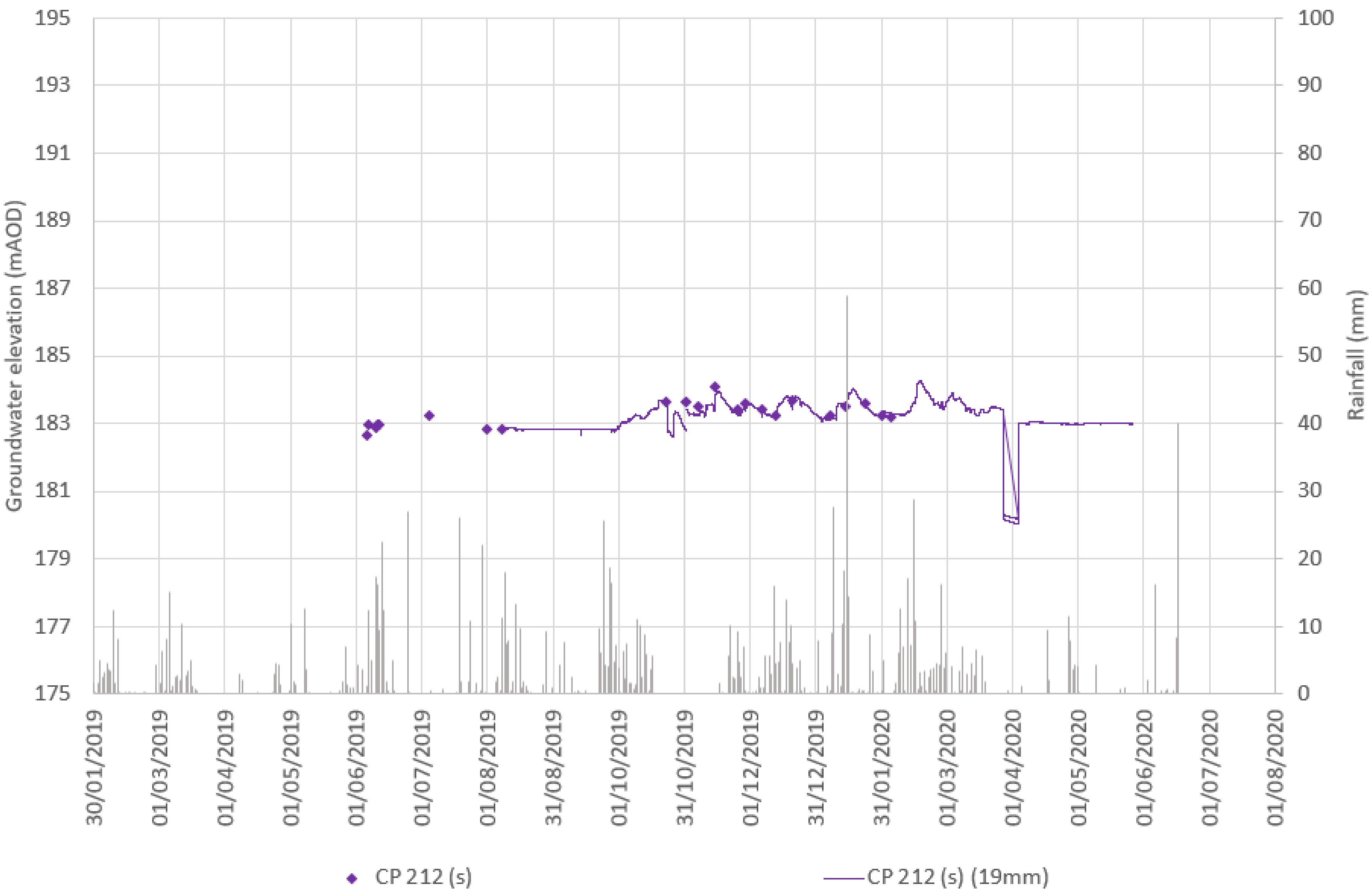


Figure C-4 Head deposits groundwater monitoring – CH1+000 to CH1+400 (southern side of A417), mid Crickley Hill

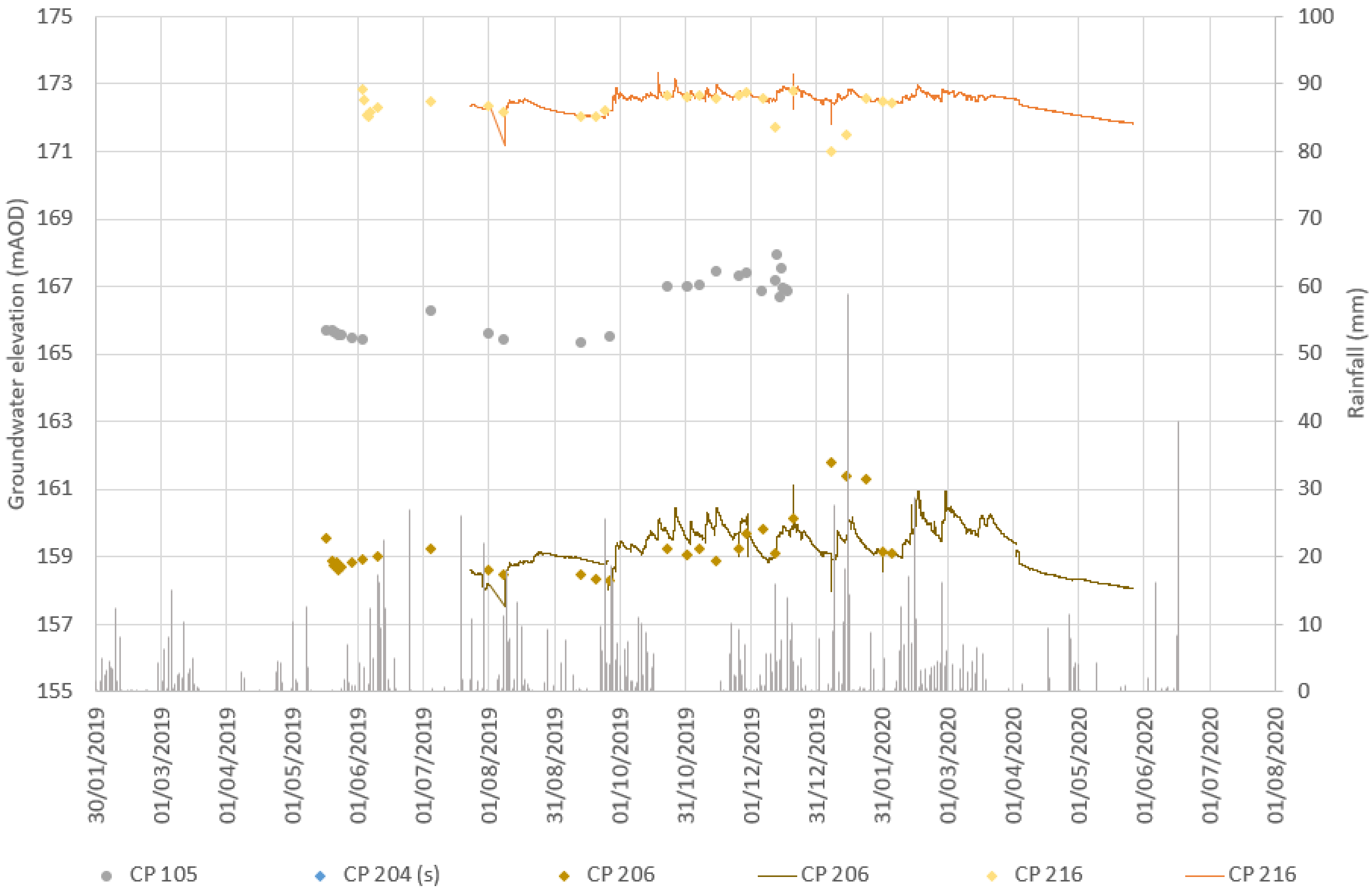


Figure C-5 Head deposits groundwater monitoring – CH1+000 to CH1+400 (southern side of A417), mid Crickley Hill

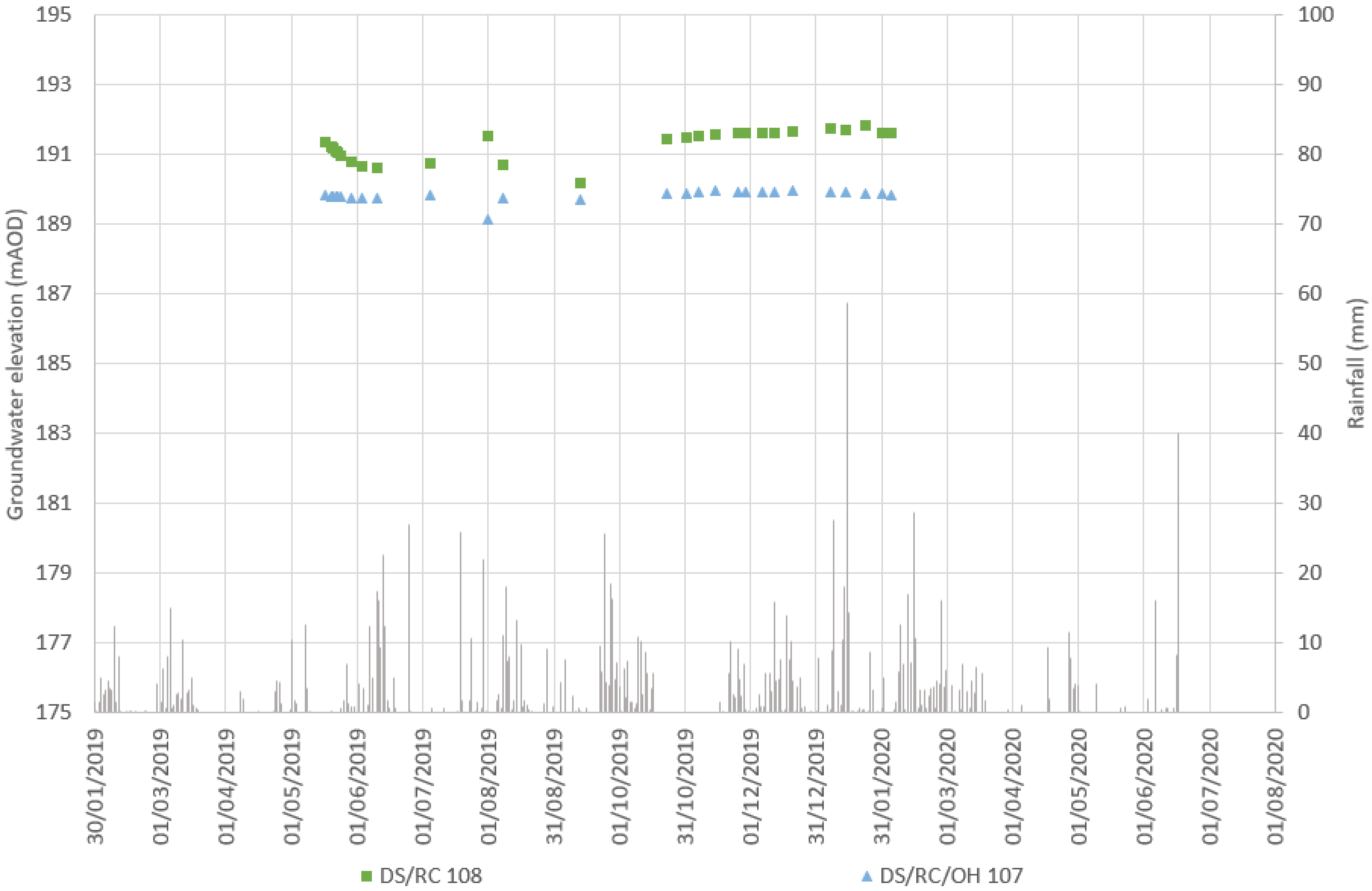


Figure C-6 Head deposits groundwater monitoring - CH1+400 to CH1+700 (southern side of A417) - upper Crickley Hill

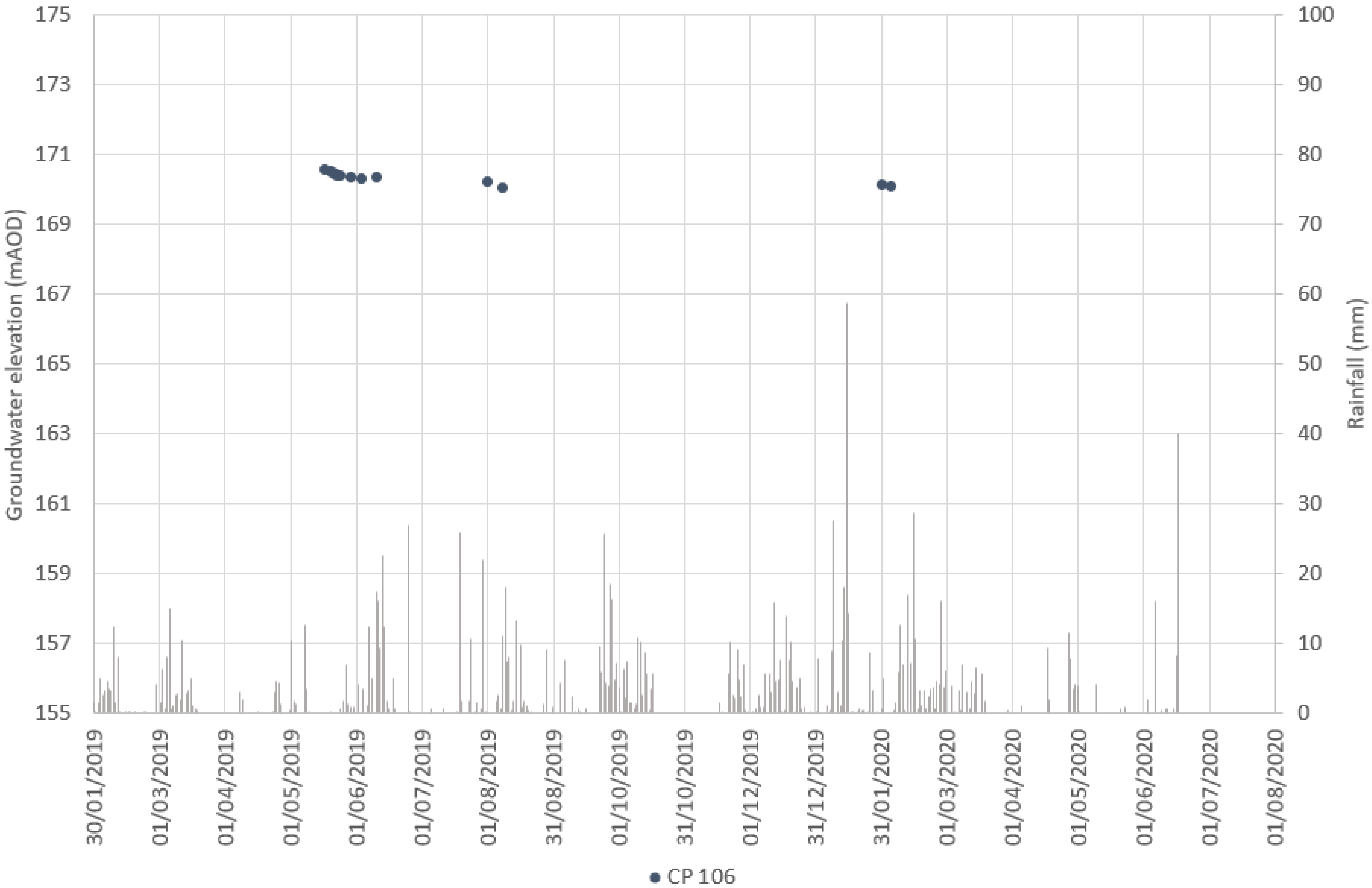


Figure C-7 Head deposits groundwater monitoring - CH1+400 to CH1+700 (southern side of A417) - upper Crickley Hill

