national highways

Lower Thames Crossing

6.3 Environmental Statement Appendices
6.3 Appendix 14.5 – Hydrogeological Risk Assessment (Part 1 of 2)

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Lower Thames Crossing

6.3 Environmental Statement Appendices Appendix 14.5 – Hydrogeological Risk Assessment

(Part 1 of 2)

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1 Introduction

1.1 Overview

1.1.1 This report presents the hydrogeological risk assessment of the A122 Lower Thames Crossing (the Project). The Project would provide a connection between the A2 and M2 in Kent, south-east of Gravesend, crossing under the River Thames through a tunnel, before joining the M25 south of junction 29.

1.2 Scope of assessment

1.2.1 This report comprises a description of the existing status of groundwater and an assessment of the impacts of the Project on groundwater quality, groundwater resources and physical characteristics of the groundwater bodies. These studies reflect the requirements of the National Policy Statement for National Networks (NPSNN) (Department for Transport, 2014) and the National Policy Statement for Energy (EN-1) (Department for Energy and Climate Change, 2011a), National Policy Statement for Gas Supply Infrastructure and Gas and Oil Pipelines (EN-4) (Department for Energy and Climate Change, 2011b) and National Policy Statement for Electricity Networks Infrastructure (EN-5) (Department for Energy and Climate Change, 2011c). However, the NPSNN forms the 'case-making' basis of the Project, and the need for nationally significant utility diversions arises solely from the need for the road element of the Project. These national policy statements form the basis of the groundwater assessment presented in the Environmental Statement Chapter 14 (Application Document 6.1). Other NPS requirements include the assessment of impacts of the Project on water bodies or protected areas under the Water Framework Directive (WFD) and source protection zones (SPZs) around potable groundwater abstractions. Further information on the NPSNN (Department for Transport, 2014), EN-1, EN-4 and EN-5 requirements and how they have been addressed are described in Chapter 14: Road Drainage and the Water Environment (Application Document 6.1).

1.2.2 The scope of this report addresses the above requirements by assessing groundwater levels and flows, groundwater quality and Groundwater Dependent Terrestrial Ecosystems (GWDTEs) as set out in the Design Manual for Roads and Bridges (DMRB) LA 113 Road Drainage and the Water Environment (Highways England, 2020a). The groundwater quality assessment covers the characterisation of regional groundwater quality, the risk of pollution caused by highway routine runoff and accidental spillage, and the potential for saline intrusion. Chapter 10: Geology and Soils (Application Document 6.1) considers the mobilisation of pre-existing contaminants from contaminated land within the Order Limits on water environment receptors.

1.2.3 This report considers the potential impact of the construction and operation of the Project. This includes the following design elements:

a. South Portal

b. The ground protection tunnel

c. The main tunnel crossing of the Thames (with cross passages)

d. North Portal

e. A13 A1089/A122 Lower Thames Crossing junction

f. A122 Lower Thames Crossing/M25 junction

g. Highway drainage infiltration basins

h. Nitrogen deposition habitat compensation areas

1.2.4 The above design elements have been assessed within this report by a simple assessment and, where necessary, a detailed assessment approach as described in DMRB LA 113 Road Drainage and the Water Environment (Highways England, 2020a). For individual design elements, if a simple assessment identifies a likely significant adverse effect on the water environment, and mitigation is not incorporated, or is not available, to prevent the adverse effect, a detailed assessment is required by DMRB LA 113. This approach has been used for the above design elements. However, professional judgement was also applied to ensure that detailed assessments were conducted for the main tunnels and associated portals which would be of internationally substantial engineering complexity as well as there being very high value, local, water environment receptors. Detailed assessment of potential impacts caused by the South Portal, the ground protection tunnel and main tunnels has been conducted using a comprehensive numerical groundwater model for south of the River Thames and is detailed in Annex J. Detailed assessment of potential impacts caused by the North Portal has been conducted using an additional numerical groundwater model for north of the River Thames and is presented in Annex K. Further, a third numerical model has been developed for detailed assessment of the proposed cutting at the A122 Lower Thames Crossing/M25 junction.

1.2.5 Nitrogen deposition habitat compensation areas are proposed as described in ES Chapter 2: Project Description (Application Document 6.1). The assessment presented in this document is based on the desk study presented in Appendix 10.6: Annex D (Application Document 6.3) which includes an appraisal of the geology and hydrogeology. This assessment approach is appropriate as only woodland and/or grassland planting is proposed at each site. Planting would not be deeper than the depth of deep ploughing and therefore would be above groundwater, and the Project's embedded mitigation includes commitments to protect groundwater quality at Nitrogen deposition compensation habitat areas. Mitigation is described in clause number LSP.27 of the Design Principles (Application Document 7.5).

1.2.6 Construction phase water supply to the tunnel boring machinery (TBM) is discussed in Chapter 14: Road Drainage and the Water Environment (Application Document 6.1).

1.2.7 The water to supply the TBM may be provided by groundwater abstracted from the existing Northumbrian Water Limited Linford public water supply well. The well has not been connected to distribution since 2011, although is still pumped for aquifer management of local artesian groundwater levels. Northumbrian Water Limited would abstract water within the limits of the current licence in order to supply the TBM. Further information is shown in the Register of

Environmental Actions and Commitment (REAC), RDWE003, detailed in the Code of Construction Practice (CoCP) (Application Document 6.3). To take a precautionary approach, the abstraction of groundwater to supply the TBM through the Linford public water supply was reflected in the modelled scenario presented for the North Portal. Further details are shown in Section 7.4.

1.2.8 Potential impacts on the following groups of groundwater receptors have been considered:

a. WFD groundwater bodies

b. Principal and secondary aquifers

c. Public water supply groundwater abstractions

d. Other groundwater abstractions (industrial, commercial and domestic)

e. Springs

f. Surface water that may be partly dependent on groundwater (such as if receiving baseflow)

g. GWDTEs

h. Other wetlands

i. Groundwater flooding susceptible areas

1.3 Study area and key features

1.3.1 The hydrogeological risk assessment study area comprises the area within the Order Limits plus a distance, or buffer, of 3km beyond the Order Limits, as set out in the Scoping Report (Highways England, 2017). Larger study areas have been used for numerical groundwater models to minimise model boundary effects, reflect the complexities associated with the construction works proposed in these areas and to cover a reasonable worst case in terms of zone of influence. Explanations are shown for the relevant detailed studies presented in Annex J, Annex K and Annex L. Key potential groundwater-related receptors are presented in Figures 14.2, 14.3, 14.4 and 14.6 (Application Document 6.2), which support Chapter 14: Road Drainage and the Water Environment. These are noted as:

a. The Chalk aquifer (principal aquifer)

b. River Terrace Deposits Secondary A aquifers, which form the Essex Gravels

c. The Lower London Tertiaries Secondary A aquifers (Thanet Formation and the Lambeth Group)

d. Public supply wells on the North Downs (south of the River Thames) and Linford public supply well (north of the River Thames), all with published SPZs

e. Private licensed potable groundwater abstractions wells with a default 50m source protection zone one (SPZ1)

f. South Thames Estuary and Marshes Site of Special Scientific Interest (SSSI), Shorne Marshes Royal Society for the Protection of Birds (RSPB) Reserve and the Thames Estuary and Marshes Ramsar site

g. Other statutory and non-statutory wetlands or marsh, such as sites of interest for nature conservation (SINCs) and local nature reserves (LNRs) near the new junction with the M25 between junctions 29 and 30

h. Springs in the North Ockendon area

1.3.2 Surface water bodies are assessed in Chapter 14: Road Drainage and the Water Environment (Application Document 6.1). In addition, biodiversity attributes are assessed in Chapter 8: Terrestrial Biodiversity (Application Document 6.1) and attributes linked to recreation are addressed in Chapter 13: Population and Human Health (Application Document 6.1).

1.4 Proposed development

1.4.1 The Project would provide a connection between the A2 and M2 in Kent, south-east of Gravesend, crossing under the River Thames through a tunnel, before joining the M25 south of junction 29. The Project route is presented in Plate 1.1.

1.4.2 The A122 road would be approximately 23km long, 4.25km of which would be in tunnel. On the south side of the River Thames, the Project route would link the tunnel to the A2 and M2. On the north side, it would link to the A13 and junction 29 of the M25. The tunnel entrances (portals) would be located to the east of the village of Chalk on the south of the River Thames and to the west of East Tilbury on the north side.

1.4.3 Junctions are proposed at the following locations:

a. New junction with the A2 to the south-east of Gravesend

b. Modified junction with the A13/A1089 in Thurrock

c. New junction with the M25 between junctions 29 and 30

1.4.4 The Project road would be three lanes in both directions, except for:

a. link roads

b. stretches of the carriageway through junctions

c. the southbound carriageway from the M25 to the junction with the A13/A1089, which would be two lanes

1.4.5 In common with other A-roads, the A122 would operate with no hard shoulder but would feature a 1m hard strip on either side of the carriageway. It would also feature technology including stopped vehicle and incident detection, lane control, variable speed limits and electronic signage and signalling. The A122 road design outside of the tunnel includes emergency areas spaced at intervals between 800 metres and 1.6km (less than one mile). The tunnel would include a range of enhanced systems and response measures instead of emergency areas.

1.4.6 The Project road would be an all-purpose trunk road, with green signs. For the benefit of safety, walkers, cyclists, horse riders and slow-moving vehicles would be prohibited from using it.

1.4.7 The Project would include adjustment to a number of side roads. There would also be changes to a number of public rights of way, used by walkers, cyclists and horse riders. Construction of the Project would also require the installation and diversion of a number of utilities, including gas pipelines, overhead power lines and underground electricity cables, as well as water supplies and telecommunications assets and associated infrastructure.

Plate 1.1 Lower Thames Crossing route

Highway drainage

1.4.8 A summary of the proposed highway drainage attenuation and treatment measures is presented in Chapter 14 (Application Document 6.1). Details are presented in Part 7: Surface Water Drainage of the Flood Risk Assessment (Appendix 14.6, Application Document 6.3).

1.4.9 A summary of the schedule of water quality treatment systems per infiltration basin is provided in Annex A of this report. These are preliminary design proposals and are subject to confirmation at detailed design stage. Key features of interest are that, south of the River Thames, drainage systems would discharge to the ground via infiltration basins. North of the river, drainage systems would generally discharge to surface watercourses via retention ponds and detention basins. However, one infiltration basin is proposed at the A13/A1089/A122 Lower Thames Crossing junction where, due to its proximity to a receiving watercourse, it was not possible to discharge to a surface watercourse. Small swales are also proposed north of the River Thames and are described in Annex O.

1.4.10 Water quality of highway runoff is improved prior to discharge by means of separate lined sediment forebay or pollution control device such as a vortex grit separator (or other appropriate pollution control device) located upstream of the infiltration basins and attenuation ponds or basins. In addition, a method of protecting receptors from the discharge of accidental spillages is required at the upstream end of all infiltration basins according to DMRB CD 532 (National Highways, 2021), regardless of the outcome of the Highways England Water Risk Assessment Tool (HEWRAT; National Highways was formerly known as Highways England) accidental spillage risk assessments. Penstock chambers, or other appropriate flow control device, are therefore provided as emergency shut-off facilities and Annex A confirms that they are proposed at all the infiltration basins. Sediment forebays, where present, would be used for containing spillages (when the penstock is closed during an incident) and therefore would be lined to prevent escape of contaminants, in line with REAC reference RDWE034 detailed in the CoCP (Application Document 6.3).

Utilities

1.4.11 A summary of the proposed utilities works is presented in Chapter 2: Project Description (Application Document 6.1). Further description is also presented in Appendix 2.1 (Application Document 6.3). The above information should be read in conjunction with Schedule 1 (Authorised Development) of the draft Development Consent Order (Application Document 3.1) and Works Plans (Application Document reference TR010032/APP/2.6).

1.4.12 An assessment of underground utility networks that have the potential to impact groundwater is presented in Section 6.12, Section 7.8 and Annex Q.

1.5 Data sources

1.5.1 Information about the baseline groundwater environment has been obtained from the following sources:

a. Environment Agency records of groundwater levels, abstraction licences, discharge consents and open-source mapping of identified GWDTEs

b. The Project field data gathered through Phase 1 and Phase 2 ground investigation (GI) and selected Phase 3 GI data from the A122/M25 junction area (Section 1.8)

c. The Project ecology survey data, used for assessment of groundwater dependency of vegetation habitats at selected sites

1.6 Stakeholder engagement

1.6.1 Meetings and liaison with statutory environmental bodies have been carried out as part of the hydrogeological risk assessment in order to regularly notify them and to clarify any key concerns. A detailed list is provided in Chapter 14: Road Drainage and the Water Environment (Application Document 6.1). Key stakeholders are the Environment Agency, Natural England and landowners.

1.6.2 The details of the liaison with the Environment Agency are included in the Statement of Common Ground between (1) National Highways and (2) the Environment Agency (Application Document TR010032/APP/5.4.1.1)

1.7 Water features survey

1.7.1 The Water Features Survey Factual Report is presented in Appendix 14.2 (Application Document 6.3). The aim of the water features survey was to identify the presence, usage and existing characteristics of surface and groundwater resources, based on desk study and site surveys. Full details of Environment Agency licensed groundwater abstractions and permits for discharge to ground are presented in the Water Features Survey Factual Report. Details of surface water features and surface water quality monitoring results at the South Thames Estuary and Marshes SSSI and the Thames Estuary and Marshes Ramsar site, south of the River Thames, are also included in the factual report. Additionally, records are also presented of observations of Manor Farm and its surrounds in North Ockendon, including observations and flow conditions in the ponds and ditch network, together with a photographic record.

1.8 Ground investigation

1.8.1 A programme of intrusive GI works was carried out in three phases to inform the preliminary design and, where data has been available, support the core assessments of the Development Consent Order (DCO) application. Phase 1 GI, completed between September 2017 and February 2018, and between September 2018 and January 2019, was focused on the alignment of the main tunnel crossing and the areas surrounding the proposed North and South Portals.

1.8.2 Phase 2 of the GI was carried out between April 2019 and June 2020. It included investigations along the Project route, as well as further works in the North and South Portal areas (additional boreholes and a pumping test at the North Portal). The Phase 2 GI areas comprised:

a. Package A – south of the River Thames.

b. Package B – area immediately to the north of the River Thames.

c. Package C – Tilbury Loop railway line, northwards to the A13 in Orsett Heath.

d. Package D – A13 to the M25, north of junction 29 in Great Warley.

e. Package E – the area of the route under the Gravesend Reach of the River Thames, between Tilbury and Gravesend. The Project route would be entirely in tunnel in this section.

1.8.3 Phase 3 of the GI was carried out between May 2020 and January 2021. The main purpose of the GI was to obtain further geotechnical information along the Project route, and to deliver one additional pumping test at the North Portal.

1.8.4 To provide a robust understanding of the groundwater environment at the A122 Lower Thames Crossing/M25 junction, the Phase 2 GI data was supplemented with additional Phase 3 GI data, including supplementary exploratory holes and groundwater monitoring standpipes that were used to develop the detailed groundwater models and assessment of the A122 Lower Thames Crossing/M25 junction (Section 6.8).

1.8.5 Overall, the GI included borehole drilling, *in situ* hydraulic testing and groundwater level and quality monitoring. Constant-rate pumping tests were conducted in the Chalk aquifer near the South Portal (30-day duration) and within the boundary of the Thames Estuary and Marshes Ramsar site (five-day duration).

1.8.6 While data from the pumping tests was not used to further develop the North Portal groundwater model, the data was used to verify key modelling assumptions.

1.8.7 GI works will continue to progress beyond the submission of the DCO application. The data obtained will be used to refine the detailed design of the groundwater mitigation measures. However, due to the precautionary approach taken within this assessment and the supporting groundwater models it is not anticipated that new GI data will change the overall conclusions of this study.

2 Baseline information

2.1 Topography and land use

2.1.1 A description of the landform in relation to the general topography and geology is presented in Chapter 10: Geology and Soils (Application Document 6.1). Information on historical and current land uses is also included in Appendix 10.6 (Application Document 6.3). Landscape description is provided in Chapter 7: Landscape and Visual (Application Document 6.1). The key points are as follows:

a. South of the River Thames, the chalk hills feature dry valleys. These valleys cross the Project at the M2 junction 1, the proposed M2/A2/Lower Thames Crossing junction and the proposed Gravesend link.

b. North of the River Thames, historical and smaller operational landfill and land raise areas are located on the Tilbury Marshes. A description and further details of these features are presented in Chapter 10: Geology and Soils (Application Document 6.1).

c. The area crossed by the Chadwell St Mary link is of low relief with shallow valley features, including Gobions Sewer watercourse and River Terrace Deposit-related higher ground.

d. The proposed A13/A1089/A122 Lower Thames Crossing junction would be located on a broad higher ground area that has an absence of surface water features.

e. North of the proposed A13/A1089/A122 Lower Thames Crossing junction, the ground falls gently to the north and towards the low-lying Mardyke valley feature.

f. Near the proposed A122 Lower Thames Crossing/M25 junction, historical gravel pit extraction, flooding of pits and landfilling have locally modified the landform.

2.2 Meteorology

2.2.1 In Kent, the wettest areas are on the hills of the North Downs as these elevated areas push prevailing south-westerly winds higher and cause relief rainfall (British Geological Survey (BGS), 2007). The North Kent coast sits in a relative rain shadow and has less rainfall (Environment Agency, 2012). Long-term average hydrologically effective rainfall, for a 5km square centred on Shorne and Higham Marshes, is 150mm per year, with the Q25 to Q75 being 73mm and 221mm respectively, calculated from the Meteorological Office Rainfall and Evaporation Calculation System (MORECS) data purchased from the Met Office (Met Office, 2020). These data are discussed in the Project water balance study presented in Annex E.

2.2.2 The South Essex groundwater resource unit is located in one of the driest parts of the UK, with a long-term annual rainfall of 556mm per year (1970 to 2008).

The assessed long-term average hydrologically effective rainfall is 158mm per year for the same period (Amec Foster Wheeler, 2016).

2.3 Surface water features

2.3.1 Details of main rivers and ordinary watercourses are described in Chapter 14: Road Drainage and the Water Environment (Application Document 6.1).

2.3.2 A summary of surface features is presented below, since some may interact with groundwater or be partly groundwater fed.

2.3.3 In summary, the main rivers that the Project would cross, from south to north, are:

a. Denton New Cut (Shorne Marshes)

b. River Thames (tidal estuary within the hydrogeological risk assessment study area)

c. Tilbury Main

d. Gobions Sewer

e. Mardyke and tributaries (Mardyke West, Orsett Fen Sewer and Golden Bridge Sewer)

2.3.4 In addition, the north-eastern extremity of the River Ingrebourne catchment is within the Order Limits.

2.3.5 Key ordinary watercourses or surface water bodies that the Project would cross or be near are:

a. Shorne Wood Country Park ponds (including New Fish Pond and two other ponds, all next to Inn on the Lake) and ditches

b. Cobham Hall ponds

c. Ordinary watercourses (ditches) in the Ramsar site (described in Section 2.4)

d. Ordinary watercourses (ditches) in Tilbury Marsh

e. The irrigation reservoir at Low Street

f. Gobions Sewer (ordinary watercourse section)

g. Ordinary watercourses and ponds associated with reported spring flow and groundwater collection drainage in the North Ockendon area

h. Recreational lakes at Stubbers Adventure Centre (those that are not lined and therefore may receive groundwater baseflow)

i. The irrigation reservoir at Manor Farm, North Ockendon (lined and therefore not expected to receive groundwater)

j. Ordinary watercourses (water-filled ditches) in the Cranham Marsh area

k. Ordinary watercourse and ponds in the Thames Chase Forest Centre area

2.3.6 Watercourses or surface water bodies that have an impermeable or low permeability base and sides have a barrier to groundwater inflow (or, conversely, seepage to ground). The barrier may be natural, such as clayey soils or man-made, such as a concrete culvert or an engineered clay liner. Some ponds at North Ockendon are described as lined (Section 3.6) and the majority of lakes at Stubbers Adventure Centre, with the exception of the Canoe Pond, are also described as lined. Therefore, these lined water bodies would not be expected to be directly affected by any changes to groundwater.

2.4 Designated ecosystems

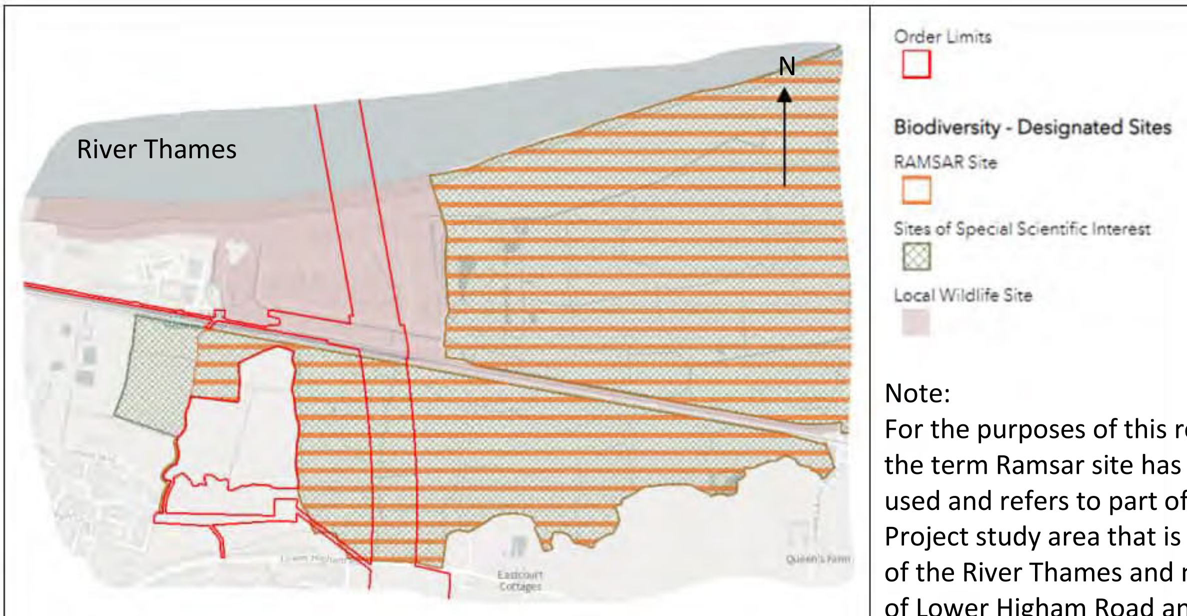
2.4.1 The details of ecosystems are described in Chapter 8: Terrestrial Biodiversity (Application Document 6.1). Water-related features of interest within the study area are presented in Table 2.1. Ingrebourne Marshes, which is at the edge of the study area, is the nearest published GWDTE (Section 3.9). The locations of the features are shown in Figure 8.1 (Application Document 6.2), with the exception of Ingrebourne Marshes SSSI which is shown in Figure 14.2 (Application Document 6.2).

Table 2.1 Environmental designations summary

Location	Environmental designation
Thames Estuary and Marshes Ramsar site (south of the River Thames)	Ramsar site
South Thames Estuary and Marshes SSSI	SSSI
Shorne Marshes	RSPB reserve (non-statutory but within the SSSI and Ramsar site)
Thames Estuary and Marshes Ramsar site (north of the River Thames)	Ramsar site
Mucking Flats and Marshes SSSI	SSSI
Cranham Marsh Local Nature Reserve (LNR)	LNR
Ingrebourne Marshes SSSI	SSSI
Hall Farm moat, paddock and St Mary Magdalene Churchyard Site of Importance for Nature Conservation (SINC) (HvBII25), fields south of Cranham Marsh SINC (HvBI03), North Ockendon Pit SINC (HvBII38), Puddle Dock Angling Centre SINC (HvBII09), Franks Wood and Cranham Brickfields SINC (HvBI02), Thames Chase Forest Centre SINC, Tomkyns East Pastures SINC (HvBI07), Carter's Brook and Paine's Brook SINC (HvBII18)	SINC

2.4.2 South of the River Thames, there is overlap of the South Thames Estuary and Marshes SSSI, Shorne Marshes RSPB Reserve and the Thames Estuary and Marshes Ramsar site. For the purposes of this report, the term Ramsar site has been used and refers to part of the Project study area that is south of the River Thames and north of Lower Higham Road (Plate 2.1). Further, the term Ramsar site describes those parts of the statutory sites that are local to the Order Limits and principally within Filborough Marshes. Where specific statutory sites or different parts of the marshes are discussed separately, then full names have been used.

Plate 2.1 Location of the 'Ramsar site'



Note:
For the purposes of this report, the term Ramsar site has been used and refers to part of the Project study area that is south of the River Thames and north of Lower Higham Road and within the designated sites shown in this plate.

2.5 Climate change

2.5.1 Climate change may cause changes to future baseline groundwater levels and flows and groundwater quality in the UK. There are no UK Government published climate change allowances for groundwater. The Environment Agency have produced a report card which summarises potential climate change impacts for water-related topics (Watts and Anderson, 2016). The report card is supported by various working technical papers, including one on changes to groundwater levels in the UK over the 21st century (Jackson *et al.*, 2013) and another assessing historical trends of groundwater levels and groundwater quality from the 20th century (Bloomfield *et al.*, 2013). The report card shows a confidence level, of high medium or low, for each of the statements of change. A confidence level reflects the degree of agreement of scientific studies and the amount of information available.

2.5.2 Historical studies show that there is no evidence of a link between groundwater levels and climate change (medium confidence level that there are no trends). This is partly because the climate change signal so far is small compared to other influences on groundwater, such as land-use change and abstraction (Watts and Anderson, 2016).

2.5.3 There is low confidence about how groundwater levels will change due to climate change. There is overall low confidence about changes to mean annual recharge in the UK. There is mostly agreement that the length of the recharge season is likely to shorten in Chalk catchments of southern England (see studies reviewed by Jackson *et al.,* (2013)). On average, the results suggested that seasonality will be enhanced with more potential recharge occurring during the winter but for a shorter period (Jackson *et al.*, 2013). This may mean an increased vulnerability to drought (BGS, 2019a).

2.5.4 Herrera-Pantoja and Hiscock (2008) investigated the most extreme consequences of a changing climate on recharge over the Chalk aquifers of southern England. The study, using a high emissions scenario, predicts precipitation would increase during the wet season (October to March) and decrease during the dry season (April to September). The magnitude of these changes increased between 2011 and 2100 resulting in a net reduction of potential recharge by 15%, 23% and 39% in the early, mid and late 21st century, respectively. Jackson *et al*. (2011) assessed the Chalk aquifer of the Marlborough and Berkshire Downs and predicted annual potential groundwater recharge changes ranging from a 26% decrease to a 31% increase by the 2080s, with most predicting a decrease. These detailed studies give varied results but support the statement in the above paragraph that, on average, seasonality will be enhanced with more potential recharge occurring during the winter but for a shorter period (Jackson *et al.*, 2013). Impacts of climate change on groundwater flooding have not been assessed in Watts & Anderson (2016) or supporting working papers.

2.5.5 Water demand may change due to climate change. Water demand for agriculture is expected to increase with temperature, as crops may need more irrigation to counteract warmer, drier periods (medium confidence in the direction of change but low confidence in scale of change) (Watts and Anderson, 2016). Demand for public water supply may increase with temperature. The main changes are expected to be for increased outdoor use, such as garden watering, and perhaps an increased frequency of showering (medium confidence in the direction of change and low confidence in rate or magnitude) (Watts and Anderson, 2016). Regionally increased population growth could also increase public water supply demand. Water demand may be met by a variety of sources, including groundwater. However, increase of groundwater abstraction could be limited because there are already licensing restrictions (Section 3.7). Careful catchment abstraction management would be important to avoid over abstraction of groundwater and consequential reduction of groundwater levels.

2.5.6 There are no clear trends of historical groundwater quality change caused by climate change. Other influences, such as intensification of agriculture, are more dominant. Overall, there is low confidence in the science (Bloomfield *et al.*, 2013). Stuart *et al*. (2011) suggests that climate change could increase leaching of nitrate from soils. However, Nitrate Vulnerable Zone (Section 4.3) control measures would be expected to alleviate potential increases. There is evidence for an historical rise in groundwater temperature of 0.0102°C/year to 0.023°C/year (medium level of confidence) in the UK (Bloomfield *et al.*, 2013). Bloomfield *et al*. (2013) suggest that long-term impacts of increasing groundwater temperature could indirectly impact GWDTEs, and other groundwater-fed water bodies. For example, an elevated temperature typically decreases the dissolved oxygen in water while leading to rises in the rate of photosynthesis by algae and aquatic plants. However, the historical rate of change is small and if used to extrapolate future change would give an increase of between 1.5 and 2.5°C after 150 years. This range is small compared with seasonal changes of surface water temperature.

2.5.7 Sea-level rise is expected to impact coastal and estuarine areas regionally, leading to increased groundwater salinities. The Flood Risk Assessment (Appendix 14.6, Part 6 in Application Document 6.3) presents the upper end Project allowances for sea-level rise at Southend, relative to 2017, of 90mm in 2030 and 1574mm in 2130. The dates are the anticipated opening data for the Project in 2030 and 100 years later. Potential relative changes to adjacent groundwater levels are discussed in the groundwater levels and flows impact assessment (Section 6). Future saline intrusion changes due to climate change are discussed in Section 7.

2.5.8 The potential for increased peak rainfall intensity due to climate change has been incorporated into the detailed assessments of the proposed infiltration basins. For the assessment of infiltration basins, groundwater modelling has evaluated the potential for groundwater flooding due to mounding caused by the infiltration basins. Included is a worst-case drainage infiltration from a 1 in 100-year storm (24 hours infiltration) associated with a 20% increase in peak rainfall intensity due to climate change and a further sensitivity test carried out with a 40% increase in peak rainfall intensity due to climate change (Annex M and Annex N). Peak rainfall intensity would normally be calculated in accordance with the Environment Agency’s guidance on climate change for flood risk assessments (Environment Agency, 2022a). When the drainage design for the Project was undertaken the guidance stipulated that to accommodate climate change, a 20% uplift was to be applied to peak rainfall intensity and that a sensitivity test for a 40% uplift was to be undertaken. However, since the design was undertaken, the guidance has been updated with higher uplifts on peak rainfall intensity. As the revised guidance was published after the drainage design was undertaken, the Environment Agency verbally agreed at a meeting held on 4 May 2022 that a 5% departure on peak rainfall intensities was acceptable[1]. With this departure taken into account, the 20% and 40% uplift on peak rainfall intensity are deemed to be accepted for drainage design.

2.5.9 Based on the information presented above and groundwater level information summarised in Annex C (groundwater level summary of the whole site) and Annex D (groundwater level summary of the Ramsar site), climate change effects on groundwater levels during the Project construction phase, would be a small signal relative to seasonal variation and, where relevant, tidal variation. Therefore, all construction phase modelling was calibrated against maximum recorded groundwater levels and the reports were approved by the Environment Agency.

[1] The departure on peak rainfall intensity is recorded in a Statement of Common Ground between National Highways and the Environment Agency (see Application Document 5.4).

2.5.10 In addition, the detailed assessments describe important operational phase circumstances, relevant to climate change. Annex J describes deep structures that would be above the water table at the South Portal and a specified low leakage rate into the main tunnel beneath the Ramsar site that is parallel to groundwater flow and is in aquifers that are covered by clayey Alluvium that is not expected to show distinguishable groundwater level change during operation. Annex K describes deep structures that would be parallel to groundwater flow in confined aquifers at the North Portal. Annex L describes mitigation at the A122/M25 junction cutting that would mean no groundwater level drawdown outside of the highway boundary. Consequently, these annexes, which are approved by the Environment Agency, demonstrate that the described Project structures and earthworks, with mitigation, would not alter groundwater levels outside of the immediate area of the Project during the operational phase. Therefore, climate change effects were not necessary to be modelled in Annex J, Annex K and Annex L as even if climate change did change groundwater levels (there is no evidence of a link between groundwater levels and climate change), the Project would not impact groundwater levels outside of the immediate area of the Project. As stated above, Annex M and Annex N have included a climate change allowance that accounts for a 20% uplift and a sensitivity test for a 40% uplift in rainfall intensity. These uplifts were also agreed with Environment Agency.

3 Baseline hydrogeology – groundwater levels and flows

3.1 Geological setting

3.1.1 Chapter 10: Geology and Soils (Application Document 6.1) details the geology of the study area. This is also presented within the Ground Model long section (Application Document 6.3, Appendix 10.5).

3.1.2 Superficial geology features of interest are as follows:

a. The general absence of superficial deposits on the hills of the North Downs, with the exception of local Head Deposits within dry valleys.

b. Alluvium, either side of the banks of the River Thames, is generally thick and includes silty clays, peat and sands.

c. Alluvium is absent beneath parts of the bed of the River Thames.

d. River Terrace Deposits are present north of the River Thames and form a patchy distribution of terraces that record former positions of the river.

e. River Terrace Deposits show in places a sequence, from shallow to deep, of three different lithologies (comprising cold climate gravels, interglacial climate river and estuary organic silts and clays), then cold climate gravels.

f. River Terrace Deposits are absent at former gravel pits located in the Ockendon link area and at the A122 Lower Thames Crossing/M25 junction. Some former pits are used as recreational lakes, an irrigation reservoir or landfill areas. London Clay Formation is mapped (BGS, 2022a) at the base of some former pits, such as at Stubbers Adventure Centre.

3.1.3 Bedrock geology features of interest are as follows:

a. South of the River Thames, the Chalk Group (Seaford Formation underlain by the Lewes Nodular Chalk Formation) forms and crops out at the chalk hills of the North Downs.

b. Lower London Tertiaries (Lambeth Group and the Thanet Formation) and the London Clay Formation outcrop in the A2 area and beneath Shorne Woods.

c. North of the River Thames, the Chalk Group (Seaford Formation underlain by the Lewes Nodular Chalk Formation) generally does not crop out in the study area and lies beneath Lower London Tertiaries between the River Thames and the A13.

d. The Eocene margin is a geological boundary that lies along a west to east line, approximately coincident with the A13. North of here, the Palaeogene strata and the Chalk Group lie beneath the thick London Clay Formation.

e. Harwich Formation appears to be a utilised aquifer in Orsett Fen (Section 3.7).

3.1.4 Structural geology features of interest are as follows:

a. A regional, general northwards dip of strata, locally changed by broad folds.

b. The Pepper Hill anticline, a broad, low-amplitude fold structure beneath the Shorne Woods area, south of the River Thames (Highways England, 2019).

c. Possible faulting is interpreted from geophysics beneath the River Thames (Highways England, 2020b).

d. The Purfleet anticline at the A13/A1089/A122 Lower Thames Crossing junction, north of the River Thames (Highways England, 2019).

e. Faults may be located in bedrock associated with the above broad folds.

3.1.5 Karst features of interest are located south of the River Thames, where chalk rock crops out or is near surface, as detailed in the Project's engineering geomorphological assessment (Highways England, 2020c). Hydrogeological studies (Section 3.4) suggest that karst is most likely at the upgradient boundary between the Chalk aquifer and the Alluvium in the Ramsar site where ancient spring lines may have existed, or in the zone of fluctuation of the water table. In addition, evidence of very permeable weathered Chalk aquifer is indicated by groundwater level monitoring of one Chalk aquifer borehole (Section 3.3) and numerical modelling of groundwater levels in the Chalk aquifer (Section 5).

3.2 Groundwater bodies

3.2.1 Annex B summarises the regional groundwater bodies. Figures 14.3 and 14.4 (Application Document 6.2) illustrate the plan distribution of superficial and bedrock aquifers. These relate to the geology described in Section 3.1. Key features are described below.

South of the River Thames

3.2.2 Superficial deposits are generally absent, with the main exception being Alluvium and River Terrace Deposits near and beneath the low-lying riverside marsh area. The Alluvium is designated by the Environment Agency as a Secondary aquifer but, as shown in Annex B the strata here is predominantly cohesive and should be considered as an aquitard.

3.2.3 The Chalk aquifer, the North Kent Medway Chalk WFD water body south of the River Thames, comprises the formations detailed in Section 3.1 and is a principal aquifer. The Lower London Tertiaries, including at Shorne Woods, are generally secondary aquifers. The London Clay Formation is unproductive strata.

North of the River Thames

3.2.4 Superficial aquifers, particularly the River Terrace Deposits, are widespread north of the River Thames and form Secondary aquifers within the Order Limits. Higher ground at the existing A13/A1089 junction and the M25 encounters glacial and interglacial deposits of various members of River Terrace Deposits. Topographically low areas, especially beside the River Thames, encounter Alluvium which is designated by the Environment Agency as a Secondary aquifer but, as shown in Annex B, should be considered as an aquitard due to the predominantly cohesive lithology.

3.2.5 The Chalk aquifer, the South Essex Thurrock Chalk WFD water body north of the River Thames, comprises the formations detailed in Section 3.1 and is a principal aquifer. These strata do not crop out north of the River Thames within the Order Limits. The Thanet Formation and the Lambeth Group, going northwards to the A13, overlie the Chalk north of the River Thames marsh area. The Lambeth Group and the Thanet Formation are Secondary A aquifers.

3.2.6 North of the Eocene margin (approximately coincident with the A13), the London Clay Formation covers and confines the basal sands (sandy deposits of Harwich Formation, Lambeth Group and the Thanet Formation), which may be in hydraulic continuity with the underlying Chalk aquifer.

3.3 Groundwater levels

Regional data

3.3.1 Monthly manual groundwater levels from the Environment Agency Chalk aquifer observation boreholes have been used to plot hydrographs (Annex C) and regional groundwater level contours.

3.3.2 Figure 1 shows the interpreted groundwater contour plot of Chalk aquifer water levels in February 2014, south of the River Thames. These are representative of high groundwater levels after a long period of wet weather. Figure 2 represents the high groundwater-level condition north of the River Thames. Figure 2 datasets comprise 2019 Environment Agency borehole water levels and late 2020 Phase 2 GI long term monitoring of boreholes, including of BH13009. As noted below in the discussion of Project GI data, more recent data until April 2022 shows similar maximum groundwater level values. Note, Environment Agency observation boreholes do not cover the A13/A1089/A122 Lower Thames Crossing junction, which coincides with an area of locally higher groundwater levels. All interpreted contours are simplified due to the spacing of Environment Agency observation boreholes, on which they are wholly or mostly based, respectively. Sketches of low water-level conditions are presented in Annex C.

3.3.3 Published Environment Agency numerical groundwater modelling reports for North Kent (Water Management Consultants, 2006) and South Essex (Amec Foster Wheeler, 2016), the BGS (2008) research report on the Chalk aquifer hydrogeology of the North Downs and the Soley *et al*. (2012) technical paper on modelling the hydrogeology of the Chalk across southern England provide hydrogeological interpretation.

3.3.4 For the Chalk aquifer, south of the River Thames, the above data show the following:

a. Groundwater is deep below high ground of the chalk hills of the North Downs.

b. Groundwater levels are likely to be influenced by public water supply wells (Water Management Consultants, 2006).

c. Groundwater hydrographs measured at the top of the North Downs are flat in places (for example, Knight's Place in Annex C). One explanation is lateral diversion of recharge within the thick unsaturated zone (Soley, et al., 2012). Another explanation is that recharge is more uniformly spread across the year because of the thick unsaturated zone and hence no marked seasonal fluctuations occur.

d. High groundwater levels in February 2014 may have been closer than normal to the ground level near Lower Higham Road, beside the southern boundary of the Ramsar site, within the Order Limits. However, Figure 1 contours are a simplification, for reasons discussed above and so the exact location of the 5mAOD (metres above ordnance datum) groundwater contour in relation to the 5mAOD topographical contour near Lower Higham Road is uncertain. However, a temporary spring line is unlikely due to the high permeability zone near the southern edge of the designated site and the draining effect at dry valleys which is deduced to cause a flattening effect on the local groundwater gradient (Section 5.5). An absence of spring line is also discussed in Section 3.6.

3.3.5 For north of the River Thames, the Chalk aquifer regional data shows the following:

a. Ceased chalk quarry dewatering at Thurrock is causing local groundwater to rebound (Scott Wilson, 2010).

b. Artesian conditions may occur locally near low ground at Linford (depending on pumping).

c. Groundwater levels, in the Chadwell St Mary link area and A13 area, are influenced by pumping, as evidenced by the approximate 5m rebound at Brook Farm and Stanford PZ3 Environment Agency boreholes, following the reduced pumping at Linford public supply well from 2011 onwards (Annex C).

d. The A13 area represents a mound of higher groundwater levels compared with levels to the north and south (Figure 2). Chalk water levels peak at 18.45mAOD at BH13009, monitored in January, 2021.

e. Historical artesian conditions at topographical low areas of the Mardyke floodplain (Water Resources Board, 1972) appear to be artesian at present based on Phase 2 boreholes in basal sand strata (see below).

f. Seasonal recharge to the Chalk aquifer is delayed by approximately three months as discussed in the Environment Agency's 2016 Essex model report (Amec Foster Wheeler, 2016).

g. Rising water levels, post 1900s pumping (Environment Agency, 2017) in London, may be the cause of rebound observed in the north part of the study area. However, it is possible that local cessation of pumping from unknown historical wells is the cause. Near Ockendon link, a rise of approximately 0.3m/year (Golder Associates, 2015) is recorded in the basal sands above the confined Chalk at Bush Farm Environment Agency observation borehole (Annex C).

Project ground investigation data

3.3.6 Annex C presents the Project's Phase 1 and Phase 2 GI groundwater monitoring level profiles, with increasing distance, shown by northing coordinates. These show maximum and minimum recorded groundwater elevations for different strata. The A122 Lower Thames Crossing/M25 junction detailed assessment also used selected groundwater level data from the Phase 3 GI and this data is summarised in Annex L.

3.3.7 South of the River Thames, the Project's Phase 1 and Phase 2 GI groundwater-level monitoring data shows the following:

a. Water strikes were encountered intermittently in the Lambeth Group and Thanet Formation, located near the A2. Monitored water levels of installations support the hypothesis of perched water being present. Presence and elevation of the perched water appears to vary locally and with recharge.

b. Superficial aquifers are generally absent between the A2 and the Project's South Portal, so no groundwater-level readings in these strata have been recorded here.

c. Chalk aquifer water levels monitored in Phase 2 GI standpipes near the M2 junction 1 and the M2/A2/Lower Thames Crossing junction confirm a deep water table of approximately 41.2 metres below ground level (mbgl) to 55.5mbgl based on data from October 2019 to March 2020 at Project GI boreholes (BH01003, BH01020, BH01025, BH01033). These are lower than maximum readings in the Environment Agency observation boreholes at Knight's Place and Orchard Lea (Annex C), although all confirm a thick unsaturated zone in this area of at least 40m.

d. Chalk aquifer water levels are below the Project's South Portal (Figure 3 and Annex C).

e. Phase 1 and Phase 2 GI Chalk aquifer water levels immediately uphill of the Ramsar site southern boundary are summarised in Table 3.1.

f. The above HyRA groundwater level assessment is based on GI data recorded until March 2020. Additional groundwater level GI data is now available until April 2022. The additional data shows no notable change in groundwater level throughout the project:

g. At the M2/A2/Lower Thames Crossing junction location, groundwater levels were previously recorded between 41.2 and 55.5 mbgl in 2020. Additional data recorded between January and April 2022, shows maximum water level between 42.2 and 52.1 mbgl.

h. At the A13/A1089/A122 Lower Thames Crossing junction, the Chalk aquifer groundwater level was previously recorded between 16.7 and 18.4 mAOD. The additional data recorded between December 2021 and April 2022, shows maximum water levels between 17.5 and 18.8 mAOD. The Lambeth Group and Thanet Formation groundwater levels were previously recorded between 17.8 and 20.1 mAOD. The additional data recorded maximum groundwater levels between 18.5 mAOD (January to August 2021) and 20.6 mAOD (January to April 2022).

i. At the A122 Lower Thames Crossing/M25 junction, groundwater levels have been previously recorded in the RTD between 16.6 and 18.3 mAOD, in the Alluvium between 17.0 and 17.7 mAOD, in the Chalk at -0.1 mAOD. The additional data, recorded between December 2021 and March 2022, shows maximum groundwater levels in the River Terrace Deposits between 16.6 and 18.4 mAOD, in the Alluvium between 17.3 and 17.4 mAOD, in the Chalk at 0.2 mAOD.

j. In the areas where the groundwater levels are tidal (between the North and the South portals of the main tunnel), the tidal effect on groundwater levels is greater than the possible fluctuation due to varied, rainfall recharge, throughout the years. Therefore, the groundwater level assessment has not been updated in these areas.

Table 3.1 Chalk aquifer groundwater levels immediately upgradient of the Ramsar site

Borehole	Arithmetic mean, mAOD	Max. mAOD	Min. mAOD	n
BH2036	2.26	2.57	1.95	37
BH04001	1.87	2.02	1.55	11
BH2301	2.13	2.36	1.89	34
BH04004	1.73	1.90	1.41	10
BH2302	2.03	2.87	1.74	31

Note: All the above boreholes are located between the A226 (Gravesend Road) and Lower Higham Road. The latter approximately forms the southern boundary of the Ramsar site. The above boreholes are ordered from south to north. Geomean not shown as values are only several centimetres different than the arithmetic mean. Mean value for BH2301 excludes a negative value which appears unreliable (caused by in situ variable head testing). 'n' is the number of water-level readings.

3.3.8 Table 3.1 shows that the groundwater-level difference between the upgradient Chalk aquifer and Ramsar site groundwater levels (Table 3.2) is generally small.

3.3.9 The Phase 1 and Phase 2 GI groundwater-level monitoring at the Ramsar site is presented in Annex D and summarised below in Table 3.2. This shows that all strata have approximately the same mean water level, with Alluvium being slightly higher. The higher water levels in the Alluvium mean that, on average, there is a tendency for slight downwards seepage of water in the Alluvium soils. The greatest range of values, for individual locations, is shown in the River Terrace Deposits and Chalk aquifers (Annex D), confirming tidal effects.

Table 3.2 Ramsar site groundwater level summary

	Geomean, mAOD	Arithmetic mean, mAOD	Max. (including VWP), mAOD	Min. (including VWP), mAOD	n
Shallow Alluvium	1.20	1.30	2.97	0.12	57
Deep Alluvium	1.30	1.31	2.68	0.32	4
River Terrace Deposits	0.97	1.15	3.08	-0.84	166
Chalk	0.98	1.22	2.56	-1.49	323

Notes: VWP means selected vibrating wire piezometer monitoring installations that have been continuously monitored with a data logger. Value 'n' refers to number of readings and comprises manual dips of standpipes only (not data logger values). Shallow Alluvium and deep Alluvium refers to nominal depths shallower and deeper than 5mAOD, respectively. Geomean and arithmetic mean calculations do not include data logger information. Information about monitoring periods is shown in Annex D. Max. = maximum. Min. = minimum.

3.3.10 Darcy flow conceptualisation of seepage shows that flow rate is proportional to water-level difference and soil hydraulic conductivity (permeability). The comparison of data presented in Table 3.2 and Table 3.3 supports the assertion that only small, or negligible, diffuse seepage of groundwater occurs along the southern boundary of the Ramsar site (Sections 3.6 and 5.5, and Annex E).

3.3.11 The Chalk aquifer is confined beneath the South Thames Estuary and Marshes SSSI, Shorne Marshes RSPB Reserve and the Thames Estuary and Marshes Ramsar site, south of the River Thames, and the piezometric level has been monitored using multiple groundwater monitoring locations at different depths (Annex D). Groundwater monitoring of the Chalk aquifer shows:

a. An arithmetic mean piezometric level of approximately 1.2mAOD (Table 3.2)

b. Sinusoidal tidal fluctuation at all locations, with tidal amplitudes generally of 0.5m to 1.9m, decreasing away from the River Thames

c. Large tidal amplitude of 1.9m at BH05006 indicating locally very high hydraulic conductivity and low storage values

3.3.12 North of the River Thames, the Project's Phase 1 and Phase 2 GI groundwater-level monitoring shows the following:

a. Alluvium groundwater levels, beneath Tilbury Marshes, have an arithmetic mean groundwater level of approximately 1 to 3mAOD (approximately 3mbgl).

b. Sinusoidal tidal fluctuation of water levels in the River Terrace Deposits and Chalk aquifer, of tidal amplitudes generally between 0.8m and 1.8m, are observed beneath Tilbury Marshes.

c. Perched water has been recorded in the Thanet Formation at the Chadwell St Mary link and is particularly likely where the Pegwell Silt Member (where clay or silt) occurs at the base of the formation.

d. At the A13/A1089/A122 Lower Thames Crossing junction, one Phase 2 GI Chalk aquifer monitoring borehole, BH13009 (ground level of 30mAOD), recorded a Chalk aquifer water level that is approximately 7m higher than the nearest Environment Agency boreholes (Brook Farm at ground level of 17mAOD and 2km distance and Standford PZ3 at ground level of approximately 12mAOD and at 4km distance). BH13009 was monitored between 16 November 2019 and 5 February 2021, with the water level ranging from 16.75mAOD to 18.45mAOD. The high Chalk water levels have been confirmed by the Phase 3 GI monitoring borehole BH13337 (maximum water level 16.75mAOD).The water levels above are included in the interpreted contours (Figure 2) and an assessment of potential mounding due to proposed new highway drainage can be found in Section 6.9. The cause of the current high groundwater levels here is uncertain and may be related to increased rainfall recharge to the overlying strata (see point e below) and, tentatively, structural effects of the Purfleet anticline (Section 3.1).

e. Phase 2 GI long-term groundwater monitoring confirms moderately high groundwater levels in the Thanet Formation and Lambeth Group that overlie the Chalk Formation at the A13/A1089/A122 Lower Thames Crossing junction. Package C Thanet Formation boreholes record maximum water levels of 20.07mAOD at BH13015 and between 17.25mAOD and 19.9mAOD in six other boreholes (up to December 2020). Average water levels in the Thanet Formation range from 16.78mAOD to 19.83mAOD at the A13, based on long-term monitoring data spanning one year from January 2020 to January 2021 for six Thanet boreholes. Borehole BH13353 in the Lambeth Group records a maximum of 17.8mAOD. Other locations record dry holes, although this is related to the base of the installations for some. The cause of the higher groundwater levels is uncertain but may be due to increased recharge through the gravelly soils (the River Terrace Deposits outcrop is extensive at the junction and is generally recorded as dry where underlain by sandy strata) and partially perched water due to horizontal layering and reduced vertical hydraulic conductivity due to silt and clay content, especially due to the presence of the Pegwell Silt Member, where present, at the base of the Thanet Formation.

f. Existing anthropogenic drainage may contribute but is not likely to be the primary cause of moderately high groundwater levels since there are only two discharge consents of private sewage in the area (Section 3.8 and the Water Features Survey Factual Report in Appendix 14.2 in Application Document 6.3). Also, the existing A13 highway drainage is not believed to outfall to ground since available information suggests that the outfall is to a surface water feature over 1km away from the existing A13/A1089 junction (Appendix 14.6: Flood Risk Assessment (Application Document 6.3)).

g. Artesian behaviour has been recorded in the Harwich Formation at Ockendon link (beneath thick London Clay Formation). Project GI boreholes OH16002, OH17001 and BH15003A recorded water levels consistently above ground, ranging between 0.3mgbl to 4.0m above ground level. The results suggest that the Harwich Formation may be the aquifer source for nearby agricultural wells.

3.4 Groundwater flow

3.4.1 A summary of typical groundwater flow types of each main groundwater body is summarised in Annex B. Details of groundwater flow are also discussed in the relevant summary conceptual site models (CSMs) (Section 5) and detailed assessments presented in this report.

3.4.2 Chalk aquifer groundwater flow is particularly controlled by local geology and past and present hydrogeology. This may result in preferential flow horizons which may be important for design of groundwater control methods and mitigation measures to be considered as part of the hydrogeological risk. Key points from published information are discussed below. In some cases, the Project’s detailed assessments have concluded the presence of preferential flow horizons within the study area (Sections 5.5 and 5.6).

3.4.3 In the unconfined chalk, the most productive fractures are found in the upper sections of the Chalk aquifer, in the zone of water table fluctuation.

3.4.4 The valley – interfluve areal distribution of fractures – suggests that a thicker zone of fractures occurs in the dry valley areas than in the interfluve areas (BGS in partnership with the Environment Agency, 1997).

3.4.5 The chalk of the North Downs has had long exposure to recharge and groundwater flow has developed Secondary fissure transmissivity. The existence of lower permeability marls or hardgrounds promote flow on top of them, often leading to bed parallel anisotropy. In the saturated system, preferential flow paths will be developed toward the lowest discharge boundary of least resistance (Soley *et al*., 2012).

3.4.6 In confined chalk, in the London Basin, most inflows in wells are from the top 30m of chalk, with most of the important fractures within the top 10m to 15m (Amec Foster Wheeler, 2016).

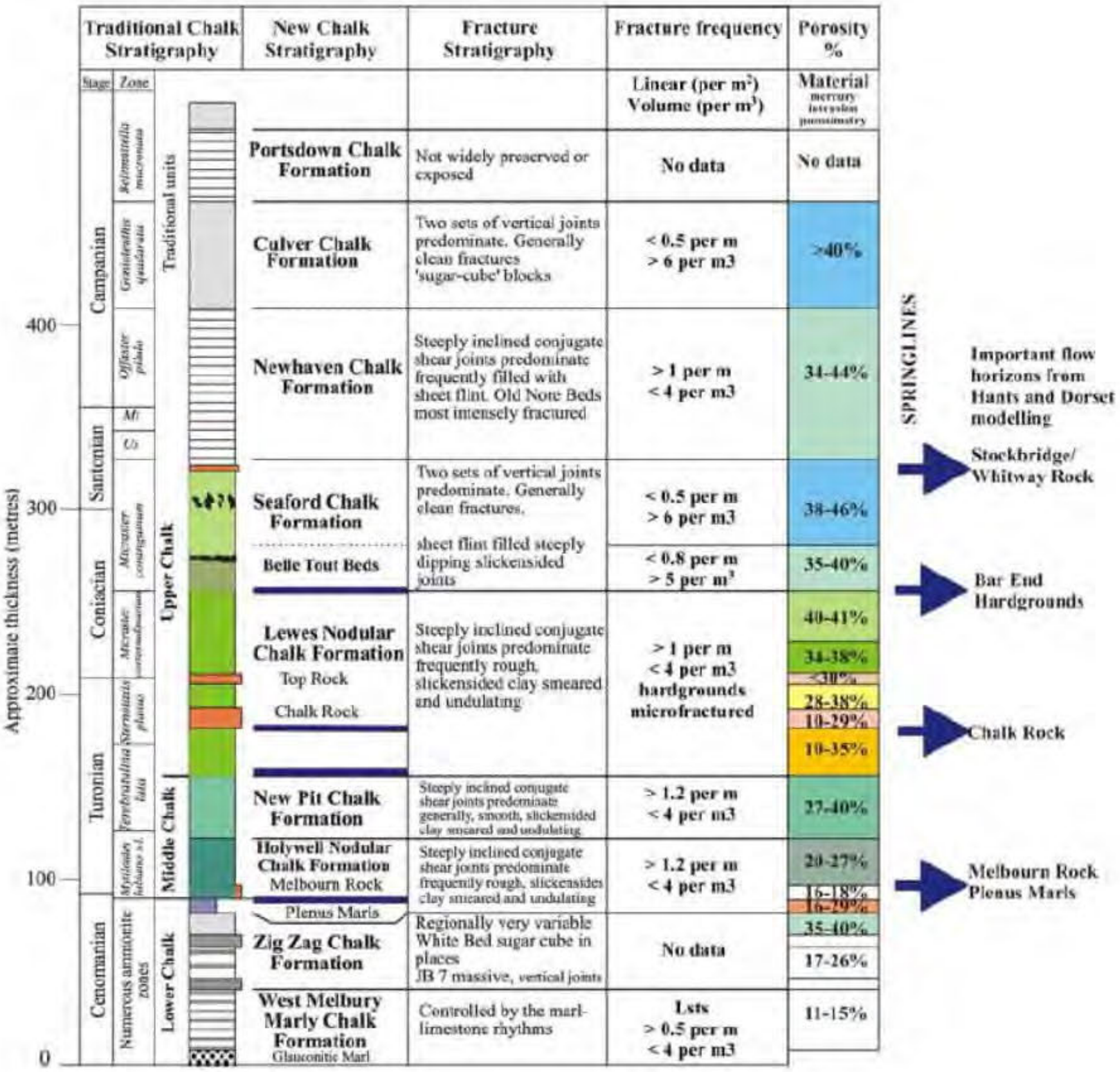
3.4.7 Chalk rock enhanced fissure flow is associated with specific horizons in southern England. Plate 3.1 summarises the stratigraphical location of these horizons. They include the Bar End Hardgrounds at the base of the Belle Tout Beds which are the lowermost strata of the Seaford Chalk Formation. Deeper preferential flow horizons are noted at the Chalk Rock Member and the Melbourn Rock Member (Soley *et al*., 2012).

3.4.8 Sheet flints can be important stratigraphical markers and may also be preferential flow horizons, since sheet flints act as aquicludes, as identified in the Seaford Chalk Formation (Mortimore *et al.,* 2011).

3.4.9 Faulting may also be important as either a barrier to flow, or to promote flow along it. There appear to be no published examples of the effect of faulting on groundwater flow in the study area.

3.4.10 Karst may be locally important. Chalk karst systems, developed during lower sea levels, can potentially carry increased groundwater flows. An example exists of a fissure with a direct link to the River Thames from the Swanscombe quarries at Northfleet (Mortimore *et al*., 2011).

Plate 3.1 Chalk aquifer and preferential flow horizons (Soley *et al.*, 2012)



Note: the large blue arrows show important groundwater flow horizons in the Chalk aquifer in other regions in southern England.

3.5 WFD quantitative status

3.5.1 Details of the WFD assessment are presented in Appendix 14.7 (Application Document 6.3). The Environment Agency mapped extent of water bodies within the Project study area is shown in Figure 14.6 (Application Document 6.2). Table 3.3 summarises this data, showing the quantitative WFD status. Section 4.2 summarises the chemical status of the water bodies.

Table 3.3 WFD groundwater bodies quantitative status

Water body name	WFD identification code	Quantitative status (Cycle 2, 2019)
South of the River Thames		
North Kent Medway Chalk	GB40601G500300	Poor
North of the River Thames		
Essex Gravels	GB40503G000400	Good
Essex South Lower London Tertiaries	GB40602G401000	Good
South Essex Thurrock Chalk	GB40601G401100	Poor

3.5.2 Good groundwater quantitative status is achieved when the groundwater level, in a groundwater body, is such that the available groundwater resource is not exceeded by the long-term annual average rate of abstraction. Accordingly, the groundwater level is not subject to anthropogenic alterations which would result in detrimental effects (UKTAG, 2012). The status of the South Essex Thurrock Chalk aquifer has changed since Cycle 2 (2016) to poor due to a poor quantitative water balance (Environment Agency, 2022).

3.6 Springs and natural discharges

South of the River Thames

3.6.1 Major chalk springs issue at the sources of many chalk dip-slope rivers of the North Downs (e.g. the Medway) (Smedley *et al.*, 2003) but these are outside the Project study area. Historical springs are mapped (Institute of Geological Sciences, 1970) at a chalk valley at Springhead House and down valley at Northfleet beside the River Thames. These are outside the Order Limits and are at 0.5km and 2.5km distance, respectively, from the most western extremity of the Order Limits near the A2.

3.6.2 A spring is also mapped (Institute of Geological Sciences, 1970) in Shorne Woods (Easting 567760, Northing 170078), 0.3km north of the A2 section of the Project, at an outcrop of Palaeogene strata. This was found to be dry during the water features survey visit in September 2017 (Application Document 6.3, Appendix 14.2).

3.6.3 Following statutory consultation, the need to assess springs that cause water to flow through Ifield Farm and Shorne village was identified. Ordnance Survey mapping suggests that water rises in the woodland of Shorne Woods Country Park and watercourses are mapped. These may be related to runoff from clayey soils of the London Clay Formation or perched water in sandy Lambeth Group or Thanet Formation strata further downhill. In both cases, they are north and on the other side of the groundwater divide (hilltop) from the A2.

3.6.4 The potential for hydraulic interaction between perched groundwater (Lower London Tertiaries aquifers) and New Fish Pond and two other ponds, all near the Inn on the Lake at Shorne, is uncertain. It is not known whether the ponds are lined. However, there are no proposed significant road cuttings near the ponds although there are proposed utility trenches which are discussed in Section 6.12.

3.6.5 The North Kent Chalk aquifer groundwater flow discharges by diffuse leakage to the North Kent marshes (herein used to describe the low-lying marsh area along the North Kent coast along the Thames Estuary, within the study area). However, the water balance of these protected wetlands is dominated by rainfall, runoff and local controls on surface water levels, rather than by groundwater abstraction impacts (Soley *et al.*, 2012).

3.6.6 A Project baseline water balance assessment for the Ramsar site within the Order Limits (Section 5.5 and Annex E) confirms the predominance of rainfall input. The walkovers for the water features survey (Section 1.7) and an e-mail communication with the RSPB (2018) support the conclusion that conspicuous springs are not present along the southern edge of the Ramsar site.

North of the River Thames

3.6.7 Published hydrogeological maps do not cover most of the study area north of the River Thames, although historical Ordnance Survey mapping (Landmark, 2020) shows springs or issues and place names can indicate an historical spring (although these can be misleading).

3.6.8 At Low Street, the reservoir, used for agricultural spray irrigation supply, appears to be groundwater fed (Figure 14.2 (Application Document 6.2)). Both groundwater flood mapping (Section 3.10), which shows a high risk of flooding here, and Phase 1 and Phase 2 GI support this assertion.

3.6.9 The 1959 Ordnance Survey map is marked ‘issues’ at the approximate location of the pond on Gobions Sewer at Chadwell St Mary link (Landmark, 2020). The pond was recorded during the water features survey (Application Document 6.3, Appendix 14.2). Phase 2 GI provides circumstantial evidence for groundwater seepage to topographical low areas because perched groundwater within the Thanet Formation has been recorded (Annex C). In addition, the underlying Chalk aquifer may be locally artesian, depending on pumping at the nearby Linford public supply well (Section 3.7).

3.6.10 The name of Springfield Farm on Stifford Clays Road, near the existing A13/A1089 junction, suggests that a spring was once recorded here. However, historical maps do not show a spring at this location. Also, no stream was observed during the water features survey (Application Document 6.3, Appendix 14.2).

3.6.11 The 1921 Ordnance Survey map shows three springs near Ockendon link at Chantry Farm, Botney Farm and Hobletts Farm. These springs are not shown from 1960 onwards.

3.6.12 Spring Wood is part of Cranham Marsh LNR, 1km west of the proposed A122 Lower Thames Crossing/M25 junction. Essex Wildlife Trust (2022) describe a seasonal stream that runs through the middle of the LNR but that is kept wet mainly by groundwater. The LNR details are presented in Section 3.9.

3.6.13 Hobbs Hole, a small pond west of North Ockendon, is shown with a spring in the 1868 and 1898 historical maps, but subsequent maps do not show a spring. Ordnance Survey mapping appears to show the pond at the head of a small watercourse that flows northwards through the Thames Chase Forest Centre SINC. Project ecology surveys have observed the small watercourse as being dry for at least one year of monthly visits. Verbal communication (June 2020) with the local farm landowner’s agent asserts that the pond is fed by a spring. The pond is also shown as having a licensed surface water abstraction and is believed to be used for fishing. This feature is discussed in the Water Features Survey Factual Report (Application Document 6.3, Appendix 14.2) and Section 6.8.

3.6.14 Liaison with the landowner's agent (Application Document 6.3, Appendix 14.2, and verbal communication in 2020) and landowner (a virtual meeting on 12 May 2021 and a site visit on 24 May 2021) has also identified two springs at North Ockendon. Historical maps (Landmark, 2020) and current Ordnance Survey maps do not identify springs here. However, these sources are said to feed a large irrigation reservoir via licensed surface water abstractions (Annex L and Appendix 14.2).

3.6.15 The first possible spring at North Ockendon is located beside St Mary Magdalene Church and feeds three ponds at Hall Farm, which are relics of an old moat (part of Hall Farm moat, paddock and St Mary Magdalene Churchyard, North Ockendon SINC). Some of these ponds are lined, as discussed in Section 5.7. An online search reveals that St Cedd's Well was a holy well and there is a built structure at the head of the northern pond which is assumed to house the well that was fed by spring flow. This is located approximately 40m south-west of the church. It is understood that there was once flowing water from the well to and through the adjacent baptism channel (Megalithic Portal, 2020). However, liaison with the landowner suggests flow from the northern pond has declined since widening of the M25 (in 2012) and generally does not flow except in wet weather periods. Indeed, a walkover on 24 May 2021 suggest the current baptism channel structure is not functional since the brickwork does not connect to the adjacent pond as would be expected if there was water flow.

3.6.16 During the same walkover as described in the above paragraph, flow at the outfall from the southern pond into the adjacent ditch was observed. A second walkover on 12 July 2021 observed the culvert connecting the same ditch system to the west side of the M25, towards the irrigation reservoir, to be dry. This suggests that existing summer ditch flow towards the irrigation reservoir from the east side to the west side of the M25 may be absent or unreliable. From October 2021 to May 2022, a monthly visit has been undertaken to Manor Farm and its surrounds in North Ockendon. During each visit, observations of flow conditions in the ponds and ditch network have been documented, together with a photographic record. These have shown generally dry or no flow conditions in the ditches. Typically, if flow was observed (for example as outflow from the historical deep drainage system, described in the below paragraph, or as outflow from the southern pond of the old moat) it then disappeared into the ground after a short distance from the observed flow location. Further information on the survey findings is provided in Appendix 14.2 of the Environmental Statement (Application Documents 6.3). Further details and photographs are shown in the Water Features Survey Factual Report (Application Document 6.3, Appendix 14.2).

3.6.17 The second feature described as a spring is located in fields east of St Magdalene Church, North Ockendon. World imagery mapping shows no indication of a water feature in these fields. However, the landowner asserts that a deep (16 foot or approximately 4.9m) Victorian drainage system exists beneath the fields and is the source of water that flows into ditches at the bottom of the hill. Therefore, what is described as a spring appears to be a historical deep drainage system designed to collect groundwater. At its nearest point, it is located 75m east of St Magdalene Church, based on the sketch plan shown in the Water Features Survey Factual Report (Application Document 6.3, Appendix 14.2). At the time of writing, no details of spatial extent, as built records or state of repair of this deep drainage system, are available. The landowner has stated (verbal communication during the walkover on 24 May 2021) that this water source is the main supply of water that is ultimately used downstream by the licensed surface water abstraction. However, the same walkover in May 2021 observed a moderately low flow from the drainage pipe outfall into the downhill ditch. Further details are shown in the Water Features Survey Factual Report (Application Document 6.3, Appendix 14.2). This area of the deep drainage system is assessed as part of the detailed assessment of the impacts of the proposed A122 Lower Thames Crossing/M25 junction cutting and is described as the North Ockendon catchment in Section 6.8.

3.6.18 A further description of the farm irrigation water supply at North Ockendon is presented in the Water Features Survey Factual Report (Application Document 6.3, Appendix 14.2).

3.7 Groundwater abstractions, public water supply and SPZs

3.7.1 Full details of Environment Agency licensed groundwater abstractions are presented in the Water Features Survey Factual Report (Section 1.7) for abstractions within the study area (area within the Order Limits plus a buffer of 3km beyond). Their locations and the published (groundwater) SPZs are shown in Figure 14.2 (Application Document 6.2). Key points are discussed below, and Table 3.4 summarises public water supply wells that are within 1km of the Project route.

Public supply wells

Table 3.4 Public water supply abstractions within 1km of the Project route

Sub-catchment (groundwater body)	Water company (licence number)	Maximum abstraction
South of the River Thames		
Boreholes, wells and adits at Three Crutches Pumping Station (PS) (N), Shorne (Chalk aquifer)	Southern Water Services Ltd 9/40/01/0511/G	Part of a large group licence for 17,700ML per year
Boreholes, wells and adits at Hazells PS, Northfleet (Chalk aquifer)	Southern Water Services Ltd 9/40/01/0511/G	Part of a large group licence for 17,700ML per year
North of the River Thames		
Linford well (Chalk aquifer)	Northumbrian Water Ltd 8/37/56/*G/0044	Part of a group licence shared with Stifford. Linford has a peak daily licence of 6.4ML per day[1]

Note [1]: correspondence with the water company (Northumbrian Water Ltd, 2020).

3.7.2 Groundwater represents approximately 70% of water supply in Kent and Medway (Kent County Council, 2020). Here, groundwater abstraction is predominantly from the Chalk aquifer and the majority of the public water supply wells are in unconfined sections of the Chalk aquifer.

3.7.3 The Medway catchment, Kent, is in the study area. Here, the Chalk aquifer supplies the largest volume of groundwater abstractions, almost 60% for industrial use (including non-consumptive uses) and approximately 40% for public water supply (Environment Agency, 2013a).

3.7.4 North Kent has significant abstraction, resulting in drawdown of groundwater levels below the main flow horizon in the Chalk (Soley *et al*., 2012). The North Kent and Medway Chalk is over licensed (Environment Agency, 2012) (not over abstracted) and there is a presumption against new licences (Environment Agency, 2013a).

3.7.5 North of the River Thames, the study area is in the Essex Supply Area of Essex and Suffolk Water company. In the Essex Supply Area only 54% of the water supplied within the area, is sourced within it in a drought year, with the rest being transferred in from outside the area. The raw water bulk supply is from reservoirs in the Lea Valley to the west. Only around 2% of total water supplied is derived from groundwater (Chalk aquifer) (Essex and Suffolk Water, 2021). The groundwater sources are at Stifford and Linford.

3.7.6 Public water supply groundwater abstraction in south Essex is only from the unconfined and/or semi-confined Thameside Chalk in the south-west of the water resource unit, at Linford and Stifford. Public supply from Linford has temporarily been paused since 2011 (Section 3.3). However, reduced pumping has continued.

Abstraction licensing strategies

3.7.7 A summary of the Environment Agency abstraction licensing strategies for groundwater is shown in Table 3.5. Any abstraction of more than 20m^3/day (4,400 gallons/day) from a ‘source of supply’, including groundwater, must have an abstraction licence.

3.7.8 In the Medway catchment, the ‘presumption against’ strategy was first introduced after the groundwater drought of the late 1980s and early 1990s, which highlighted the vulnerability of this important water source.

3.7.9 Restrictions to licensed abstraction in the North Kent Medway Chalk are required in some areas due to the potential of saline intrusion (Environment Agency, 2013a).

3.7.10 In the Mardyke sub-catchment, north of the River Thames, the confined Chalk aquifer has no water available for abstraction (Environment Agency, 2019a). The previous report version (Environment Agency, 2013b) states that this is because of already being impacted due to existing licences.

Table 3.5 Abstraction licensing strategies

Sub-catchment (groundwater body)	Water resource availability
South of the River Thames	
Medway (unconfined Chalk aquifer)	Presumption against granting new abstraction licences for unconstrained consumptive use.
North of the River Thames	
RBIM (unconfined Chalk aquifer)	Same as for surface water, i.e. restricted water availability during Q95 (low flow condition). Proof required that no adverse effect on ecology.
Mardyke (confined Chalk aquifer)	No new consumptive abstractions will be granted.

Note: RBIM is the abbreviation for the Roding, Beam, Ingrebourne and Mardyke river catchments.

Source protection zones

3.7.11 A summary of SPZ descriptions (Environment Agency, 2019b) is shown in Table 3.6, while the location of SPZs within the study area is shown in Figure 14.2 (Application document 6.2).

3.7.12 The Environment Agency has defined SPZs to show the level of risk to groundwater sources intended for human consumption. Wells, boreholes and springs used for major potable uses, particularly public drinking supply, have had SPZs defined. The Environment Agency's approach is that all abstractions that are used for drinking water supply or food production purposes are, by default, in an SPZ1 or SPZ2. A minimum radius of 50m is applied to a SPZ1. In some cases depending on volumes abstracted, a default SPZ2 with a minimum radius of 250m applies (Environment Agency, 2018). Further the Environment Agency (2019c) state that a minimum SPZ2 radius of 250m applies for sources with a protected yield of less than 2000m^3/day and a minimum SPZ2 radius of 500m applies for sources with a protected yield of greater than 2000m^3/day (as long as the respective radii do not exceed the size of the total catchment).

Table 3.6 Groundwater SPZ descriptions

Zone	Name	Description
SPZ1	Inner zone	This zone is 50-day travel time of pollutant to source, with a radius of no less than 50m.
SPZ2	Outer zone	This zone is 400-day travel time of pollutant to source. This has a 250m or 500m minimum radius around the source, depending on the amount of water taken.
SPZ3	Total catchment	This is the area around a supply source within which all the groundwater ends up at the abstraction point. This is the point from where the water is taken. This could extend some distance from the source point.

Note: other types of zones exist but are not present within the Project study area.

3.7.13 South of the River Thames, in Kent, there are approximately eight published SPZ1s within the study area. Here, the Project route does not cross any SPZ1s, although the Project would cross over a small part of an SPZ2 and much of the A2 widening work would be within a combined SPZ3. A summary of proposed

Project elements, including utilities (Annex Q), is shown in Table 3.7, especially since SPZ1 and SPZ2 areas represent areas that are of very high importance and high importance, respectively, with SPZ3 areas being of medium value (Appendix 14.1, Application Document 6.3).

Table 3.7 Public water supply SPZs within the Order Limits and Project elements within SPZs – Kent

Licence no., operator, (area), aquifer	Proposed Project elements in stated SPZ types
9/40/01/0511/G, Southern Water Services Ltd, (Three Crutches PS, north and south, Shorne), Chalk aquifer	• A multi-utility route comprising trenching and trenchless installation would cross the south-western edge of the **SPZ2** (construction duration of less than six months) and into the **SPZ3.** • Installation of a gas utility pipeline, constructed using trench excavation methods, from the Inn on the Lake (outside the SPZs) to Park Pale that is in the **SPZ3**. The duration of works is expected to be 21 months approximately. The pipeline will require a connection to the existing pipeline via stopple arrangements of circa 50m x 50m x 3m at Park Pale (**SPZ3**). • A multi-utility route, constructed using trench excavation methods, would be located along the southern side of the A2 within the **SPZ3**. Construction duration of approximately six months. • A new non-motorised user route crosses part of the **SPZ2**. • New infiltration basin (POS01-001 outfall location) at the outer edge of the **SPZ2** and an existing infiltration basin in the combined **SPZ3**. • Two nitrogen deposition habitat compensation area would be located wholly or partly within the merged **SPZ3**.
9/40/01/0511/G, Southern Water Services Ltd, (including Northfleet PS, Windmill Hill PS and Hazells PS at Northfleet), Chalk aquifer	A multiple utility route would be near to the A2 and would cross near the edge of one **SPZ1**, and a combined **SPZ2** and **SPZ3**. Works would include open cut techniques and trenchless techniques. Various other utility networks would be placed within the combined **SPZ3** in vicinity of the A122/A2 junction and would comprise five multiple utility routes, three gas networks, overhead electricity and a new electricity substation. Construction of all the multi-utility routes, with the exception of one, would be for less than six months. The gas networks would be constructed with an open cut technique in the vicinity of Claylane Wood and extend beyond the SPZ3 area where they would be deeper. A nitrogen deposition habitat creation area is proposed in the merged **SPZ3**. Permanent Project road and highway drainage within the combined **SPZ3** of the multiple sources would be: • A2/Lower Thames Crossing A122 junction (west side) • A2 (west of the A2/A122 junction) • Existing infiltration basin, EXPOS02-001 outfall • New infiltration basin outfall location, POS02-001

3.7.14 North of the River Thames, in Essex, there are two published SPZ1s within the study area. The Project route does not cross either of these. Here, the Project works would pass over a published SPZ2, near Linford. Much of the Project route overlaps the combined SPZ3s of the public water supply abstractions at Linford and Stifford. The SPZ3 extends over a wide area from beside the River Thames to north of the M25 junction 28. This includes areas where the Chalk aquifer is unconfined or semi-confined, south of the Eocene margin, and confined, north of the Eocene margin, beneath the London Clay Formation. A summary of proposed Project elements, including utilities (Annex Q), is shown in Table 3.8. Project elements that are located in the SPZ3 north of the Eocene margin are not shown in the table since they would not impact the Chalk aquifer due to the thick overlying confining strata (Section 3.1).

Table 3.8 Public water supply SPZs within the Order Limits and Project elements within SPZs – Essex

Licence no., operator, (area), aquifer	Proposed Project elements in the stated SPZ types
8/37/56/*G/0044, Northumbrian Water Ltd, (Linford), Chalk aquifer	Proposed utility networks would be restricted to a limited number of utilities mostly outside of the SPZ1 or towards the outer edge of the zone. These comprise: • A north-south multiple utility route in the **SPZ1**, of construction duration of one year. Proposed methods include trenchless techniques and trenching with the majority of works comprising overhead lines work. • Diverted utility networks would follow the diverted Muckingford Road, in the **SPZ3** and **SPZ2**, which then re-joins the original road at the outer edge of the SPZ1. Trenching methods are proposed and construction durations of four to six months are expected for each multi-utility route. • Proposed National Grid overhead powerlines that would cross the **SPZ1, SPZ2 and SPZ3**. Within the **SPZ1**, there would be one new temporary pylon, one new permanent pylon, plus two new pylons of footprint overlapping that of existing pylons. • A temporary water supply route for the TBM constructed using a mixture of open cut and trenchless techniques that would cross the **SPZ1, SPZ2 and SPZ3** and be of six months construction duration. • A gas network diversion in the Baker Street to Stanford Road area of the A13/A122 junction area comprising open cut and trenchless techniques in the **SPZ3** and be of two years construction duration. • Various other utilities in the **SPZ3,** mostly comprising proposed overhead or buried electricity routings.

Licence no., operator, (area), aquifer	Proposed Project elements in the stated SPZ types
	Permanent Project road and highway drainage would comprise: • A temporary access route, the eastern tip of the diverted Muckingford Road, part of a new, lined surface water pond (outfall location, POS10-001) and a planted landscaped area that would overlap part of the **SPZ1** near Linford. • The Chadwell St Mary link road alignment, including embankments and cuttings, within the **SPZ2**. • Much of the Project route north of, and including, the Chadwell St Mary link and parts of the A13 junction passes over a combined **SPZ3**.

Private licensed abstractions

3.7.15 There are private licensed abstractions, having a possible human consumptive use, which have a default 50m radius SPZ1 within the Order Limits. In addition, the Environment Agency has a 250m or 500m minimum radius SPZ2 around the source, as discussed earlier in this report section. The private licensed abstractions, having a possible human consumptive use, are located north of the River Thames only and are listed in Table 3.9.