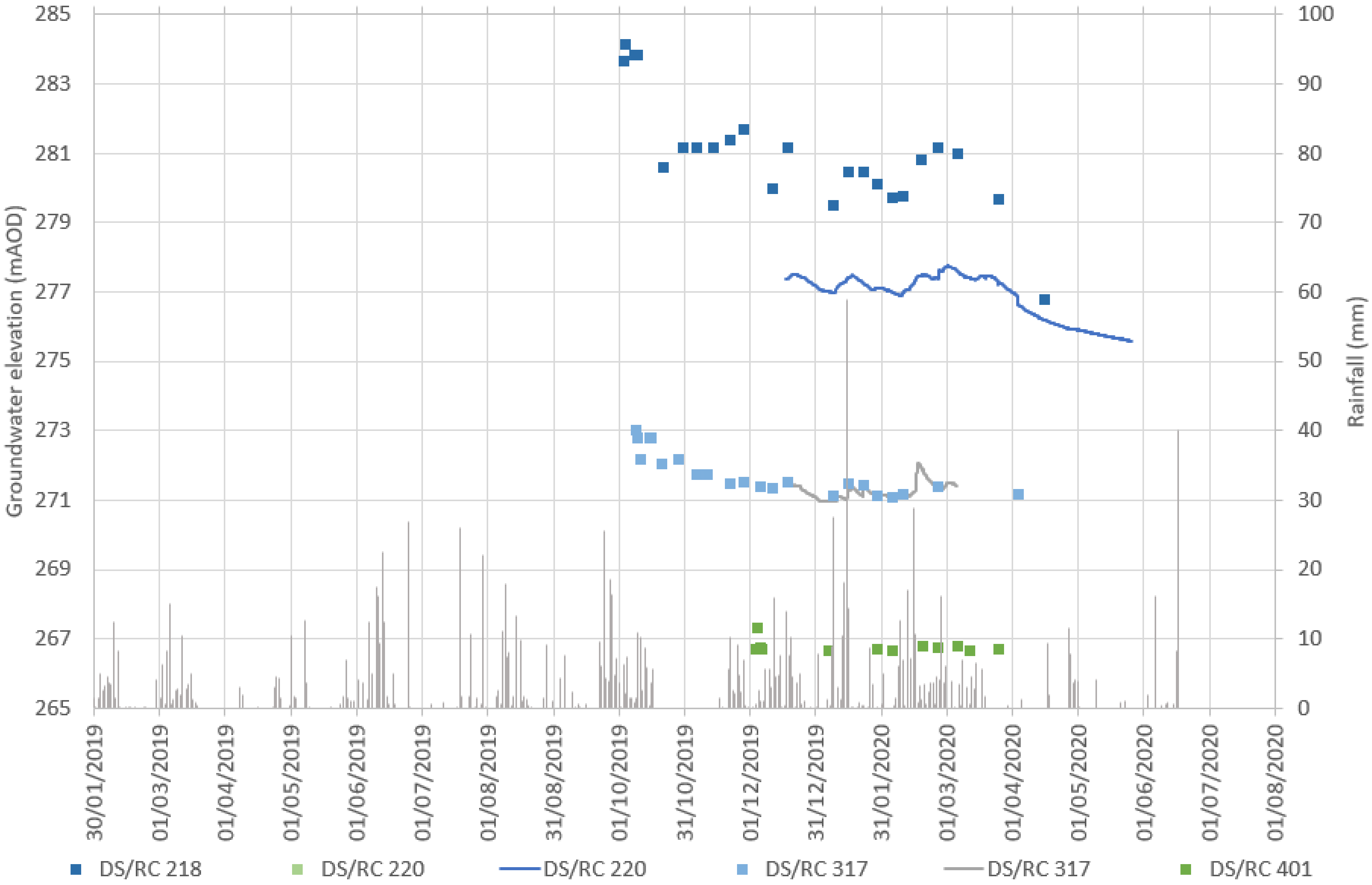


Figure C-8 Great Oolite limestone groundwater monitoring – CH3+500 to CH5+000 - Stockwell-Nettleton

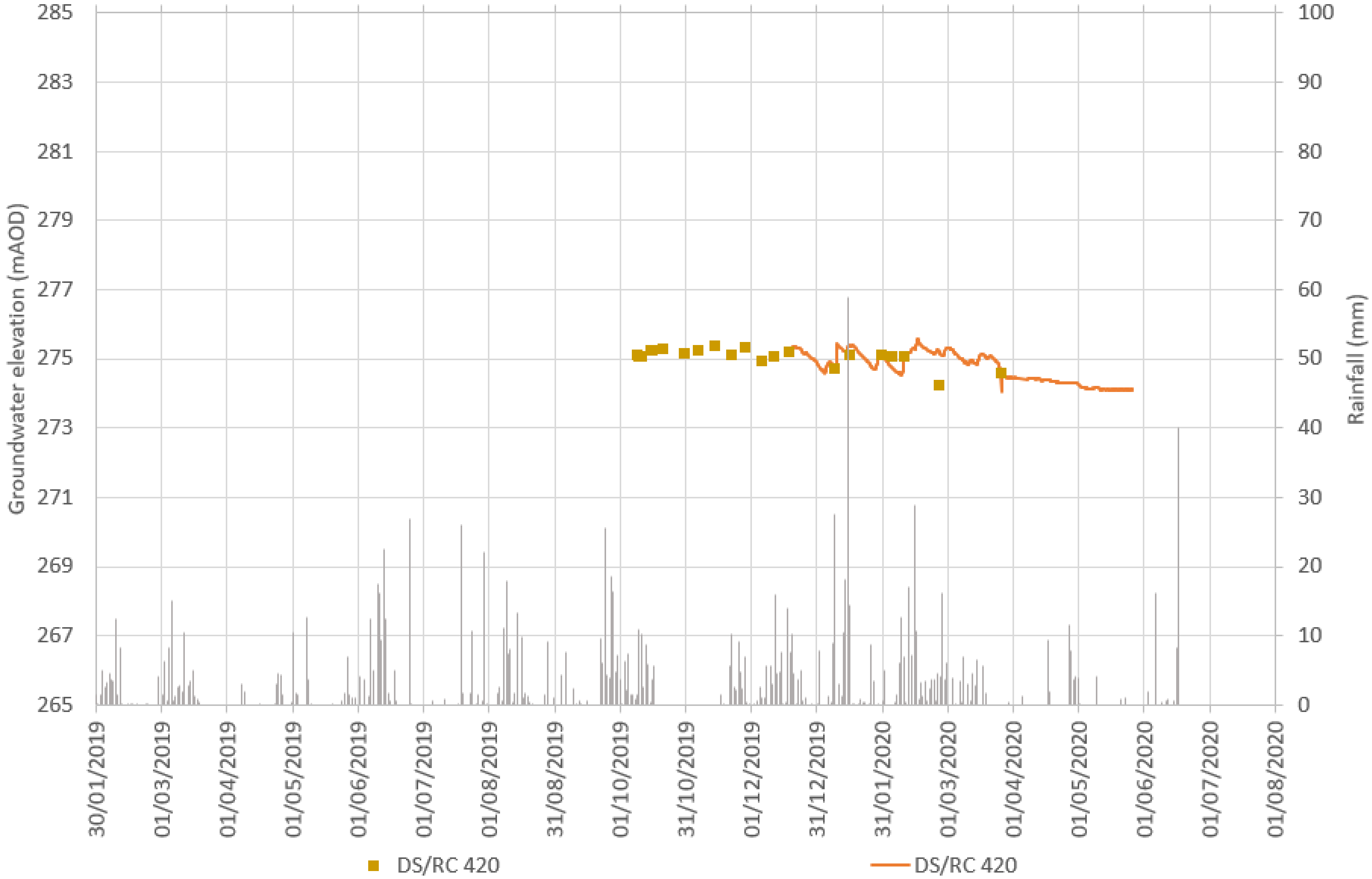


Figure C-9 Great Oolite limestone groundwater monitoring – Bushley Muzzard SSSI

Figure C-10 Great Oolite Group – Fuller's Earth Formation groundwater monitoring

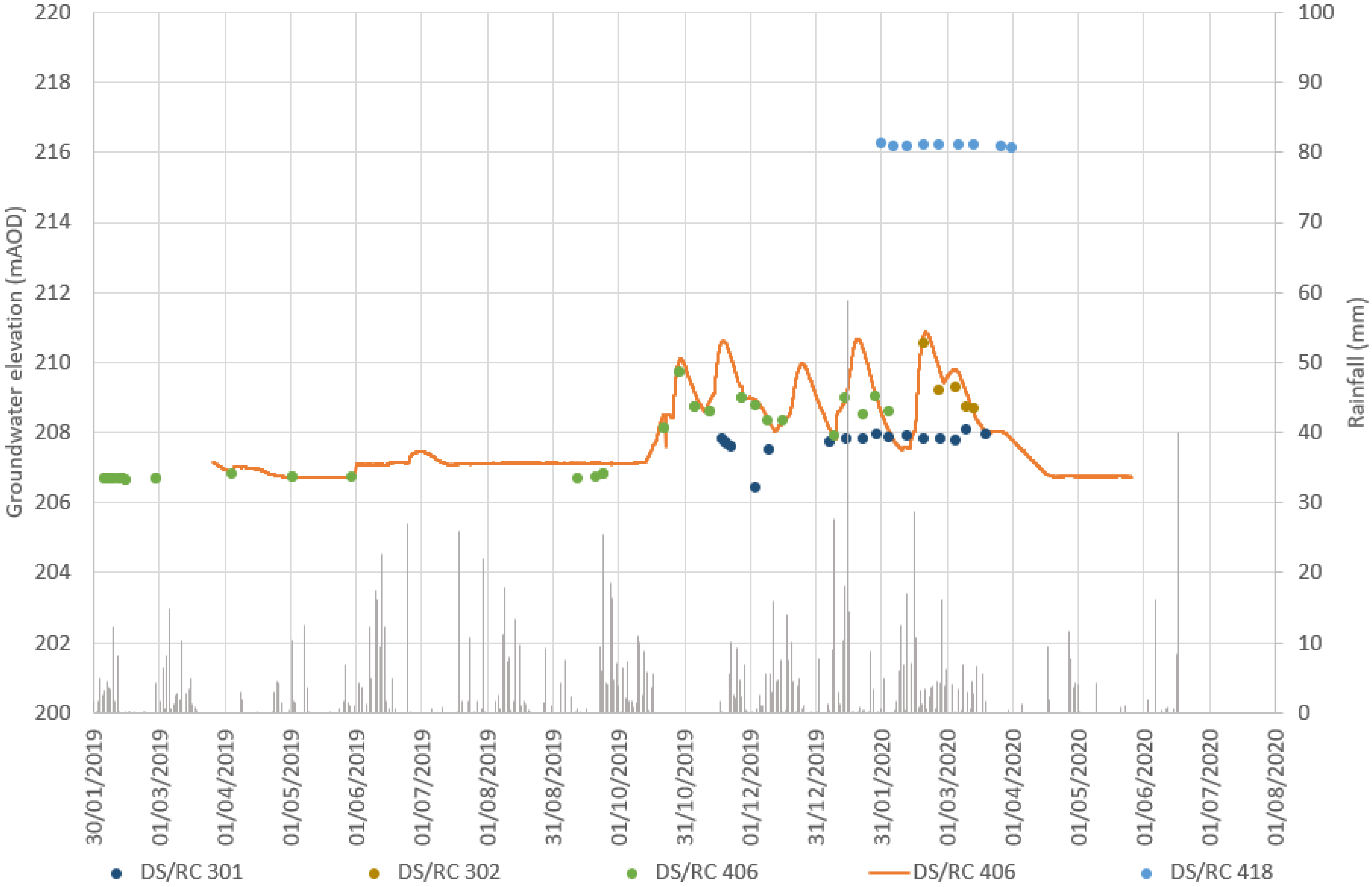


Figure C-11 Inferior Oolite Group groundwater monitoring – Air Balloon

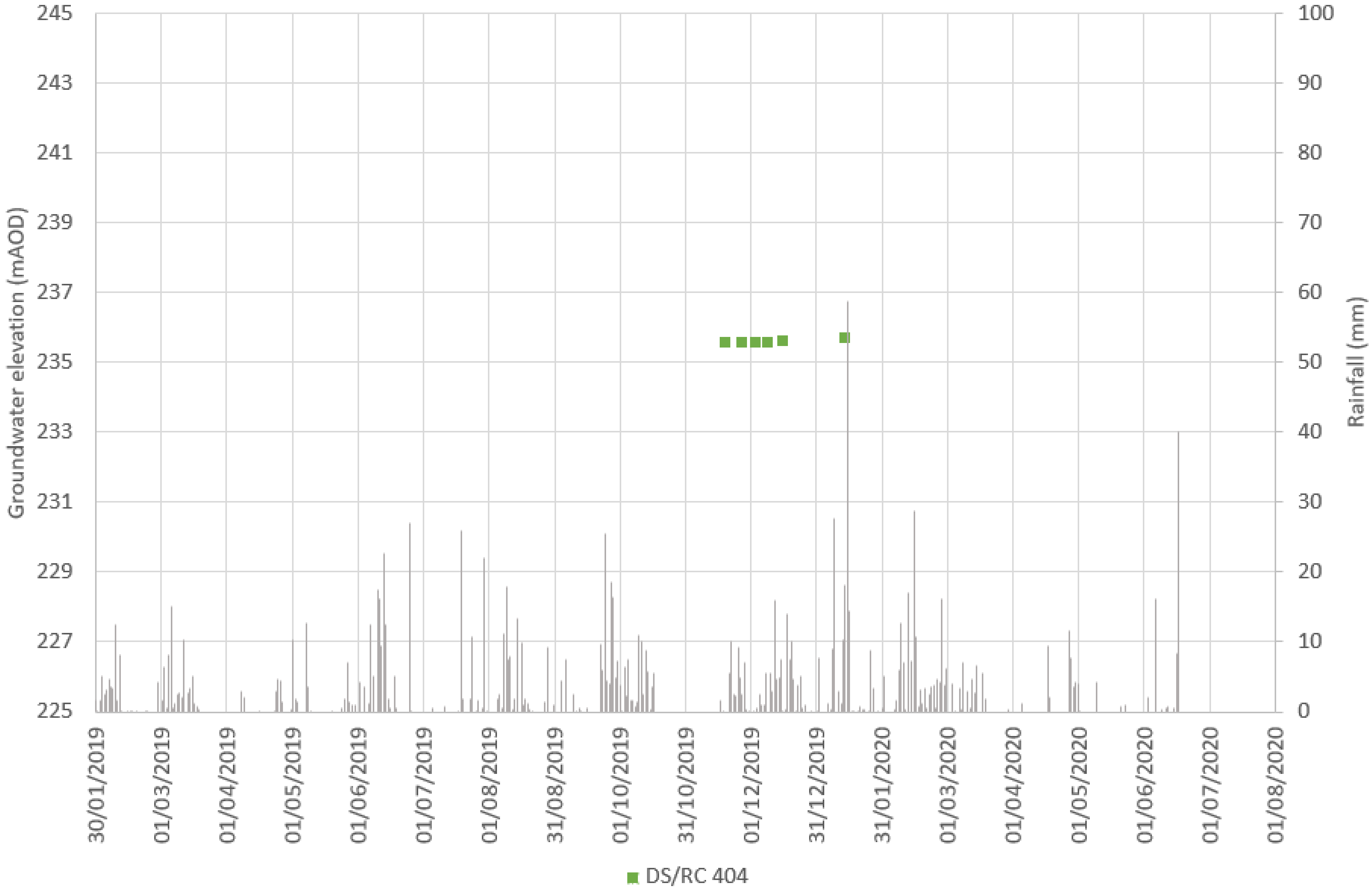


Figure C-12 Inferior Oolite Group groundwater monitoring – Barrow Wake

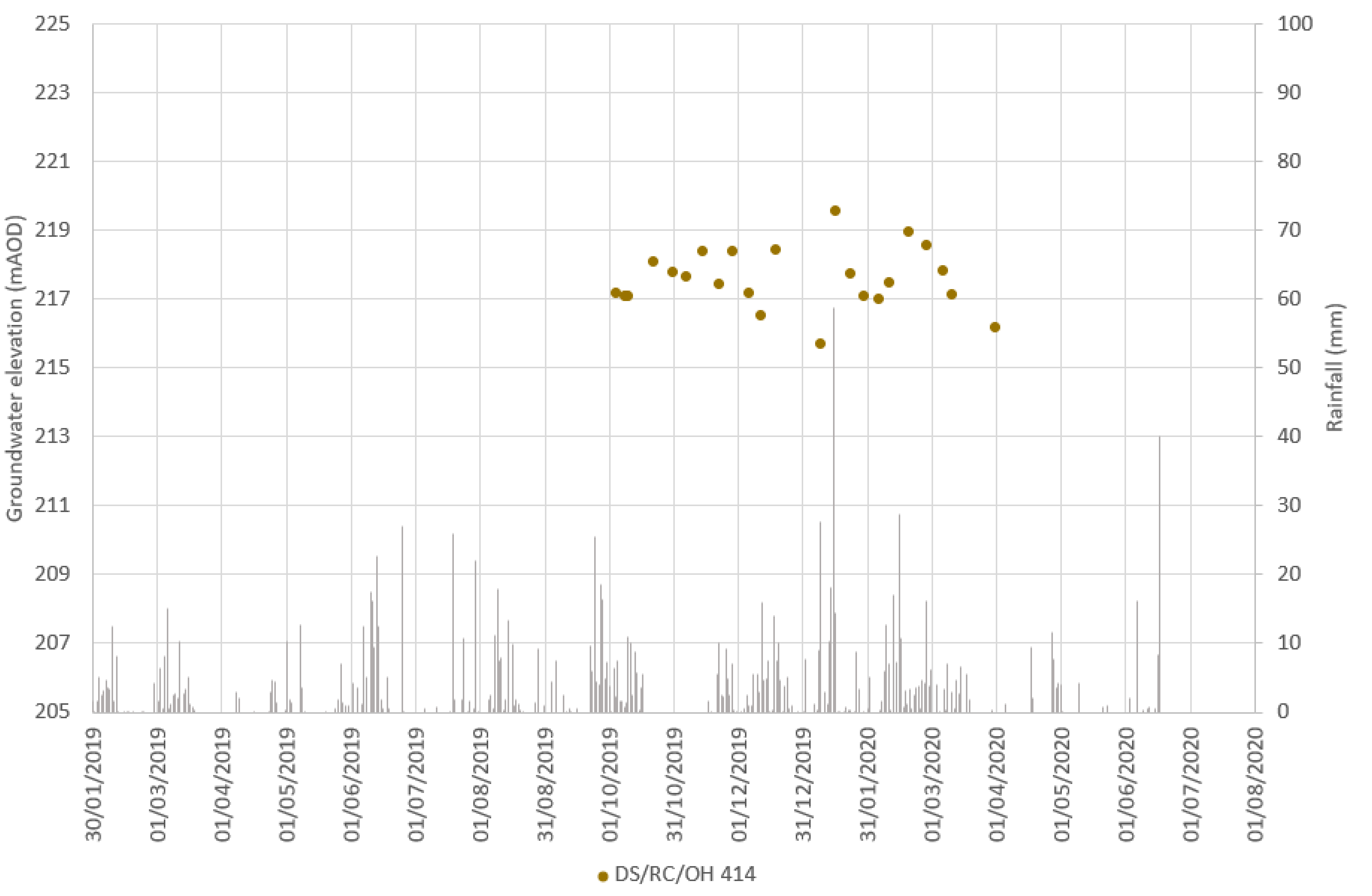


Figure C-13 Inferior Oolite Group groundwater monitoring – Barrow Wake

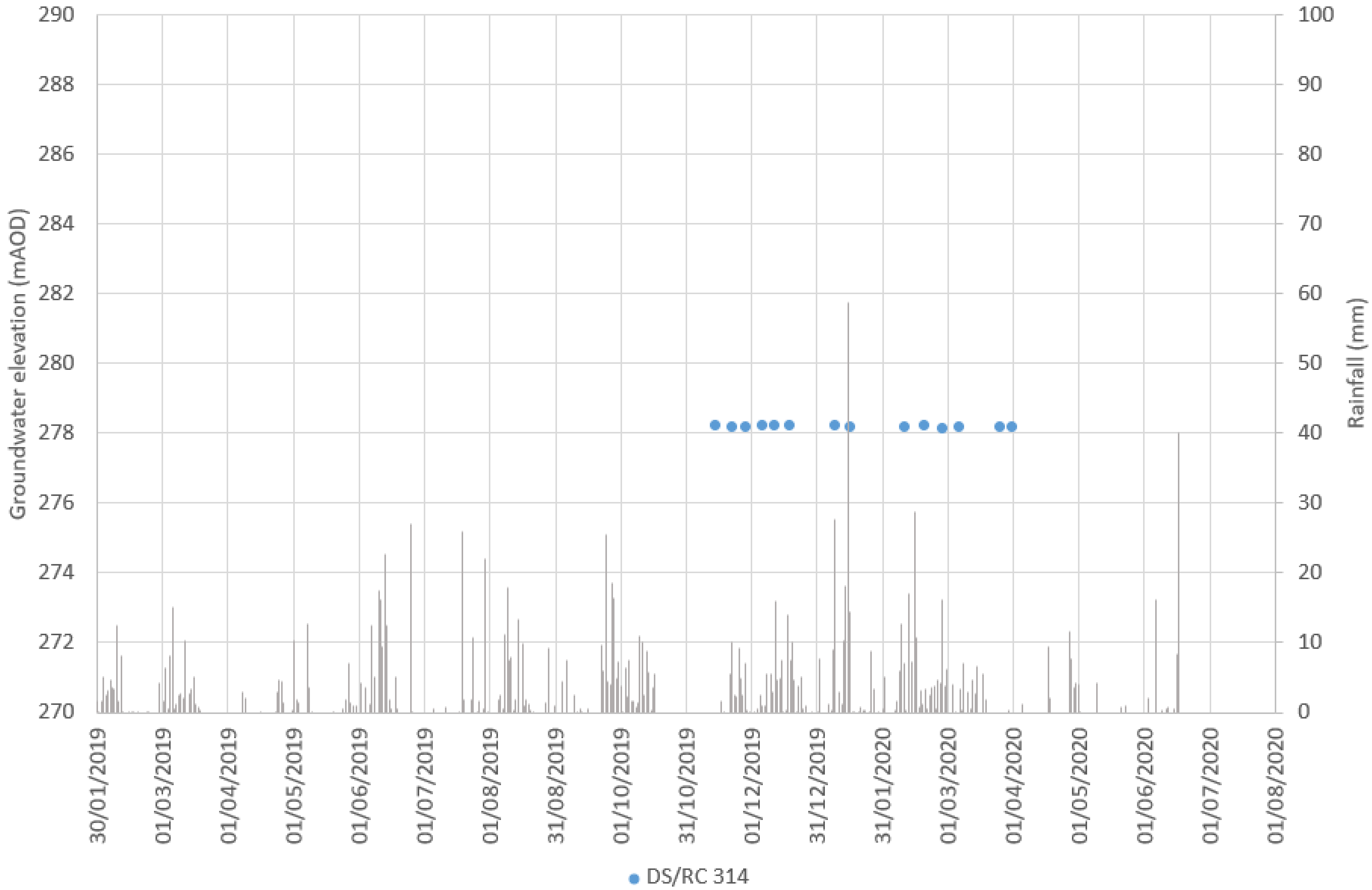


Figure C-14 Inferior Oolite Group groundwater monitoring – B4070 realignment

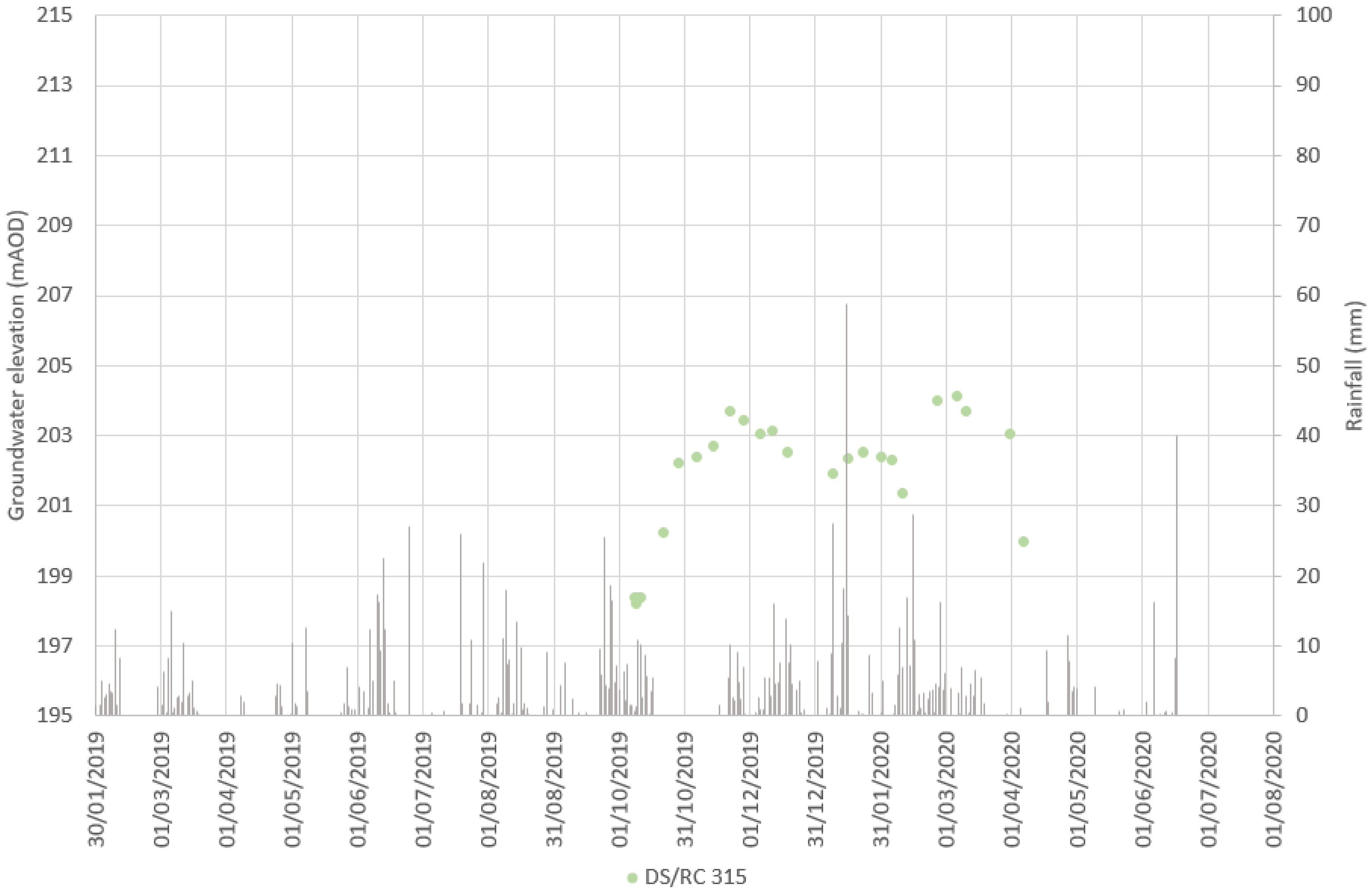


Figure C-15 Inferior Oolite Group groundwater monitoring – Shab Hill Junction