Table 3.9 Private groundwater abstractions (human consumptive use)

Private licence no. [owner] (area) {aquifer }[1] and daily licensed quantity	Use description	Default 50m SPZ1 [default 250m SPZ2, unless otherwise shown] within the Order Limits
8/37/56/*G/0073 [RWE Generation UK PLC] (Low St., East Tilbury) {Chalk } Aggregated daily quantity of 5500 m^3/day	• Licence says '*General use relating to Secondary category (medium loss)*' • Wells not currently in use [2]	Tilbury Viaduct 100m to the west of SPZ1 boundary. [Tilbury viaduct, construction compound CA 5, construction compound CA 5A, utilities logistics hub ULH 12, works numbers MU27, MU28,MU29, MU30, MU31, MU32, MU33, MUT6, MUT9, OH4, TFGP1 are located within 500m of the licence grid reference]
8/37/56/*G/0006 [C H COLE & SONS] (Well 1 at Polwicks, West Tilbury) {Fluvial sands and gravels} Part of a combined licence of 1300m^3/day	• General farming • Domestic	Licence location coincident with irrigation reservoir. Tilbury Viaduct 50m to east of licence grid reference. [Utilities logistics hub, ULH 12, Works numbers MU28 and MU33 and a non-motorway user route are located within 250m of the licence grid reference]

Private licence no. [owner] (area) {aquifer }[1] and daily licensed quantity	Use description	Default 50m SPZ1 [default 250m SPZ2, unless otherwise shown] within the Order Limits
8/37/56/*G/0032 [C H COLE & SONS] (Botney Farm, Orsett) {Fluvial sands and gravels – reassessed as Harwich Formation by Cascade – Section 3.3} 5m^3/day	• General farming • Domestic	Mardyke Viaduct embankment partly covers the SPZ1. [Construction compound CA 11 and Works numbers MUT22 and MUT25 are within 250m of licence grid reference]
8/37/56/*G/0032 [C H COLE & SONS] (Hobletts Farm, Orsett) {Fluvial sands and gravels – reassessed as Harwich Formation by Cascade – Section 3.3} 5m^3/day	• General farming • Domestic	Mardyke Viaduct is 400m west of SPZ1. [Construction compound CA 11 and Works numbers MUT22 and MUT25 are within 250m of licence grid reference]
8/37/56/*G/0032 [C H COLE & SONS] (Castles Farm, Orsett) {Fluvial sands and gravels – reassessed as Harwich Formation by Cascade – Section 3.3} 16m^3/day	• General farming • Domestic	Well grid reference location is 10m outside of the Order Limits but SPZ1 is partly within the Order Limits, based on the grid reference. [No Project features within 250m of grid reference]

Notes:
1 Only abstractions are shown that are likely to be within the Order Limits.
2 Communication with landowner (Highways England, 2020d).

Private water supplies

3.7.16 As discussed in Chapter 14: Road Drainage and the Water Environment (Application Document 6.1), the local authorities recorded no private water supplies (as defined by the Private Water Supplies Regulations 2016 (as amended)) within the study area.

3.8 Discharges to ground

3.8.1 Full details of Environment Agency discharge consents are presented in the Water Features Survey Factual Report (Application Document 6.3, Appendix 14.2). Key points are discussed below.

3.8.2 South of the River Thames, disposal of sewage comprises the majority of consents for discharge to ground. None belong to a water company. All are outside of published SPZ1s and most are outside of published SPZ2s. The Filborough Farm barn discharge is located on the southern boundary of the Ramsar site and 100m east of the Order Limits.

3.8.3 North of the River Thames, trade disposal to ground is consented at several main road petrol stations and business parks near the A13, including Orsett Filling Station and Orsett Industrial Park. Disposal of sewage to ground is consented near the A13 and beside the A122 Lower Thames Crossing/M25 junction. Further north, consents are mostly for domestic sewage disposal. None are within a published SPZ1 or SPZ2.

3.9 Groundwater Dependent Terrestrial Ecosystems

3.9.1 In accordance with best practice to assess compliance of the Project with the WFD, GWDTEs have been assessed. The DMRB LA 113 Road Drainage and the Water Environment (Highways England, 2020a) methodology and assessment of potential impacts is described in Section 8. This includes reference to assessments by the United Kingdom Technical Advisory Group wetland task team (UKTAG WTT). Details of the GWDTE assessment are shown in Annex P.

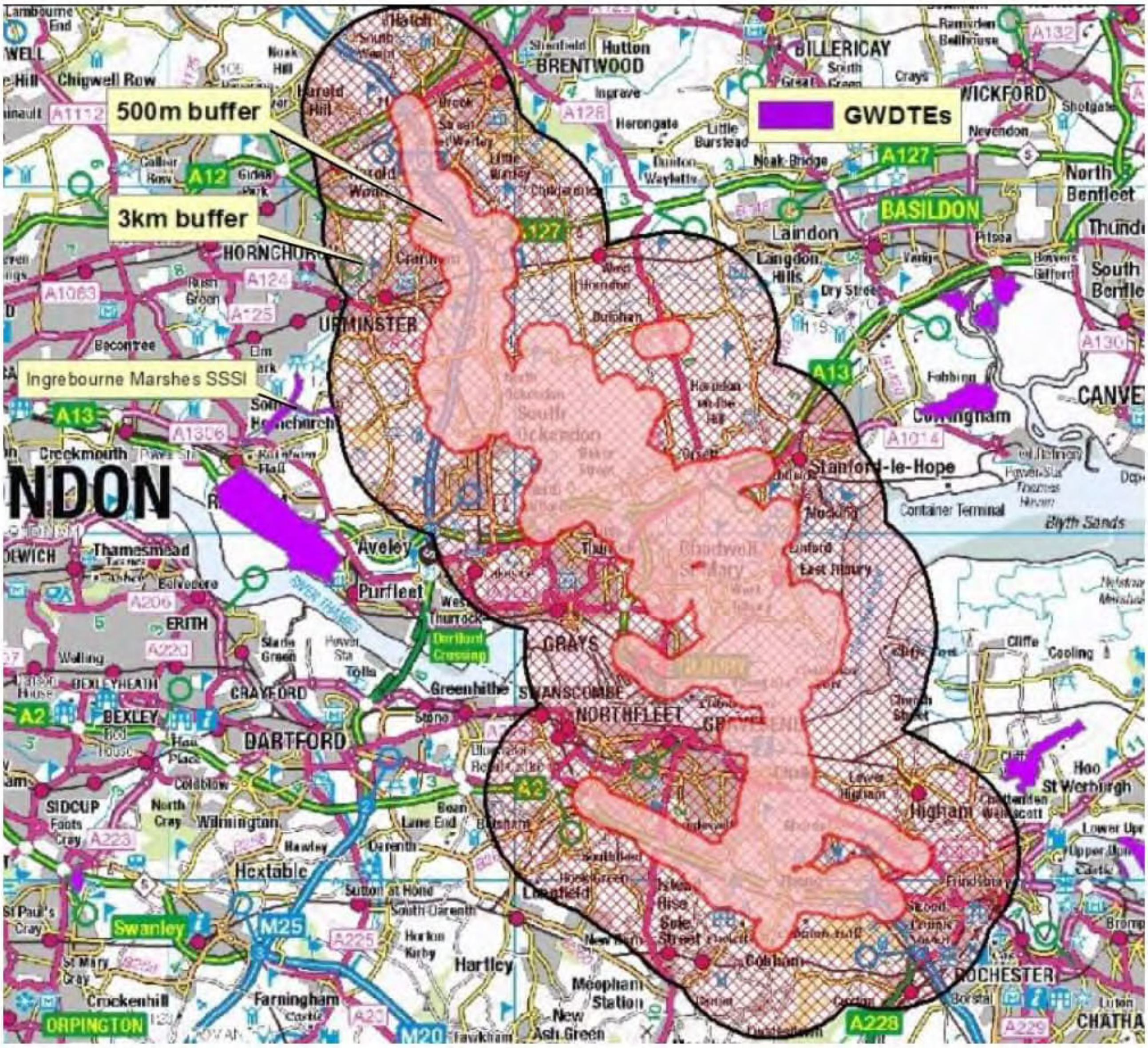
3.9.2 GWDTEs are wetlands that critically depend on groundwater flows and/or chemistries, shown in WFD-UKTAG (2014). A river system or permanent lake fed by a spring would not be considered as a GWDTE, but an aquatic ecosystem (European Communities, 2012). Further information, including methodology is discussed in Section 8.

Published GWDTE data

3.9.3 Environment Agency open-source mapping of GWDTEs is shown in Plate 3.2 (Environment Agency, 2021). The SSSIs identified are outside the study area, with the exception of the eastern tip of the Ingrebourne Marshes SSSI, which is just within the 3km distance from the Order Limits, north of the River Thames. The citation for this site indicates that the eastern part of the SSSI supports fen (marsh and swamp) and is in unfavourable, declining condition due to the build-up of Himalayan balsam.

3.9.4 The South Thames Estuary and Marshes SSSI (south of the River Thames) and Mucking Flats and Marshes SSSI (north of the River Thames) are not assessed as being GWDTEs by the Environment Agency (Environment Agency, 2020b). Together with assessed low groundwater dependency and assessed dominance of non-groundwater inflow, these two SSSIs are therefore screened out from the GWDTE assessment.

Plate 3.2 Environment Agency mapped GWDTEs (SSSI sites only) (Environment Agency, 2021)



Note: buffers are shown for 500m and 3km distance from the Order Limits. Only the name of the GWDTE that is partly within the Order Limits is shown.

3.9.5 Project vegetation habitat surveying comprised Phase 1 habitat surveys (used to compare with UKTAG WTT habitats) and the more detailed National Vegetation Classification (NVC) surveys, both of which were used to assess potential groundwater dependency. Locations of identified potential GWDTEs are shown in Figure 14.2 (Application Document 6.2) (excluding areas screened out of the GWDTE assessment) and in Appendix 8.2 (Application Document 6.3).

Phase 1 surveyed habitats

3.9.6 Phase 1 habitat surveys, compared with UKTAG WTT habitat types, identified potential groundwater dependent habitats in a number of small ditches, watercourse margins and ponds. South of the River Thames, Jeskyns

Community Woodland car park was identified as having a swamp habitat. North of the River Thames, identified areas were Cooper Shaw Road ditch, two small areas in Tilbury and four areas in North Ockendon Pit SINC.

3.9.7 A Phase 1 habitat survey was undertaken from Public Rights of Way at Cranham Marsh LNR, with the exception of Bonus Wood where there is no public access. Much of the LNR has a vegetation cover of broadleaved woodland, which is not groundwater dependent. One small area of low groundwater dependency (Environment Agency, 2014) swamp habitat was recorded. The survey also recorded three discrete areas of fen (valley mire). This habitat is likely to be of high groundwater dependency (Environment Agency, 2014). The LNR is discussed in Section 8.

3.9.8 Screening was undertaken to remove locations that are not relevant to the assessment of GWDTEs. Phase 1 habitat locations surveyed but screened out include main rivers and highway drainage infrastructure.

NVC surveyed habitats

3.9.9 Low groundwater dependency vegetation (NVC mapping) was identified in marginal vegetation beside ditch networks south of the River Thames, in the Filborough and Shorne Marshes (part of the South Thames Estuary and Marshes SSSI, Shorne Marshes RSPB Reserve and the Thames Estuary and Marshes Ramsar site). Aquatic vegetation showed no groundwater dependency.

3.9.10 North of the River Thames, ditches and marsh at Goshems Farm Landfill Local Wildlife Site (LWS) and Low Street Pit LWS, show moderate groundwater dependency. However, the Project would cause the direct physical loss of part of these sites. Related mitigation measures and assessment of impacts are detailed in Chapter 8: Terrestrial Biodiversity (Application Document 6.1). As a consequence of physical loss, these two sites are screened out from the GWDTE assessment of impacts.

3.9.11 NVC surveying of the North Ockendon Pit SINC area found low groundwater dependency vegetation.

3.9.12 NVC surveys were conducted at Hall Farm moat, paddock and St Mary Magdalene Churchyard SINC and Thames Chase Forest Centre SINC. Both sites contained small and very discreet areas (less than 2m by 2m areas) of fen (swamp and mire) marginal habitat and both sites were generally species poor. It is noted that fen (swamp and mire) habitats are indicative of low groundwater dependency (UKTAG, 2004).

3.10 Groundwater flood risk areas

3.10.1 Groundwater flooding is detailed in Appendix 14.6: Flood Risk Assessment (Application Document 6.3). Groundwater flooding is the result of water rising from an underlying aquifer or water flowing from ephemeral springs. It tends to occur following prolonged periods of wet weather when the water table becomes high, although other causes of water rise are possible as shown in Table 3.10.

Table 3.10 Types of groundwater flooding

Ref.	Type of groundwater flooding
1	Rise of typically high groundwater levels to extreme levels in response to prolonged extreme rainfall.
2	Rise of groundwater level in aquifers in hydraulic continuity with high in-bank river levels or extreme tidal conditions.
3	Increases in groundwater levels and changed groundwater flow paths due to artificial obstructions or pathways (e.g. foundation structures), and loss of natural storage and drainage paths.
4	Rising groundwater levels in response to reduced groundwater abstraction in an urban area (groundwater rebound) or a mining area (mine water rebound).
5	Rise in groundwater levels associated with leaks from sewers, drains or water supply mains.

3.10.2 Assessment of baseline groundwater flooding for the Project study area has comprised reference to Lead Local Flood Authority strategic flood risk assessments and bespoke digital mapping products by the BGS (BGS, 2017) and GeoSmart (GeoSmart, 2019). Reported groundwater flooding is shown in Table 3.11. Full details are shown in Appendix 14.6: Flood Risk Assessment (Application Document 6.3). GeoSmart mapping of groundwater flooding susceptibility is presented in Flood Risk Assessment Drawing HE540039-CJV-EFR-SZP_GNZZZZZZZZ-DR-LF-00151 to Drawing HE540039-CJV-EFR-SZP_GNZZZZZZZZ-DR-LF-00153 inclusively (Appendix 14.6, Application Document 6.3).

Table 3.11 Reported groundwater flooding

Reported groundwater flooding incidents	References
South of the River Thames	
No reported groundwater flooding events in Thameside (prior to 2013) Groundwater flooding in Kent, 25 January 2014 (no details)	(Kent County Council, 2013) (Kent County Council, 2014a)
North of the River Thames	
No incidents recorded in Thurrock	(Thurrock Council, 2015)
Flood incidents in London Borough of Havering: Great Warley Hall (east of M25 J29, just south of the A127) in September 2005 Near Heron Way, Cranham (January 2005)	(London Borough of Havering, 2016)
Groundwater flooding near Stubbers Adventure Centre on Stubbers Lane (west of the A122 Lower Thames Crossing/M25 junction)	(Cascade, 2018)

3.10.3 South of the River Thames, the GeoSmart groundwater flooding susceptibility mapping (Flood Risk Assessment Drawing HE540039-CJV-EFR-SZP_GNZZZZZZZZ-DR-LF-00151-00153, Appendix 14.6, Application Document 6.3) shows areas of low to moderate risk at the lower slopes of the North Downs chalk hills near Lower Higham Road. Here, one small ‘hot spot’ of high risk (also shown as at risk of groundwater flooding at ground surface in the BGS mapping) is shown in cut ground to the south of Lower Higham Road.

3.10.4 North of the River Thames, the flood mapping (GeoSmart, 2019) shows the A13/A1089/A122 Lower Thames Crossing junction to be in an area entirely of negligible risk from groundwater flooding. The BGS mapping shows a wide area of potential groundwater flooding below ground level within the Order Limits, and smaller areas of potential flooding at the surface at the east end of the junction.

3.10.5 The digital groundwater flood mapping (GeoSmart, 2019) shows low and moderate risk in the Ockendon link area in the Mardyke floodplain.

3.10.6 The GeoSmart flood risk mapping (GeoSmart, 2019) identifies the A122 Lower Thames Crossing/M25 junction area to be mostly at negligible risk from groundwater flooding. The Western Mardyke is mapped as a low-risk area.

3.10.7 The BGS (BGS, 2017) mapping of the area of the A122 Lower Thames Crossing/M25 junction shows a more complex pattern. Groundwater flooding potential at surface is shown coincident with Mardyke West, but also at the top end of the tributary of the River Ingrebourne and at the top end of a tributary to the Mardyke West through Thames Chase (Hobbs Hole). Potential for groundwater flooding for property below ground is shown in the area of the A122 Lower Thames Crossing/M25 junction's proposed northbound carriageway. Further assessment of this area is presented in a detailed assessment in Section 6.8.

3.11 Groundwater instability risk areas

3.11.1 Geohazards, including ground materials and geomorphological processes that have the potential to cause instability, are presented in Appendix 10.2: Stability Report (Application Document 6.3). Key points are that instability risk areas, associated with groundwater, are as follows:

a. Compressible deposits – very soft soils that may be compressed if loaded

b. Running sand deposits – loosely packed sand layers that become fluidised by flowing water

c. Collapsible deposits – soils that can collapse if they become saturated by water

d. Karst – dissolution features in carbonate rocks (that could collapse)

3.11.2 An assessment of groundwater-related instability risks is presented as part of wider assessments in this report (Section 6.9). However, assessment of ground instability for specific strata and locations is addressed in the Stability Report (Appendix 10.2 in Application Document 6.3).

4 Baseline hydrogeology – groundwater quality

4.1 Overview

4.1.1 Baseline groundwater quality presented in this report comprises discussion of WFD chemical status, regional water types and their influence, saline intrusion, and nutrient concentrations. Discussion of anthropogenic groundwater contamination and baseline exceedances of drinking water standards and environmental quality standards for freshwater is presented in Chapter 10: Geology and Soils (Application Document 6.1).

4.2 WFD chemical status

4.2.1 The status of water bodies is shown in Appendix 14.7 (Application Document 6.3). Key points are shown in Table 4.1.

Table 4.1 WFD groundwater bodies chemical status

Water body name	WFD reference number	Chemical status (Cycle 2, 2019)
South of the River Thames		
North Kent Medway Chalk	GB40601G500300	Poor
North of the River Thames		
Essex Gravels	GB40503G000400	Poor
South Essex Lower London Tertiaries	GB40602G401000	Good
South Essex Thurrock Chalk	GB40601G401100	Poor

4.2.2 The North Kent Medway Chalk water body is currently not achieving good status. The stated reasons for not achieving good status are mostly agricultural and rural land management issues (Environment Agency, 2022a). The Essex Gravels water body is of poor chemical status (Environment Agency, 2022b) due to high nitrate concentrations of the groundwater. This is assessed to be mostly due to diffuse source pollution from agricultural and land management sources. The South Essex Thurrock Chalk status has changed since Cycle 2, 2016, to Poor, due to the ‘general chemical test’ and ‘chemical status element’ (Environment Agency, 2022c).

4.3 Nitrate Vulnerable Zones and drinking water protection

4.3.1 The North Kent groundwater Nitrate Vulnerable Zone is shown in Figure 14.6 (Application Document 6.2). Legally required rules apply for agricultural and landowner use of nitrogen fertilisers and storage of organic manure.

4.3.2 North of the River Thames, there is no groundwater Nitrate Protection Zone. However, part of the study area north of the River Thames lies within a surface water Nitrate Protection Zone (Figure 14.6 (Application Document 6.2)).

4.3.3 Drinking water protection safeguard zones are located around public water supply wells in the North Kent Medway Chalk water body. Their location is also shown in Figure 14.6 (Application Document 6.2).

4.4 Aquifer vulnerability

4.4.1 Vulnerability to aquifer pollution from point contaminative sources (for example, petrol filling stations and historical contaminative land uses) is assessed in Chapter 10: Geology and Soils (Application Document 6.1). Regional contamination issues, including those due to saline intrusion and widespread agricultural practices, are discussed in this report.

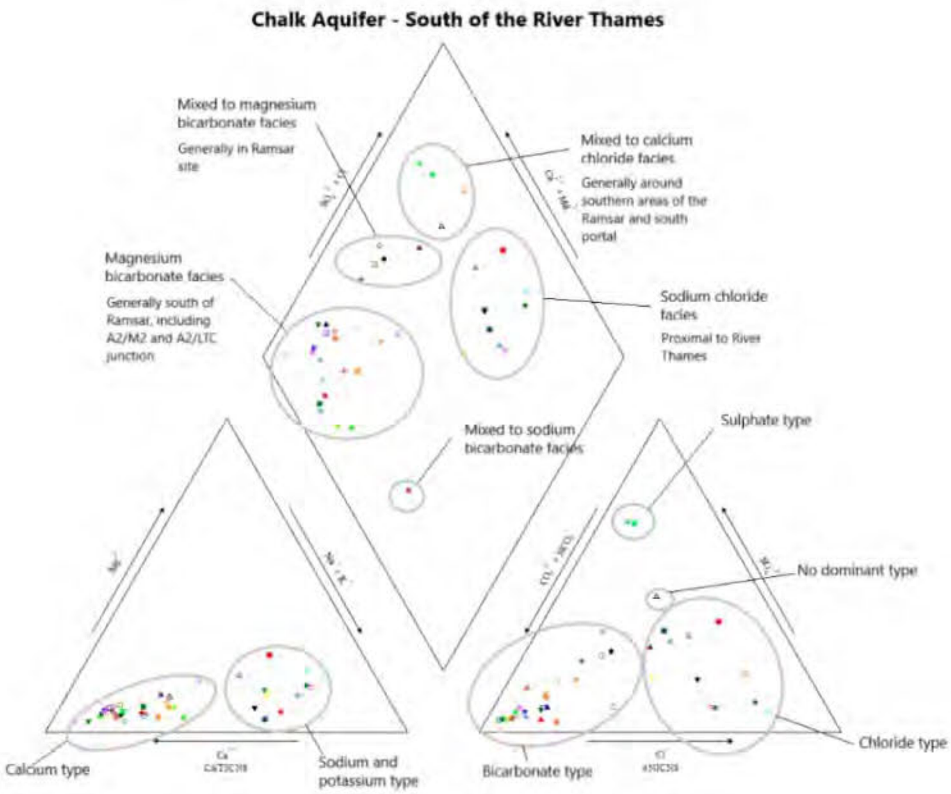
4.4.2 Areas of highest vulnerability to principal aquifers comprise areas where there is unconfined Chalk aquifer which has permeable or no soil cover. A shallow water table increases vulnerability as do fractures since pollution could enter the water table more rapidly. In addition, limited attenuation would be available in the unsaturated zone.

4.5 Groundwater types

4.5.1 Piper plots have been used to determine overall groundwater types, based on the concentrations of specific major ions. Piper plots for different strata and main design elements are presented in Annex F and have used Phase 1 and 2 GI monitoring data. Plots for the Chalk aquifer, south and north of the River Thames, are presented below.

South of the River Thames

Plate 4.1 Piper plot – Chalk aquifer – south of the River Thames



4.5.2 South of the Thames, distinct water types are evident in the Chalk aquifer (Plate 4.1). In the unconfined Chalk aquifer, magnesium bicarbonate water is present, which is typical of recently recharged groundwater.

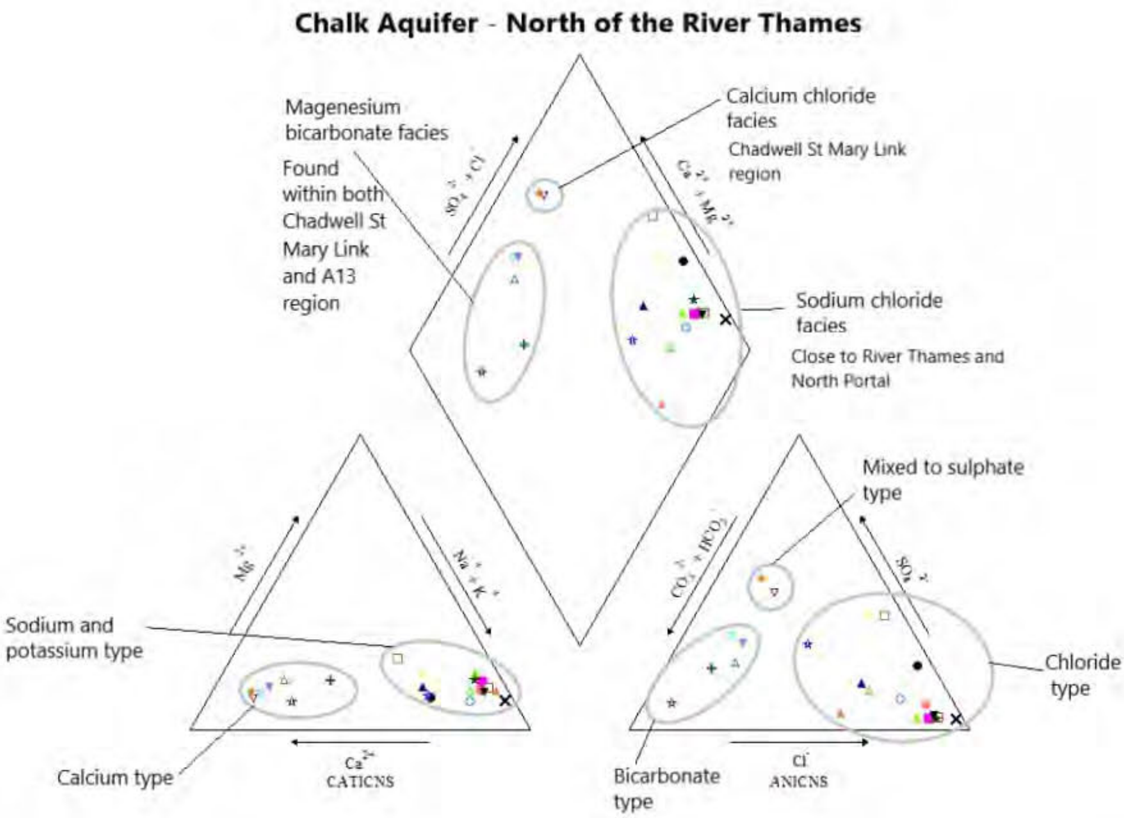
4.5.3 The confined Chalk aquifer water, beneath the Alluvium at the Ramsar site, is sodium chloride water, reflecting saline intrusion effects from the River Thames. Calcium chloride type and mixed water are recorded at the interface between the confined and unconfined chalk southern edge of the Ramsar site, which show cation (positively charged ions) exchange effects due to mixing (either mixing of freshwater and brackish water or mixing of different facies in the transition between unconfined and confined conditions).

4.5.4 South of the River Thames, the River Terrace Deposits show two distinct water types: the sodium chloride type and magnesium bicarbonate type, with some locations in the Ramsar site showing a mixed composition. A sodium bicarbonate type is shown at the southern edge of the Ramsar site by Alluvium boreholes, BH04006 and BH04007, which are installed in shallow Alluvium. The Alluvium shows a sodium chloride type nearer to the River Thames.

North of the River Thames

4.5.5 North of the Thames, at Tilbury Marshes, the Chalk aquifer shows a sodium chloride composition (Plate 4.2) where it is confined by overlying Alluvium and Made Ground. The River Terrace Deposits also show a sodium chloride composition here (Annex F). This composition may be indicative of saline intrusion although landfill may also influence chloride concentrations here (Section 5.6).

Plate 4.2 Piper plot – Chalk aquifer – north of the River Thames



4.5.6 In the Chadwell St Mary link area and the Linford public supply well, the water quality of the Chalk aquifer becomes magnesium bicarbonate, which is typical of recently recharged water. This is consistent with a main recharge area shown nearby by Environment Agency groundwater modelling (Amec Foster Wheeler, 2016).

4.6 Saline intrusion

4.6.1 Saline intrusion can occur naturally in coastal and estuarine aquifers where seawater or tidal water is in hydraulic connection with groundwater. The different densities of the waters mean that the interface is a diffuse zone, but the position of the zone may vary (Kelly, 2005).

4.6.2 Groundwater becomes more sodium and chloride rich due to saline intrusion. Saline intrusion also increases concentrations of magnesium, potassium and sulphate in more saline groundwaters (Smedley et al., 2003).

4.6.3 Saline intrusion has historically been caused by water from the tidal River Thames entering the Chalk aquifer. Low groundwater levels (especially where chalk is at outcrop beneath the river) increased intrusion in the last century. Lowest water levels, due to extensive over abstraction in the London area, occurred in 1965 (Environment Agency, 2017).

4.6.4 The current baseline saline intrusion extent is presented as various plots in Plate 4.3 and in Annex F and Annex G.

4.6.5 The future baseline (without the Project) is likely to include raised water levels in the River Thames. Saline intrusion of the Chalk aquifer could increase, depending on natural and anthropogenic (abstractions) influences on inland groundwater levels (Section 2.5).

Filborough Marshes area of the Ramsar site

4.6.6 Current baseline groundwater quality is represented by the GI data and shows highest values of chloride and electrical conductivity nearest to the River Thames. Upgradient groundwater samples show low chloride and conductivity values, confirming fresh groundwater in the upgradient Chalk aquifer (Annex F and Annex G.).

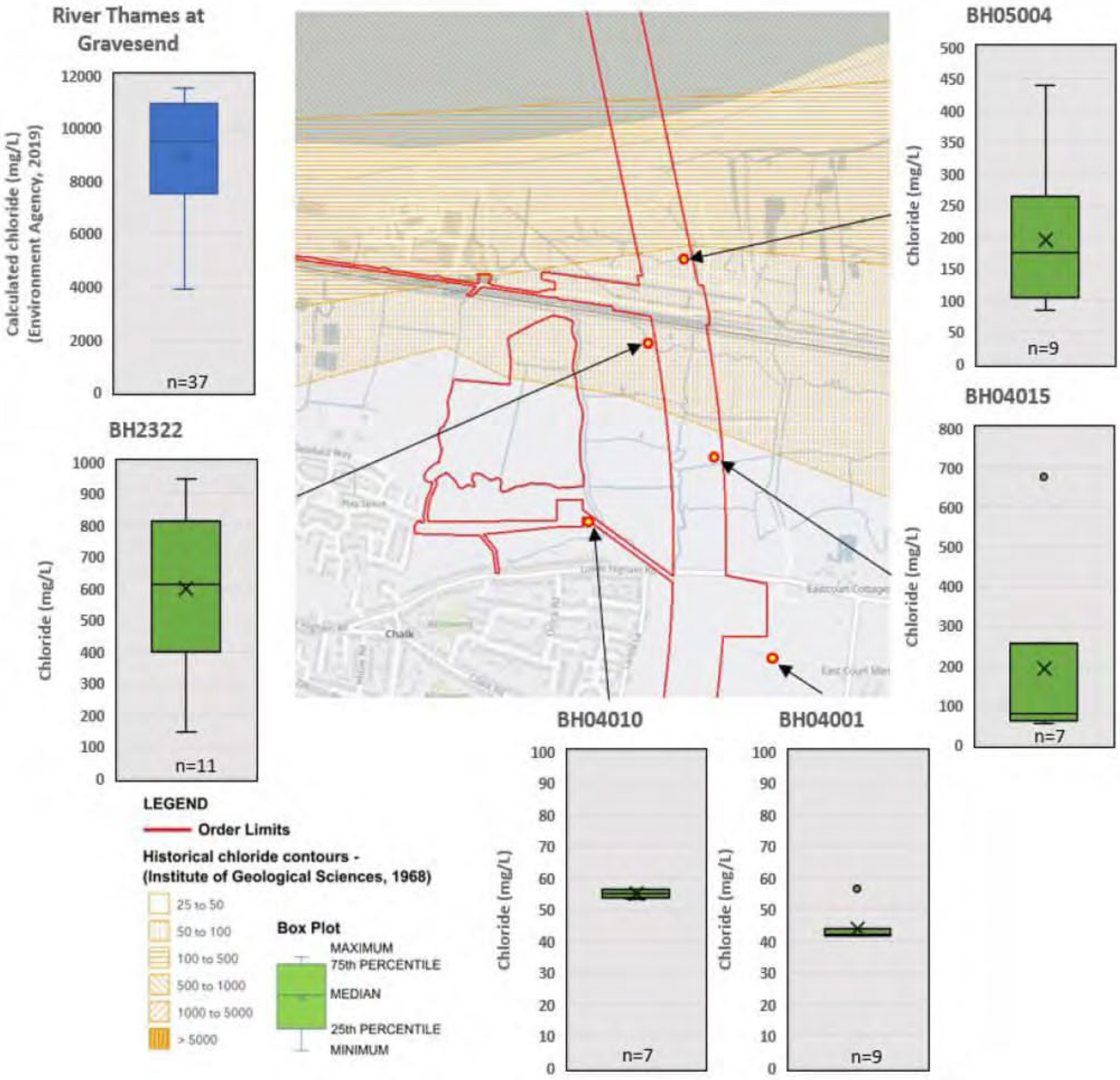
4.6.7 Generally, surface water records the lowest electrical conductivity values and chloride concentrations at the southern edge of the Ramsar site. The Water Features Survey Factual Report (Appendix 14.2, Application Document 6.3) presents the surface water data.

4.6.8 Shallow Alluvium groundwater chloride concentrations increase with distance towards the River Thames, beyond the North Kent Railway line. Chloride concentrations are highest in the deep Alluvium.

4.6.9 Beneath the Alluvium of the Ramsar site, the deep aquifers (River Terrace Deposits underlain by the Chalk aquifer) show varied values, both spatially and between sampling rounds, indicating saline intrusion but of mixed distribution. Freshwater (approximately 790 micro siemens per centimetre, µS/cm) was abstracted during the August 2019 five-day constant pumping test in the Ramsar site.

4.6.10 Plate 4.3 (adapted from Annex F) shows that during the GI (current baseline) chloride concentrations were found to be higher than historical mapping (Institute of Geological Sciences, 1968), within the Order Limits. A box plot versus northing plot is also shown in Annex F. Comparison of the GI versus the historical contours suggests increased saline intrusion.

Plate 4.3 Historical and current baseline chloride (Chalk aquifer) – south of the River Thames



Note: historical chloride contours show chloride concentrations as mg/L. Box plots are based on data from Phase 1 and 2 GI monitoring between September 2018 and November 2020. Coloured circles and triangles on the map comprise exploratory holes.

4.6.11 Comparison with River Thames water quality data (Environment Agency, 2019d) shows that current Chalk aquifer concentrations beneath the Ramsar site are lower than River Thames' calculated chloride concentration. Calculated chloride concentrations of the River Thames are shown in Plate 4.3. Detailed assessment of the Project's potential to increase saline intrusion is presented in Section 7 and Annex J. A conservative sea water chloride concentration is used in the assessment.

4.6.12 Borehole BH2322 has been sampled monthly and tested for chloride between January 2021 and February 2022. The results are similar to the ones reported on the box plots above, with a maximum chloride concentration reaching 1100 mg/L and an average at 747 mg/L.

Tilbury Marshes area and proposed North Portal

4.6.13 Current baseline is represented by the GI groundwater monitoring (plots are included in Annex F). In the North Portal area, values of chloride and electrical conductivity may be influenced by landfill leachate (Chapter 10: Geology and Soils (Application Document 6.1)) as well as saline intrusion effects. A semi-quantitative differentiation between landfill and seawater influences is discussed further below.

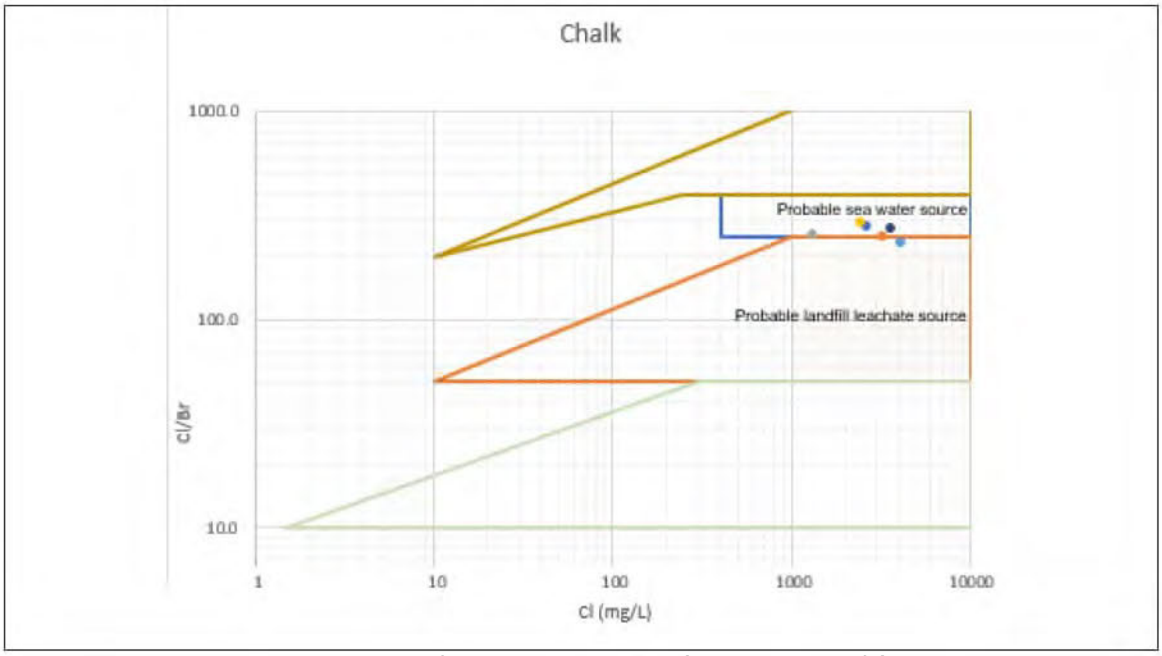
4.6.14 Current baseline data show that chloride north of the River Thames is greatest near the River Thames. Values in the Made Ground are generally high, with no strong trend further away from the River Thames. The underlying Alluvium shows a high degree of variation. The River Terrace Deposits and Chalk aquifers also show variability. Available data shows values with a notable decrease of chloride concentrations north of the Tilbury Loop railway line.

4.6.15 Annex F shows that current baseline data shows higher chloride concentration compared with the 1965 historical chloride contours (Institute of Geological Sciences, 1968), presented in a mapped area and as chloride box plots versus northings.

4.6.16 Comparison with River Thames water quality data (Environment Agency, 2019d) shows that all Chalk aquifer groundwater has a lower chloride concentration than that calculated for the River Thames (using the same river quality data as discussed above).

4.6.17 A check on landfill influence on chloride concentrations using a chloride/bromide ratio approach (Klassen, Allen and Kirste, 2014) has been used and plots are presented in Annex F. The plots for all the Made Ground groundwater samples indicate a landfill source with a less clear trend, trending towards landfill, for Alluvium groundwater. Over half of the available Chalk aquifer ratio plots indicate a seawater origin (Plate 4.4, adapted from Annex F). The one Chalk aquifer borehole tentatively shown as having a landfill leachate source is borehole OH07035, which is beneath Goshems Landfill and approximately 230m west of East Tilbury Landfill.

Plate 4.4 North Portal Chalk aquifer chloride/bromide versus chloride plot



Note: concentrations are based on data from Phase 1 and 2 GI monitoring of September 2018 to January 2020

4.7 Nutrient contaminants

4.7.1 Phosphorus and nitrogen are the main nutrients typically assessed. Sewage effluent and agriculture are the largest phosphate sources (Environment Agency, 2019e). Agriculture is the largest nitrate source in the study area (Section 4.2). Both nutrients can cause eutrophication in surface water bodies. Nitrogen is associated with eutrophication of freshwater and saline waters. Phosphorus may play a large role in eutrophication of estuaries (Environment Agency, 2019e).

4.7.2 Groundwater concentrations of nitrogen and phosphorus are important because of potential seepage to surface water. In addition, drinking water resource protection requires protection against nitrate pollution. The drinking water standard for nitrate is 50mgNO3/L (Schedule 1, Table B of the Water Supply (Water Supply (Water Quality) Regulations, 2016). Generally, phosphorus does not cause widespread pollution problems in groundwater because of attachment to clay or iron minerals.

4.7.3 Nitrate concentrations in groundwater can fluctuate seasonally and the phenomena appears to be associated with wetter winter conditions bringing more nitrate to or near the water table (BGS, 2022b). Denitrification decreases nitrate concentrations in confined sections of the Chalk aquifer to reduced species (Smedley *et al.*, 2003), such as ammoniacal nitrogen.

4.7.4 Based on river water testing at Gravesend, the River Thames' average nitrate concentration was 17mgNO3/L from 1997 to 2008 and average phosphate concentration was 1.3mg/L from 1997 to 2004 (Environment Agency, 2019d).

South of the River Thames

4.7.5 Annex F plots summarise nitrate concentrations south of the River Thames from the M2 junction 1 to the Ramsar site and the River Thames. Baseline GI groundwater monitoring confirms lowest concentrations beneath high ground of the chalk hills of the North Downs, although there are fewer monitoring locations here. Highest concentrations appear to be between the Project's South Portal area and the Ramsar site. Downhill (and down groundwater gradient) beneath the Ramsar site, values are generally less, which may indicate denitrification, due to reduced oxygen in the confined aquifer. Beneath the Ramsar site, the confined River Terrace Deposits and Chalk aquifer record nitrate concentrations that range to higher concentrations (Annex G) than the above river water concentrations.

4.7.6 Annex F plots of phosphorus (as phosphate) concentrations show concentrations that are generally below or near the limit of detection but markedly increase north of the landward boundary of the Ramsar site, towards the River Thames. Here phosphate concentrations range to higher concentrations than the above River Thames water concentrations.

North of the River Thames

4.7.7 The summary plot of concentrations of nitrate with distance, as well as a table of results, are shown in Annex F. These show mostly undetected nitrate concentrations beneath the Tilbury Marshes and the Project's North Portal area. Upper concentrations of ammoniacal nitrogen (related to ammonia) are very high and may coincide with the low values of nitrate, indicating reducing conditions and possible landfill leachate influence (Chapter 10: Geology and Soils (Application Document 6.1)).

4.7.8 North of the Tilbury Loop railway line in the Tilbury Viaduct area, all three River Terrace Deposit boreholes record very high nitrate concentrations which exceed the drinking water standard of 50mgNO3/L (Water Supply (Water Quality) Regulations, 2016). Further north, in the Chadwell St Mary link, one River Terrace Deposit beside Muckingford Road records a very high nitrate concentration and all three Thanet Formation boreholes also record very high nitrate concentrations which exceed the drinking water standard. Overall, the readings may be indicative of the water quality flowing southwards (and outwards) from the shallow Thameside aquifers. Conversely, the Chalk aquifer in the Chadwell St Mary link area records nitrate concentrations that are lower and are less than the drinking water standard.

4.7.9 In the Ockendon link area, including the Mardyke floodplain, locally high nitrate concentrations have been observed in shallow strata comprising the Alluvium and Head deposits. The A122 Lower Thames Crossing/M25 junction also shows nitrate concentrations above the drinking water standard in the River Terrace Deposits.

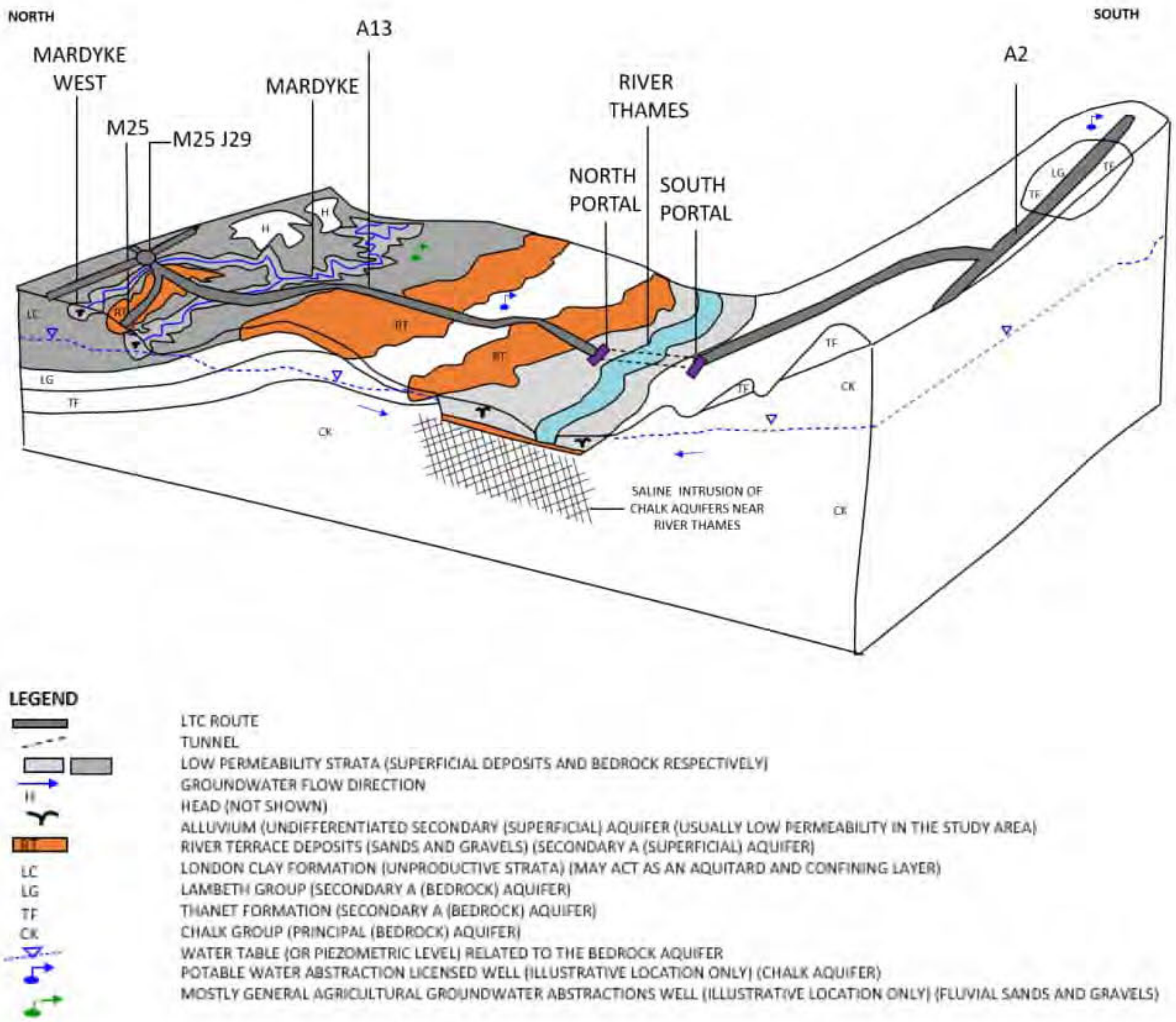
4.7.10 Groundwater phosphate concentrations, north of the River Thames, are much lower than recorded in the river.

5 Hydrogeological conceptual model (baseline)

5.1 Whole study area

5.1.1 Plate 5.1 presents a sketch of the hydrogeological baseline CSM for the whole study area.

Plate 5.1 Sketch hydrogeological CSM for the whole study area



5.1.2 Hydrogeological CSMs are described in this report section for:

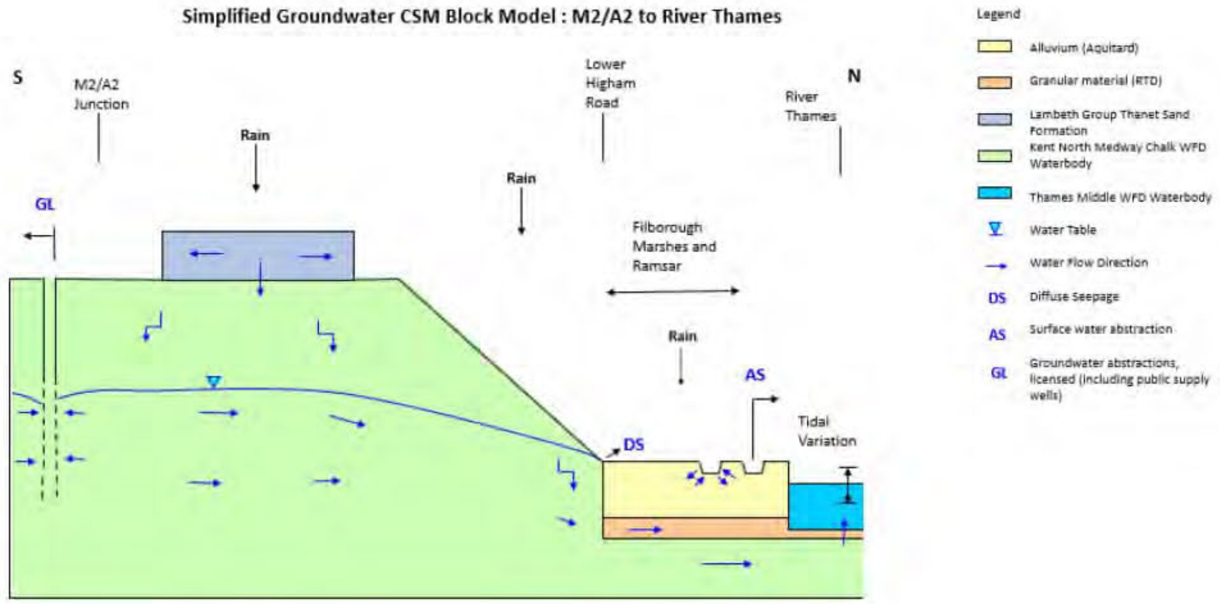
a. South of the River Thames
b. River Thames to the A13
c. A13 to the M25

5.1.3 More detailed baseline CSMs are presented for specific areas of interest where detailed assessments have been conducted, comprising: the Ramsar site (south of the River Thames); the North Portal area; and the A122 Lower Thames Crossing/M25 junction. Key points are shown in this section and further CSM interpretation used in the numerical models for south of the Thames and north of the Thames is presented in the detailed assessments contained within the Annexes (refer to the table of contents for detailed annexes).

5.2 South of the River Thames

5.2.1 Plate 5.2 presents the key features of the baseline hydrogeological CSM for south of the River Thames. The image is schematic. A detailed CSM for the Ramsar site and the uphill area of the Project's South Portal of the main tunnel crossing is presented in Figure 3. Details of the CSM used in the numerical groundwater model for south of the Thames are shown in Annex J.

Plate 5.2 Sketch hydrogeological CSM – south of the River Thames



5.2.2 Attributes of the baseline hydrogeological CSM are collated in Table 5.1. Key features, as illustrated in Plate 5.2, are as follows:

a. The Chalk aquifer is dominated by fracture/fissure flow, enhanced locally.

b. The water table is deep at the North Downs, approximately 41.2mbgl to 55.5mbgl beneath the A2, with a thick unsaturated zone above.

c. Diffuse seepage may occur along the southern edge of Filborough Marshes (Ramsar site) but flow rates are small due to the low Chalk aquifer upgradient groundwater levels (Section 3.3) and lower Alluvium permeability.

d. Upwards seepage from beneath Filborough Marshes is small due to the overlying clayey Alluvium (of low horizontal and lower vertical permeability) and insufficient piezometric level in the Chalk aquifer.

e. The water balance of the Filborough Marshes of the Ramsar site is dominated by rainfall, evapotranspiration, surface water and managed water levels (drainage ditches, pumping, a weir and small dams).

f. Groundwater flows, under the Alluvium, to the River Thames.

Table 5.1 Baseline CSM summary – south of the River Thames

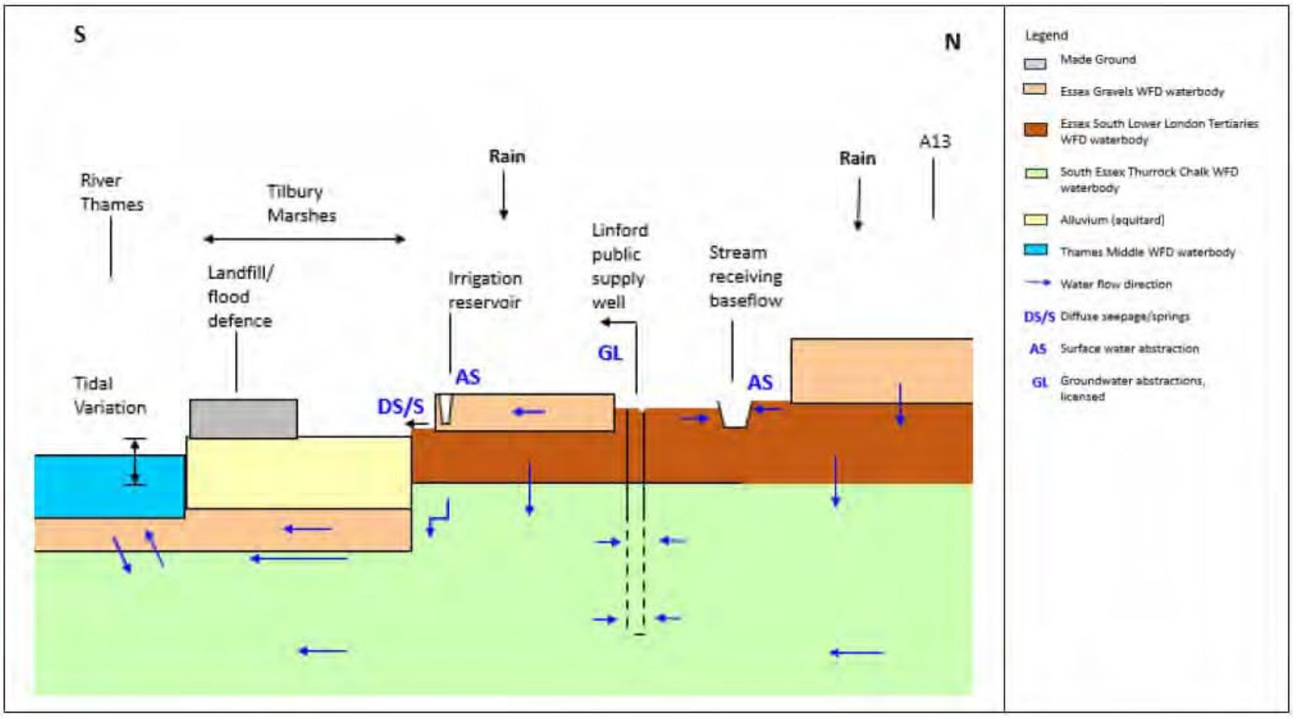
Attribute	Information
Summary	The hydrogeology is dominated by the Chalk aquifer (principal aquifer). This is the source for significant public water supply well abstractions. Along the A2, there are outcrops of overlying Lambeth Group and Thanet Formation (Secondary A aquifers) (unconsolidated bedrock), which may have perched water. This could locally feed small surface water features. There are no significant superficial aquifers here.
WFD water body	North Kent Medway Chalk.
Catchment summary	Rainfall recharge on the Chalk aquifer outcrop (Section 2.2). Outflow at North Kent marshes and the River Thames. Chalk aquifer is unconfined beneath the North Downs chalk hills and is confined beneath the North Kent marshes. Groundwater divide at Shorne Woods, influenced by seasonal and abstraction variation.
Aquifer layering	Lambeth Group and Thanet Formation (Secondary A aquifers) crop out, and overlie the chalk, in the Shorne Woods, Jeskyns Community Woodland area and smaller areas further west along the A2. These have layering of sand, silts and clays. The Chalk aquifer (Seaford Chalk Formation underlain by the Lewes Nodular Chalk Formation) is partly layered with sub-horizontal sheet flint layers, marl beds and solution enhanced fissures.
Groundwater levels	Perched water may be present in the Palaeogene strata. The Chalk aquifer water table is tens of metres below ground surface beneath the North Downs, near the A2. Large seasonal water-level fluctuations (up to approximately 5m) are possible in the unconfined Chalk aquifer due to typically low storage characteristics of the aquifer. The water table is deep below the A2. Falling topography northwards means that the water table nears ground surface at the bottom and the Chalk aquifer becomes confined beneath the North Kent marsh area. Tidal variation of Chalk aquifer and gravels groundwater levels is observed beneath the marsh area.
Groundwater flow paths	Chalk aquifer is dominated by fracture flow with solution enhancement along sub-horizontal marl layers, sheet flints and palaeo water tables. Dry valleys may represent areas of increased transmissivity. Local karst features and sediment filled solution hollows may exist.
Groundwater interaction with surface water and dependent ecosystems	Several ponds are located on Palaeogene strata (Shorne Woods Country Park and the Cobham Hall ponds) and here perched groundwater may feed these features as well as rainfall. Diffuse seepage (depending on groundwater levels) may occur along the southern edge of the Ramsar site, at least during higher water-level periods, but flow rates are small due to the low Chalk aquifer upgradient groundwater levels (Section 3.3). Discrete springs have not been observed here. The water balance of the Ramsar site is dominated by rainfall, evapotranspiration and surface water and local man-made controls of surface water including drainage

Attribute	Information
	ditches, pumping, a weir and dams (Section 1.7 and Section 5.5). Therefore, the ordinary water courses and the main rivers in the Ramsar site do not receive significant baseflow from groundwater.
Water quality – natural	Unconfined Chalk aquifer water quality records show the groundwater is a calcium bicarbonate water, typical of recently recharged water. Water quality records, from the confined River Terrace Deposits/chalk, at the Ramsar site, show the groundwater is a sodium chloride water (Section 4), probably reflecting saline intrusion effects from the River Thames. Saline intrusion of the Chalk aquifer beneath Filborough Marshes is indicated. However, fresh to brackish Chalk aquifer groundwater beneath the Ramsar site is present (Section 4).
Water quality – man-made influences	Baseline nitrate concentrations in the Chalk aquifer, south of the Thames, show elevated nitrate which may be related to agricultural practices (Section 4.2). Drinking water safeguard zones and a Nitrate Vulnerability Zone are located within the study area (Figure 14.6 (Application Document 6.2)).

5.3 River Thames to the A13

5.3.1 Plate 5.3 presents the key features of the baseline hydrogeological CSM for the River Thames to the A13. The image is schematic. A detailed CSM for the Tilbury Marsh area (the location of the Project's North Portal) is presented in Figure 4.

Plate 5.3 Sketch hydrogeological CSM – the River Thames to the A13



5.3.2 Attributes of the baseline hydrogeological CSM are collated in Table 5.2. Key features, as illustrated in Plate 5.3, are as follows:

a. The confined Chalk aquifer, beneath Tilbury Marshes, is most permeable in the top part of the aquifer and water flows southward to the River Thames.

b. Near the northern boundary of Tilbury Marshes, groundwater appears to be the main inflow to an irrigation reservoir and may also contribute to downstream ditches (Goshems Landfill and Low Street Pit).

c. Linford public supply well is artesian and, when pumped, influences Chalk aquifer water levels in the Chadwell St Mary link area.

d. Partially perched water has been recorded in the Thanet Formation at Chadwell St Mary link, and baseflow to Gobions Sewer may occur.

e. A13/A122 junction Boyn Hill Gravel Member is expected to be generally under drained and dry but perched water is possible where underlain by clayey bedrock.

f. A13/A122 junction Lambeth Group and Thanet Formation may contain perched groundwater of up to 20mAOD.

g. Groundwater levels in the Chalk aquifer increase northwards from the River Thames and peak at the A13/A122 junction.

Table 5.2 Baseline CSM summary – River Thames to the A13

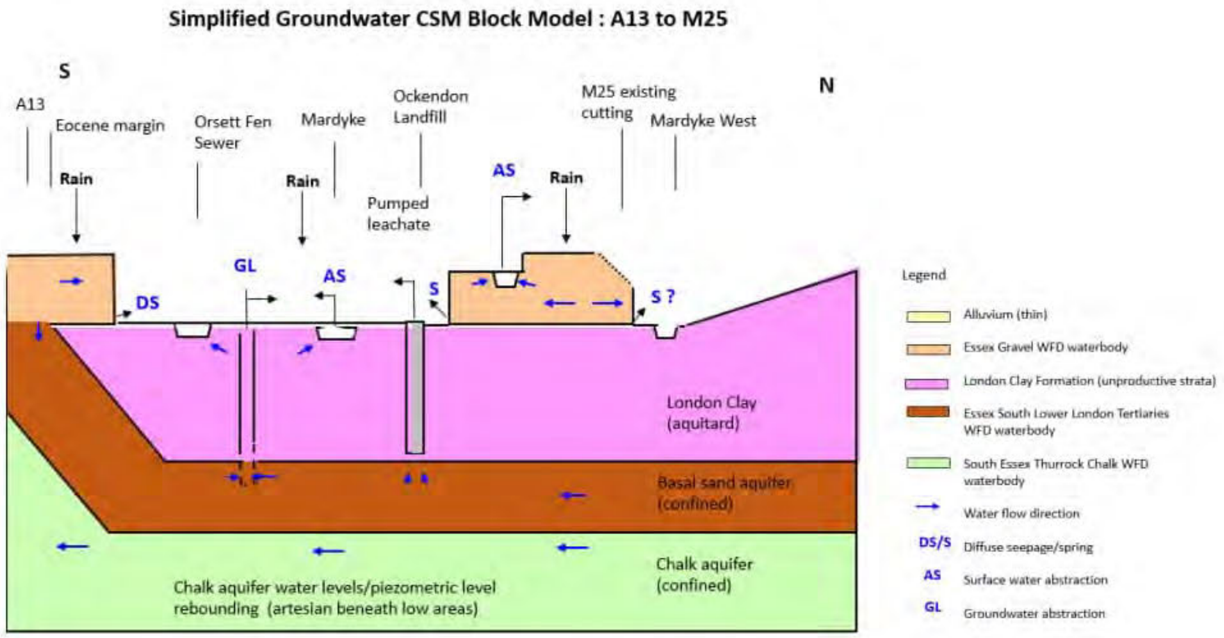
Attribute	Information
Summary	Low-lying marsh area, located beside the River Thames, comprises thick Alluvium, thinning northwards, over gravels and the confined Chalk aquifer. Landfills are present. Further north, Thanet Formation and Lambeth Group (Secondary A aquifers) overlie the Chalk aquifer (principal aquifer) in shallow valleys (Chadwell St Mary link), with River Terrace Deposits on higher ground, including at the A13.
WFD water bodies	Essex Gravels, South Essex Lower London Tertiaries (Lambeth Group and Thanet Formation) and the South Essex Thurrock Chalk.
Catchment summary	Outflow to the River Thames, from the Chalk and Lower London Tertiaries, is relatively low (Amec Foster Wheeler, 2016) and is limited due to groundwater flow directions being influenced by groundwater abstractions drawing water towards abstractions (if used). River Terrace Deposits and the Lower London Tertiaries act as leaky aquifers and recharge the Chalk aquifer. Greatest recharge occurs to the unconfined and semi-confined Chalk aquifer in the Chadwell St Mary, Linford area. Most occurs as direct recharge to the unconfined Thameside Chalk, with Secondary contributions from vertical leakage from overlying strata and stream leakage (Amec Wheeler Foster Wheeler, 2016). A Chalk aquifer groundwater divide (during dry periods) is located east to west through Stanford-le-Hope and to the north of Mardyke (Amec Foster Wheeler, 2016).
Aquifer layering	Lambeth Group has layers of sand, silts and clay. Thanet Formation locally has a basal stiff silt, occasionally clay (Phase 2 GI). Partial perched water conditions and locally reduced leakage to the chalk may occur as a result. The unconfined and semi-confined chalk, south of the Eocene margin, exhibits the highest transmissivity of the south Essex region possibly due to enhanced carbonate solution induced by higher recharge and groundwater flow rates. Typically, the upper parts of the Chalk aquifer are more permeable than deeper parts.
Groundwater levels	In the Tilbury Marshes area, there are perched and variable water levels in the Made Ground, shallow water in the Alluvium and shallow piezometric level of the confined Chalk aquifer. Groundwater-level tidal fluctuation occurs in the Chalk aquifer and the gravel aquifer. Linford public supply well is artesian and, when pumped, influences Chalk aquifer water levels at Chadwell St Mary link. Partially perched water may exist in the Thanet Formation. A13 Boyn Hill Gravel Member is expected to be generally under drained and dry but perched water is possible where underlain by clayey bedrock. Lambeth Group and Thanet Formation may have perched water.

Attribute	Information
	Chalk groundwater levels rise towards the north and peak at the A13/A1089/A122 Lower Thames Crossing junction (7m higher than distant Environment Agency monitoring boreholes). Perched groundwater levels also appear to form a mounded distribution of maximum 20mAOD in the Thanet Formation at the junction.
Groundwater flow paths	Groundwater flow in the Chalk aquifer is predominantly southwards and towards abstractions such as at Linford (when in full operation). Groundwater flow in the Chalk aquifer is principally by fracture flow. Solution enhancement of fissures and fractures along sub-horizontal marl layers, sheet flints and palaeo water tables may have caused locally higher groundwater flow zones.
Groundwater interaction with surface water and dependent ecosystems	Medium groundwater dependency of ditches at Goshems Farm Landfill and Low Street Pit is indicated by NVC mapping. The Mucking Flats and Marshes SSSI swamp habitat vegetations shows low groundwater dependency and is not mapped as a GWDTE by the (Environment Agency, 2020b) (Section 3.9). Groundwater appears to be the main inflow to the Cole irrigation reservoir at Low Street. This is used for licensed agricultural water supply. Water from immediately the other side of the Tilbury Loop railway line joins the network of water-filled ditches in the Tilbury Marshes (main river and ordinary water courses) and therefore may have a groundwater component fed from groundwater emerging from the southern margin of the River Terrace Deposits outcrop. Baseflow may occur at Gobions Sewer, varying with seasonal groundwater levels and abstraction (Linford). However, low groundwater dependency is indicated by the swamp habitat vegetation here. No watercourses are present near the A13/A1089/A122 Lower Thames Crossing junction.
Quality	Essex Gravels (River Terrace Deposits) has a poor chemical status due to nitrate. The Chalk aquifer shows no saline intrusion at Linford public supply well (Section 4).

5.4 A13 to the M25

5.4.1 Plate 5.4 presents the key features of the baseline hydrogeological CSM for the area between the A13 and the M25, along the proposed Project route. The image is schematic. Detailed conceptual models for the A13 and M25 are presented in Annex N and Annex L, respectively.

Plate 5.4 Sketch hydrogeological CSM – A13 to M25



5.4.2 Attributes of the baseline hydrogeological CSM are collated in Table 5.3. Key features, as illustrated in Plate 5.4, are as follows:

a. North of the Eocene margin, the London Clay Formation deeply confines the Chalk aquifer, minimising hydraulic connection to shallow ground.

b. The Mardyke floodplain comprises thin cohesive Alluvium underlain by shallow London Clay Formation, as indicated by the Phase 2 GI.

c. Farm abstraction wells at Orsett Fen appear to abstract water from the Harwich Formation, underlying the London Clay Formation (not fluvial sands and gravels as shown on the licence details) (Section 3.3).

d. Pumping at Ockendon Landfill acts to keep the leachate head lower than the basal sand groundwater (Golder Associates, 2015) (Chapter 10: Geology and Soils (Application Document 6.1)).

e. River Terrace Deposits (Boyn Hill and Lynch Hill members), located at the A122 Lower Thames Crossing/M25 junction, are water bearing and are layered glacial and interglacial deposits (Section 5.7).

f. Springs, ponds and a groundwater drainage system are located at North Ockendon and are associated with the River Terrace Deposits. They may be related to streams used for agricultural surface water abstraction and may contribute water to ordinary watercourses in the Cranham Marsh LNR, Fields South of Cranham Marsh SINC and the Thames Forest Centre SINC.

Table 5.3 Baseline CSM summary – A13 to the M25

Attribute	Information
Summary	North of the A13 the hydrogeology is dominated by the broad valleys of the Mardyke and by River Terrace Deposits (Essex Gravels) and Head Deposits. North of the Eocene margin, the Chalk aquifer and overlying basal sands are confined by thick London Clay Formation (unproductive strata). Bagshot Formation and Claygate Beds crop out at the north end of the study area. The Chalk aquifer is deeply confined.
WFD water bodies	Essex Gravels is mapped (Section 3.5) as underlying the Mardyke valley area and as several outcrops near the M25. The Phase 2 GI boreholes suggest that the Essex Gravels are absent beneath the Mardyke, where investigated.
Catchment summary	The spatial extent of the superficial aquifers appears to be patchy due to lithological variability of glacial and interglacial deposits. Also, the aquifer may be compartmentalised by historical gravel pit excavations and subsequent landfilling or flooding of pits. Recharge to the River Terrace Deposit aquifers is expected to be most at gravel outcrops on terrace landforms. Reduced hydraulic connection is expected between different terrace deposit members.
Aquifer layering	Within the River Terrace Deposits glacial and interglacial deposits are dominantly granular and cohesive, respectively. Each member forms a terrace landform of different elevation and hydraulic continuity between them may be limited.
Groundwater levels	At the Mardyke, shallow water may be encountered from waterlogging of poorly draining Alluvium soils and weathered London Clay Formation. River Terrace Deposits have been encountered as water bearing during the Phase 2 and Phase 3 GI near the A122 Lower Thames Crossing/M25 junction (Annex L). Locally confined behaviour is shown in some granular layers. The Harwich Formation is present at depth, below the London Clay Formation beneath the Mardyke floodplain and exhibits artesian (piezometric level above the ground surface) behaviour (Phase 2 GI). Historical records show the Chalk aquifer was artesian beneath the Mardyke floodplain and recent monitoring indicates that the basal sands and Chalk aquifer piezometric levels are rising due to rebound (Section 3.3).
Groundwater flow paths	Groundwater flow within water-bearing superficial deposits is expected to vary locally, depending on lithology, interaction with streams and man-made excavations. Interflow in the weathered, upper parts of outcrop of the London Clay Formation contributes to flows in the Mardyke (Amec, 2016). Lateral groundwater flows in the confined Chalk and Lower London Tertiaries are generally southwards but of low flow rate (Amec Foster Wheeler, 2016).

Attribute	Information
Groundwater interaction with surface water and dependent ecosystems	Springs are reported near North Ockendon, associated with River Terrace Deposits (Section 3.6). The spring at North Ockendon appears to feed the three ponds (relics of an old moat) at the Hall Farm moat, paddock and St Mary Magdalene Churchyard SINC (Section 3.6). This spring and groundwater collected from a deep drainage system are said to be the sources of a licensed agricultural surface water abstraction (Section 3.6). Surface water receives increased flow from shallow groundwater during wet conditions (Amec, 2016). No interaction between the confined Chalk aquifer and surface water occurs. Cranham Marsh LNR (Section 3.9), near the top end of the Ingrebourne catchment, includes discrete areas of vegetation habitat which indicate high groundwater dependency. Essex Wildlife Trust (2022) describe a seasonal stream that runs through the middle of the LNR but that is kept wet mainly by groundwater (Section 3.6).

5.5 Ramsar site (south of the River Thames)

5.5.1 The Ramsar site lies above the proposed main tunnel crossing. The site is of international importance and has therefore been subject to detailed assessments. Studies have informed the development of the preliminary design, and as a result the South Portal would be above the water table, uphill of the Ramsar site (Section 3.3). Therefore, no groundwater control measures (including dewatering) would be needed. The baseline CSM for the area between and including the proposed South Portal and Ramsar site is presented in Figure 3 and further interpretation of the CSM used for the numerical groundwater model is presented in Annex J. GI (Section 3.3), groundwater monitoring (Annex G), surface water monitoring (Section 1.7) and vegetation surveys (Appendix 8.2 (Application Document 6.3)) have greatly improved knowledge of the hydrogeology and ecohydrology of the Ramsar site, south of the River Thames.

5.5.2 Figure 3 summarises water flows and levels, and the major groundwater flow paths. A detailed analytical water balance, including use of MORECS data, assesses the proportion of inflows and outflows of the part of the Ramsar site that is in the Order Limits (Annex E). Distribution of hydraulic conductivity, layering and spatial variation of hydrogeological units, tidal response of groundwater levels, and interconnection or otherwise between hydrogeological units is explored in the numerical modelling assessment (Section 6.5). Key features of the baseline CSM, as illustrated in Figure 3, are as follows:

a. Groundwater flow in the Chalk aquifer is generally northwards, flowing beneath the Alluvium soils of the Ramsar site towards the River Thames.

b. Upgradient Chalk aquifer water levels are of very shallow gradient and only of slightly greater elevation than water levels at the Ramsar site.

c. Diffuse seepage of Chalk aquifer groundwater at the southern boundary of the Ramsar site is expected to be small or absent due to the small hydraulic gradient. No springs are visible at Filborough Marshes.

d. Upwards seepage of Chalk aquifer water levels to the shallow water system of the Ramsar site is small or absent due to the generally low (vertical) hydraulic conductivity of Alluvium soils and the small hydraulic head difference.

e. The shallow water system of Filborough Marshes and Shorne Marshes of the Ramsar site is dominated by rainfall, evapotranspiration and surface water management. Groundwater is a small component of inflow.

f. Project vegetation habitat surveys show low groundwater dependency of marginal habitats alongside ditches and no groundwater dependency of aquatic vegetation at Filborough Marshes and Shorne Marshes (Section 3.9).

g. Groundwater flow beneath the Alluvium soils of the Ramsar site follows preferential flow paths of high hydraulic conductivity within granular River Terrace Deposits and particularly within discrete zones within the Chalk aquifer.

h. High hydraulic conductivity zones in the chalk are located immediately upgradient (south) of the Alluvium and, beneath the Ramsar site, along sub-horizontal karstic zones within the Chalk aquifer, some of which coincide with the interpreted Belle Tout beds.

i. Groundwater flow in the Chalk aquifer may seep or up well into the River Thames where chalk or gravels are exposed at the riverbed.

j. Hydraulic connection between the River Thames and the River Terrace Deposits and the Chalk aquifer causes tidal variation of water levels and saline intrusion.

k. Saline intrusion is evident in the Chalk aquifer beneath the Ramsar site, but freshwater is found immediately up the hydraulic gradient (Section 4).

5.6 North Portal

5.6.1 The Tilbury Marshes area (where the North Portal would be located) has been assessed in detail (Section 6.7) and the CSM used in the numerical groundwater model for north of the Thames is shown in Annex K. Detailed hydrogeological assessment is required because the proposed bored tunnel portal would be beneath the piezometric level in the aquifer system comprising the River Terrace Deposits and the Chalk aquifers, and therefore groundwater control would be needed for the North Portal excavation and construction of the North Portal ramp. In addition, existing groundwater contamination is present due to historical landfills on top of the Alluvium of the marshes (Chapter 10: Geology and Soils (Application Document 6.1)) and there is potential to increase saline intrusion (Section 7).

5.6.2 Figure 4 summarises water flows and levels, and the major groundwater flow paths. Distribution of hydraulic conductivity, layering and spatial variation of hydrogeological units, tidal response of groundwater levels, and interconnection or otherwise between units is explored in detail in the numerical modelling assessment (Section 6.7). In addition, saline intrusion and contaminant particulate tracking modelling is assessed in Section 7. Key features of the baseline CSM, as illustrated in Figure 4, are as follows:

a. Groundwater flow in the Chalk aquifer is generally southwards, flowing beneath the Alluvium soils of Tilbury Marshes towards the River Thames.

b. The ditch network includes main river flow, probably partly groundwater fed from the groundwater seepage zone at the northern boundary of the marsh, as indicated by seepage at Low Street irrigation reservoir (Section 3.6) and vegetation surveys (Section 3.9). Some groundwater seepage from the

Made Ground into the surface water drainage network may also occur from discontinuous perched water horizons in the Made Ground.

c. Made Ground, particularly of the landfill areas, represents historical and recent filling on top of Alluvium and the old marsh ground surface.

d. Laterally discontinuous perched groundwater has been observed in the Made Ground (Phase 2 GI).

e. Alluvium shallow soils exhibit shallow groundwater that may have local hydraulic connection with surface water ditches, where the Alluvium is granular. Water levels of the shallow Alluvium soils show no tidal fluctuation.

f. The Alluvium has thicker and more continuous peat layers than encountered beneath the Ramsar site, south of the River Thames.

g. Granular Alluvium and River Terrace Deposits lie on top of the Chalk aquifer. Lower hydraulic conductivity interglacial deposits (clay) may be present within the River Terrace Deposits.

h. Groundwater flow beneath the Alluvium soils of Tilbury Marshes follows preferential flow paths of very high hydraulic conductivity within granular River Terrace Deposits and particularly within discrete zones within the Chalk aquifer.

i. High hydraulic conductivity zones in the chalk are located beneath Tilbury Marshes, including along sub-horizontal zones within upper parts of the Chalk aquifer.

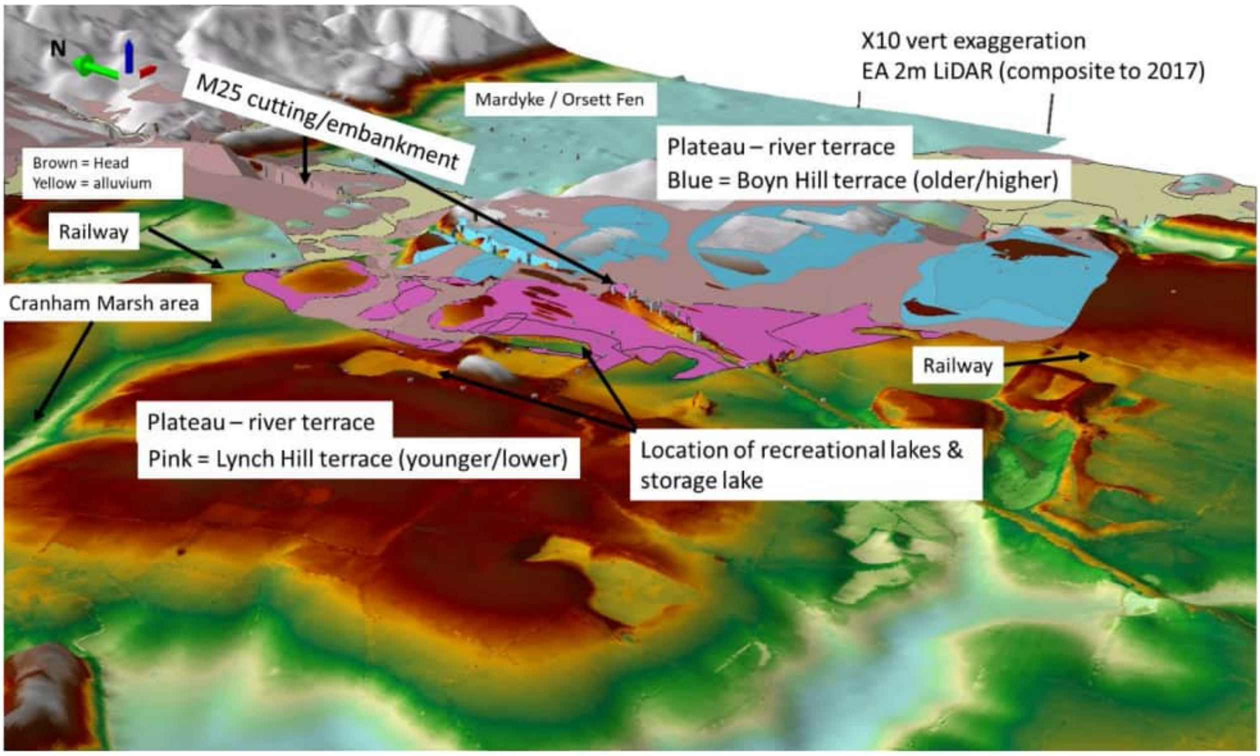
j. Groundwater flow in the Chalk aquifer is able to seep or up well into the River Thames where chalk or gravels are exposed at the riverbed.

k. Hydraulic connection between the River Thames and the River Terrace Deposits and the Chalk aquifer causes tidal variation of water level and saline intrusion.