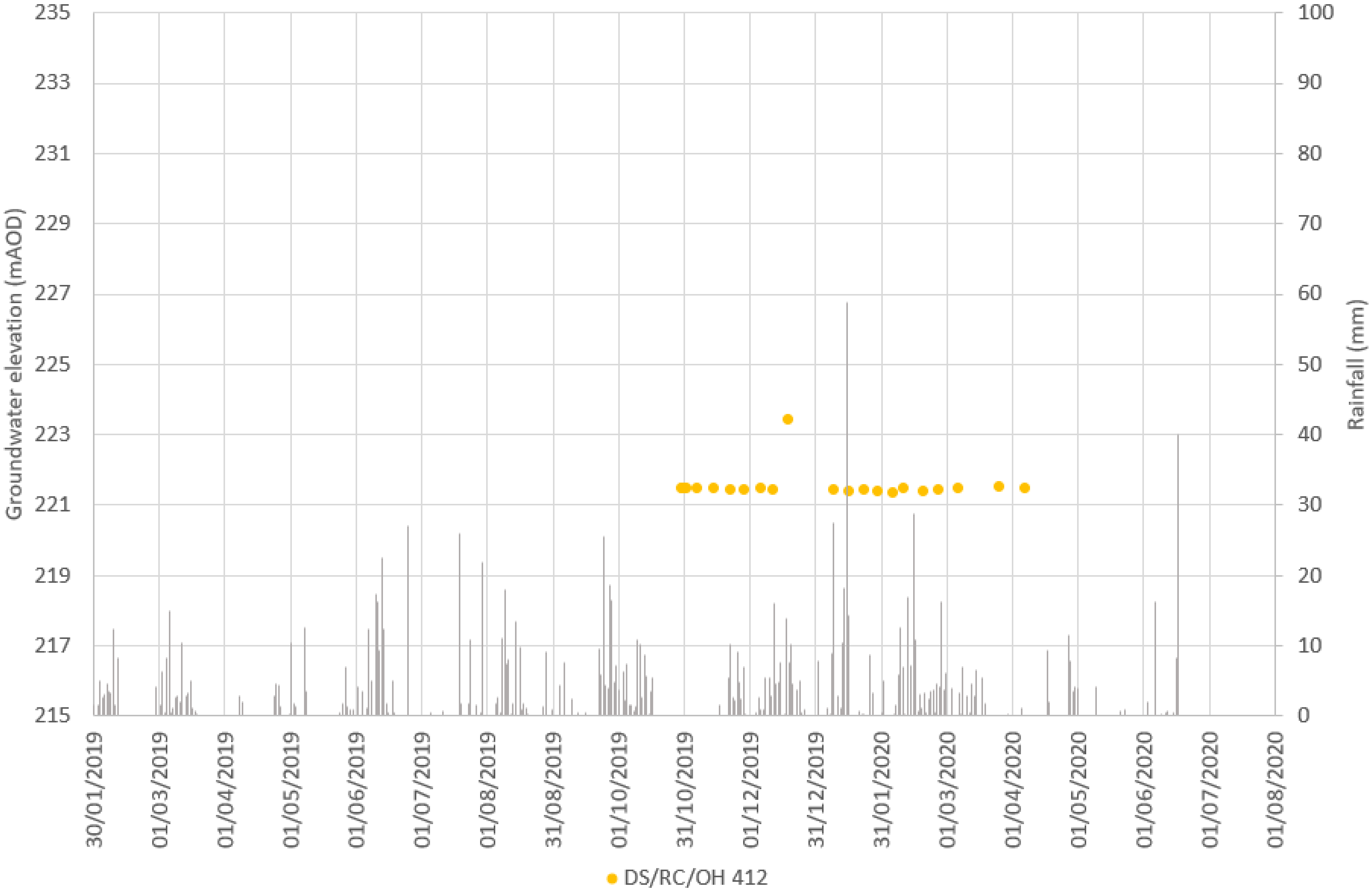


Figure C-16 Inferior Oolite Group groundwater monitoring – Shab Hill Junction

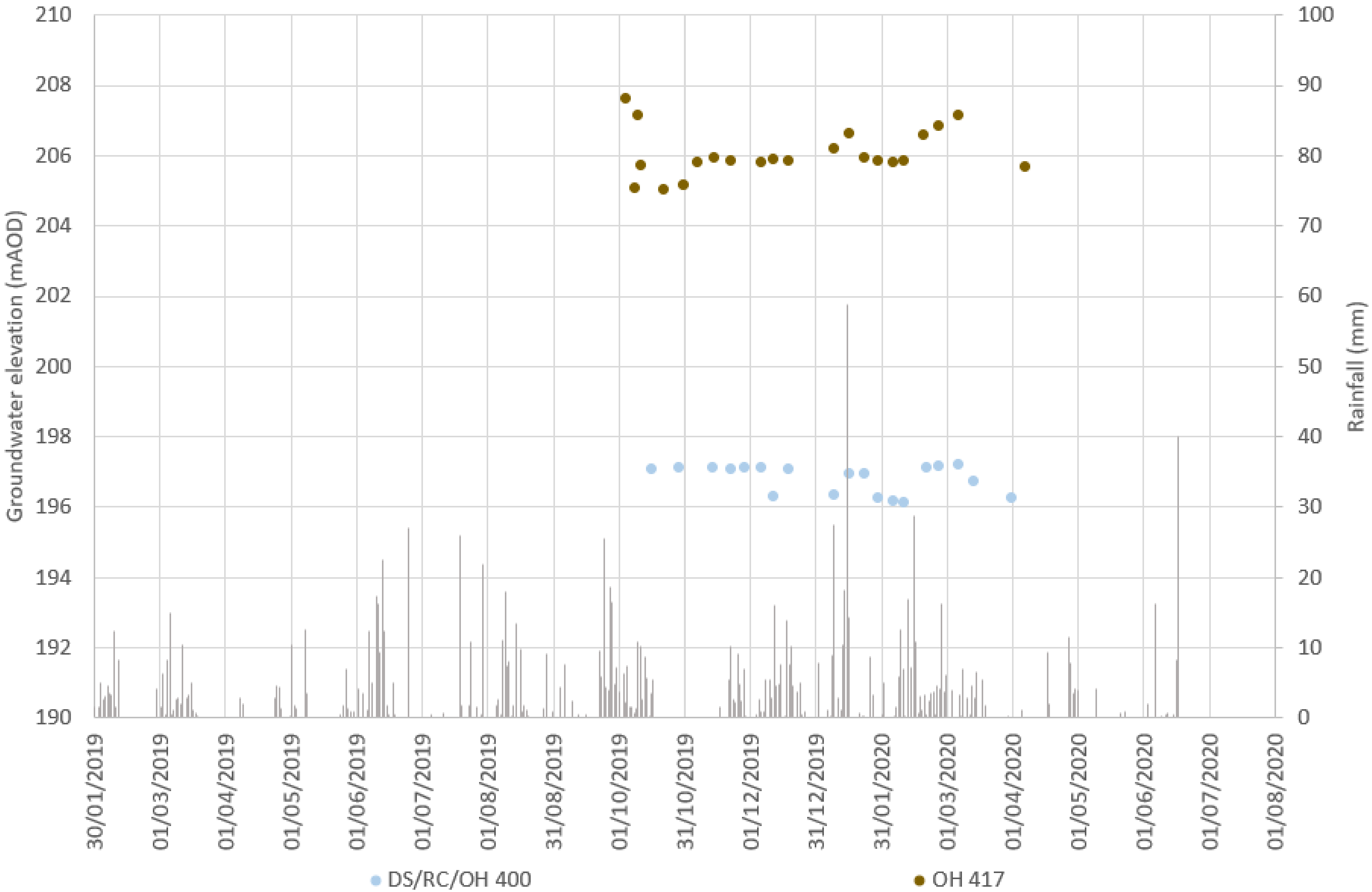


Figure C-17 Inferior Oolite Group groundwater monitoring – Stockwell-Nettleton

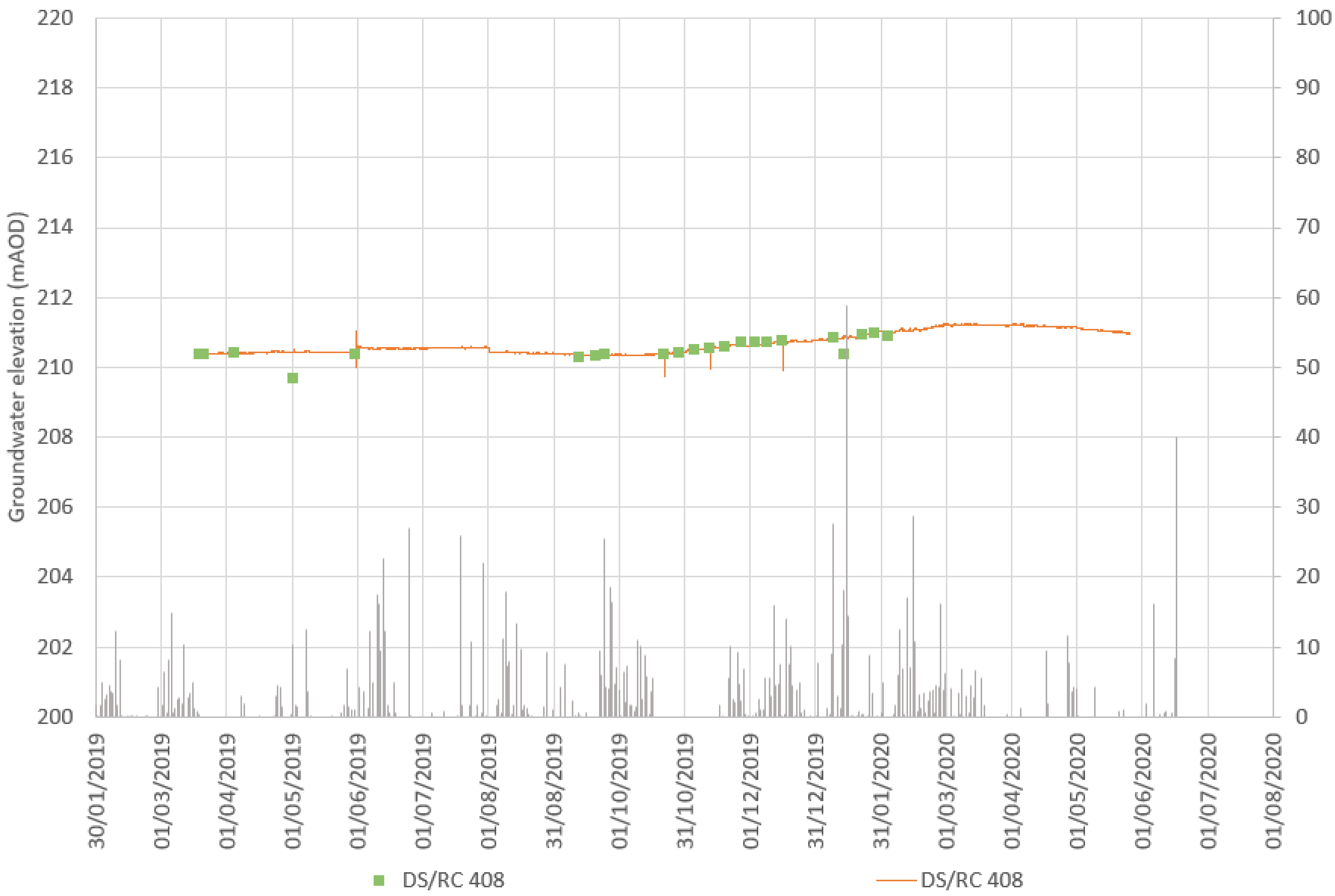


Figure C-18 Lias Group, Bridport Sand Formation groundwater monitoring – Air Balloon

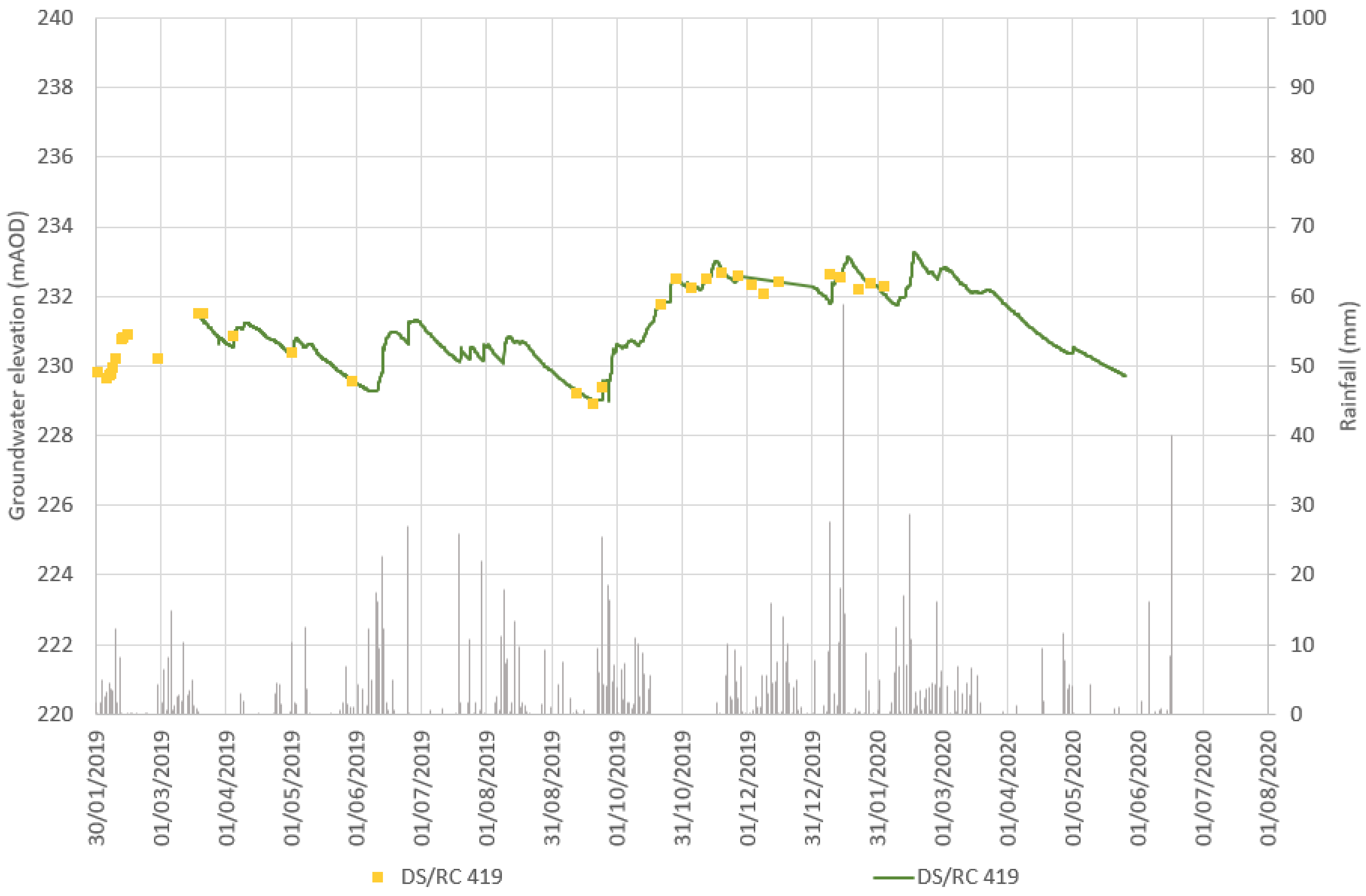


Figure C-19 Lias Group, Bridport Sand Formation groundwater monitoring – Barrow Wake

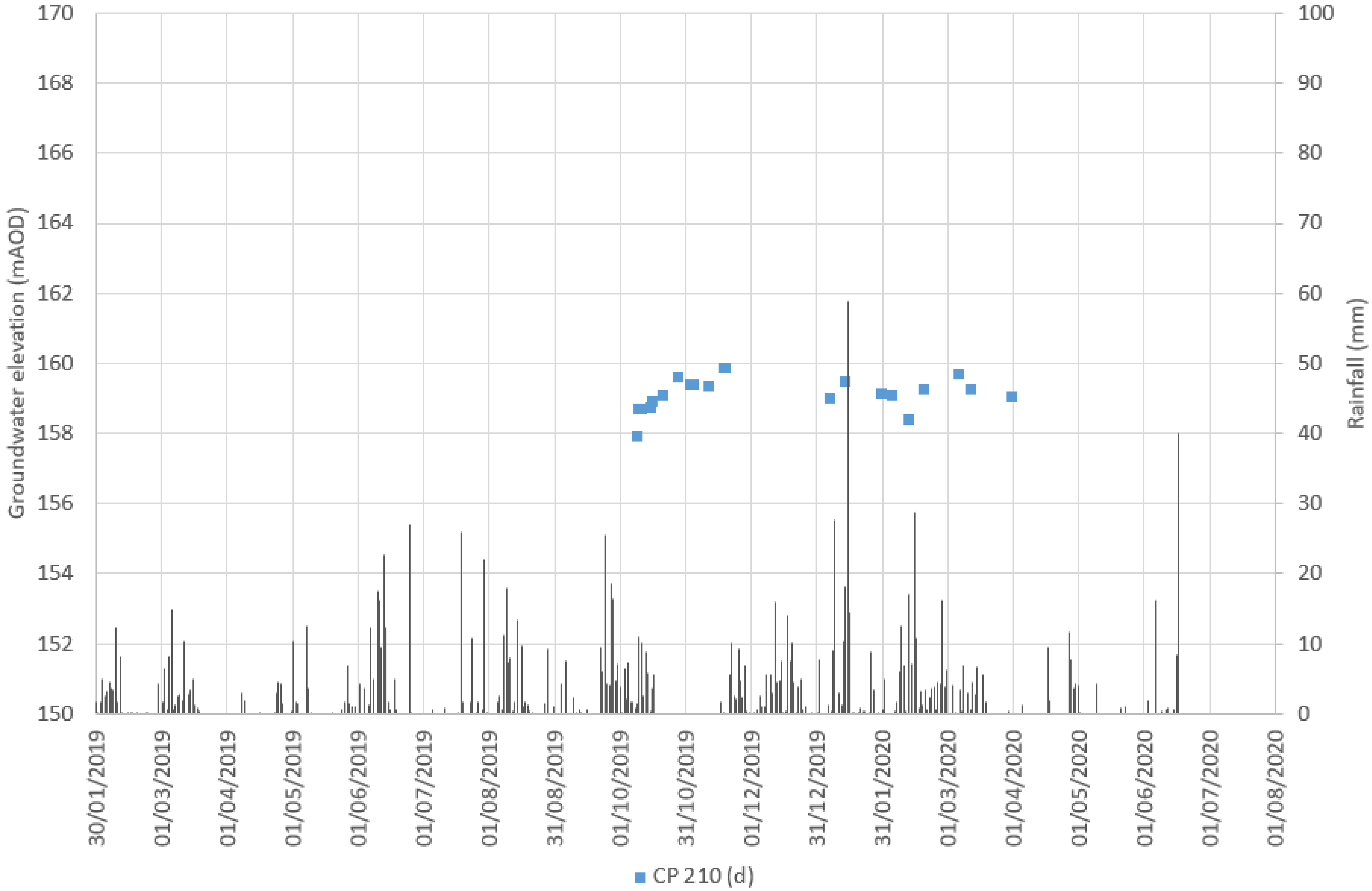


Figure C-20 Lias Group groundwater monitoring – CH1+000 to CH1+400 (northern side of A417) – mid Crickley Hill

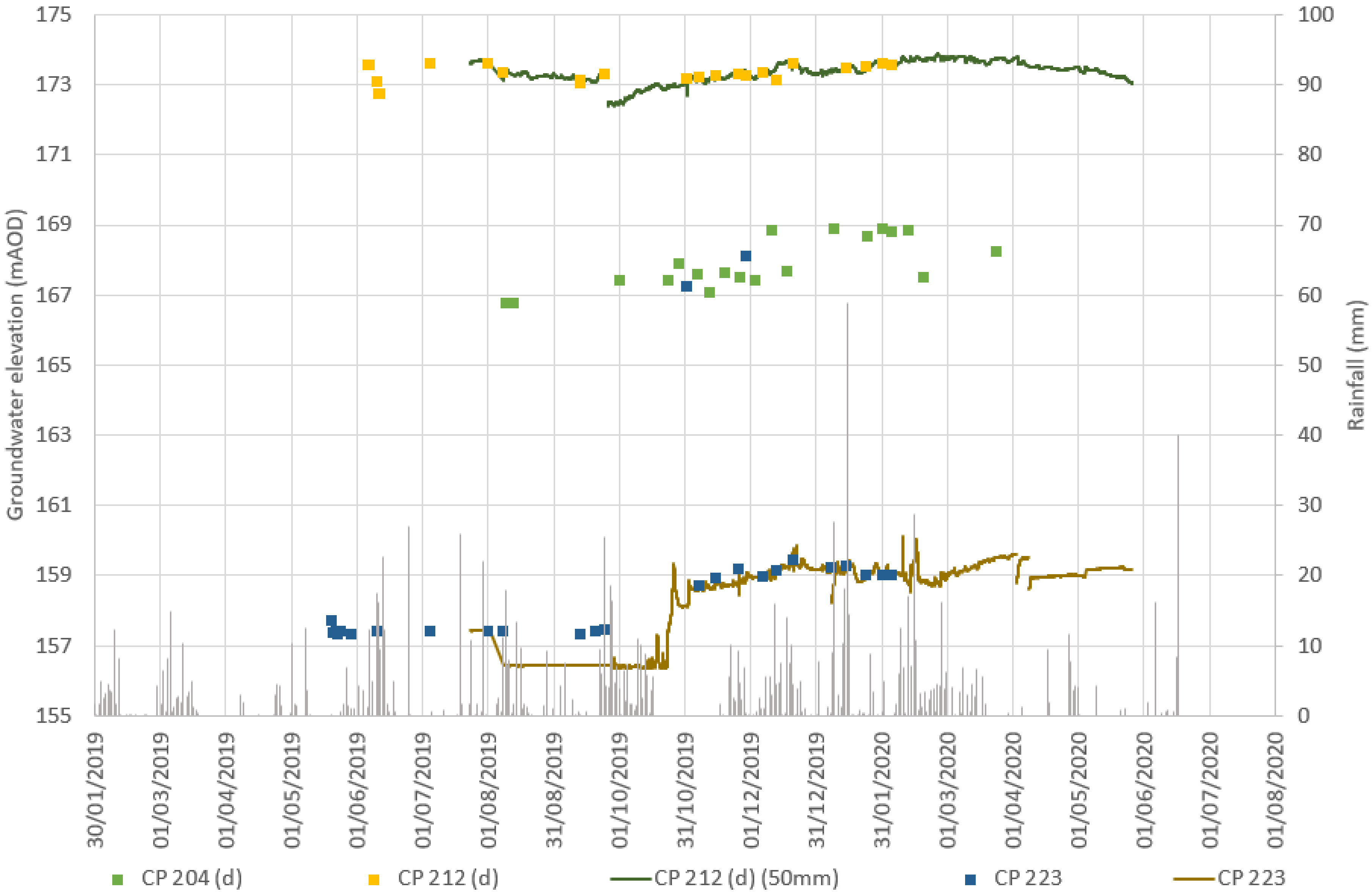


Figure C-21 Lias Group groundwater monitoring – CH1+000 to CH1+400 (southern side of A417) – mid Crickley Hill

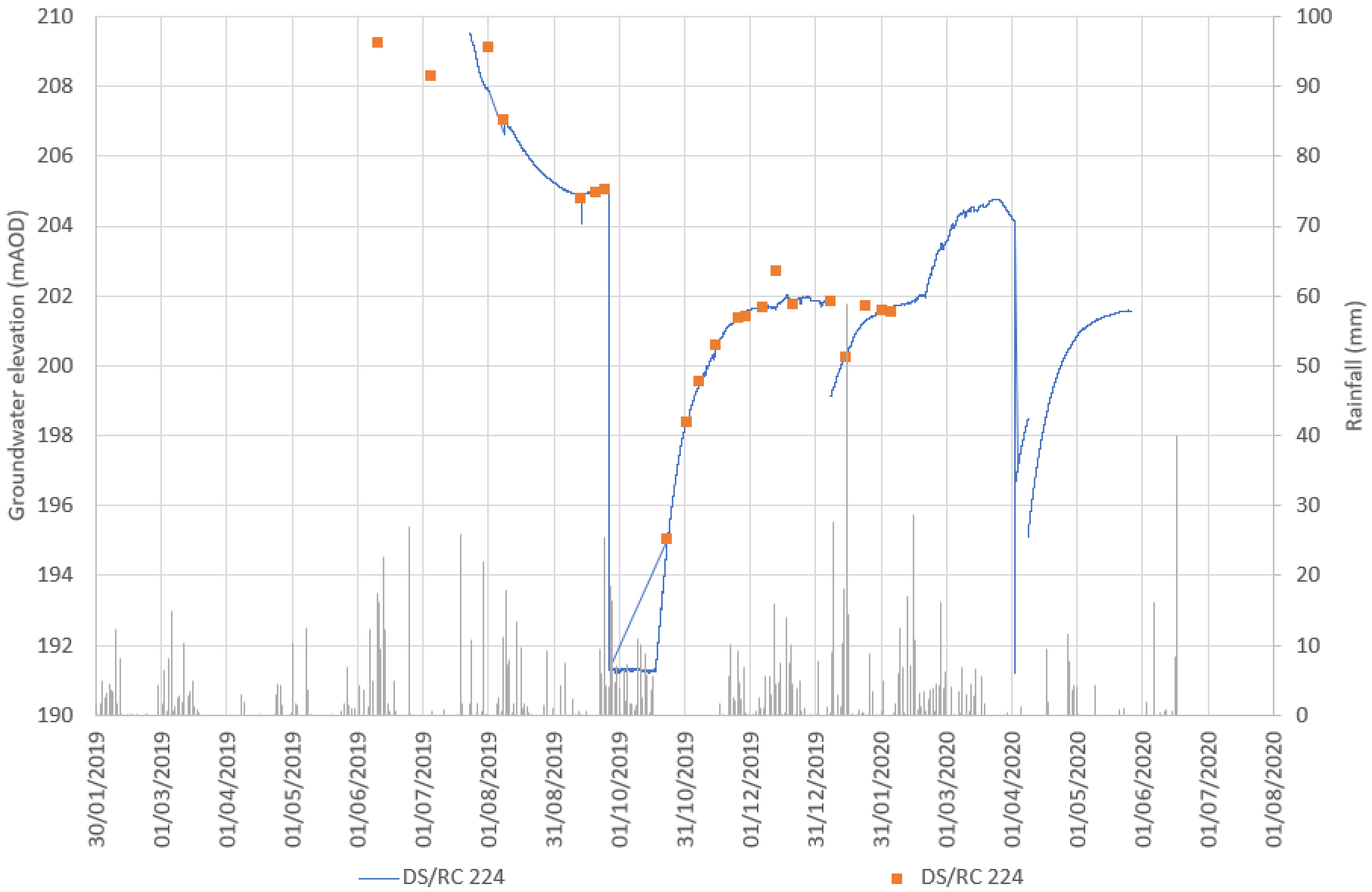


Figure C-22 Lias Group groundwater monitoring – CH1+000 to CH1+400 (southern side of A417) – Upper Crickley Hill