5.7 A122 Lower Thames Crossing/M25 junction

5.7.1 A detailed baseline CSM is shown in the groundwater modelling report (Annex L), comprising the assessment of potential impacts of the Project on the local groundwater levels. Plate 5.5 presents a three-dimensional ground model showing the M25 area. Topography is exaggerated, but the model shows topography generally decreasing to the south and south-west, with local variations. As noted in Section 5.4, the hydrogeology units relevant to the A122 Lower Thames Crossing/M25 junction are all superficial aquifers.

Plate 5.5 M25 ground model and layout of superficial deposits



5.7.2 Plate 5.5 demonstrates that the older river terraces are found at increasingly higher elevations. Key features to note, in addition to attributes noted in Section 5.4, are listed below:

a. The existing M25 includes a cutting, beneath the B1421 Ockendon Road, that cuts into River Terrace Deposits by approximately 15m and deepens northwards, eventually fully cutting through the superficial deposits so that the base and part of the cutting slopes are within London Clay Formation.

b. Within the River Terrace Deposits, lateral and horizontal lithological variation is present. Glacial and interglacial depositional environments relate to dominantly granular and cohesive lithologies, respectively. Head Deposits may have similar lithologies, adding further complexity.

c. Data from historical GIs is believed to have been misinterpreted. The Boyn Hill Gravel (shown in blue in Plate 5.5) is shown at lower elevations to the west of the existing M25 but is instead believed to be the Lynch Hill Gravel Member. Hence, additional evaluation was carried out by the Cascade geomorphologists, through detailed review of the sediment descriptions, validated by Phase 3 GI. The study also allowed for sequencing high and low permeability horizons within the vertical profile of the River Terrace Deposits.

d. The possible spring (Cedd's Well) at North Ockendon (Section 3.6) appears to be fed from groundwater of the River Terrace Deposits. An unknown proportion of groundwater baseflow may contribute to the ponds at the Hall Farm moat, paddock and St Mary Magdalene Churchyard SINC. In addition, the landowner has said that a deep drainage system lies further east, to collect groundwater from the same strata (Section 3.6).

e. Three surface water bodies are noted near Dennis Lane and comprise recreational lakes and a spray irrigation reservoir. These water bodies are former gravel pits at which BGS geological mapping (BGS, 2020b) shows outcrop of London Clay Formation at the bases of the lakes. Correspondence with a land agent states that the spray irrigation reservoir is lined (Strutt and Parker, 2020). Also, the head of operations at Stubbers Adventure Centre has confirmed that the recreational lakes are likely to be clay lined (Stubbers Adventure Centre, 2020) although the small Canoe Pond is believed not to be lined. Lateral continuity of the water bodies with granular strata is uncertain. However, if the lakes are lined then the hydraulic continuity between the surface water bodies and groundwater would be limited.

f. Cranham Marsh LNR (Sections 3.6 and 3.9) is located to the west of the existing M25. Discrete parts of the LNR have vegetation habitat that indicates high groundwater dependency. The majority of the LNR is broadleaved woodland, which is not groundwater dependent. Adjacent to the LNR is the Fields South of Cranham Marsh SINC.

g. Nearly 3km further down valley of Cranham Marsh LNR is Ingrebourne Marshes SSSI, which is mapped as a GWDTE (Environment Agency, 2020b) (Section 3.9).

h. Phase 2 and Phase 3 long term groundwater level monitoring has been assessed in the baseline groundwater model (Annex L) as showing that the existing M25 cutting locally acts as a drain.

6 Groundwater levels and flows impact assessment

6.1 Methodology

6.1.1 Construction and operation of a highway has the potential to impact groundwater flow and levels. Potential impacts to groundwater flows and levels are summarised in Table 6.1.

Table 6.1 Potential impacts to groundwater flow and levels

Risk	Potential causes of impacts
Construction phase activities (Construction Industry Research and Information Association (CIRIA), 2006)	• Dewatering activities during excavation (including for utilities), earthworks and tunnelling • Temporary stockpiles and temporary impermeable hardstanding, reducing recharge
Operational phase activities and features	Altered drainage regime, for example caused by: • Cuttings intercepting groundwater • Permanent drainage of a cutting or tunnel • Permanent drainage caused by a granular filled utility trench • Soakaways adding water to ground • Ground surface changed, causing change of rainfall recharge to the aquifer • Creation of a physical barrier, for example caused by: • Deep embedded retaining walls, or piling • Ground improvement including grouting • Consolidation of soils

6.1.2 The assessment approach set out in this report follows the steps listed below, which are in accordance with DMRB LA 113 Road Drainage and the Water Environment (Highways England, 2020a). First, a proposed road construction and operational phase structure is assessed using a simple assessment and then, if found to potentially cause a significant impact, using a detailed assessment. The general approach to the simple assessment comprises:

a. Step 1: establish the regional groundwater status

b. Step 2: develop a conceptual model of the surrounding area

c. Step 3: identify potential features that are susceptible

6.1.3 Sections 3 and 5 of this report summarise information for Steps 1 and 2. For Step 3, potential features that could be susceptible are discussed in Section 3 and are identified in the relevant assessments of this section.

6.1.4 Table 6.2 summarises the simple and detailed hydrogeological assessments that have been conducted.

Table 6.2 Simple and detailed assessments of potential impacts to groundwater flow and levels

Project element that could potentially cause an impact	Simple assessment	Detailed assessment
Highway cuttings (construction and operational phases)	√	
Highway embankments (and landscape embankments) (mostly operational phase)	√	
South Portal (construction phase)	√	
Ground protection tunnel and main tunnel crossing (including cross passages) (construction and operational phases)		√
North Portal and ramp (construction phase)		√
A122 Lower Thames Crossing/M25 junction cutting (construction and operational phase)		√
Infiltration basins and mounding potential (operational phase)		√
Stockpiles and hardstanding (construction phase)	√	
Utilities (construction and operation phase)	√	

Notes: √ mark shows an assessment has been completed, is detailed within this report and assesses the potential impact of the associated works

6.1.5 The importance (value) of groundwater attributes based on quality indicators and measures is shown in Appendix 14.1 (Application Document 6.3). Further information is given in DMRB LA 113 Road Drainage and the Water Environment (Highways England, 2020a). A summary of the groundwater attributes, based on groundwater levels and flows and quality, as described in Sections 3, 4 and 5, is shown in Table 6.3. Values for GWDTEs are shown separately in Section 8 and surface water attribute values are shown in Chapter 14: Road Drainage and the Water Environment (Application Document 6.1).

Table 6.3 Summary of groundwater attribute value

Receptor	Attribute quality	Importance	Rationale
South of the River Thames			
Chalk aquifer (North Kent Medway Chalk water body)	17,700ML/a licensed volume for public supply Presumption against new consumptive abstractions	Very high	Used for public water supply and possible, albeit limited, contribution to fresh water in North Kent Marshes including Thames and Medway Marshes Ramsar site
Public water supply wells and SPZ 1s (North Kent)	73% of public supply in Kent is from groundwater (mostly chalk)	Very high	Used for public water supply
North of the River Thames			
Chalk aquifer (South Essex and Thurrock Chalk water body)	3,728ML/a total licensed public water supply Presumption against new licences in confined aquifer and restricted during low flow periods for unconfined chalk Poor quantitative water balance	Very high	Used for public water supply, although only 2% of total in the Essex Supply Area (Essex and Suffolk Water, 2021)
Public water supply well (Linford) and SPZ 1	One of two public supply wells in south Essex	Very high	Currently offline for public supply but assumption is that it will be used again for public supply (including drinking water)
Lower London Tertiaries water body	High nitrates (>50mg/L) recorded in Phase 2 GI	Medium	Not used for groundwater abstractions Baseflow to local stream Leakage to underlying South Essex and Thurrock Chalk water body
Essex Gravels water body	Poor overall WFD status due to high nitrates confirmed by Phase 2 GI	Medium	Agricultural water supplies Baseflow to local surface water bodies
Private supply wells, including agricultural, industrial and golf course uses	5,889ML/a (south Essex)	Medium	Local water use that may sustain an agricultural or other business

6.2 Highway cuttings

6.2.1 A simple assessment has been conducted to assess the likely impact that the proposed cuttings may have on the groundwater environment (groundwater flow and levels). The operational phase represents the worst-case scenario for the simple assessments, due to the potential impact from long term drainage effects of cuttings. Therefore, the qualitative results shown in Annex H are for the operational phase only. The deepest and longest road cuttings are proposed at the Gravesend link on the North Downs, the main alignment under the existing A13, a link road at the A13/A1089/A122 Lower Thames Crossing junction and the northbound alignment at the A122 Lower Thames Crossing/M25 junction.

6.2.2 Hydrogeological conceptual site models (Section 5) have been used to inform understanding of potential interaction of road cuttings with groundwater.

6.2.3 Most road cuttings have been assessed as unlikely to intercept groundwater. Consequently, no groundwater drawdown or barriers to groundwater flow would be caused where groundwater is below a cutting. In these cases, the magnitude of impact is negligible, resulting in no significant risk to groundwater levels and flows. This means there would be negligible impact to groundwater levels or flows since the water table would not be intercepted.

6.2.4 Where the base of the road cutting may intercept the groundwater table, each cutting has been assessed on a case-by-case basis using conceptual understanding of the geology and hydrogeology anticipated (proven by GI). Comparison of cutting invert levels with groundwater monitoring levels shows that the following proposed cuttings are deeper than GI monitored groundwater levels at the following locations:

a. A13 westbound to Lower Thames Crossing southbound (Link road 3) has a lowest road elevation of 17.3mAOD

b. A122/M25 junction cutting (road elevation approximately 13mAOD beneath Ockendon Bridge)

6.2.5 All proposed road levels at the A13 junction, with the exception of one, are not lower than the nearest GI maximum groundwater level. The potential for groundwater seepage is inferred at the deepest cutting, the A13 westbound to southbound A122 link road, as the maximum groundwater levels recorded in the Phase 2 GI long-term monitoring are estimated to be up to 20mAOD in the Thanet Formation, which is higher than the lowest road level. However, in the vicinity of the lowest part of the link road the maximum groundwater level is 18mAOD. This is equivalent to a maximum required groundwater drawdown of 1.5m, based on a conservative design minimum of 770mm depth of groundwater below road surface, taken from DMRB CD 225 (Highways England, 2020e) and DMRB CD 226 (Highways England, 2020f). This would be for a road section, of less than 100 metres length, at which the Thanet Formation would be intersected. Here, the top of the Chalk aquifer would be 18m lower than the base of the cutting and is separated from the Thanet Formation aquifer by the clayey Pegwell Silt Member. Therefore, at the A13 westbound to southbound A122 link road, a negligible adverse potential impact is assessed to the underlying Lower London Tertiaries aquifer and the South Essex Thurrock Chalk WFD water body. Further detail is shown in Annex H.

6.2.6 The area with the greatest potential for impacts was identified as the proposed cuttings at the A122 Lower Thames Crossing/M25 junction. Here a moderate to large potential impact was assessed, as a result of the simple assessment. The simple assessment concluded that there was a potentially significant effect due to the potential for drawdown to impact groundwater bodies in local SINCs, a spring source said to be indirectly feeding a spray irrigation reservoir and Cranham Marsh LNR. A detailed assessment has been conducted consequently and is introduced in Section 6.8.

6.3 Highway embankments

6.3.1 Annex I presents the simple assessment of the potential impact of proposed embankments (operational phase) on the groundwater environment (groundwater flow and levels). These comprise the following:

a. Engineered embankment comprising engineered fill earthworks which would support the highway above the existing ground level

b. Landscape embankments to be used for visual, noise and/or ecological benefit and which include 'false cuttings'

6.3.2 The longest engineered embankments proposed are at Tilbury link, Chadwell St Mary link and the non-viaduct sections crossing the Mardyke floodplain at Ockendon link. The main areas of proposed landscape embankments are at the M2/A2/Lower Thames Crossing junction, Chadwell St Mary link, parts of the A13/A1089/A122 Lower Thames Crossing junction and the southbound alignment at the A122 Lower Thames Crossing/M25 junction.

6.3.3 This assessment focuses on three main types of potential impact on groundwater that could cause changes to groundwater levels and flows:

a. Compression of soils causing locally reduced hydraulic conductivity of shallow aquifers

b. Permanent covering of the natural ground surface causing locally reduced rainfall recharge

c. Ground improvement measures, beneath the embankment, altering the local hydraulic conductivity of material within an aquifer or creating a barrier to groundwater flow

6.3.4 Hydrogeological conceptual site models (Section 5) have been used to inform understanding of potential interaction of embankments with groundwater.

6.3.5 The results of the simple assessment show that there is no potential significant impact on groundwater flow and levels as a result of the proposed embankments. In particular, changes to recharge would cause a negligible impact. Also, no significant barriers to groundwater flow would be caused since any foundations to the embankments would be shallow or not within an aquifer. In summary, the assessment shows no significant effect would be caused and, therefore, no detailed assessment is required.

6.4 Main tunnel crossing – construction of the South Portal

6.4.1 The South Portal would be constructed above the Chalk aquifer water table (Figure 4) as evidenced by regional (including nearly 40 years of groundwater level monitoring at the nearby Church Lane Environment Agency borehole) and Phase 1 and 2 GI groundwater level monitoring. Therefore, there is negligible risk to groundwater levels and flows from construction of the South Portal since there would be no dewatering to lower groundwater levels and nor would there be creation of a significant barrier to groundwater flow.

6.5 Ground protection tunnel and main tunnel crossing

6.5.1 The proposed ground protection tunnel and main tunnel crossing (construction phase and operational phase) have been assessed in detail due to the sensitivity of the internationally important South Thames Estuary and Marshes SSSI, Shorne Marshes RSPB Reserve and the Thames Estuary and Marshes Ramsar site and the potential for groundwater drawdown beneath it from construction and operation of the proposed main tunnel crossing. Details of the south of the River Thames numerical modelling are shown in Annex J.

6.5.2 Cutting-edge numerical groundwater modelling has been conducted using MODFLOW 2005 (Harbaugh, 2005). Python coding was used to assist with the build, run and postprocess MODFLOW-related programs. The BGS (BGS, 2019b) digital lithostratigraphic geological model and Phase 1 and 2 GI data were used to produce the model inputs and inform the calibration process. The model has been used for assessment of groundwater flows and levels. The same model has also been used to assess saline intrusion (Section 7).

Ground protection tunnel and shafts

6.5.3 Details of the proposed spatial arrangement of the ground protection tunnel and shafts and underlying ground conditions are included in Annex J.

6.5.4 Large scale pumping of groundwater (dewatering) is not proposed. Therefore, the main cause of any groundwater drawdown here would be leakage from the structures as any water pumped would be water that has leaked into the shafts and tunnel. It is assumed that the design would specify maximum leakages rates to be compliant to British Tunnelling Association standards (British Tunnelling Society and Institution of Civil Engineers, 2010), i.e.:

a. 0.2 litres per square metre per day (L/m^2/d) for the ground protection tunnel shafts

b. 0.1L/m^2/d for the ground protection tunnel

6.5.5 The results of the numerical modelling show that predicted groundwater inflow into the ground protection tunnel and shafts is moderately low following the implementation of mitigation measures (i.e. generally wet construction of shafts, use of an earth pressure balancing machine that inhibits groundwater inflow during boring, use of grout blocks for possible TBM maintenance and adherence to the above design maximum leakage rates). The proposed grout blocks (to provide a very low permeability zone in which maintenance of the TBM or switching of parts or systems can occur without significant groundwater inflow) would be 20m wide and the modelling shows no significant barrier effect is caused since no significant groundwater mounding is shown in the model output (Annex J). The combined drawdowns for the ground protection tunnel and main tunnel crossing are shown in Annex J.

6.5.6 The Project commitments for construction mitigation of the ground protection tunnel are shown in the REAC, detailed in the CoCP (Application Document 6.3). These comprise REAC reference RDWE018a and RDWE018b which require the ground protection tunnel and shafts, if used, to be constructed using methods to control groundwater pumping and ingress and to be decommissioned by backfilling with suitable materials.

Main tunnel crossing beneath the Ramsar site

6.5.7 A summary of the works is included in Annex J. Construction of the main tunnel (twin bore) would be by TBM with concrete liner segments. Adherence to the above specified maximum leakage rate for the main tunnel crossing and the above grout blocks (in case of TBM maintenance) would mean that there would be low groundwater inflow to the main tunnel crossing (during construction and operational phases) and groundwater drawdown would not be significant (Annex J).

6.5.8 Grouting conducted from the ground protection tunnel would significantly minimise possible groundwater drawdown and disturbance of the Ramsar site (and near the North Kent Railway line and Thames and Medway Canal) during construction of the main tunnel crossing twin bores and cross passages.

6.5.9 The Project commitments for mitigation during the operational phase are shown in the REAC, detailed in the CoCP (Application Document 6.3). This includes REAC reference RDWE027 which provides that water infiltration into the tunnel bores and cross passages would be reduced by measures including gaskets and membranes compliant with the Lower Thames Crossing specification.

Controlling slurry loss during tunnelling

6.5.10 Loss of bentonite slurry to ground surface (sometimes termed blow out) should not occur even where there is reduced cover over the tunnelling. This is because best practice measures would be employed during tunnelling. Best practice measures would include appropriate and dynamic monitoring of tunnel face pressures and thorough assessment of ground conditions and accurate locating and sealing of any known paths for potential loss (e.g. exploratory boreholes).

6.5.11 Tunnelling above the water table would be required at the approach to the South Portal. Figure 3 shows the portion of the main tunnel crossing above the water table. Depending on the tunnel method, the slurry-water mix could then be lost to ground during tunnelling. The rate of loss and lateral extent of receiving ground would depend on local ground conditions and viscosity of the slurry-water mix. Viscous mixtures would not be extensive while predominantly water losses could form temporary saturated zones above the water table and, for this reason, are unlikely to cause any significant impact on groundwater flows and levels.

Combined drawdown and inflows

6.5.12 The numerical model predicted groundwater drawdown in the Chalk aquifer, from the combined effect of the ground protection tunnel and main tunnel crossing, is not significant. This is a consequence of the mitigation measures described above (and in Annex J).

6.5.13 Mitigation is secured in the REAC, detailed in the CoCP (Application Document 6.3). As discussed above, these comprise REAC reference RDWE018a and RDWE018b which require the ground protection tunnel and shafts, if used, to be constructed using methods to control groundwater pumping and ingress and to be decommissioned by backfilling with suitable materials. The groundwater commitments during the operational phase include REAC reference RDWE027 which confirms that water infiltration into the tunnel bores and cross passages would be reduced by measures including gaskets and membranes compliant with the Lower Thames Crossing specification.

6.5.14 Actual groundwater drawdowns in the shallow water system of ditches and partially waterlogged soils at the Ramsar site would be expected to be smaller than any drawdown in the Chalk aquifer. This is because the silty clays of Alluvium act as an aquitard and confine the underlying River Terrace Deposits and Chalk aquifers (Section 5.5 and Annex J). Evidence for this is seen in the results of the Ramsar site pumping test (Project GI) and the water balance studies (Annex E).

6.5.15 Considering the groundwater model assumptions and limitations, the drawdown from the ground protection tunnel or the main tunnel crossing is anticipated to be within the numerical accuracy of the model itself and is unlikely to be significant and perceptible. This is also supported by the water balance assessment of the Ramsar site (Annex E) that has concluded that construction and operation activities are unlikely to lead to any significant loss of water on a monthly basis, even in summer months.

6.6 Main tunnel crossing – construction of cross passages

6.6.1 Cross passages would be formed using grouting or ground freezing groundwater control measures to reduce dewatering requirements (Chapter 14: Road Drainage and the Water Environment (Application Document 6.1)). Therefore, no significant change to groundwater levels and flows from construction of the cross passages is assumed as no active dewatering would be required.

6.6.2 Mitigation is secured in the REAC, detailed in the CoCP (Application Document 6.3). REAC reference RDWE020 requires the use of groundwater control techniques, such as grouting or ground freezing, to reduce dewatering requirements in connection with the construction of the cross passages between the main tunnels

6.7 Main tunnel crossing – North Portal

6.7.1 The Tilbury area (the location of the Project's North Portal) has been assessed in detail because of the need for construction phase groundwater control, the existing groundwater contamination (Chapter 10: Geology and Soils (Application Document 6.1)) and potential to increase saline intrusion (Section 5.6), which in particular could impact the Chalk aquifer and Linford public water supply (Section 7.3).

6.7.2 Details of proposed spatial arrangement of diaphragm walls and other construction mitigation measures such as basal grouting (also known as a grout plug) are presented in Annex K. The schematic layout of the diaphragm walls and portal are shown in the long section in Figure 4. In addition, ground improvement may be necessary including zones of shallow and deep soil mixing. A map of proposed shallow and deep soil mixing zones is presented in Annex K.

6.7.3 The modelling assesses hydrogeological properties and spatial extent of geological units in detail, with Monte Carlo simulations to perfect most likely hydraulic conductivity (permeability) values. Scenarios with different extents of the above mitigation measures have been explored. The Annex K report presents model groundwater drawdowns and pumping (dewatering) rates.

6.7.4 The modelling confirms that the implementation of diaphragm walls, plus appropriate basal grouting thickness and permeability (or equivalent engineering measures to ensure minimal groundwater inflows into the excavation) would ensure that construction phase groundwater pumping abstraction rates (dewatering) and groundwater drawdown are kept to insignificant levels in the Chalk aquifer. The final arrangement of the mitigation measures would be determined during detailed design by the Contractor in consultation with the Environment Agency in accordance with the REAC reference GS021 (Chapter 10: Geology and Soils (Application Document 6.1)).

6.7.5 The operational phase modelling simulated the inflows to the Project's main tunnel crossing only. The inflow to the North Portal ramp and portal area is negligible during the operational phase because the permanent structure will be lined with a waterproof membrane. The inflow to the main tunnel crossing has been modelled as $0.1L/m^2/d$ (Section 6.5). The modelling results show that groundwater drawdown would not be significant during the operational phase. Mitigation is secured in the REAC, detailed in the CoCP (Application Document 6.3). Infiltration into the tunnel bores and cross passages would be reduced by measures including gaskets and membranes compliant with the Lower Thames Crossing specification [REAC RDWE027].

6.7.6 The diaphragm walls at the North Portal would be parallel with the groundwater flow direction, so would not create a barrier effect during construction or operational phases.

6.7.7 Modelling of the effects of the proposed deep soil mixing show that the drawdown remains constrained to an area very near to the Project alignment. This is likely because the assumed hydraulic conductivity of the ground improvement zones is marginally lower than clay within the alluvium superficial deposits.

6.8 A122 Lower Thames Crossing/M25 junction

6.8.1 DMRB LA 113 Road Drainage and the Water Environment (Highways England, 2020a) requires detailed assessment of groundwater flow or levels at locations where the simple assessment shows there to be potentially significant impacts. The cutting at the A122 Lower Thames Crossing/M25 junction was identified for detailed assessment (Section 6.2). Annex L presents the detailed assessment of cuttings at the proposed A122 Lower Thames Crossing/M25 junction.

6.8.2 Key potential groundwater receptors are in the North Ockendon area, either side of the existing M25, and are as follows:

a. Cranham Marsh LNR

b. A reported spring in the Hall Farm moat, paddock and St Mary Magdalene Churchyard SINC and an area described as the North Ockendon catchment, which may indirectly feed an irrigation reservoir, via a watercourse and licensed surface water abstraction

c. Hall Farm moat, paddock and St Mary Magdalene Churchyard SINC

d. Recreational lakes if not lined (Stubbers Adventure Centre)

e. Thames Chase Forest Centre SINC (Hobbs Hole)

f. Fields South of Cranham Marsh SINC

g. Other SINC sites that have been identified as potential GWDTEs and are listed in Annex P

h. Ordinary watercourses, including those flowing to or within the above sites, that may receive groundwater baseflow including those which have licensed surface abstractions for agricultural use

i. The Essex Gravels WFD groundwater body (comprising the River Terrace Deposits aquifer)

6.8.3 The detailed modelling results and assessment are presented in Annex L and include a presentation of predicted groundwater drawdown for three scenarios comprising no mitigation (no groundwater control measures), full mitigation (complete exclusion of groundwater from the cutting and therefore no groundwater seepage into the cutting) and partial mitigation (50% of the seepage of the no mitigation scenario). The results are summarised below:

a. If no groundwater control measures are taken, the zone of impact (considered conservatively as an impact of 0.1m groundwater drawdown or more) would extend to some of the key potential groundwater receptors outside the footprint of the cutting, during the construction and operational phases of the Project.

b. If mitigation measures are used to reduce the seepage inflow into the proposed cutting by 50%, the zone of impact would extend only slightly outside the footprint of the cutting, during the construction and operational phases of the Project, leaving all key potential groundwater receptors unaffected.

c. In the case of a hypothetical scenario of complete exclusion of groundwater from the cutting (full mitigation) then the drawdown impact would be temporary (during the construction phase) and a slight rise in the water table would follow during the operational phase.

d. No barrier effects to groundwater flow are anticipated in the no mitigation or partial mitigation scenarios. However, simulations of a completely lined underpass and cutting (full mitigation) suggest groundwater would rise by up to 1m, immediately behind the proposed impermeable structures. These levels would remain local, although potentially over a length of 1.4km but would be significantly below the ground surface. The full mitigation scenario represents a worst-case barrier effect, but which shows no detrimental impacts.

e. The results show groundwater drawdown would not occur at Cranham Marsh LNR or the Fields South of Cranham Marsh SINC, with or without mitigation. Further, the ground beneath the ordinary water courses that flow towards the LNR, would not experience groundwater drawdown, in either the partial or full mitigation scenarios.

f. The results show that the one of the worst-case drawdowns (without mitigation), could occur at St Cedd's Well in the Hall Farm moat, paddock and St Mary Magdalene Churchyard SINC. This well is said to be a spring although the local farmer's land agent has reported that it has produced low, to no, flow since the widening of the M25 in 2012 (Section 3.6).

g. The same spring is associated with the three ponds (relics of an old moat) at the Hall Farm moat, paddock and St Mary Magdalene Churchyard SINC. Although there is no discernible spring flow into the ponds, inflow may include a proportion of (groundwater) baseflow as well as direct rainfall and surface runoff from the surrounding higher ground. (Section 3.6 and Section 5.7). The model simulates a groundwater drawdown at the St Cedd's Well area that would be limited to 0.7m in the worst-case scenario simulation (without mitigation). However, all mitigation options modelled show that this impact would be mostly to fully eliminated.

h. The deep drainage system, located in the North Ockendon catchment, and said to be used for the irrigation reservoir supply above, is of uncertain spatial extent (Section 3.6). Therefore, there are difficulties simulating drawdown for the system, as distances from the cutting are unclear. However, based on the approximate line of drainage suggested by the landowner (Appendix 14.2: Water Features Survey Factual Report (Application Document 6.3)), then drawdown could be between less than 0.1m to 0.7m for the without mitigation scenario. However, all mitigation options modelled show that this impact would be mostly to fully eliminated.

i. Lakes located at the Stubbers Adventure Centre are situated outside the worst-case zone of impact that has been modelled to extend out from the A122 Lower Thames Crossing/M25 junction cutting. Additionally, these lakes are likely to be clay lined (Stubbers Adventure Centre, 2020), with the possible exception of the Canoe Pond, and therefore no impact is anticipated on these features.

j. Thames Chase Forest Centre SINC, especially Hobbs Hole at the southern end, has one of the worst-case predicted drawdowns (without mitigation). Drawdowns of up to 1.0m could occur in the southern third of the SINC, including at Hobbs Hole. However, all mitigation options modelled show that this impact would be fully eliminated.

k. The ordinary water courses and Essex Gravels WFD waterbody, listed in the above paragraph, would have limited groundwater drawdown in the no mitigation scenario, full mitigation and partial mitigation scenario as described in points a, b and c of this paragraph.

l. Seepage estimations show very low seepage into the proposed cutting in all modelled scenarios. Variations in seepage at different locations of the cutting may occur.

6.8.4 SINC sites near the M25, listed in Annex P, have been assessed as part of the GWDTE assessment (Section 8). The assessment concludes that there is a negligible risk to these potential GWDTEs.

6.8.5 In summary, without mitigation, there is predicted groundwater drawdown and therefore potential impacts to some of the key potential groundwater receptors. These are the:

a. Thames Chase Forest Centre SINC including Hobbs Hole (pond of mapped historical spring)

b. Hall Farm moat, paddock and St Mary Magdalene Churchyard SINC

c. North Ockendon catchment

6.8.6 The Project would secure essential mitigation for the A122/M25 junction cutting and underpass, as set out in the below paragraph. This would ensure a reduced groundwater drawdown extent for the protection of the three locations listed in the above paragraph. Consequently, the water sources of the irrigation reservoir, indirectly pumped from licensed surface water abstractions in connecting watercourses, would be maintained. Measures to reduce groundwater drawdown beyond the proposed M25 cutting, for example through the implementation of seepage control, would be confirmed and its effectiveness during both construction and operation demonstrated in consultation with the Environment Agency.

6.8.7 Mitigation is secured in the REAC, detailed in the CoCP (Application Document 6.3).

6.8.8 Findings from groundwater modelling of the A122 Lower Thames Crossing/M25 junction cutting shows that, without mitigation, there could be up to 0.7m groundwater drawdown at St Cedd's Holy Well, at the Hall Farm moat, and up to 1.1m groundwater drawdown at Hobbs Hole and the southern edge of Thames Chase Forest Centre. These features are illustrated in ES Appendix 14.5, Annex L (Application Document 6.3). Therefore, during detailed design, having regard for ground investigation data and monitoring (groundwater levels, surface water levels and, where feasible, flows), the need for measures to reduce groundwater drawdown beyond the M25 cutting, for example through the implementation of seepage control, would be confirmed in consultation with the Environment Agency the London Borough of Havering and, if confirmed to be necessary, the detail of such measures would be agreed in consultation by the Secretary of State following consultation with the Environment Agency and the London Borough of Havering. [REAC RDWE038].

6.9 Highway drainage (infiltration basins) – impact on groundwater flows and levels

6.9.1 DMRB CD 530 Design of Soakaways (National Highways, 2021a) requires that soakaways do not cause deleterious change to groundwater levels and flows. Relevant considerations are that soakaways should be designed to avoid:

a. Washing out of fines or harmful dissolution of the subsurface or other instability of the subsurface, subsidence or heave

b. Discharge into areas of known landslip hazard

c. Harmful groundwater emergence downgradient

d. Surcharge of groundwater leading to harmful water logging or exacerbation of groundwater flooding

6.9.2 It is good practice to maximise depth of unsaturated zone below a soakaway device (to allow for pollutant attenuation) but also to maximise below ground storage. DMRB CD 530 Design of Soakaways (National Highways, 2021a) suggests design depths of unsaturated zone below a soakaway device of 3m to 4m to provide the optimum opportunity for attenuation purposes. However, DMRB CD 530 and DMRB CD 532 Vegetated Drainage Systems for Highway Runoff (National Highways, 2021b) say a soakaway and an infiltration basin respectively should have a separation of at least 1.2m between the base of the basin and the highest recorded groundwater level.

6.9.3 Bullets (a) and (b) in the above paragraph have been addressed by the evolution of the Project. Soakaways would comprise wide, shallow infiltration basins or small grassed swales. In particular, the infiltration basin designs maximise the seepage area and so minimise potential washing out of dissolution features and the potential for local instability to occur.

6.9.4 Annex M and Annex N present the detailed assessments of the proposed soakaways south of the River Thames and north of the River Thames, respectively. These include modelling of the potential mounding effect of the water table beneath the soakaways and further downgradient.

6.9.5 The detailed assessment of the proposed soakaways south of the River Thames demonstrates that the potential mounding effect of the water table would not exceed the thickness of the unsaturated zone (even using the high groundwater level condition of February 2014) and therefore the risk of harmful downgradient emergence of groundwater and groundwater flooding is negligible.

6.9.6 The detailed assessment of the proposed soakaways north of the River Thames demonstrates that highway drainage runoff could be drained to a combination of soakaways (swales and an infiltration basin) at the A13/A1089/A122 Lower Thames Crossing junction, without causing mounding at unacceptable shallow depths.

6.10 Construction phase stockpiles and hardstanding

6.10.1 Stockpiling, including the volumes and locations of stockpiles, would be stipulated in a Materials Management Plan by the Contractor. Details are discussed in Appendix 2.1 (Application Document 6.3) including estimated stockpile areas. Key points are that stockpiles would be of predominately site-won material and range from chalk, south of the River Thames, to clays, sands and gravels, north of the river.

6.10.2 Impacts to groundwater levels and flows could be caused by reduction of aquifer recharge and consolidation-related permeability reduction. However, recharge is not likely to be significantly affected as much of the materials would allow seepage of rainwater to ground, with the exception of any specific measures for contamination. Also, consolidation of aquifers is unlikely to be significant due to the underlying geology. The relatively small area that would have stockpiles compared with the total catchment of the underlying aquifer means that, with consideration of the temporary nature of the stockpiles, the magnitude of impact from stockpiles would be no change to negligible.

6.10.3 Temporary hardstanding areas would be located within site compounds and on temporary access routes. Details are presented in Appendix 2.1 (Application Document 6.3) and Figure 2.2 (Application Document 6.2). The hardstanding is likely to comprise compacted stone or asphalt surfaced areas and some form of designed concrete foundations, so would be predominately impermeable. The hardstanding areas are temporary and would be removed prior to the beginning of the operational phase. The haul routes running parallel to the main Project route would be expected to comprise a compacted stone surface. Again, these access routes would be temporary and would be removed at the end of the construction phase. Therefore, considering the small extent and temporary nature of the construction phase hardstanding, the magnitude of impact to groundwater levels and flows from hardstanding would be no change to negligible.

6.10.4 Deep soil mixing columns would be constructed and remain permanently beneath the location of haul roads at the North Portal. The effects of the deep soil mixing are assessed separately in Annex K.

6.11 Nitrogen deposition habitat compensation areas

6.11.1 Considering the Appendix 10.6 (Application 6.3) desk study results and the proposed planting and maintenance of vegetation then a magnitude of impact of no change for groundwater levels and flows is assessed for all sites and underlying groundwater bodies.

6.12 Utilities

6.12.1 Utility works include the diversion of, protection of, and connection to, the utility networks and are required as part of the Project. Electricity, water, gas and telecommunications utilities would need to be provided, replaced or rerouted as part of the Project and are summarised in Chapter 2: Project Description (Application Document 6.1), Appendix 2.1 (Application Document 6.3) and Figure 2.2 and Figure 2.5 (Application Document 6.2).

6.12.2 In total, there are approximately 130 proposed underground utility diversion corridors of 125km overall length. It is estimated that 95% of the proposed total underground utility corridor distance would be constructed using shallow (within 3m depth) open cut trenches. The remaining distances would be completed by trenchless methods which are often used to cross beneath existing features such as strategic road network, railway, local road network and watercourses. Utility works would be conducted by either individual utility companies or the Contractor who would complete the works on their behalf.

6.12.3 Construction of new utilities has the potential to impact groundwater flows and levels, where assets are below ground level. In addition, potential operational phase impacts could result from permanent drainage and below ground barriers to groundwater flow.

6.12.4 Annex Q presents the simple assessment of the potential impact of proposed underground utilities on the groundwater environment (groundwater levels and flow). The methodology follows DMRB LA 113 and considers the requirements for NSIPs (Appendix 14.8: Legislation and Policy (Application Document 6.3)). Utility information used for the simple assessment has comprised indicative design information about location, depth, construction methodology and duration presented in Chapter 2: Project Description. The assessment has been informed via collaborative dialogue between the Project and the Statutory Undertakers utilising their construction and design experience, including adherence to all relevant design standards, guidance and legislation. The information should be read in conjunction with Schedule 1 (Authorised Development) of the Development Consent Order (Application Document reference TR010032/APP/3.1) and the Works Plans (Application Document reference TR010032/APP/2.6).

6.12.5 Utilities which constitute NSIPs are gas pipelines Work Numbers G2, G3 and G4 and the overhead powerline Work Number OH7.

South of the River Thames

6.12.6 South of the River Thames approximately 35km of underground utility corridors are proposed of which 95% would be shallow (within 3m depth). The deepest excavations are the sections within gas pipeline corridors Works numbers G1b, G3 and G4 which include shafts and micro-tunnels.

6.12.7 The simple assessment concludes that for all the utility corridors the effect of these works would be not significant.

6.12.8 The REAC sets out Project commitments for mitigation during the construction phase and operational phase, as detailed in the CoCP (Application Document 6.3). This includes the Project commitments summarised in Table 6.4.

Table 6.4 Utilities – project commitments (south of the River Thames)

Location	REAC ref no	Project commitment
A122 Lower Thames Crossing/A2 junction	RDWE051	The medium pressure gas pipeline (Work number G1b) is proposed to cross beneath the A122 Lower Thames Crossing by construction of deep shafts and a microbore tunnel. The works are above the Chalk aquifer water table. However, shallower Lower London Tertiary aquifers (Thanet Formation) may be present at shaft locations for Work number G1b. Should perched groundwater be encountered then the shafts shall be sealed after construction to prevent ingress of groundwater and potential permanent draining of any perched groundwater.
Pond beside the Inn on the Lake, Shorne	RDWE052	Multi utilities corridors and gas pipelines are proposed close to New Fish Pond beside the Inn on the Lake, Shorne. It is not known whether the pond is lined and there is potential hydraulic connection between the pond and the Lambeth Group aquifer and the Harwich Formation aquifer. Perched groundwater could be present. There is a potential for utility trenches to act as a permanent drain where the base of a trench slopes downwards away from the pond. In addition, crossings of utility corridors may require locally deeper trenches which could increase the draining effect if extended down slope. Should New Fish Pond be unlined then, where within 50m distance of the pond, gas pipeline Work number G1b (western section), multiple utility Work number MU12 and temporary multiple utility Work number MUT2 shall be constructed to reduce the potential draining effect away from the pond area.
Lower Higham Road	RDWE053	There is a requirement to replace an approximately 100 metres section of existing water pipeline on Lower Higham Road. This utility diversion, Work number MU26, would be approximately 10m distance south of the South Thames Estuary and Marshes SSSI and Thames Estuary and Marshes Ramsar. Any pumped water removal and subsequent disposal of water from the utility works shall be subject to approval from the Environment Agency and comply with Environment Permitting Regulations to protect the adjacent areas of nature conservation.

North of the River Thames

6.12.9 North of the River Thames approximately 90km of underground utility corridors are proposed of which 95% would be shallow (within 3m depth). The deepest excavations would be sections of corridor within gas pipeline corridors Works numbers G6 (three separate crossings beneath existing or proposed road), G7, G10 and two multiple utility crossings Works numbers MU72 and MU73.

6.12.10 The simple assessment concludes that for all the utility corridors the effect of these works would be not significant.

6.12.11 The REAC sets out Project commitments for mitigation during the construction phase and operational phase, as detailed in the CoCP (Application Document 6.3). This includes the Project commitments summarised in Table 6.5.

Table 6.5 Utilities – project commitments (north of the River Thames) (groundwater levels and flows)

Location	REAC ref no.	Project commitment
Irrigation Reservoir at Low Street	RDWE054	The irrigation reservoir at Low Street, is groundwater fed. Utility corridors are proposed to the east, west and north of the reservoir (Works numbers MU28 and MU33) and have the potential to form a barrier to groundwater flow, cause draining of groundwater that would otherwise flow towards the unlined reservoir or cause direct drainage from the reservoir. The spatial arrangement of the utility corridors and the below ground materials shall be designed to prevent drainage from the reservoir, or barrier effects reducing groundwater flow to the reservoir.
Chadwell St Mary Link	RDWE055	Shallow groundwater conditions are expected at land in the small valley feature near where Hoford Road would cross the Project and at the continuation of the valley feature where Brentwood Road would cross the A122 Lower Thames Crossing, near Brook Farm. Multiple utility corridors Works numbers MU37, MU38 and MU40 would be aligned perpendicular to the valley and could cause a barrier to groundwater flow. The design of the utility corridors, where at the topographical low, shall consider the depth to formation level and below ground materials to reduce barrier effects to groundwater flow.
A122 Lower Thames Crossing/M25 junction area	RDWE056	Complex layered superficial geology at the proposed A122 Lower Thames Crossing/M25 junction area is water bearing and may contribute base flow to unlined surface water bodies such as Hobbs Hole, part of the Thames Chase Forest Centre SINC. Multiple utility corridor Work Number MU72 is a proposed trenchless installation of a multi-utility corridor beneath the London, Tilbury and Southend railway. The utility diversion would require works beneath groundwater. Temporary groundwater level lowering outside of the Order Limits shall be reduced by total or partial temporary exclusion of water flow into the shafts. On completion of placing the utility diversion, the shaft walls shall be removed, and the pits shall be backfilled with soil arisings in the same order as excavated in order to reduce change of the layered geology. Any groundwater removal during the works shall be subject to Environment Permitting Regulations.
A122 Lower Thames Crossing/M25 junction area	RDWE057	Complex layered superficial geology at the proposed A122 Lower Thames Crossing/M25 junction is water bearing and may contribute base flow to unlined surface water bodies such as the ponds at Hall Farm moat, paddock and

Location	REAC ref no.	Project commitment
		St Mary Magdalene Churchyard SINC and Fields south of Cranham Marsh SINC. Multiple utility corridor Work number MU73 is a proposed trenchless installation of a multi-utility corridor from west of the London, Tilbury and Southend railway, under the proposed cutting of the A122 Lower Thames Crossing, to east of the M25. The construction method shall reduce the depths of the temporary launch pit and reception pit so that the pits are above the groundwater level and the trenchless equipment is launched from above groundwater. After completion of the utility works, the pits shall be backfilled with soil arisings in the same order as excavated in order to reduce change of the layered geology. Should the temporary launch pit and reception pit be required to be excavated to below groundwater level then temporary groundwater level lowering outside of the Order Limits shall be reduced by temporary total or partial exclusion of water flow into the pits. On completion of placing the utility diversion, the pit water exclusion measures shall be removed and the pits shall be backfilled with soil arisings in the same order as excavated, unless otherwise agreed with the Environment Agency. Any groundwater removal during the works shall be subject to Environment Agency Permitting Regulations.

6.13 Climate change

6.13.1 A general introduction of themes is presented in Section 2.5.

6.13.2 Construction of the Project is not anticipated to be impacted by or to increase impacts from climate change, with respect to groundwater levels and flows. This is because the presented assessments have considered high groundwater levels based on historical monitoring periods of over 20 years, within which high and low groundwater-level conditions were experienced. Therefore, assessed construction phase conditions are likely to be within the range of groundwater levels that would be encountered during the construction period.

6.13.3 There is low confidence that groundwater levels would change due to climate change (Section 2.5). Therefore, the Project is unlikely to be impacted by or increase impacts from climate change, with respect to groundwater levels and flows, during the operational phase of the Project. Should prolonged droughts occur, then the Project is not anticipated to exaggerate groundwater lowering effects as the tunnel assessments (Sections 6.4 and 6.5) demonstrate insignificant drawdown effects. Similarly, in the area of the A122 Lower Thames Crossing/M25 cutting, the Project would include permanent mitigation to alleviate potential draining effects of the proposed cutting. Shallow aquifers of small catchment may not be resilient to prolonged drought periods, although there is no available data to demonstrate significant reduced levels or flows in the superficial aquifers. Should extreme wet weather periods occur, then groundwater flooding could be more likely especially in areas already susceptible to river or tidal flooding, where there is permeable ground. However, the Project assessments (Section 6.2 to 6.8) show that no significant barriers to groundwater flow would be created within aquifers, below the water table. An example of deep structures beneath the water table are the deep diaphragm walls at the North Portal, but these are in line with the groundwater flow direction, so would not create a barrier effect.

6.13.4 The current CSMs (Figures 3 and 4) show Chalk aquifer groundwater dominantly discharges to the Thames Estuary but with local inversion at high tides. Predicted sea-level rise values stated in Section 2.5, could cause changes to the relative levels of the river water and groundwater and therefore to the discharge. However, as discussed in Section 2.5, the management of groundwater abstraction would be important to maintain a positive head of groundwater. This would influence the potential for saline intrusion that is discussed in Section 7.8. The detailed assessments presented in Section 6 show that the Project would not have a significant impact on groundwater levels and therefore negligible influence on any climate related changes to discharge to the Thames Estuary.

6.13.5 Allowances for climate change have been incorporated into the preliminary design of the drainage features across the Project, in line with DMRB LA 113 Road Drainage and the Water Environment (Highways England, 2020a). This would mitigate against potential increased vulnerability to groundwater flooding caused by the Project. Further discussion on climate mitigation and drainage is presented in Appendix 14.6: Flood Risk Assessment (Application Document 6.3). Elsewhere the Project would not exacerbate potential flood problems that could be caused by extreme wet weather events associated with climate change effects. This is because proposed deep structures are parallel to groundwater flow at the North Portal, above the water table at the South Portal and are not embedded into an aquifer at the Mardyke viaduct.

6.13.6 As explained in Section 2.5, the groundwater modelling assessments have been approved by the Environment Agency.

6.14 Monitoring

6.14.1 Selected groundwater-level monitoring is proposed, as presented in Chapter 14: Road Drainage and the Water Environment (Application Document 6.1). Monitoring is required where significant effects are identified following the inclusion of the design and mitigation measures. However, while no likely significant effects have been identified, relating to the water environment, monitoring is an integral part of implementing the mitigation outlined in Chapter 10: Geology and Soils (Application Document 6.1) and Chapter 14: Road Drainage and the Water Environment (Application Document 6.1). Monitoring is secured at the:

a. Ramsar site

b. North Portal

c. A122 Lower Thames Crossing/M25 junction

6.14.2 A commitment to carry out groundwater monitoring at the Ramsar site has been agreed with Natural England and the Environment Agency and is detailed in the CoCP (Application Document 6.3). Surveillance of groundwater levels will be carried out within the Thames Estuary and Marshes Ramsar in the vicinity of the tunnelling works for the duration of the construction period at borehole locations to be agreed with the Secretary of State in consultation with Natural England and the Environment Agency. The Contractor would complete an annual review, for the period of construction and first five years of operation, of the groundwater levels and consult on any implications for qualifying features of the Ramsar site, and any necessary remedial measures with Natural England and the Environment Agency [REAC HR008].

6.14.3 A groundwater monitoring programme around the North Portal would be agreed with the Environment Agency before beginning excavation works to construct the North Portal box structure. Monitoring commitments are secured in the REAC, detailed in the CoCP (Application Document 6.3). The need for any supplementary mitigation measures and any necessary monitoring would be informed by the results of modelling and consultation with the Environment Agency prior to the commencement of excavation works [REAC GS021].

6.14.4 Monitoring at the A122 Lower Thames Crossing/M25 junction is secured in the REAC, detailed in the CoCP (Application Document 6.3). Groundwater monitoring would be undertaken to confirm the effectiveness of the mitigation [RDWE038]. The monitoring regime would be developed in consultation with the Environment Agency and to validate the Contractor's final design solution [RDWE045].

6.15 Summary of the assessment

6.15.1 As described in Chapter 14 (Application Document 6.1), the Project includes a range of commitments to avoid or reduce effects on the groundwater, which are summarised below. These include embedded mitigation measures, additional Project specific measures (essential mitigation) and good practice approaches and actions needed to avoid, reduce or offset potential adverse impacts that could otherwise result from the construction and operation phases. Table 6.6 summarises the resultant impact magnitude of groundwater receptors.

Table 6.6 Summary of Project activities and impacts on groundwater levels and flows

Receptor	Works description	REAC summary[1] and reference number	Magnitude of impact (after mitigation) summary
Construction phase			
All aquifers	Site compounds and hardstanding	None required	No change to negligible – reduction of aquifer recharge would be small and temporary.
Essex Gravels	Utilities	Crossings of railway and road at the A122 Lower Thames Crossing/M25 junction	Negligible

Receptor	Works description	REAC summary[1] and reference number	Magnitude of impact (after mitigation) summary
Thames Chase Forest Centre SINC including Hobbs Hole (pond of mapped historical spring); and Hall Farm moat, paddock and St Mary Magdalene Churchyard SINC, Fields south of Cranham Marsh SINC		[RWDE056 and RWDE057]	
North Kent and Medway Chalk	Highway cuttings (south of the River Thames) (construction phase)	None required	No change – cuttings would be above the Chalk aquifer water table.
North Kent and Medway Chalk	South Portal construction	None required	No change – the South Portal construction would be above the water table.
North Kent and Medway Chalk	Ground protection tunnel and shafts (construction phase) and main tunnel crossing construction	The ground protection tunnel and shafts, if used under REAC Ref. RDWE017, would be constructed using methods to control groundwater pumping and ingress such as: • Wet excavation and grout plug placement to form the shafts • Use of an earth pressure balancing TBM to form a lined tunnel with a specified maximum leakage rate compliant with the Lower Thames Crossing tunnelling specification Water and flow monitoring would be undertaken for the periods that the ground protection tunnel is being used for construction purpose, in consultation with	Negligible – the modelled drawdowns are unlikely to be significant and perceptible.
Ramsar site			Negligible – actual groundwater drawdowns in the shallow water system of ditches and partially waterlogged soils at the Ramsar site would be expected to be smaller than any drawdown in the Chalk aquifer. The

Receptor	Works description	REAC summary[1] and reference number	Magnitude of impact (after mitigation) summary
		Environment Agency, to verify compliance with the tunnels design specification regarding maximum permissible rates of water ingress. The ground protection tunnel and shafts, if used under REAC Ref. RDWE017, would be decommissioned by backfilling with suitable materials to ensure the ground protection tunnel and shafts are completely filled. No temporary works would be left in the upper 2m of ground. Shaft sites would be returned to their current land use [RDWE018a and RDWE018b].	Chalk aquifer is not an important source of water to the Ramsar site function within the study area.
South Essex and Thurrock Chalk	North Portal construction	Mitigation is secured through the construction of a deep barrier around the excavations to reduce groundwater ingress. The depth of the barrier walls would be informed by the results of modelling and consultation with the Environment Agency and Thurrock Council unless otherwise agreed with the Secretary of State prior to the commencement of excavation works to construct the North Portal box structure and ramps. The need for any supplementary mitigation measures and any necessary monitoring would be informed by the results of modelling and consultation with the	Negligible – the modelled drawdowns and dewatering rates can be kept to insignificant levels.
Existing abstractions and water supply systems (Linford public supply well)	North Portal construction		No change to negligible adverse impact – modelled drawdown is less than the numerical accuracy of the model at Linford.

Receptor	Works description	REAC summary[1] and reference number	Magnitude of impact (after mitigation) summary
		Environment Agency prior to the commencement of excavation works. Technical solutions would be developed by the Contractor following further investigation and assessment [GS021]. No REAC required for the deep soil mixing as it would not extend into the Chalk aquifer.	
South Essex and Thurrock Chalk	Highway cuttings (north of the River Thames) (construction phase)	None required	Negligible adverse impact – all cuttings are above the Chalk aquifer. However, groundwater control during construction of the deepest cutting in the Lower London Tertiaries at the A13/A1089/A122 junction could cause short term, locally reduced recharge to the underlying Chalk aquifer.
South Essex Lower London Tertiaries	Highway cuttings (north of the River Thames, particularly at the A13/A1089/A122 Lower Thames Crossing junction) (construction phase)	None required	Negligible impact – Phase 2 GI long-term monitoring shows some perched water levels, especially during winter periods, above the proposed road levels at one A13/A1089/A122 junction cutting. Construction groundwater control (dewatering) is expected to be limited and of small flows.
Existing abstractions and water supply systems (agricultural supply wells at Orsett Fen)	Mardyke Viaduct and embankments construction	None required	No change – Phase 2 GI indicates that the aquifer source of the wells is the Harwich Formation, which would be deeper than the

Receptor	Works description	REAC summary[1] and reference number	Magnitude of impact (after mitigation) summary
			proposed foundation works.
Potential for groundwater flooding	Mardyke Viaduct and embankments construction	None required	No change – a barrier effect to shallow groundwater would not occur as Phase 2 GI confirms absence of a significant shallow aquifer.
Thames Chase Forest Centre SINC including Hobbs Hole (pond of mapped historical spring); and Hall Farm moat, paddock and St Mary Magdalene Churchyard SINC	A122 Lower Thames Crossing/M25 junction cutting construction	During detailed design, having regard for GI data and monitoring (groundwater levels, surface water levels and, where feasible, flows), the need for measures to reduce groundwater drawdown beyond the M25 cutting, for example through the implementation of seepage control, would be confirmed in consultation with the Environment Agency and the London Borough of Havering and, if confirmed to be necessary, the detail of such measures would be agreed by the Secretary of State following consultation with the Environment Agency and the London Borough of Havering. [RDWE038]. Groundwater monitoring would be undertaken to confirm the effectiveness of the mitigation RDWE038. The monitoring regime would be developed in consultation with the Environment Agency and to validate the Contractors' final design solution [RDWE045].	Negligible adverse impact – modelling shows drawdown could occur at these locations. Therefore, mitigation measures would be provided. In consultation with the Environment Agency, the Project would agree a mitigation method and construction method.
Existing abstractions and water supply systems (surface water abstractions potentially fed by groundwater)	A122 Lower Thames Crossing/M25 junction cutting construction		No change to negligible – modelling shows drawdown could impact a spring and deep drainage system area at North Ockendon. These are the stated indirect source of a surface water abstraction (that feeds an irrigation reservoir). Therefore, mitigation measures would be provided, as described in the REAC summary row of this table.
Essex Gravels	A122 Lower Thames Crossing/M25 junction cutting construction		Negligible to minor adverse impact – modelling indicates drawdown would be caused by the cutting, although this would be for a small area and the expected mitigation described above would mean only a small extent of drawdown resulting in only a negligible impact.

Receptor	Works description	REAC summary[1] and reference number	Magnitude of impact (after mitigation) summary
Operational phase			
New Fish Pond, near the Inn on the Lake, Shorne	Utilities	Utility trenches in vicinity to New Fish Pond [RDWE052]	No change to negligible
Lower London Tertiaries aquifers		Gas pipeline G1b deep crossing shafts [RDWE051]	No change to negligible
The irrigation reservoir at Low Street		Utility trench design to prevent adverse groundwater drainage or barrier effect [RWDE054]	No change to negligible
Local land and minor roads at Hoford Road and Brentwood Road at the Chadwell St Mary link		Utility trench design to reduce groundwater barrier effects (groundwater flooding) [RWDE055]	No change to negligible
Thames Chase Forest Centre SINC including Hobbs Hole (pond of mapped historical spring); and Hall Farm moat, paddock and St Mary Magdalene Churchyard SINC, Fields south of Cranham Marsh SINC		Crossings of railway and road at the A122 Lower Thames Crossing/M25 junction [RWDE056 and RWDE057]	No change to negligible
North Kent and Medway Chalk	Highway cuttings (south of the River Thames) (construction phase)	None required	No change – cuttings would be above the Chalk aquifer water table.
North Kent and Medway Chalk	Main tunnel crossing construction	Water infiltration into the tunnel bores and cross passages during operation would be reduced by measures including gaskets (for segmentally lined tunnels) and membranes (for sprayed concrete lined tunnels), compliant with the Lower Thames Crossing tunnelling specification [RDWE027].	Negligible – the modelled drawdowns are anticipated to be within the numerical accuracy of the model itself and unlikely to be significant and perceptible.
South Essex and Thurrock Chalk			

Receptor	Works description	REAC summary[1] and reference number	Magnitude of impact (after mitigation) summary
South Essex and Thurrock Chalk	Highway cuttings (north of the River Thames) (operational phase)	None required	Negligible impact – all cuttings are over 10m above the top of the Chalk aquifer. The deepest cutting at the proposed A13/A1089/A122 junction may reduce the long-term recharge from the overlying Thanet Formation, which in this area is separated from the Chalk aquifer by the low permeability Pegwell Silt Member (basal unit of the Thanet Formation). However, this reduction is assessed as negligible.
South Essex Lower London Tertiaries	Highway cuttings (north of the River Thames, particularly at the A13/A1089/A122 Lower Thames Crossing junction)	None required	Negligible impact – Phase 2 GI long-term monitoring shows some perched water levels, especially during winter periods, above proposed road levels at one A13/A1089/A122 junction cutting.
Potential for groundwater flooding	Mardyke Viaduct construction and embankments	None required	No change – a barrier effect to shallow groundwater would not occur as Phase 2 GI confirms absence of a shallow gravel aquifer here (or any other significant shallow aquifer such as a permeable Alluvium aquifer of significant extent).
Potential groundwater-fed surface water features at the: a. Thames Chase Forest Centre SINC including Hobbs Hole (pond of mapped historical spring); and b. Hall Farm moat, paddock and St Mary	A122 Lower Thames Crossing/M25 junction cutting operation	During detailed design, having regard for GI data and monitoring (groundwater levels, surface water levels and, where feasible, flows), the need for measures to reduce groundwater drawdown beyond the M25 cutting, for example through the implementation of	No change to negligible – modelling shows drawdown, with mitigation, would not occur at the stated potential groundwater-fed surface water features. During detailed design, the need for mitigation measures would be confirmed as described

Receptor	Works description	REAC summary[1] and reference number	Magnitude of impact (after mitigation) summary
Magdalene Churchyard SINC		seepage control, would be confirmed in consultation with the Environment Agency and the London Borough of Havering and, if confirmed to be necessary, the detail of such measures would be agreed by the Secretary of State following consultation with the Environment Agency and the London Borough of Havering. [RDWE038]. Groundwater monitoring would be undertaken to confirm the effectiveness of the mitigation [RDWE038]. The monitoring regime would be developed in consultation with the Environment Agency and to validate the Contractor's final design solution [RDWE045].	in the REAC summary column. In addition, a monitoring regime to verify existing or new modelling would be agreed as described in the REAC summary column.
Existing abstractions and water supply systems, (surface water abstractions potentially fed by groundwater)	A122 Lower Thames Crossing/M25 junction cutting		Negligible – modelling shows drawdown at an existing spring and deep drainage system (that may be the indirect source of an existing surface water abstraction for irrigation via a lined storage reservoir) would be negligible. Anticipated mitigation measures, for Hall Farm moat, paddock and St Mary Magdalene Churchyard SINC and Thames Forest Centre SINC would also have a beneficial effect on the groundwater supply to the irrigation.
Essex Gravels	A122 Lower Thames Crossing/M25 junction cutting		Negligible impact – modelling indicates drawdown would be caused by the cutting although this would be for a small proportion of the Essex Gravels aquifer and anticipated mitigation measures for Hall Farm moat, paddock and St Mary Magdalene Churchyard SINC and Thames Forest Centre SINC would also have a beneficial effect resulting in a negligible impact

Note:1 – Full wording of each REAC is detailed in the CoCP (Application Document 6.3).

7 Groundwater quality impact assessment

7.1 Methodology

7.1.1 Potential impacts to groundwater quality may occur during the construction and operational phases of the Project.

7.1.2 Chapter 10: Geology and Soils (Application Document 6.1) describes sources and activities for potential construction phase impacts. In summary, CIRIA C648 (CIRIA, 2006) describes potential construction phase impacts to the water environment and mitigation measures for linear construction projects. Potential pollutant sources include fuels and chemical use, use of grouts, uncontrolled discharges and works in contaminated land. Construction activities that create potential pollution pathways to groundwater include all excavations.

7.1.3 Construction and operation activities that are relevant to the Project are shown in Table 7.1.

Table 7.1 Pollution risks to groundwater quality

Risk	Potential causes of impacts
Construction activities	• Dewatering of excavations, potentially causing: – Saline intrusion (from the River Thames) • Dewatering of tunnel cross passages potentially causing: – Saline intrusion (from the River Thames) • Dewatering near landfill, potentially causing: – Remobilisation of contaminants
Highway drainage (operational phase)	• Highway drainage to soakaways from: – Routine runoff – Spillages potentially causing groundwater pollution
Changes caused to GWDTEs (construction or operational phase)	• Any change, including changes to drainage, that could cause: – Change in nutrient loading (nitrate and phosphate) • Increased quantities of potentially toxic chemicals (metalloid and organic compounds) from road runoff and drainage

7.1.4 DMRB LA 113 Road Drainage and the Water Environment (Highways England, 2020a) details the assessment methodology for highway drainage and discusses the potential need to assess nutrients, metalloid and organic compounds at GWDTEs (Section 8).

7.1.5 This requires a hierarchical assessment approach. Should the simple assessment criteria fail, then a detailed assessment is required. Table 7.2 summarises the simple and detailed groundwater quality assessments that have been completed.

Table 7.2 Simple and detailed assessments of potential impacts to groundwater quality

Project element that could potentially cause an impact	Simple assessment	Detailed assessment
Ground protection tunnel and main tunnel (construction and operation). Dewatering potentially causing saline intrusion beneath the Ramsar site		√
North Portal and ramp (construction and operation) Dewatering and seepage potentially causing saline intrusion north of the River Thames		√
North Portal and ramp (construction). Dewatering potentially causing mobilisation of landfill contaminants north of the River Thames		√
North Portal and TBM groundwater supply		√
Highway drainage – runoff	√	
Highway drainage – spillage	√	
Highway drainage – infiltration basins and detailed impact assessment of the Ramsar site, public water supply wells and groundwater quality		√
Utilities (various) – construction and operation	√	

Note: √ mark shows an assessment has been completed, is presented within this document and assesses the potential impact of the associated works.

7.1.6 The importance of groundwater attributes based on quality indicators and measures is described in DMRB LA 113 Road Drainage and the Water Environment (Highways England, 2020a). Further information is shown in paragraph 6.1.5. A summary of the groundwater attributes, based on groundwater levels and flows and quality, as described in Sections 3, 4 and 5, is shown in Table 7.4.

7.2 Ground protection tunnel and main tunnel construction and operation

7.2.1 The south groundwater numerical model (Annex J) includes a computer programme called SEAWAT (Annex J lists all the relevant modelling references) that simulates 3D variable density groundwater flow and solute transport. The resultant modelling shows that there would be no increase in salinity below the Ramsar site, as a result of the underground infrastructure comprising the ground protection tunnel, associated shafts and the main tunnel including associated cross passages. The model predicts no significant movement of the saline/freshwater interface, either during construction or operation.

7.3 North Portal and ramp construction and operation

7.3.1 The North Portal numerical model (Annex K) has been used to model movement of potentially contaminated groundwater to the Project from the East Tilbury Landfill. The modelling shows that basal grouting (in combination with diaphragm walls) or equivalent engineering measures to ensure minimal groundwater inflows into the excavation (in combination with diaphragm walls)

(Section 6.7) would reduce the dewatering rate and therefore minimise mobilisation of a large quantity of potentially contaminated groundwater towards the North Portal. The reduced dewatering rate would also reduce the pressure on any water treatment system.

7.3.2 Annex K reporting includes preliminary modelling of slurry wall options in relation to potential contaminants from East Tilbury Landfill. However, this work is superseded by Appendix 10.7: East Tilbury Landfill Risk Assessment Technical Memorandum. The latter confirms that there are no significant risks posed by East Tilbury Landfill as a result of the Project.

7.3.3 The North Portal numerical model (Annex K) shows that saline intrusion would not be significantly increased by the construction phase groundwater pumping if basal grouting (in combination with diaphragm walls) or equivalent engineering measure is employed. The saline interface is not predicted to impact the Project or the Linford abstraction well. Operational phase modelling also shows no significant saline intrusion.

7.3.4 The details of the North Portal construction phase mitigation would be determined during detailed design by the Contractor in accordance with the REAC, reference GS021 (Chapter 10: Geology and Soils (Application Document 6.1).

7.4 North Portal and TBM groundwater supply

7.4.1 In addition to groundwater control during the North Portal construction, water supply to the main tunnel crossing TBM would be supplied from the Linford public water supply well (not connected to distribution since 2011). Modelling confirms that groundwater control at the North Portal would not cause significant changes to saline intrusion or mobilisation of landfill contaminants, with mitigation in place. Indeed, effects have been modelled local to the Tilbury Marshes area in vicinity of the North Portal. Pumping from the Linford well would be within the existing licensed abstraction rate and therefore drawdown from the Linford well would be no greater than before 2011. For this reason, combined (superposition) effects of drawdown and saline intrusion from the North Portal and Linford well are assessed as not significant.

7.5 Highway drainage – runoff

7.5.1 Potential pollution sources of highway runoff water relate to vehicles, road construction and maintenance (e.g. de-icing and herbicides). Non-maintenance sources include fuel combustion, vehicle corrosion and tyre, road and brake wear. Atmospheric deposition is possible too.

7.5.2 Informative studies, for the development of the HEWRAT, comprised sampling in 2004 to 2005 of untreated highway runoff at two sites. This was continued until December 2006 and at 24 sites across England. A minimum 24-hour antecedent dry weather periods were required of assessed events.

7.5.3 The research resulted in assessed significant pollutants that are mostly for total determinands, reflecting the higher concentrations of pollutants in sediment derived from dust and solids washed from the road surface.

7.5.4 A key conclusion from the stage 4 model (Crabtree *et al*., 2008) development was that individual event mean concentrations are a result of a combination of traffic density (the main factor) and other variables, including rainfall, antecedent dry weather periods and seasonality.

7.5.5 Potential significant pollutants of highway runoff, determined from the research (Crabtree *et al*., 2008) and agreed between National Highways and the Environment Agency, are:

a. Copper (total and dissolved)

b. Zinc (total and dissolved)

c. Cadmium (total)

d. Pyrene (total)

e. Fluoranthene (total)

f. Total polycyclic aromatic hydrocarbons

7.5.6 Cadmium, fluoranthene and pyrene, as well as total polycyclic aromatic hydrocarbons, have been excluded from the assessment because they are only significant pollutants as particulate matter (total) and particulate matter would not enter groundwater due to the treatment measures presented in Chapter 14 (Application Document 6.1); the dissolved concentrations in runoff are negligible (see Table 4.4 in Crabtree et al. (2008)). It is assumed that any particulate matter in runoff would settle out in the sediment forebays and infiltration basins before percolation to the ground.

7.5.7 Maintenance requirements and removal of silt from highway runoff soakaway systems are important for the purposes of functionality and removal of potentially contaminated silt. Chapter 14: Road Drainage and the Water Environment (Application Document 6.1) details the asset inspection and asset maintenance standards that would be adhered to during construction and maintenance of the Project. Further details are set out in DMRB GM 701: Asset delivery asset maintenance requirements (Highways England 2020g) and DMRB GS801: Asset delivery asset inspection requirements (Highways England 2020h)

7.5.8 DMRB LA 113 Road Drainage and the Water Environment (Highways England, 2020a) requires a simple assessment after which a detailed assessment may be required. The simple assessment uses the HEWRAT, which is a publicly available Microsoft Excel application (Highways England, 2013).

7.5.9 Annex O presents the HEWRAT assessment, including a summary of the proposed infiltration basins and swales, catchment input data, assessment results and conclusions.

7.5.10 The results of the simple routine runoff assessment show that each of the infiltration basin catchments has a medium risk of causing an adverse impact to groundwater quality. Based on these results, a detailed assessment is required on potential impacts from routine runoff. The detailed assessment is presented in Section 7.7.

7.6 Highway drainage – spillage

7.6.1 The simple assessment of spillage risk is also presented in Annex O. The results of the simple spillage assessment show that individual infiltration basins' probability scores are below the most stringent pass criteria (0.5%). The use of the most stringent criteria acknowledges the importance of nearby SPZ2s along the A2 corridor and the downgradient Ramsar site.

7.6.2 The combined spillage risk to the Chalk aquifer from all the infiltration basins (south of the River Thames) is higher and HEWRAT confirms that pollution reduction measures are required to pass the most stringent pass criteria.

7.6.3 The proposed mitigation measures fulfil the required pollution reduction measures and include use of lined sediment forebays (at bigger infiltration basin systems) and pollution interceptors. Details are shown in Annex A. The combined spillage risk, with pollution reduction measures, passes the most stringent pass criteria (0.5%).

7.6.4 The simple spillage assessment of the swales also shows that all swales have a below 0.5% risk of pollution incident. Therefore, no further assessment is required.

7.6.5 Drainage related Project commitments are secured in the REAC, detailed in the CoCP (Application Document 6.3). REAC reference RDWE034 commits to specific treatment systems as set out in Annex A. REAC reference RDWE012 commits to drainage infrastructure and treatment systems that would be maintained to ensure they continue to operate to their design standard to safeguard surface and groundwater quality. REAC reference RDWE043 states that infiltration basins shall only be used to receive runoff from completed sections of highway and that general site runoff during the construction phase shall not be discharged to these infiltration basins. .

7.7 Highway drainage – infiltration basins and detailed impact assessment of the Ramsar site, public water supply wells and groundwater quality

7.7.1 A detailed assessment of potential groundwater quality impacts has been conducted for the combined effect of the proposed infiltration basins, south of the River Thames and north of the River Thames. The assessments are presented in Annex M and Annex N and show that the environmental effect on groundwater quality would not be significant.

7.7.2 The potential for the Ramsar site to be affected by road salt from the Project has been explored. The detailed assessment (Annex M) includes an appraisal of the effects of winter salting and follows a precautionary approach since the Ramsar site water balance is assessed as dominated by rainfall and not groundwater (Section 5.5). Salting is an essential maintenance activity and therefore an intermittent seasonal activity causing a large range of chloride concentrations to be found in runoff (Crabtree *et al*., 2008). Annex M demonstrates that chloride concentrations in groundwater would be below the fresh water Environmental Quality Standard at the Ramsar site boundary. Therefore, the environmental effect on the Ramsar site would not be significant even if groundwater inflow occurs.

7.8 Construction phase site compounds

7.8.1 The location of main works construction compounds and utility logistics hubs are shown in the Temporary Works Plans (Application document 2.17).

7.8.2 Activities related to use of heavy mechanical machinery (construction plant) and equipment have the potential to cause pollution due to spillages. This could cause pollution of groundwater, if a groundwater body is present, and to impact potable water supplies especially where within a published or default SPZ1 or SPZ2.

7.8.3 The Project commits to mitigation to reduce release of point sources of pollution (spillages), to prevent groundwater pollution during the construction phase, as detailed in REAC reference GS004, shown in the REAC, detailed in the CoCP (Application Document 6.3). The Project commitment includes requiring that there should be no fuel storage or fuel filling within a SPZ1 and in addition to reduce the risk of a pollution event caused by spillages, measures would be followed when refuelling on worksites such as use of drip trays, spill kits and only construction equipment and vehicles free of oil/fuel leaks would be permitted on worksites. As a result, a magnitude of impact of no change for groundwater quality is assessed for all underlying groundwater bodies, including published and default SPZ1s and SPZ2s at each site. Further detail is shown in Chapter 10: Geology and Soils.

7.9 Nitrogen deposition habitat compensation areas

7.9.1 Appendix 10.6 (Application 6.3) desk study results and the proposed planting and maintenance of vegetation have been assessed. Following a precautionary principle, the Project commits to mitigation to reduce release of diffuse (rural) sources of pollution such as nitrate (fertilisers) and pesticides (including herbicides), to prevent groundwater pollution diffuse during the construction phase and operational phase, as detailed in clause number LSP.27 of the Design Principles (Application Document 7.5). As a result, a magnitude of impact of no change for groundwater quality is assessed for all underlying groundwater bodies at each site.

7.10 Utilities

7.10.1 Discussion about the assessment of utilities is introduced in Section 6.12. Annex Q presents the simple assessment of the potential impact of proposed underground utilities on the groundwater environment, including groundwater quality. Emphasis is on whether saline intrusion effects could be caused, although the assessment also notes where any activity would be close to existing groundwater abstractions. It should be noted that pollution issues related to contaminated land are assessed separately in Chapter 10: Geology and Soils (Application Document 6.1)).

7.10.2 Construction of utilities has the potential to impact groundwater quality, especially where construction is below ground level and groundwater abstraction (dewatering) could mobilise contaminants. Further, operational phase impacts could result from any permanent drainage.

South of the River Thames

7.10.3 Construction of utility corridors south of the River Thames is generally above groundwater. Therefore, since no large scale dewatering is proposed there would be no groundwater drawdown effects which would be caused near the tidal River Thames and consequently there would be no increased saline intrusion effects. In addition, no utility works are proposed within a SPZ1 of a public water supply well or other licensed well.

7.10.4 The simple assessment concludes that for all the utility corridors the effect of these works would be not significant.

North of the River Thames

7.10.5 North of the River Thames, no large scale dewatering is proposed for construction of the utility corridors and therefore no saline intrusion effects would occur from the tidal River Thames.

7.10.6 Utility works do include the replacement and diversion of overhead power lines at Linford. Here, within the SPZ1, there would be one new temporary pylon, one new permanent pylon, plus two new pylons of footprint overlapping that of existing pylons. Shallow, pad, foundations are anticipated and therefore these would not penetrate into aquifer source of the abstraction well. Also, within the Linford SPZ1 would be Work Numbers MU28 and MU36 corridors; these would be expected to be shallow only. Further discussion about Project commitments is shown below.

7.10.7 The Project commitments for mitigation during the construction phase and operational phase are shown in the REAC, detailed in the CoCP (Application Document 6.3). This includes the Project commitments summarised in Table 6.4. Other Project commitments are secured in the REAC. REAC reference GS026 requires appropriate foundation risk assessments to be conducted and this would be relevant for utility works requiring foundations (for example pylon foundations). Also, REAC reference GS028 secures a Project commitment to mitigate the potential for contaminant mobilisation during construction phase earthworks. Table 7.3 shows an additional Project commitment for the prevention of pollution in the SPZ1, including works associated with utilities.

Table 7.3 Utilities – project commitment (groundwater quality)

Location	REAC ref no.	Project commitment
Lower Higham Road	RDWE053	There is a requirement to replace an approximately 100 metres section of existing water pipeline on Lower Higham Road. This utility diversion, Work Number MU26, would be approximately 10m distance south of the South Thames Estuary and Marshes SSSI and Thames Estuary and Marshes Ramsar. Any pumped water removal and subsequent disposal of water from the utility works shall be subject to approval from the Environment Agency and comply with Environment Permitting Regulations(England and Wales) 2016 to protect the adjacent areas of nature conservation.
Linford (SPZ1)	RDWE058	The temporary water pipeline for the Lower Thames Crossing TBM supply (Work Number MUT6) would cross

Location	REAC ref no.	Project commitment
		Gobions Sewer, within the SPZ1 area of the Linford groundwater source. Should the crossing be below ground, such as using a trenchless methodology, the design, implementation and subsequent removal of the underground sections of the utility corridor within the SPZ1 shall be conducted in consultation with Northumbrian Water and the Environment Agency
Linford (SPZ1)	GS005	A published source protection zone 1 (SPZ1), for the protection of groundwater used for potable supply, is located at Linford. No refuelling shall be allowed within a SPZ1 where a potable water abstraction is identified .

7.11 Climate change

7.11.1 There is low confidence in the science that links historical groundwater quality changes to climate change (Bloomfield et al., 2013). A general introduction of climate change themes is presented in Section 2.5.

7.11.2 Climate change has the potential to alter highway runoff quality, although details are uncertain (Highways England, 2016). Drier summers in south-east England are anticipated and could cause longer antecedent dry weather periods. Conversely, warmer, wetter winters are expected and could reduce the need for salting. Further, increased extreme weather events are anticipated which could increase the potential variation of runoff water quality. Changes other than climate change may also alter highway runoff quality in the future, including changes to vehicles and non-maintenance sources.

7.11.3 Construction and operation of the Project is not anticipated to be impacted by or to increase impacts from climate change, with respect to groundwater quality. Saline intrusion of aquifers in the vicinity of the Thames Estuary could increase should groundwater levels be reduced relative to river water levels. If it occurred, the Project is not anticipated to exaggerate groundwater saline intrusion since the Project assessments (Section 7.2 and 7.3) demonstrate that drawdown related saline intrusion effects would not be significant. Also, as stated in Section 2.5 and Section 6.13, the Project would not have a significant impact on groundwater levels and therefore negligible influence on any climate change related changes to saline intrusion.

7.12 Monitoring

7.12.1 Monitoring is required where significant effects are identified following the inclusion of design and mitigation measures.

7.12.2 However, while no likely significant effects have been identified, relating to groundwater quality, monitoring is an integral part of implementing the mitigation outlined in Chapter 10: Geology and Soils (Application Document 6.1) and Chapter 14: Road Drainage and the Water Environment (Application Document 6.1). Monitoring commitments are secured in the REAC, detailed in the CoCP (Application Document 6.3). REAC reference GS021 includes for groundwater monitoring at the North Portal.

7.13 Summary of the assessment

7.13.1 As described in Chapter 14 (Application Document 6.1), the Project includes a range of commitments to avoid or reduce effects on the groundwater, which are summarised below. These include embedded mitigation measures, additional Project-specific measures (essential mitigation) and good practice approaches and actions needed to avoid, reduce or offset potential adverse impacts that could otherwise result from the construction and operation phases. Table 7.4 summarises the resultant impact magnitude on groundwater receptors.

Table 7.4 Summary of Project activities and impacts on groundwater quality

Receptor	Works description	REAC summary[1] and reference number	Impact magnitude (after mitigation) and summary
Construction phase			
Ramsar site	Utilities	Disposal of any water removed from the utility works to comply with Environment Agency abstraction regulations and permitting regulations. [RDWE053]	No change
SPZ1	Utilities	Foundations of pylons to be designed to prevent impact to the aquifer source and prevention of fuel spillage related to Project works. [GS004, GS005 and GS026]	No change
North Kent and Medway Chalk	Ground protection tunnel and shafts (construction phase)	The ground protection tunnel and shafts, if used under REAC Ref RDWE017, would be decommissioned by backfilling with suitable materials to ensure the ground protection tunnel and shafts are completely filled. No temporary works would be left in the upper 2m of ground. Shaft sites would be returned to their current land use. [RDWE018a and RDWE018b]	Negligible – the model predicts no significant movement of the saline/freshwater interface.
North Kent and Medway Chalk	Main tunnel crossing construction	Construction of cross passages between the main tunnels would use groundwater control	Negligible – the model predicts no significant movement of the saline/freshwater interface.

Receptor	Works description	REAC summary[1] and reference number	Impact magnitude (after mitigation) and summary
Ramsar site		techniques, such as grouting or ground freezing, to reduce the requirement for dewatering and therefore local groundwater drawdown. [RDWE020]	Negligible – the model predicts no increase in salinity below the Ramsar site, as a result of the Project underground infrastructure.
South Essex and Thurrock Chalk	North Portal construction	Mitigation is secured through the construction of a deep barrier around the excavations to reduce groundwater ingress. The depth of the barrier walls would be informed by the results of modelling and consultation with the Environment Agency and Thurrock Council unless otherwise agreed with the Secretary of State prior to the commencement of excavation works to construct the North Portal box structure and ramps. The need for any supplementary mitigation measures and any necessary monitoring would be informed by the results of modelling and consultation with the Environment Agency prior to the commencement of excavation works. Technical solutions would be developed by the Contractor following further investigation and assessment. [GS021]	Negligible – modelling shows that saline intrusion would not be significantly increased by construction phase groundwater pumping.
Linford public supply well	North Portal construction		Negligible – modelling predicts no change of salinity at Linford.
Operational phase			
SPZ1 (Linford)	Utilities	Foundations of pylons to be designed to prevent impact to the aquifer source [GS026]	No change
North Kent and Medway Chalk	Main tunnel crossing operation	Water infiltration into the tunnel bores and cross passages during operation would be reduced by measures including	Negligible – the model predicts no significant movement of the saline/freshwater interface.