Appendix D Water quality results

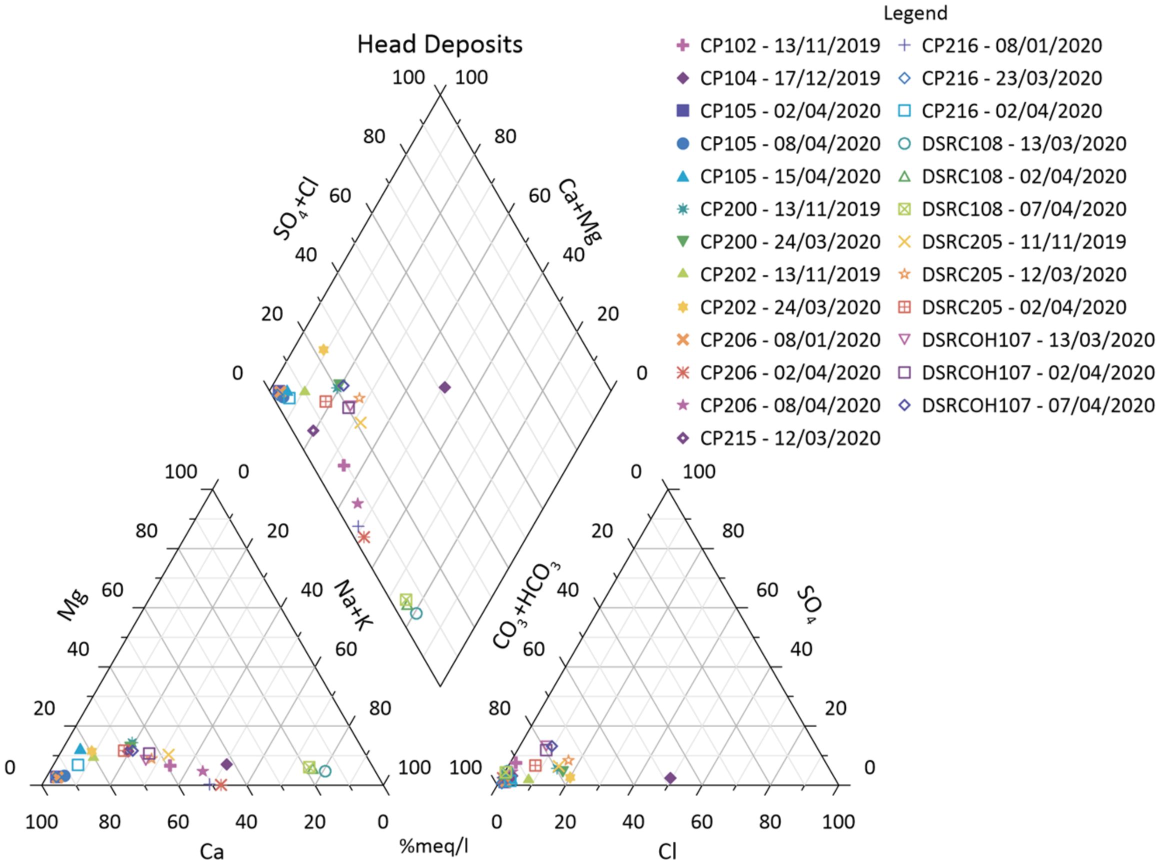


Figure D-1 Head deposits groundwater quality

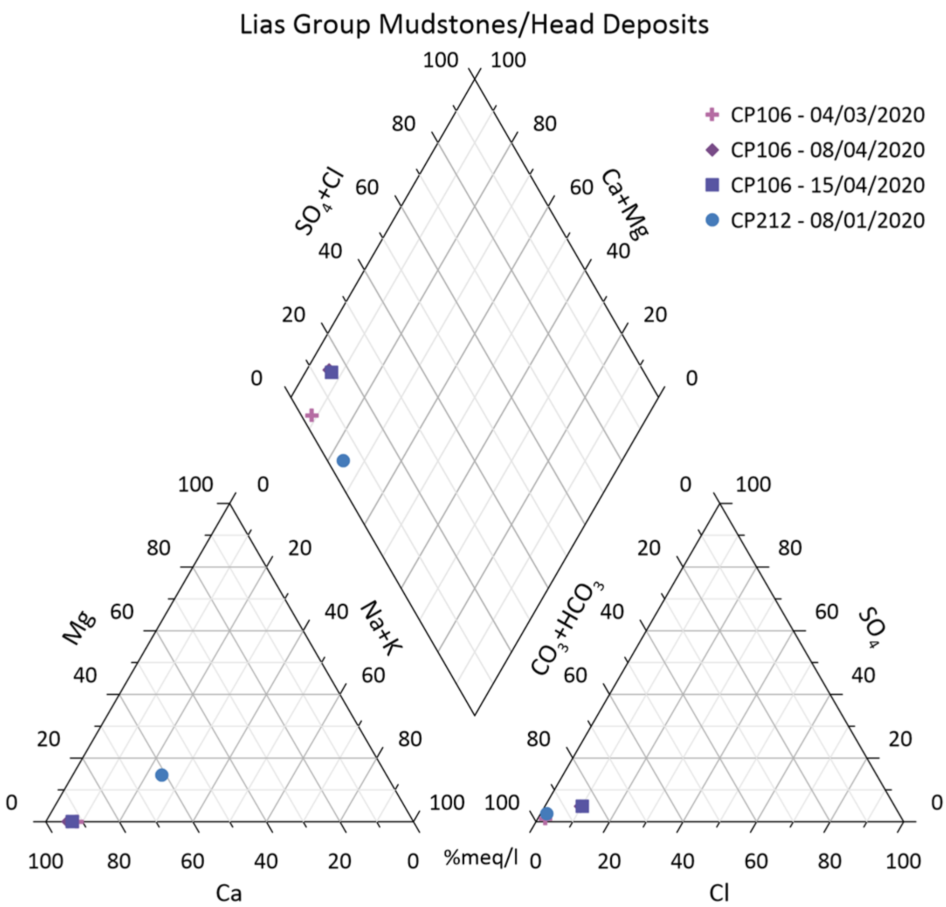


Figure D-2 Head deposits/Lias Group mudstone groundwater quality

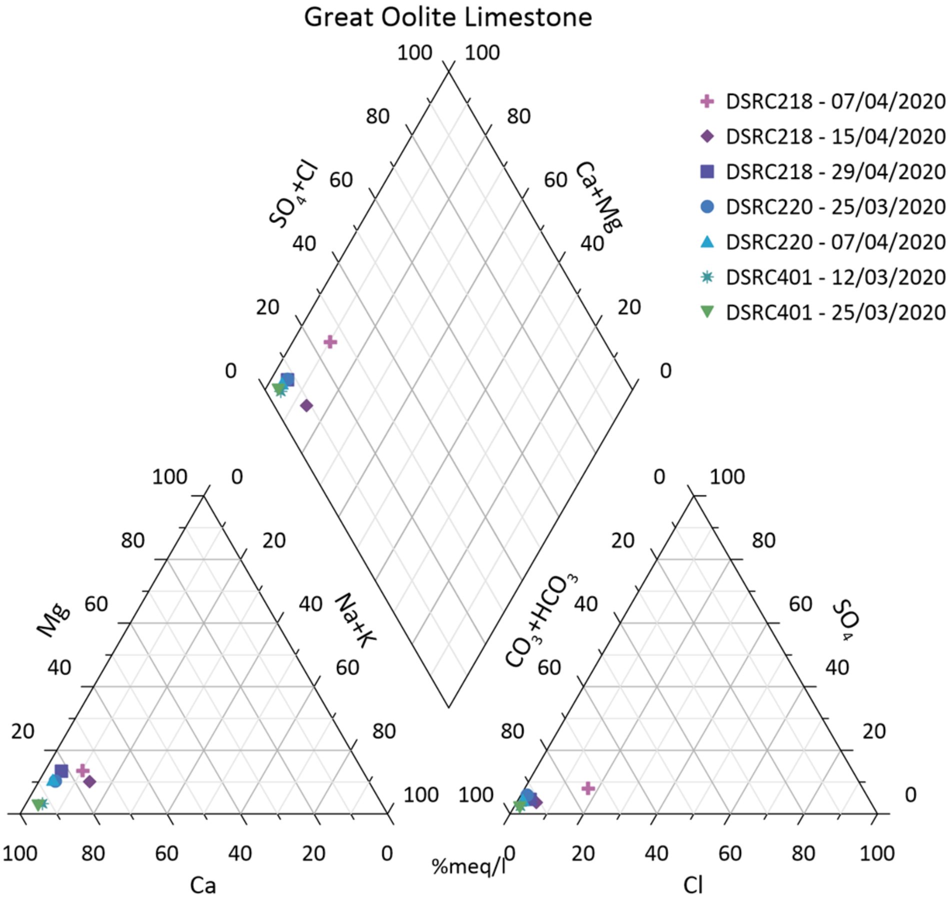


Figure D-3 Great Oolite limestone groundwater quality

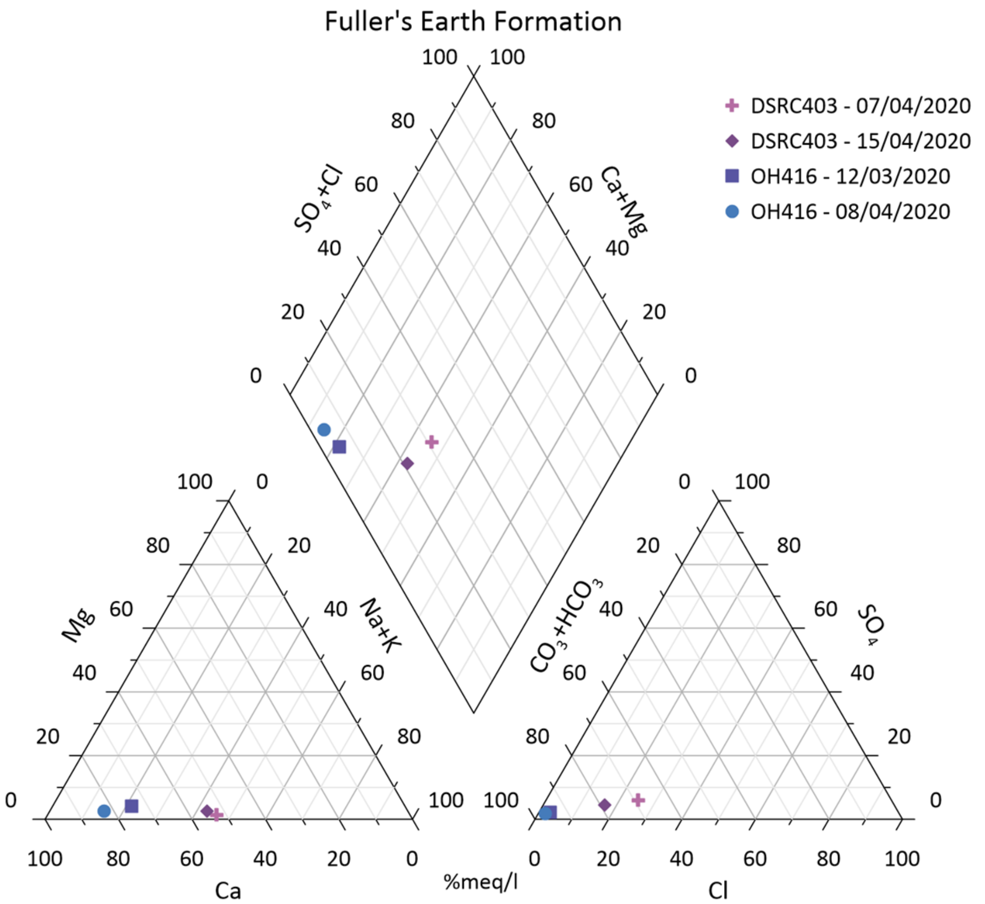


Figure D-4 Fuller’s Earth Formation groundwater quality

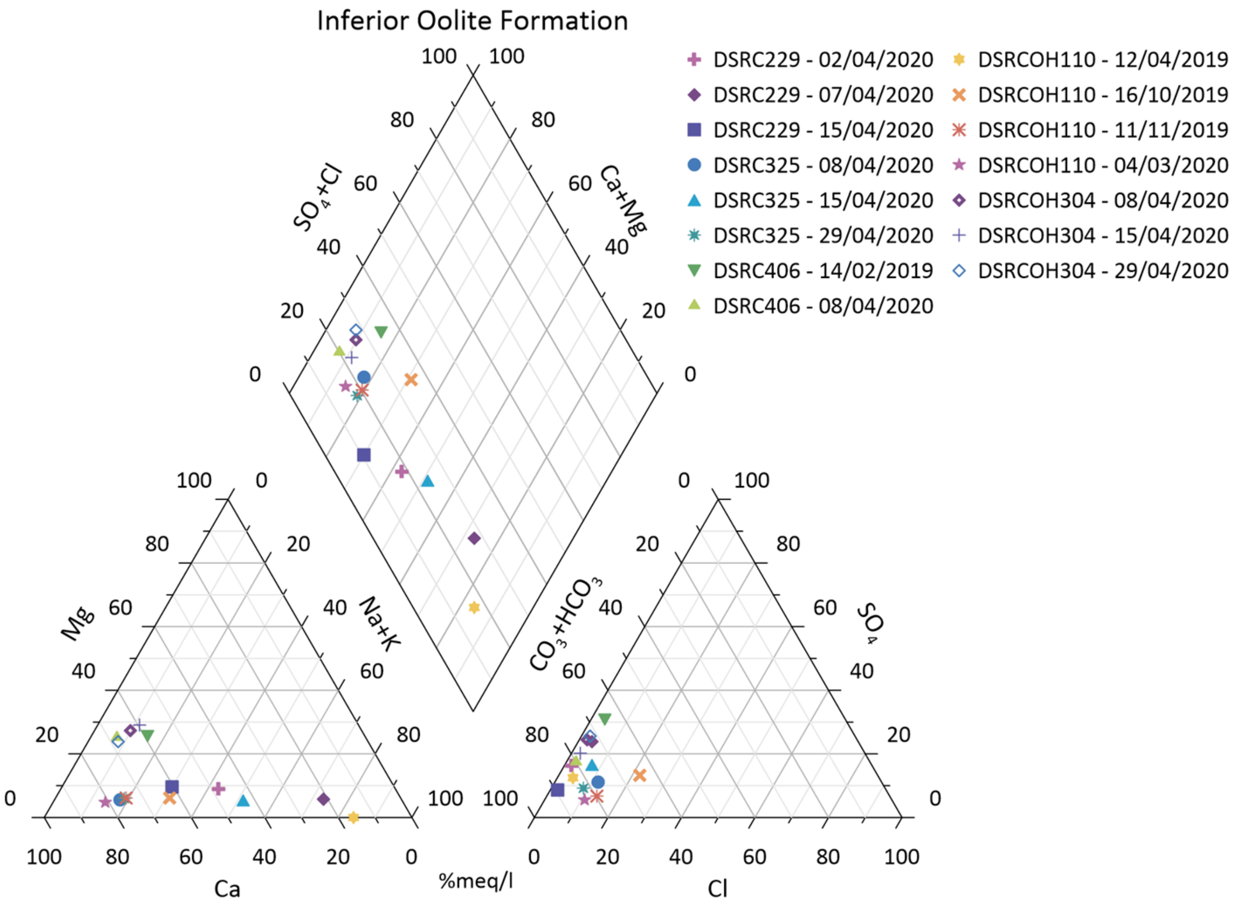


Figure D-5 Inferior Oolite Group groundwater quality

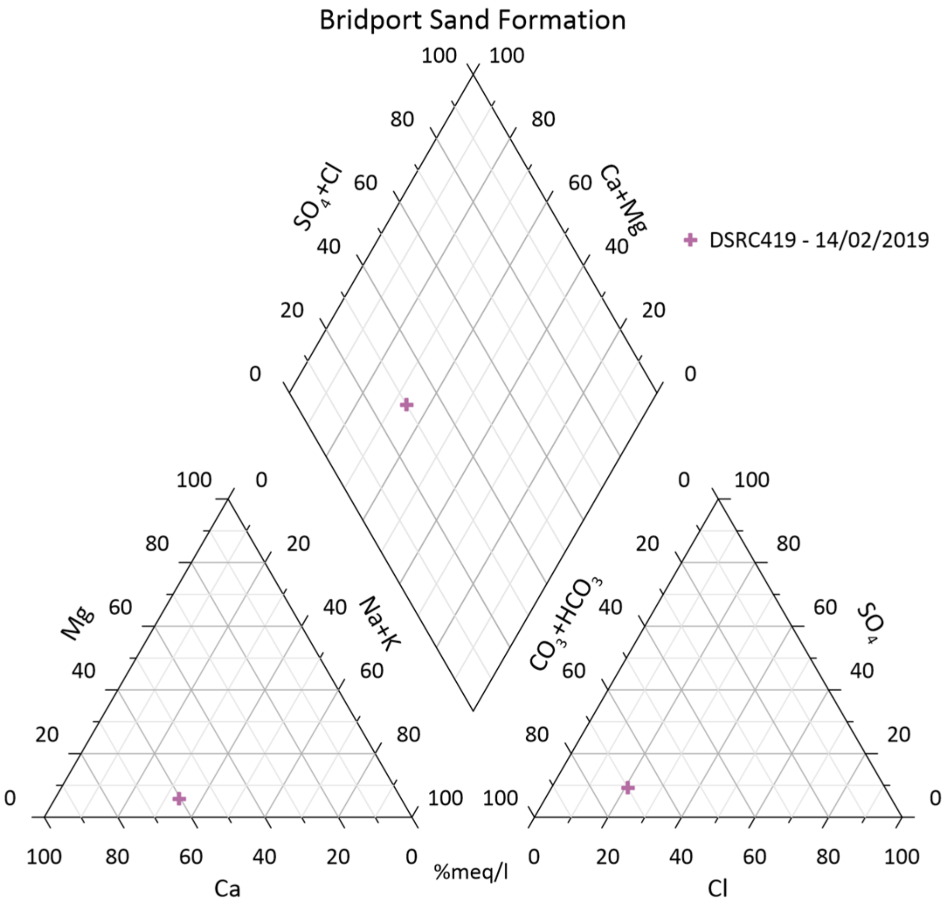


Figure D-6 Bridport Sand Formation groundwater quality

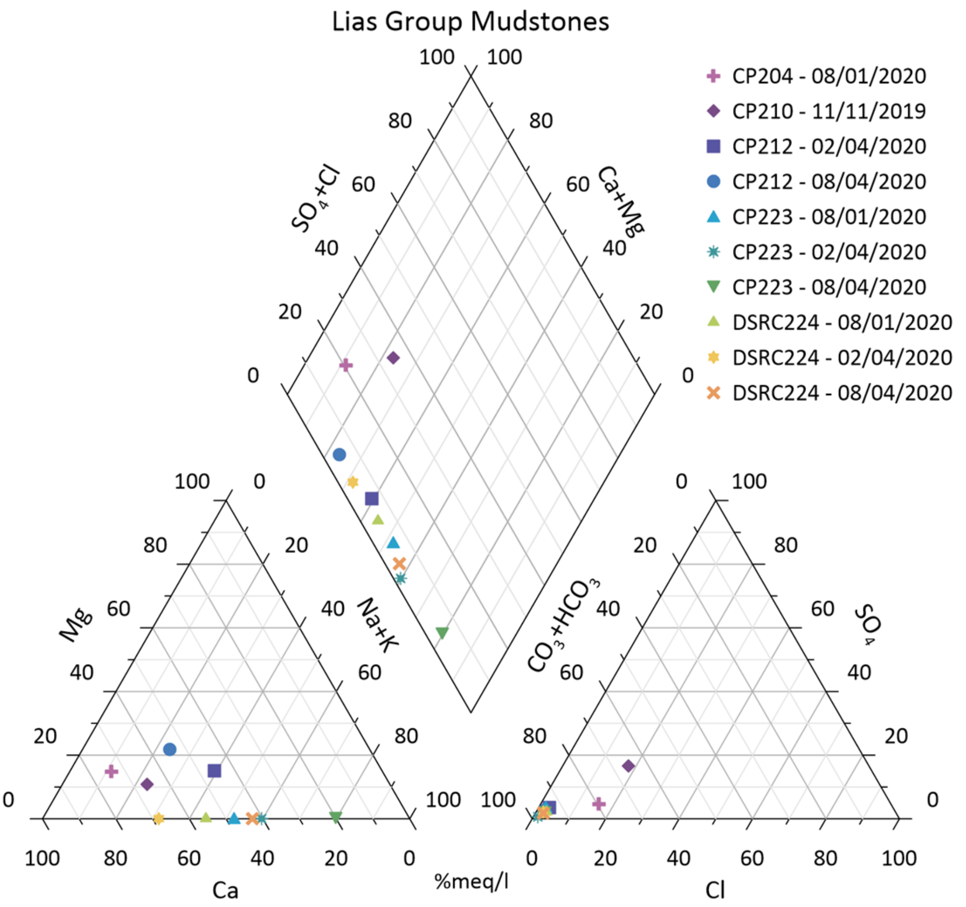


Figure D-7 Lias Group mudstones groundwater quality

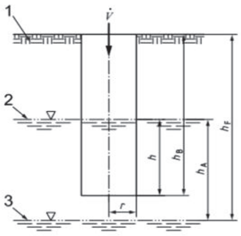
Appendix E Hydraulic testing results

Constant Head test Analysis in Unsaturated Aquifer
BS 22282-2

A417 Missing Link Phase 1 GI
Borehole DS/RC 404

Rest water level (RWL)		229.58	mAOD	RWL in BH DS/RC 419
Constant head test WL		240.9	mAOD	
Ground level (gl)		269	mAOD	
Response zone depth (BH base)		235	mAOD	
BH diameter (standpipe)		0.05	m	
Response zone diameter (gravel pack)		0.15	m	
RWL		39.42	m bgl	
Borehole depth (response zone base)	hB	34	m bgl	
RWL (below BH base)	hf	39.42	m bgl	
Constant Head (CH) test WL		28.1	m bgl	
Height of CH test WL above RWL	hA	11.32	m	
Height of CH test WL above BH base	h	5.9	m	
Response zone radius	r	0.075	m	
Injection flow rate	V	0.002	m3/s	

BS EN ISO 22282-2:2012
ISO 22282-2:2012(E)



Key
1 ground surface
2 raised water surface
3 unconfined water surface

Figure B.11 — Hydrogeological conditions for a constant head test in unsaturated soils (unconfined groundwater surface below borehole bottom)

h/r > 10	Yes	h <= hA <= 3h	Yes
hA > 3h	No	hA < h	No

h <= hA <= 3h

$$k_f = 0{,}159 \cdot \frac{\dot{V}}{h^2} \cdot \frac{\ln\left(\frac{h}{r}\right)}{0{,}1667 + \frac{h_A}{3 \cdot h}}$$

ln (h/r) = 4.3652
hA / 3h = 0.6395
V/h^2 = 0.00006

Kf =	**4.95E-05**	**m/s**

Notes: Constant head could only be maintained for 1 minute
Dip readings could only be taken once injection pipe removed
RWL below datalogger

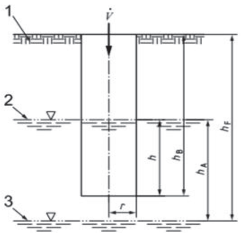
Constant Head test Analysis in Unsaturated Aquifer
BS 22282-2

A417 Missing Link Phase 1 GI — **Note: RWL is within sandstone below mudstone unit in Bridport Sand**
Borehole DS/RC 404 — **Assume RWL is at base of Inferior Oolite (top of mudstone unit):**

Rest water level (RWL)	234.1	mAOD	RWL =	hf	34.9	m bgl
Constant head test WL	240.9	mAOD	RWL =		234.1	mAOD
Ground level (gl)	269	mAOD				
Response zone depth (BH base)	235	mAOD				
BH diameter (standpipe)	0.05	m				
Response zone diameter (gravel pack)	0.15	m				

RWL		34.9	m bgl
Borehole depth (response zone base)	hB	34	m bgl
RWL (below BH base)	hf	34.9	m bgl
Constant Head (CH) test WL		28.1	m bgl
Height of CH test WL above RWL	hA	6.8	m
Height of CH test WL above BH base	h	5.9	m
Response zone radius	r	0.075	m
Injection flow rate	V	0.002	m3/s

BS EN ISO 22282-2:2012
ISO 22282-2:2012(E)



Key
1 ground surface
2 raised water surface
3 unconfined water surface

Figure B.11 — Hydrogeological conditions for a constant head test in unsaturated soils (unconfined groundwater surface below borehole bottom)

h/r > 10	Yes	h <= hA <= 3h	Yes
hA > 3h	No	hA < h	No

h <= hA <= 3h

$$k_f = 0{,}159 \cdot \frac{\dot{V}}{h^2} \cdot \frac{\ln\left(\frac{h}{r}\right)}{0{,}1667 + \frac{h_A}{3 \cdot h}}$$

ln (h/r) = 4.3652
hA / 3h = 0.3842
V/h^2 = 0.00006

Kf =	**7.24E-05**	**m/s**

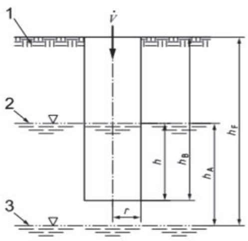
Notes: Constant head could only be maintained for 1 minute
Dip readings could only be taken once injection pipe removed
RWL below datalogger

Constant Head test Analysis in Unsaturated Aquifer
BS 22282-2

A417 Missing Link Phase 1 GI
Borehole OH 405

Rest water level (RWL)		206.75	mAOD	RWL in BH DS/RC 406
Constant head test WL		226.75	mAOD	
Ground level (gl)		239.5	mAOD	
Response zone depth (BH base)		221.5	mAOD	
BH diameter (standpipe)		0.05	m	
Response zone diameter (gravel pack)		0.15	m	
RWL		32.75	m bgl	
Borehole depth (response zone base)	hB	18	m bgl	
RWL (below BH base)	hf	32.75	m bgl	
Constant Head (CH) test WL		12.75	m bgl	
Height of CH test WL above RWL	hA	20	m	
Height of CH test WL above BH base	h	5.25	m	
Response zone radius	r	0.075	m	
Injection flow rate	V	0.002	m3/s	

BS EN ISO 22282-2:2012
ISO 22282-2:2012(E)



Key
1 ground surface
2 raised water surface
3 unconfined water surface

Figure B.11 — Hydrogeological conditions for a constant head test in unsaturated soils (unconfined groundwater surface below borehole bottom)

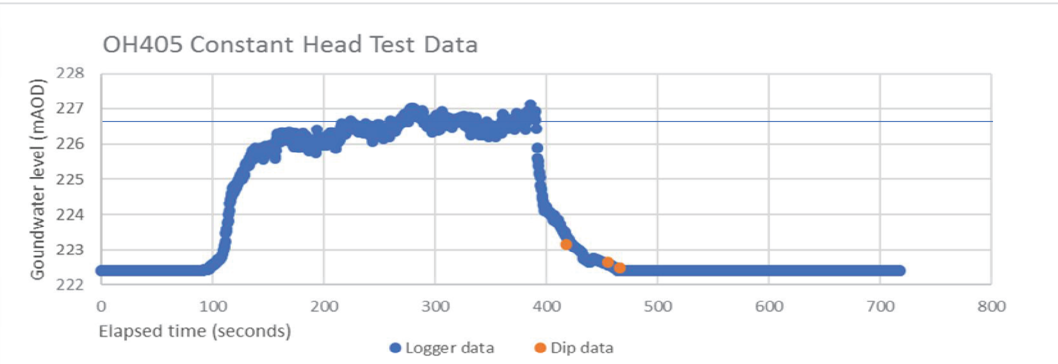
h/r > 10	Yes	h <= hA <= 3h	No
hA > 3h	Yes	hA < h	No

hA > 3h

$$k_f = 0{,}159 \cdot \frac{\dot{V}}{h^2} \cdot \left[\ln\left(\frac{h}{r} + \sqrt{\left(\frac{h}{r}\right)^2 + 1} \right) - 1 \right]$$

h/r = 70.0000
V/h^2 = 0.00007

Kf =	**5.69E-05**	**m/s**



Notes: Dip readings could only be taken once injection pipe removed
RWL below datalogger