<table>
<tr><th>Receptor</th><th>Works description</th><th>REAC summary[1] and reference number</th><th>Impact magnitude (after mitigation) and summary</th></tr>
<tr><td></td><td></td><td>gaskets (for segmentally lined tunnels) and membranes (for sprayed concrete lined tunnels), compliant with the Lower Thames Crossing tunnelling specification. [RWDE027]</td><td></td></tr>
<tr><td>Southern Water Services Ltd supply wells
(south of the River Thames)</td><td>Highway drainage including infiltration basins</td><td rowspan="2">Drainage infrastructure and treatment systems would be maintained in accordance with the Highways England’s DMRB GS 801 Asset Delivery Asset Inspection Requirements and DMRB GM 701 Asset Delivery Asset Maintenance Requirements, as applicable, to ensure they continue to operate to their design standard to safeguard surface and groundwater quality. [RDWE012]

To safeguard groundwater WFD chemical status, infiltration basins, provided at the locations identified on the Environmental Masterplan (Application Document 6.2), would be fitted with treatment systems as identified in Annex A [RDWE034].</td><td>Negligible – modelling of the impacts of the infiltration basins shows that pollutant concentrations would be significantly lower than the screening drinking water standards at the SPZ1 and SPZ2 of the wells.</td></tr>
<tr><td>North Kent and Medway Chalk</td><td>Highway drainage including infiltration basins</td><td>Negligible – modelling of the impacts of the infiltration basins shows relevant environmental quality standards and drinking water standards would not be exceeded at the Environment Agency agreed compliance points.</td></tr>
<tr><td>North Kent and Medway Chalk</td><td>Nitrogen deposition habitat creation sites</td><td>During the management of vegetation and landform the Project would reduce release of diffuse (rural) sources of pollution such as nitrate (fertilisers) and pesticides (including herbicides), to prevent groundwater pollution as set out in the Environment Agency’s (2018c) approach to groundwater protection and to avoid surface water pollution.</td><td>No change</td></tr>
</table>

Receptor	Works description	REAC summary[1] and reference number	Impact magnitude (after mitigation) and summary
		[Design Principle LSP.27]	
South Essex and Thurrock Chalk	Main tunnel crossing operation	Water infiltration into the tunnel bores and cross passages during operation would be reduced by measures including gaskets (for segmentally lined tunnels) and membranes (for sprayed concrete lined tunnels), compliant with the Lower Thames Crossing tunnelling specification [RWDE027].	Negligible – the model predicts no significant movement of the saline/freshwater interface.
Linford public water supply well (north of the River Thames)	Highway drainage including infiltration basins	Drainage infrastructure and treatment systems would be maintained in accordance with the Highways England's DMRB GS 801 Asset Delivery Asset Inspection Requirements and DMRB GM 701 Asset Delivery Asset Maintenance Requirements, as applicable, to ensure they continue to operate to their design standard to safeguard surface and groundwater quality [RDWE012]. To safeguard groundwater WFD chemical status, infiltration basins, provided at the locations identified on the Environmental Masterplan (Application Document 6.2), would be fitted with treatment systems as identified in Annex A [RDWE034].	Negligible – modelling of the impacts of the infiltration basins shows that pollutant concentrations would be significantly lower than the screening drinking water standards at the SPZ1 and SPZ2 of the well.

Note: 1 Full wording of each REAC is detailed in the CoCP (Application Document 6.3). Where applicable the relevant clause number of the Design Principles (Application Document 7.5) has also been shown.

8 Groundwater Dependent Terrestrial Ecosystems impact assessment

8.1 GWDTE assessment methodology

8.1.1 Locations of identified potential GWDTEs are shown in Figure 14.2 (Application Document 6.2) (excluding areas screened out of the GWDTE assessment) and in Appendix 8.2 (Application Document 6.3).

8.1.2 Assessment of potential impacts on GWDTEs is set out in Appendix B of DMRB LA 113 Road Drainage and the Water Environment (Highways England, 2020a). The identification of potential GWDTEs is presented in Section 3.9 and has used NVC data, where available, and Phase 1 habitat survey data to compare against the UKTAG WTT 11 broad habitat categories where NVC data is not available, following the DMRB methodology.

8.1.3 Details of the assessment of importance (value) of the potential GWDTEs, together with the potential magnitude of impacts due to the Project, are presented in Annex P.

8.2 Small areas of potential GWDTEs

8.2.1 Table 8.1 summarises the various small areas with ditches and ponds that have been identified as being potential GWDTEs (Section 3.9). SINC sites (eCountability Ltd, 2020) in the vicinity of the A122 Lower Thames Crossing/M25 junction are discussed separately below.

Table 8.1 Summary of small potential GWDTEs and potential impacts

Location	Importance as a GWDTE	Potential Project impacts, without mitigation (cause)	Significance of effect
South of the River Thames			
Jeskyns Community Woodland car park pond (TN63)	Low	Negligible	Not significant
North of the River Thames			
Ditches at Cooper Shaw Road (Tilbury) (TN144)	Low	Negligible	Not significant
Golf course pond margins at Thames Chase (TN148)	Low	Negligible	Not significant
North Ockendon Pit SINC (TN147)	Low	Minor to moderate adverse (groundwater drawdown)	Not significant

Note: TN refers to the target note number shown in vegetation surveys detailed in Appendix 8.2 (Application Document 6.3).

8.2.2 North Ockendon Pit SINC, 300m north east of the A122 Lower Thames Crossing/M25 junction cutting, is an area near the Ockendon link comprising rough ground including some ditches and ponds. It has been assessed as having low importance as a GWDTE due to the low groundwater dependency score and the low ecological value of the area. The proposed cutting at the A122 Lower Thames Crossing/M25 junction could cause permanent groundwater drawdown of 0.5m to 0.6m (Annex L), without mitigation and therefore minor to moderate adverse impact to the potential GWDTE. However, with the implementation of mitigation secured through REAC 038, no drawdown is expected at or within the boundary of the SINC. Considering the described value and the magnitude of impact following mitigation, Chapter 14: Road Drainage and Water Environment (Application Document 6.1) has assessed that the environmental impact would be not significant.

8.2.3 Hall Farm moat, paddock and St Mary Magdalene Churchyard SINC, 300m east of A122 Lower Thames Crossing/M25 junction cutting, is an area including ponds that is described in Section 3.6. Since the site is characterised by permanent ponds, rather than wetland, it is not a GWDTE (Environment Agency, 2014) and therefore has not been assessed as a GWDTE. As noted in Section 3.9, the NVC survey results show very limited extent of marginal swamp habitat of low groundwater dependency. Assessment details and mitigation to reduce impacts to the ponds, is shown in Section 6.8. Details of the NVC survey are presented in Appendix 8.2: Plants and Habitats (Application Document 6.3).

8.2.4 Hobbs Hole, a pond at the southern end of Thames Chase Forest Centre SINC, was also the subject of a NVC survey. Again, because it is a permanent pond, it is not a GWDTE and therefore has not been assessed as a GWDTE. The same survey also examined the mapped watercourse shown starting from Hobbs Hole and extending northwards into the Thames Chase Forest Centre SINC. The watercourse was dry when surveyed and has been verbally reported as dry, by Project ecologists, during monthly bird surveys conducted for one year at the site. As noted in Section 3.9, the NVC survey results show very limited extent of marginal swamp and mire habitat of low groundwater dependency. Assessment details and mitigation to reduce impacts to the pond, are shown in Section 6.8. Details of the NVC survey are presented in Appendix 8.2: Plants and Habitats (Application Document 6.3).

8.2.5 All other SINC sites have been assessed as having a low to moderate importance, with respect to GWDTE. The assessed impacts from the Project are negligible and therefore the assessed significance of effect is not significant (Annex P).

8.3 Cranham Marsh LNR

8.3.1 Cranham Marsh LNR, located 500m west of the A122 Lower Thames Crossing/M25 junction cutting as measured from the eastern extremity of the LNR, comprises mostly broadleaved woodland habitat as described in Section 3.9 and Annex P. However, it has been identified as having small, discrete areas of fen (valley mire) habitat that have been assigned as having high groundwater dependency (Environment Agency, 2014). This habitat is assessed as of medium value as a GWDTE.

8.3.2 Detailed assessment shows that the cutting at the A122 Lower Thames Crossing/M25 junction would not cause temporary or permanent groundwater drawdown at the LNR, even without mitigation (Section 6.8).

8.4 Ingrebourne Marshes SSSI

8.4.1 Ingrebourne Marshes SSSI is designated as a GWDTE by the Environment Agency (2020) (Section 3.9) and therefore is of high value with respect to the GWDTE assessment. The SSSI is located over 2km further south-west of Cranham Marsh LNR and almost 3km from the Order Limits. The modelling (Annex L) demonstrates that drawdown, due to the A122 Lower Thames Crossing/M25 junction cutting, would not be discernible at the SSSI. Therefore, due to its large distance from the Project dewatering activities, the modelling results support a conclusion of no measurable change (a negligible magnitude of impact) at this GWDTE during the construction and operational phases (Annex P).

8.5 Climate change

8.5.1 Climate change effects have the potential to change the future baseline with respect to groundwater levels and flows and groundwater quality and therefore GWDTEs. However, there is low confidence about how groundwater levels will change due to climate change and there is low confidence that historical groundwater quality has changed due to climate change (Section 2.5).

8.5.2 Construction and operation of the Project is not anticipated to increase impacts to GWDTEs from climate change, relating to groundwater levels and flows. Should prolonged droughts occur, then the Project is not anticipated to exaggerate groundwater lowering effects.

8.5.3 Groundwater quality changes to GWDTEs due to climate change are not anticipated. Agricultural control of nutrients is likely to remain the biggest potential influence on any future changes. Project highway runoff quality would not increase the nutrient loading of GWDTEs as no outfalls are proposed upstream of GWDTEs (Annex P) and climate change impacts to runoff are unlikely in any case (Section 7.8).

8.6 Monitoring

8.6.1 Monitoring is required where significant effects are identified following the inclusion of design and mitigation measures. However, no monitoring is proposed with respect to GWDTEs since no likely significant effects have been identified, even without mitigation.

8.7 Summary of the assessment

8.7.1 As described in Chapter 14 (Application Document 6.1), the Project includes a range of commitments to avoid or reduce effects on the groundwater, which are summarised below. These include embedded mitigation measures, additional Project-specific measures (essential mitigation) and good practice approaches and actions needed to avoid, reduce, or offset potential adverse impacts that could otherwise result from the construction and operation phases. Table 8.2 summarises the resultant impact magnitude of groundwater receptors.

Table 8.2 Summary of Project activities and impacts on GWDTEs

Receptor	Works description	REAC summary[1] and reference number	Impact magnitude (after mitigation) and summary
Construction and operational phases			
Ingrebourne Marshes SSSI	A122 Lower Thames Crossing/M25 junction cutting construction	During detailed design, having regard for GI data and monitoring (groundwater levels, surface water levels and, where feasible, flows), the need for measures to reduce groundwater drawdown beyond the M25 cutting, for example through the implementation of seepage control, would be confirmed in consultation with the Environment Agency and the London Borough of Havering and if confirmed to be necessary, the detail of such measures would be agreed by the Secretary of State following consultation with the Environment Agency and the London Borough of Havering [RDWE038].	No change – modelling shows no discernible drawdown in vicinity of the SSSI.
Cranham Marsh LNR	A122 Lower Thames Crossing/M25 junction cutting construction		No change – modelling shows the cutting would not cause groundwater drawdown. No mitigation.
SINC sites (assessed as potential GWDTEs)	A122 Lower Thames Crossing/M25 junction cutting construction		Negligible – no discernible drawdown shown by the modelling.

Note: 1. Full wording of each REAC is detailed in the CoCP (Application Document 6.3). 2. See Table 8.1 *for the small GWDTEs.*

9 Summary of annexes

9.1.1 Table 9.1 summarises the Hydrogeological Risk Assessment annexes. For each annex, the key words, main annex content and, where relevant, key conclusions, are shown. The content of the annexes are also discussed in the relevant Appendix 14.5 sections, in particular Section 6, groundwater levels and flows impact assessment, Section 7, groundwater quality impact assessment and Section 8, groundwater dependent terrestrial ecosystems impact assessment.

Table 9.1 Summary of Appendix 14.5 annexes

Annex	F/I [1]	S/D/- [2]	Key words, Main content, [Key conclusions (for interpretative annexes only)]
Annex A	F	-	**Infiltration basins** Schedule of water quality treatment systems and accidental spillage control per infiltration basin
Annex B	F	-	**Regional groundwater bodies** Table summarising the hydrogeology of the regional groundwater bodies
Annex C	F	-	**Groundwater levels, whole Project** Graphs of groundwater levels versus time for regional Environment Agency boreholes; location map of the Environment Agency boreholes; Phase 1 and Phase 2 GI minimum, mean and maximum groundwater water level monitoring charts; Chalk aquifer groundwater level contour plans for the Chalk aquifer (low condition); tidal hydrograph for multiple strata monitored at the North Portal area
Annex D	F	-	**Groundwater levels, Ramsar site** Groundwater level summary for the Ramsar site including tidal hydrographs, a borehole location plan and tables of groundwater levels
Annex E	I	S	**Water balance, Ramsar site** Conceptualisation of water inflows, outflows, storage and estimated component volumes per month; leakage from the Thames and Medway Canal; calculation of soil moisture deficit and discussion of the site specific MORECS data; presentation and analysis of Sentinel-2 optical satellite imagery for two dry periods that indicate there was no moisture stress during extended dry summer conditions [Groundwater flow into the Ramsar site is mostly horizontal and contribution to the water balance is small (typically less than 2%)]

Annex	F/I [1]	S/D/- [2]	Key words, Main content, [Key conclusions (for interpretative annexes only)]
Annex F	F	-	**Groundwater quality, whole Project** Piper plots for different strata; chloride box plots and historical chloride concentration contours in groundwater; box plots of various water quality determined concentrations versus northing value; chloride/ bromide ratio plots for tentative chloride source in the North Portal area; table summarising nitrate and chloride concentrations of Phase 1 and Phase 2 GI, arranged per area and per strata type
Annex G	F	-	**Groundwater quality, Ramsar site** Chloride box plot versus northing value Tables summarise nitrate and chloride laboratory tested concentrations and field testing of electrical conductivity per strata type.
Annex H	I	S	**Highway cuttings, assessment of potential impacts to groundwater levels and flows** Table summarising depth of cuttings, groundwater levels, potential receptors and assessed significance of environmental effect; plate showing A13 westbound to A122 southbound (link road 3) groundwater level and proposed road levels. [KEY CONCLUSIONS: No significant effects were found for all the proposed cuttings except for one at the proposed A122 Lower Thames Crossing/M25 junction}. See Annex L (detailed assessment)]
Annex I	I	S	**Highway embankments, assessment of potential impacts to groundwater levels and flows** Table summarising any ground improvement measures, groundwater levels, potential receptors and assessed significance of environmental effect. [KEY CONCLUSIONS: No potential significant effect on groundwater flow and levels as a result of the proposed embankments]
Annex J	I	D	**Ground protection tunnel , main tunnels, Ramsar site, groundwater modelling** Detailed BGS lithostratigraphic geological model updated using Phase 1 and Phase 2 GI data. Packer and variable head test results; discussion of Chalk aquifer hydraulic conductivity variation with depth, description of high transmissivity zones in the Chalk; description of ground protection tunnel and proposed grout blocks and specified maximum tunnel leakage; description of the main tunnel; model boundaries and calibration of groundwater numerical model; modelled groundwater level effect in the strata including the Alluvium and Chalk; SEAWAT saline intrusion modelling. [KEY CONCLUSIONS: Predicted groundwater drawdowns due to the construction phase ground protection tunnel and shafts are not significant. Predicted groundwater drawdowns due to the main tunnels (operation) is small in the Alluvium with no drawdown predicted in the underlying Chalk aquifer due to the low flow rates into the tunnel and presence of the high transmissivity zones in the Chalk aquifer. The SEAWAT modelling predicts no measurable movement of the saline interface due to the Project].

Annex	F/I [1]	S/D/-[2]	Key words, Main content, [Key conclusions (for interpretative annexes only)]
Annex K	I	D	**North Portal shaft, ramp, diaphragm walls, grout plug, deep soil mixing, East Tilbury Landfill. Linford abstraction well, groundwater modelling** Detailed BGS lithostratigraphic geological model updated using Phase 1 and Phase 2 GI data with descriptions of groundwater numerical model input and approach to model boundaries and calibration being similar to Annex J. tidal hydrographs as evidence for high transmissivity zone; sensitivity analysis of diaphragm wall depth, grout plug thickness, slurry wall depth and deep soil mixing depth. [KEY CONCLUSIONS: Scenario with no embedded mitigation (ie pumping from an open void) results in a predicted a pumping rate of 62L/s-124L/s and a drawdown radius of over 3km. However the scenario with embedded mitigation, comprising diaphragm walls and a grout plug, results in a predicted smaller pumping rate and radius of drawdown of 9.4L/s - 11.7L/s and 1km respectively and insignificant drawdowns. The SEAWAT modelling predicts, that during construction, the combined effect of North Portal dewatering (with embedded mitigation) and pumping of 3.5ML/d-6ML/d at the Linford abstraction would be no salinity increase at Linford or at the North Portal but a small saline interface movement along the edge (150m to 300m thick strip) of the River Thames. Also ground improvement deep soil mixing at zones defined in the annex would cause only small drawdowns very close to the North Portal and no barrier effect would be caused. Annex K also includes preliminary modelling of slurry wall options in relation to potential contaminants associated with local made ground. However, the slurry wall modelling is superseded by Appendix 10.7: East Tilbury Landfill Risk Assessment Technical Memorandum.
Annex L	I	D	**A122/M25 junction cutting, Cranham Marsh LNR, SINCs, springs, agricultural water supply, North Ockendon, groundwater modelling** Detailed BGS lithostratigraphic geological model updated using Phase 2 and Phase 3 GI data and re-interpreted by Cascade geomorphologists to explain the complex layering of the River Terrace Deposits; groundwater level monitoring and in-situ hydraulic conductivity test results; 11 detailed geological cross-sections; descriptions of groundwater numerical model input and approach to model boundaries and calibration; three modelled scenarios of the road cutting construction and operation (no mitigation, full mitigation and partial mitigation), drawdown assessment at virtual observation wells. [KEY CONCLUSIONS: without mitigation of the proposed cutting, there is predicted groundwater drawdown and therefore potential impacts to Thames Chase Forest Centre SINC including Hobbs Hole (pond), Hall Farm moat, paddock, and St Mary Magdalene Churchyard SINC and the North Ockendon catchment. However with mitigation the model shows that these impacts would be mostly to fully eliminated. In addition, groundwater levels would remain well below ground level with mitigation, so that barrier effects would be not significant. Cranham Marsh LNR would not be impacted even without mitigation.

Annex	F/I [1]	S/D/- [2]	Key words, Main content, [Key conclusions (for interpretative annexes only)]
Annex M	I	D	**Infiltration basins, south of the Thames, highway runoff, groundwater mounding, pollution assessment, groundwater modelling** Description of the Chalk aquifer and hydrogeological parameters, unsaturated zone slow matrix flow and quick fracture flow water movement; drainage design and catchment description; analytical assessment of groundwater mounding for three different infiltration scenarios and comparison with the unsaturated zone thickness; numerical modelling to check for mounding superposition effects; analytical fate and transport model (ConSim) simulation of chloride, copper, lead and zinc concentrations at compliance points at boundaries of described SPZ1s, SPZ2s and the Ramsar site. [KEY CONCLUSIONS: the potential mounding effect of the water table would not exceed the thickness of the unsaturated zone and therefore the risk of groundwater flooding is negligible. Chloride concentrations in groundwater would be below the fresh water environmental quality standard (EQS) at the Ramsar site boundary. The described heavy metal pollutant levels would be below the EQS values at the Ramsar site, and below the drinking water standard (DWS) at the edge of the described SPZ1 and SPZ2 after 120 years of Project operation.
Annex N	I	D	**Swales, infiltration basin, north of the Thames, highway runoff, groundwater mounding, pollution assessment, Linford, groundwater modelling** Hydrogeological description including three geological long sections with December 2020 groundwater levels added; Basal Sands description including the basal Pegwell Silt Member that likely reduces the hydraulic connection to the underlying Chalk aquifer; groundwater level contour maps; hydraulic conductivity values and soakaway test results; analytical assessment of groundwater mounding for the combined effect of swales SWS11-002A, SWS11-008 and infiltration basin POS11-003; analytical fate and transport model (ConSim) simulation of chloride, copper, lead and zinc concentrations at compliance points at boundaries of the Linford SPZ1 and SPZ2 and the midpoint distance from source area to the Orsett Golf Club well. [KEY CONCLUSIONS: the potential mounding effect of the water table would not exceed the thickness of the unsaturated zone, with the less conservative hydraulic conductivity value having lower predicted mounding. 95^{th} percentile concentrations of chloride and the described heavy metal pollutant levels in groundwater would all be below the DWS at the Linford SPZ1, SPZ2 and the Orsett Golf Club compliance points after 120 years of Project operation.
Annex O	I	S	**HEWRAT, water risk assessment tool, runoff, spillage, groundwater quality** Infiltration basin catchments and basin design assumptions, locations of infiltration basins and swales, risk assessment background, runoff and spillage input information sources, assessment results for infiltration basins and swales.

Annex	F/I [1]	S/D/-[2]	Key words, Main content, [Key conclusions (for interpretative annexes only)]
			[KEY CONCLUSIONS: the simple assessment of groundwater pollution risk from routine run off showed that there was a medium risk from all infiltration basins and over half of the swales, with the remaining being of low risk. Therefore a detailed runoff risk assessment was required (see Annex M and Annex N). The cumulative spillage incident risk at the infiltrtaion basins is calculated as less than 0.5% which is a pass.
Annex P	I	S	**GWDTE, groundwater dependent terrestrial ecosystems, NVC surveys, Phase 1 surveys** Screening of Project Phase 1 habitat results using UKTAG WTT habitats; Cranham Marsh LNR Phase 1 habitat results shows discrete areas of fen (valley mire) habitat recorded in the Middle Wood and Spring Wood parts of the LNR; Groundwater dependent vegetation was identified in some SINC sites using UKTAG habitat categories, NVC surveys of marginal species at Hall Farm moat, paddock, and St Mary Magdalene Churchyard SINC and Thames Chase Forest Centre SINC identified discreet areas of low groundwater dependency although both of these sites have been assessed as permanent ponds (rather than GWDTEs); simple assessment of risk of impact to identified potential GWDTEs [KEY CONCLUSIONS: a negligible risk was assessed for all the identified potential GWDTE within the Project study area
Annex Q	I	S	**Utilities, open cut trenches, trenchless methods, indicative design** Summary of utility works and depths, typical trench details and trenchless construction methods; trenchless methods (often used to cross beneath existing roads, railway, and watercourses) that may require dewatering of shafts are identified as micro-tunnelling and thrust bore techniques. KEY CONCLUSIONS: Majority of utility works would comprise shallow trenches (within 3m depth). Location of sites where utility works would be beneath groundwater, such as where groundwater is shallow or where deeper works are proposed, are identified and Project commitments have been made to reduce potential draining effects or potential groundwater flow barrier effects.

Notes:

Factual (F) or Interpretative (I) annex

Simple assessment (S); Detailed assessment (D); other, such as collation of values or charts (-)

10 Conclusion

10.1.1 This hydrogeological risk assessment presents the evaluation of groundwater receptors, groundwater flows and levels, potentially groundwater supported surface water bodies, groundwater quality and potential GWDTEs within the Project study area. The assessment has drawn on a comprehensive body of work comprising GIs, water features surveys, groundwater monitoring, desk studies, liaison with key stakeholders, complementary ecological and surface water surveys, numerical groundwater modelling and peer review by groundwater industry experts. In doing so, the assessment has addressed the requirements of the NPSNN (Department for Transport, 2014), the National Policy Statement for Energy (EN-1) (Department for Energy and Climate Change, 2011a), the National Policy Statement for Gas supply Infrastructure and Gas and Oil Pipelines (EN-4) (Department for Energy and Climate Change, 2011b) and the National Policy statement for Electricity Networks Infrastructure (EN-5) (Department for Energy and Climate Change, 2011c). This hydrogeological risk assessment forms the basis of the groundwater assessment presented in Chapter 14: Road Drainage and the Water Environment (Application Document 6.1). Methodology used includes that set out in DMRB LA 113 Road Drainage and the Water Environment (Highways England, 2020a).

10.1.2 The baseline studies presented in this report have identified the receptors considered as part of the groundwater environment, which include superficial and bedrock aquifers, springs, public water supply and private licensed groundwater abstractions, SPZs, surface water bodies, and GWDTEs. The local authorities confirmed no recorded private water supplies (as per the Private Water Supplies Regulations 2016, as amended). The presented baseline CSMs form the basis of the impact assessments.

10.1.3 Potential effects have been assessed by a combination of simple and detailed assessments. These depend on the value of the receptor (detailed in Chapter 14: Road Drainage and the Water Environment (Application Document 6.1)) and the potential magnitude of the impact. Potential impacts from climate change have also been assessed in the drainage studies.

10.1.4 Assessment of potential changes to groundwater levels and flows (including to surface water bodies potentially fed by groundwater, where relevant) has included detailed assessments of the impact of construction of the Project's main tunnel crossing beneath the Ramsar site; the North Portal excavation below the shallow piezometric level of the Chalk aquifer; the proposed road cutting at A122 Lower Thames Crossing/M25 junction; the impact of highway drainage soakaways; and the impact of utility diversions .

10.1.5 Assessment of potential changes to groundwater quality has included detailed assessments of the potential saline intrusion impacts of the Project's tunnel and portals, as well as impacts of highway drainage from soakaways.

10.1.6 GWDTEs have been identified using prescribed vegetation habitat methodology defined by the Environment Agency (2014) and as set out in DMRB LA 113 Road Drainage and the Water Environment (Highways England, 2020a). A combination of simple and detailed (groundwater modelling) assessments has been carried out to assess potential groundwater lowering in discrete areas of potential groundwater-fed wetland and surface water bodies.

10.1.7 Assessment of the impacts and any necessary mitigation are presented in this report and annexes. Chapter 14: Road Drainage and the Water Environment (Application Document 6.1) describes the potential environmental effects. In summary:

a. The assessed impact to the Ramsar site from the ground protection tunnel or the main tunnel crossing is anticipated to be within the numerical accuracy of the groundwater model (Annex J) and is unlikely to be significantly perceptible. Mitigation measures to reduce construction drawdown and operational leakage into the tunnels are secured in REAC references RDWE018a, RDWE018b and RWE027.

b. Construction phase groundwater control (including dewatering) at the North Portal has the potential to lower groundwater levels, increase saline intrusion and mobilise contaminants. However, mitigation can be achieved by deep diaphragm walls plus a suite of potential technical solutions, including a grout plug (or equivalent engineering measure to minimise groundwater inflows into the excavation or drawdown). The potential technical solutions are secured in the REAC [Ref. GS021] (Application Document 6.3) through the DCO requirements. The numerical modelling demonstrates that mitigation would minimise saline intrusion effects and appropriately limit remobilisation of historical landfill contaminants.

c. The A13/A1089/A122 junction includes one section of cutting that is deeper than perched water in the Lower London Tertiaries aquifer. However, the flow into this section of the cutting is likely to be small and therefore the impacts on the Secondary aquifers and principal Chalk aquifer are not considered to be significant. This is because the GI maximum groundwater level, for the lowest section of cutting, is 1.5m higher than the conservative depth of water required below the road. This is the case for a section of road length of less than 100 metres. In addition, the underlying Chalk aquifer is 18m below the base of the cutting and is separated from the overlying Lower London Tertiaries aquifer by the clayey Pegwell Silt Member.

d. The road cutting at the A122 Lower Thames Crossing/M25 junction has the potential to cause local draining of the superficial aquifer which, without mitigation, could cause reduced spring flow and impact on local licensed abstractions and cause reduced groundwater levels at Thames Chase Forest Centre SINC and at Hall Farm moat, paddock and St Mary Magdalene Churchyard SINC. However, these impacts are shown to be greatly reduced through seepage control measures, causing no impact on the surrounding key receptors. Therefore, mitigation is secured in the REAC [Ref. RDWE038] (Application Document 6.3) through the DCO requirements.

e. Assessment of highway drainage soakaways, including allowance for increased infiltration rates due to climate change, demonstrates that mounding effects to local groundwater levels and groundwater flood risk to the north and south of the River Thames would not be significant.

f. Assessment of the proposed utility diversions and replacements has concluded that approximately 95% of the underground utility corridors would be of shallow (within 3m) open cut trench construction. Most would have a neutral magnitude of impact since the trenches would be above groundwater. However, there are three local areas where groundwater could be impacted as groundwater levels are shallow and/or where utility corridor trenches would be locally deeper and below groundwater (G1b, MU12, MUT2, MU28, MU33, MU37, MU38 and MU40). For these areas mitigation is secured in the REAC [Ref. RDWE052, RDWE054 and RDWE055)] (Application Document 6.3) to reduce potential draining or barrier effects. Trenchless installations, proposed to cross beneath existing features such as existing roads, railway and watercourses, would only require construction phase groundwater control measures, such as exclusion, wet working methods or pumping methods, the detail of which would be determined at detailed design, for launch pits or shafts and reception pits or shafts that would be below groundwater. The G1b micro-TBM trenchless section includes shafts that would penetrate the Thanet Formation and, following the precautionary principle, mitigation is secured in the REAC [Ref. RDWE051] to prevent permanent draining of the strata, should perched water be present. Two proposed trenchless utility corridor sections (MU72 and MU73) near the A122 Lower Thames Crossing/M25 junction would lie beneath groundwater in the complex layered superficial geology and mitigation is secured in the REAC [Ref. RDWE056,and RDWE057)] to ensure decreased drawdown to protect nearby sites of interest for nature conservation. Elsewhere any foundations of utility related structures (for example, pylon foundations) would be addressed by the Project commitment to conduct a foundation risk assessment, as described in REAC reference GS026.

10.1.8 Mitigation measures, where required, are explored in the assessments contained within this report and annexes and are detailed in Chapter 14: Road Drainage and the Water Environment (Application Document 6.1).

10.1.9 A summary of the residual significance of impacts, after mitigation, is shown in Table 10.1.

Table 10.1 Summary of residual significance of impacts

Impact description	Importance	Committed mitigation secured in the REAC [REAC reference]	Impact magnitude	Effect	Residual significance
Construction phase					
Impacts on groundwater levels and flows due to tunnelling, cuttings and excavations (including for utilities)	Very high (North Kent Medway Chalk and South Essex Thurrock Chalk)	GS021 RDWE003 RDWE018a RDWE018b RDWE020 RDWE043	Negligible	Slight adverse	Not Significant
	Very high (Thames Estuary and Marshes Ramsar site)	RDWE018a RDWE018b RDWE020 RDWE053	Negligible	Slight adverse	Not Significant
	Medium (Lower London Tertiaries)	RDWE055	Negligible	Slight adverse	Not Significant
	Medium (Essex Gravels)	RDWE002 RDWE038 RDWE056 RDWE057	Minor negative	Slight adverse	Not Significant
Deterioration of groundwater quality due to saline intrusion or pollution	Very high (North Kent Medway Chalk and South Essex Thurrock Chalk)	GS021 RDWE001 RDWE002 RDWE018a RDWE018b RDWE019 RDWE020	Negligible	Slight adverse	Not Significant
	Very high (Thames Estuary and Marshes Ramsar site)	RDWE001 RDWE002 RDWE018a RDWE018b RDWE019 RDWE020	No change	Neutral	Not Significant
	Medium (Essex Gravels and Lower London Tertiaries)	GS004 RDWE001 RDWE002	Negligible	Slight adverse	Not Significant

Impact description	Importance	Committed mitigation secured in the REAC [REAC reference]	Impact magnitude	Effect	Residual significance
Detriment to existing abstractions and water supply systems	Very high (public groundwater supplies and SPZ1s)	GS004 GS005 GS021 GS026 RDWE003 RDWE019 RDWE032 RDWE058	Negligible	Slight adverse	Not significant
	Medium (private groundwater supplies for agriculture/ recreational use)	RDWE015 RDWE019 GS004 GS005	Negligible	Neutral to slight adverse	Not significant
	Medium (surface water abstractions potentially fed by groundwater)	RDWE015 RDWE038 RDWE054	No change	Neutral	Not significant
Detriment to surface water bodies potentially receiving groundwater baseflow	Medium (Shorne Woods Country Park ponds and ditches, Cobham Hall ponds)	RDWE052	No change	Neutral	Not significant
	Medium (ponds at the Hall Farm moat, paddock and St Mary Magdalene Churchyard SINC)	RDWE038 RDWE045 RDWE057	Negligible	Slight adverse	Not significant
	Medium (ponds and watercourse at Thames Chase Forest Centre SINC)	RDWE038 RDWE045 RDWE056	Negligible	Slight adverse	Not significant
Detriment to GWDTEs due to changes in groundwater quantity or quality	High (Ingrebourne Marshes SSSI)	Not needed	Negligible	Negligible	Not significant
	Moderate (Cranham Marsh LNR)	Not needed	Negligible	Negligible	Not significant

Impact description	Importance	Committed mitigation secured in the REAC [REAC reference]	Impact magnitude	Effect	Residual significance
	Low (other GWDTEs)	Not needed	Negligible	Negligible	Not significant
Operational phase					
Deterioration of groundwater quality due to saline intrusion and receipt of road drainage	Very high (North Kent Medway Chalk and Thames Estuary and Marshes Ramsar site)	RDWE012 RDWE018b RDWE027 RDWE032 RDWE034	Negligible	Slight adverse	Not significant
	Medium (Lower London Tertiaries)	RDWE034	Negligible	Slight adverse	Not significant
Detriment to existing abstractions and water supply systems	Very high (public groundwater supplies)	RDWE032 RDWE034 GS026	Negligible	Slight adverse	Not significant
	Medium (private groundwater supplies for agriculture/recreational use)	RDWE015 RDWE019 GS016	Negligible	Slight adverse	Not significant
	Medium (surface water abstractions potentially fed by groundwater)	RDWE015 RDWE054	Negligible	Slight adverse	Not significant
Effects on groundwater levels and flows due to shaft leakage, tunnel leakage, grout blocks and infiltration drainage	Very high (North Kent Medway Chalk, South Essex Thurrock Chalk and Linford public water supply)	RDWE027	Negligible	Slight adverse	Not significant
	Medium (Lower London Tertiaries)	RDWE051	Negligible	Neutral	Not significant
Effects on groundwater levels and flows at cuttings and	Very high (South Essex Thurrock Chalk and Linford	Not needed	No change	Neutral	Not Significant

Impact description	Importance	Committed mitigation secured in the REAC [REAC reference]	Impact magnitude	Effect	Residual significance
embankments and near utilities	public water supply)				
	Medium (Essex Gravels, private water supplies)	RDWE038	Minor negative	Slight adverse	Not significant
Detriment to surface water bodies potentially receiving groundwater baseflow	Medium (Shorne Woods Country Park ponds and ditches, Cobham Hall ponds)	RDWE052	No change	Neutral	Not significant
	Medium (ponds at the Hall Farm moat, paddock and St Mary Magdalene Churchyard SINC)	RDWE038 RDWE057	Negligible	Slight adverse	Not significant
	Medium (ponds and watercourse at Thames Chase Forest Centre SINC)	RDWE038 RDWE056	Negligible	Slight adverse	Not significant
Detriment to GWDTEs due to changes in groundwater quantity or quality	High (Ingrebourne Marshes SSSI)	Not needed	Negligible	Negligible	Not significant
	Moderate (Cranham Marsh LNR)	Not needed	Negligible	Negligible	Not significant
	Low (other GWDTEs)	Not needed	Negligible	Negligible	Not significant

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Glossary

Term	Abbreviation	Explanation
Above ordnance datum	AOD	
British Geological Survey	BGS	
Construction Industry Research and Information Association	CIRIA	
Code of Construction Practice	CoCP	
Conceptual site model	CSM	
Development Consent Order	DCO	
Design Manual for Roads and Bridges	DMRB	
Electrical conductivity	EC	
Event mean concentration	EMC	
Flood Risk Assessment	FRA	
Ground investigation	GI	
Groundwater Dependent Terrestrial Ecosystems	GWDTE	
Highways England Water Risk Assessment Tool	HEWRAT	
kilometre	km	
$L/m^2/d$ – litres per square metre per day	$L/m^2/d$	
Local Nature Reserve	LNR	
Local Wildlife Site	LWS	
metres	m	
metres below ground level	mbgl	
metres above Ordnance datum	mAOD	
milligrams per litre (unit of concentration)	mg/L, mg/l	

Term	Abbreviation	Explanation
micro siemens per centimetre)	**μS/cm**	unit of electrical conductivity
The United Kingdom Meteorological Office Rainfall and Evaporation Calculation System.	**MORECS**	Used to calculate soil moisture deficit and hydrologically effective rainfall (recharge).
mega litre per annum (year)	**ML/a**	
mega litre per day	**ML/day**	
National Policy Statement	**NPS**	
National Policy Statement for National Networks	**NPSNN**	
National Vegetation Classification	**NVC**	a type of detailed vegetation survey typically done at a SSSI
Pumping station	**PS**	
Port of London Authority	**PLA**	
	Q25	Lower quartile, 25% of data lie below this value
	Q75	Upper quartile, 25% of data lie above this value
Preliminary Sources Study Report	**PSSR**	
Register of Environmental Actions and Commitments	**REAC**	
Royal Society for the Protection of Birds	**RSPB**	
Strategic Flood Risk Assessment	**SFRA**	
Site of Importance for Nature Conservation	**SINC**	Site of Importance for Nature Conservation, as recognised by the Greater London Authority and London borough councils as important wildlife sites
Source protection zone	**SPZ**	
Site of Special Scientific Interest	**SSSI**	
Sustainable Drainage Systems	**SuDS**	
Tunnel boring machine	**TBM**	
UK Climate Projections 2009	**UKCP09**	

Term	Abbreviation	Explanation
United Kingdom Technical Advisory Group	**UKTAG**	United Kingdom Technical Advisory Group advising on the WFD
UKTAG wetland task team	**UKTAG WTT**	
Vibrating wire piezometer	**VWP**	
Water Framework Directive	**WFD**	
Abstraction	-	The taking of water from either a ground or surface (river) resource.
Adit	-	Horizontal or near horizontal passage leading to a mine for the purposes of access or drainage.
Anisotropy	-	The variation in rock properties with direction.
Anticline	-	A geological fold that is an arch-like shape and has its oldest beds at its core.
Aquiclude	-	Geological formation through which virtually no water moves.
Aquifer	-	'*A subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater*' (source: Water Framework Directive 2000/60/EC).
Aquifer vulnerability	-	Vulnerability of groundwater to a pollutant discharged at ground level based on the hydrological, geological, hydrogeological and soil properties.
Arithmetic mean	-	More simply known as 'mean' or 'average', the arithmetic mean is the sum of a collection of numbers divided by the count of numbers in the collection.
Basal grout	-	Placement of grout in rock or soil to locally reduce the hydraulic conductivity (a groundwater control measure). Same as grout plug term.
Basal sands	-	Usually refers to the sandy deposits of Harwich Formation, Lambeth Group and the Thanet Formation that may be in hydraulic continuity with the underlying Chalk aquifer.
Baseflow	-	That part of the flow in a watercourse made up of groundwater and discharges. It sustains the watercourse in dry weather.
Bed parallel anisotropy	-	The variation in physical properties across parallel beds of which make up a geological formation.
Cation exchange	-	A measure of how many cations can be retained on soil particle surfaces.
Conceptual model	-	A simplified representation of how the real system is thought to behave. It is based on a qualitative analysis of field data. A quantitative conceptual model includes preliminary calculations for key processes.
Confined	-	Aquifer where permeable strata are covered by a substantial depth of impermeable strata such that the cover prevents infiltration.
Controlled waters	-	Defined by the Water Resources Act 1991 section 104. They include all groundwater and inland waters and estuaries.

Term	Abbreviation	Explanation
Crops out	-	When part of a geological formation is exposed at the surface.
Cutting	-	(Noun) part of a road where construction and operation has required removal (cut) of soil or rock so that the road level is below the original ground level.
Darcy flow conceptualisation of seepage (Darcian flow)	-	Seepage of water abides by Darcy's Law of water flow through porous medium.
Deep ploughing	-	This refers to the ploughing of soils to depth below the normal plough depth (which is often no more than 300mm below the surface) to depths of up to 1m below the surface, for example where the profile is being inverted to promote the establishment of species-rich habitats.
Denitrification	-	Denitrification is a microbially facilitated process where nitrate (and nitrite) is reduced and ultimately produces molecular nitrogen through a series of intermediate gaseous nitrogen oxide products.
Derogation	-	Term used for loss of water resources or deterioration in water quality (usually relating to a source).
Detailed assessment	-	DMRB LA 113 describes a detailed assessment as detailed field surveys and/or quantified modelling techniques to understand complex environmental effects.
Dewatering	-	Temporary or construction phase pumping of water from excavations to surface water such as pumping water out of excavations on a building site.
Discharge	-	Putting water back to the ground or to a surface (river) water resource.
Downgradient	-	A position down along a gradient from a starting point, i.e. a location that receives groundwater from another location.
Eocene margin	-	The geological boundary, north of which the London Clay Formation (deposited in the Eocene epoch) overlies and confines the Chalk aquifer.
Eutrophication	-	When a body of water becomes overly enriched with minerals and nutrients which induce excessive growth of algae.
Fault	-	A fracture or a zone of fractures along which there has been displacement of the sides relative to one another parallel to the fracture.
Flood Zone 3	-	Land assessed as having a 1 in 100 or greater annual probability of river flooding (>1%), or a 1 in 200 or greater annual probability of flooding from the sea (>0.5%) in any year.
Fracture/fissure flow	-	Groundwater movement through fissures rather than between grains in the rock. There may be a combination of fissure and intergranular flow in some aquifers.
Geomean (geometric mean)	-	A mean or average, which indicates the central tendency or typical value of a set of numbers by using the product of their values.
Groundwater	-	'*All water that is below the surface of the ground in the saturation zone (below the water table) and in direct contact with the ground or subsoil*' (source: Water Framework Directive 2000/60/EC).

Term	Abbreviation	Explanation
Groundwater level	-	The elevation of the water table or potentiometric surface at a particular place or area, as represented by the water level measured in a borehole or well.
Groundwater flow	-	The movement of groundwater through geological material, e.g. the flow of water from a stream, infiltrating into the ground and later discharging at a spring.
Grout plug	-	Placement of grout in rock or soil to locally reduce the hydraulic conductivity (a groundwater control measure).
Hydraulic conductivity	-	A measure of the ability of a material (usually a geological stratum) to transmit water. It is effectively a measure of how well pore spaces are interconnected.
Hydraulic gradient	-	A measure of the change in groundwater head (or level) over a given distance. The maximum groundwater flow will normally be in the direction of the maximum hydraulic gradient.
Interfluve	-	An area of higher ground between the valleys of two rivers in the same drainage system.
Infiltration basin	-	Vegetated depressions designed to store runoff on the surface and infiltrate it gradually into the ground. They are dry except in periods of heavy rainfall.
Karst	-	Terrain composed of or underlain by carbonate rocks that have been significantly altered by dissolution.
Limit of detection	-	The lowest quantity of a substance that can be distinguished from the absence of that substance with a stated confidence level.
Lower London Tertiaries	-	The strata between the Chalk Group and the London Clay Formation comprising the undifferentiated Harwich Formation, Lambeth Group and Thanet Formation.
Marl(s)	-	A calcium carbonate or lime-rich mud or mudstone that contains variable amounts of clays and silt.
Nitrate vulnerable zone	-	Areas designated as being at risk from agricultural nitrate pollution
Non-statutory site	-	Areas of local conservation interest. Non-statutory sites include those that are a LWS or SINC.
Ordinary watercourse	-	A watercourse that does not form part of a main river. The Lead Local Flood Authority in whose area the watercourse lies has powers to consent works to ordinary watercourses and permissive powers to undertake works where necessary.
Ordnance datum	OD	Mean sea level calculated from observation taken at Newlyn, Cornwall, and used as the official basis for height calculation on British maps.
Outcrop	-	The part of a geologic formation or structure that appears at the surface.
Packer test	-	A field test for measuring permeability of ground in sections of boreholes.
Palaeogene strata	-	In the London Basin area, of which the study area is located, the stratigraphic group comprise Eocene (London Clay Formation and Harwich Formation) and Palaeocene strata (Lambeth Group and the Thanet Formation). See also Lower London Tertiaries and basal sands.
Penstock chamber	-	A chamber with a sluice gate that can be closed to isolate flows to the downstream drainage system.

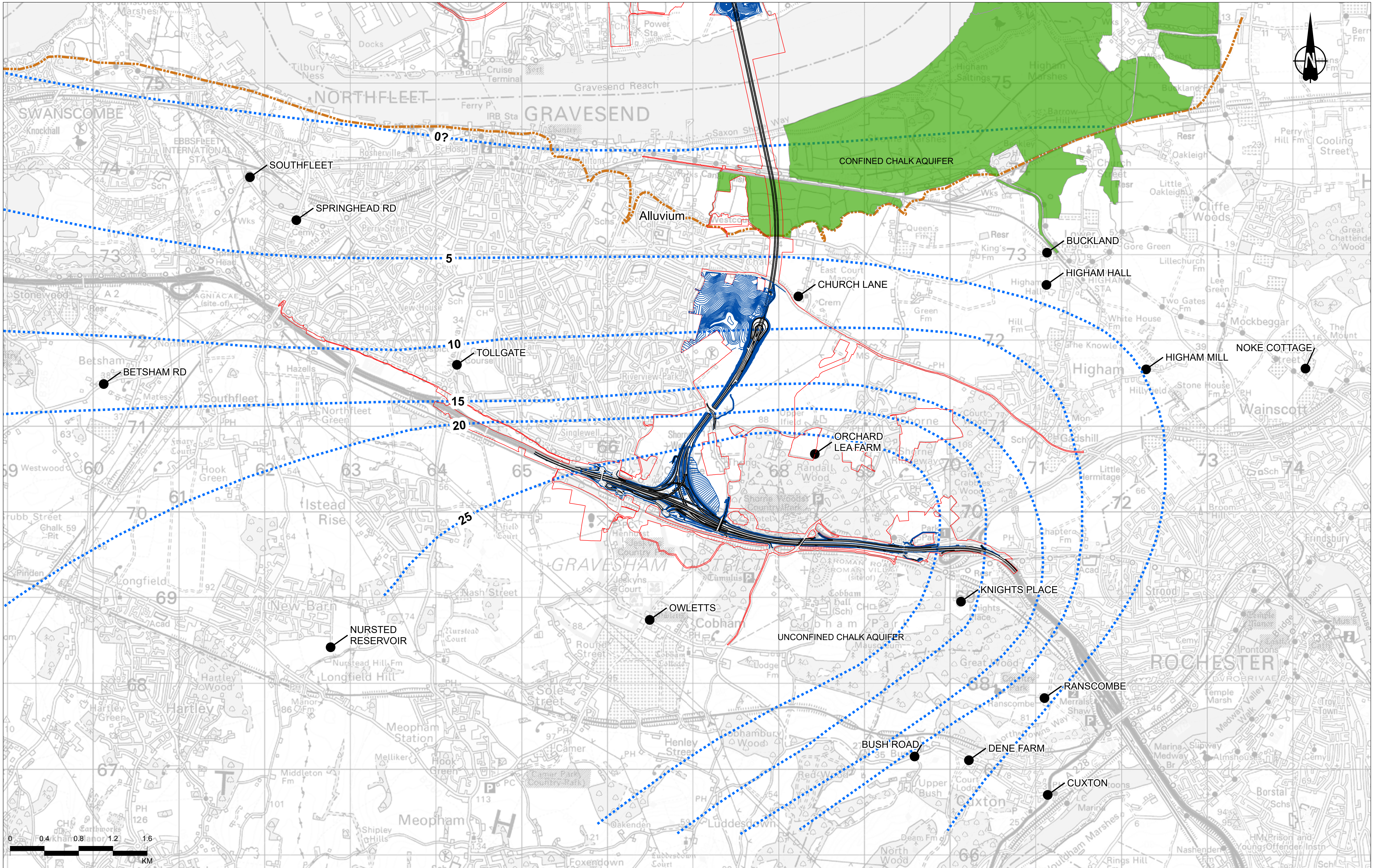
Term	Abbreviation	Explanation
Perched water table	**-**	Water level supported by an underlying low permeability layer above the main water table. The groundwater body is limited in lateral and vertical extent.
Periglacial	**-**	An area adjacent to a glacier or ice sheet or otherwise subject to repeated freezing and thawing.
Permeability	**-**	The capability of a porous rock or sediment to permit the flow of fluids through its pore spaces.
Permeable	**-**	A material that will allow the transmission of a fluid.
Piezometric level (or surface)	**-**	An imaginary or hypothetical surface of the piezometric pressure or hydraulic head throughout all or part of a confined or semi-confined aquifer; analogous to the water table of an unconfined aquifer.
Potable water	**-**	Water intended for human consumption. Defined as: (a) All water either in its original state or after treatment, intended for drinking, cooking, food preparation or other domestic purposes, regardless of its origin and whether it is supplied from a distribution network, from a tanker, or in bottles or containers. (b) All water used in any food production for the manufacture, processing, preservation or marketing of products or substances intended for human consumption unless the competent national authorities are satisfied that the quality of the water cannot affect the wholesomeness of the foodstuff in its finished form (source: Directive 98/83/EC). Potable water does not include water that is used for the irrigation of crops.
Pollution	**-**	'*The direct or indirect introduction, because of human activity, of substances or heat into the air, water or land, which may be harmful to human health or the quality of aquatic ecosystems or terrestrial ecosystems directly depending on aquatic ecosystems, which result in damage to material property, or which impair or interfere with amenities and other legitimate uses of the environment*.' (Source: Water Framework Directive 2000/60/EC.)
Public water supply well	**-**	Clean water well used for public water supply of drinking water. Within the Project study area public water supply wells are operated by Suffolk and South Essex Water Company (Northumbrian Water) and Southern Water Services Ltd.
Pumping test	**-**	A field experiment in which a well is pumped at a controlled rate and water-level response is measured in one or more surrounding observation wells/boreholes.
Principal aquifer	**-**	Geological strata that exhibit high permeability and usually provide a high level of water storage. They can support water supply on a strategic scale and are often of major importance to river base flow (formerly known as major aquifer).
Productive strata	**-**	Soils or rock, typically of moderate or high hydraulic conductivity that have sufficient groundwater to be a viable water supply source.
Ramsar	**-**	An internationally important wetland site adopted from the Convention of Wetlands of International

Term	Abbreviation	Explanation
		Importance especially as water flow habitats (1971) and ratified by the UK Government in 1976.
Ramsar site	-	For the purposes of this report the term Ramsar site has been used and refers to part of the Project study area that is south of the River Thames and north of Lower Higham Road. Further, the term Ramsar site describes those parts of the statutory sites that are local to the Order Limits and principally within Filborough Marshes. Where specific statutory sites or different parts of the marshes are discussed separately then full names have been used.
Risk	-	The consequence(s) of a hazard(s) being realised, and their likelihoods/probabilities.
Saturated zone	-	Zone of aquifer where all fissures and pores contain water (that is, below the water table).
SEAWAT	-	SEAWAT is a generic MODFLOW/MT3DMS-based computer program designed to simulate three-dimensional variable-density groundwater flow coupled with multi-species solute and heat transport. Produced by the United States Geological Survey. Further details are shown in Annex J.
Secondary aquifer	-	A wide range of geological strata with a correspondingly wide range of permeability and storage. Depending on the specific geology, these subdivide into permeable formations capable of supporting small to moderate water supplies and base flows to some rivers, and those with generally low permeability but with some localised resource potential. (Includes the former minor aquifers but also some of the former non-aquifers.)
Secondary A aquifer	-	Aquifers with permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of baseflow to rivers. Formerly classified as minor aquifers.
Secondary B aquifer	-	Aquifers of predominantly lower permeability layers that may store and yield limited amounts of groundwater due to localised features such as fissures, thin permeable horizons and weathering. Generally, the water-bearing parts of the former non-aquifers.
Secondary Undifferentiated	-	Secondary aquifers assigned in cases where it is not possible to attribute either A or B to a rock type.
Sediment forebay	-	A water treatment process where a shallow pond is used to allow particulate matter to settle out of highway drainage.
Solution/dissolution	-	A process of chemical weathering by which mineral and rock material passes into solution, e.g. slow dissolving of carbonate rock along planes of weakness.
Slurry wall	-	A civil engineering technique used to build reinforced concrete walls in areas of soft earth close to open water, or with a high water table.
Source protection zones	**SPZ**	SPZ1 Inner protection zone – 50-day travel time from any point below the water table to the source. This zone has a minimum radius of 50m around the source.

Term	Abbreviation	Explanation
		SPZ2 Outer protection zone – 400-day travel time from a point below the water table. This zone has a minimum radius of 250 or 500m around the source depending on the size of the abstraction. SPZ3 Source catchment protection zone (also referred to as the total capture zone or total catchment) – the area around a source within which all groundwater recharge is presumed to be discharged at the source.
Simple assessment	**-**	DMRB LA 113 describes a simple assessment as the collection and assessment of data and information that is readily available to reach an understanding of the likely environmental effects of a project. NOTE: This informs the final design or need for further 'detailed assessment
Sinusoidal tidal fluctuation	**-**	Sinusoidal is a description of the smooth oscillating curve that is observed in tidal fluctuations (tides naturally oscillate between high and low levels at a regular time interval).
Spring	**-**	Natural emergence of groundwater at surface.
Statutory Environmental Body(ies)	**-**	Any principal council as defined in subsection (1) of section 270 of the Local Government Act 1982 for the area where the land is situated. Where the land is situated in England; Natural England, Historic England, the Environment Agency, Natural Resources Wales and the National Assembly for Wales where, in the opinion of the Secretary of State, the land is sufficiently near to Wales to be of interest to them and any other public authority that has environmental responsibilities and which the Secretary of State considers likely to have an interest in the Project.
Statutory site	**-**	If a site of nature conservation importance has 'Statutory Protection', it means that it receives protection by means of certain legislation. Statutory sites include those that are a Ramsar site, SSSI, SAC, SPA or LNR.
Storage capacity	**-**	The maximum volume of water that can be stored in an aquifer.
Surface water	**-**	Any inland waters, including streams, rivers, lakes, wetlands, reservoirs and creeks except groundwater; transitional waters and coastal waters.
Thameside	**-**	Area in south Essex that drains towards the Thames Estuary.
Thameside Chalk	**-**	'Thameside Chalk' corresponds to the groundwater management unit E10, as defined by the Environment Agency's 2001 Water Resources for the future document.
Transmissivity	**T**	Product of the average hydraulic conductivity and the saturated thickness of the aquifer. Consequently, transmissivity is the rate of flow under a unit hydraulic gradient through a cross-section of unit width over the whole saturated thickness of the aquifer.
Unproductive strata	**-**	Geological strata with low permeability that have negligible significance for water supply or river base flow (formerly formed part of the non-aquifers).

Term	Abbreviation	Explanation
Unsaturated zone	**-**	Zone of aquifer above the water table that may be partly saturated (that is, that part of the aquifer above the water).
Upgradient	**-**	A position up along a gradient from a starting position, i.e. the source of groundwater for another location.
Water table	**-**	Top surface of the saturated zone within the aquifer.
Well	**-**	An excavation or borehole, generally cylindrical in form, sunk into the ground for the purpose of penetrating water yielding rock or soil to allow water to flow or be pumped to the surface.
Vortex grit separator	**-**	The use of centrifugal and other rotation forces to assist gravitation forces in the separation of grit from organics and liquids. Used in highway drainage systems to clean the drained water. It is a type of pollution control device.

Figures



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Rev	Status	Rev. Date	Purpose of revision	Drawn	Chck'd	Apprv'd
P01	S8	11/10/2022	DCO Application	SW	BP	SH

Notes:

1. High groundwater level condition shows water levels monitored during February 2014 (monthly manual water level readings by the Environment Agency).
2. All levels are shown in metres above Ordnance Datum.

Legend

- Route alignment
- Earthworks
- Order Limits
- Ramsar site
- Alluvium boundary
- Chalk aquifer groundwater level contours (February 2014) (contours are in mAOD)
- Environment Agency monitoring boreholes

Client: national highways

Project: LOWER THAMES CROSSING

Status: DCO APPLICATION

Original Size: A3

Revision: P01

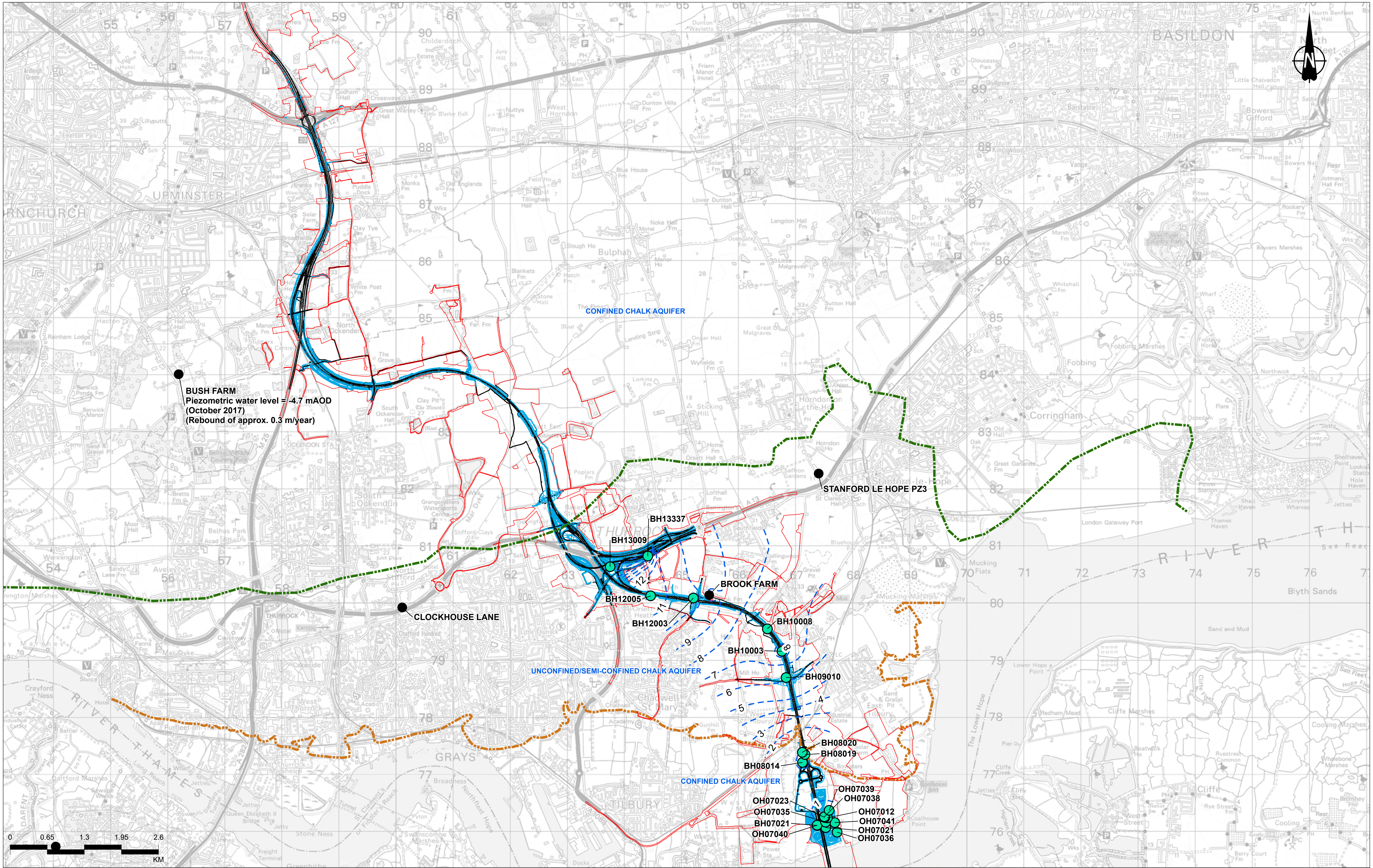
Application Document Number: TR010032/APP/6.3

Scale: 1:40,000

Drawing Title: Figure 1 - High groundwater level condition - south of the River Thames (Chalk aquifer)

Drawing Number: HE540039-CJV-EWE-SZP_EGNE00000000-DR-LE-50153

Z:\Environment\Environmental Statement\14. Road Drainage and the Water Environment\Fig14.5 Appendices\HE540039-CJV-EWE-SZP_EGNE00000000-DR-LE-50153 - Figure_1_High Groundwater Level Condition- South.aprx



Rev	Status	Rev. Date	Purpose of revision	Drawn	Chck'd	Apprv'd
P01	S8	17/10/2022	DCO Application	SW	BP	SH

Notes:
1. High groundwater level condition assessed by combining 2020 highest water levels of LTC ground investigation monitored boreholes with highest 2019 Environment Agency observation borehole levels.
2. High groundwater level at the Project's junction with the A13 is related to LTC ground investigation borehole BH13009.
3. Linford public water supply pumping at reduced rate.
4. All levels are shown in metres above Ordnance Datum.

Legend

- Route alignment
- Earthworks
- Order Limits
- LTC monitoring borehole
- Environment Agency monitoring borehole
- Alluvium boundary
- Eocene margin (approx.)
- Chalk aquifer groundwater level contours (2019) (contours are in mAOD)

Client: national highways

Project: LOWER THAMES CROSSING

Status: DCO APPLICATION

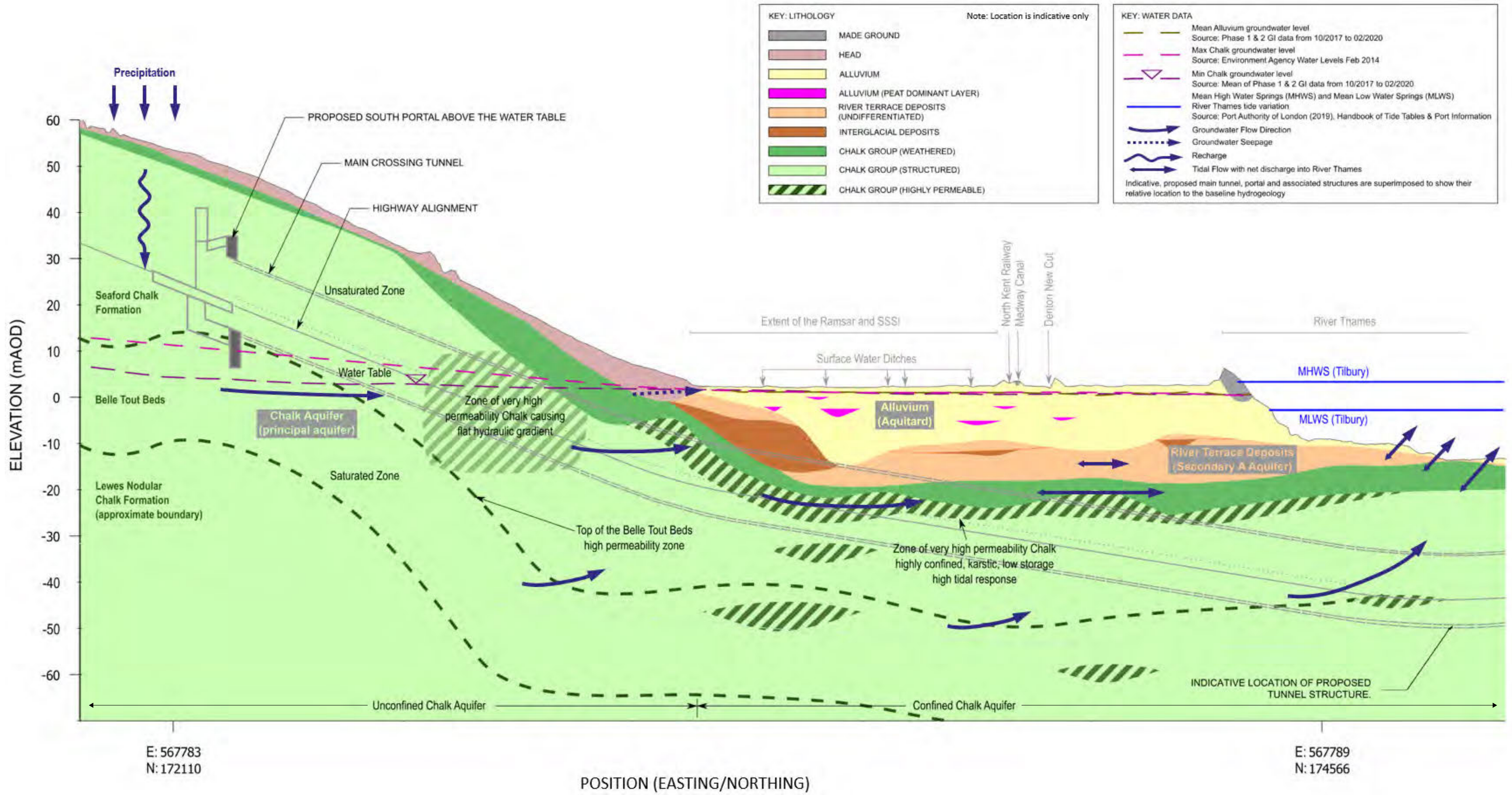
Application Document Number: TR010032/APP/6.3

Original Size: A3 | Revision: P01 | Scale: 1:60,000

Drawing Title: Figure 2 - High groundwater level condition - north of the River Thames (Chalk aquifer)

Drawing Number: HE540039-CJV-EWE-SZP_EGNE00000000-DR-LE-50154

Z:\Environment\Environmental Statement\14. Road Drainage and the Water Environment\Fig14.5 Appendices\HE540039-CJV-EWE-SZP_EGNE00000000-DR-LE-50154 - Figure_2 High Groundwater Level Condition - North.aprx



Rev	Status	Rev. Date	Purpose of revision	Drawn	Chck'd	Apprv'd
P01	S8	11/10/2022	DCO Application	SW	CD	FF

Client: national highways

Project: LOWER THAMES CROSSING

Status: DCO APPLICATION

Original Size: A3

Revision: P01

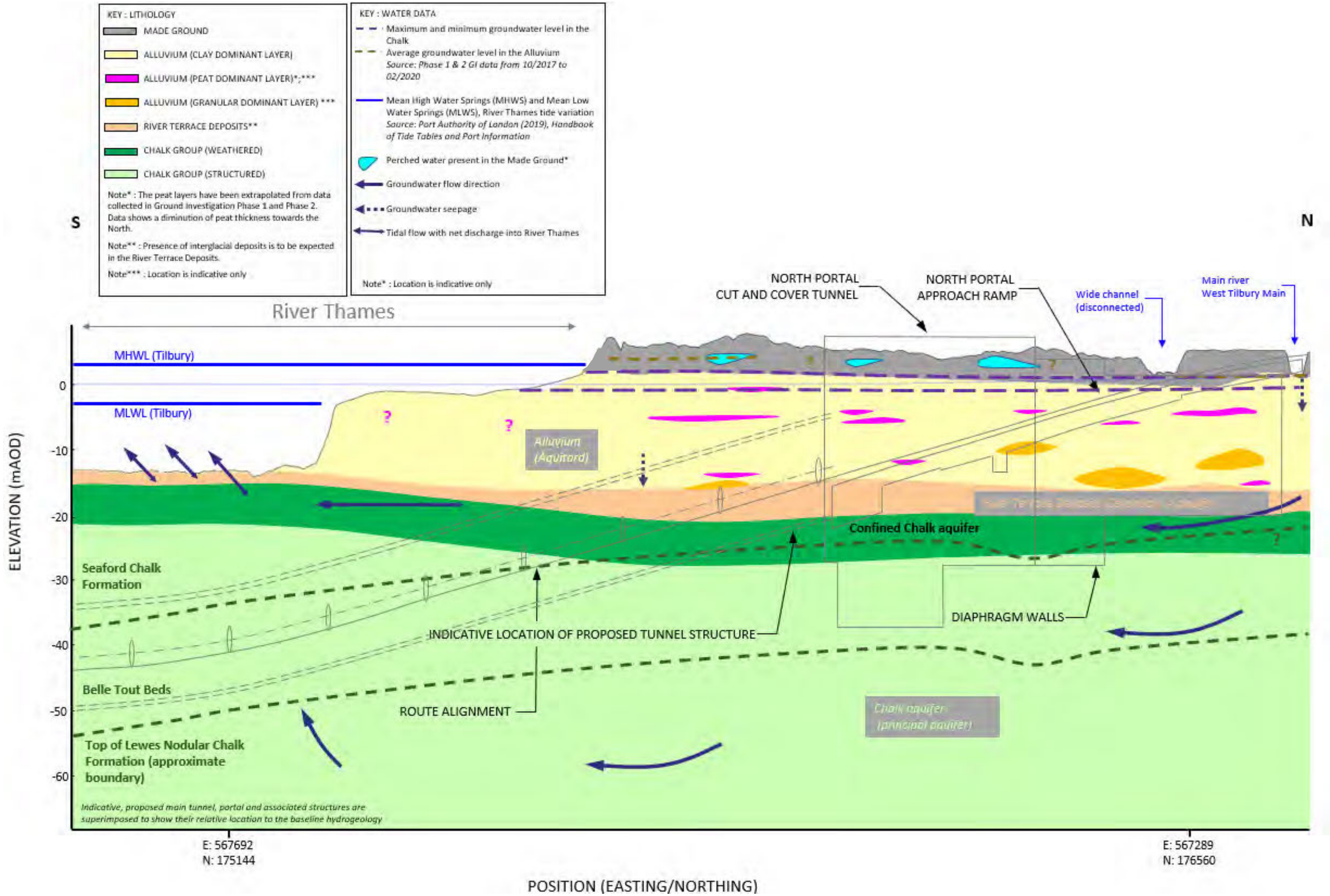
Application Document Number: TR010032/APP/6.3

Scale: N/A

Drawing Title: Figure 3 - Hydrogeological conceptual site model - South Portal to the Ramsar Site

Drawing Number: HE540039-CJV-EWE-SZP_EGNE00000000-DR-LE-50155

Z:\Environment\Environmental Statement\14. Road Drainage and the Water Environment\Fig14.5 Appendices\HE540039-CJV-EWE-SZP_EGNE00000000-DR-LE-50155 - Figure_3 Hydrogeological Conception Site Model- South.aprx



Rev	Status	Rev. Date	Purpose of revision	Drawn	Chck'd	Apprv'd
P01	S8	11/10/2022	DCO Application	SW	CD	FF

Client: national highways

Project: LOWER THAMES CROSSING

Status: DCO APPLICATION

Original Size: A3

Revision: P01

Application Document Number: TR010032/APP/6.3

Scale: N/A

Drawing Title: Figure 4 - Hydrogeological conceptual site model - North Portal

Drawing Number: HE540039-CJV-EWE-SZP_EGNE00000000-DR-LE-50156

Z:\Environment\Environmental Statement\14. Road Drainage and the Water Environment\Fig14.5 Appendices\HE540039-CJV-EWE-SZP_EGNE00000000-DR-LE-50156 - Figure_4 Hydrogeological Conceptual Site Model - North.aprx

Annexes

Annex A Schedule of proposed infiltration basin treatment systems

Table A.1 Schedule of proposed infiltration basin treatment systems

Outfall reference number	Status	Proposed water quality treatment and protection measures
South of the River Thames		
EXPOS01-001	Existing (modified)	Existing oil interceptor to be replaced with a lined sediment forebay, Penstock chamber (or other appropriate flow control device) for shut-off for accidental spillages
POS01-001	Proposed	Lined sediment forebay, Penstock chamber (or other appropriate flow control device) for shut-off for accidental spillages
EXPOS02-001	Existing (modified)	Existing lined sediment forebay, Penstock chamber (or other appropriate flow control device) for shut-off for accidental spillages
POS02-001	Proposed	Vortex grit separator (or other appropriate pollution control device), Penstock chamber (or other appropriate flow control device) for shut-off for accidental spillages
POS02-002	Proposed	Lined sediment forebay, Penstock chamber (or other appropriate flow control device) for shut-off for accidental spillages
POS02-003	Proposed (cascading infiltration basins)	Lined sediment forebay, Penstock chamber (or other appropriate flow control device) for shut-off for accidental spillages
POS02-004	Proposed	Vortex grit separator (or other appropriate pollution control device), Penstock chamber (or other appropriate flow control device) for shut-off for accidental spillages
EXPOS02-005	Existing (modified)	Existing oil interceptor to be replaced with vortex grit separator (or other appropriate pollution control device) , Penstock chamber for shut-off (or other appropriate flow control device) for accidental spillages

Outfall reference number	Status	Proposed water quality treatment and protection measures
POS04-001	Proposed (cascading infiltration basins)	Lined sediment forebay, Penstock chamber (or other appropriate flow control device) for shut-off for accidental spillages
North of the River Thames		
POS11-003	Proposed	Vortex grit separator (or other appropriate pollution control method), Penstock chamber (or other appropriate flow control device) for shut-off for accidental spillages

Notes:

Details of the infiltration basins, treatment systems and pollution prevention control systems are shown in Part 7 of Appendix 14.6: :Flood Risk Assessment (Application Document 6.3).

Locations of the outfalls are shown in the HEWRAT report, presented in Annex O.

Highway runoff would flow through the sediment forebay before the outfall into the infiltration basin(s). Sediment forebays are proposed where shown in the table.

The table also shows the locations of penstock chambers for shut-off for accidental spillages, which are a pollution control system.

Annex B Regional groundwater bodies and attributes

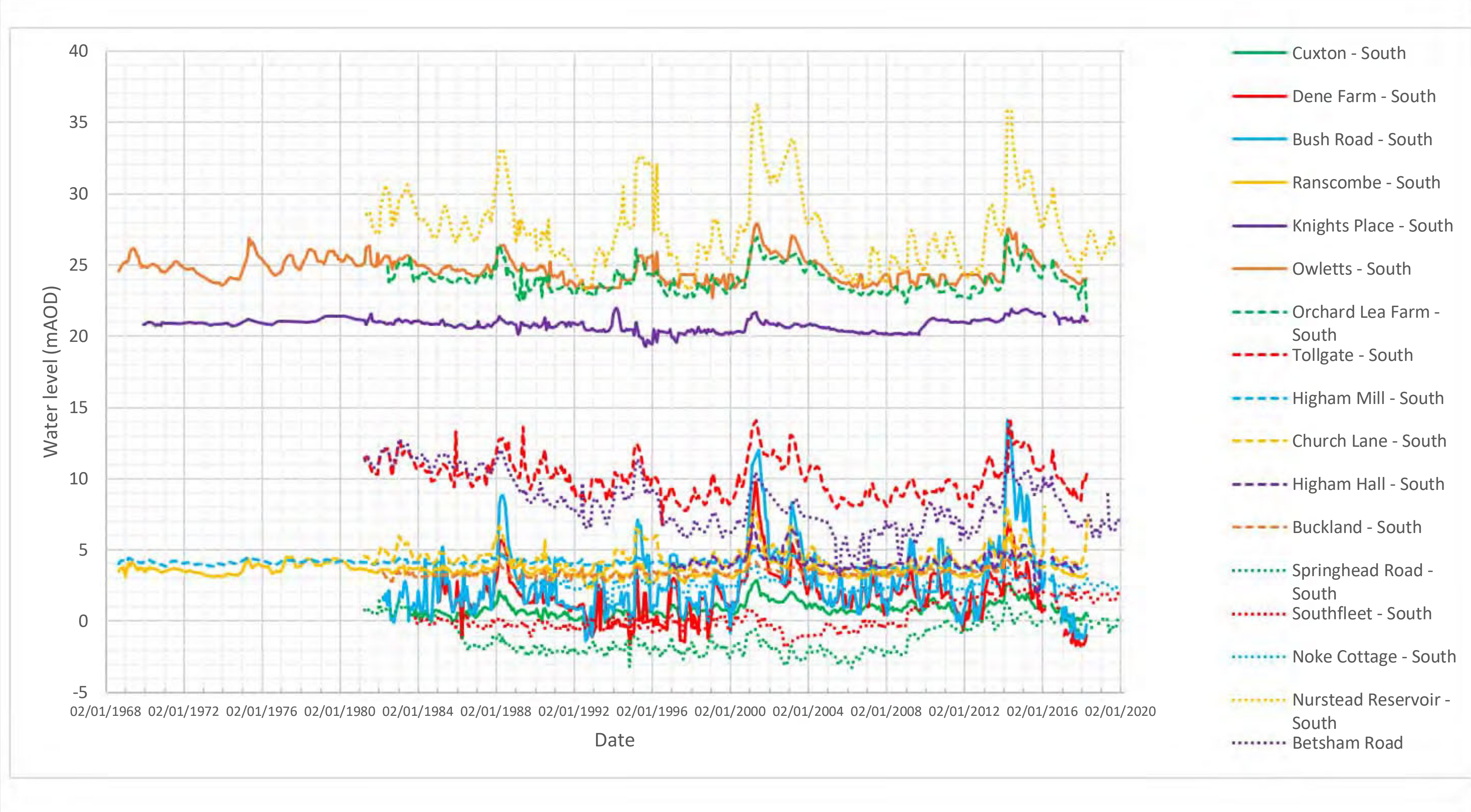
Table B.1 Regional groundwater bodies and attributes

Geological unit		Hydrogeological model	Designation, Environment Agency	Groundwater levels	Permeability and groundwater flow type
Made Ground	Superficial aquifers	Not considered an aquifer	None	May be locally perched water but often dry. Landfills may influence local groundwater levels.	Variable permeability, often not water bearing but may have locally perched water. Intergranular flow.
Head		Potentially an aquifer but usually very limited spatial extent so not significant	Secondary Undifferentiated	Insignificant water content is likely.	Lithology depends on underlying strata. Where underlying clay strata, the Head Deposits expected to be of low permeability and have insignificant water content. Intergranular flow.
Alluvium		May act as an aquitard	Secondary A or Undifferentiated	May be shallow and similar to a local river/stream level. Generally low hydraulic conductivity of Alluvium means tidal response is unlikely to be strong.	Generally low hydraulic conductivity. Locally may be more permeable where sands and gravels within the unit. River Thames Alluvium comprises mostly silts and clays (with some peat layers) so generally low permeability. Intergranular flow.
River Terrace Deposits		Main superficial aquifer	Secondary A	Shallow and responsive (tidal near River Thames) to stream/river water levels where extensive and near large surface water bodies. Strata may not be significantly water bearing where of limited lateral extent or not nearby streams.	Potentially high hydraulic conductivity where large gravel proportion and low clay and silt content. Water bearing where in hydraulic contact with surface water, e.g. beneath the River Thames. Elsewhere, beside the River Thames, it forms a single confined unit with the Chalk aquifer where it is beneath cohesive Alluvium. Some interglacial deposits are encountered within the River Terrace Deposits beside the River Thames. Intergranular flow.
London Clay Formation		Aquitard between superficial aquifer and basal sands and Chalk aquifer	Unproductive	Insignificant water content. Porewater pressure profile influenced by surface recharge and underlying deep aquifer.	Typically, not significantly water bearing and acts as an aquiclude. Fissured shallow weathered layers and occasional silt layers may be water bearing.
London Clay Formation		Aquitard between superficial aquifer and basal sands and Chalk aquifer	Unproductive	Insignificant water content. Porewater pressure profile influenced by surface recharge and underlying deep aquifer.	Typically, not significantly water bearing and acts as an aquiclude. Fissured shallow weathered layers and occasional silt layers may be water bearing.
Harwich Formation			Secondary A	Influenced by water levels in underlying deep aquifer.	May be locally water bearing and a potential local source. Intergranular flow.
Lambeth Group (excluding Upnor Formation)			Secondary A	Typically, perched water may occur due to interlayering of low permeability layers. May also be influenced by water levels in underlying deep aquifer.	Typically, not significantly water bearing but sand channels if present may be locally significant. Outcrop and sub-outcrop beneath superficial deposits in vicinity of the A13. Intergranular flow.

Geological unit		Hydrogeological model	Designation, Environment Agency	Groundwater levels	Permeability and groundwater flow type
Lambeth Group, Upnor Formation	Bedrock aquifers	Basal sands and Chalk aquifer	Secondary A	Regional influence.	Upnor Formation may be an aquifer in hydraulic continuity with underlying Thanet Formation aquifer. Intergranular flow.
Thanet Formation			Secondary A	Regional influence. Deeper silty layers and/or presence of the Pegwell Silt Member, where clayey, may cause a perched water effect.	Outcrop and sub-outcrop beneath superficial deposits north of River Thames and south of A13. South of River Thames there is a patchwork of outcrops on high ground overlying the chalk; related to a broad anticline structure. Intergranular flow.
Chalk North Kent Medway Chalk – (south of the River Thames) and South Essex Thurrock Chalk (north of River Thames)			Principal	Regional influence. Shallow and tidal fluctuation expected beside the River Thames. Groundwater-level rebound is indicated in Ockendon area and may be associated with post-1960s cessation of industrial pumping. In addition, groundwater rebound from reduction of Linford public supply well pumping is recorded in Environment Agency observation boreholes (Section 3.3).	Regionally important for public water supply (particularly in the North Downs but also the well near Linford). Typically, a low storage, moderately high transmissivity aquifer when unconfined. Most flow occurs in the fractures. Typically, high transmissivity Chalk is present in valleys including at the River Thames. Extensive outcrop on the North Downs. Semi-confined and confined, north of the River Thames. Fracture flow is dominant.

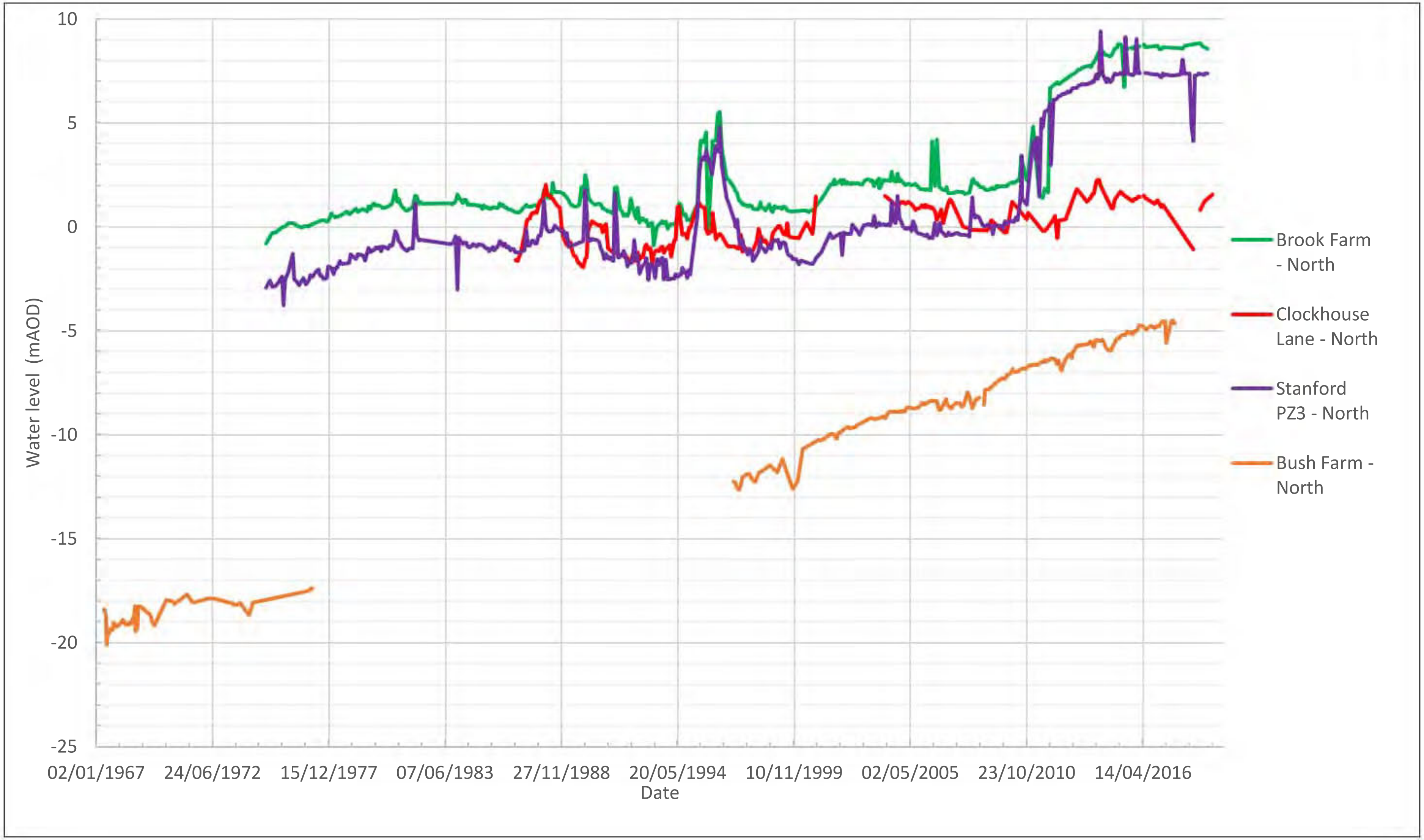
Annex C Groundwater-level data summary – whole study area

Plate 1.1 Chalk aquifer groundwater level hydrographs – south of the River Thames



Note:
The hydrographs present Environment Agency observation borehole water level readings (mostly monthly manual readings).

Plate 1.2 Chalk aquifer groundwater level hydrographs – north of the River Thames



Note:
The hydrographs present Environment Agency observation borehole water level readings (mostly monthly manual readings).

Plate 1.3 Location of Environment Agency observation boreholes

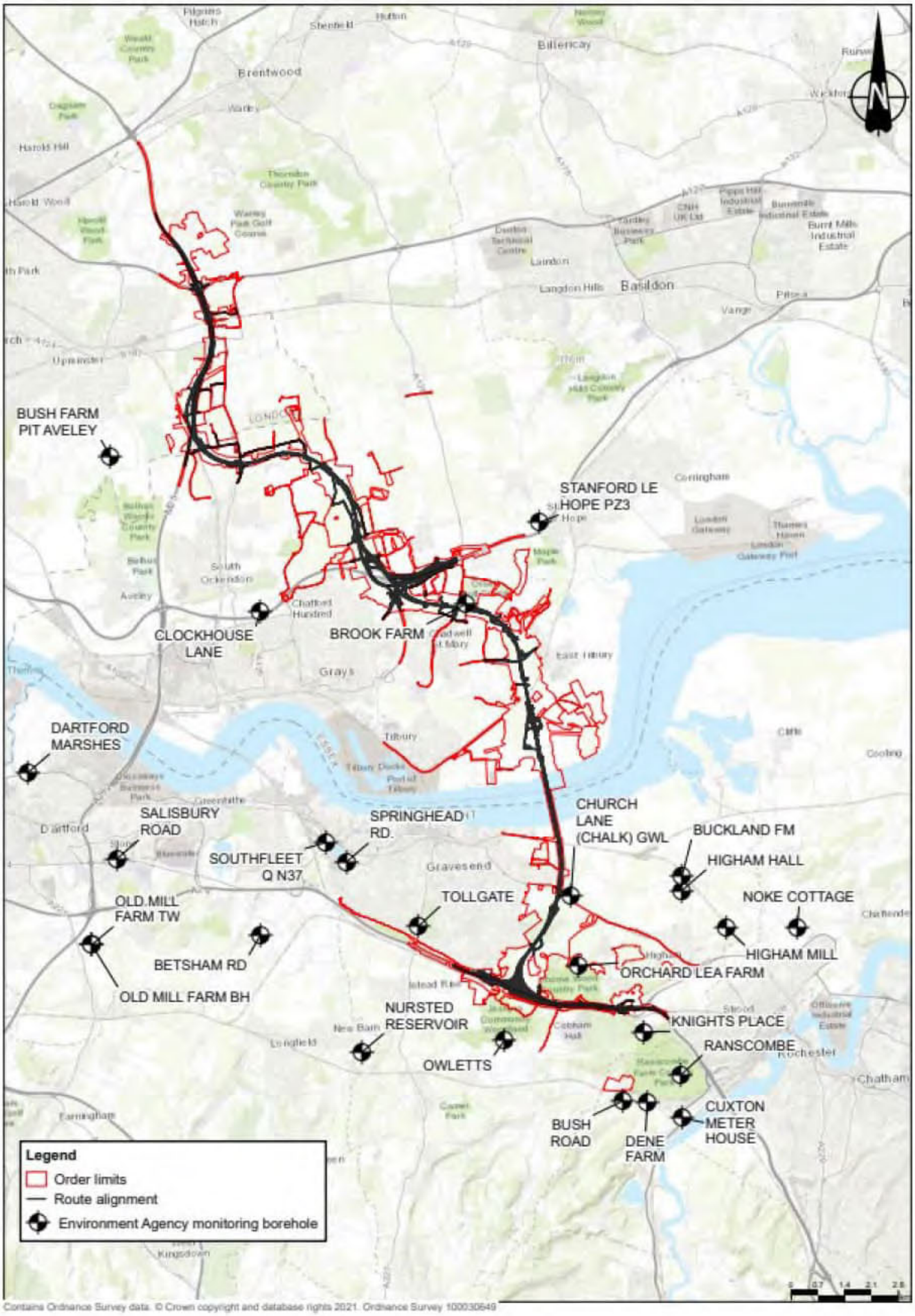
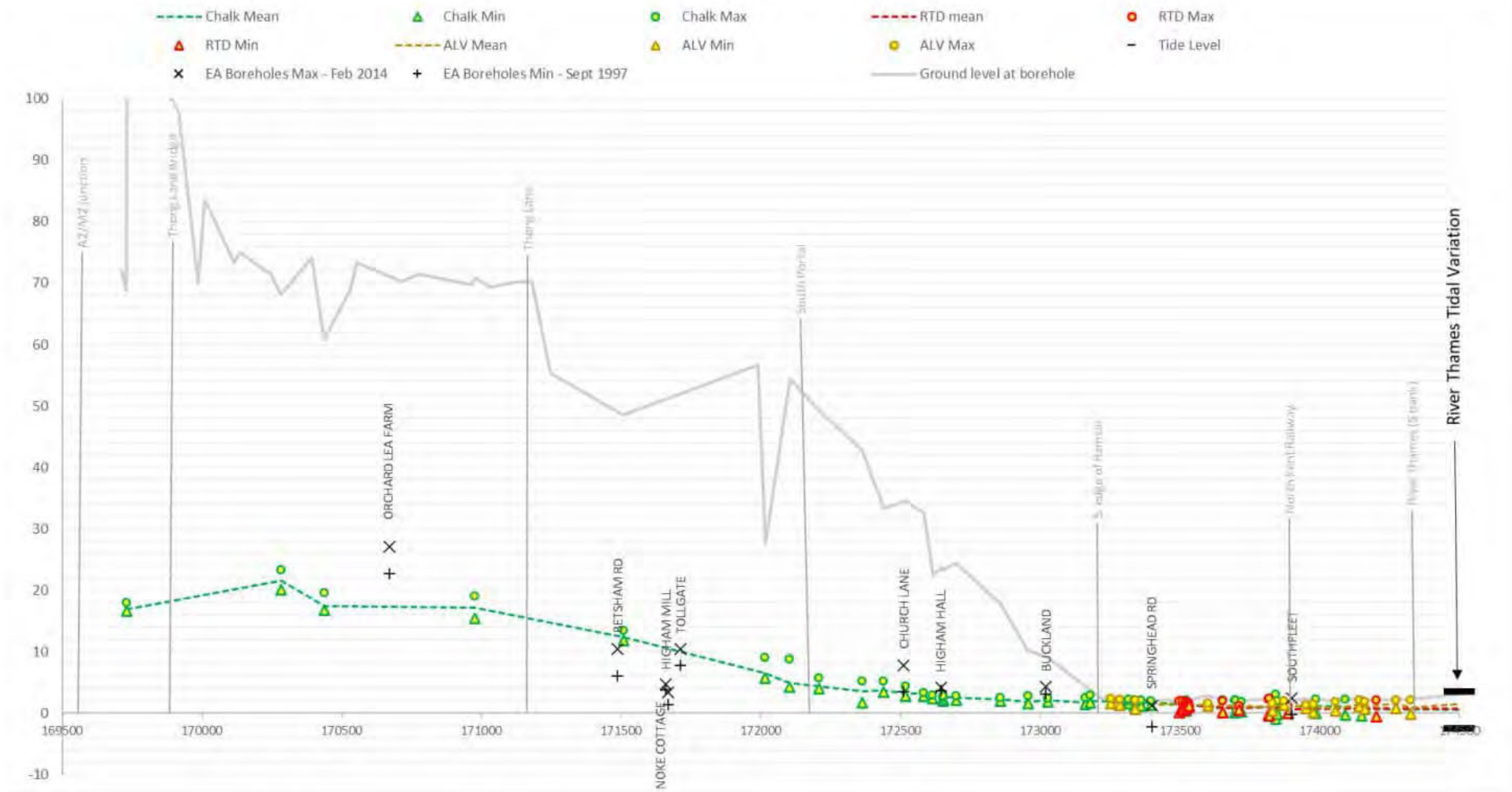


Plate 1.1 and Plate 1.2 present hydrographs of the Environment Agency observation boreholes shown on Plate 1.3.

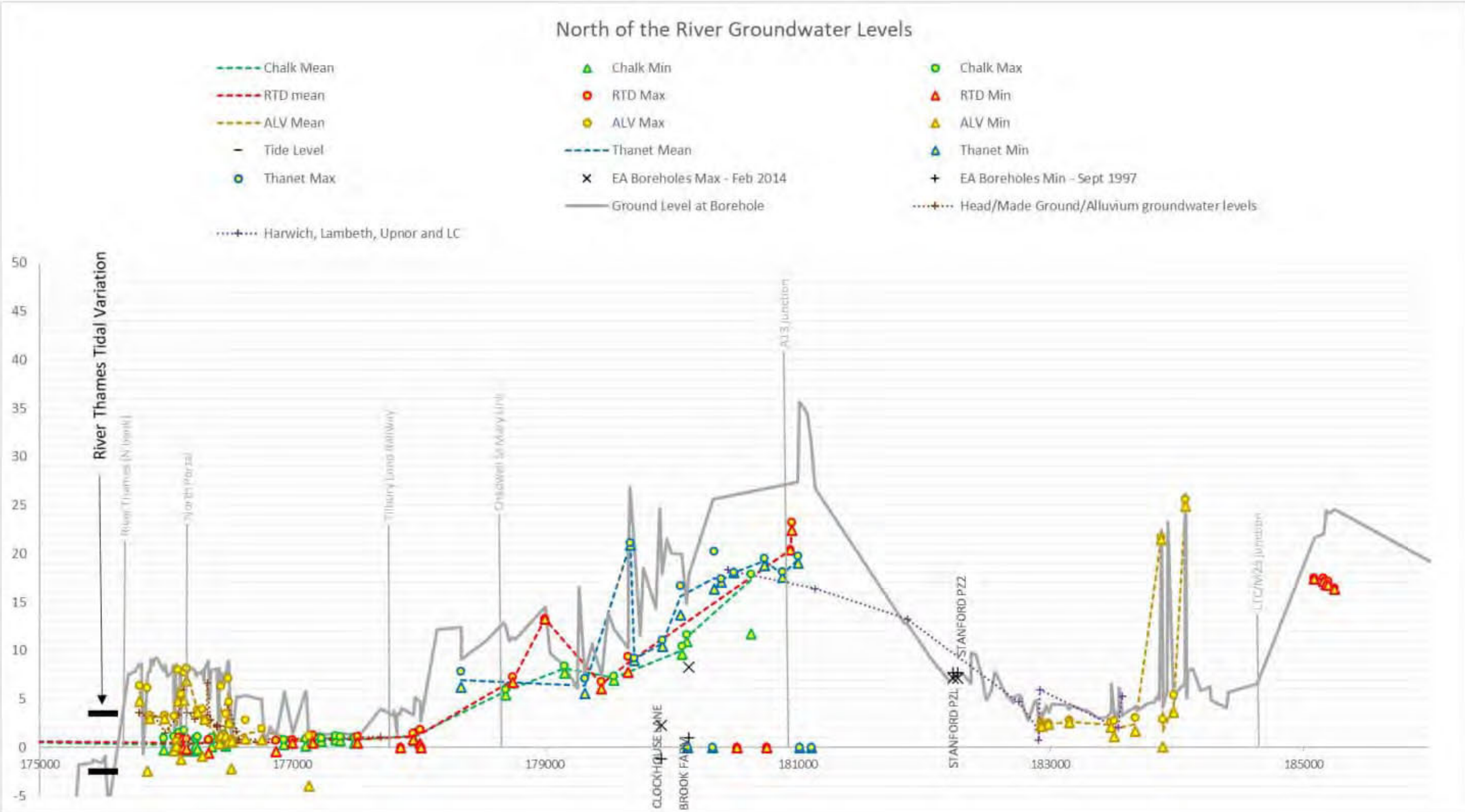
Plate 1.4 Phase 1 and Phase 2 groundwater level monitoring plot – south of the River Thames



ALV = Alluvium; RTD = River Terrace Deposits; EA = Environment Agency

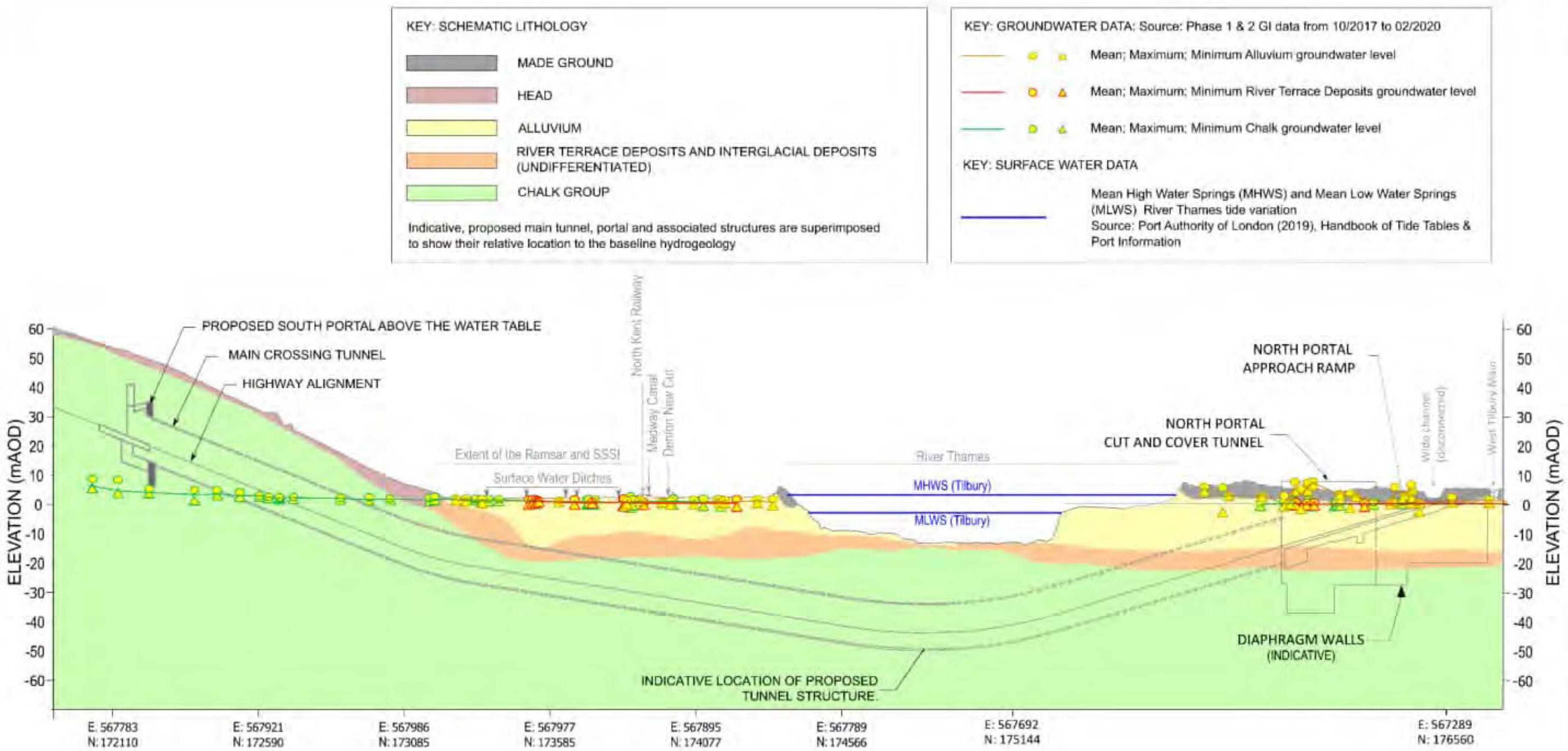
Note: Groundwater level data comprises manual dip data

Plate 1.5 Phase 1 and Phase 2 groundwater level monitoring plot – north of the River Thames



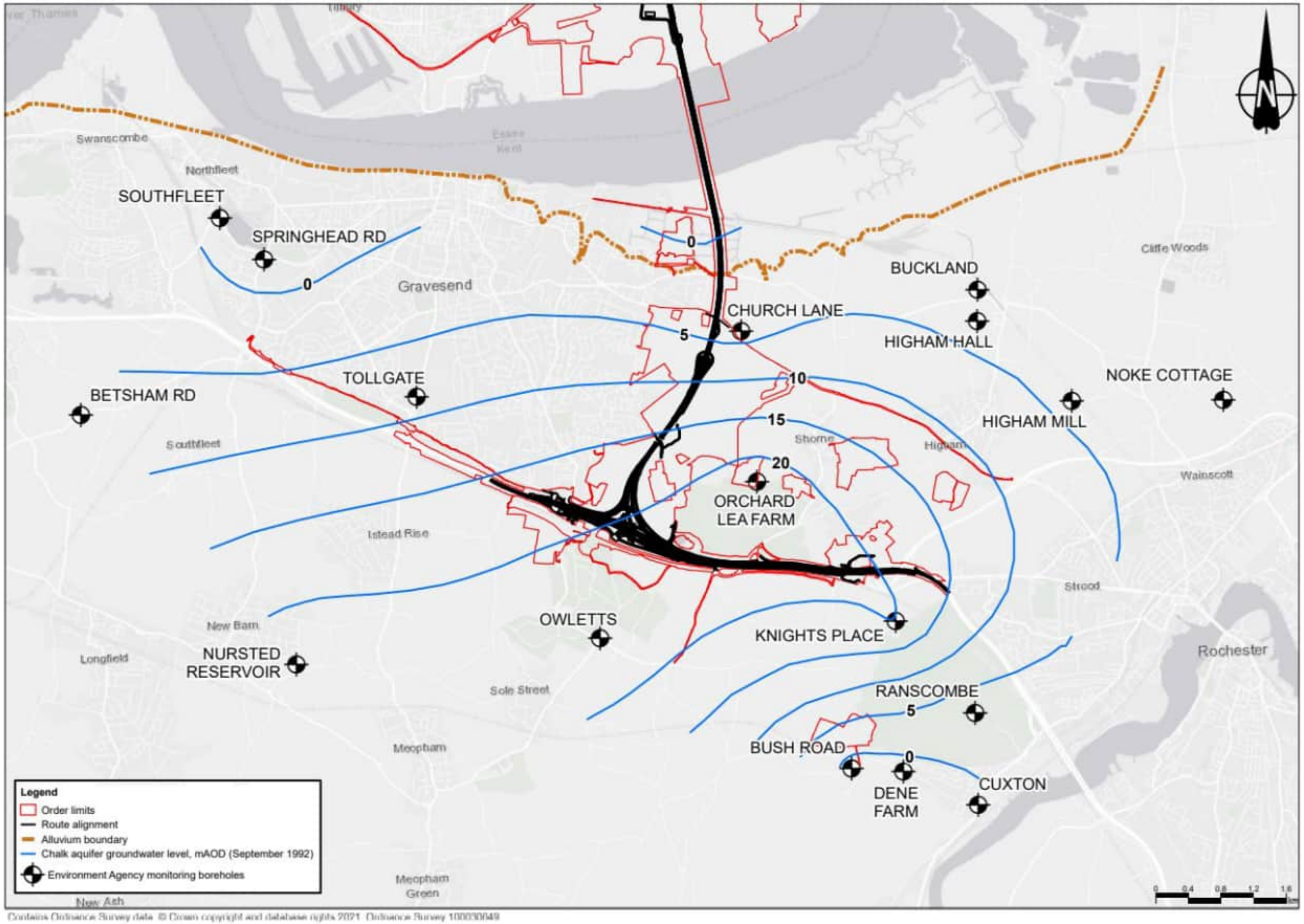
ALV = Alluvium; RTD = River Terrace Deposits; Thanet = Thanet Formation; EA = Environment Agency;
Note: Groundwater level data comprises manual dip data

Plate 1.6 Phase 1 and Phase 2 groundwater level monitoring plot – Main Crossing Tunnel



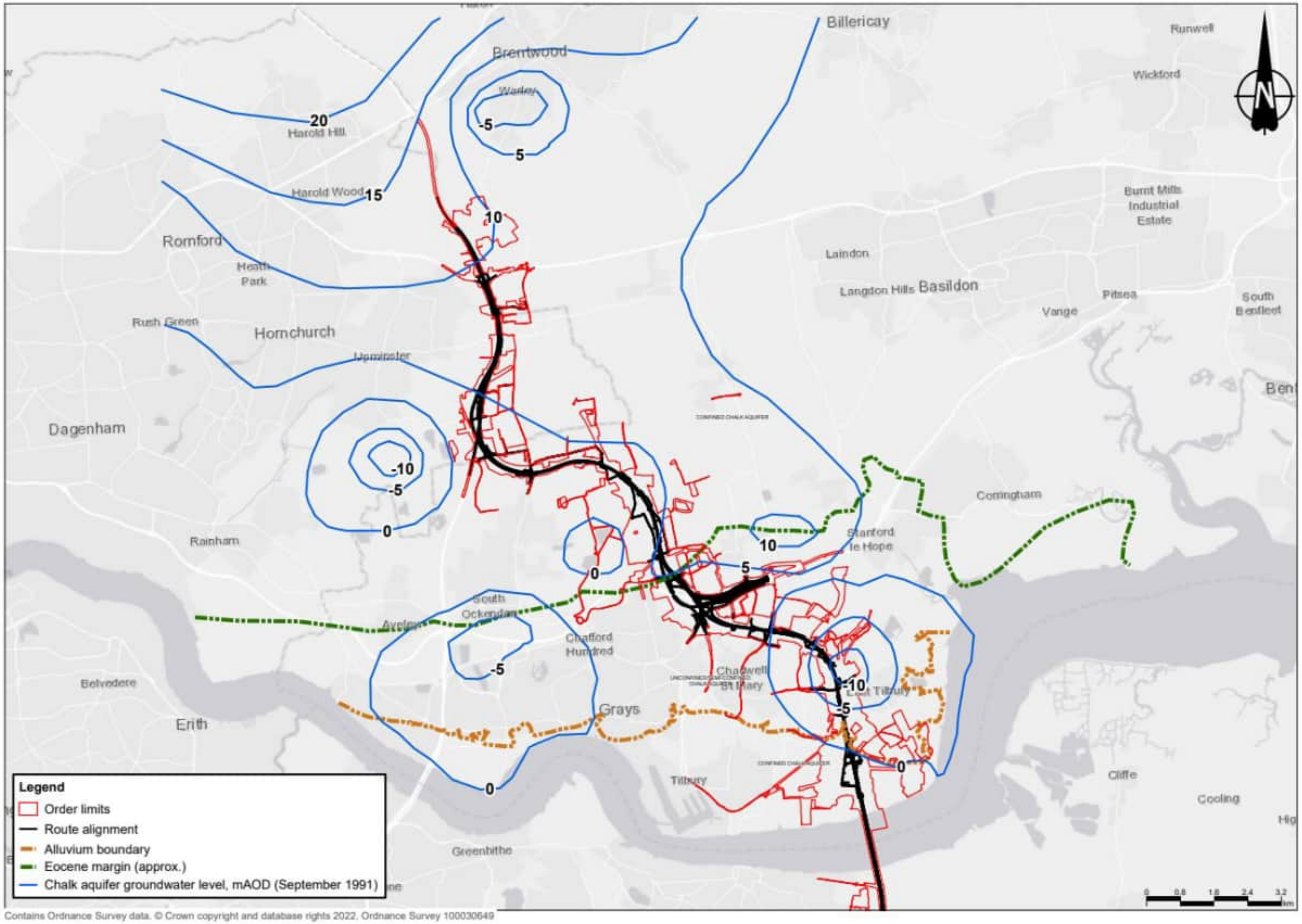
Note:
Geological section is schematic and has been simplified for display.
Groundwater data presented are the same as Plate 1.4 and Plate 1.5.

Plate 1.7 Chalk aquifer groundwater level contours – low condition (1992) – south of the River Thames



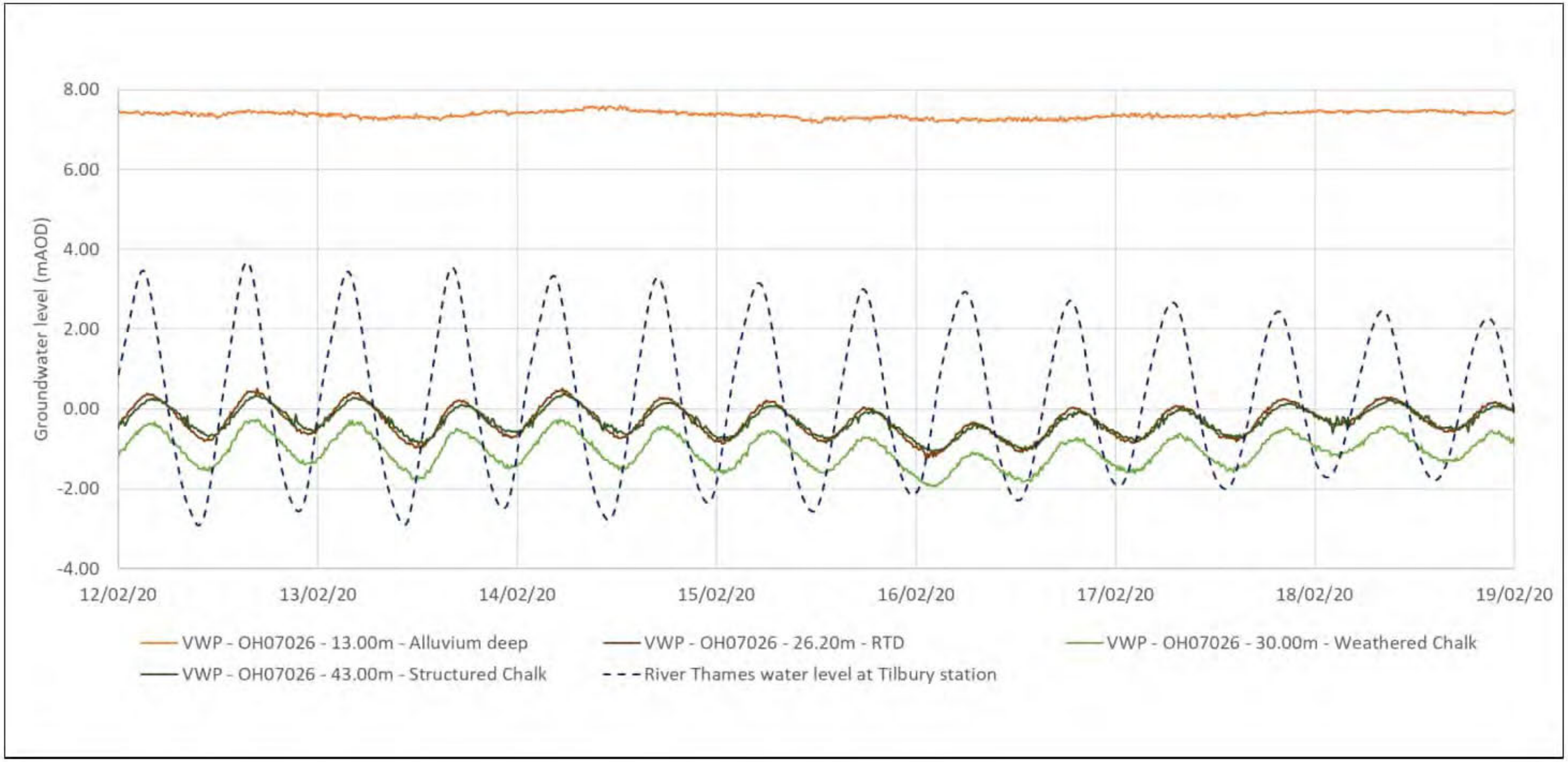
Groundwater level contours of the 1992 lowest water levels from Environment Agency boreholes (boreholes are labelled)

Plate 1.8 Chalk aquifer groundwater level contours – low condition (1991) – north of the River Thames



Notes: Modelled contours have been digitised from Figure TS 1 of Amec (2016) Essex Groundwater Investigation Final Report: South Essex Catchments. Amec Foster Wheeler (for the Environment Agency). They are for a dry period, September 1991.

Plate 1.9 Representative tidal hydrograph from Project ground investigation borehole OH07026 showing multiple strata and River Thames tidal water levels (North Portal area)



Annex D Baseline water balance for the Ramsar site (Filborough Marshes) – technical note

Lower Thames Crossing

Annex D Baseline Water Balance for the Ramsar Site (Filborough Marshes) – Technical Note

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1 Executive summary

1.1.1 An assessment of the current and historical baseline water conditions within the South Thames Estuary and Marshes Site of Special Scientific Interest, Shorne Marshes Royal Society for the Protection of Birds (RSPB) Reserve and the Thames Estuary and Marshes Ramsar site is required to determine the potential impact of the Project works.

1.1.2 This assessment comprises a hydrogeological summary of the baseline water balance in the shallow water system within part of the Ramsar site above the proposed tunnels and immediately adjacent to the Project route. Key findings resulting from this assessment are as follows:

a. The major source of water to the study area is precipitation.

b. The major outflows of water from the study area are evapotranspiration from the soil and evaporation from surface water ditches.

c. Groundwater contribution to the system is likely to be small with typically <2% of the total water input per month from diffuse shallow groundwater seepage.

d. Water balance and remote imaging of vegetation indicate no signs of significant water stress during representative dry periods.

e. During the Project construction and operation, inflow to proposed built structures could decrease the water transferred annually to storage but is unlikely to lead to any significant loss of water on a monthly basis, even in summer months.

2 Introduction

2.1 Background

2.1.1 The A122 Lower Thames Crossing (the Project) would provide a connection between the A2 and M2 in Kent, east of Gravesend, crossing under the River Thames through a tunnel, before joining the M25 south of junction 29.

2.1.2 The A122 road would be approximately 23km long, 4.25km of which would be in tunnel. On the south side of the River Thames, the Project route would link the tunnel to the A2 and M2. On the north side, it would link to the A13 and junction 29 of the M25. The tunnel entrances would be located to the east of the village of Chalk on the south of the River Thames and to the west of East Tilbury on the north side.

2.1.3 This technical note presents an hydrogeological review of the baseline water balance for the part of the internationally designated South Thames Estuary and Marshes Site of Special Scientific Interest, Shorne Marshes Royal Society for the Protection of Birds (RSPB) Reserve and the Thames Estuary and Marshes Ramsar site (herein described as the Ramsar site) which lies above the proposed tunnel alignment.

2.2 Objectives

2.2.1 The objectives of this technical note are to:

a. estimate water inflows and outflows and determine the overall annual change in storage within the shallow water system at the water balance study area, within the Ramsar site

b. provide a preliminary baseline assessment of interactions between groundwater and surface water

c. qualitatively identify potential connectivity which may be impacted by the Project construction and operation

2.3 Assumptions and limitations

2.3.1 The following assumptions and limitations have been factored into this assessment:

a. For the purposes of this assessment the defined water balance systeem is in the area shown in Plate 3.2 (an area of approximately 350,000m^2) of thickness of approximately 2m. This is considered as appropriate to analyse the shallow water conditions at the Ramsar site within and surrounding the Order Limits.

b. The default calculation period of this preliminary water balance is the calendar month. All water components enter or leave the defined water balance system within this time interval.

c. Daily rainfall, actual evapotranspiration, and soil moisture deficit (SMD) data covering the period between 2000 and 2019 have been purchased from the Meteorological Office Rainfall and Evaporation Calculation System (MORECS) (Met Office, 2020) or provided by the Environment Agency (2020) and then grouped over the calendar month.

d. Evaporation has been calculated based on freely available public information combining daily data (2000–2012) from the Climate, Hydrology and Ecology research Support System (CHESS) (UK Centre for Ecology and Hydrology, 2019) or monthly average historical weather data from World Weather Online (2019).

e. The horizontal and vertical hydraulic conductivity values of the shallow Alluvium are based on the Ramsar Ground Protection Tunnel and Main Tunnels Numerical Model (Application Document 6.3, Appendix 14.5, Annex J).

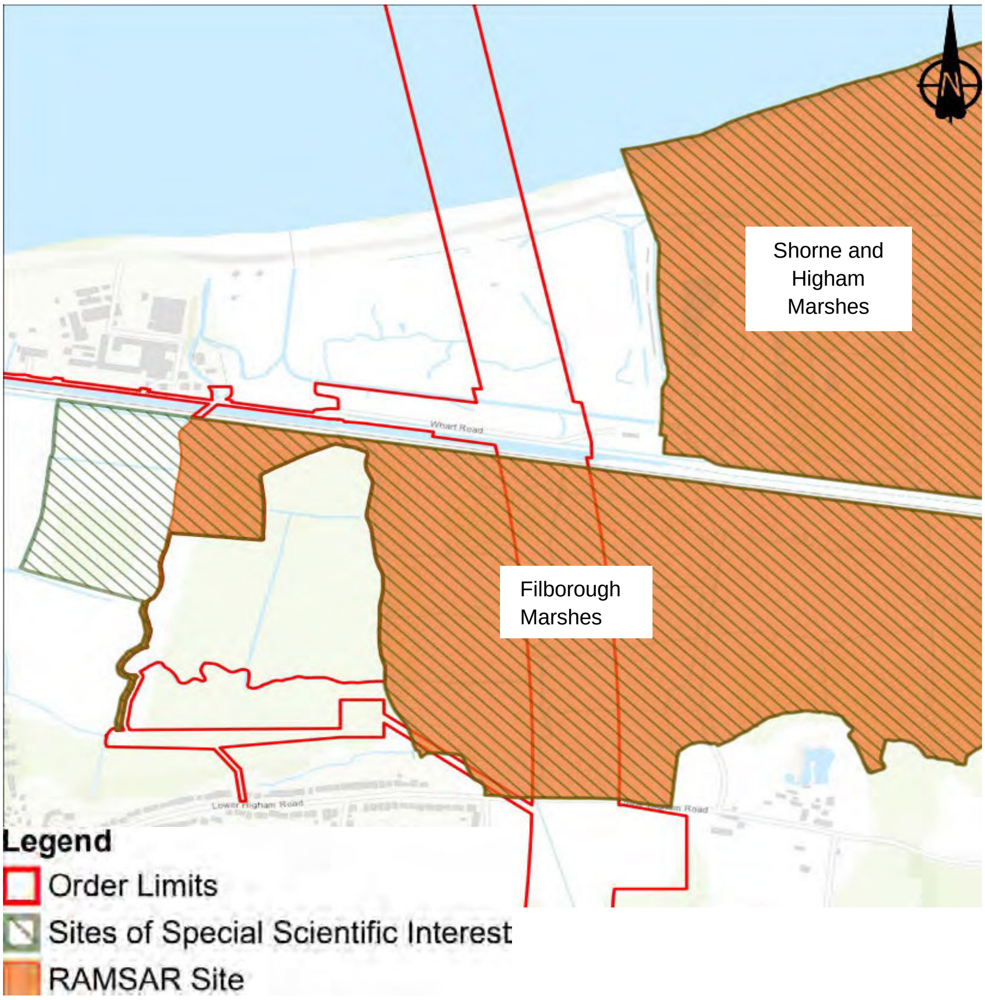
f. The assessment covered within this technical note is based on Project ground investigation data.

3 Water balance assessment

3.1 Filborough Marshes water balance area

3.1.1 The Project route crosses the Filborough Marshes area of the Ramsar site (Plate 3.1). This area of the Ramsar site is therefore considered to have the greatest potential to be impacted by the Project construction and operation.

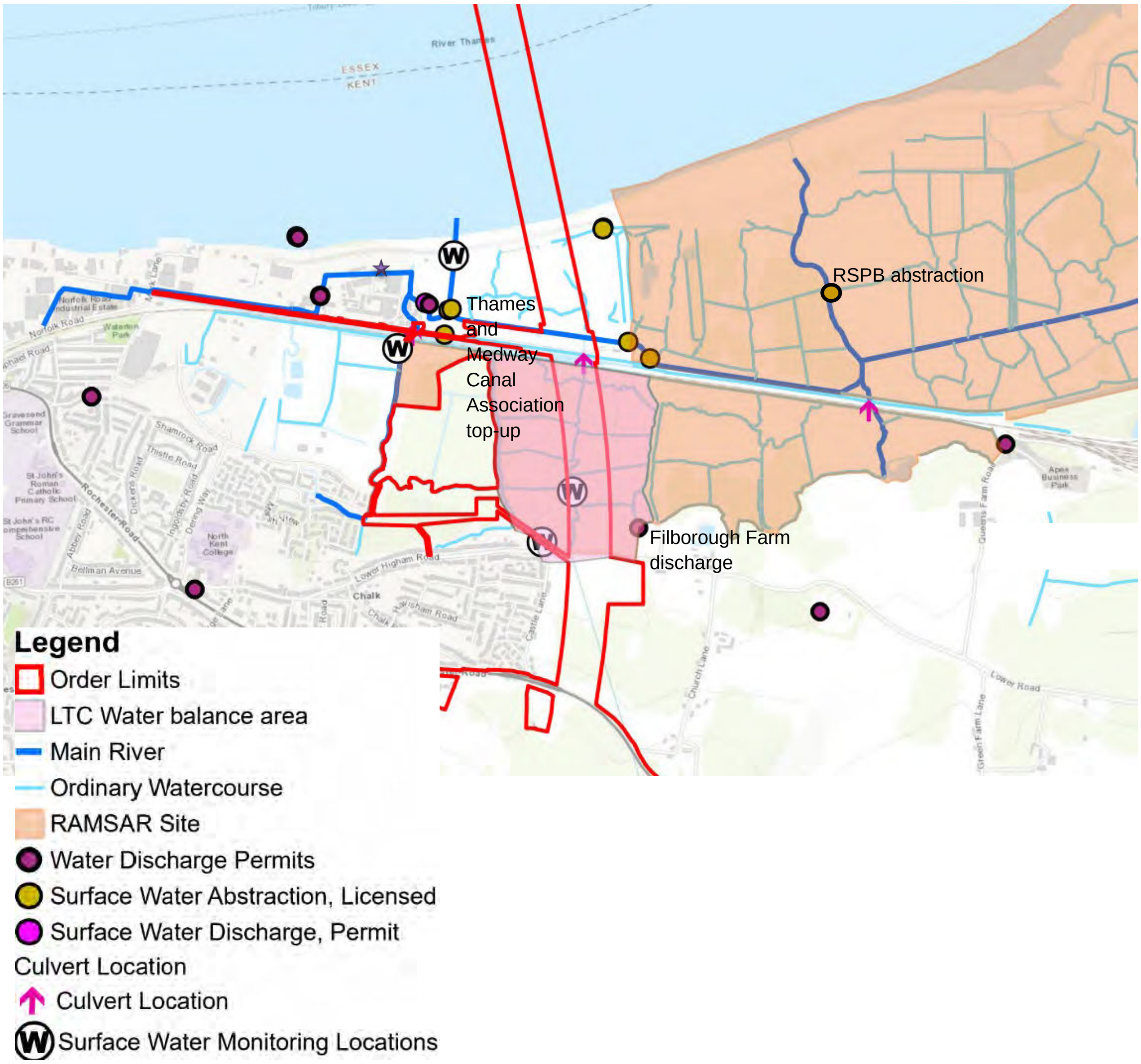
Plate 3.1 Designated sites



3.1.2 The water balance study area (herein described as the study area) is shown in Plate 3.2. The water balance assessment accounts for water movement into and out of the shallow water system within part of the Filborough Marshes (the area which lies above the proposed tunnel alignment within the Ramsar site) immediately next to the Order Limits. The study area comprises an area of approximately 350,000m^2 and is relatively flat lying with an average elevation of 2.2m above ordnance datum (AOD). It is bounded by the railway line to the north and Lower Higham Road to the south. The east–west extent is defined by drainage ditches running roughly parallel to the Project route approximately 100m to 200m outside of the Order Limits.

3.1.3 The shallow water system examined in the water balance calculation includes the soil, subsurface strata and surface water ditches that lie within this area from the ground surface down to 0m AOD. The shallow water system is assumed to be approximately 2m thick.

Plate 3.2 Water balance study area



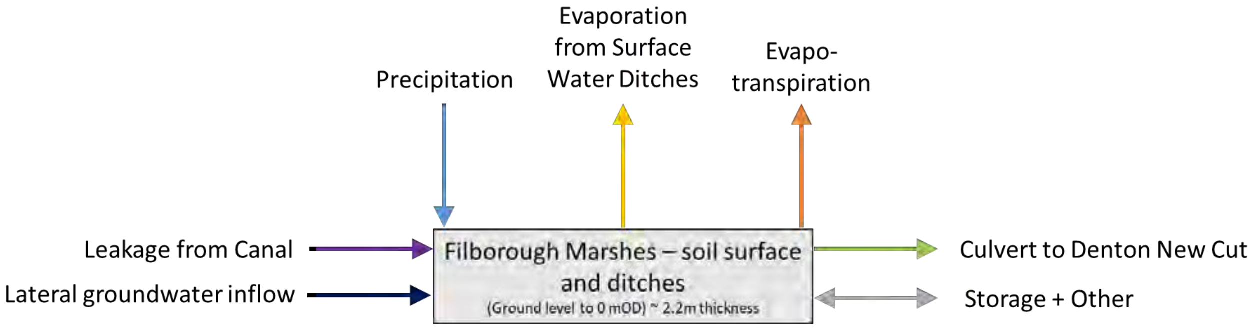
3.2 Water balance conceptual model

3.2.1 The water balance approach has considered site-specific, potential inflows and outflows which can be described generally in the form:

Input – Output = Change in Storage

3.2.2 Water balance assessments are used to help manage water supply and predict where there may be shortages. Plate 3.3 shows a conceptual summary of the significant inflows to and outflows from the Filborough Marshes shallow water system.

Plate 3.3 Conceptual diagram of water inflows, outflows and storage within the study area



3.3 Water balance components and estimated values

Inflows

3.3.1 Table 3.1 lists the potential inputs of water to the study area and considers the potential magnitude and sources of available data related to each factor.

Table 3.1 Summary of potential inputs to the water balance study area

Type of input	Nature of water input	Estimated input per month	Data sources
Precipitation	Precipitation directly onto the land surface area	5mm to 170mm Up to 60,000m^3	Site-specific precipitation data purchased from the MORECS – 5km grid square and specified ‘rough grazing’ land use (Met Office, 2020)
Recharge from surface water – ditches	Ditches within the study area are considered as part of the surface water system and therefore do not contribute to the	Not applicable Ditches act as water storage bodies rather than a source. Water	

Type of input	Nature of water input	Estimated input per month	Data sources
	overall water balance equation.	balance calculates change of storage.	
Recharge from surface water – Thames and Medway Canal	Although historical reports maintain that the Thames and Medway Canal has an impermeable lining, no field evidence was found indicating the presence of an impermeable barrier. Evidence from 2018, when no manual top-up occurred, suggests that leakage from the Thames and Medway Canal to the north edge of site is occurring (see discussion in Section 3.4).	Around 400m^3 to 3,000m^3 These estimates are based on a canal lined with material with an average permeability of 4x10^{-8}m/s with all leakage directed towards the study area and are therefore considered a low estimate of possible inflows.	Assuming a constant water level of 3.72m AOD for water level of the Thames and Medway Canal (Thames and Medway Canal Association, 2019). Calculated using a representative average permeability derived from the volume of water required to fully top up the Thames and Medway Canal following 126 days of no manual top-up in 2018. For discussion of canal leakage, refer to Section 3.4.
Seawater intrusion	Conductivity data from surface water ditches across the study area suggests that there is no significant input of saltwater into the shallow water system at this location.	Insignificant	Project field data (Cascade, 2019a)
Lateral groundwater inflow and leakage from other aquifers	Any movement of groundwater into this location is likely to occur by diffuse seepage horizontally from the Chalk aquifer to the Alluvium underlying the surface water system. Vertical groundwater inflow not considered in the water balance because similar groundwater levels in Alluvium and Chalk (i.e. no driving vertical hydraulic gradient), based on the information analysed to date (Annex A).	Around 50m^3 to 150m^3	Calculated using modelled mean conductivity of the underlying and surrounding Alluvium. K_h = 7.9x10^{-7}m/s and K_v = 0.1 * K_h (Annex J)*. For discussion of Alluvium conductivity refer to Section 3.4. Calculation also uses hydraulic head of groundwater interpolated from Church Lane borehole (Environment Agency, 2018). This record ends on 20/04/2018 with a level of 7.17m AOD and

Type of input	Nature of water input	Estimated input per month	Data sources
	Groundwater modelling at the Ramsar site (Hydrogeological Risk Assessment, Application Document 6.3, Annex J) suggests groundwater flow is mainly horizontal, towards the River Thames, the main discharge point. No springs have been identified during Project water features surveys, and the RSPB Reserve manager stated no springs are observed on site.		has been extrapolated to remain constant at this level for calculations later than this date. Nearby Project wells indicate actual water levels several meters lower than this static level from the start of monitoring in November 2018.
Discharge	One Environment Agency discharge consent has been identified at Filborough Farm Barn (P09544) near the south-east corner of the study area. This is described as an outlet for sewage into the land, but no further information related to the nature and volume of this discharge consent is available.	Unknown – assumed to be insignificant	Environment Agency data

*Note: K_h refers to horizontal hydraulic conductivity; K_v refers to vertical hydraulic conductivity.

Outflows

3.3.2 Table 3.2 lists the potential outflows of water from the study area and considers the potential magnitude and sources of available data.

Table 3.2 Summary of potential outflows from the water balance study area

Outflow type	Nature of water outflow	Estimated flow per month	Data sources
Abstraction	No current or historical abstractions have been identified within the study area. There are two abstractions downgradient of the study area from Denton New Cut (see Plate 3.2). The closest is managed by the RSPB to top-up Shorne Marshes, and the abstraction further downstream is	Not applicable	Project communications with Thames and Medway Canal Association Chairman (Thames and

Outflow type	Nature of water outflow	Estimated flow per month	Data sources
	licensed by Gravesham Borough Council and is used to top-up the Thames and Medway Canal to maintain the water level. These abstractions are therefore limited by flow from the study area to Denton New Cut and not applicable to the water balance model.		Medway Canal Association, 2019)
Baseline flow in rivers	No rivers have been identified outflowing from the study area. The surface water system (ditches) is considered separately below.	Not applicable	
Surface water flow	Site observations indicate that surface water within the study area is contained in a network of drainage ditches which ultimately outflows via a culvert (Plate 3.2) into Denton New Cut. The outflow is understood to be adjusted by the landowner by manual removal of a stopper board from the culvert opening.	Source of uncertainty – not included in calculations. Forms part of 'Storage + Other' system.	Water features survey (Appendix 14.2) and Project communications with Thames and Medway Canal Association Chairman (Thames and Medway Canal Association, 2019)
Discharge to the sea	No direct discharge from the study area to the sea or to the Thames Estuary is anticipated.	Not applicable	
Flows to other aquifers	Seepage of water from the study area downwards into lower strata. Groundwater level data from boreholes within the Ramsar show similar water levels in the Alluvium, Chalk and River Terrace Deposits. This suggests that there is insufficient hydraulic head difference to drive quantifiable net flow from the study area to lower strata.	Not applicable	See Annex A
Evapo-transpiration	Evapotranspiration from the soil surface – estimated as total surface area minus area of surface water ditches. The topsoil and Alluvium have been considered to be covered with rough grass based on information from Appendix 14.2: Water Features Survey Factual Report (Application Document 6.3)	10mm to 90mm Up to 30,000m^3	Site-specific potential evaporation and actual evaporation data purchased from the MORECS (Met Office, 2020). Additional potential evaporation and actual evapotranspiration

Outflow type	Nature of water outflow	Estimated flow per month	Data sources
			data provided by the Environment Agency (2020) for comparison.
Open water evaporation	Evaporation from the surface of shallow drainage ditches. The salinity of the ditches has been considered to be <1% for the purpose of calculations. This is in line with conductivity and geochemical data collected from ditches onsite (Cascade, 2019a).	20mm to 250mm 500m^3 to 6,500m^3 based on a total ditch surface area of approximately 26,000m^2 (from Geographic Information System (GIS) polygon), and an average channel width of 3m (Cascade, 2019b).	Calculated using daily air temperature, air pressure and specific humidity data (UK Centre for Ecology and Hydrology, 2019) between 2000 and 2012, and monthly average temperature and humidity data (World Weather Online, 2019) between 2013 and 2019.
Change of storage and other	Field data relating to water storage could not be collected. As a result, this has been assumed from the difference between total inflows and outflows on a monthly basis. Storage occurs in autumn and winter and is released during periods of low rainfall. This variable potentially includes unquantifiable surface water outflow as discussed above.	Up to 45,000m^3 (from water balance). Capacity of ditches likely to be up to 50,000m^3 based on approximate 2m depth (Cascade, 2019b). Storage in excess of this is likely to cause surface water flooding.	Water balance assessment.

3.4 Water balance results

Balance of inputs and outputs

3.4.1 Plate 3.4 shows the balance of input and output volumes and expected change in storage or unquantifiable flows between 2000 and 2020.

Alluvium permeability

3.4.2 Alluvium permeability affects the calculated magnitude of inflows from groundwater and canal leakage. Data collected from the Project ground investigation was used to assess the likely permeability of the Alluvium. Results are summarised in Table 3.3. Full results are presented in (Annex B)

Table 3.3 Summary of alluvium permeabilities from analysis of ground investigation data

	Southern edge of the study area	Centre of the Ramsar study area	Northern edge of the study area
Conductivity used for water balance calculations (this report)	$K_h = 7.9 \times 10^{-7}$m/s $K_v = 0.1 * K_h$ (refer to Annex J for further details)		
Values interpreted from cone penetrometer test data	$K = 1 \times 10^{-10}$ to 1×10^{-8} Surface layer (top 2m) has a higher K ($\sim 1 \times 10^{-6}$ to 1×10^{-8}m/s)	$K = 1 \times 10^{-9}$m/s Surface layer (top 0.8m) has a higher K ($\sim 1 \times 10^{-6}$ to 1×10^{-8}m/s)	$K < 1 \times 10^{-10}$m/s Surface layer (top 0.5m) has higher K ($\sim 1 \times 10^{-7}$m/s)
Values interpreted from variable head tests	-	$K = 8.0 \times 10^{-8}$m/s	-

Note: K_h refers to horizontal hydraulic conductivity; K_v refers to vertical hydraulic conductivity; K refers to isotropic hydraulic conductivity.

3.4.3 This assessment indicates that the values for horizontal conductivity (K_h) and vertical conductivity (K_v) used in this report are within the range given by a variety of testing approaches from the ground investigation data. Cone penetrometer test (CPT) data indicates that the topmost layer of the Alluvium may have a slightly higher permeability but that the bulk hydraulic conductivity is similar or lower than the hydraulic conductivity used in the water balance calculations presented in this report. Using values towards the high conductivity end of the range indicated by modelling and ground investigation work ensures that the water balance presents a conservative estimate of the groundwater dependency of the surface water system.

Canal leakage

3.4.4 The inflow from the Thames and Medway Canal to the surface water system has also been estimated with some uncertainty. Although historical reports maintain that the Thames and Medway Canal has an impermeable lining, no field evidence was found during water features surveys to indicate the presence of an impermeable barrier (Cascade, 2019b). Data from a period in 2018 during which no manual top-up of the canal occurred does suggest that leakage from the canal is occurring, as the volume of water required to top up the canal following this period was greater than expected had the only output been to evaporation (Cascade, 2019c). Initial calculations indicate an average permeability of between $8.5x10^{-8}$m/s and $4.0x10^{-8}$m/s for the canal lining. However, it is unknown whether this leakage is localised to cracks or degraded areas in a less permeable barrier or occurs uniformly across the entire canal.

3.4.5 For the purpose of this baseline water balance report, the assumption is a lined canal which leaks into the study area both horizontally and vertically at $4.0x10^{-8}$m/s as a conservative scenario to produce a low estimate of the expected inflow from a leaking canal.

Storage depletion

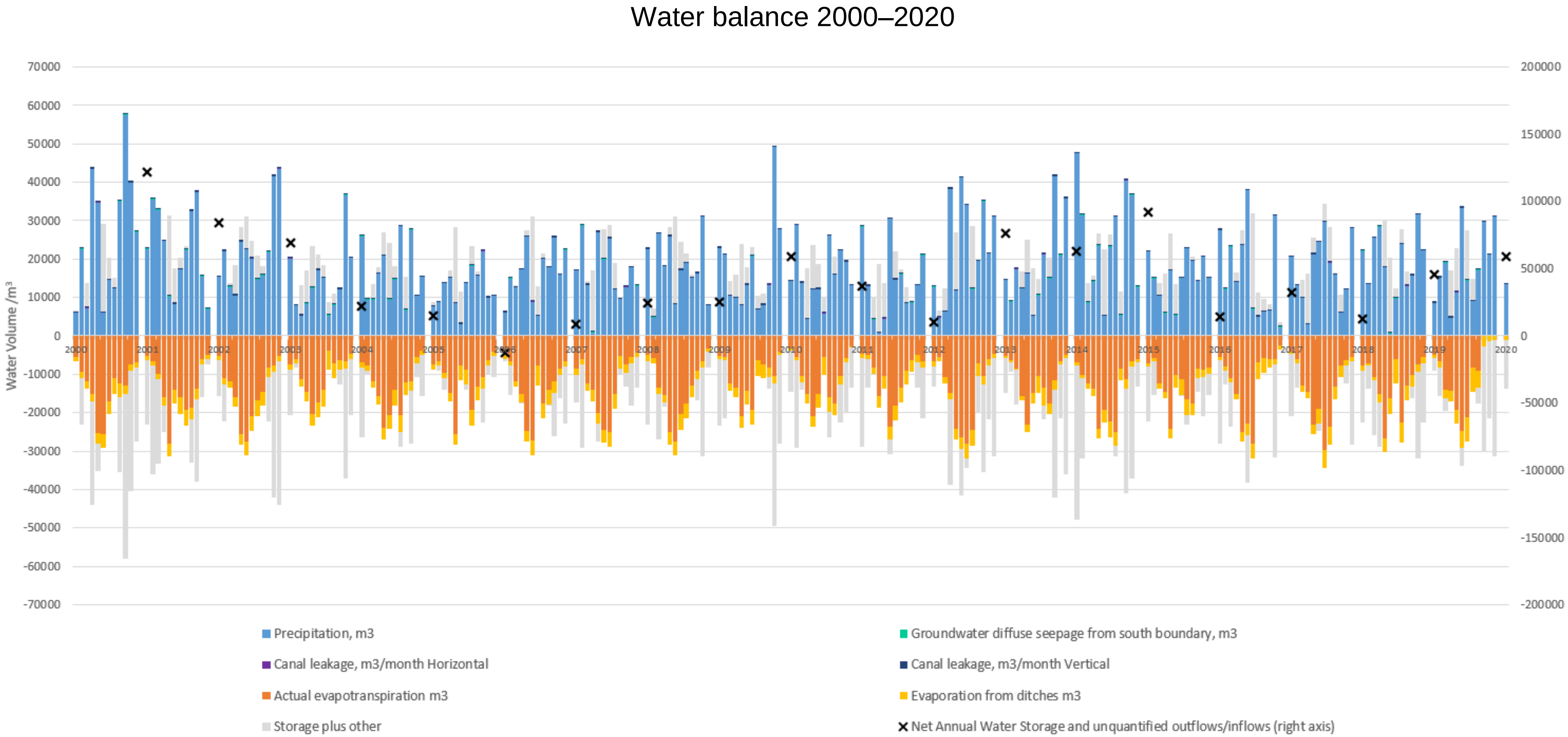
3.4.6 Plate 3.5 shows the seasonal water budget based on the major water inflow (precipitation) and major outflow (evapotranspiration). Potential storage depletion is indicated when evapotranspiration (orange line) exceeds the precipitation (blue line).

3.4.7 The role of SMD in water balance calculations is important. Recharge into the soil system is assumed possible only if the soil moisture is replenished. Additionally, evapotranspiration can, theoretically, only occur in soils with a soil moisture deficit of less than a maximum, here estimated as 110mm (MET Éireann, 2019) and progressively decreases with increasing soil moisture deficit.

3.4.8 SMD datasets from the MORECS and the Environment Agency record a similar seasonal pattern with low SMD throughout the winter increasing to a summer peak – typically in August or September. The MORECS data is considered to be most representative of conditions in the Ramsar site, as it uses a smaller 5km grid square and specified ‘rough grazing’ land use type across the square to represent vegetation specific to the Ramsar, which is grazed by animals and not mown extensively. The SMD dataset from the MORECS indicates that high summer SMD does not become a limiting factor to evapotranspiration from the Ramsar site.

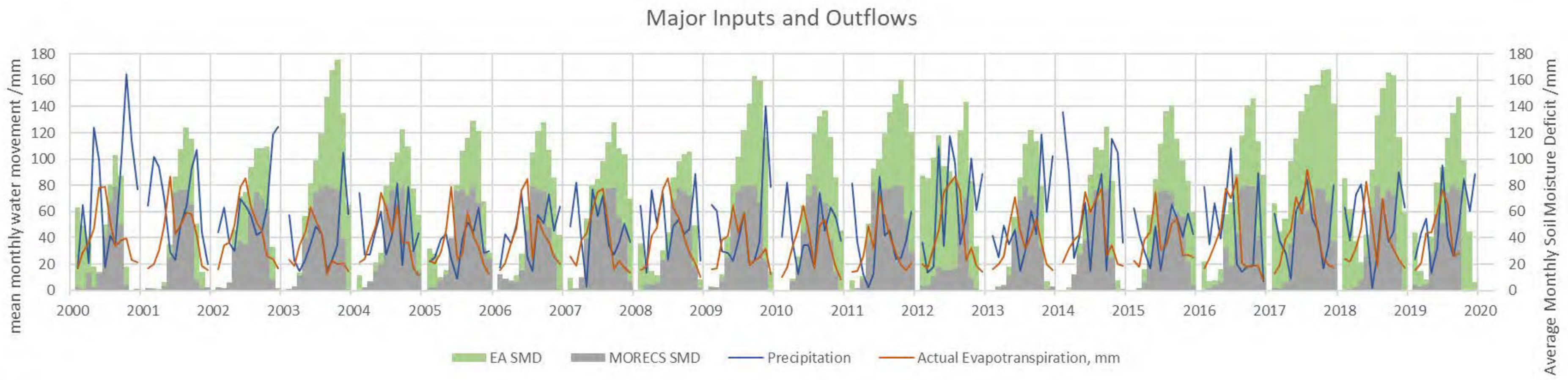
3.4.9 Visual analysis of imagery from Sentinel-2 optical satellite (European Space Agency, 2019) indicates that there is no sign of moisture stress during extended dry conditions during two representative years (2016 and 2018) with low summer precipitation (Annex C). This supports the MORECS interpretation of a lower soil moisture deficit which reduces, but does not limit, evapotranspiration during dry periods.

Plate 3.4 Histograms representing total monthly water volume change within the study area and net annual water to storage and unknown outflows or inflows at the end of each year



Note: Histogram bars are scaled against the left axis; net annual water to storage and other unknown outflows or inflows is plotted against the right axis.

Plate 3.5 Major inflows – precipitation vs major water outflows – evapotranspiration and the effect of soil moisture deficit (SMD) on water loss through actual evapotranspiration



Effect of drainage into proposed structures

3.4.10 The Project involves constructing the east and west main tunnel structures and ground protection tunnel beneath the Ramsar site. Models indicate that prescribed inflow to the structures would produce localised drawdown (Annex J) and could cause additional outflows from the study volume as a result of underdrainage both during the construction phase when all three tunnels are active and during operation after the ground protection tunnel has been decommissioned.

3.4.11 This study is intended to present a baseline (without the Project); however, the magnitude of these potential additional outflows have been considered in Table 3.4 for comparison with inflows and outflows in the water balance.

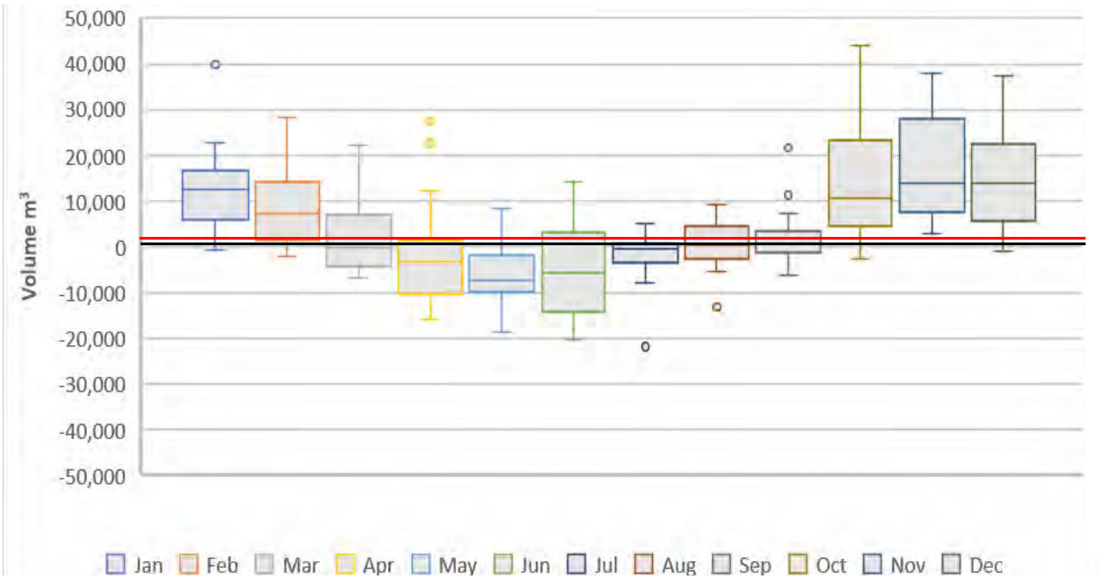
3.4.12 Specification of the maximum leakage rates based on the British Tunnelling Society and Institution of Civil Engineers (2010) prescribed leakage rates for tunnels and advice from the Cascade Tunnels Portal Team under ideal (prescribed) and worst-case scenarios (see Table 3.4).

3.4.13 Calculations indicate that the additional outflow from the system to tunnels is likely to be low in comparison to the existing outflows in the water balance model. Plate 3.6 shows the total monthly balance of inflows minus outflows from the system – an indication of water transferred to/from storage or not quantifiable by the model. The red line indicates the amount of additional monthly outflow which could occur under worst-case tunnel inflow rates. Considered on an annual basis, this may represent up to 3,100m^3 (prescribed) or 15,600m^3 (worst case) while the ground protection tunnel is operational, and 2,660m^3 (prescribed) to 13,300m^3 (worst case) during normal tunnel operation, compared to annual excess storage averaging 43,000m^3. This would result in slightly less water transferred annually to storage, but it is unlikely to lead to any significant loss of water on a monthly basis even in summer months.

Table 3.4 Leakage to tunnels directly below the Ramsar site

British Tunnelling Society leakage scenario	Tunnel inflow rate	Total leakage rate directly below the Ramsar site	Average monthly leakage
Prescribed	0.1 litres/m^2/day	8.5m^3/day	239–265m^3
Worst case	0.5 litres/m^2/day	42.7m^3/day	1,196–1,324m^3

Plate 3.6 Box plots showing the magnitude of monthly outflows to or inflows from storage and other flows

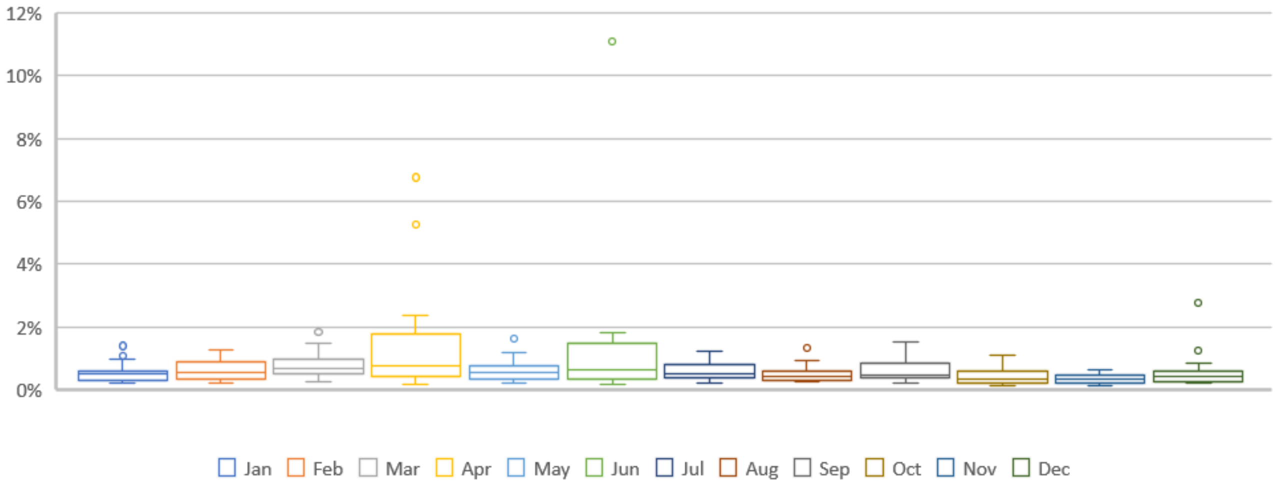


Note: Outflows from storage and other flows are represented by positive volumes; inflows to storage and other flows are represented by negative volumes. Red line indicates additional monthly outflow from storage caused by worst-case infiltration to proposed structures. Circles denote statistical outliers (>1.5 * interquartile range from the 1st or 3rd quartile).

3.5 Summary of results

3.5.1 The assumed low permeability of Alluvium appears to impede significant inflow of water to the Ramsar site from other aquifers and water sources. Of these flows, the dominant input is rainfall, which makes up between 95% and 98% of the total annual water inputs. Minor inputs may come from leakage from the Thames and Medway Canal and from diffuse shallow groundwater seepage. Monthly calculations indicate that the groundwater body does not contribute significantly to the total surface water system inflows. Groundwater inflow is likely to be limited to horizontal flow due to a lack of a driving vertical head through the system (Plate A.1). The horizontal inflow is driven by the hydraulic gradient from the southern boundary of the study area and typically contributes <2% of the total inflows per month (Plate 3.7). Of the 237 months analysed for the water balance calculations, only three (April 2007, 2011 and June 2018) required more than 5% of the monthly total inflows from groundwater. These months have anomalously low precipitation (less than 2.7mm over the month) and are considered extreme scenarios.

Plate 3.7 Box plots of calculated percentage contribution of groundwater to total inflows to the study area by month between 2000 and 2020



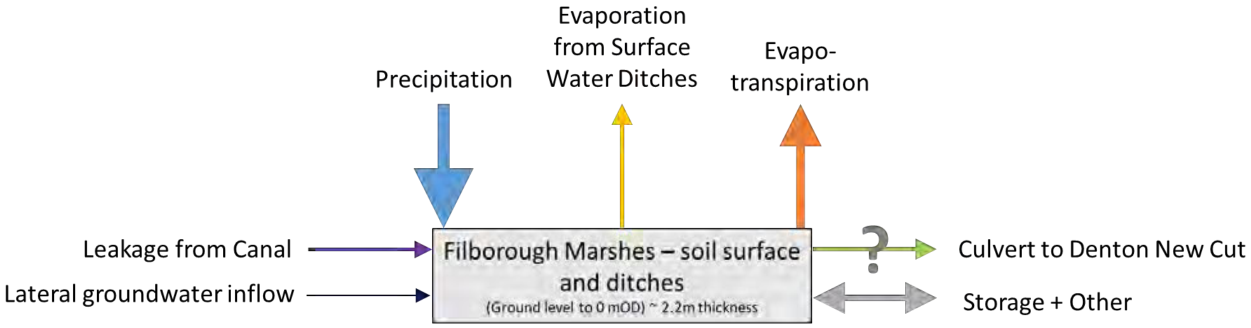
Note: Circles denote statistical outliers (>1.5 * interquartile range from the 3rd quartile).

3.5.2 Evapotranspiration and evaporation are the major outflows, with vertical groundwater seepage assumed to be negligible given the results from modelling and groundwater levels. Evapotranspiration has been assumed to occur across the entire soil surface area of the Ramsar site (taken as 92.6% by area) and accounts for approximately 77% to 86% of the annual outflows. Evaporation has been taken to occur across the remaining water-covered area of the Ramsar site (7.4% by area assuming a 3m ditch width) and accounts for the remaining 14% to 23% of annual outflow.

3.5.3 The greatest source of uncertainty in the water balance is surface water outflow from the system. Surface water outflow to Denton New Cut is manually adjusted by use of a stopper board by the landowner and historical data is not available. The water from Denton New Cut is used to top up the Thames and Medway Canal to maintain water levels of 3.72m AOD (Thames and Medway Canal Association, 2019). Historical data of monthly pump operation from 2014–2019 is available (Thames and Medway Canal Association, 2019) and allows the potential magnitude of this abstraction to be estimated. However, it is inappropriate to include data from the abstraction directly in the water balance as it lies outside the boundaries of the study area and the volume of water available to pump from Denton New Cut would include other sources than surface water runoff from the culverted outflow.

3.5.4 The water balance indicates that up to 120,000m^3 of water is transmitted to storage or unquantifiable outflows annually. Therefore, without additional outflow, flooding is likely to occur during times of high precipitation as storage requirements exceed the expected storage capacity of the drainage ditches within the site (estimated to be approximately 50,000m^3 based on a <2m ditch depth).

Plate 3.8 Conceptual diagram of assessed main water inflows, outflows and storage within the study area (width of arrows indicates proportional magnitude)



4 Conclusions

4.1 Conclusions

4.1.1 A water balance assessment has been conducted of the shallow water system within part of the Filborough Marshes, immediately next to the Project route (the study area). This is part of the Ramsar site that lies above the proposed tunnel. Baseline water balance calculations suggest the following:

g. The major source of water to the study area is precipitation and provides between 95% and 98% of the total annual water inputs.

h. Groundwater flow is mostly horizontal and contribution to the system is small with typically <2% of the total water input per month from diffuse shallow groundwater seepage.

i. The Thames and Medway Canal is likely to be a minor contributor to total water inflows as the rate of leakage is generally lower than the conductivity of the surrounding Alluvium.

j. The major outflows of water from the study area are evapotranspiration from the soil and evaporation from surface water ditches.

k. The major uncertainty in the system is the amount of surface water drained by manual removal of the stopper board between the ditches and the culvert to Denton New Cut. Water pumped from Denton New Cut to the Thames and Medway Canal is not an appropriate proxy for the magnitude of this outflow as it is outside the study area and is likely to include additional unquantified water sources.

l. Without additional surface water outflow to Denton New Cut, flooding is likely to occur during times of high precipitation as storage requirements exceed the calculated storage capacity of surface ditches.

m. Water storage depletion (of the soils and ditches) occurs when rainfall is low and is exceeded by evaporation plus evapotranspiration.

n. Evaporation volume calculation is sensitive to the surface area of ditches. These calculations assume a width of 3m.

o. The water balance indicates that up to 120,000m^3 of water is transmitted to storage or unquantifiable outflows annually.

p. In prolonged dry periods where soil moisture deficit is high, the amount of water lost to evapotranspiration is reduced, but remote imaging of vegetation indicates no signs of significant water stress during representative dry periods.

q. Magnitude of lateral groundwater inflow and leakages are based on vertical hydraulic conductivity (K_v) and horizontal hydraulic conductivity (K_h) of Alluvium, from numerical modelling, geometric averages of the Project Phase 1 and Phase 2 ground investigation and published sources (e.g. Annex J; Bevan *et al*., 2010). Significant continuous peat or sand layers could represent potential pathways for increased water movement.

r. During construction and operation, inflow to structures could decrease the water transferred annually to storage, but is unlikely to lead to any significant loss of water on a monthly basis, even in summer months.