Calculation of Permeability from Variable Head testing
A417 'Missing Link'

DS/RC 406

Calculation using Hvorslev method, as described in BS 22282-2:

$$k = \frac{r^2 \cdot \ln\left(\frac{L}{R}\right)}{2 \cdot L \cdot t_0}$$

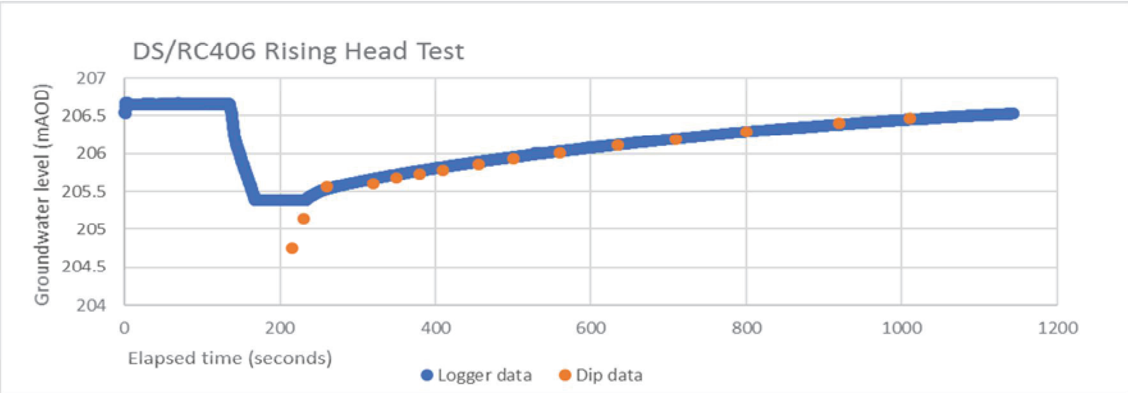
Where:

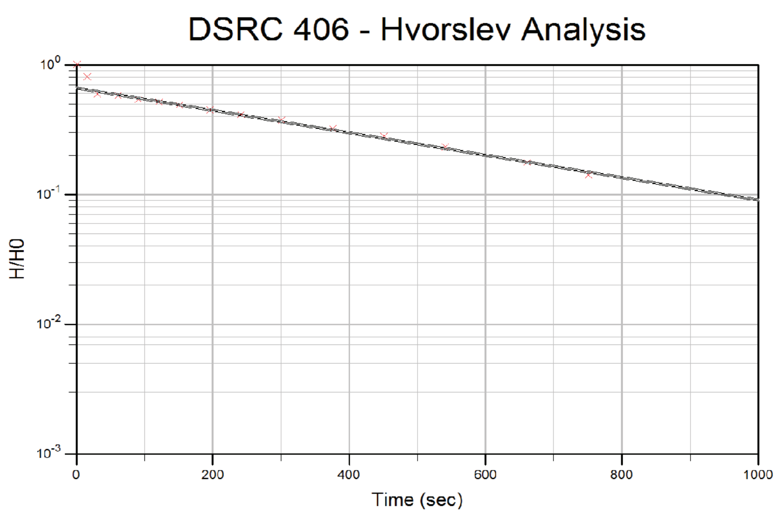
K	=	permeability coefficient (m/s)
r	=	radius of the measuring tube (m)
R	=	radius of the test section (m)
L	=	length of the slotted section/head in borehole at rest (m)
t_0	=	the time it takes for the water level to rise or fall to 37 percent of the initial change in head (secs)

Borehole Dimensions: **The following parameters were used in the calculation:**

Base of slotted section	=	34 mbgl	L	=	2.1
Test section diameter	=	0.15 m	t_0	=	250
Standpipe diameter	=	0.05 m			
Filter medium	=	Granular			
Rest water level	=	206.75 mAOD			
Ground level	=	238.65 mAOD			

k_f = 0.000002





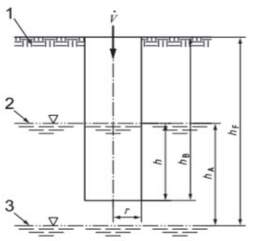
Constant Head test Analysis in Unsaturated Aquifer
BS 22282-2

A417 Missing Link Phase 1 GI
Borehole OH 407

Rest water level (RWL)	210.4	mAOD	RWL in DS/RC 408
Constant head test WL	222.75	mAOD	
Ground level (gl)	231.75	mAOD	
Response zone depth (BH base)	216.25	mAOD	
BH diameter (standpipe)	0.05	m	
Response zone diameter (gravel pack)	0.15	m	

RWL		21.35	m bgl
Borehole depth (response zone base)	hB	15.5	m bgl
RWL (below BH base)	hf	21.35	m bgl
Constant Head (CH) test WL		9	m bgl
Height of CH test WL above RWL	hA	12.35	m
Height of CH test WL above BH base	h	6.5	m
Response zone radius	r	0.075	m
Injection flow rate	V	0.002	m3/s

BS EN ISO 22282-2:2012
ISO 22282-2:2012(E)



Key
1 ground surface
2 raised water surface
3 unconfined water surface

Figure B.11 — Hydrogeological conditions for a constant head test in unsaturated soils (unconfined groundwater surface below borehole bottom)

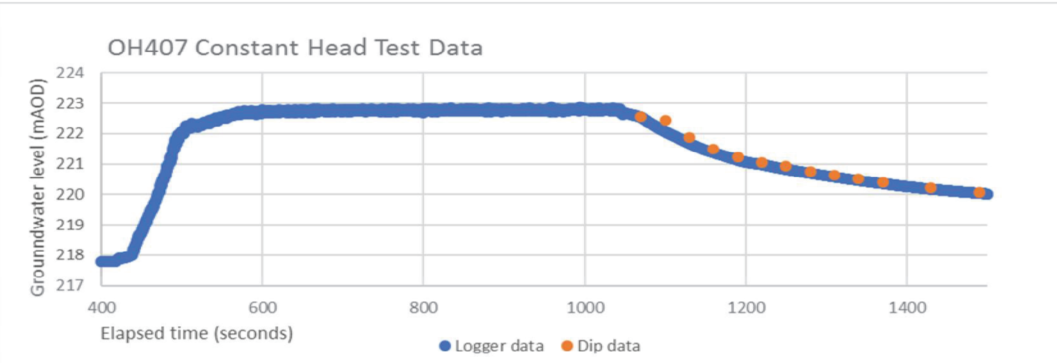
h/r > 10	Yes	h <= hA <= 3h	Yes
hA > 3h	No	hA < h	No

h <= hA <= 3h

$$k_f = 0{,}159 \cdot \frac{\dot{V}}{h^2} \cdot \frac{\ln\left(\frac{h}{r}\right)}{0{,}1667 + \frac{h_A}{3 \cdot h}}$$

ln (h/r) = 4.4621
hA / 3h = 0.6333
V/h^2 = 0.00005

Kf =	**4.20E-05**	**m/s**



Notes: Dip readings could only be taken once injection pipe removed
RWL below datalogger

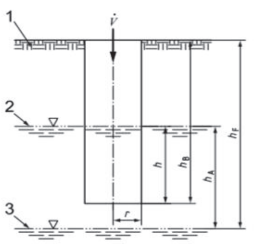
Constant Head test Analysis in Unsaturated Aquifer
BS 22282-2

A417 Missing Link Phase 1 GI
Borehole OH 407

Note: RWL is within sandstone below mudstone unit in Bridport Sand
Assume RWL is at base of Inferior Oolite (top of mudstone unit):

Rest water level (RWL)		216.65	mAOD
Constant head test WL		222.75	mAOD
Ground level (gl)		231.75	mAOD
Response zone depth (BH base)		216.25	mAOD
BH diameter (standpipe)		0.05	m
Response zone diameter (gravel pack)		0.15	m
RWL		15.1	m bgl
Borehole depth (response zone base)	hB	15.5	m bgl
RWL (below BH base)	hf	15.1	m bgl
Constant Head (CH) test WL		9	m bgl
Height of CH test WL above RWL	hA	6.1	m
Height of CH test WL above BH base	h	6.5	m
Response zone radius	r	0.075	m
Injection flow rate	V	0.002	m3/s

BS EN ISO 22282-2:2012
ISO 22282-2:2012(E)



Key
1 ground surface
2 raised water surface
3 unconfined water surface

Figure B.11 — Hydrogeological conditions for a constant head test in unsaturated soils (unconfined groundwater surface below borehole bottom)

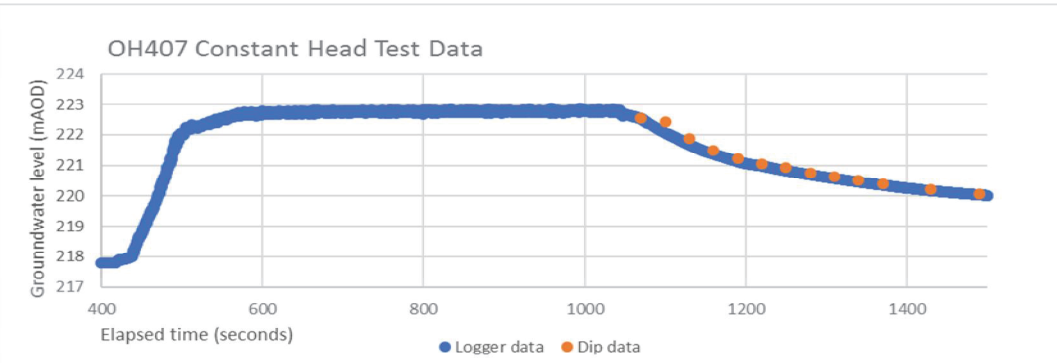
h/r > 10	Yes	h <= hA <= 3h	Yes
hA > 3h	No	hA < h	Yes

h <= hA <= 3h

$$k_f = 0{,}159 \cdot \frac{V}{h^2} \cdot \frac{\ln\left(\frac{h}{r}\right)}{0{,}1667 + \frac{h_A}{3 \cdot h}}$$

ln (h/r) = 4.4621
hA / 3h = 0.3128
V/h^2 = 0.00005

Kf =	**7.00E-05**	**m/s**



Notes: Dip readings could only be taken once injection pipe removed
RWL below datalogger

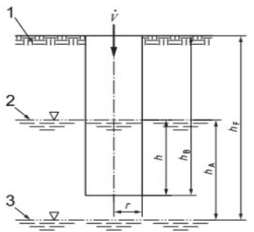
Constant Head test Analysis in Unsaturated Aquifer
BS 22282-2

A417 Missing Link Phase 1 GI
Borehole DS/RC 408

Rest water level (RWL)	210.4	mAOD
Constant head test WL	226.5	mAOD
Ground level (gl)	232.5	mAOD
Response zone depth (BH base)	208.5	mAOD
BH diameter (standpipe)	0.05	m
Response zone diameter (gravel pack)	0.15	m

RWL		22.1	m bgl
Borehole depth (response zone base)	hB	24	m bgl
RWL (below BH base)	hf	22.1	m bgl
Constant Head (CH) test WL		6	m bgl
Height of CH test WL above RWL	hA	16.1	m
Height of CH test WL above BH base	h	18	m
Response zone radius	r	0.075	m
Injection flow rate	V	0.002	m3/s

BS EN ISO 22282-2:2012
ISO 22282-2:2012(E)



Key
1 ground surface
2 raised water surface
3 unconfined water surface

Figure B.11 — Hydrogeological conditions for a constant head test in unsaturated soils (unconfined groundwater surface below borehole bottom)

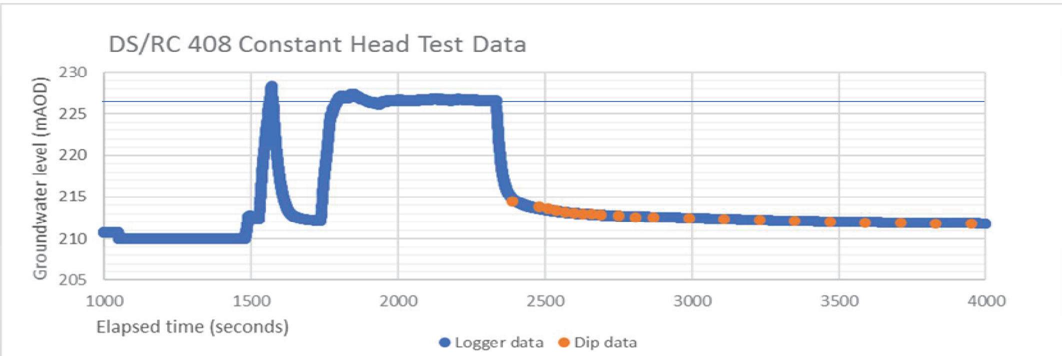
h/r > 10	Yes	h <= hA <= 3h	No
hA > 3h	No	hA < h	Yes

hA < h

$$k_f = 0{,}159 \cdot \frac{V}{h^2} \cdot \frac{\ln\left(\frac{h}{r}\right)}{\frac{h_A}{h} - 0{,}5 \cdot \left(\frac{h_A}{h}\right)^2}$$

ln (h/r) = 5.4806
hA / h = 0.8944
V/h^2 = 0.00001

Kf =	**1.09E-05**	**m/s**



Notes: Dip readings could only be taken once injection pipe removed
Constant head level taken as 226.5 mAOD
RWL below datalogger

DS/RC 415

Calculation of Permeability from Infiltration testing
A417 'Missing Link'

Calculation based on BRE 365 Soakaway Design Guidance (2016):

$$f = \frac{V_{p75-25}}{a_{s50} \times t_{p75-25}}$$

Where:

f	=	Soil infiltration rate (m/s)
V_{p75-25}	=	the effective storage volume of water in the borehole between 75% and 25% effective storage depth
α_{s50}	=	the internal surface area of the borehole up to 50% effective storage depth
t_{p75-25}	=	the time for the water level to fall from 75% to 25% effective storage depth
αs50	=	$(2pi*r_{borehole}*h)/2$
$V_{borehole}$	=	$Pi*(r_{borehole}-r_{standpipe})^2*h*porosity$
$V_{standpipe}$	=	$Pi*r_{standpipe}{}^2*h$
V_{total}	=	$V_{standpipe} + V_{borehole}$
r	=	radius
h	=	head

Borehole Dimensions:

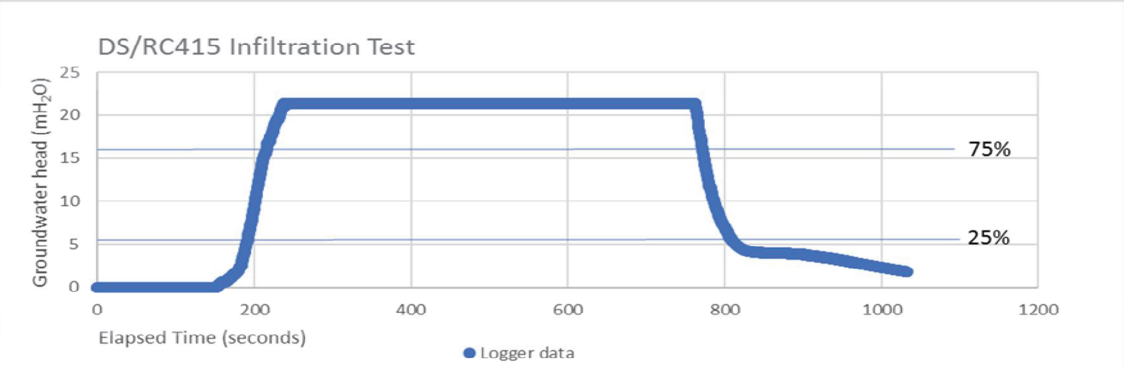
Base of filter	=	50 mbgl
Top of filter	=	25.5 mbgl
Test interval	=	24.5 m
Test section diameter	=	0.15m
Standpipe diameter	=	0.05m
Filter Medium	=	Granular
Rest water level	=	Dry

The following parameters were used in the calculation:

$radius_{borehole}$	=	0.075m
$radius_{standpipe}$	=	0.025m
porosity	=	0.3
$head_{100}$	=	21.37m
$head_{75}$	=	16.0275m
$head_{25}$	=	5.3425m
t_{p75-25}	=	38 seconds

Result:

f = 0.000372



Note: During the infiltration test, the water level exceeded the range of the data logger. The maximum head recorded by the data logger was taken at 100% head value (21.37m).