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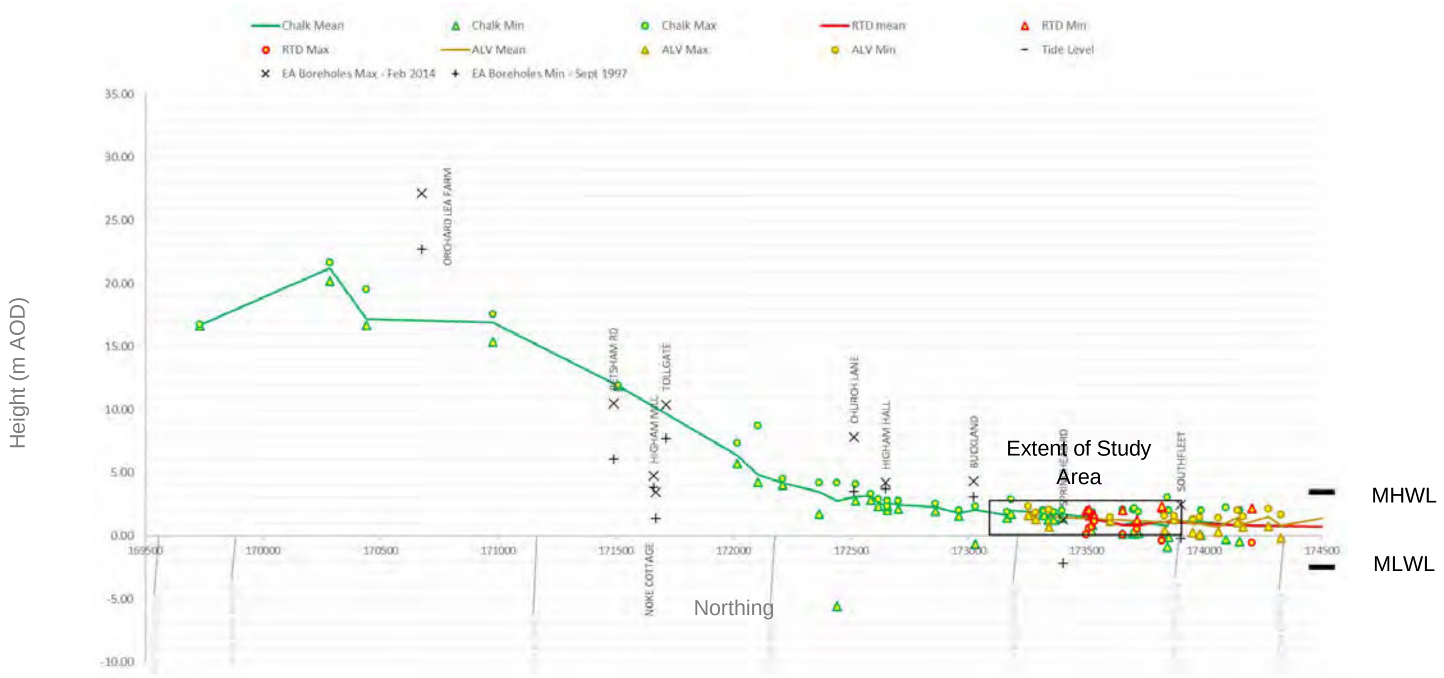
Annexes

Annex A Additional plates

A.1 Preliminary groundwater data

A.1.1 Plate A.1 shows preliminary manual dip data collected between October 2017 and February 2020 during the Project Phase 1 and Phase 2 ground investigations. This shows that the Alluvium, River Terrace Deposits and Chalk aquifer all have a similar piezometric head and there appears to be no hydraulic pressure difference to drive significant flow from the surface Alluvium to lower strata.

Plate A.1 Groundwater levels from manual dips of Environment Agency boreholes (black crosses), Phase 1 and Phase 2A boreholes installed in different strata south of the Thames. Vertical and lateral extent of study area is outlined to scale.



Note: MHWL=Mean High Water Level; MLWL=Mean Low Water Level; RTD=River Terrace Deposits; ALV=Alluvium; EA=Environment Agency.

A.1.2 Plate A.2 shows water levels from the Environment Agency borehole on Church Lane (blue points). This record ends on 20 April 2018 with a level of 7.17m AOD and has been extrapolated to remain constant at this level (orange line) for calculations later than this date.

A.1.3 Nearby Project groundwater monitoring wells OH03001 and OH03003 show actual water levels several metres lower than this static level from the start of monitoring in November 2018 (yellow and grey lines). Extrapolation assuming a linear gradient from the locations of these boreholes to the Church Lane monitoring point indicates lower water levels of between 4m AOD and 5m AOD between 2018 and 2019 (green line).

Plate A.2 Groundwater levels from the Environment Agency's Church Lane monitoring borehole and interpolated series used to calculate horizontal groundwater flows

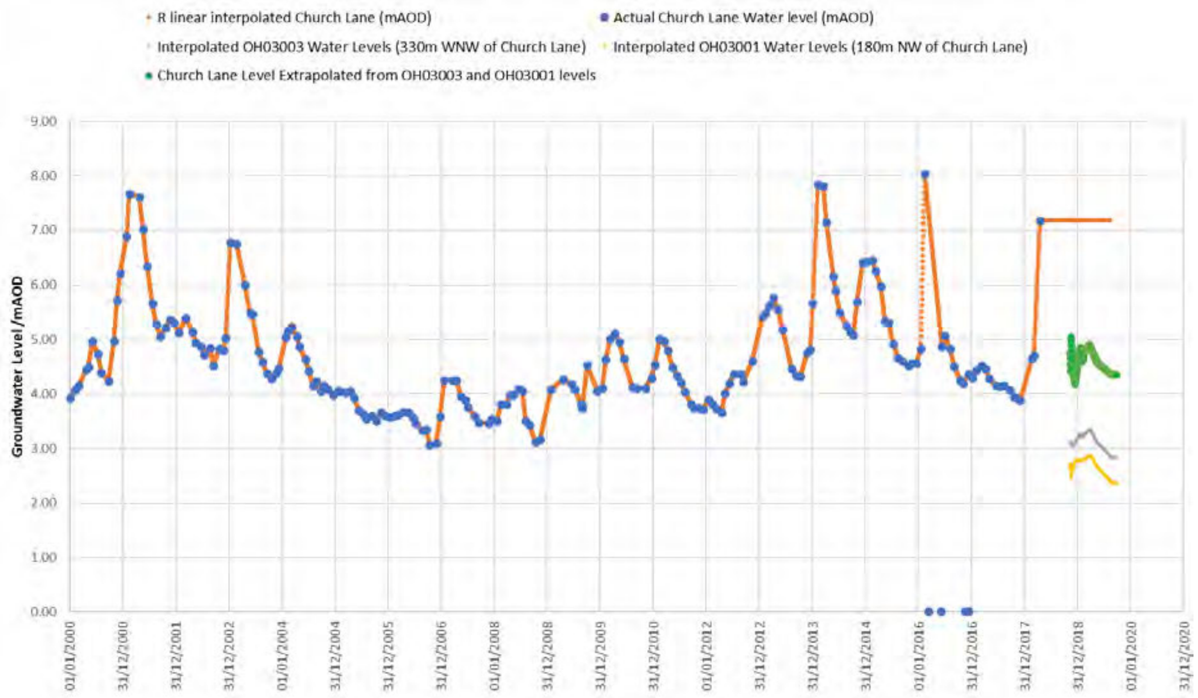


Plate A.3 Locations of ground investigations within or close to the Ramsar study area with vibrating wire piezometer (VWP) installations or dataloggers

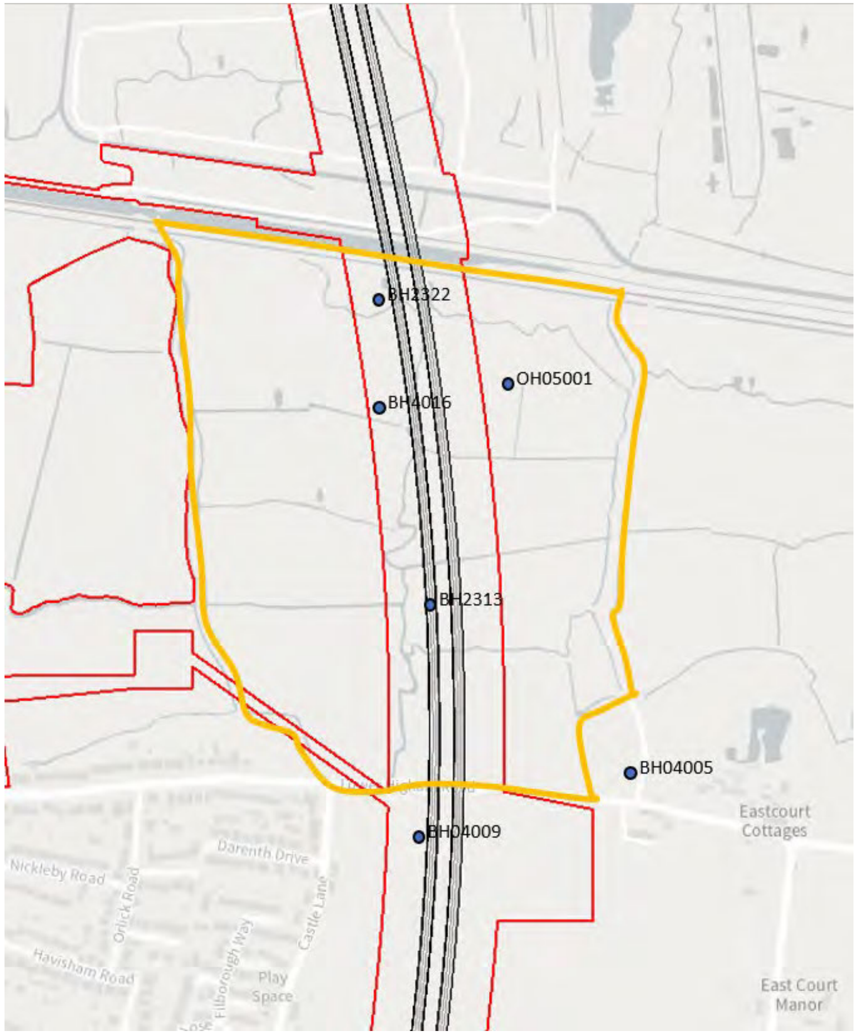
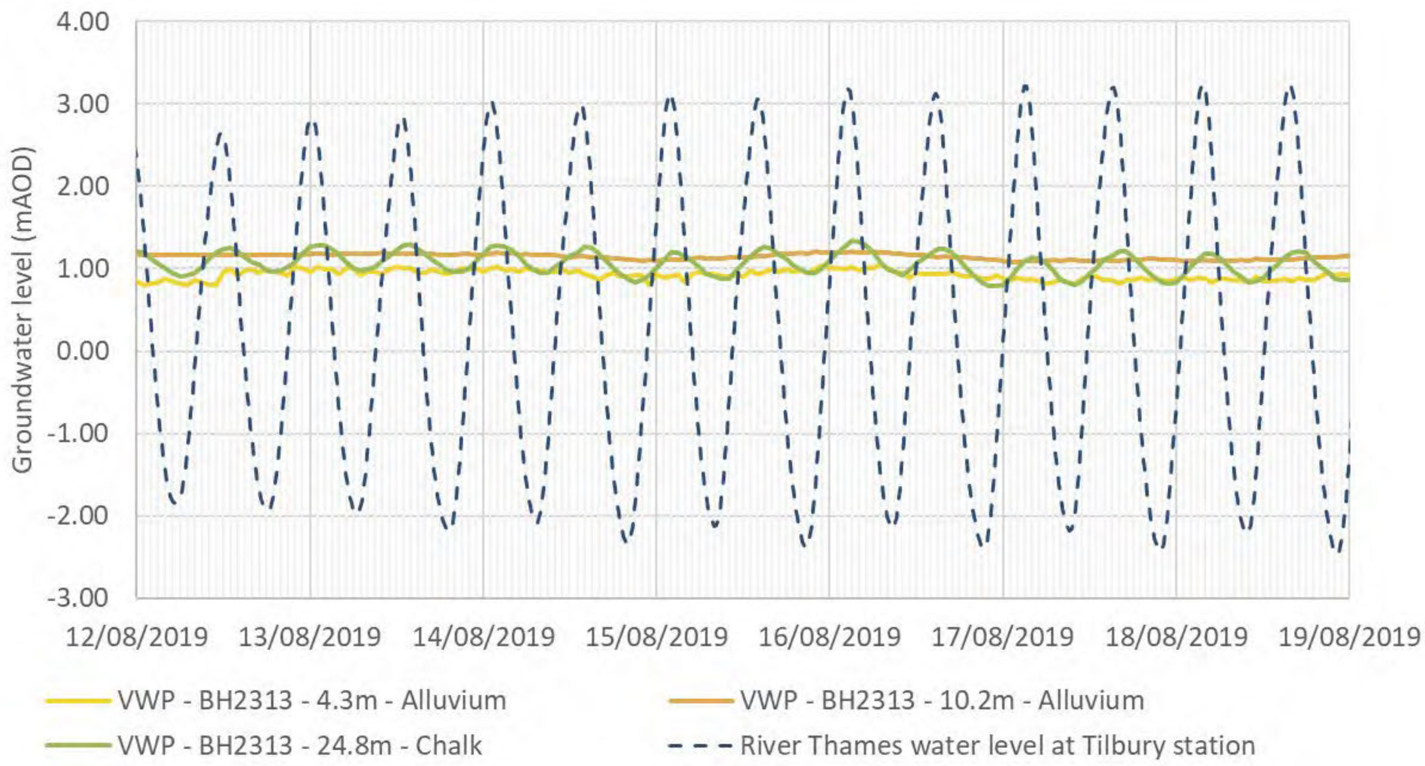


Plate A.4 Representative hydrograph from VWP installation in BH2313 within the study area



A.1.4 Plate A.4 shows groundwater levels from multiple vibrating wire piezometers installed as part of the Phase 2 ground investigation. These confirm observations from manual dip data (Plate A.1) that Chalk and River Terrace Deposit water levels are similar to those in the Alluvium but with an increased tidal response due to higher hydraulic conductivity. This supports the assumption that there is no significant head difference driving a vertical inflow to the Ramsar site.

A.1.5 Hydrographs from OH05001 are not included due to suspected faulty installation and BH04016 not included due to suspected data channel errors which have been queried with the contractor. BH2322 only has a Chalk response zone and is not relevant to comparisons between stratigraphic units.

Annex B Vertical hydraulic connectivity around the Ramsar site

B.1 Background

B.1.1 This annex reports the assessment on the hydraulic vertical connectivity between the Ramsar site, the ground protection tunnel and deeper aquifer system, based on field and laboratory data from ground investigations.

B.2 Methodology

B.2.1 This assessment is mainly based on the Phase 2 ground investigation results (see location of these ground investigations in Plate B.1), comprising the following field and laboratory data:

a. Lithology (borehole logs)

b. Variable head tests (VHTs)

c. Cone penetrometer tests (CPTs)

d. piezocone penetration (CPTu) dissipation tests

e. Groundwater level monitoring

B.2.2 The areal extent of this assessment is determined based on the influence zone of the ground protection tunnel where the natural groundwater regime is predicted to show some level of adverse impact (see Plate B.2 to Plate B.5).

B.2.3 CPT data is processed using the methods outlined in Robertson (2010).

B.2.4 Hydraulic conductivity ranges for the relevant lithologies obtained using the VHT and CPT data are compared with the hydraulic conductivity values used in the groundwater numerical model.

B.2.5 The obtained hydraulic conductivity data (outlined above) is then interpreted together with Phase 2 borehole logs and groundwater levels data, within three main areas of the ground protection tunnel: the Launch Shaft, the Reception Shaft, and the area in between (Mid Tunnel).

B.2.6 The Launch Shaft and Reception Shaft are both outside the limits of the protected Ramsar site (Plate B.2) and outside of the water balance volume. Properties of the Alluvium around the Launch and Reception site have been assessed in order to gauge the amount of lateral variation in conductivity that may be present across the Ramsar.

Plate B.1 Location of Phase 2A ground investigations

Note: CPTu refers to piezocone penetration dissipation tests.

Plate B.2 Cross-section showing the ground protection tunnel and grout blocks

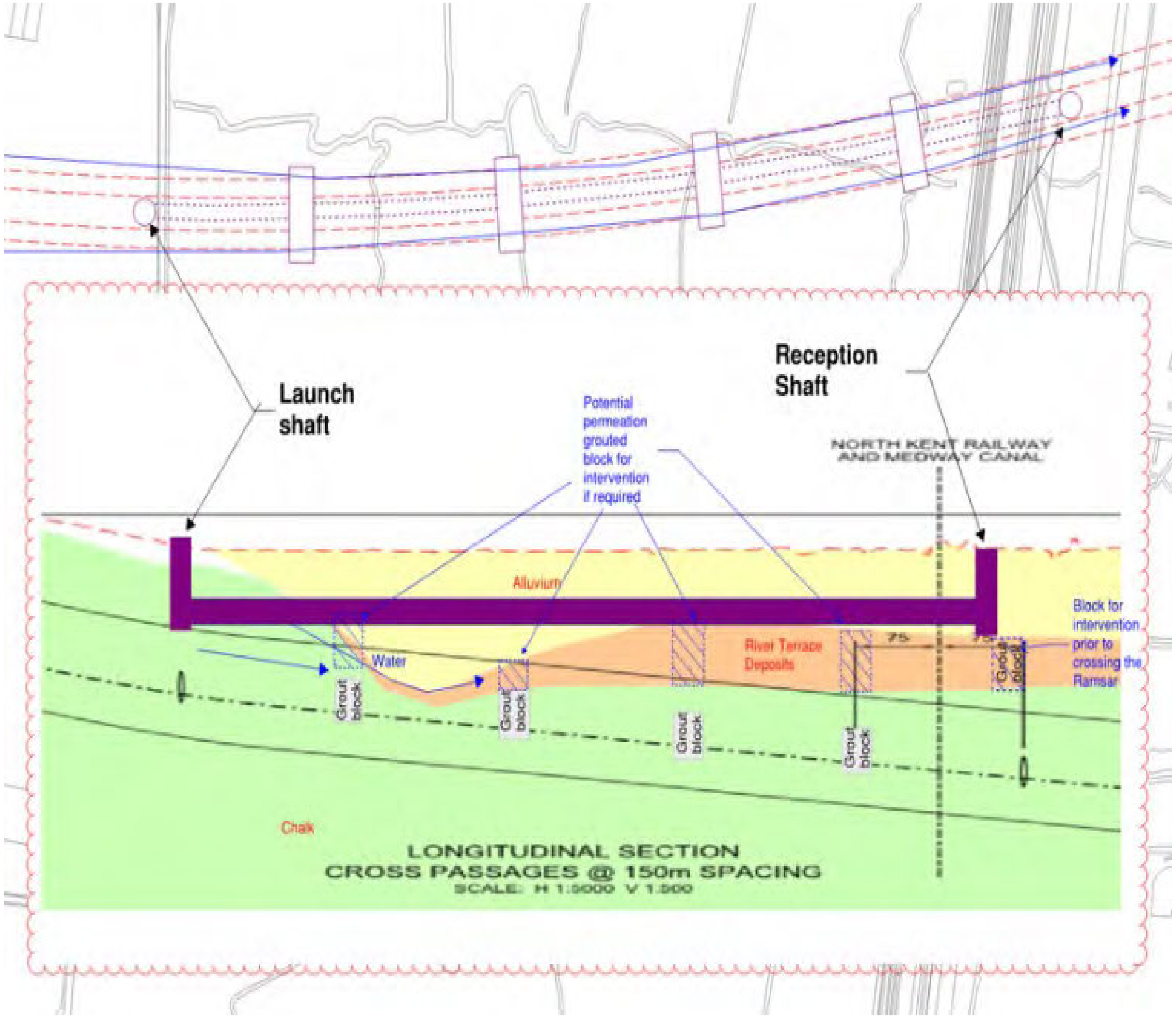


Plate B.3 Ground protection tunnel and main tunnels alignment showing portals and grouting blocks

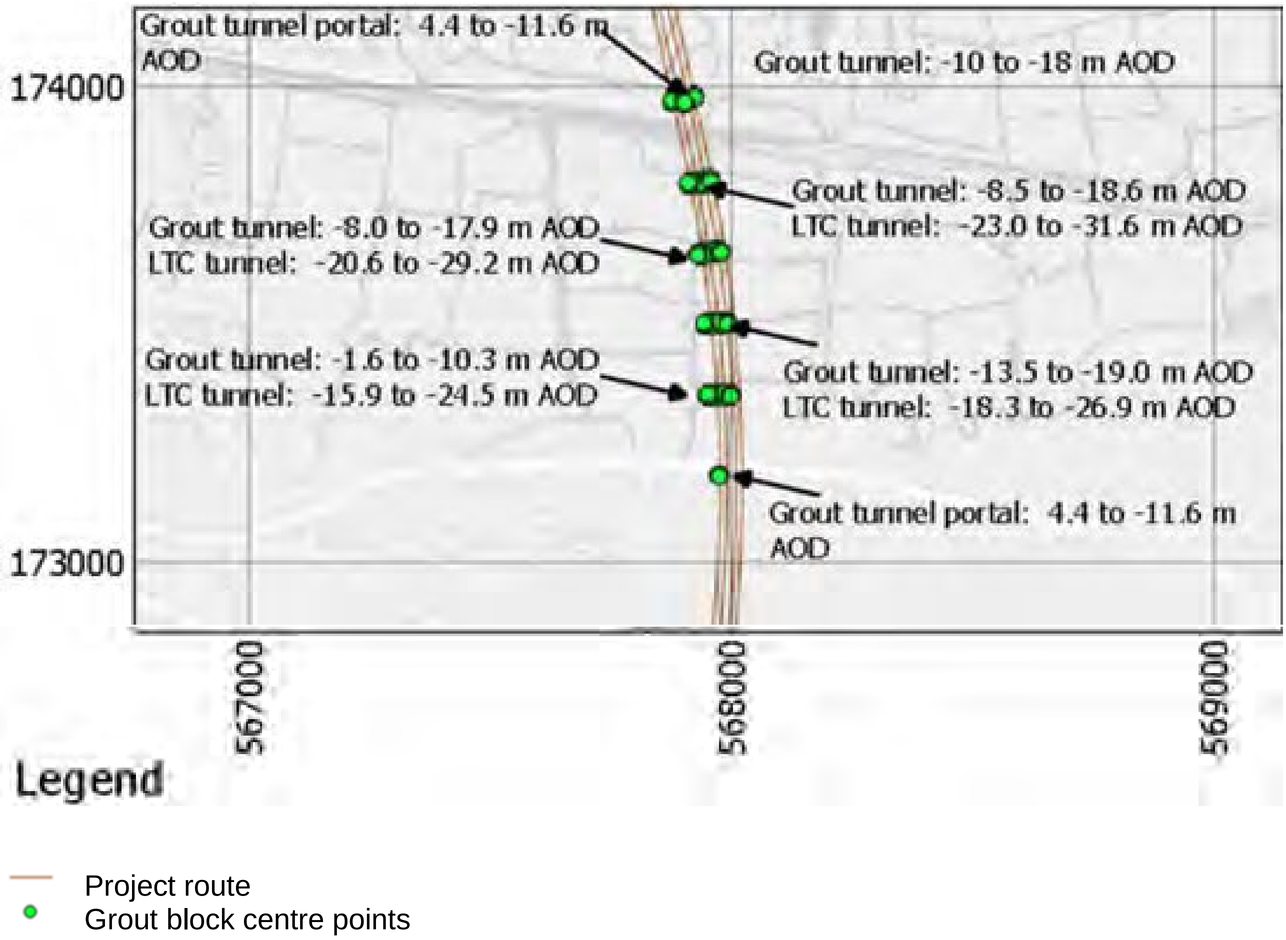


Plate B.4 Drawdown from the ground protection tunnel with inflow rate of 0.1L/s/m²

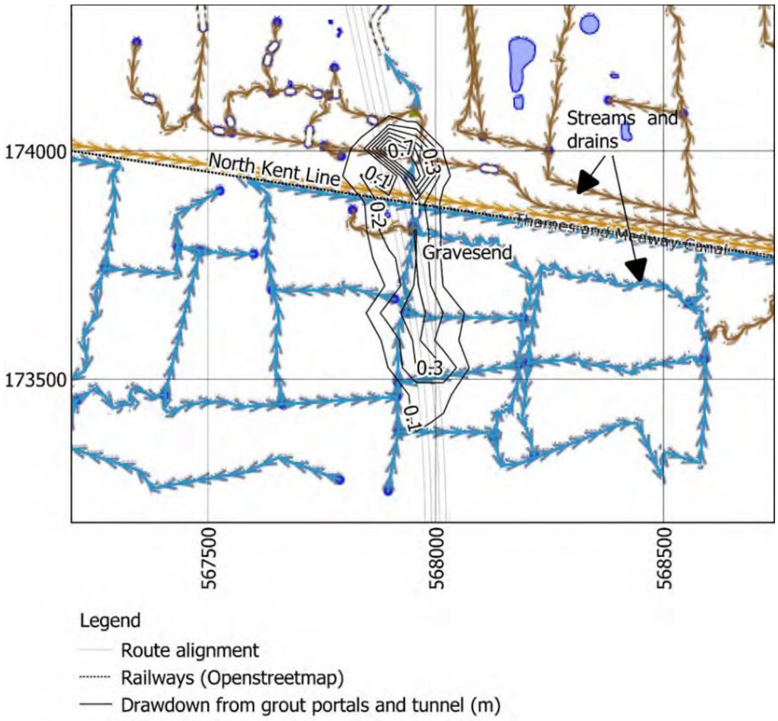
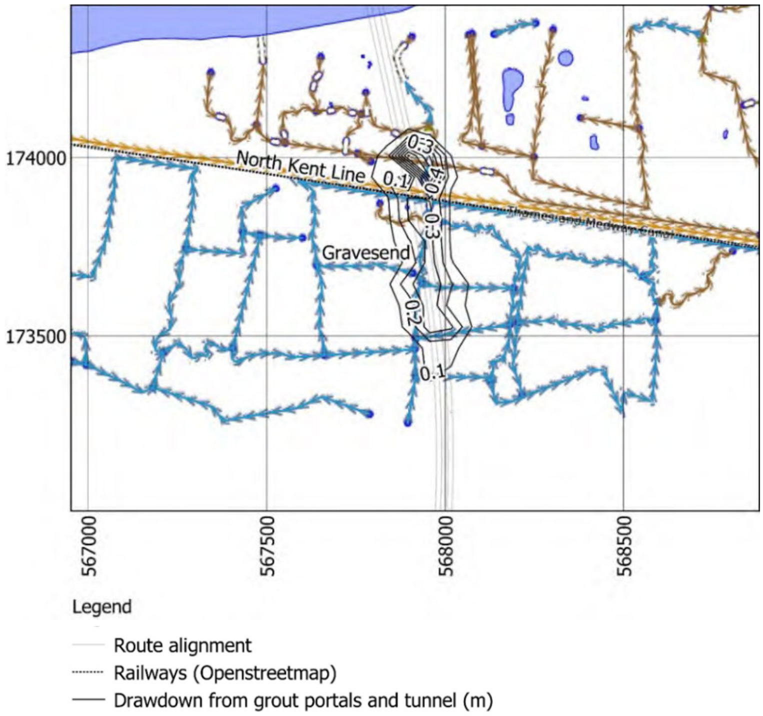


Plate B.5 Drawdown from the ground protection tunnel with inflow rate of 0.5L/s/m²



B.3 Hydraulic conductivity estimates

Hydraulic conductivity estimates from CPTs

B.3.1 Cone penetrometer tests (CPT) were used to estimate the hydraulic conductivity according to two methods, as outlined in the following sections.

Permeability estimates based on CPTu dissipation test

B.3.2 The dissipation of pore pressures during a piezocone penetration (CPTu) dissipation test is controlled by the coefficient of consolidation in the horizontal direction which is directly proportional to the hydraulic conductivity. Various methods allow estimation of hydraulic conductivity (K) using the time for 50% dissipation (t50) from a CPTu dissipation test (Bevan *et al*., 2010).

B.3.3 Only a few dissipation tests were available for the Alluvium. The corresponding K values are presented in Table B.1.

Table B.1 Permeability estimates based on CPTu dissipation test

Borehole ID	CPT test ID	Depth of dissipation test (mbgl)	Strata	Lithology	Area of proposed ground protection tunnel	Hydraulic conductivity (m/s)
BH04004	CT04003	1.50	Alluvium	Sandy gravelly SILT	Launch Shaft	1.5E-08
BH04005	CT04004	2.00	Alluvium	Silty gravelly SAND	Launch Shaft	1.50E-08
BH04015	CT04009	10.29	Alluvium	Silty CLAY	Mid Tunnel	1.20E-08

B.3.4 These limited dissipation test results confirm the Alluvium in the Launch Shaft area to be very low permeability in its shallower portion (0–2 metres below ground level (mbgl)).

Permeability estimates based on soil type

B.3.5 While detailed explanation of this method is included in Bevan *et al*. (2010), in brief, the hydraulic conductivity is estimated as a function of the Soil Behaviour Type (SBT) Index, Ic, which is directly proportional to the normalised cone resistance (Qtn) and the normalised friction ratio (Fr) which are determined with the CPTu tests.

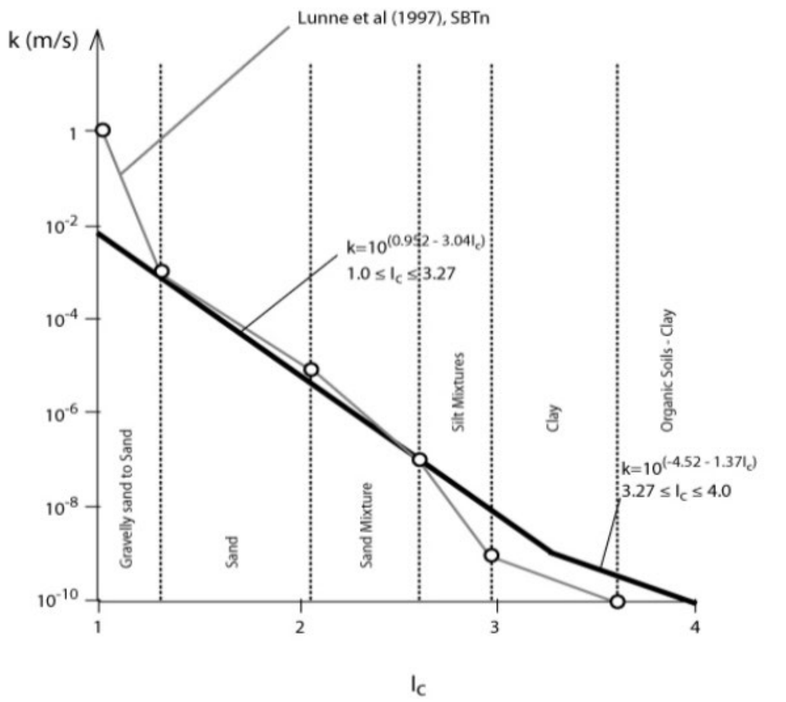
a. $Ic = [(3.47 - \log Qtn)^2 + (\log Fr + 1.22)^2]^{0.5}$

B.3.6 The proposed relationship between hydraulic conductivity (K) and SBT Ic, shown in Plate B.6, can be represented by the following:

a. When $1.0 < Ic \leq 3.27$ $K = 10^{(0.952 - 3.04\, Ic)}$ m/s

b. When 3.27 < Ic < 4.0 K = $10^{(-4.52 - 1.37\ Ic)}$m/s

Plate B.6 Variation of hydraulic conductivity (K) as a function of SBT Ic. (Robertson, 2010)



B.3.7 The equations above can be used to provide an estimate of hydraulic conductivity (K) and to show the variation of soil permeability with depth from a CPT sounding. Since the normalised CPT parameters (Qtn and Fr) respond to the mechanical behaviour of the soil and depend on many soil variables, the suggested relationship between K and Ic is approximate and should only be used as a guide.

B.3.8 Table B.2 summarises the available K estimates from a selection of CPT tests carried out in the three ground protection tunnel areas, together with explanation and interpretation notes. It should be noted that, according to Plate B.6, where Ic is greater or equal to 4, the corresponding estimated K value is assumed to be lower or equal to 1E-10m/s (very low permeability); estimates of K using values of Ic greater than 4 are unrealistically low.

Table B.2 Summary of K estimates results in Alluvium (from CPT tests)

CPT ID	BH ID	Area	Geology	Layer depth (mbgl)	Layer thickness (m)	CPTu test extent	Interval(s) where Ic<=4 (K>= 1E-10) (mbgl)	Hydraulic conductivity K (m/s) geometric mean	Notes
CT04003	BH04004	Launch Shaft	TOPSOIL/ALV	0.0–2.20	0.20	0.0–15.0	0–0.20 CLAY	6.5E-08	For most of their layer thickness, ALV and K are relatively low.
					1.46		0.74–2.2 SAND and SILT	4.5E-06	
CT04004	BH04005	Launch Shaft	HEAD/ALV	0.0–7.8	7.80	0.0–13.52	0.0–0.70 CLAY	7.2E-07	ALV is of low K for the majority of the layer.
							1.00–1.84 SAND	2.7E-06	
							1.92–5.14 SAND, GRAVEL, CLAY	3.4E-10	
							7.48–7.62 CLAY	1.8E-08	
CT04001	BH04014	Mid Tunnel East	TOPSOIL/ALV	0.0–21.90	21.90	0.0–4.04	0.0–0.30 CLAY	5.4E-08	Alluvium generally of very low permeability.
							3.20–3.94 CLAY and GRAVEL	1.1E-05	
CT04011	BH04017	Mid Tunnel West	TOPSOIL/ALV	0.0–15.10	15.10	0.0–14.76	0.0–0.2 CLAY	5.6E-08	Alluvium generally

CPT ID	BH ID	Area	Geology	Layer depth (mbgl)	Layer thickness (m)	CPTu test extent	Interval(s) where Ic<=4 (K>= 1E-10) (mbgl)	Hydraulic conductivity K (m/s) geometric mean	Notes
							14.42–14.68 CLAY	1.1E-08	very low permeability.
CT04002	BH04013	Mid Tunnel	TOPSOIL/ALV	0.0–17.90	17.90	0.0–17.92	0.0–0.8 CLAY	6.0E-07	The thick Alluvium at this location is of relatively low permeability.
CT04010	BH04016	Mid Tunnel	TOPSOIL/ALV	0.0–13.0	13.00	0.0–15.0	0.0–0.58 CLAY	3.2E-06	Alluvium generally very low permeability (K less than 1E-10m/s) apart from the top portion.
							10.3–10.72 Clayey GRAVEL	3.9E-09	
CT04013	BH04020	Reception Shaft	TOPSOIL/ALV	0.0–14.10	14.10	0.0–15.36	0.0–0.34 CLAY	4.8E-07	Alluvium generally very low permeability (K less than 1E-10), apart from very

CPT ID	BH ID	Area	Geology	Layer depth (mbgl)	Layer thickness (m)	CPTu test extent	Interval(s) where Ic<=4 (K>= 1E-10) (mbgl)	Hydraulic conductivity K (m/s) geometric mean	Notes
									superficial portion.
CT04012	BH04019	Reception Shaft	TOPSOIL/ALV	0.0–10.15	10.15	0.0–14.58	1.2–10.12 organic CLAY	<1E-10	CPT test failed up to 1.2mbgl. Alluvium generally very low permeability (K less than 1E-10m/s).
CT04014	BH05001	Reception Shaft	TOPSOIL/ALV	0.0–13.80	13.80	0.0–13.76	0.0–0.76 CLAY	2.9E-07	Alluvium generally very low permeability (K less than 1E-10), apart from very superficial portion, slightly more permeable but still low K.
							13.64–13.64 CLAY	4.80E-10	

Note: TOPSOIL/ALV is abbreviation for undefined topsoil or Alluvium strata; HEAD/ALV is abbreviation for undefined Head or Alluvium strata. Ic represents Soil Behaviour Type (SBT) Index and has been used to estimate hydraulic conductivity (K)

B.3.9 The overall summary of Alluvium K estimated results based on CPT tests is as follows:

a. Launch Shaft – The top portion (up to 2m) shows relatively low K values of 1E-06m/s to 1E-08m/s; however, where the strata has significant thickness, K values decrease significantly (1E10-8m/s to less than 1E-10m/s).

b. Mid Tunnel – generally very low permeability (K less than 1E-09m/s), with a superficial portion (up to 0.8m) with K values in the order of 1E-06m/s to 1E-08m/s and one lens with K values in the order of 1E-05m/s.

c. Reception Shaft – generally, very low permeability (K less than 1E-10m/s) apart from the top portion (less than 0.5m) with K around 1E-07m/s.

Permeability estimates from variable head tests

B.3.10 Only one VHT is available in the ground protection tunnel area at BH05002, located at the Mid Tunnel (West) area in the Alluvium (Plate B.1). The hydraulic conductivity was measured to be 8.06E-08m/s between 8.0mbgl and 10.0mbgl in a silty CLAY with frequent pockets of peat.

B.4 Discussion

B.4.1 Considered all together, the K estimates from the CPTs and VHT presented in the previous sections for the three ground protection tunnel areas can be summarised as follows:

a. **Launch Shaft:** In this area, the Alluvium appears to be very heterogeneous, with a wide range of K between 1E-06m/s to less than 1E-10m/s. This supports use of the literature values (1E-08m/s to 1E-07m/s); the initial assumption for K in the groundwater model (Annex J).

b. **Mid Tunnel:** In this area, the Alluvium overall confirms its fairly low conductivity of between 1E-10m/s and 1E-08m/s, and it appears to be less heterogeneous and of lower conductivity than in the Launch Shaft area.

c. **Reception Shaft:** In this area, the Alluvium K value is overall of low hydraulic conductivity. CPT tests suggest very low K (1E-10m/s). Borehole logs confirm the presence of abundant very low permeability deposits (silt, clay), confirming the suitability of CPT tests estimates. K values support the suitability of the values used in the numerical model and water balance.

Annex C Remote imaging data

C.1 Methodology

C.1.1 Imagery from Sentinel-2 optical satellite (European Space Agency, 2019) for two representative years with extended dry periods was visually analysed to qualitatively determine whether vegetation across the Ramsar site shows signs of moisture stress during dry conditions. Datasets with a resolution of 10m to 20m were analysed using Normalized Difference Vegetation Index (NDVI) and Moisture Stress Index (MSI) (Weier and Herring, 2000) during pre-dry (May to July), driest period (July to August) and post-dry conditions (September to November) for 2016 and 2018.

C.2 Normalised Difference Vegetation Index

C.2.1 NDVI is the most widely used vegetation index and normalises green leaf scattering (near infra-red) and chlorophyll absorption (red) and can be used to indicate the presence of grassland as opposed to barren rock or soil. In both dry years (Plate C.1 and Plate C.2), the NDVI indicates a reduction in chlorophyll content between the pre-dry and dry period, but continued shrub or grassland coverage throughout the driest period with no evidence for barren conditions in areas of the Ramsar site within 3km of the Project route. Recovery from dry period conditions is slow, with post-dry period NDVI values notably lower than pre-dry conditions.

C.3 Moisture Stress Index

C.3.1 MSI is a measurement of reflectance which is sensitive to increasing leaf water content, where higher values indicate greater water stress. In both dry years (Plate C.3 and Plate C.4), the data from pre-dry conditions indicates low water stress across the Ramsar site within 3km of the Project route. MSI generally increases during the driest period but remains within typical values for green vegetation, and in both years the MSI is highest during the post dry period.

Plate C.1 NDVI imagery from 2016 dry period. (A) Pre-dry period – 06/07/2016; (B) Driest period – 08/12/2016; (C) Post-dry period – 30/11/2016; (D) 2016 daily rainfall records with arrows indicating date of each image

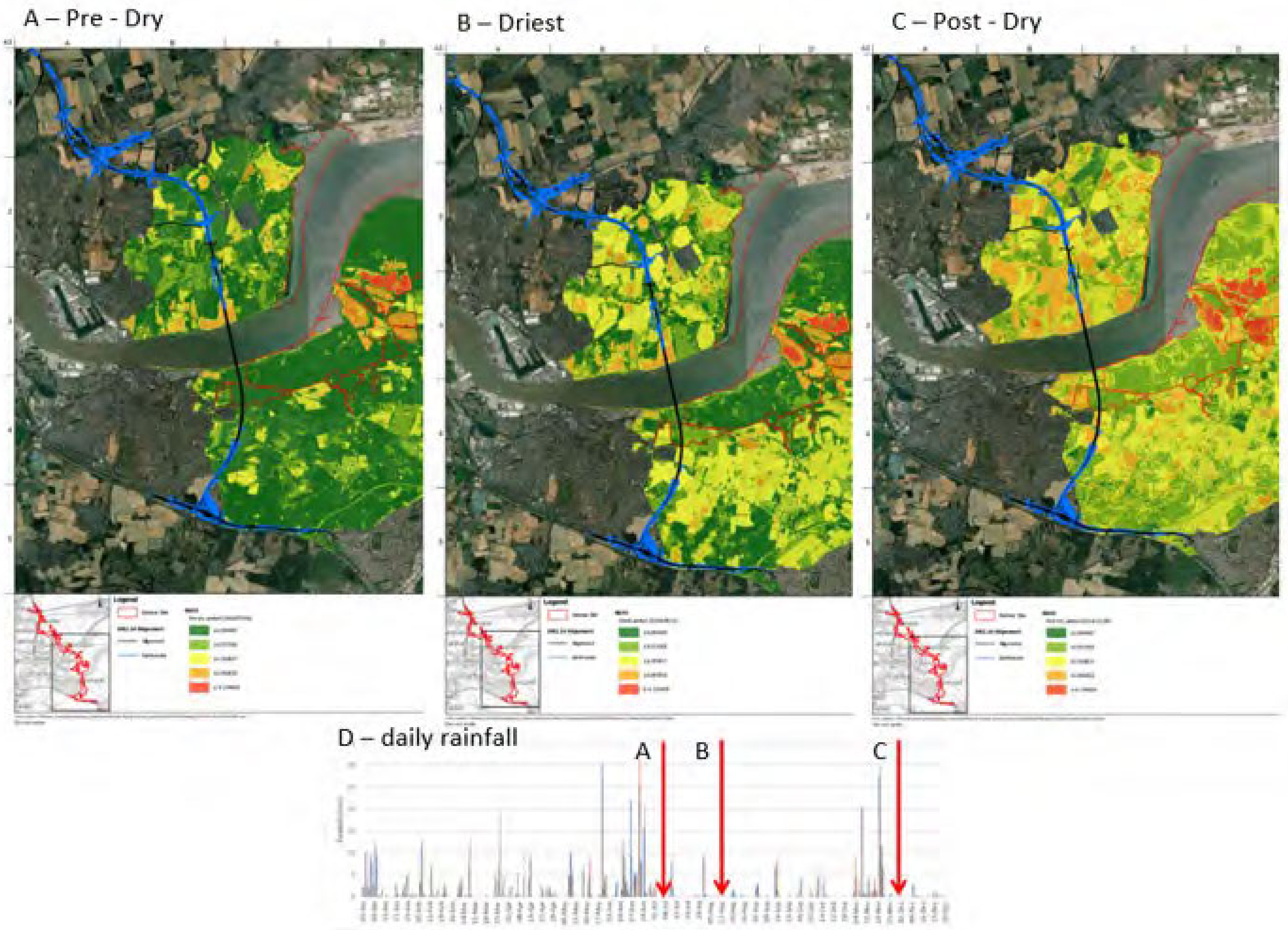


Plate C.2 NDVI imagery from 2018 dry period. (A) Pre-dry period – 19/05/2018; (B) Driest period – 13/07/2018; (C) Post-dry period – 26/09/2018; (D) 2018 daily rainfall records with arrows indicating date of each image

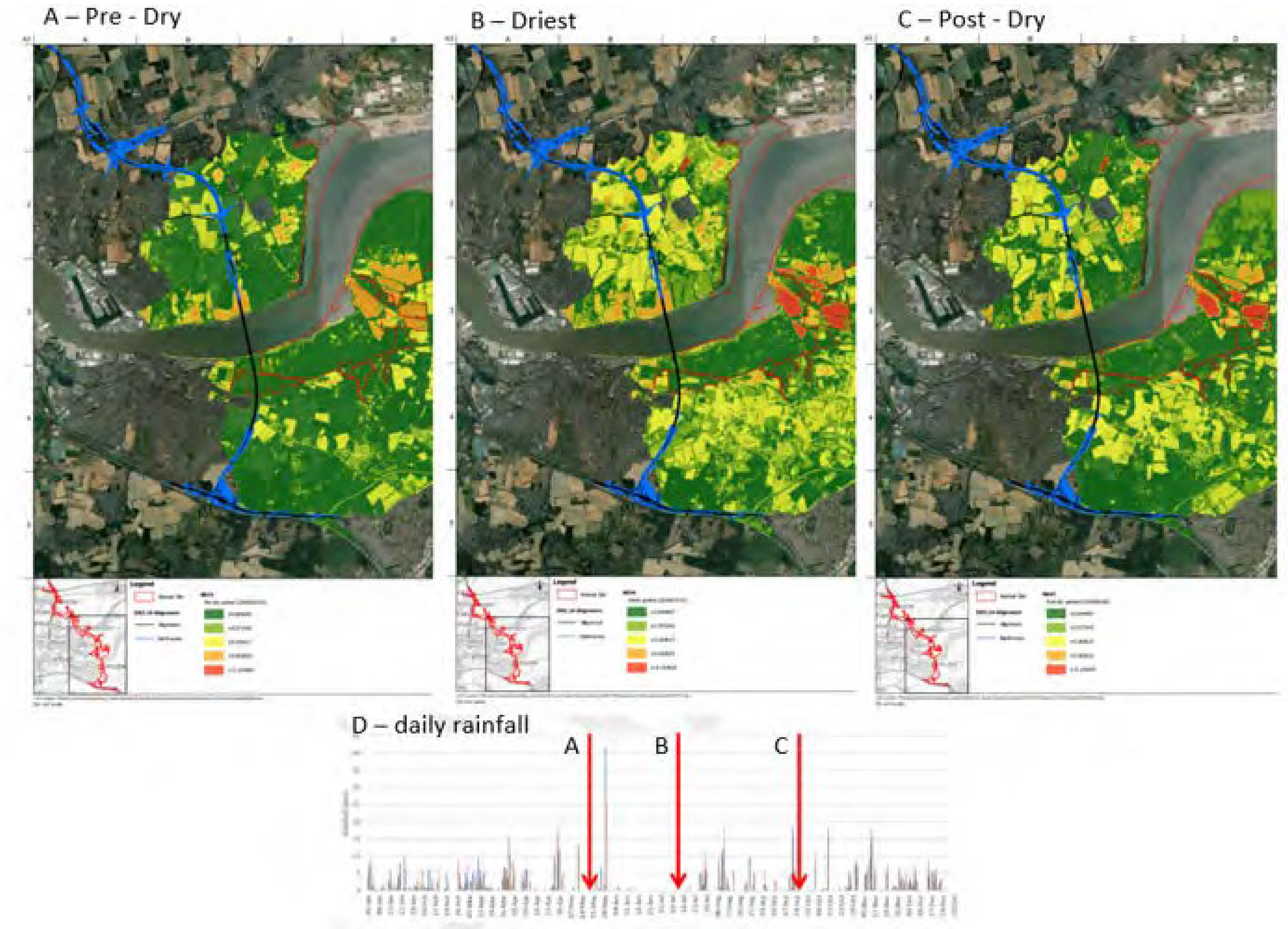


Plate C.3 MSI imagery from 2016 dry period. (A) Pre-dry period – 06/07/2016; (B) Driest period – 08/12/2016; (C) Post-dry period – 30/11/2016; (D) 2016 daily rainfall records with arrows indicating date of each image

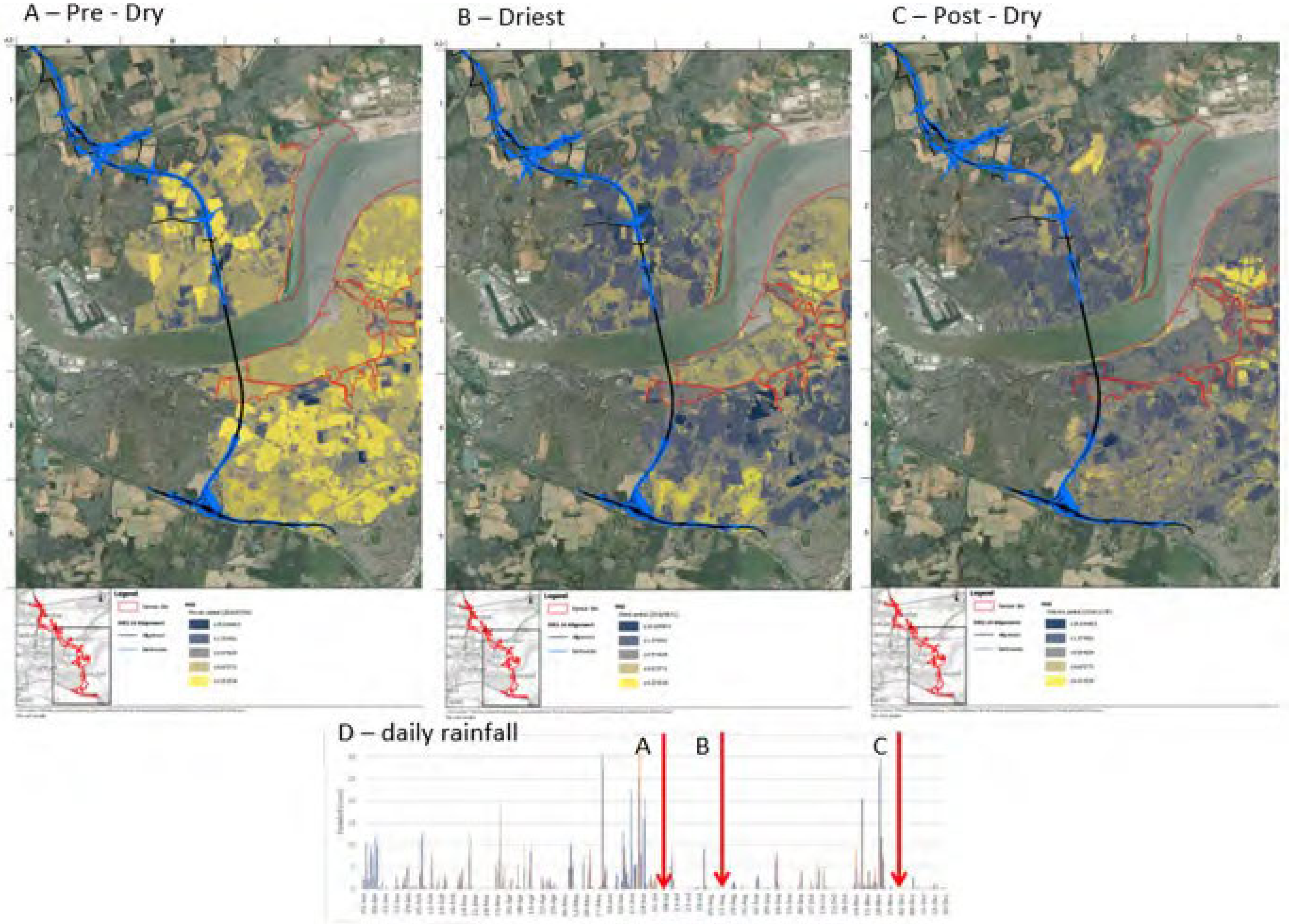
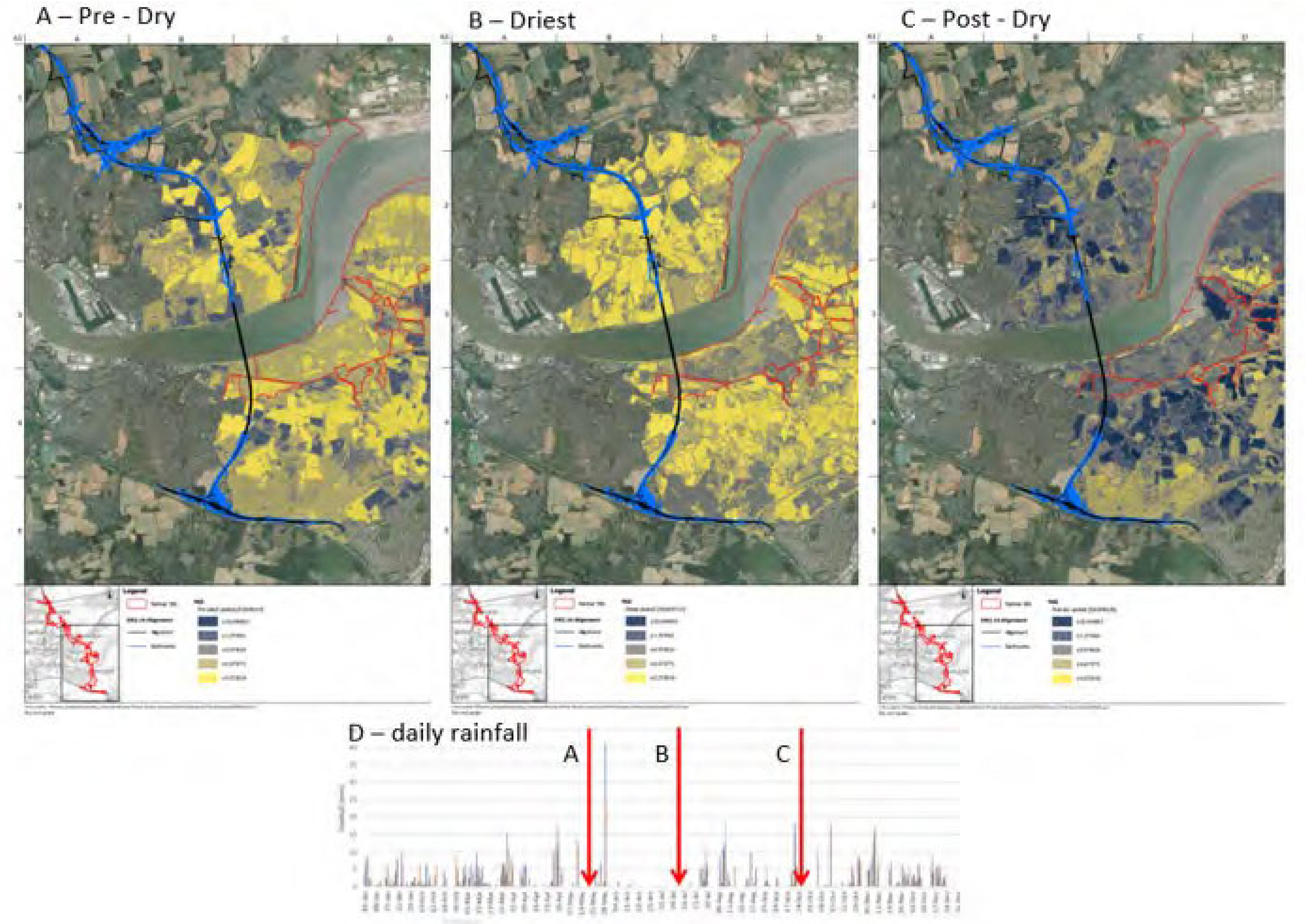


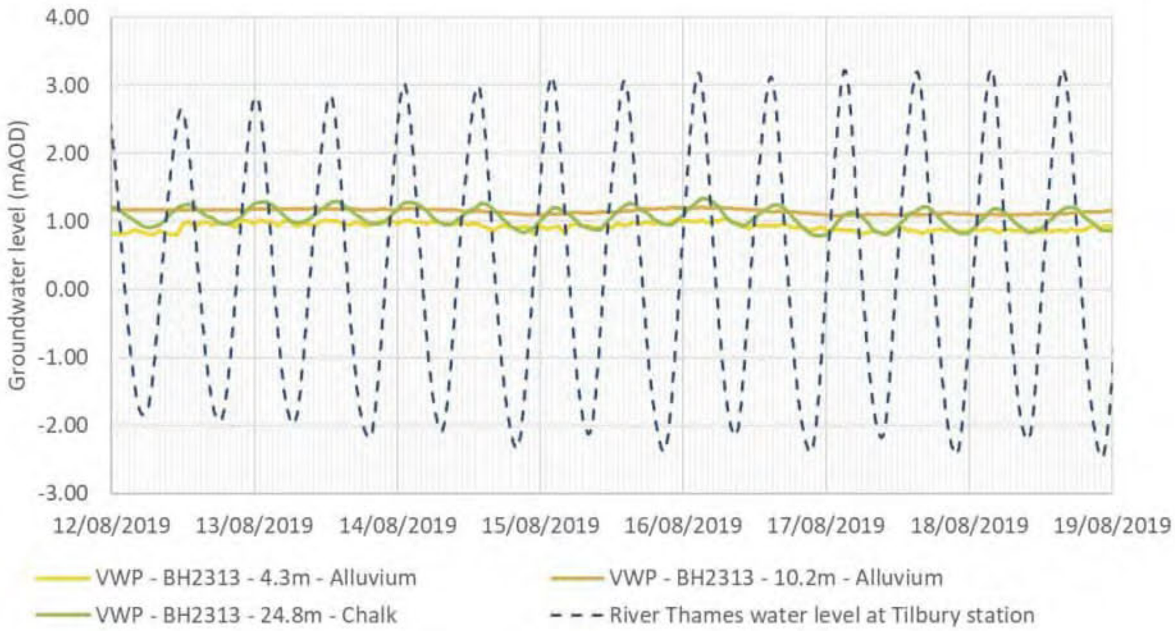
Plate C.4 MSI imagery from 2018 dry period. (A) Pre-dry period – 19/05/2018; (B) Driest period – 13/07/2018; (C) Post-dry period – 26/09/2018; (D) 2018 daily rainfall records with arrows indicating date of each image



Annex E Groundwater-level data summary – Ramsar site

Annex E Groundwater level data summary – Ramsar site

Plate 1.1 Representative tidal hydrograph from BH2313 showing multiple strata and River Thames tidal water levels



VWP = Vibrating wire piezometer

Plate 1.2 Representative tidal hydrograph from BH2322 diver showing Chalk water levels and River Thames tidal water levels

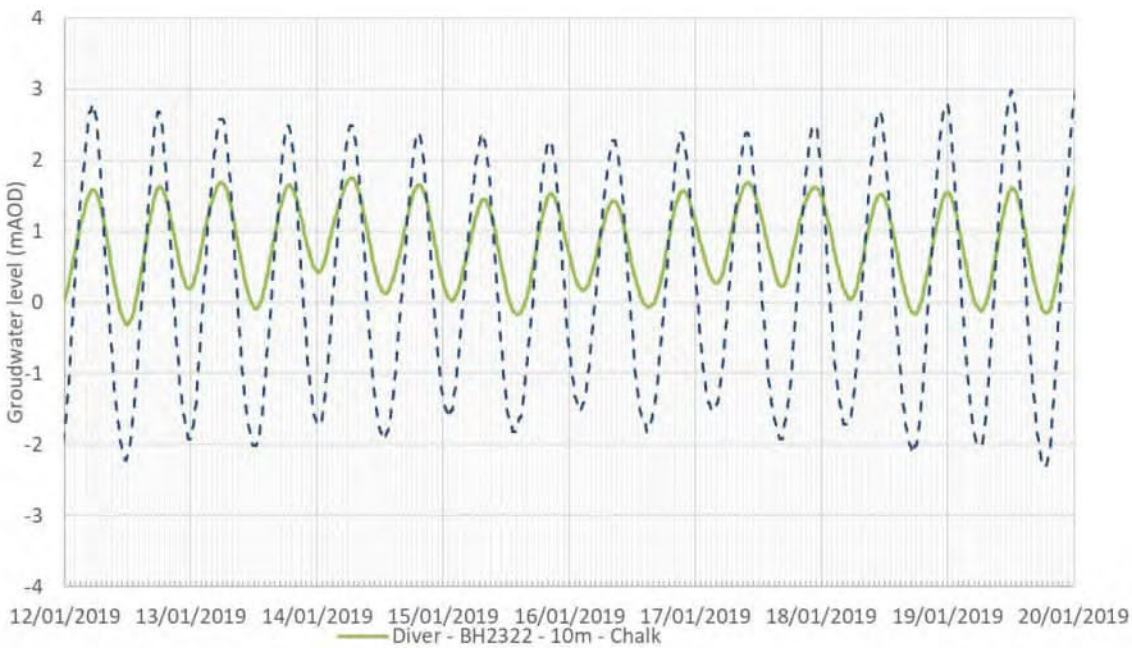
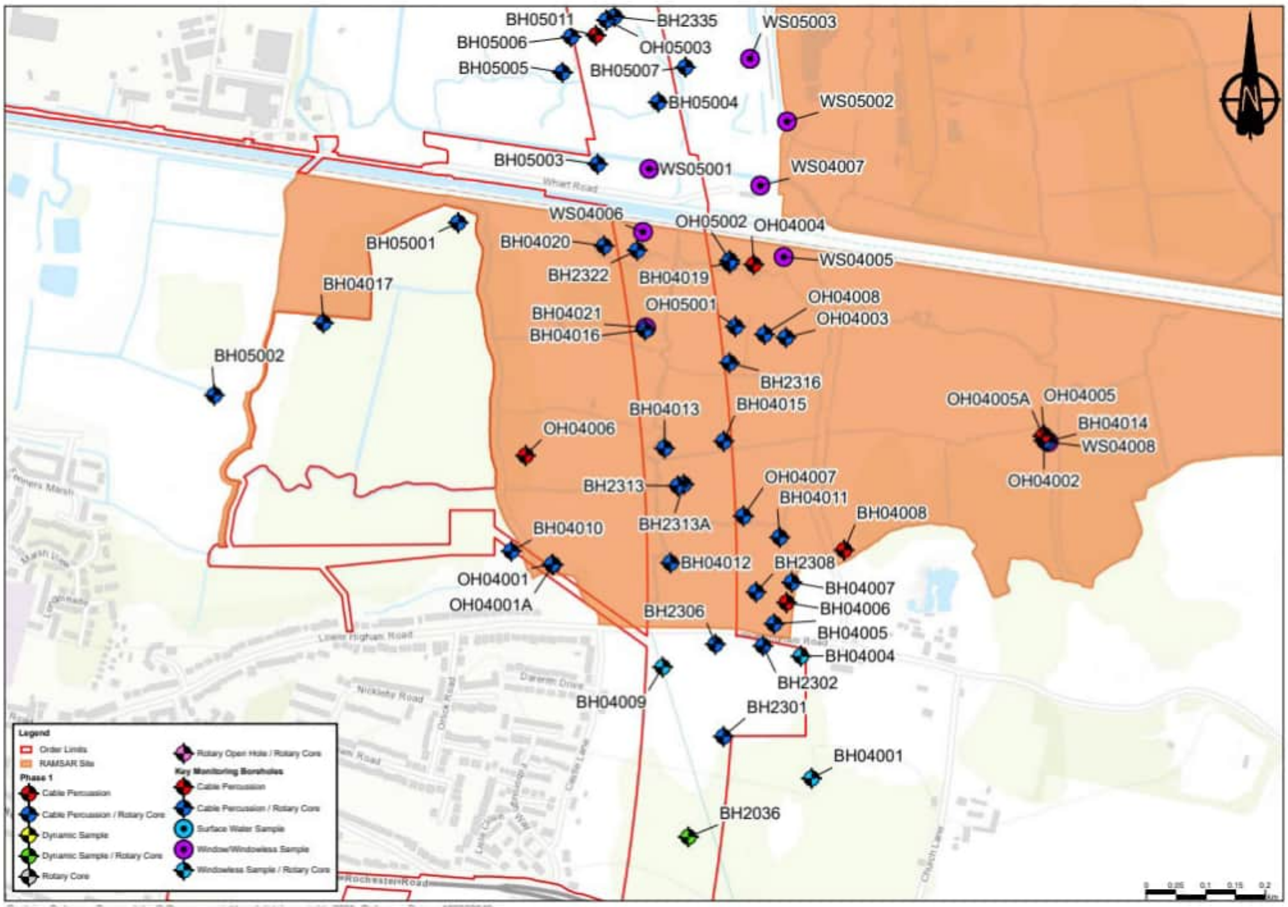


Plate 1.3 Map of Ramsar site showing locations of key monitoring boreholes



Notes: Order Limits shown in red, Ramsar area (that is within the Order Limits) is shown in yellow. Upgradient monitoring boreholes (Table 3.1 of Appendix 14.5: Hydrogeological Risk Assessment) in blue. All other boreholes within the Ramsar area (or considered representative of hydraulic conditions within the Ramsar area) in green.

Table 1.1 Summary of borehole groundwater levels at the Ramsar site

Borehole	Groundwater levels				
	Geomean mAOD	Mean mAOD	Max. mAOD	Min. mAOD	n
Shallow Alluvium < -5 mAOD					
BH04006	1.83	1.85	2.33	1.62	7
BH04007	1.42	1.43	1.84	1.30	8
BH04008	1.45	1.52	2.07	0.70	8
WS04005	1.04	1.11	1.58	0.45	10
WS04006	1.42	1.42	1.55	1.32	8
WS04007*	0.85	0.93	1.28	0.25	8
WS05001*	0.83	0.98	1.47	0.12	8
BH2313	NA	1.86	2.47	0.65	VWP
BH04005*	NA	2.45	2.97	1.69	VWP
Deep Alluvium > -5 mAOD					
BH05002*	1.30	1.31	1.49	1.21	4
BH2313	NA	1.82	2.39	1.08	VWP
River Terrace Deposits					
BH04013	1.24	1.34	2.05	0.58	9
WS04008*	1.01	1.05	1.63	0.70	9
BH04019	1.08	1.28	2.35	0.23	8
BH2316_1	0.62	0.87	2.03	0.12	43
OH04006	1.10	1.24	1.98	0.11	30
OH04005A	1.50	1.51	1.67	1.09	20
OH04005	1.32	1.33	1.51	1.14	9
OH04004	1.02	1.21	2.24	0.15	30
BH04021	0.79	0.83	1.23	0.56	8
BH04016	NA	1.44	3.08	-0.84	VWP
Chalk aquifer					
BH04012	1.72	1.72	1.98	1.61	6
BH04010	1.54	1.55	2.00	1.25	11
BH04011	1.66	1.67	1.90	1.25	7
BH04014*	1.35	1.40	1.81	0.85	9
BH04015	1.07	1.18	1.54	0.40	6
BH04017*	0.86	1.02	1.90	0.22	7
BH04020	1.29	1.38	2.00	0.50	9
BH05003*	0.83	1.12	2.00	0.06	13

Borehole	Groundwater levels				
	Geomean mAOD	Mean mAOD	Max. mAOD	Min. mAOD	n
BH2322	0.48	0.79	2.14	0.04	36
OH04001A	1.83	1.83	2.02	1.68	26
OH04007	1.75	1.76	2.02	1.39	29
OH04002	1.44	1.48	1.92	0.87	30
OH04003	0.76	0.98	1.85	0.15	31
OH04008	0.99	1.16	2.18	0.16	30
PW04001A	0.24	0.24	0.24	0.24	1
OH05002	0.75	0.94	1.95	0.10	29
BH2316_2	0.65	0.86	2.07	0.15	43
BH2313	NA	1.73	2.38	0.79	VWP
BH04005 (CKD)*	NA	1.93	2.56	1.31	VWP
BH04005 (CKABC)*	NA	1.04	1.62	0.45	VWP
BH04016 (CKD)	NA	0.70	2.33	-1.49	VWP
BH04016 (CKABC)	NA	0.78	2.30	-1.28	VWP

Notes:
* indicates boreholes that are to the east or west of the Ramsar but are considered representative of hydraulic conditions within the Ramsar area.
'NA' is 'not applicable'.
'Min.', 'Max.' are 'minimum' and 'maximum' respectively. 'Mean' is representative of the arithmetic mean, and 'geomean' is the geometric mean.
'mAOD' is 'metres above ordnance datum'.
'VWP' is a 'vibrating wire piezometer'.
'Shallow Alluvium' and 'deep Alluvium' refer to nominal depth of -5mAOD used to group readings, 'CKD' refers to 'weathered Chalk' (CIRIA grade D); 'CKABC' refers to 'structured Chalk' (CIRIA grades A, B or C).
'n' shows the number of readings. Monitoring periods of some boreholes vary. The 'n' value indicates the approximate duration of the monitoring period. Locations with n>35 have typically been monitored between October 2017 and August 2019, n>25 between October 2018 and August 2019, and n>15 between September 2019 and January 2020.
Data represents a mixture of manually dipped water levels, data logger monitored standpipes and vibrating wire piezometers. BH04016 is not included because the data is not valid.

Annex F Groundwater quality data summary – whole study area

Annex F Groundwater quality data summary – whole study area

Plate 1.1 Piper plot – Chalk aquifer – south of the River Thames

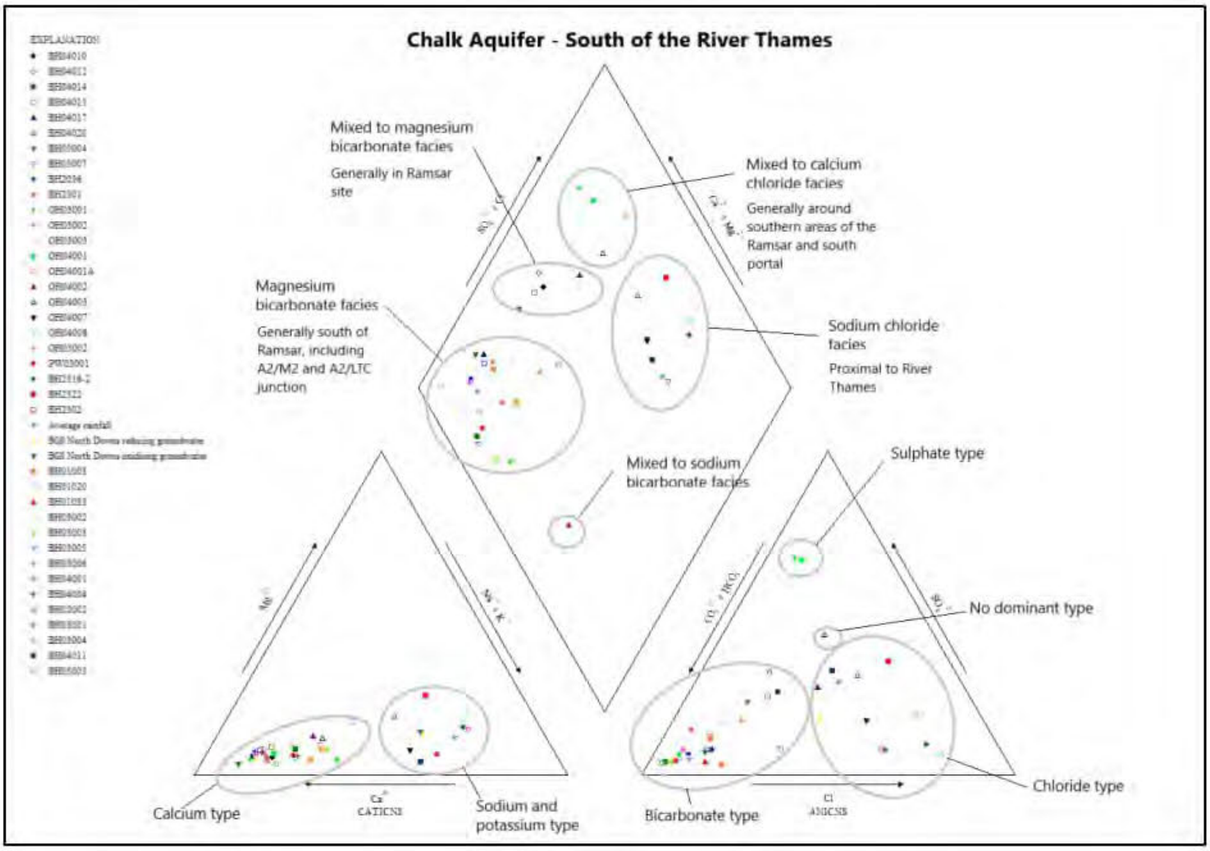


Plate 1.2 Piper plot – Chalk aquifer – north of the River Thames

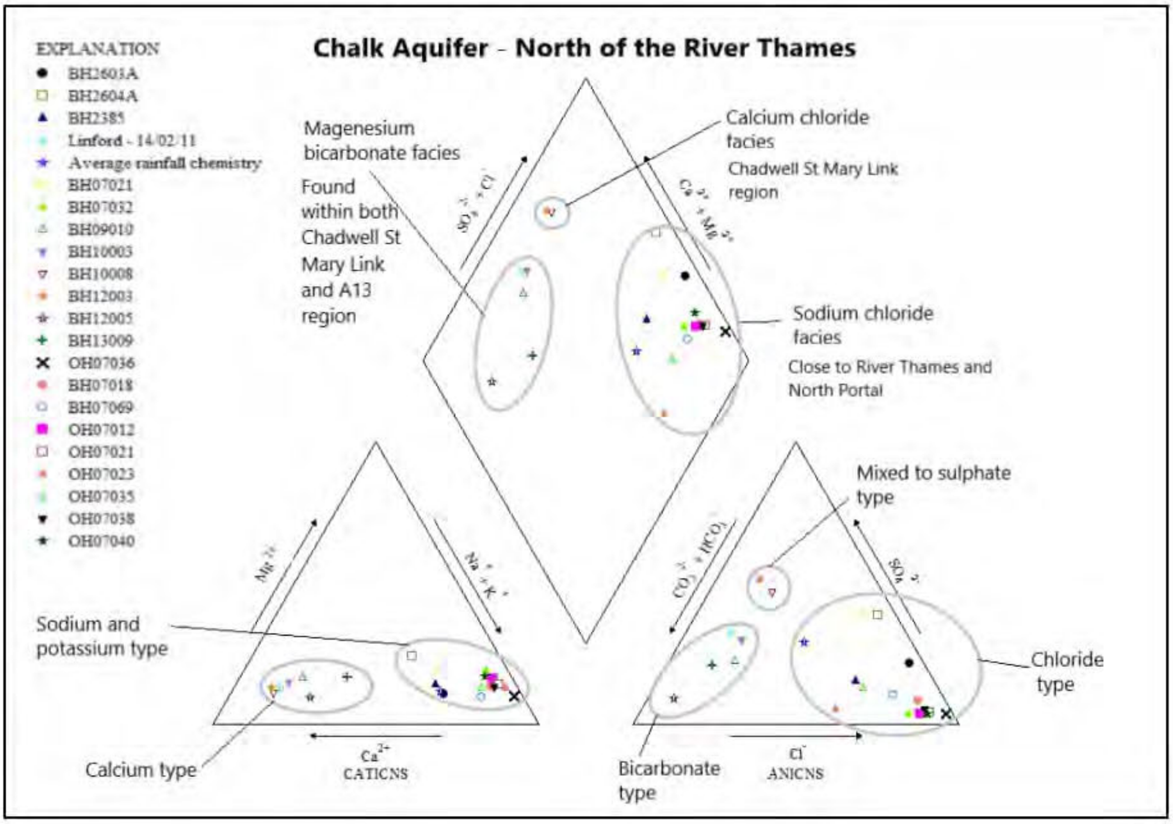
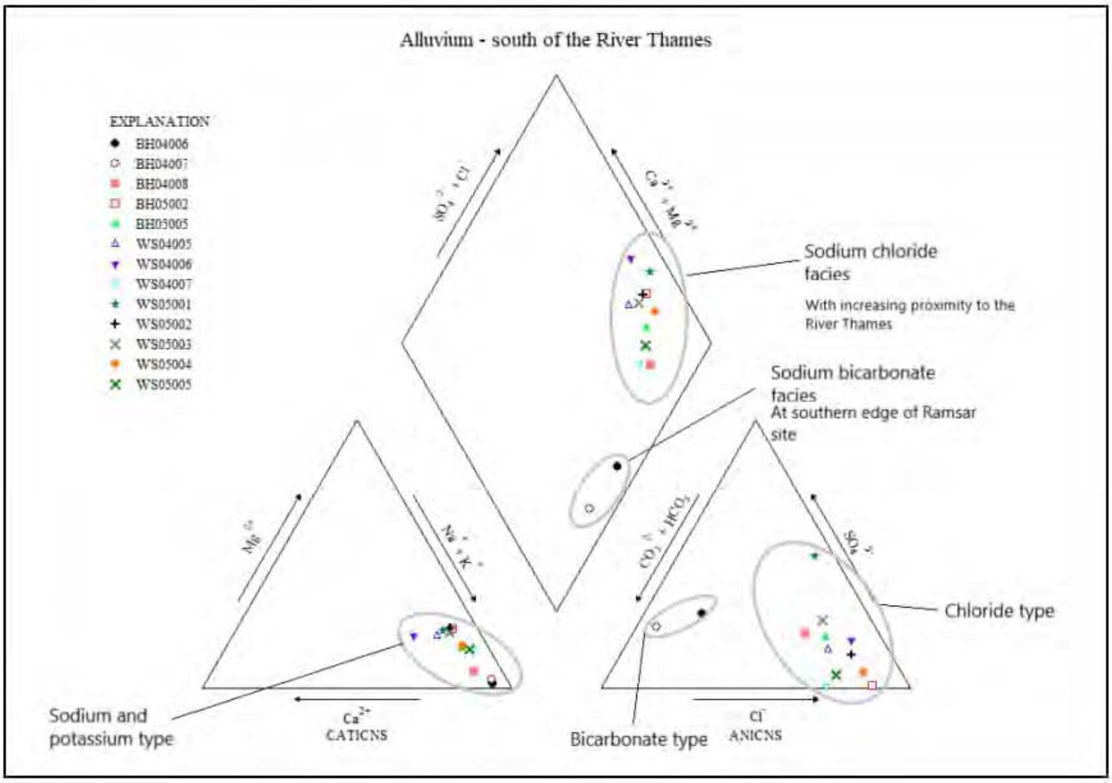


Plate 1.3 Piper plot – Alluvium – south of the River Thames



** Note: Alluvium strata refer to the Alluvium at Filborough Marshes between Lower Higham Road and the bank of the River Thames.

Plate 1.4 Piper plot – Alluvium – north of the River Thames

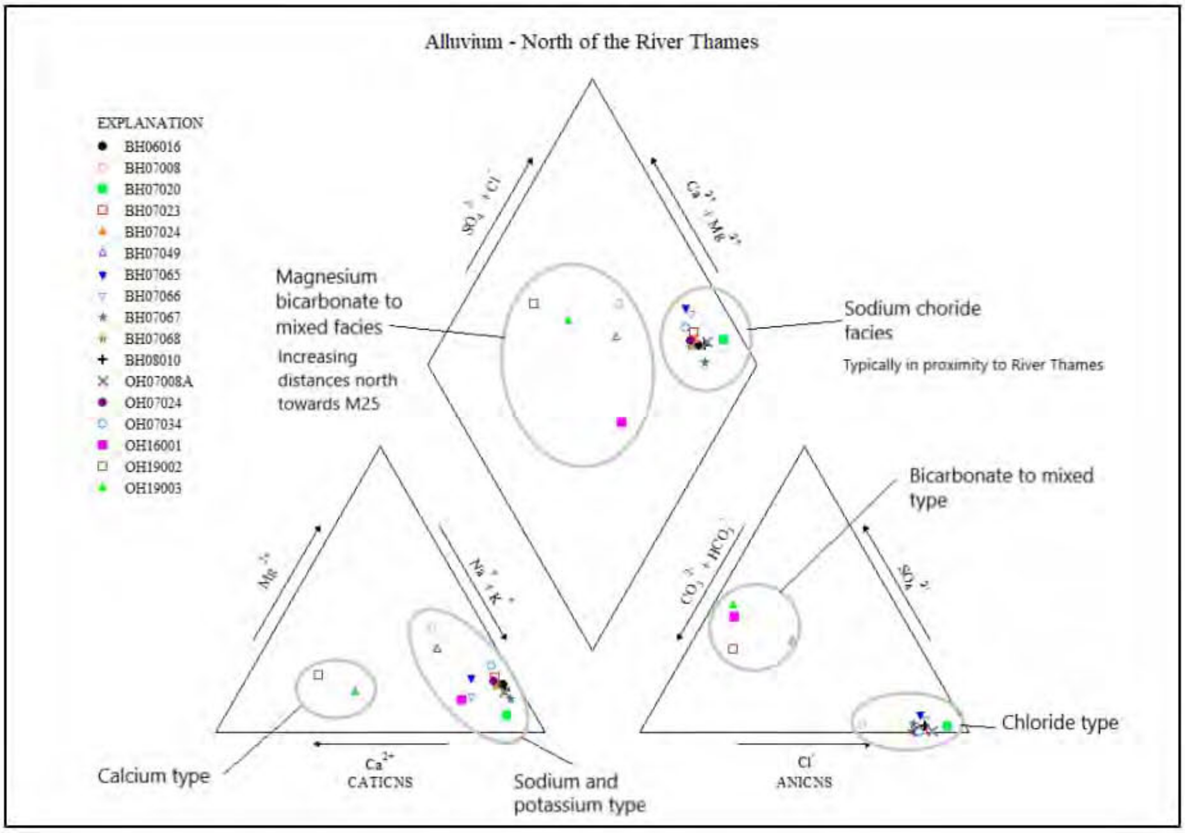


Plate 1.5 Piper plot – River Terrace Deposits – south of the River Thames

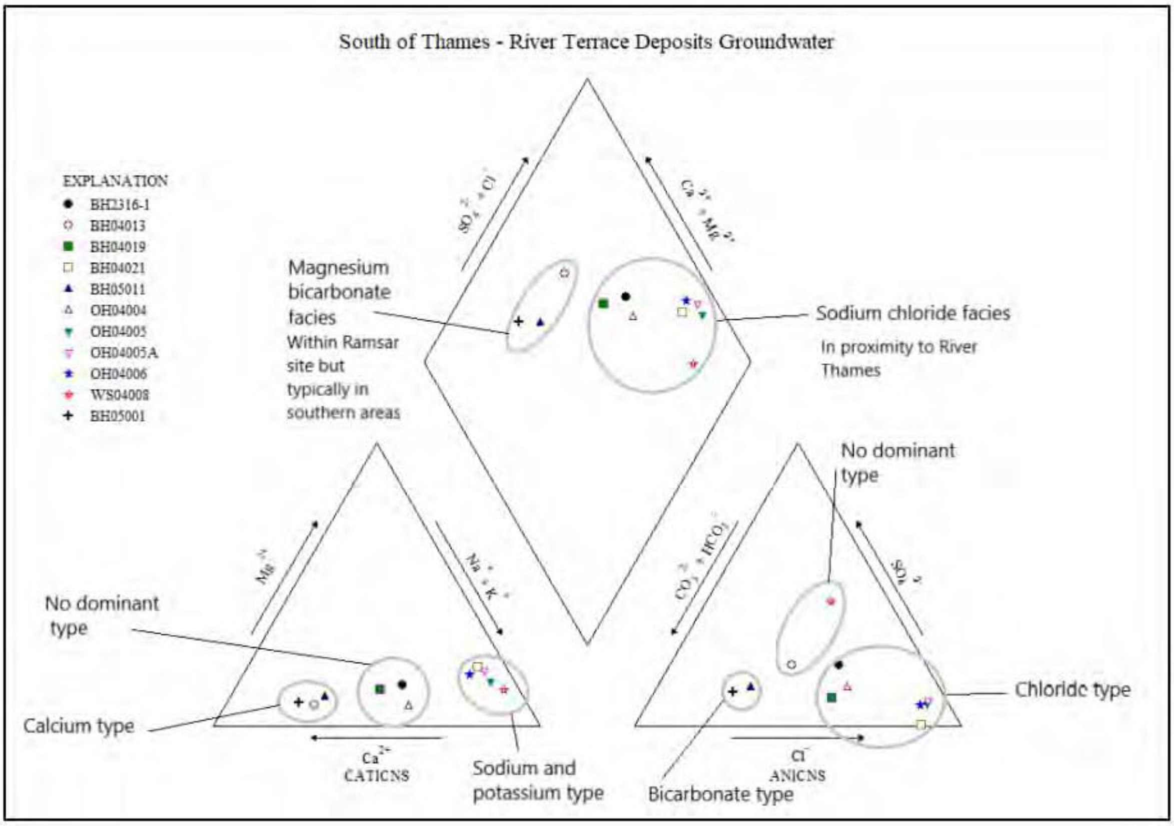


Plate 1.6 Piper plot – River Terrace Deposits – north of the River Thames

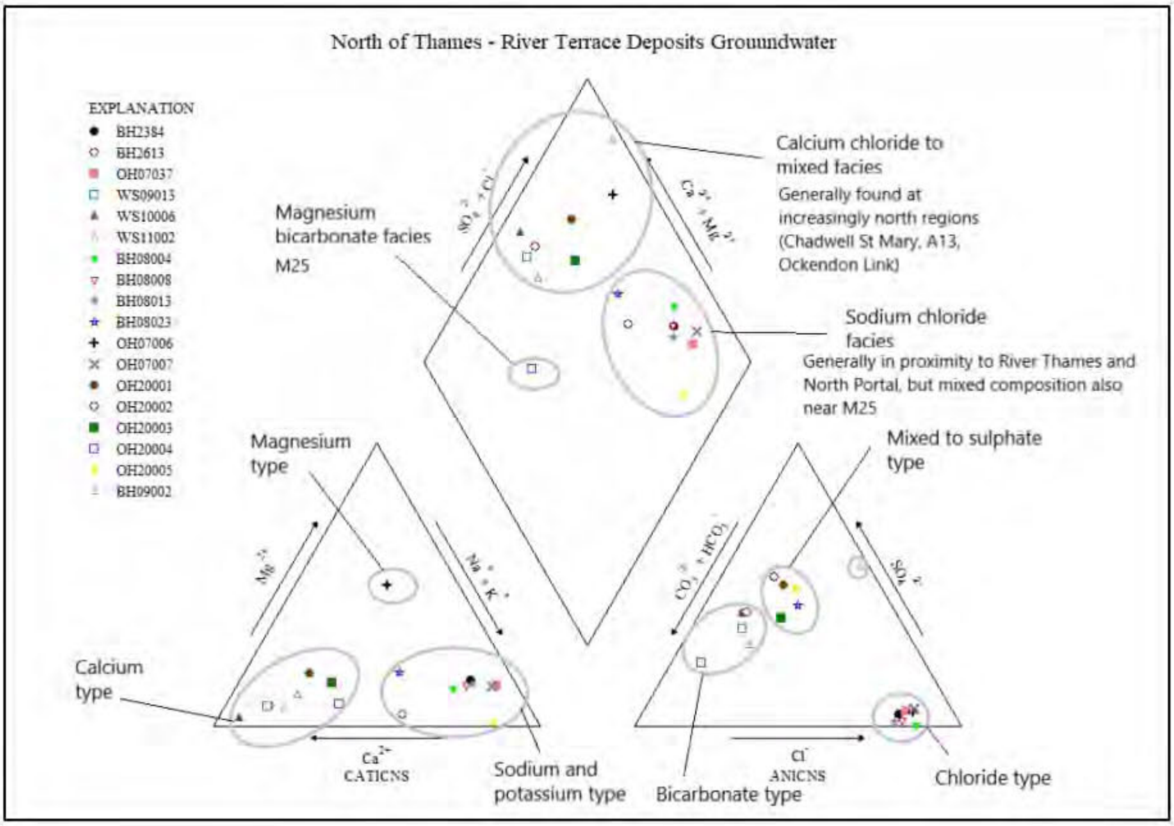


Plate 1.7 Piper plot – Lower London Tertiaries – south of the River Thames

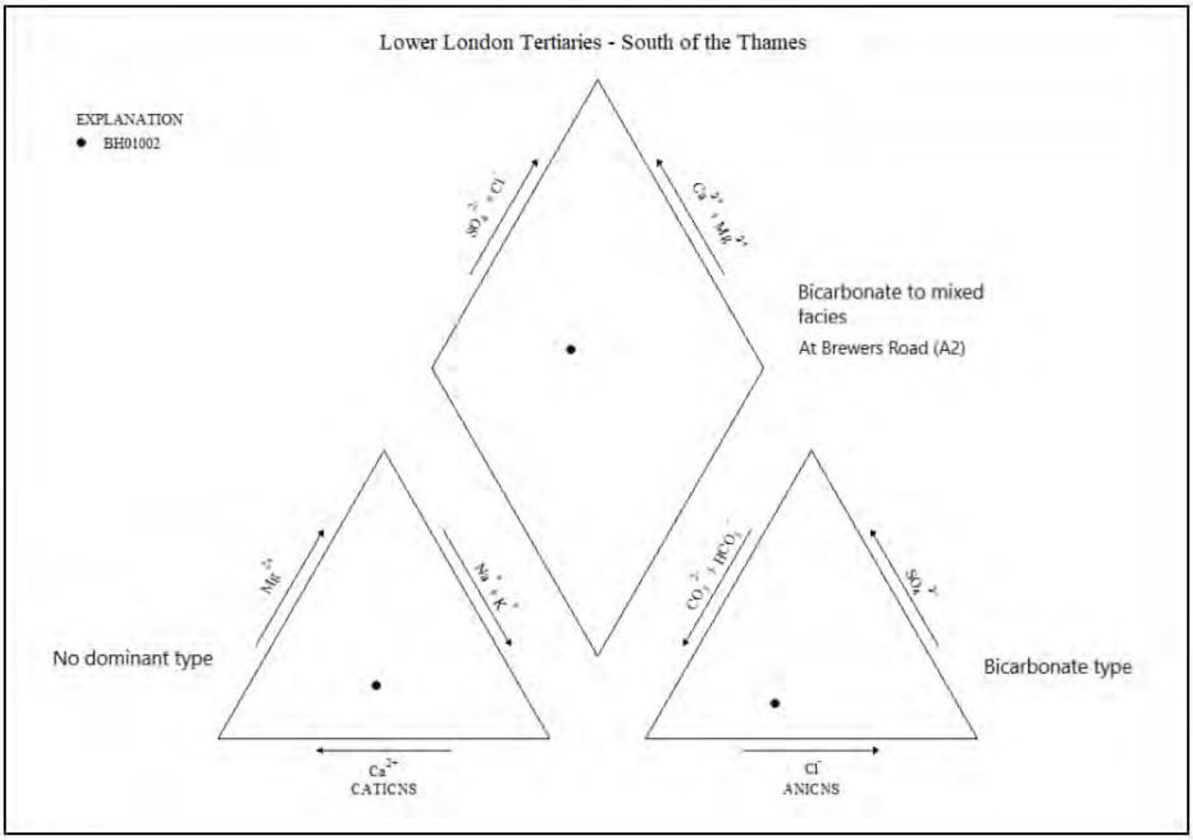


Plate 1.8 Piper plot – Lower London Tertiaries – north of the River Thames

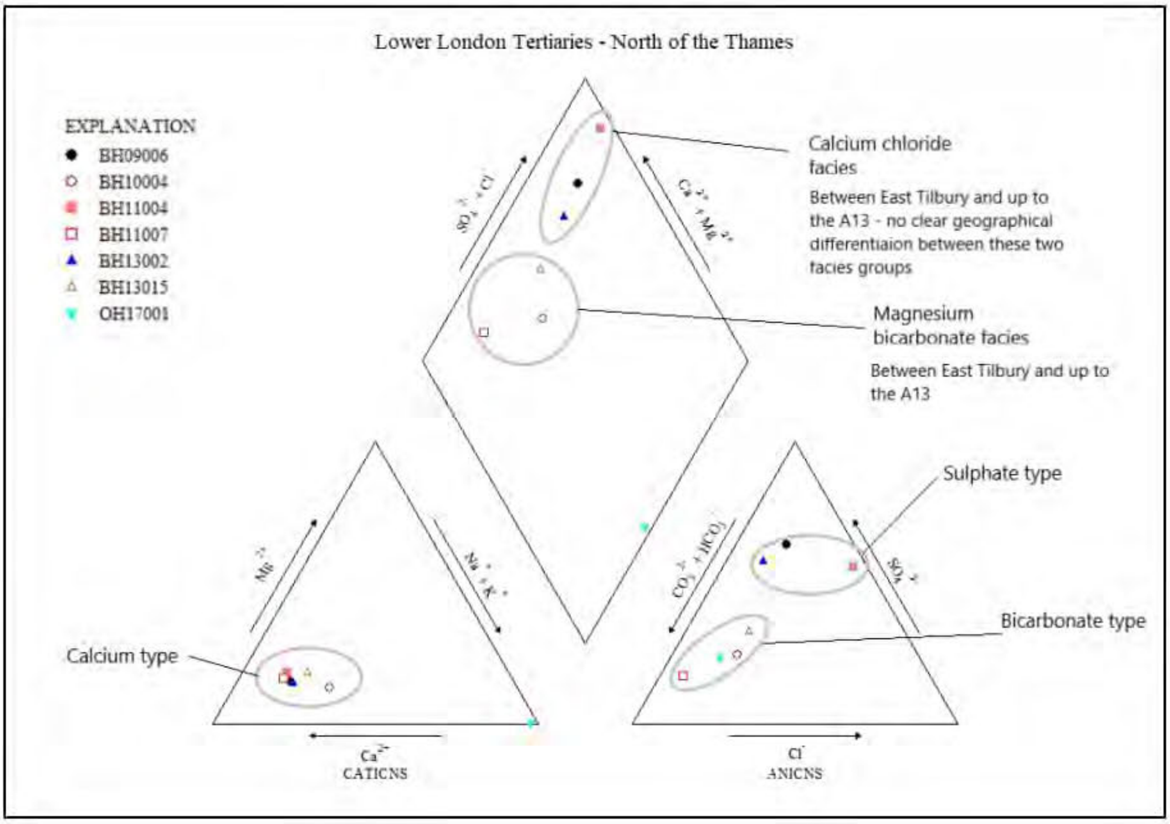
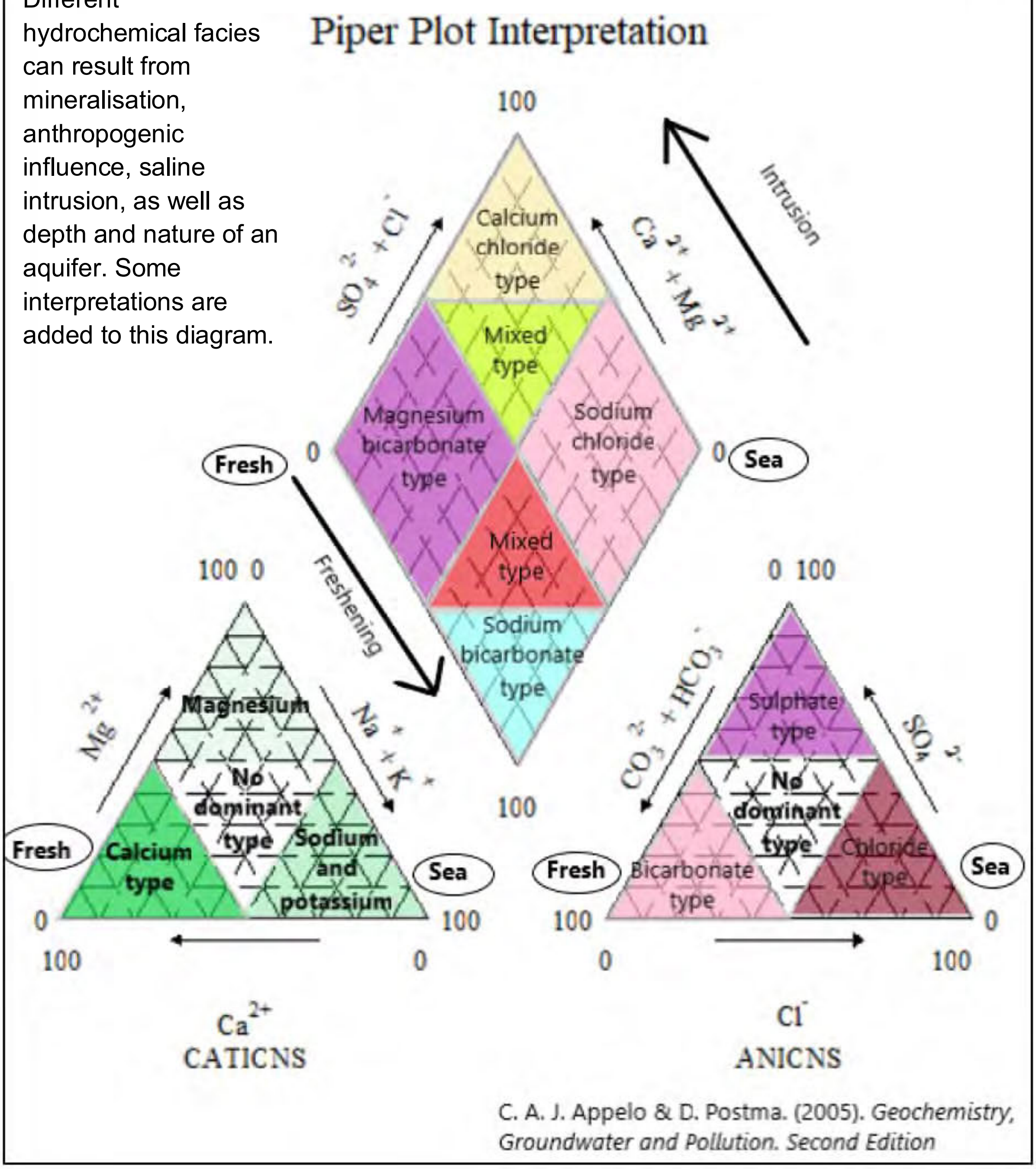


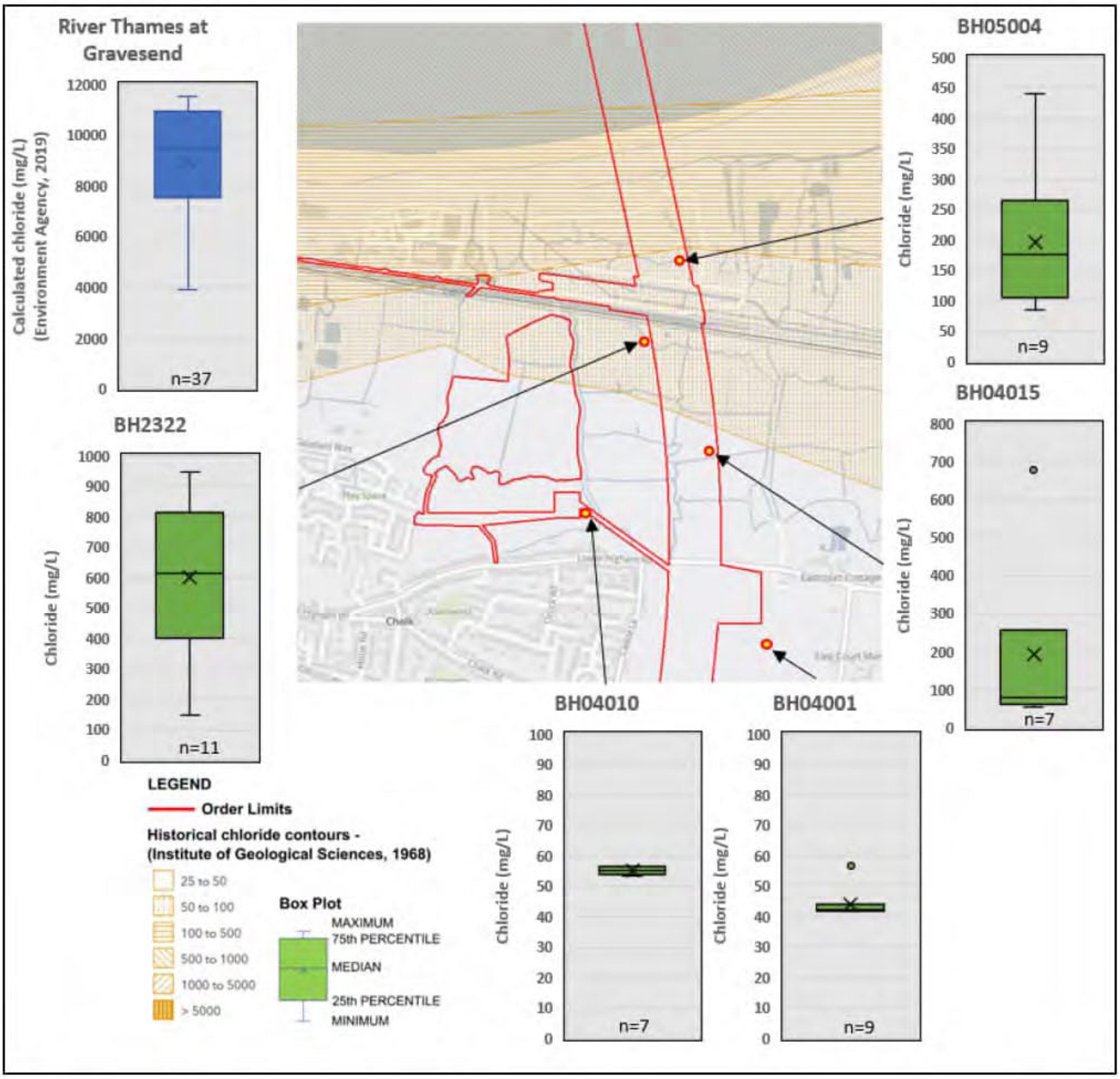
Plate 1.9 Piper plot interpretation diagram – general interpretation (adapted from (Appelo and Postma, 2005)[1,2]

Different hydrochemical facies can result from mineralisation, anthropogenic influence, saline intrusion, as well as depth and nature of an aquifer. Some interpretations are added to this diagram.



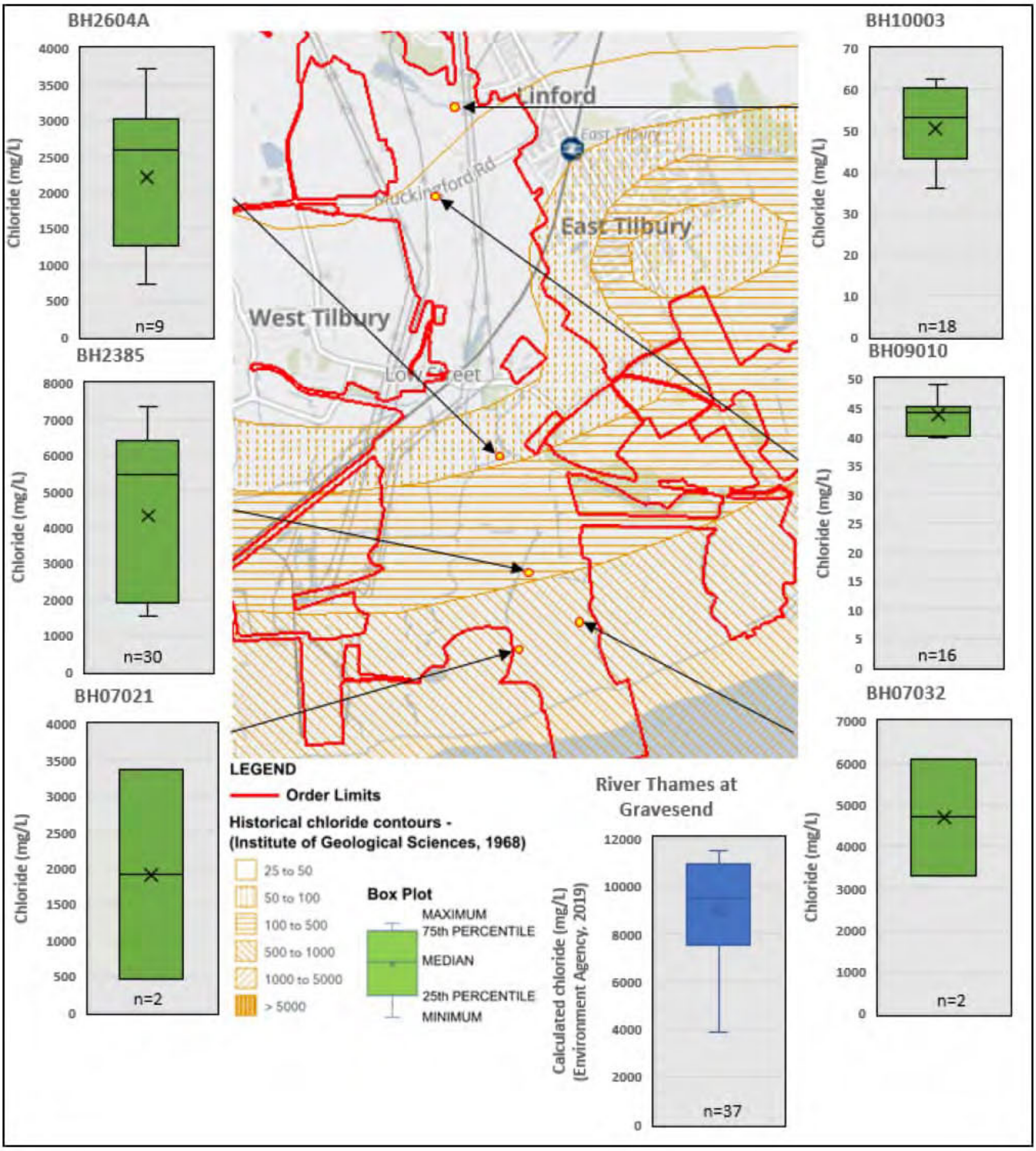
Notes:
[1].Appelo, C. and Postma, D. (2005). Geochemistry, groundwater and pollution, 2nd edition. Rotterdam: Balkema.
[2] Appelo and Postma (2005) has been adapted with annotations and coloured areas in the above illustration.

Plate 1.10 Chloride box plots and historical map contours – south of the River Thames (Chalk aquifer groundwater)



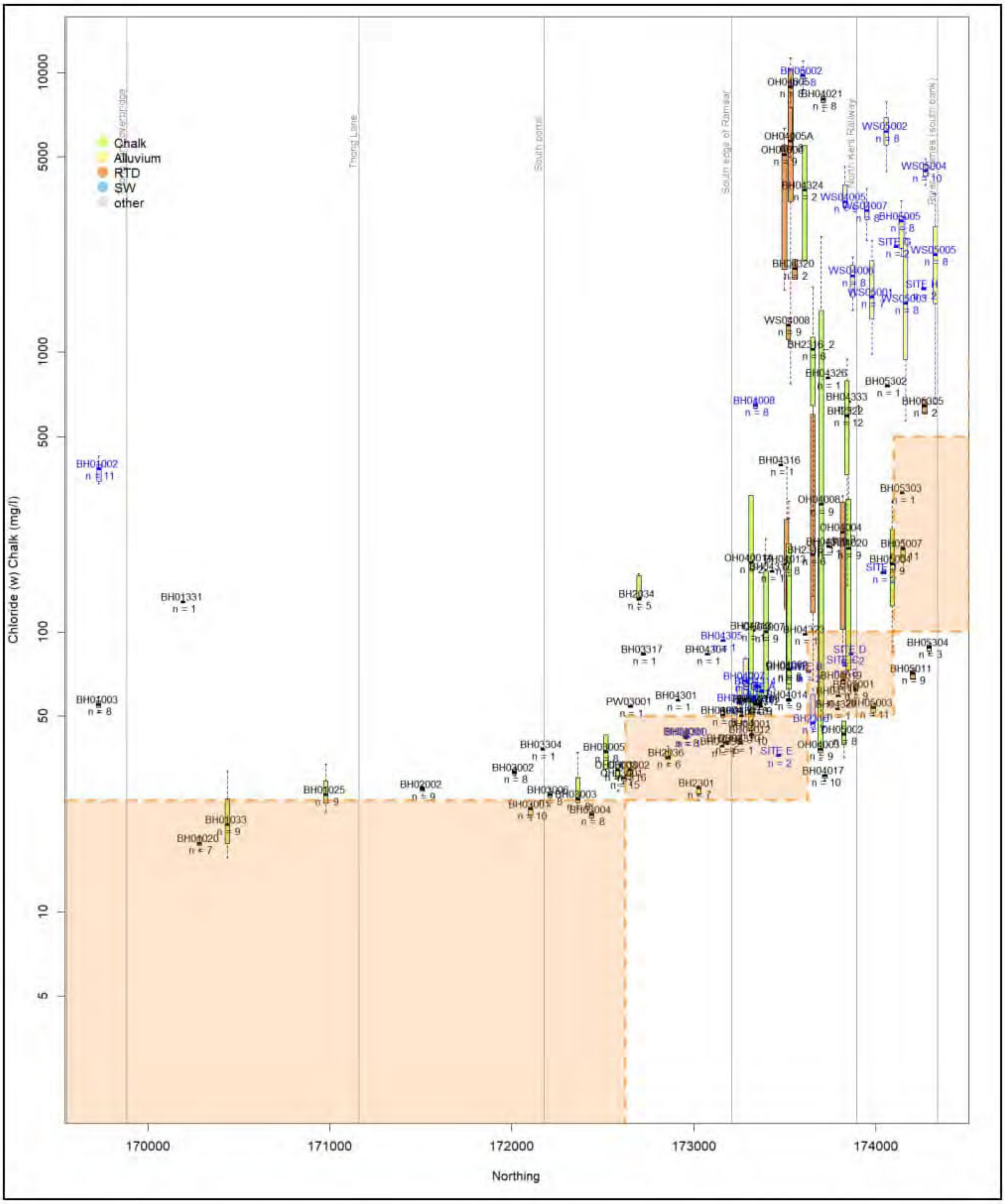
Note: n shows the number of samples used for construction of the box plot. Green coloured box plots are for the Chalk aquifer groundwater. A selection only of Chalk aquifer monitoring boreholes is shown. Historical chloride contours show chloride concentrations as mg/L. Box plots are based on data from Phase 1 and 2 GI monitoring between September 2018 and November 2020. Historical chloride contours are for mg/L chloride concentrations. The dark blue box plot is calculated chloride content of the River Thames using Environment Agency river water quality records received from a data request (Environment Agency, 2019d).

Plate 1.11 Chloride box plots and historical map contours – north of the River Thames (Chalk aquifer groundwater)



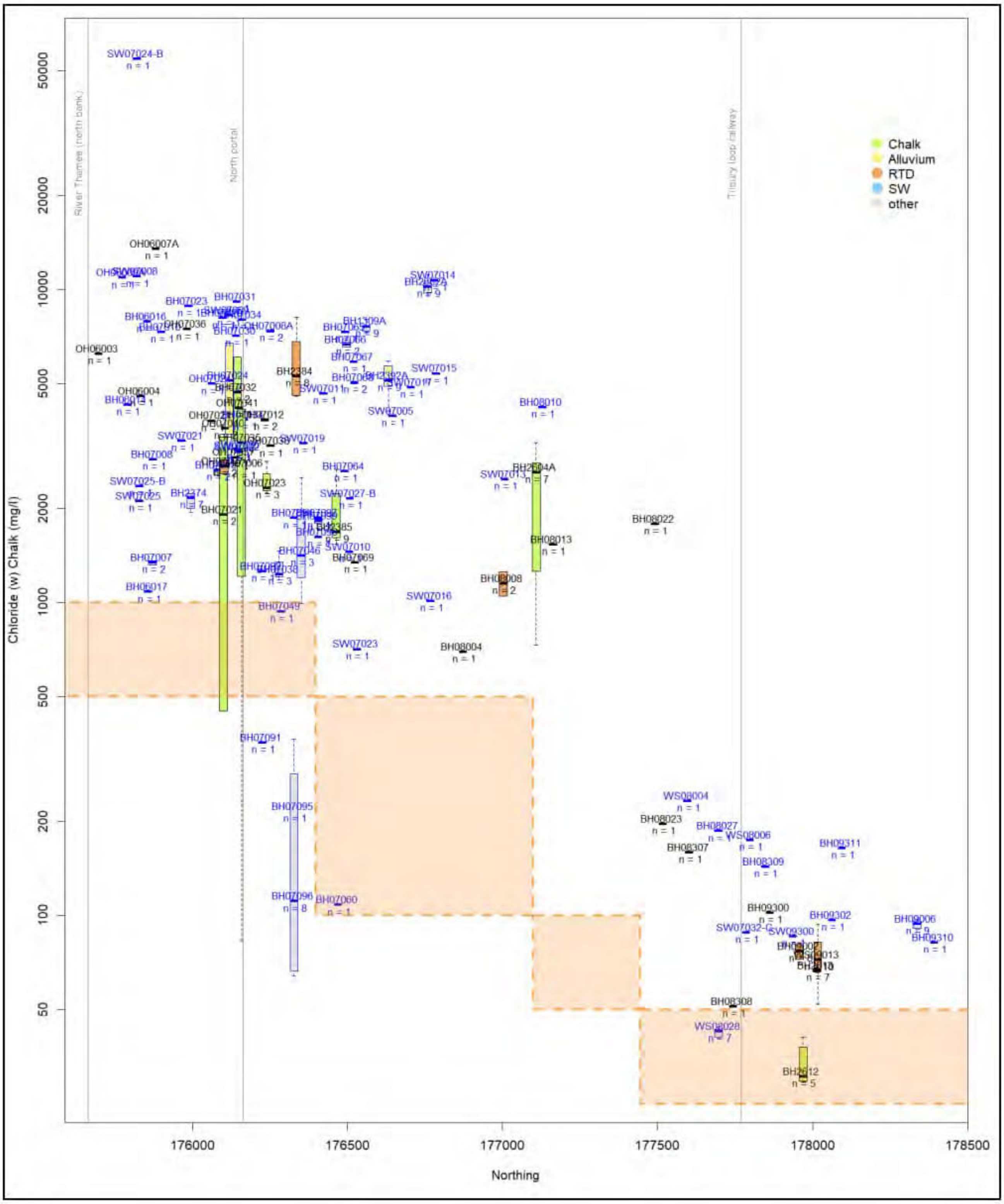
Note: n shows the number of samples used for construction of the box plot. Green coloured box plots are for the Chalk aquifer groundwater. A selection only of Chalk aquifer monitoring boreholes is shown. Historical chloride contours show chloride concentrations as mg/L. Box plots are based on data from Phase 1 and 2 GI monitoring between December 2017 and December 2020. Historical chloride contours are for mg/L chloride concentrations. The dark blue box plot is calculated chloride content of the River Thames using Environment Agency river water quality records received from a data request (Environment Agency, 2019d).

Plate 1.12 Box plots vs. northing – chloride – all strata – south of the River Thames (groundwater)



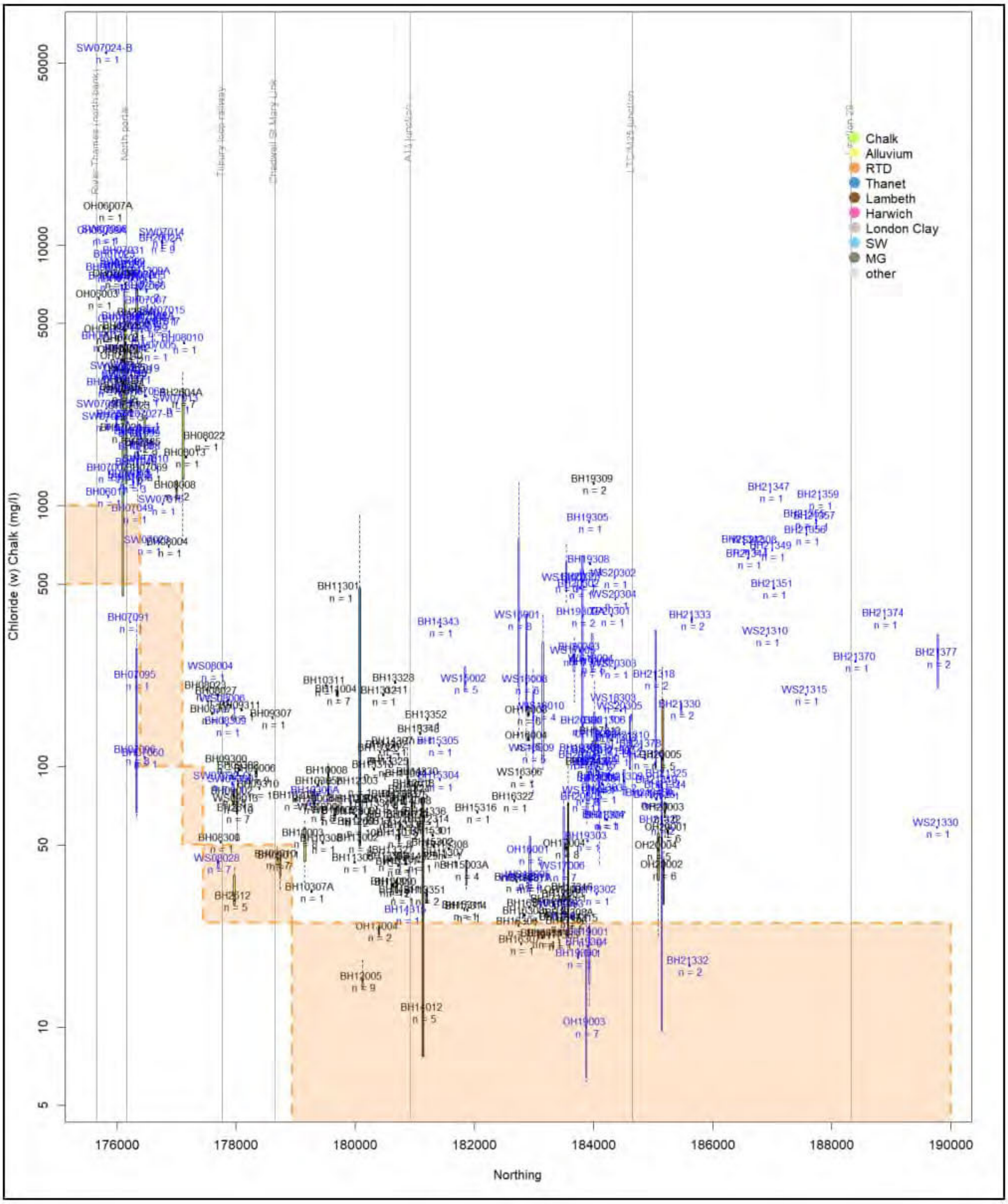
Note: Blue box outline and blue text show results for shallower strata. Black box outline and black text refer to deeper strata such as those that comprise the Chalk aquifer. Shaded orange areas indicate maximum and minimum values of historical Chalk aquifer chloride contour data (adapted from Institute of Geological Sciences, 1968). Box plots are based on data from Phase 1 and 2 GI monitoring between September 2018 and January 2021.

Plate 1.13 Box plots vs. northing – chloride – all strata – north of the River Thames (north portal) (groundwater and surface water)



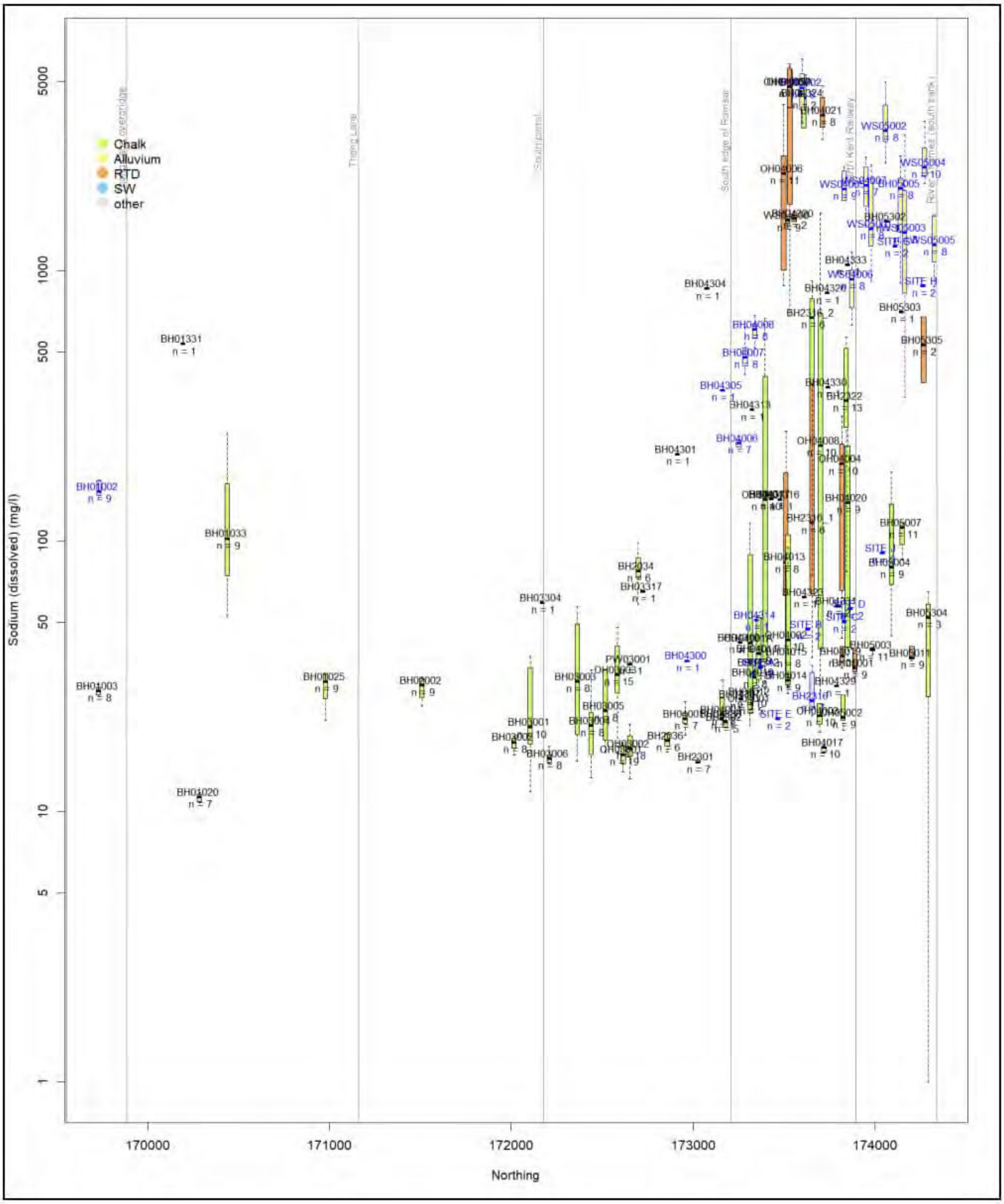
Note: Blue box outline and blue text show results for shallower strata. Black box outline and black text refer to deeper strata such as those that comprise the Chalk aquifer. SW is a surface water sample. Shaded orange areas indicate maximum and minimum values of historical Chalk aquifer chloride contour data (adapted from Institute of Geological Sciences, 1968). Box plots are based on data from Phase 1 and 2 GI monitoring between November 2017 and January 2021.

Plate 1.14 Box plots vs. northing – chloride – all strata – north of the River Thames (groundwater)



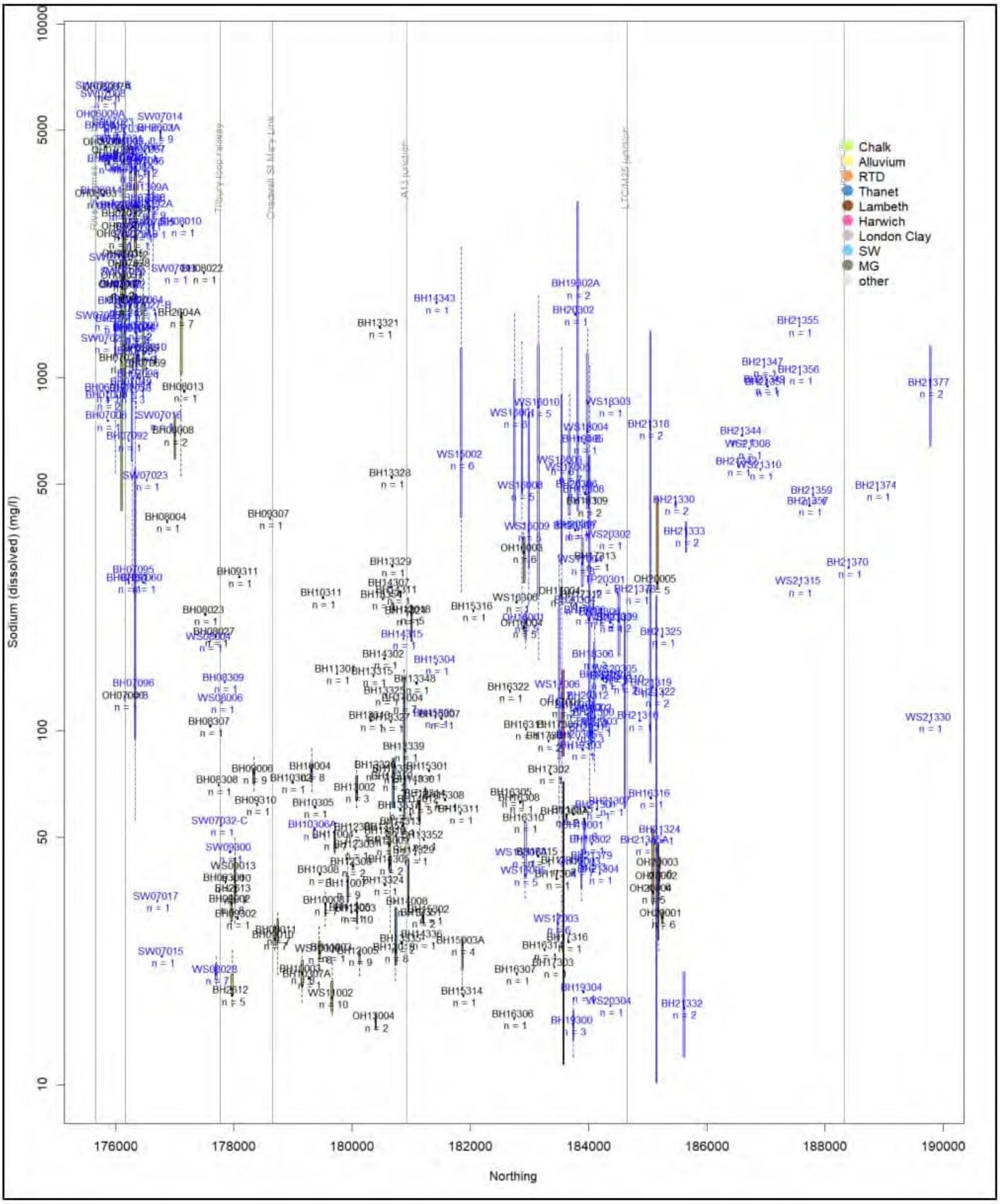
Note: Blue box outline and blue text show results for shallower strata. Black box outline and black text refer to deeper strata such as those that comprise the Chalk aquifer. SW is a surface water sample. Shaded orange areas indicate maximum and minimum values of historical Chalk aquifer chloride contour data (adapted from Institute of Geological Sciences, 1968). Box plots are based on data from Phase 1 and 2 GI monitoring between November 2017 and January 2021.

Plate 1.15 Box plots vs. northing – sodium – all strata – south of the River Thames (groundwater)



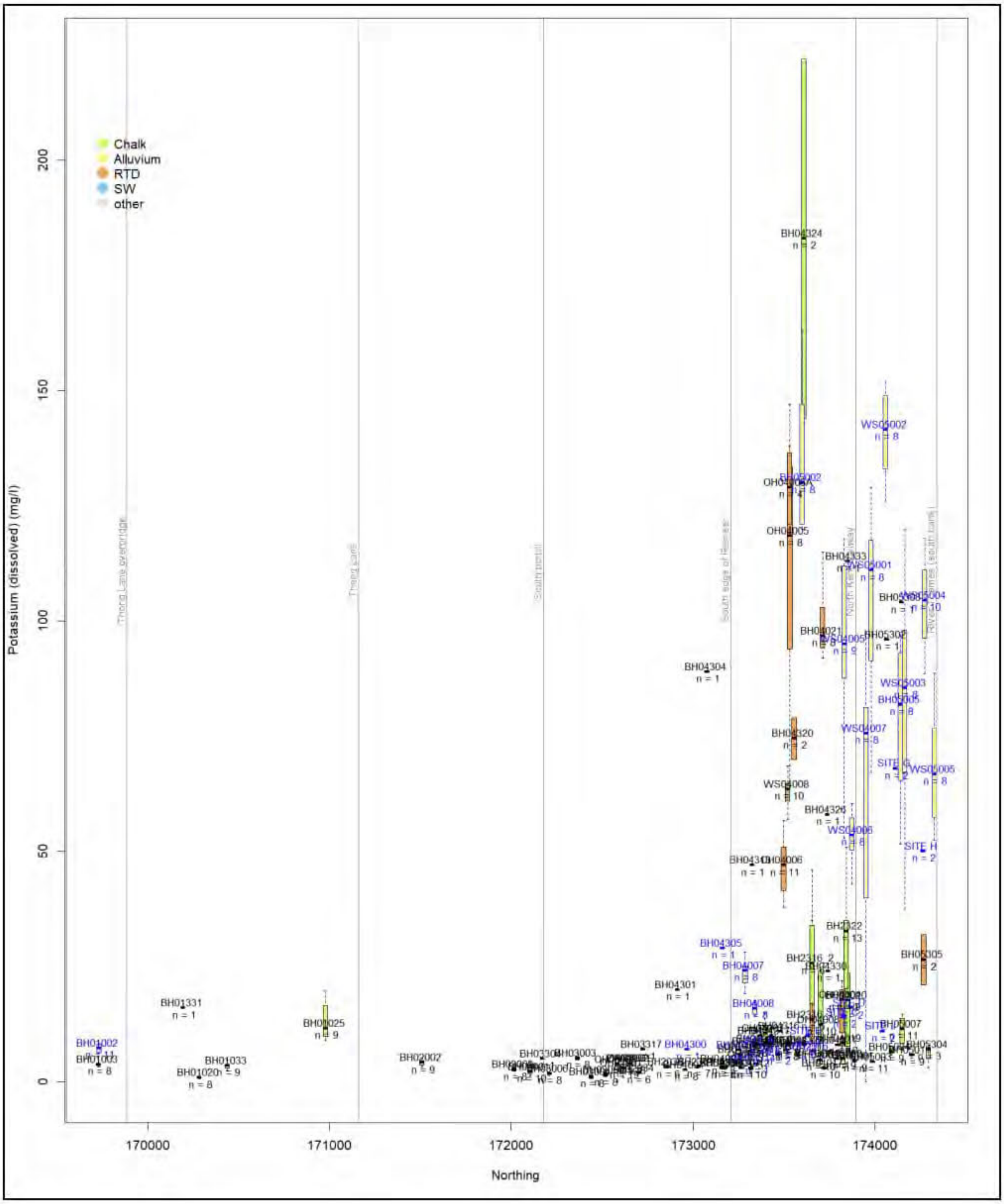
Note: Blue box outline and blue text show results for shallower strata. Black box outline and black text refer to deeper strata such as those that comprise the Chalk aquifer. SW is a surface water sample. Box plots are based on data from Phase 1 and 2 GI monitoring between September 2018 and January 2021.

Plate 1.16 Box plots vs. northing – sodium – all strata – north of the River Thames (groundwater)



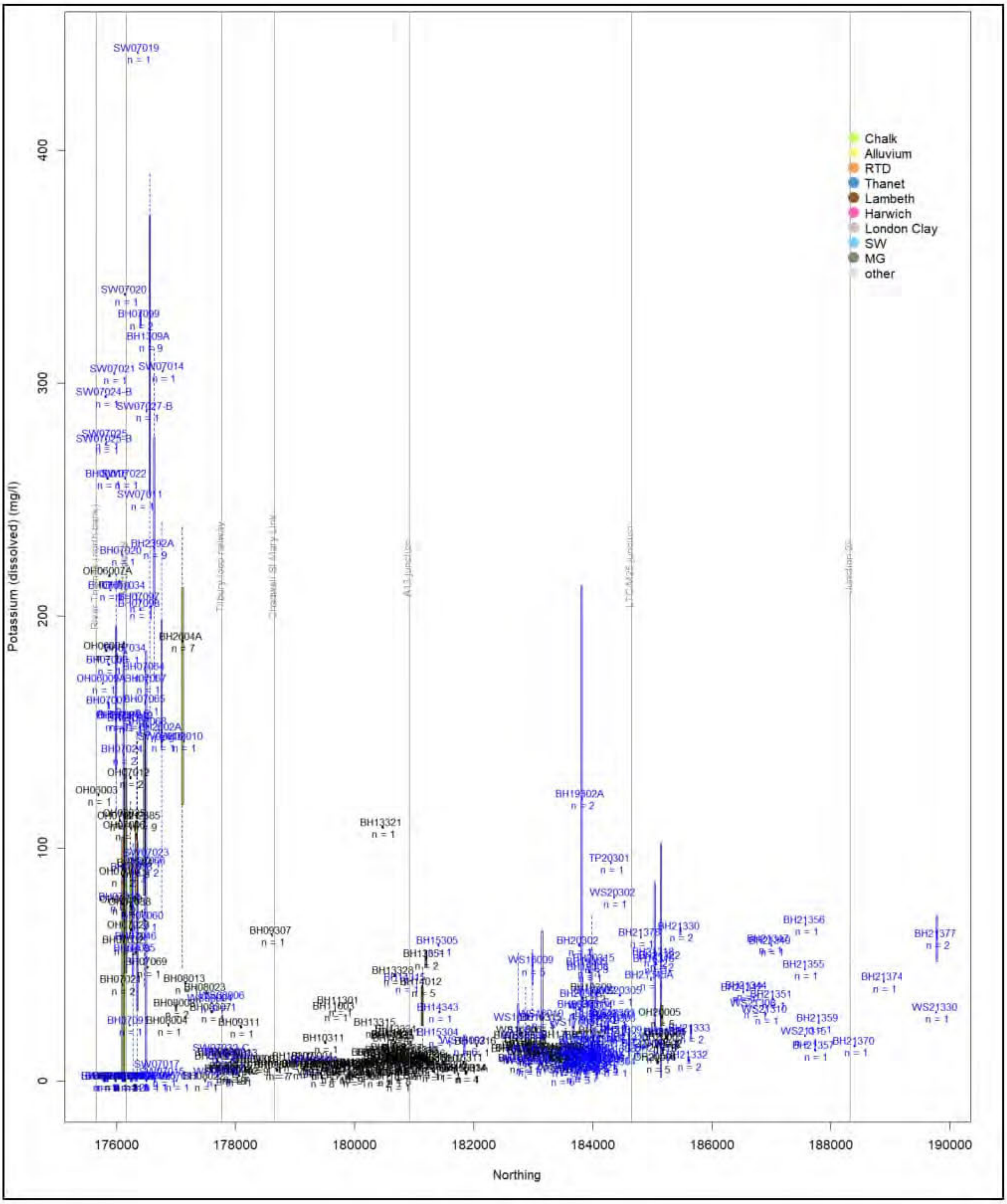
Note: Blue box outline and blue text show results for shallower strata. Black box outline and black text refer to deeper strata such as those that comprise the Chalk aquifer. SW is a surface water sample. Box plots are based on data from Phase 1 and 2 GI monitoring between November 2017 and January 2021.

Plate 1.17 Box plots vs. northing – potassium – all strata – south of the River Thames (groundwater)



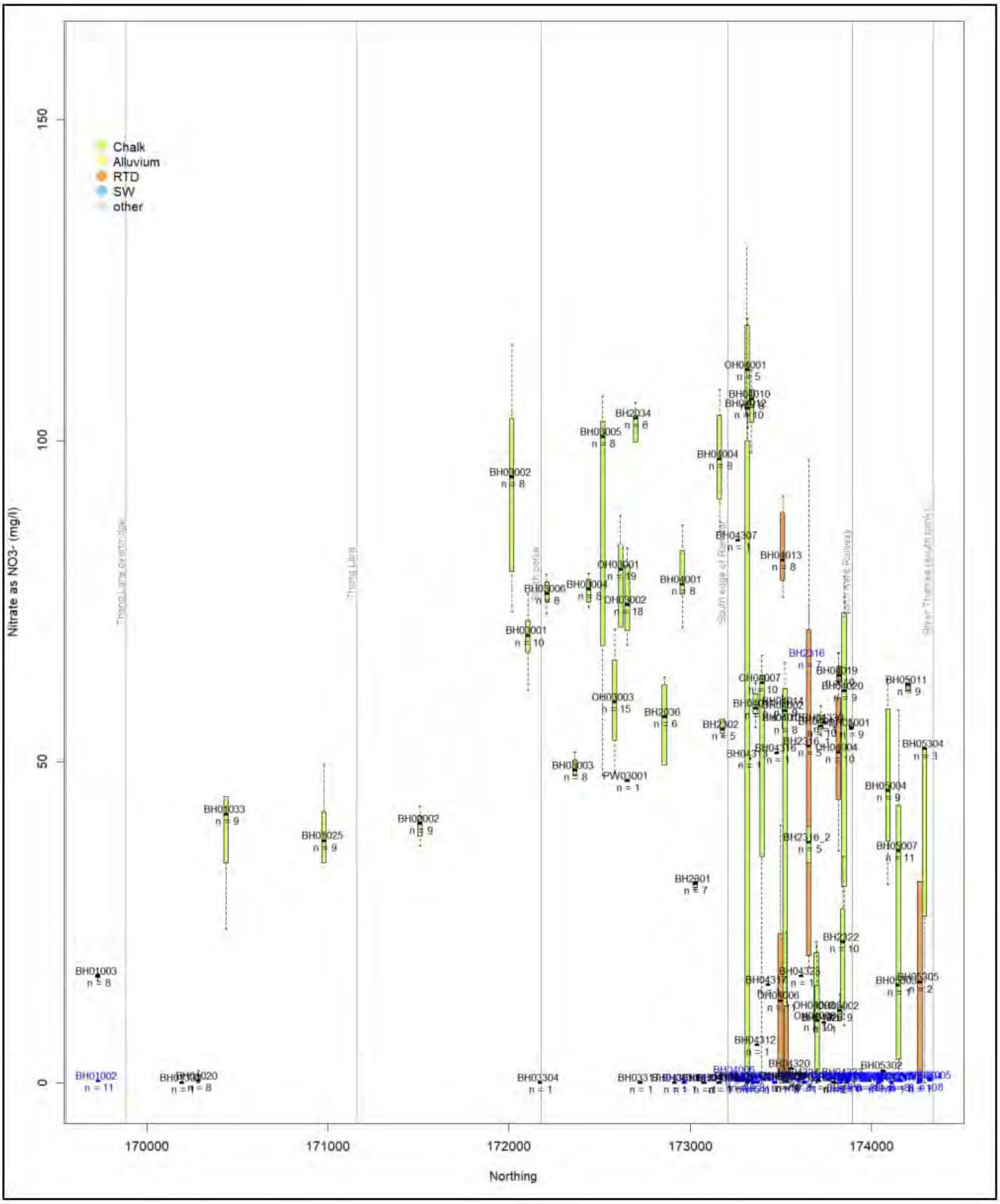
Note: Blue box outline and blue text show results for shallower strata. Black box outline and black text refer to deeper strata such as those that comprise the Chalk aquifer. SW is a surface water sample. Box plots are based on data from Phase 1 and 2 GI monitoring between September 2018 and January 2021.

Plate 1.18 Box plots vs. northing – potassium – all strata – north of the River Thames (groundwater)



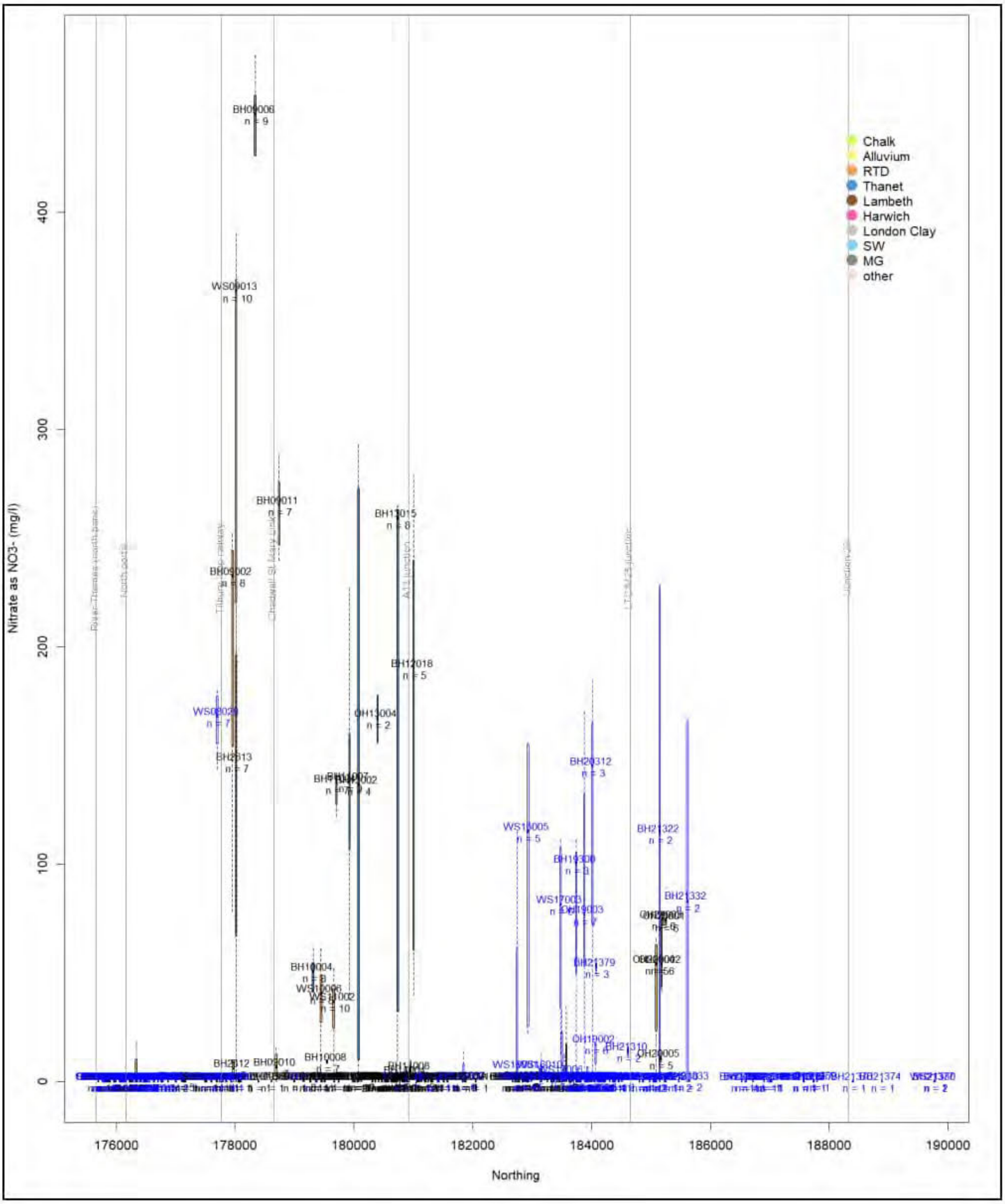
Note: Blue box outline and blue text show results for shallower strata. Black box outline and black text refer to deeper strata such as those that comprise the Chalk aquifer. SW is a surface water sample. Box plots are based on data from Phase 1 and 2 GI monitoring between November 2017 and January 2021.

Plate 1.19 Box plots vs. northing – nitrate – all strata – south of the River Thames (groundwater)



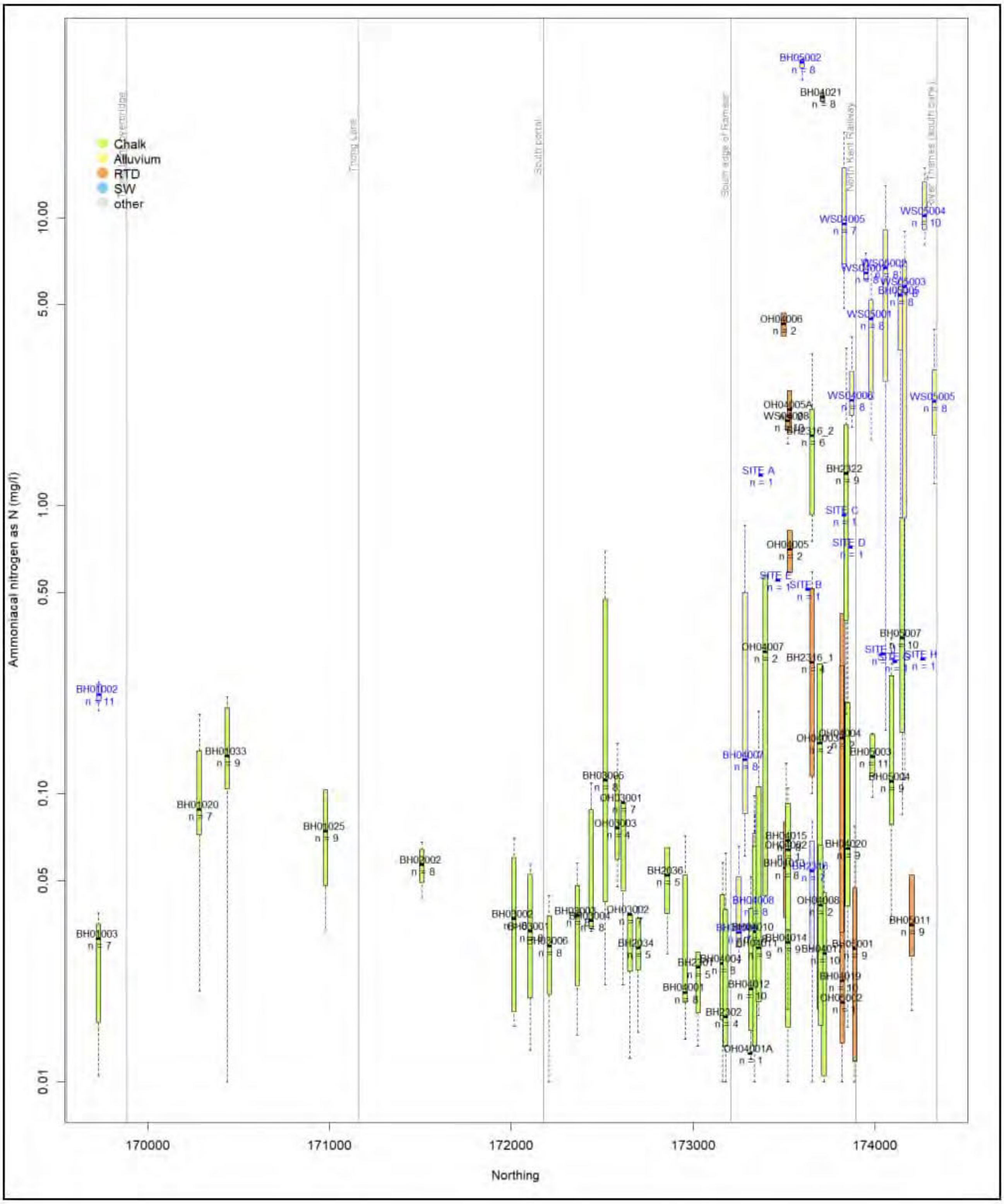
Note: Blue box outline and blue text show results for shallower strata. Black box outline and black text refer to deeper strata such as those that comprise the Chalk aquifer. SW is a surface water sample. Nitrate as mg NO_3/L. Box plots are based on data from Phase 1 and 2 GI monitoring between September 2018 and January 2021.

Plate 1.20 Box plots vs. northing – nitrate – all strata – north of the River Thames (groundwater)



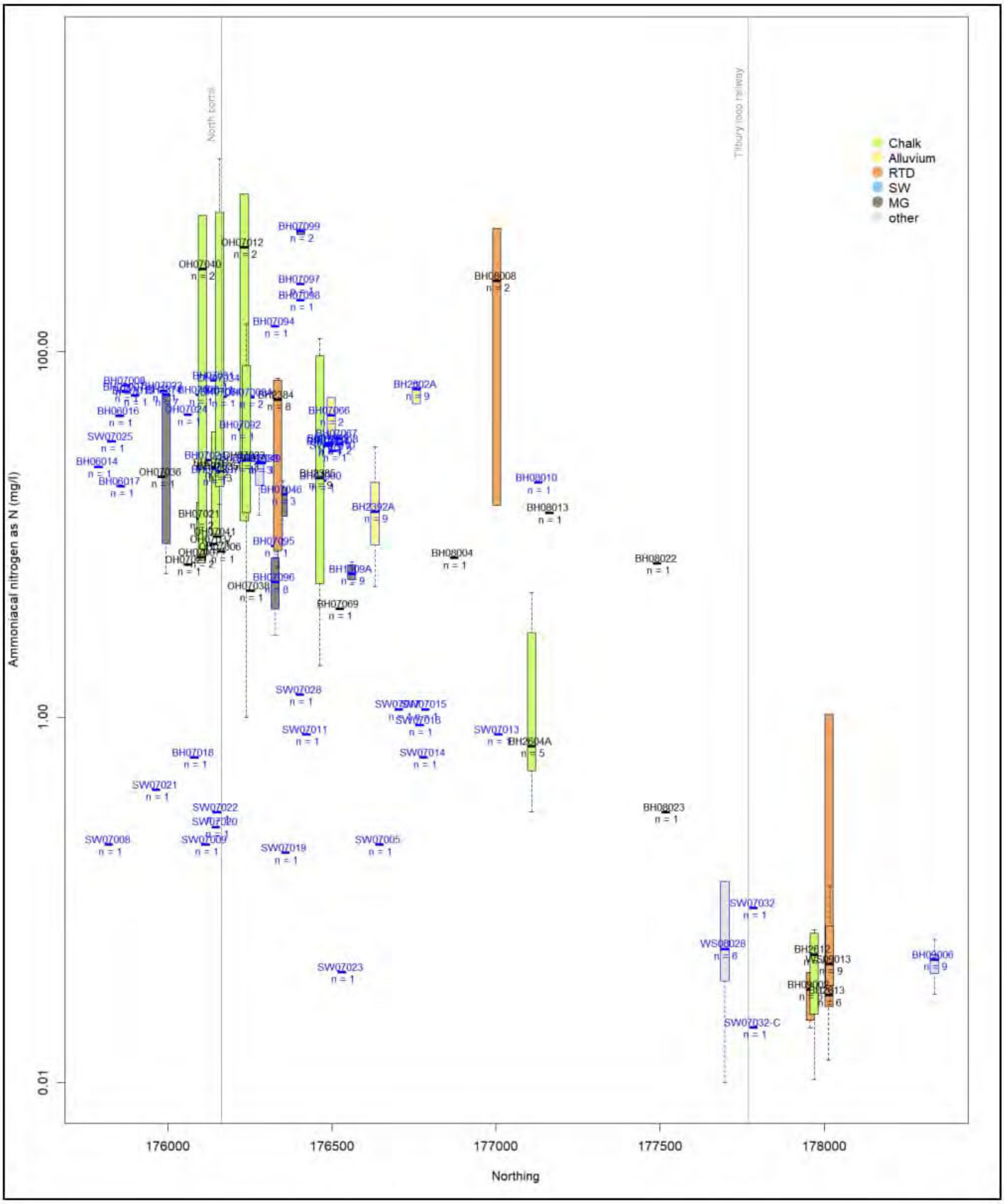
Note: Blue box outline and blue text show results for shallower strata. Black box outline and black text refer to deeper strata such as those that comprise the Chalk aquifer. SW is a surface water sample. Nitrate as mg NO_3/L. Box plots are based on data from Phase 1 and 2 GI monitoring between September 2018 and January 2021.

Plate 1.21 Box plots vs. northing – ammoniacal nitrogen – all strata – south of the River Thames (groundwater)



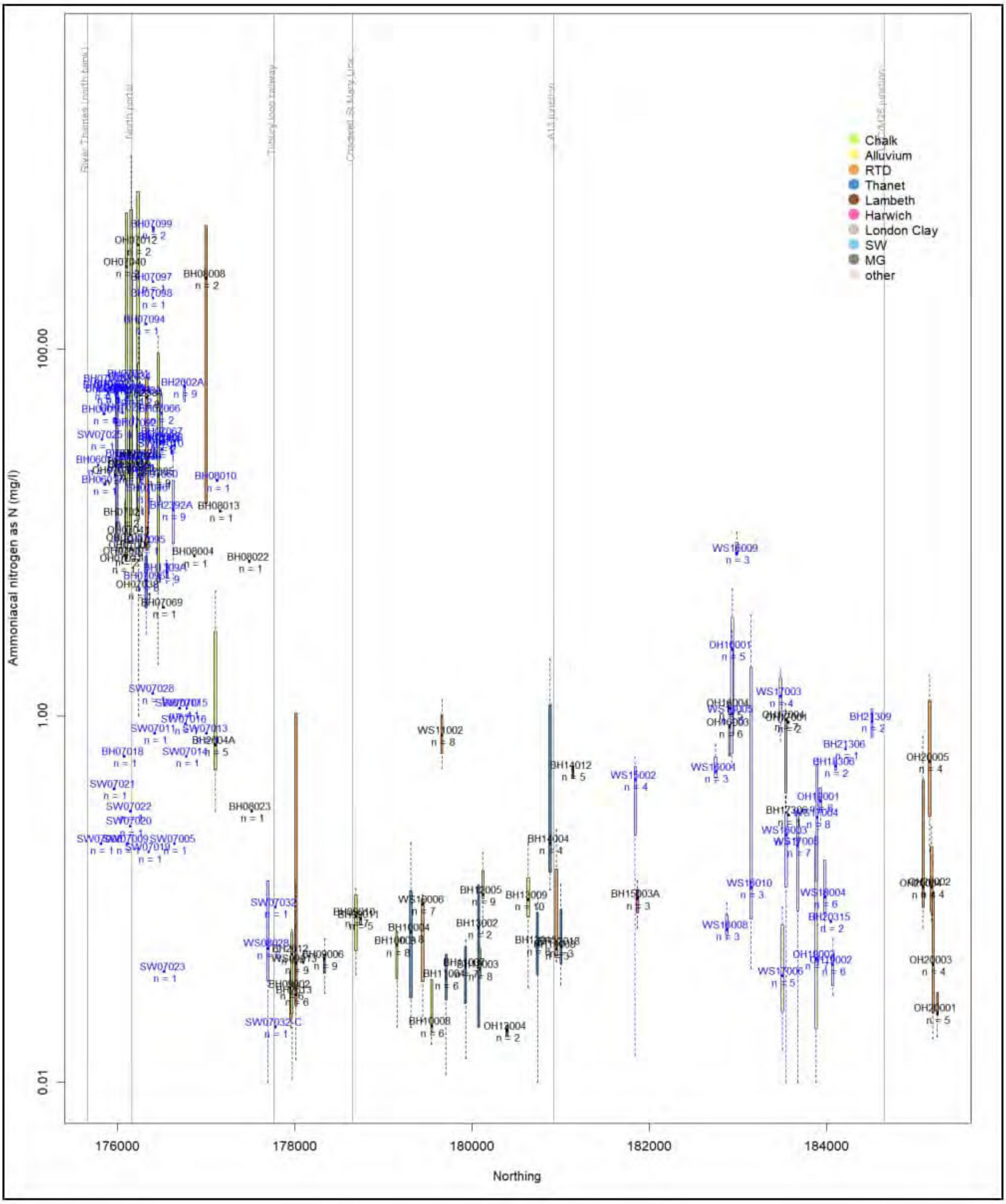
Note: Ammoniacal nitrogen presented as N. Blue box outline and blue text show results for shallower strata. Black box outline and black text refer to deeper strata such as those that comprise the Chalk aquifer. SW is a surface water sample. Box plots are based on data from Phase 1 and 2 GI monitoring between September 2018 and January 2021.

Plate 1.22 Box plots vs. northing – ammoniacal nitrogen – all strata – north of the River Thames – North Portal (groundwater)



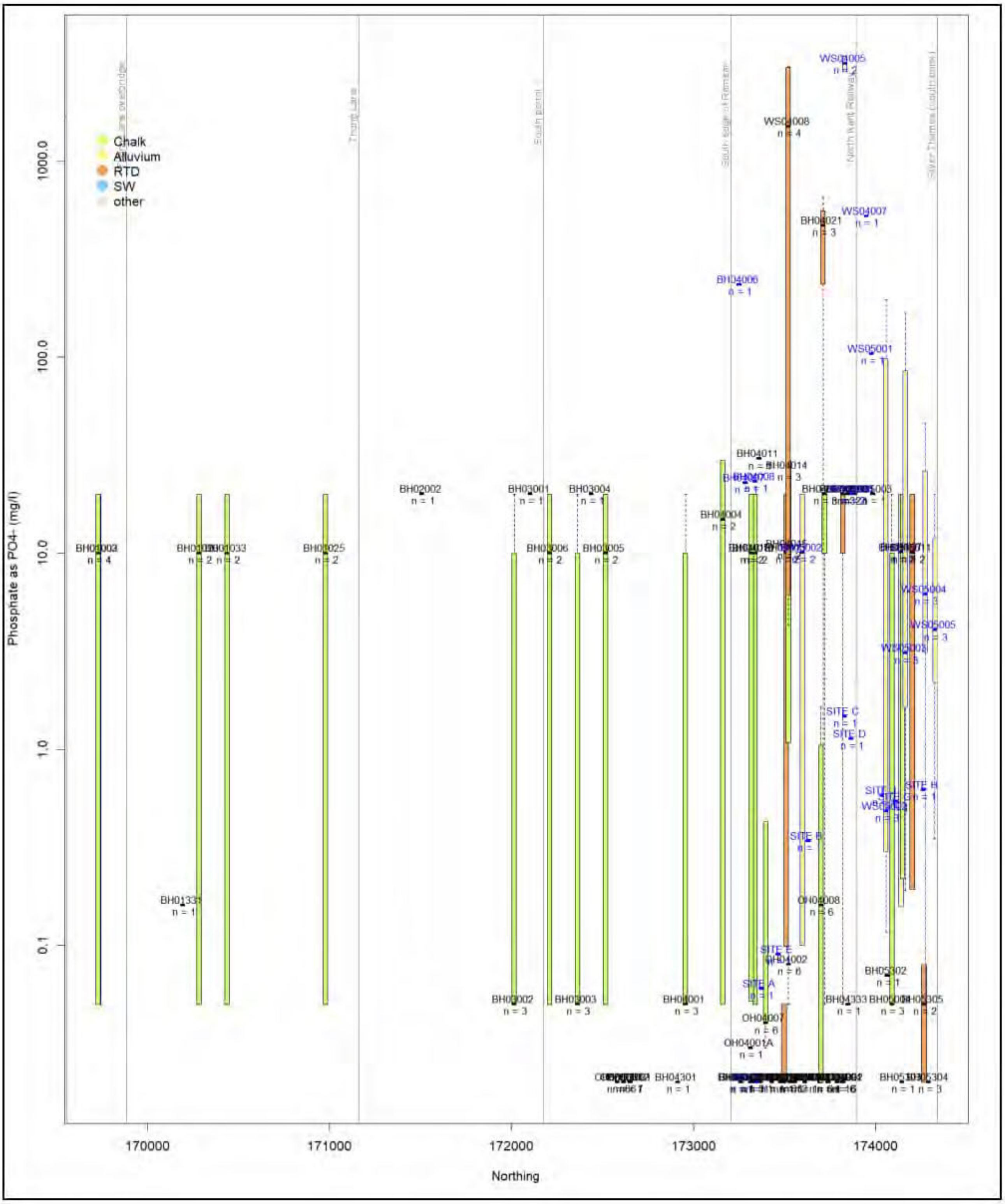
Note: Ammoniacal nitrogen presented as N. Blue box outline and blue text show results for shallower strata. Black box outline and black text refer to deeper strata such as those that comprise the Chalk aquifer. SW is a surface water sample. Box plots are based on data from Phase 1 and 2 GI monitoring between November 2017 and January 2021.