Calculation of Permeability from Variable Head testing
A417 'Missing Link'

OH 416

Calculation using Hvorslev method, as described in BS 22282-2:

$$k = \frac{r^2 \cdot \ln\left(L/R\right)}{2 \cdot L \cdot t_0}$$

Where:

K	=	permeability coefficient (m/s)
r	=	radius of the measuring tube (m)
R	=	radius of the test section (m)
L	=	length of the test section (m)
t_0	=	the time it takes for the water level to rise or fall to 37 percent of the initial change in head (secs)

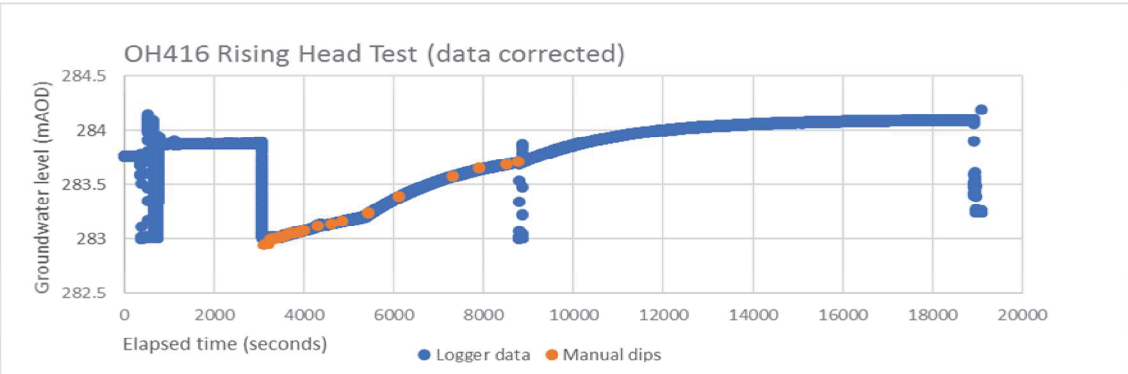
Borehole Dimensions:

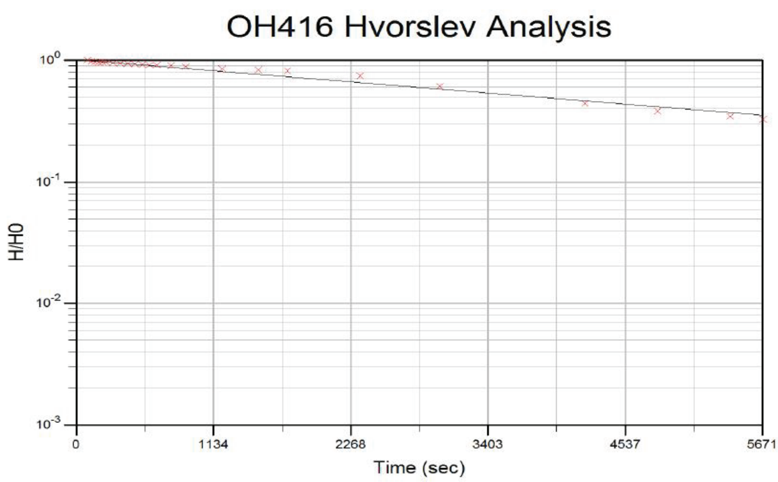
Top of test section	=	3 mbgl
Base of slotted section	=	4.5 mbgl
Test section diameter	=	0.15 m
Standpipe diameter	=	0.05 m
Filter medium	=	Granular
Rest water level	=	284.08 mAOD
Ground level	=	286.85 mAOD

The following parameters were used in the calculation:

L	=	1.5
t_0	=	2800

k_f = 0.00000023





Calculation of Permeability from Variable Head testing
A417 'Missing Link'

DS/RC 419

Calculation using Hvorslev method, as described in BS 22282-2:

$$k = \frac{r^2 \cdot \ln\left(L/R\right)}{2 \cdot L \cdot t_o}$$

Where:

K	=	permeability coefficient (m/s)
r	=	radius of the measuring tube (m)
R	=	radius of the test section (m)
L	=	length of the test section/head in borehole at rest (m)
t_0	=	the time it takes for the water level to rise or fall to 37 percent of the initial change in head (secs)

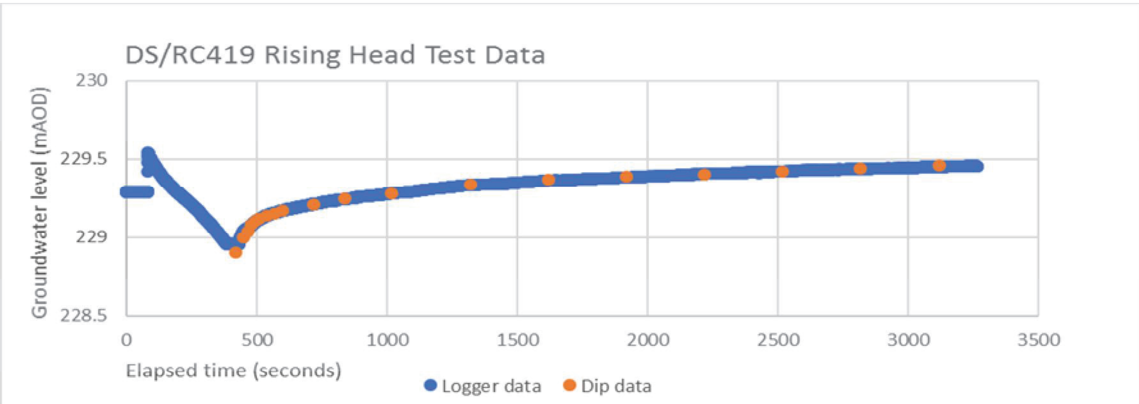
Borehole Dimensions:

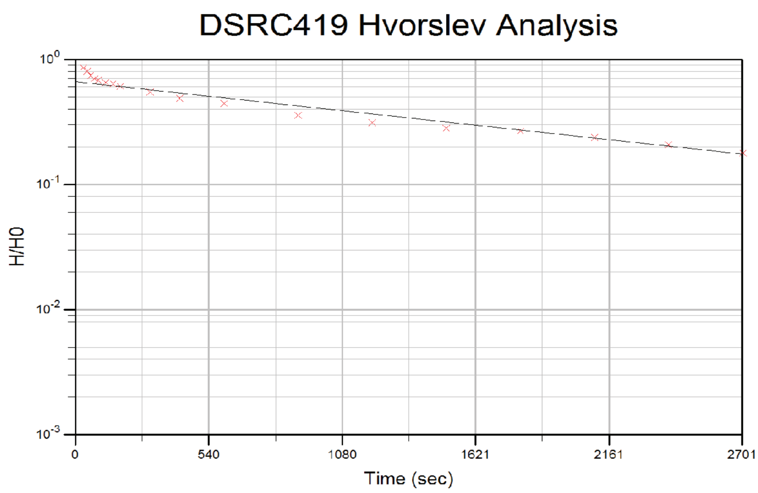
Base of test section	=	41.5 mbgl
Test section diameter	=	0.15 m
Standpipe diameter	=	0.05 m
Filter medium	=	Granular
Rest water level	=	229.58 mAOD
Ground level	=	268.9 mAOD

The following parameters were used in the calculation:

L	=	2.18
t_0	=	150

k_f = 0.0000032





End notes & References

[i] Geotechnical Engineering Ltd (2019). HE551505 A417 Missing Link Ground Investigation, Factual Report on Ground Investigation
[ii] Environment Agency (2013). Severn Corridor Abstraction Licensing Strategy, Reference No. LIT7848, [Online]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/291406/LIT_7848_c0b50e.pdf (Accessed 11/02/2020)
[iii] Environment Agency (2019). Cotswolds Abstraction Licensing Strategy, [Online]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/796112/Cotswolds-Abstraction-Licensing-Strategy.pdf (Accessed 11/02/2020)
[iv] Environment Agency (2013). Severn Vale Abstraction Licensing Strategy, Reference No. LIT3254, [Online]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/291759/LIT_3254_9f2621.pdf (Accessed 11/02/2020)
[v] Environment Agency (2017). Aquifers [Online]. Available at: http://apps.environment-agency.gov.uk/wiyby/117020.aspx (Accessed 11/02/2020)
[vi] Environment Agency (2019). Aquifer Designation Map (Bedrock Geology) [Online]. Available at: https://magic.defra.gov.uk/magicmap.aspx (Accessed 11/02/2020)
[vii] Environment Agency (2019). Aquifer Designation Map (Bedrock Geology). [Online] Available at: https://magic.defra.gov.uk/magicmap.aspx (Accessed 11/02/2020)
[viii] Jones, H K, Morris, B L, Cheney, C S, Brewerton, L J, Merrin, P D, Lewis, M A, MacDonald, A M, Coleby, L M, Talbot, J C, McKenzie, A A, Bird, M J, Cunningham, J, and Robinson, V K (2000). The physical properties of minor aquifers in England and Wales. British Geological Survey Technical Report, WD/00/4. 234pp. Environment Agency RandD Publication 68.
[ix] Environment Agency (2019). Aquifer Designation Map (Bedrock Geology). [Online] Available at: https://magic.defra.gov.uk/magicmap.aspx (Accessed 11/02/2020)
[x] Maurice L., Barron A. J. M., Lewis M. A. and Robins N. S. (2008). The geology and hydrogeology of the Jurassic limestones in the Stroud-Cirencester area with particular reference to the position of the groundwater divide, British Geological Survey Commissioned Report, CR/08/146.
[xi] Environment Agency (2019). Catchment Data Explorer [Online]. Available at: https://environment.data.gov.uk/catchment-planning/ (Accessed 11/02/2020)
[xii] Environment Agency (2019). Catchment Data Explorer [Online]. Available at: https://environment.data.gov.uk/catchment-planning/ (Accessed 11/02/2020)
[xiii] British Geological Survey (2019). Superficial Geology 1:50,000 scale map [Online]. Available at: https://www.bgs.ac.uk/products/digitalmaps/digmapgb_50.html (Accessed 11/02/2020)
[xiv] British Geological Survey (2019). Mass Movement Deposits 1:50,000 scale map [Online]. Available at: https://www.bgs.ac.uk/products/digitalmaps/digmapgb_50.html (Accessed 11/02/2020)
[xv] British Geological Survey (2019). Bedrock Geology 1:50,000 scale map [Online]. Available at: https://www.bgs.ac.uk/products/digitalmaps/digmapgb_50.html (Accessed 11/02/2020)
[xvi] Paul, J.D. (2014). The relationship between spring discharge, drainage and periglacial geomorphology of the Frome valley, central Cotswolds, UK, Proceedings of the Geologists' Association, Vol. 125, pp. 182-194
[xvii] Arup (2019). Crickley Hill Slope Hazard Assessment, Technical Note.
[xviii] British Geological Survey (2019). Bedrock Geology 1:50,000 scale map [Online]. Available at: https://www.bgs.ac.uk/products/digitalmaps/digmapgb_50.html (Accessed 11/02/2020)
[xix] Arup (2019). Crickley Hill Slope Hazard Assessment, Technical Note
[xx] Arup (2019). Crickley Hill Slope Hazard Assessment, Technical Note
[xxi] Arup (2019). Big Cut Geohazard Assessment, Technical Note
[xxii] Self, C.A. and Boycott, A. (2004). Landslip Caves of the Middle Cotswolds, Proceedings of the University of Bristol Spelæological Society, Vol. 23, Issue 2, pp 97-117
[xxiii] Neumann, I, Brown, S., Smedley, P. and Besien, T. (2003). Baseline Report Series: 7. The Great and Inferior Oolite of the Cotswolds District, British Geological Survey Commissioned Report No. CR/03/202c
[xxiv] Jones, H.K., Morris, B.L., Cheney, C.S., Brewerton, L.J., Merrin, P.D., Lewis, M.A., MacDonald, A.M., Coleby, L.M., Talbot, J.C., McKenzie, A.A., Bird, M.J., Cunningham, J. and Robinson, V.K. (2000). The physical properties of minor aquifers in England and Wales. British Geological Survey Technical Report, WD/00/4. 234pp. Environment Agency RandD Publication 68.
[xxv] Environment Agency (2017). Nitrate Vulnerable Zones (NVZ) 2017 – Combined (Final Designations), [Online] Available at: https://magic.defra.gov.uk/magicmap.aspx (Accessed 11/02/2020)

[xxvi] Environment Agency (2017). Nitrate Vulnerable Zones (NVZ) 2017 – Combined (Final Designations), [Online] Available at: https://magic.defra.gov.uk/magicmap.aspx (Accessed 11/02/2020)
[xxvii]Environment Agency (2017). Nitrate Vulnerable Zones (NVZ) 2017 – Combined (Final Designations), [Online] Available at: https://magic.defra.gov.uk/magicmap.aspx (Accessed 11/02/2020)
[xxviii] Morgan-Jones, J. and Eggboro, M.D., 1981, The hydrogeochemistry of the Jurassic limestones in Gloucestershire, England, Quaterly Journal of Engineering Geology, Vol. 14, pp. 25-39
[xxix] Neumann, I., Brown, S., Smedley, P. and Besien, T (2003). Baseline Report Series: 7. The Great and Inferior Oolite of the Cotswolds District, British Geological Survey Commissioned Report No. CR/03/202c
[xxx] Neumann, I., Brown, S., Smedley, P. and Besien, T (2003). Baseline Report Series: 7. The Great and Inferior Oolite of the Cotswolds District, British Geological Survey Commissioned Report No. CR/03/202c
[xxxi] Neumann, I., Brown, S., Smedley, P. and Besien, T (2003). Baseline Report Series: 7. The Great and Inferior Oolite of the Cotswolds District, British Geological Survey Commissioned Report No. CR/03/202c
[xxxii] Environment Agency (2019). Catchment Data Explorer [Online]. Available at: https://environment.data.gov.uk/catchment-planning/ (Accessed 11/02/2020)
[xxxiii] Neumann, I., Brown, S., Smedley, P. and Besien, T (2003). Baseline Report Series: 7. The Great and Inferior Oolite of the Cotswolds District, British Geological Survey Commissioned Report No. CR/03/202c
[xxxiv] Neumann, I., Brown, S., Smedley, P. and Besien, T (2003). Baseline Report Series: 7. The Great and Inferior Oolite of the Cotswolds District, British Geological Survey Commissioned Report No. CR/03/202c
[xxxv] Neumann, I., Brown, S., Smedley, P. and Besien, T (2003). Baseline Report Series: 7. The Great and Inferior Oolite of the Cotswolds District, British Geological Survey Commissioned Report No. CR/03/202c
[xxxvi] Rushton, K.R., Owen, M., Tomlinson, L.M. (1992). The water resources of the Great Oolite aquifer in the Thames Basin, UK, Journal of Hydrology, Vol. 132, pp. 225-248
[xxxvii] Morgan-Jones, J. and Eggboro, M.D. (1981). The hydrogeochemistry of the Jurassic limestones in Gloucestershire, England, Quarterly Journal of Engineering Geology, Vol. 14, pp. 25-39
[xxxviii] Maurice L., Barron A. J. M., Lewis M. A. and Robins N. S. (2008). The geology and hydrogeology of the Jurassic limestones in the Stroud-Cirencester area with particular reference to the position of the groundwater divide, British Geological Survey Commissioned Report, CR/08/146.
[xxxix] Mott Macdonald Sweco Joint Venture (2019). Water features survey, Report reference not available
[xl] Environment Agency (2019). Consented Discharges to Controlled Waters with Conditions [Online]. Available at: https://data.gov.uk/dataset/b3df52da-3e27-4343-9ec3-e630a9cbb52c/consented-discharges-to-controlled-waters-with-conditions (Accessed 11/02/2020)
[xli] Environment Agency (2015). Part 1: Severn River Basin District River Basin Management Plan, policy paper
[xlii] Environment Agency (2015). Part 1: Thames River Basin District River Basin Management Plan, policy paper
[xliii] Arup (2019), Ground Investigation Specification Addendum, A417 Missing Link, Highways England, December 2019
[xliv] Maurice L., Barron A.J.M., Lewis M.A. and Robins N.S. (2008). The geology and hydrogeology of the Jurassic limestones in the Stroud-Cirencester area with particular reference to the position of the groundwater divide, British Geological Survey Commissioned Report, CR/08/146.
[xlv] Mott MacDonald Sweco Joint Venture (2019). Preliminary Groundwater Report, Doc No. HE551505-MMSJV-HGT-000-RP-CE-00004
[xlvi] Mott MacDonald Sweco Joint Venture (2019). Preliminary Groundwater Report, Doc No. HE551505-MMSJV-HGT-000-RP-CE-00004