Plate 1.23 Box plots vs. northing – ammoniacal nitrogen – all strata – north of the River Thames (groundwater)



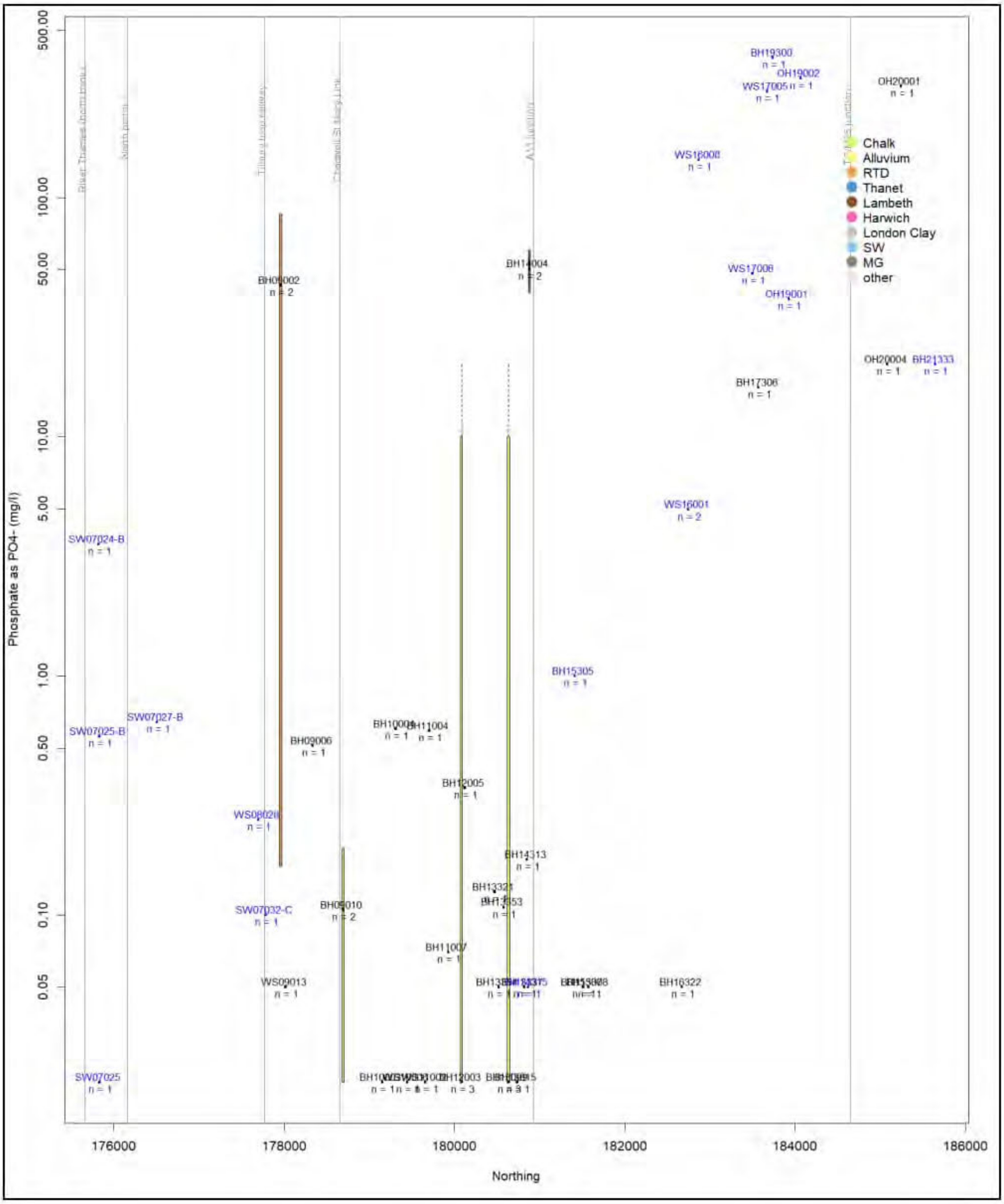
Note: Ammoniacal nitrogen presented as N. Blue box outline and blue text show results for shallower strata. Black box outline and black text refer to deeper strata such as those that comprise the Chalk aquifer. SW is a surface water sample. Box plots are based on data from Phase 1 and 2 GI monitoring between November 2017 and January 2021.

Plate 1.24 Box plots vs. northing – phosphate – all strata – south of the River Thames (groundwater)



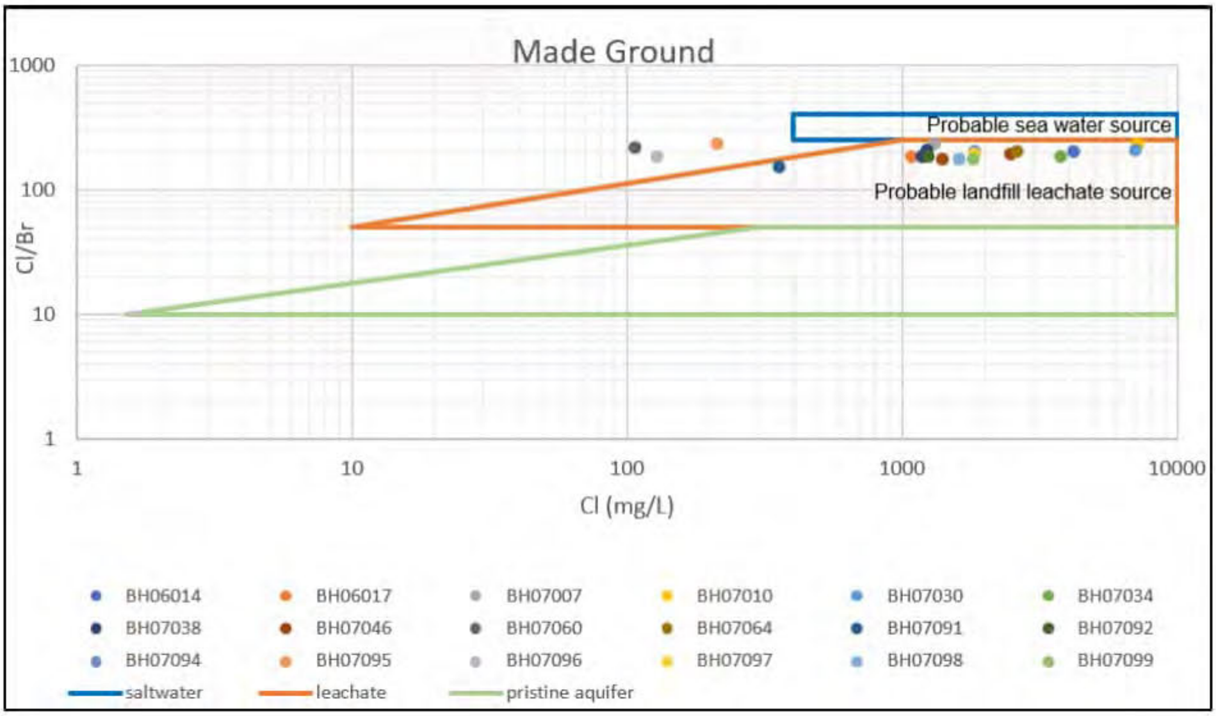
Note: Blue box outline and blue text show results for shallower strata. Black box outline and black text refer to deeper strata such as those that comprise the Chalk aquifer. SW and site C, D etc. are surface water samples. WS are window sample boreholes. Phosphorus presented as phosphate. Box plots are based on data from Phase 1 and 2 GI monitoring between September 2018 and January 2021.

Plate 1.25 Box plots vs. northing – phosphate – all strata – north of the River Thames (groundwater)



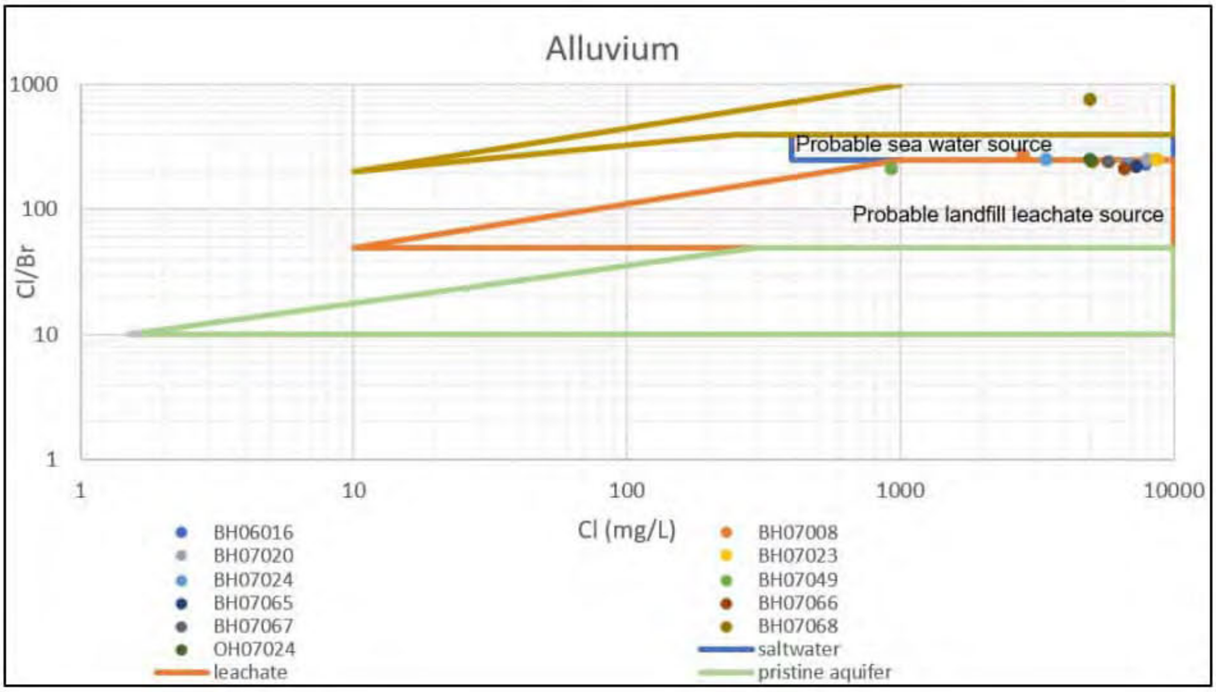
Note: Blue box outline and blue text show results for shallower strata. Black box outline and black text refer to deeper strata such as those that comprise the chalk aquifer. SW and site C, D etc. are surface water samples. WS are window sample boreholes. Phosphorus presented as phosphate. Box plots are based on data from Phase 1 and 2 GI monitoring between November 2017 and January 2021.

Plate 1.26 Chloride/bromide ratio plots for tentative interpretation of source – North Portal – made ground (groundwater)



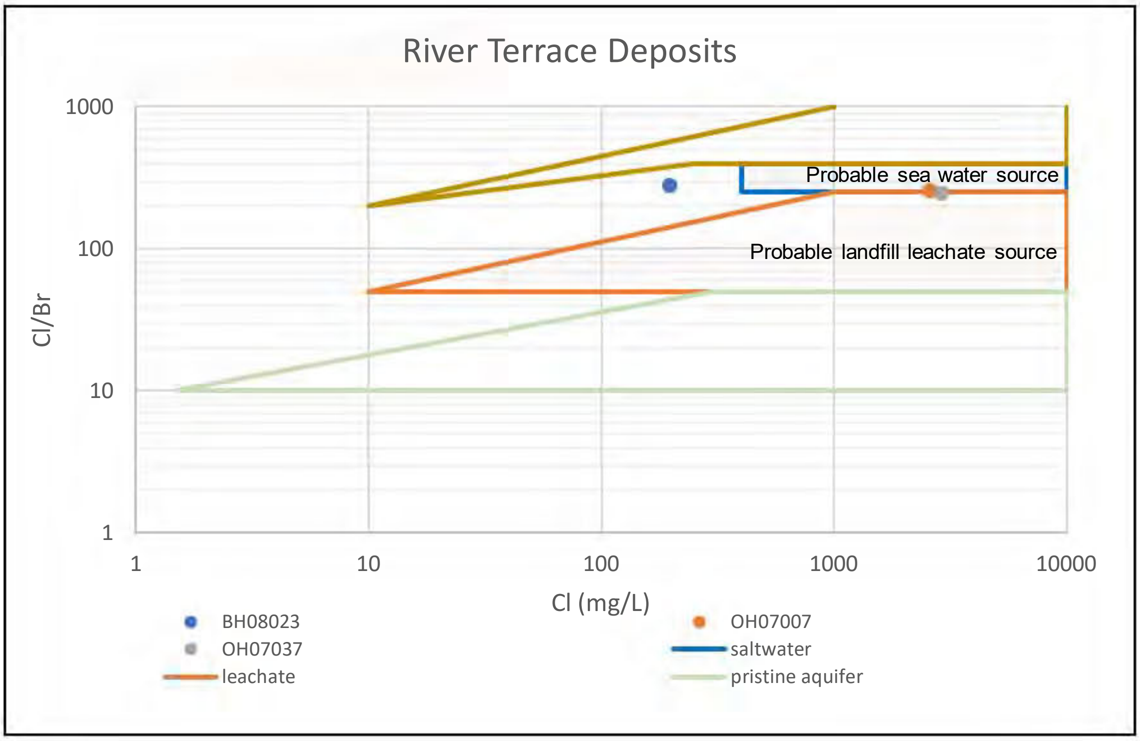
Note: Method adopted from Klaseen, Allen, & Kirste (2014)

Plate 1.27 Chloride/bromide ratio plots for tentative interpretation of source – North Portal – Alluvium (groundwater)



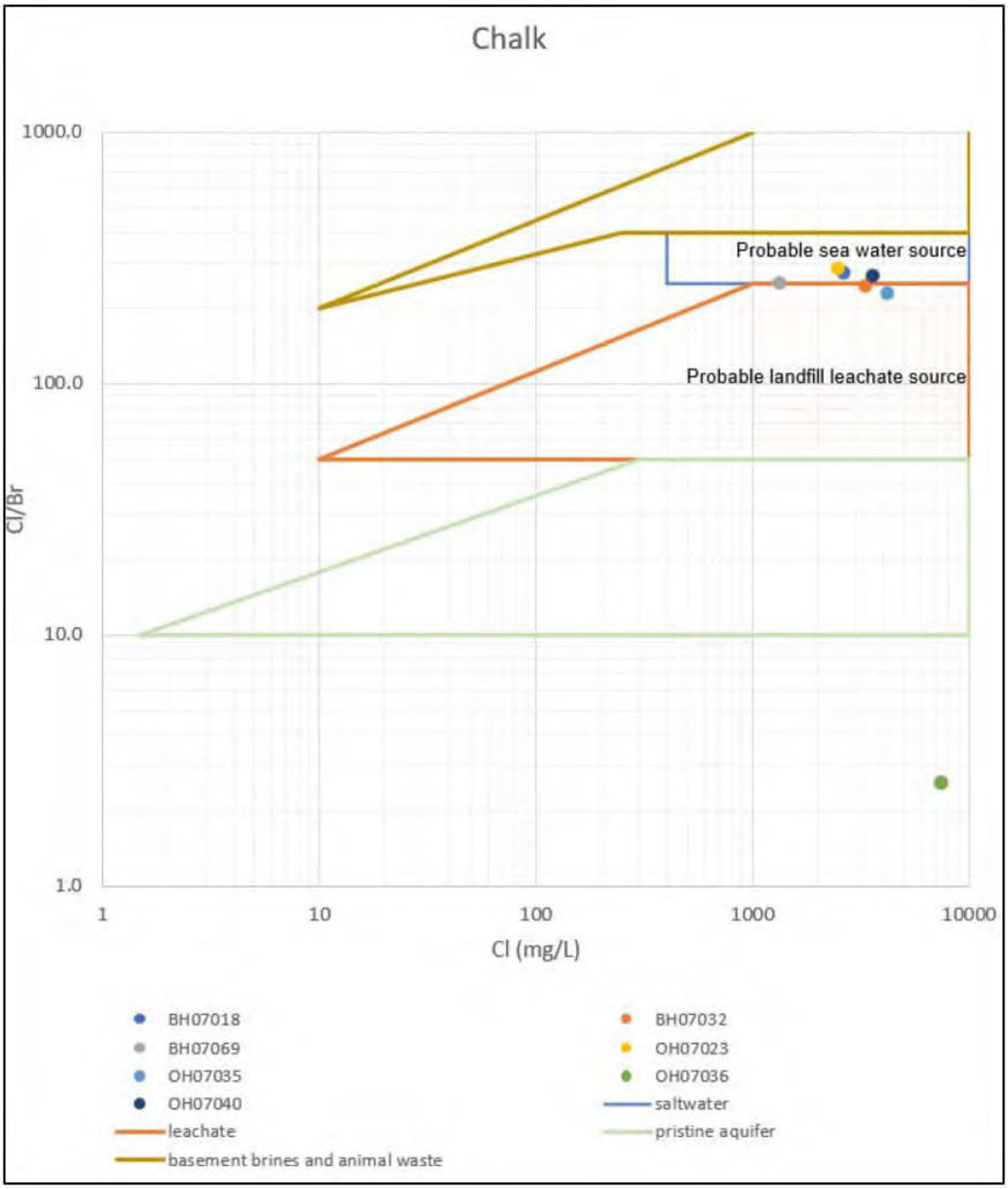
Note: Method adopted from Klaseen, Allen, & Kirste (2014)

Plate 1.28 Chloride/bromide ratio plots for tentative interpretation of source – North Portal – River Terrace Deposits (groundwater)



Note: Method adopted from Klaseen, Allen, & Kirste (2014)

Plate 1.29 Chloride/bromide ratio plots for tentative interpretation of source – North Portal – Chalk aquifer (groundwater)



Note: Method adopted from Klaseen, Allen, & Kirste (2014).

Table 1.1 Regional groundwater quality summary – south of the River Thames

Geographical region, geology and BH ID	Nitrate (mg NO_3/L)				Chloride (mg/L)			
	Minimum	Maximum	Average	n	Minimum	Maximum	Average	n
A2/M2/A122 Lower Thames Crossing junction:	**0.0**	**94.5**	**19.3**	**46**	**0**	**425**	**100**	**46**
Chalk	**0.0**	**94.5**	**25.2**	**35**	**0**	**128**	**33**	**35**
BH01003	15.9	18.2	16.8	8	52	59	55	8
BH01020	0.0	3.0	0.8	8	0	19	16	8
BH01025	17.9	49.5	36.0	9	23	37	28	9
BH01033	24.0	94.5	46.4	9	16	32	22	9
BH01331	0.0	0.0	0.0	1	128	128	128	1
Harwich Formation	**0.3**	**0.3**	**0.3**	**11**	**7**	**425**	**315**	**11**
BH01002	0.3	0.3	0.3	11	7	425	315	11
Gravesend link:	**27.8**	**43.2**	**38.9**	**9**	**26**	**33**	**28**	**9**
Chalk	**27.8**	**43.2**	**38.9**	**9**	**26**	**33**	**28**	**9**
BH02002	27.8	43.2	38.9	9	26	33	28	9
South Portal and approach:	**0.0**	**115.0**	**69.2**	**35**	**19**	**38**	**27**	**35**
Chalk	**0.0**	**115.0**	**69.2**	**35**	**19**	**38**	**27**	**35**
BH03001	43.4	76.2	67.1	10	19	24	23	10
BH03002	73.4	115.0	92.9	8	31	33	32	8
BH03003	44.4	51.6	48.8	8	23	37	28	8
BH03006	73.1	85.7	77.1	8	24	28	26	8
BH03304	0.0	0.0	0.0	1	38	38	38	1

Geographical region, geology and BH ID	Nitrate (mg NO_3/L)				Chloride (mg/L)			
	Minimum	Maximum	Average	n	Minimum	Maximum	Average	n
Bored tunnel:	**0.0**	**108.0**	**38.3**	**227**	**0**	**7,860**	**853**	**227**
Alluvium	**0.0**	**1.9**	**0.5**	**65**	**0**	**7,860**	**2,791**	**65**
BH04006	0.3	1.8	1.1	7	40	120	62	7
BH05005	0.3	0.7	0.3	8	1,210	3,480	2,674	8
WS04007	0.3	0.7	0.4	8	2,510	3,850	3,199	8
WS05001	0.0	0.3	0.3	8	0	2,520	1,495	8
WS05002	0.3	0.3	0.3	8	4,420	7,860	6,179	8
WS05003	0.3	1.9	0.5	8	566	3,050	1,702	8
WS05004	0.3	0.3	0.3	10	577	5,510	4,159	10
WS05005	0.3	1.1	0.5	8	653	3,680	2,174	8
Chalk	**0.0**	**108.0**	**54.1**	**151**	**0**	**755**	**69**	**151**
BH03004	74.0	88.1	77.8	8	21	24	22	8
BH03005	3.5	107.0	81.7	8	31	64	40	8
BH04001	70.9	86.9	78.9	8	41	57	44	9
BH04004	85.7	108.0	97.2	8	48	53	50	8
BH05003	0.3	1.4	0.4	11	50	195	67	11
BH05004	3.0	62.9	44.1	9	85	440	197	9
BH05007	0.3	58.1	26.4	11	83	458	206	11
BH2034	0.0	106.0	86.1	6	0	162	117	6
BH2036	0.0	63.2	48.1	6	34	39	36	6
BH2301	0.0	31.9	26.6	7	10	28	25	7

Geographical region, geology and BH ID	Nitrate (mg NO_3/L)				Chloride (mg/L)			
	Minimum	Maximum	Average	n	Minimum	Maximum	Average	n
BH2302	54.0	93.0	62.6	5	35	41	39	5
OH03001	0.0	88.3	63.9	19	0	33	24	19
OH03002	0.0	83.3	68.0	18	0	34	28	18
OH03003	0.0	70.7	53.2	15	0	64	30	15
PW03001	47.0	47.0	47.0	1	54	54	54	1
BH03317	0.0	0.0	0.0	1	83	83	83	1
BH04301	0.0	0.0	0.0	1	57	57	57	1
BH04304	0.0	0.0	0.0	1	83	83	83	1
BH04306	0.0	0.0	0.0	1	39	39	39	1
BH04307	84.5	84.5	84.5	1	50	50	50	1
BH04310	0.3	0.3	0.3	1	40	40	40	1
BH05302	1.9	1.9	1.9	1	755	755	755	1
BH05303	15.2	15.2	15.2	1	313	313	313	1
BH05304	0.0	52.3	34.8	3	83	91	87	3
River Terrace Deposits	**0.0**	**64.6**	**45.9**	**11**	**53**	**677**	**174**	**11**
BH05011	0.3	64.6	52.7	9	53	87	71	9
BH05305	0.0	31.4	15.7	2	605	677	641	2

Notes:
The above data is from Phase 1 and available Phase 2 of the Project ground investigation, for all groundwater sites located south of the River Thames.
The data was collected between September 2018 and January 2021.
The limit of detection varies between laboratories. On this Project, the limit of detection for nitrate as NO_3 varies between 0.1 and 0.3.
n = count of data points.
Average shown is the arithmetic mean.

Table 1.2 Regional groundwater quality summary – north of the River Thames

Geographical region, geology and BH ID	Nitrate (mg NO_3/L)				Chloride (mg/L)			
	Minimum	Maximum	Average	n	Minimum	Maximum	Average	n
Bored tunnel:	**0.1**	**0.5**		**20**	**451**	**13,500**	**4,410**	**27**
Alluvium	0.2	0.2	0.2	7	**2,560**	**10,900**	**6,110**	**8**
BH06016	0.2	0.2	0.2	1	7,880	7,880	7,880	1
BH07008	0.2	0.2	0.2	1	2,860	2,860	2,860	1
BH07018	0.2	0.2	0.2	2	2,560	2,740	2,650	2
BH07020	0.2	0.2	0.2	1	8,100	8,100	8,100	1
BH07023	0.2	0.2	0.2	1	8,850	8,850	8,850	1
OH07024	0.2	0.2	0.2	1	4,990	4,990	4,990	1
OH06009A					10,900	10,900	10,900	1
Chalk	**0.2**	**0.2**		**4**	**451**	**13,500**	**5,802**	**6**
BH07021	0.2	0.2	0.2	2	451	3,370	1,911	2
OH07021	0.2	0.2	0.2	1	3,810	3,810	3,810	1
OH07036	0.2	0.2	0.2	1	7,460	7,460	7,460	1
OH06003					6,220	6,220	6,220	1
OH06007A					13,500	13,500	13,500	1
Made Ground	**0.1**	**0.5**		**9**	**1,080**	**7,300**	**2,568**	**12**
BH06014	0.2	0.2	0.2	1	4,280	4,280	4,280	1
BH06017	0.2	0.2	0.2	1	1,080	1,080	1,080	1
BH07007	0.2	0.2	0.2	2	1,320	1,360	1,340	2
BH07010	0.2	0.2	0.2	1	7,300	7,300	7,300	1

Geographical region, geology and BH ID	Nitrate (mg NO_3/L)				Chloride (mg/L)			
	Minimum	Maximum	Average	n	Minimum	Maximum	Average	n
BH2374	0.1	0.5	0.15	4	1,940	2,930	2,210	7
River Terrace Deposits					**4,560**	**4,560**	**4,560**	**1**
OH06004					4,560	4,560	4,560	1
North Portal and approach:	**0.1**	**48.2**		**99**	**0**	**11,800**	**4,171**	**116**
Alluvium	**0.1**	**27.7**		**26**	**0**	**11,800**	**6,849**	**32**
BH07024	1.6	1.6	1.6	2	3,460	6,770	5,115	2
BH07031	0.2	0.2	0.2	2	0	9,140	4,570	2
BH07049	0.2	0.2	0.2	1	937	937	937	1
BH07065	0.2	0.2	0.2	1	7,310	7,310	7,310	1
BH07066	0.2	0.2	0.2	2	6,560	6,780	6,670	2
BH07067	0.2	0.2	0.2	1	5,860	5,860	5,860	1
BH07068	0.2	0.2	0.2	2	5,010	5,070	5,040	2
BH2392A	0.1	23.1	3.9	6	4,080	5,910	5,183	9
BH2602A	0.1	27.7	5.0	6	9,520	11,800	10,317	9
OH07008A	0.2	0.2	0.2	2	7,310	7,450	7,380	2
OH07034	0.2	0.2	0.2	1	8,010	8,010	8,010	1
Chalk	**0.1**	**48.2**		**29**	**83**	**7,370**		**55**
BH07032	0.2	0.2	0.2	2	3,310	6,080	4,695	2
BH07069	0.2	0.2	0.2	1	1,340	1,340	1,340	1
BH2385	0.1	48.2	7.0	7	1,540	7,370	4,325	30
BH2603A	0.1	40.1	7.1	6	2,540	4,760	3,929	9

Geographical region, geology and BH ID	Nitrate (mg NO_3/L)				Chloride (mg/L)			
	Minimum	Maximum	Average	n	Minimum	Maximum	Average	n
OH07012	0.2	0.2	0.2	2	3,810	3,860	3,835	2
OH07023	0.2	0.2	0.2	3	2,240	2,830	2,463	3
OH07035	0.2	0.2	0.2	4	83	4,160	2,681	4
OH07038	0.2	0.2	0.2	1	3,160	3,160	3,160	1
OH07040	0.2	0.2	0.2	2	3,600	3,610	3,605	2
OH07041	0.2	0.2	0.2	1	4,190	4,190	4,190	1
Made Ground	**0.1**	**0.8**		**29**	**64**	**8,230**		**32**
BH07030	0.2	0.2	0.2	1	7,110	7,110	7,110	1
BH07034	0.2	0.2	0.2	1	3,840	3,840	3,840	1
BH07046	0.2	0.2	0.2	3	990	2,510	1,637	3
BH07060	0.2	0.2	0.2	1	108	108	108	1
BH07064	0.2	0.2	0.2	1	2,630	2,630	2,630	1
BH07091	0.2	0.2	0.2	1	357	357	357	1
BH07092	0.2	0.2	0.2	1	1,260	1,260	1,260	1
BH07094				0	1,860	1,860	1,860	1
BH07095	0.2	0.2	0.2	1	215	215	215	1
BH07096	0.2	0.2	0.2	8	64	1,580	321	8
BH07097	0.2	0.2	0.2	1	1,860	1,860	1,860	1
BH07098				0	1,620	1,620	1,620	1
BH07099	0.2	0.2	0.2	2	1,790	1,850	1,820	2
BH1309A	0.1	0.8	0.2	6	7,290	8,230	7,626	9

Geographical region, geology and BH ID	Nitrate (mg NO_3/L)				Chloride (mg/L)			
	Minimum	Maximum	Average	n	Minimum	Maximum	Average	n
Made Ground/Alluvium	**0.2**	**0.2**		**3**	**1,180**	**1,460**		**3**
BH07038	0.2	0.2	0.2	3	1,180	1,460	1,290	3
River Terrace Deposits	**0.1**	**18.2**		**18**	**695**	**8,160**		**15**
BH08004	0.2	0.2	0.2	1	695	695	695	1
BH08008	0.2	0.2	0.2	2	1,050	1,250	1,150	2
BH2384	0.1	18.2	5.6	5	801	8,160	5,290	8
OH07006	0.2	0.3	0.1	5	2,680	2,680	2,680	1
OH07007	0.2	0.2	0.2	4	2,580	2,870	2,725	2
OH07037	0.2	0.2	0.2	1	2,910	2,910	2,910	1
Tilbury Viaduct:	**0.0**	**390.0**	**121.8**	**53**	**29**	**4,210**	**468**	**55**
Alluvium	**0.0**	**0.0**	**0.0**	**2**	**232**	**4,210**	**2,221**	**2**
BH08010	0.0	0.0	0.0	1	4,210	4,210	4,210	1
WS08004	0.0	0.0	0.0	1	232	232	232	1
Chalk	**0.0**	**150.0**	**14.2**	**13**	**29**	**3,240**	**1,124**	**15**
BH08022	0.0	0.0	0.0	1	1,780	1,780	1,780	1
BH2604A	0.0	13.3	2.9	5	731	3,720	2,215	9
BH2612	0.0	150.0	33.9	5	29	41	34	5
BH08307	0.0	0.0	0.0	1	159	159	159	1
BH08308	0.0	0.0	0.0	1	51	51	51	1
Head Deposits	**0.0**	**180.0**	**126.8**	**8**	**41**	**143**	**55**	**8**
WS08028	0.0	180.0	144.9	7	41	44	42	7

Geographical region, geology and BH ID	Nitrate (mg NO_3/L)				Chloride (mg/L)			
	Minimum	Maximum	Average	n	Minimum	Maximum	Average	n
BH08309	0.0	0.0	0.0	1	143	143	143	1
Made Ground	**0.0**	**0.0**	**0.0**	**1**	**174**	**174**	**174**	**1**
WS08006	0.0	0.0	0.0	1	174	174	174	1
River Terrace Deposits	**0.0**	**390.0**	**187.8**	**28**	**52**	**1,530**	**130**	**28**
BH08013	0.0	0.0	0.0	1	1,530	1,530	1,530	1
BH08023	0.0	0.0	0.0	1	196	196	196	1
BH09002	0.0	252.0	189.3	8	70	82	76	8
BH2613	0.0	233.0	129.6	7	54	72	66	7
WS09013	0.0	390.0	283.8	10	52	94	74	10
BH09300	0.0	0.0	0.0	1	102	102	102	1
Thanet Formation	**0.0**	**0.0**	**0.0**	**1**	**186**	**186**	**186**	**1**
BH08027	0.0	0.0	0.0	1	186	186	186	1
Chadwell St Mary link:	**0.0**	**472.0**	**81.3**	**111**	**0**	**915**	**88**	**130**
Chalk	**0.0**	**34.9**	**3.7**	**37**	**36**	**184**	**64**	**56**
BH09010	0.0	34.9	10.4	7	40	49	44	16
BH10003	0.0	0.3	0.2	8	36	62	51	18
BH10008	5.4	10.0	8.6	7	77	184	101	7
BH12003	0.0	0.3	0.3	10	57	63	59	10
BH10302	0.0	0.0	0.0	1	74	74	74	1
BH10308	0.0	0.0	0.0	1	51	51	51	1
BH12300	0.0	0.0	0.0	2	64	65	64	2

Geographical region, geology and BH ID	Nitrate (mg NO_3/L)				Chloride (mg/L)			
	Minimum	Maximum	Average	n	Minimum	Maximum	Average	n
BH12303	0.0	0.0	0.0	1	84	84	84	1
Head Deposits	**0.0**	**0.0**	**0.0**	**1**	**77**	**77**	**77**	**1**
BH10306A	0.0	0.0	0.0	1	77	77	77	1
River Terrace Deposits	**0.0**	**288.0**	**99.7**	**25**	**34**	**82**	**60**	**25**
WS10006	0.0	61.0	36.8	8	60	82	68	8
WS11002	0.0	75.7	35.9	10	62	75	67	10
BH09011	240.0	288.0	262.7	7	34	46	41	7
Thanet Formation	**0.0**	**472.0**	**133.2**	**48**	**0**	**915**	**122**	**48**
BH09006	0.0	472.0	392.1	9	88	97	93	9
BH10004	0.0	61.4	44.4	8	67	88	75	8
BH11004	0.0	142.0	116.1	7	177	199	190	7
BH11007	0.0	227.0	125.7	9	68	74	71	9
BH13002	0.0	293.0	141.5	4	49	915	267	4
BH11003	0.0	0.0	0.0	1	0	0	0	1
BH09302	0.0	0.0	0.0	1	97	97	97	1
BH09307	0.0	0.0	0.0	1	153	153	153	1
BH09310	0.0	0.0	0.0	1	82	82	82	1
BH09311	0.0	0.0	0.0	1	164	164	164	1
BH10305	0.0	0.0	0.0	1	84	84	84	1
BH10307A	0.0	0.0	0.0	1	33	33	33	1
BH10311	0.0	0.0	0.0	1	204	204	204	1

Geographical region, geology and BH ID	Nitrate (mg NO_3/L)				Chloride (mg/L)			
	Minimum	Maximum	Average	n	Minimum	Maximum	Average	n
BH11301	0.0	0.0	0.0	1	469	469	469	1
BH11305	0.0	0.0	0.0	1	43	43	43	1
BH12305	0.0	0.0	0.0	1	72	72	72	1
A13/A1089/A122 Lower Thames Crossing junction:	**0.0**	**279.0**	**29.2**	**89**	**0**	**470**	**68**	**89**
Chalk	**0.0**	**7.8**	**0.8**	**23**	**11**	**75**	**31**	**23**
BH12005	0.0	7.8	1.7	9	11	18	15	9
BH13009	0.0	0.5	0.3	11	31	40	35	11
BH13335	0.0	0.0	0.0	2	57	57	57	2
BH13337	0.0	0.0	0.0	1	75	75	75	1
Harwich Formation	**0.0**	**0.3**	**0.2**	**6**	**34**	**48**	**42**	**6**
BH15003A	0.3	0.3	0.3	4	34	44	39	4
BH15307	0.0	0.0	0.0	1	45	45	45	1
BH15308	0.0	0.0	0.0	1	48	48	48	1
Head Deposits	**0.0**	**13.8**	**3.8**	**6**	**0**	**470**	**205**	**6**
WS15002	0.0	13.8	3.8	6	0	470	205	6
Lambeth Group	**0.3**	**0.3**	**0.3**	**5**	**8**	**97**	**40**	**5**
BH14012	0.3	0.3	0.3	5	8	97	40	5
London Clay Formation	**0.0**	**0.0**	**0.0**	**1**	**67**	**67**	**67**	**1**
BH15316	0.0	0.0	0.0	1	67	67	67	1
River Terrace Deposits	**3.3**	**9.8**	**6.0**	**3**	**59**	**76**	**69**	**3**

Geographical region, geology and BH ID	Nitrate (mg NO_3/L)				Chloride (mg/L)			
	Minimum	Maximum	Average	n	Minimum	Maximum	Average	n
BH14008	3.3	9.8	6.0	3	59	76	69	3
Thanet Formation	**0.0**	**279.0**	**56.5**	**45**	**22**	**209**	**75**	**45**
BH13015	0.0	265.0	171.8	8	50	88	57	8
BH14004	0.3	6.8	3.4	7	83	129	98	7
BH12018	39.8	279.0	161.9	5	70	100	83	5
OH13004	156.0	178.0	167.0	2	22	24	23	2
BH12314	0.0	0.0	0.0	1	60	60	60	1
BH13310	0.0	0.0	0.0	1	63	63	63	1
BH13313	0.0	0.0	0.0	1	97	97	97	1
BH13315	0.0	0.0	0.0	1	69	69	69	1
BH13320	0.0	0.0	0.0	1	113	113	113	1
BH13324	0.0	0.0	0.0	1	59	59	59	1
BH13325	0.0	0.0	0.0	1	100	100	100	1
BH13328	0.0	0.0	0.0	1	209	209	209	1
BH13331	0.0	0.0	0.0	1	41	41	41	1
BH13339	0.0	0.0	0.0	1	63	63	63	1
BH13348	0.0	0.0	0.0	1	133	133	133	1
BH13351	0.0	0.0	0.0	2	30	34	32	2
BH13352	0.0	0.0	0.0	1	151	151	151	1
BH14302	0.0	0.0	0.0	1	116	116	116	1
BH14305	0.0	0.0	0.0	2	75	75	75	2

Geographical region, geology and BH ID	Nitrate (mg NO_3/L)				Chloride (mg/L)			
	Minimum	Maximum	Average	n	Minimum	Maximum	Average	n
BH14310	0.0	0.0	0.0	2	33	36	35	2
BH14329	0.0	0.0	0.0	1	43	43	43	1
BH14330	0.0	0.0	0.0	1	91	91	91	1
BH15302	0.0	0.0	0.0	1	49	49	49	1
BH15314	0.0	0.0	0.0	1	28	28	28	1
Ockendon Link:	**0.0**	**216.0**	**18.8**	**132**	**0**	**1,230**	**143**	**132**
Alluvium	**0.0**	**170.0**	**27.9**	**77**	**0**	**1,230**	**159**	**77**
OH16001	0.3	17.9	4.1	5	32	86	51	5
OH19002	0.6	31.8	15.5	6	115	139	127	6
OH19003	3.9	170.0	88.9	7	6	28	14	7
WS16005	22.3	156.0	94.8	5	33	47	39	5
WS17003	12.7	111.0	71.4	6	27	33	29	6
WS17006	0.0	123.0	21.9	8	0	899	144	8
WS17005	0.3	26.6	4.2	7	176	423	272	7
WS16009	0.3	1.5	0.7	5	79	233	146	5
WS17004	0.3	18.5	2.6	8	61	111	84	8
WS16010	0.0	12.8	5.1	5	0	379	160	5
WS16001	0.3	115.0	31.7	8	132	1,230	500	8
WS18004	0.0	3.7	0.8	6	0	463	248	6
WS16307A	0.0	0.0	0.0	1	36	36	36	1

Geographical region, geology and BH ID	Nitrate (mg NO_3/L)				Chloride (mg/L)			
	Minimum	Maximum	Average	n	Minimum	Maximum	Average	n
Harwich Formation	**0.0**	**0.3**	**0.0**	**14**	**22**	**36**	**29**	**14**
OH17001	0.3	0.3	0.3	2	32	32	32	2
BH16305	0.0	0.0	0.0	1	36	36	36	1
BH16310	0.0	0.0	0.0	1	29	29	29	1
BH16314	0.0	0.0	0.0	1	22	22	22	1
BH16315	0.0	0.0	0.0	1	22	22	22	1
BH17301	0.0	0.0	0.0	2	29	30	30	2
BH17302	0.0	0.0	0.0	1	29	29	29	1
BH17304	0.0	0.0	0.0	1	25	25	25	1
BH17305	0.0	0.0	0.0	1	31	31	31	1
BH17308A	0.0	0.0	0.0	2	26	27	26	2
BH17316	0.0	0.0	0.0	1	33	33	33	1
Head Deposits	**0.3**	**216.0**	**36.4**	**6**	**105**	**841**	**318**	**6**
WS16008	0.3	216.0	36.4	6	105	841	318	6
Head Deposits or Alluvium	**0.3**	**12.4**	**4.3**	**3**	**426**	**709**	**548**	**3**
WS16003	0.3	12.4	4.3	3	426	709	548	3
Lambeth Group	**0.0**	**34.4**	**11.6**	**3**	**20**	**120**	**55**	**3**
BH17306	0.0	34.4	11.6	3	20	120	55	3
London Clay Formation	**0.0**	**9.9**	**1.5**	**23**	**36**	**171**	**100**	**23**
OH16003	0.3	7.0	1.7	6	155	171	161	6
OH16004	0.3	9.9	2.3	5	112	134	125	5

Geographical region, geology and BH ID	Nitrate (mg NO_3/L)				Chloride (mg/L)			
	Minimum	Maximum	Average	n	Minimum	Maximum	Average	n
OH17004	0.3	9.4	1.5	8	45	68	51	8
BH16311	0.0	0.0	0.0	1	36	36	36	1
BH16322	0.0	0.0	0.0	1	73	73	73	1
BH17312	0.0	0.0	0.0	1	100	100	100	1
WS16306	0.0	0.0	0.0	1	91	91	91	1
Superficial Deposits	**0.3**	**20.0**	**4.7**	**6**	**12**	**25**	**20**	**6**
OH19001	0.3	20.0	4.7	6	12	25	20	6
A122/M25 Junction	**0.0**	**91.5**	**44.2**	**34**	**22**	**1,220**	**184**	**34**
Harwich Formation	**0.0**	**0.0**	**0.0**	**1**	**25**	**25**	**25**	**1**
BH17315	0.0	0.0	0.0	1	25	25	25	1
Head Deposits	**0.0**	**0.0**	**0.0**	**1**	**878**	**878**	**878**	**1**
BH21357	0.0	0.0	0.0	1	878	878	878	1
London Clay Formation	**0.0**	**0.0**	**0.0**	**3**	**131**	**1,220**	**854**	**3**
BH17313	0.0	0.0	0.0	1	131	131	131	1
BH19309	0.0	0.0	0.0	2	1,210	1,220	1,215	2
Made Ground/Alluvium	**0.0**	**0.0**	**0.0**	**1**	**892**	**892**	**892**	**1**
BH21355	0.0	0.0	0.0	1	892	892	892	1
River Terrace Deposits	**2.4**	**91.5**	**53.7**	**28**	**22**	**240**	**68**	**28**
OH20001	55.1	88.1	73.0	6	54	63	57	6
OH20002	41.8	75.1	57.2	6	30	47	38	6
OH20003	72.2	91.5	77.2	6	54	76	67	6

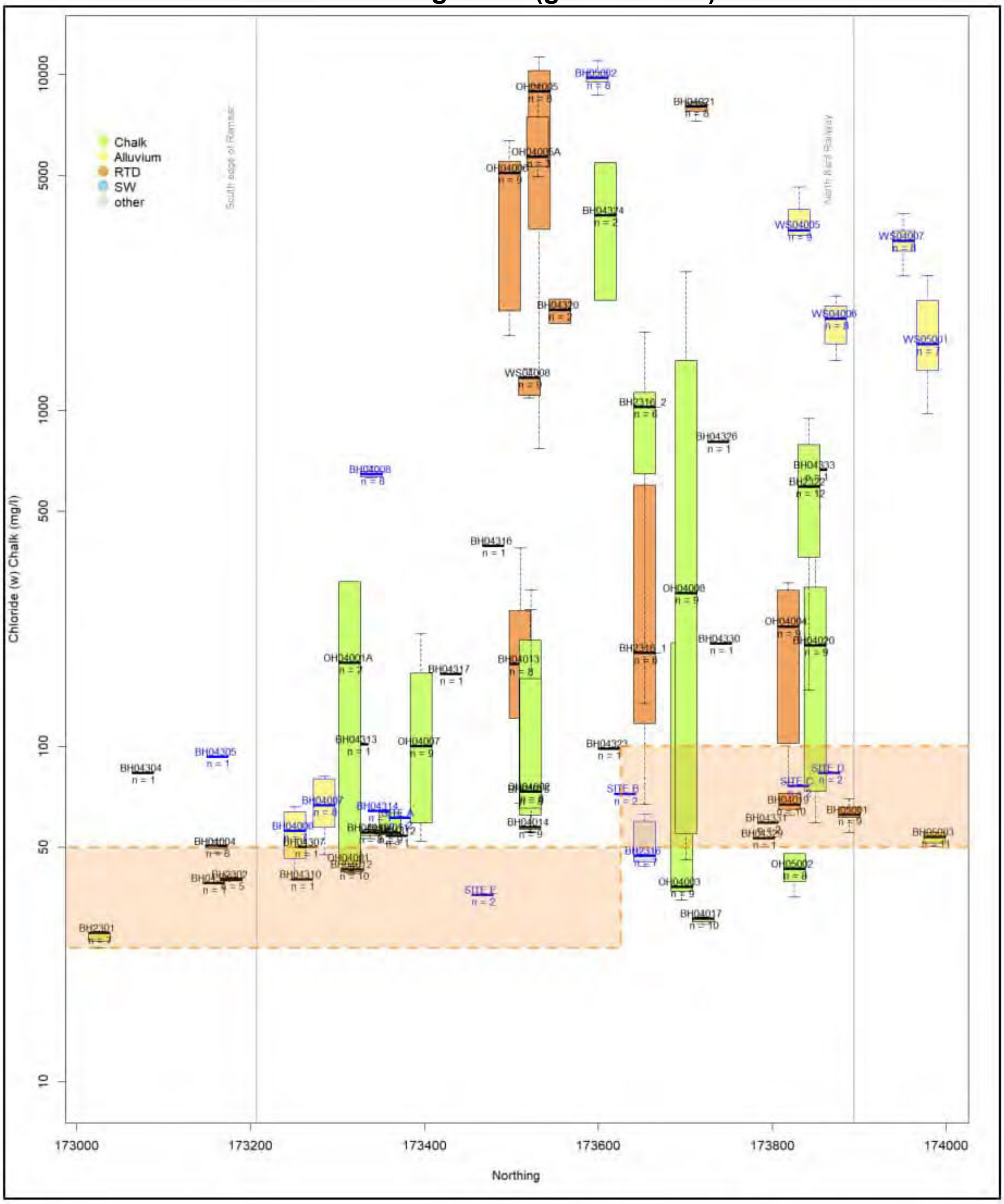
Geographical region, geology and BH ID	Nitrate (mg NO_3/L)				Chloride (mg/L)			
	Minimum	Maximum	Average	n	Minimum	Maximum	Average	n
OH20004	2.4	65.6	41.7	5	22	61	45	5
OH20005	6.7	12.7	10.1	5	92	240	143	5

Notes:
The above data is from Phase 1 and available Phase 2 of the Project ground investigation, for all groundwater sites located north of the River Thames.
The data was collected between September 2018 and January 2021 as part of ongoing ground investigation works.
The limit of detection varies between laboratories. On this Project, the limit of detection for nitrate varies between 0.1 and 0.3.
n = count of data points.
Average shown is the arithmetic mean.

Annex G Groundwater quality data summary – Ramsar site

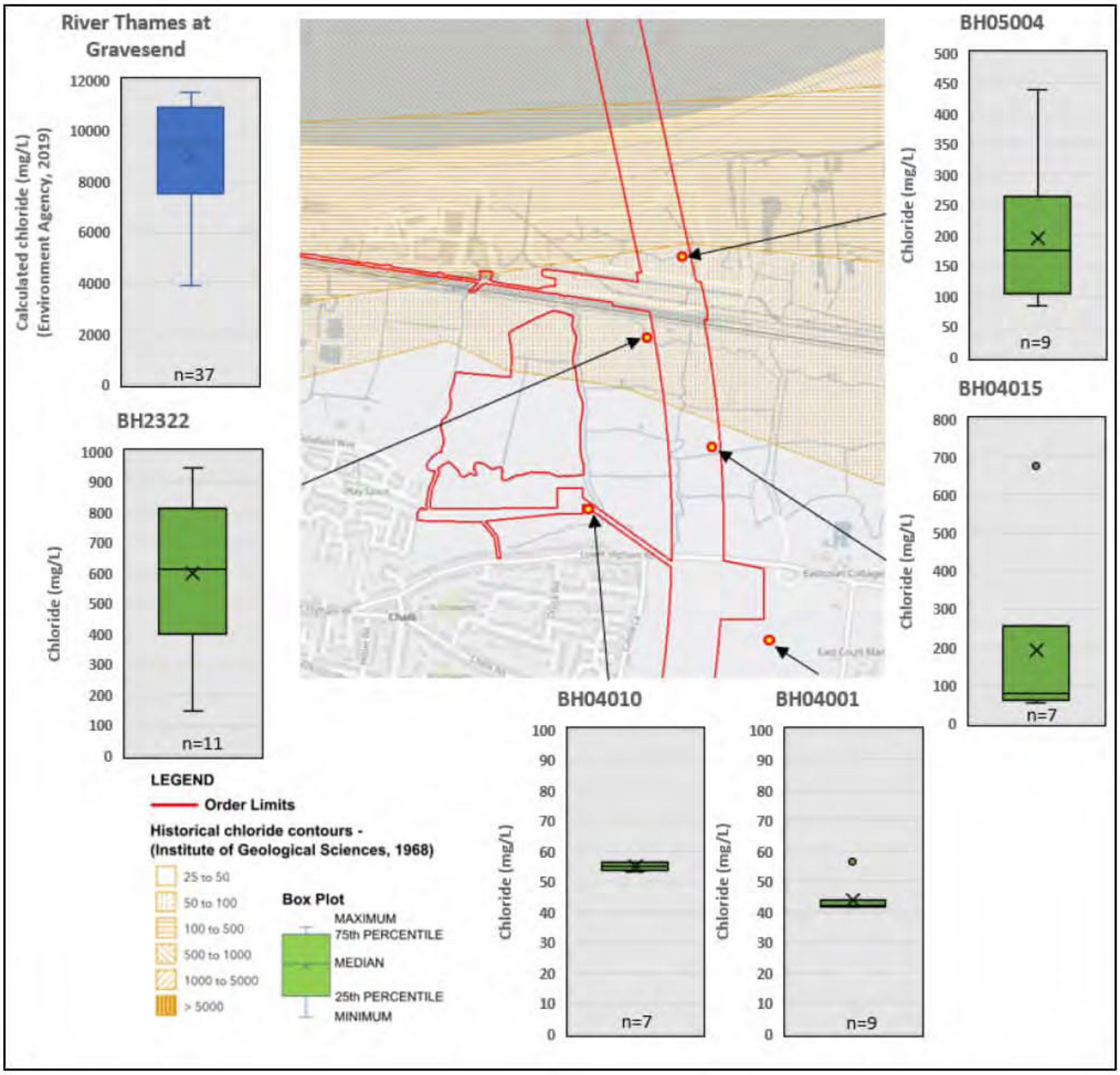
Annex G Groundwater quality data summary – Ramsar Site

Plate 1.1 Box plots vs. northing – chloride – all strata – in the Ramsar site and surrounding areas (groundwater)



Note: Blue box outline and blue text show results for shallower strata. Black box outline and black text refer to deeper strata such as those that comprise the Chalk aquifer. Shaded orange areas indicate maximum and minimum values of historical Chalk aquifer chloride contour data (adapted from Institute of Geological Sciences, 1968). Box plots are based on data from Phase 1 and 2 GI monitoring between September 2018 and January 2021.

Plate 1.2 Historical and current baseline chloride concentrations (Chalk aquifer) – south of the River Thames



Note: Plate 1.2 repeated from Annex F for completeness.

Table 1.1 Ramsar site groundwater quality (nitrate and chloride)

Geographical region, geology and BH ID	Nitrate (mg NO_3 /L)				Chloride (mg/L)			
	Minimum	Maximum	Average	n	Minimum	Maximum	Average	n
Ramsar surface:	**0.3**	**1.5**	**0.4**	**41**	**48**	**11,000**	**3,169**	**41**
Alluvium	**0.3**	**1.5**	**0.4**	**41**	**48**	**11,000**	**3,169**	**41**
BH04007	0.3	0.5	0.3	8	48	146	75	8
BH04008	0.3	0.4	0.3	8	630	681	648	8
BH05002	0.3	0.3	0.3	8	8,690	11,000	9,821	8
WS04005	0.3	1.0	0.4	9	1,240	5,860	3,441	9
WS04006	0.3	1.5	0.5	8	1,410	2,190	1,826	8
Ramsar deep:	**0.0**	**159.0**	**40.0**	**230**	**0**	**11,300**	**1,043**	**234**
Chalk	**0.0**	**159.0**	**44.6**	**143**	**0**	**5,470**	**291**	**146**
BH5004	3	63	44	9	85	440	197	9
BH04010	98.2	111.0	105.5	8	53	57	55	8
BH04011	49.4	62.3	58.0	9	51	145	66	9
BH04012	102.0	159.0	110.9	10	42	45	43	10
BH04014	39.9	61.3	57.0	9	56	123	65	9
BH04015	45.5	61.4	55.4	8	56	676	177	8
BH04017	54.1	58.7	56.1	10	29	31	30	10
BH04020	8.9	78.9	50.4	9	59	521	231	9
BH2316_2	4.4	51.4	33.5	5	134	1,710	944	6
BH2322	10.8	35.3	21.5	10	147	947	577	12
OH04001A	0.0	130.0	46.0	5	0	309	71	5
OH04002	0.0	65.5	40.9	10	0	293	95	10

Geographical region, geology and BH ID	Nitrate (mg NO_3 /L)				Chloride (mg/L)			
	Minimum	Maximum	Average	n	Minimum	Maximum	Average	n
OH04003	0.0	59.3	16.1	10	0	470	111	10
OH04007	0.0	66.6	46.8	10	0	1,290	214	10
OH04008	0.0	21.4	9.1	10	0	4,230	952	10
OH05002	0.0	16.4	9.4	9	0	65	40	9
BH04312	5.9	5.9	5.9	1	54	54	54	1
BH04313	50.5	50.5	50.5	1	101	101	101	1
BH04317	15.3	15.3	15.3	1	164	164	164	1
BH04323	16.6	16.6	16.6	1	98	98	98	1
BH04324	0.0	1.7	0.9	2	2,130	5,470	3,800	2
BH04326	9.4	9.4	9.4	1	806	806	806	1
BH04329	0.1	0.1	0.1	1	53	53	53	1
BH04331	0.0	0.0	0.0	2	59	59	59	2
BH04333	0.9	0.9	0.9	1	665	665	665	1
River Terrace Deposits	**0.0**	**97.0**	**32.6**	**87**	**0**	**11,300**	**2,291**	**88**
BH04013	75.6	91.4	83.0	8	68	389	194	8
BH04019	56.3	67.0	63.3	10	62	643	133	10
BH04021	0.3	0.3	0.3	8	7,280	8,310	7,966	8
BH05001	50.5	56.5	55.0	9	56	70	63	9
BH2316_1	18.0	97.0	51.6	5	67	1,090	375	6
OH04004	0.0	66.9	47.7	10	0	610	214	10
OH04005	0.0	0.3	0.1	8	772	11,300	7,172	8
OH04005A	0.1	23.6	6.1	4	0	9,300	4,988	4

Geographical region, geology and BH ID	Nitrate (mg NO_3 /L)				Chloride (mg/L)			
	Minimum	Maximum	Average	n	Minimum	Maximum	Average	n
OH04006	0.0	40.2	15.0	11	0	6,340	3,394	11
WS04008	0.0	0.8	0.3	10	0	1,330	1,080	10
BH04316	51.4	51.4	51.4	1	395	395	395	1
BH04320	2.1	2.3	2.2	2	1,820	2,150	1,985	2
BH04330	56.1	56.1	56.1	1	202	202	202	1

Table 1.2 Ramsar site groundwater quality (electrical conductivity)

Test type, geographical region, geology and BH ID	Electrical conductivity (µS/cm)			
	Minimum	**Maximum**	**Average**	**n**
Field Test Results				
Ramsar deep:	**561**	**30,230**	**4,065**	**1,022**
Chalk	561	13,450	1,896	710
BH2316_2	1,069	4,950	2,707	71
BH2322	1,284	4,303	3,138	64
OH04001A	728	2,521	944	92
OH04002	748	5,628	1,242	84
OH04003	628.1	1,391	814	107
OH04007	668.1	5,088	1,773	89
OH04008	835	13,450	3,897	110
OH05002	561.1	4,757	928	89
PW04001A	1,456	1,483	1,475	4
River Terrace Deposits	921	30,230	9,001	312
BH2316_1	1,343	6,098	3,573	61
OH04004	921	5,698	1,877	93
OH04005	3,999	13,466	9,115	3
OH04005A	1,177	30,230	26,033	55
OH04006	3,142	18,479	9,566	100
Laboratory Test Results				
Ramsar deep:	**864**	**5,500**	**3,026**	**24**
Chalk	1,140	5,500	3,445	16

Test type, geographical region, geology and BH ID	Electrical conductivity (µS/cm)			
	Minimum	Maximum	Average	n
BH2316_2	1,140	5,500	3,652	8
BH2322	2,390	3,890	3,237	8
River Terrace Deposits	864	4,720	2,189	8
BH2316_1	864	4,720	2,189	8

Notes:

The above data pertains only to the Ramsar site.

The limit of detection for nitrate testing within the ground investigation Package A is 0.3mg NO_3/L.

Average shown is the arithmetic mean.

'n' is the count or number of samples tested.

The date range for conductivity testing is September 2018 to January 2020.

The date range for nitrate and chloride concentration data is September 2018 to January 2021.

Annex H Highway cuttings – simple assessment

Annex H Highway cuttings – simple assessment

1.1 Introduction

1.1.1 The A122 Lower Thames Crossing (the Project) would provide a connection between the A2 and M2 in Kent, east of Gravesend, crossing under the River Thames through a tunnel, before joining the M25 south of junction 29.

1.1.2 The A122 road would be approximately 23km long, 4.25km of which would be in tunnel. On the south side of the River Thames, the Project route would link the tunnel to the A2 and M2. On the north side, it would link to the A13 and junction 29 of the M25. The tunnel entrances would be located to the east of the village of Chalk on the south of the River Thames and to the west of East Tilbury on the north side.

1.1.3 For an impact on a receptor to occur, both a source and a pathway need to be present. Design Manual for Roads and Bridges (DMRB) LA 113 Road Drainage and the Water Environment (Highways England, 2020a) provides methods for the simple and more detailed assessment of the construction of road schemes.

1.1.4 A simple assessment has been conducted to assess the likely impact that the proposed cuttings (during the operational phase) may have on the groundwater environment (groundwater flow and levels). The general approach to the simple assessment, including that for assessment of embankments, is set out in DMRB LA 113 Appendix A and comprises:

a. Step 1: establish the regional groundwater status

b. Step 2: develop a conceptual model of the surrounding area

c. Step 3: identify potential features that are susceptible

1.1.5 Sections 6.1 of Appendix 14.5 (Application Document 6.3) confirms the information used to inform the three steps. Section 6.2 of Appendix 14.5 provides further information on the matters considered in the simple assessment of cuttings.

1.1.6 This annex presents the qualitative results of the simple assessment and is based on the vertical alignment of the Project route and the proposed ground levels along the alignment (westbound carriageway along the A2, central line north of the Thames and as per detail of individual junction slipways). The vertical alignment is summarised in the A122 Lower Thames Crossing plan and profile drawings (Application Document TR010032/APP/2.9). These drawings have been used to assess the deepest elevation of each cutting along the alignment; although minor variation may occur in cross-section. These deepest elevations have then been compared to the likely groundwater level elevation, thereby indicating whether the base of the cutting is likely to intercept groundwater.

1.1.7 Groundwater-dependent receptors, including licensed groundwater abstractions, source protection zones (SPZs), aquifer bodies, Water Framework Directive (WFD) groundwater bodies, groundwater and surface water abstractions, surface waters, Groundwater Dependent Terrestrial Ecosystems

(GWDTEs) and areas susceptible to groundwater flooding, have then been identified near the main cuttings.

1.1.8 As described in Chapter 4: EIA Methodology of the Environmental Statement (Application Document 6.1), the significance of environmental effects was determined taking into account the value (sensitivity) of the receptor and the potential magnitude of impact.

1.1.9 The value (sensitivity) of the identified receptors/resources was determined using the criteria shown in Table 3.70 of DMRB LA 113 (Highways England, 2020a). The magnitude of impacts on receptors/resources was determined using the criteria outlined in Table 3.71 and Table B.3 of DMRB LA 113. Significance of effect was then determined using the matrix approach shown in Table 4.3 of Chapter 4: EIA Methodology (Application Document 6.1). Effects can be either beneficial or adverse. Where an impact magnitude is negligible, its overall significance of effect is classified as neutral, regardless of the sensitivity of the receptor.

1.1.10 The deepest and longest road cuttings are proposed at Gravesend link on the North Downs, the A122 main alignment under the existing A13 (A13/A1089/ A122 Lower Thames Crossing junction) and the northbound A122 alignment under the M25 (A122 Lower Thames Crossing/M25 junction)

1.1.11 Table 1.1 presents the simple assessment of highway cuttings including a comparison of the deepest elevation of the cutting (shown as the proposed road level) and available groundwater levels. The table shows that most road cuttings have been assessed as unlikely to intercept groundwater. In these cases, the magnitude of impact is negligible, resulting in no significant risk to groundwater levels and flows.

1.1.12 The highest potential impact has been assessed at the proposed A122 Lower Thames Crossing/M25 junction, since the cutting here is below the groundwater levels monitored during the ground investigations (GI). Nearby are potential groundwater receptors which are listed in Table 1.1. A potentially significant impact (without mitigation) has been concluded from the simple assessment. Therefore, a detailed assessment was subsequently conducted and is presented in Annex L.

Table 1.1 Highways cuttings – simple assessment

Cutting general area	Road level (minimum for cutting)	Maximum cutting depth (from natural ground level)	Length of cutting(s) (approx.)	Hydrogeology	Max. groundwater level (mAOD)	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels (based on the simple assessment
A2/M2		**No cutting** [7]							
A2		**No cutting** [7]							
M2/A2/Lower Thames Crossing junction Total of 18 cuttings	112 to 57mAOD	1.3 to 12m	6,760m	Potentially perched water in Lambeth Group and Thanet Formation aquifers. Underlain or sometimes outcropping Chalk aquifer with a deep water table	Perched water encountered in Lambeth Group and Thanet Formation – various depths 28mAOD (Chalk aquifer in Owletts Environment Agency observation borehole), i.e. tens of metres below Project.	• North Kent Medway Chalk WFD water body (very high importance) • Combined Source Protection Zone 2 (SPZ2) of public water supply wells (high importance) • Thanet Formation aquifer – Secondary A aquifer (medium importance) • Ponds that may be fed by perched groundwater	Negligible impact as: - Chalk aquifer water table is tens of metres below so no direct impact on flows or levels - Phase 2 ground investigation suggests perched water closest to respective cuttings is below cuttings.	**(Very high to Low importance) x Negligible magnitude of impact = Slight to neutral or slight adverse**	**Not significant**

Cutting general area	Road level (minimum for cutting)	Maximum cutting depth (from natural ground level)	Length of cutting(s) (approx.)	Hydrogeology	Max. groundwater level (mAOD)	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels (based on the simple assessment
						in Shorne and Ashenbank Woods Site of Special Scientific Interest (low to medium importance) • Jeskyns Community Woodland car park pond potential GWDTE (low importance)			
Gravesend link One cutting	31 to 22mAOD	29m	1,000m	Chalk aquifer with a deep water table	27mAOD (Chalk aquifer in Orchard Lea Environment Agency borehole) but water level lowers northwards as per Figure 1 of Appendix 14.5.	• North Kent Medway Chalk WFD water body (very high importance) • Ramsar (internationall y important wetland but assessed as not a GWDTE)	Negligible impact as: Chalk aquifer water table below the cutting so no direct impact.	**(Very high importance) x** **Negligible magnitude of impact =** **Slight adverse**	**Not significant**

Cutting general area	Road level (minimum for cutting)	Maximum cutting depth (from natural ground level)	Length of cutting(s) (approx.)	Hydrogeology	Max. groundwater level (mAOD)	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels (based on the simple assessment
South Portal and approach One cutting	34mAOD	25m	1,000m	Chalk aquifer with a deep water table	Base of the proposed cutting would be above the projected maximum groundwater levels based on February 2014 as per Figure 1 of Appendix 14.5.	• North Kent Medway Chalk WFD water body (very high importance) • Ramsar (internationally important wetland but assessed as not a GWDTE)	Negligible impact as: Chalk aquifer water table below the excavation. The tunnel headwall extends deeper so could cause minor change due to a local barrier effect but of negligible effect (Annex J).	**(Very high importance) x** **Negligible magnitude of impact =** **Slight adverse**	**Not significant**
North Portal approach One cutting	-4.8mAOD	10m	400m	Alluvium aquitard that overlies and confines the River Terrace Deposits and the underlying Chalk aquifers	Shallow groundwater level, above the excavation level	• South Essex Thurrock Chalk WFD water body (very high importance) • Irrigation reservoir at Low Street (medium importance) • Various ditches on Tilbury Marsh (low	. Negligible magnitude of impact (with mitigation as described in Annex K)	Detailed assessment in Annex K) **Very high importance) x** **Negligible magnitude of impact =** **Slight adverse**	**Not significant**

Cutting general area	Road level (minimum for cutting)	Maximum cutting depth (from natural ground level)	Length of cutting(s) (approx.)	Hydrogeology	Max. groundwater level (mAOD)	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels (based on the simple assessment
						importance potential GWDTE) • Mucking Flats Site of Special Scientific Interest (assessed as not a GWDTE) • Various private wells at Low Street (medium importance)			
Tilbury		**No cutting** [7]							
Chadwell St Mary link One cutting	12.4mAOD	2.9m	250m	Mostly Thanet Formation Secondary A aquifer (locally exhibiting a perched water level) overlying the Chalk aquifer. Some River Terrace Deposits overlying the Thanet Formation	Phase 2 ground investigation shows groundwater levels are several metres below the cutting depth (Thanet groundwater level 10.9mAOD at BH11007).	• South Essex Thurrock Chalk WFD water body (very high importance) • Linford public supply well and SPZ1 (very high importance) • Orsett Golf Course well	No change (groundwater level below the cutting)	(**Very high to medium importance) x Negligible magnitude of impact =** **Slight to neutral or slight adverse**	Not significant

Cutting general area	Road level (minimum for cutting)	Maximum cutting depth (from natural ground level)	Length of cutting(s) (approx.)	Hydrogeology	Max. groundwater level (mAOD)	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels (based on the simple assessment
						(medium importance) • South Essex Lower London Tertiaries WFD water body (medium importance) • Essex Gravels WFD water body (medium importance) • Gobians Sewer watercourse (baseflow) (medium importance)			

Cutting general area	Road level (minimum for cutting)	Maximum cutting depth (from natural ground level)	Length of cutting(s) (approx.)	Hydrogeology	Max. groundwater level (mAOD)	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels (based on the simple assessment
A13 / Project Main cuttings are the northbound and southbound A122 carriageways. There are various link roads of which some have cuttings. Total of 14 cuttings	29.5 to 17.3mAOD (different cuttings)	1.5m to 8.5m (different cuttings)	11,400m (total of all roads)	River Terrace Deposits overlying Lambeth Group and Thanet Formation Secondary A aquifers. The Chalk aquifer is below the above strata and is not expected to be excavated by the cuttings.	Phase 2 ground investigation borehole groundwater level at BH13009 (Chalk aquifer) is high at over 18mAOD and is over 7m higher than nearest Environment Agency monitoring borehole (Stanford shown in Annex C). Other Phase 2 and 3 groundwater level monitoring shows high groundwater in the Lambeth	• South Essex Thurrock Chalk WFD water body (very high importance) • Irrigation reservoir at Low Street (medium importance) • Linford public supply well (very high importance) • Orsett Golf course well (medium importance) • South Essex Lower London Tertiaries WFD water body (medium importance) • Essex Gravels WFD water body (medium importance)	A negligible impact to groundwater flows and levels (and related receptors), based on available groundwater level monitoring, has been assessed. This is because groundwater levels appear to be generally lower than proposed cutting levels, while in the deepest section of the A13 westbound to A122 southbound (link road 3), which cuts through the Thanet Formation, the estimated average	**(Very high to Medium importance) x Negligible magnitude of impact =** **Slight to neutral or slight adverse**	Not significant

Cutting general area	Road level (minimum for cutting)	Maximum cutting depth (from natural ground level)	Length of cutting(s) (approx.)	Hydrogeology	Max. groundwater level (mAOD)	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels (based on the simple assessment
					Group and Thanet Formation (up to 17.80mAOD at BH13353 along the main carriage cutting, and 20.07mAOD at BH13015 to the east). Groundwater in the Lambeth Group and Thanet Formation is known to be connected (see Annex N). Recorded groundwater levels would be generally below all cuttings, except for part of the		groundwater seepage into the road drainage is expected to be small. Highway drainage would intercept runoff and includes swale and an infiltration basin so some water would be returned to ground at appropriate locations. The total percentage footprint area of earthworks at the A13 is discussed in the embankment assessment (Section 6.3 and Annex I)		

Cutting general area	Road level (minimum for cutting)	Maximum cutting depth (from natural ground level)	Length of cutting(s) (approx.)	Hydrogeology	Max. groundwater level (mAOD)	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels (based on the simple assessment
					A13 westbound to A122 southbound (link road 3) cutting, , where the groundwater level in the Thanet Formation is estimated to be, on average, 0.9m above the proposed base of the road drainage.				

Cutting general area	Road level (minimum for cutting)	Maximum cutting depth (from natural ground level)	Length of cutting(s) (approx.)	Hydrogeology	Max. groundwater level (mAOD)	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels (based on the simple assessment
Ockendon link Northbound carriageway that approaches the A122 Lower Thames Crossing/M25 junction becomes a cutting near North Road and deepens towards the M25 One cutting	14.4mAOD	8.9m	2,150m	Alluvium (Phase 2 ground investigation encountered mostly cohesive soils) overlying London Clay Formation aquitard. Extent and hydrogeologic al properties the of River Terrace Deposits is unclear but assumed may extend into the area of the cutting.	Groundwater level information presented in Annex L. Cutting would be below the groundwater level.	• Essex Gravels WFD water body (WFD water body is mapped here but Phase 2 ground investigation suggests that gravels are thin or absent so may not applicable here) (medium importance, if present) • Licensed agricultural wells (aquifer source likely to be below the London Clay Formation and screened in the Harwich Formation) (medium importance)	Phase 2 ground investigation suggests that the thickness of the superficial deposits in this area are thin. No change would be expected at the licensed agricultural wells as the source aquifer is separate to the River Terrace Deposits. Drawdown (without mitigation) would be expected in the River Terrace Deposits/Essex Gravels WFD and is assessed in Annex L.	This cutting is continued as the cutting described in the below row and is included in the detailed assessment presented in Annex L.	**Potentially significant (without mitigation)**

Cutting general area	Road level (minimum for cutting)	Maximum cutting depth (from natural ground level)	Length of cutting(s) (approx.)	Hydrogeology	Max. groundwater level (mAOD)	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels (based on the simple assessment
Project / M25 Cutting along the northbound carriageway that approaches and passes beyond the M25 underpass and then extends northwards beneath Ockendon Road, eventually joining the existing M25 cutting. One cutting	10.0mAOD	15.6m	2,250m	River Terrace Deposits (glacial and interglacial deposits) and Head Deposits	Groundwater level information presented in Annex L. Cutting would be below the groundwater level.	• Essex Gravels WFD water body (medium importance) • Springs including one that feeds local water course which is the source of an irrigation reservoir (medium importance) • Cranham Local Nature Reserve (moderate importance as a GWDTE) • Recreational lakes - Stubbers Adventure Centre (medium importance) • Small ponds and ditches at North	Drawdown (without mitigation) would be expected in the River Terrace Deposits/Essex Gravels WFD and is assessed in Annex L.	This cutting is a continuation of the cutting described in the above row and is included in the detailed assessment presented in Annex L.	**Potentially significant (without mitigation)**

Cutting general area	Road level (minimum for cutting)	Maximum cutting depth (from natural ground level)	Length of cutting(s) (approx.)	Hydrogeology	Max. groundwater level (mAOD)	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels (based on the simple assessment
						Ockendon Landfill Site of Importance for Nature Conservation (SINC) (low importance – potential GWDTE) • SINC sites listed in Annex P (low to moderate importance – potential GWDTE)			

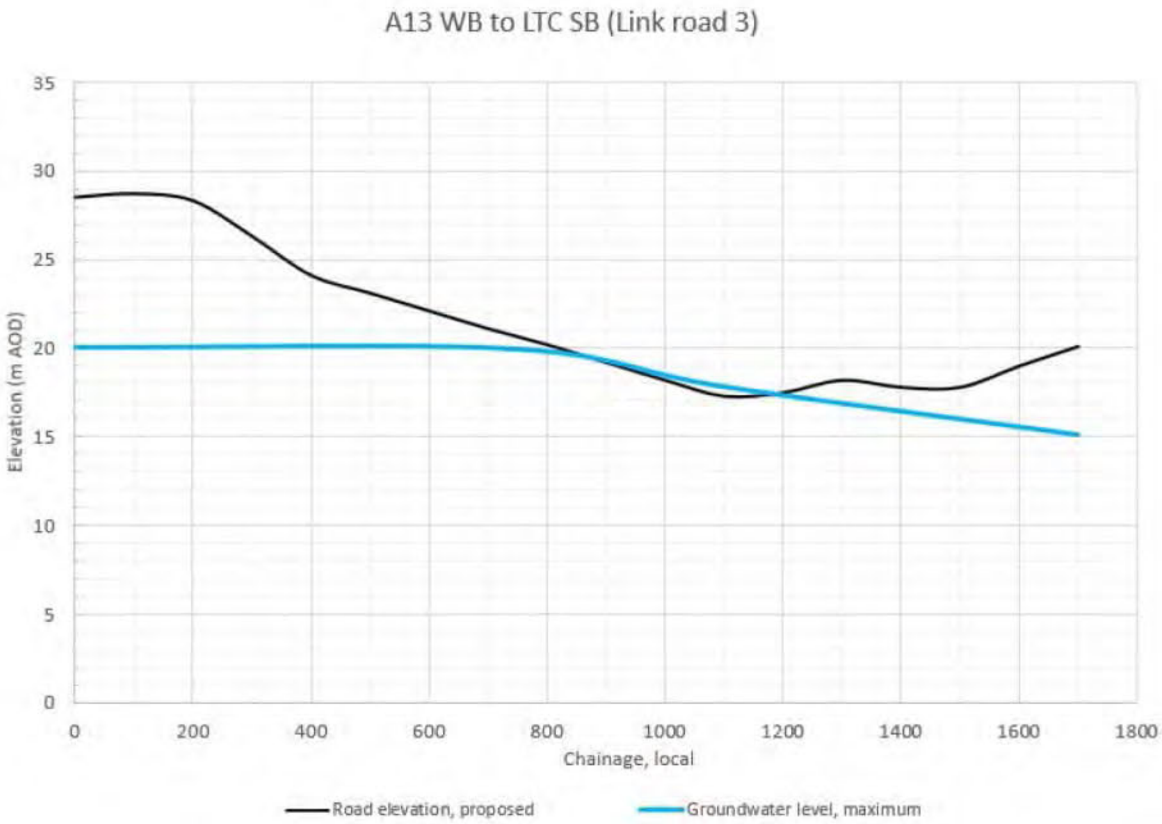
Notes:
[1] m – metres.
[2] mAOD – metres above ordnance datum.
[3] mbgl – metres below ground level.
[4] Ch – chainage.
[5] Importance (also known as value) based on criteria shown in Chapter 14: Road Drainage and the Water Environment (Application Document 6.1).
[6] Lowest value of A13 proposed road elevation does not include where existing ground level is 10.1mAOD as this is at the southern approach where ground levels are lower.
[7] Cuttings of 1mbgl or less have not been considered in the cutting assessment.
[8] The number of cuttings per area refers to number of separate cuttings along the road in the section discussed and/or additional cuttings associated with slip roads at junctions. Where a cutting continues from another then it is counted as one cutting in the above simple assessment.
[9] The proposed road elevations and coordinates of the deepest road cutting at the A13 junction, the A13 westbound to A122 southbound (link road 3), are listed in Table 1.2 and shown in Plate 1.1, which also shows a profile of the recorded maximum water levels from ground investigation groundwater monitoring.

[10] A conservative design minimum depth of groundwater level below road surface is 770mm based on 200mm subbase thickness assuming a California Bearing Ratio (CBR) of 5% according to DMRB CD 225 (Highways England, 2020c), 270mm asphalt based on DMRB CD 226 (Highways England 2020d) and 300mm water level below formation according to DMRB CD 225 (Highways England, 2020c).

Table 1.2 A13 westbound to A122 southbound summary proposed road elevations

Easting	Northing	Chainage (local)	Proposed road elevation (mAOD)	Road
564264.2	180805.9	600	22.1	Link road 3
564164.8	180794.6	700	21.1	Link road 3
564061.8	180778.4	800	20.2	Link road 3
563977.2	180730.5	900	19.2	Link road 3
563917.3	180652.2	1000	18.2	Link road 3
563887.0	180559.8	1100	17.3	Link road 3
563902.5	180461.1	1200	17.5	Link road 3
563951.1	180371.5	1300	18.2	Link road 3
564030.1	180309.5	1400	17.8	Link road 3
564118.2	180266.5	1500	17.8	Link road 3
564198.6	180228.4	1600	19.0	Link road 3
564299.5	180193.9	1700	20.1	Link road 3
564391.1	180166.4	1796	22.1	Link road 3

Plate 1.1 A13 westbound to A122 southbound summary profile



Annex I Highway embankments – simple assessment

Annex I Highway embankments – simple assessment

1.1 Introduction

1.1.1 The A122 Lower Thames Crossing (the Project) would provide a connection between the A2 and M2 in Kent, east of Gravesend, crossing under the River Thames through a tunnel, before joining the M25 south of junction 29.

1.1.2 The A122 road would be approximately 23km long, 4.25km of which would be in tunnel. On the south side of the River Thames, the Project route would link the tunnel to the A2 and M2. On the north side, it would link to the A13 and junction 29 of the M25. The tunnel entrances would be located to the east of the village of Chalk on the south of the River Thames and to the west of East Tilbury on the north side.

1.1.3 This simple assessment has been conducted to assess the likely impact that the proposed embankments (during the operational phase) may have on the groundwater environment (groundwater flow and levels).

1.1.4 For an impact on a receptor to occur, both a source and a pathway need to be present. Design Manual for Roads and Bridges (DMRB) LA 113 Road Drainage and the Water Environment (Highways England, 2020a) provides methods for the simple and more detailed assessment of the construction of road schemes.

1.1.5 The general approach to the simple assessment, including that for assessment of embankments, is set out in DMRB LA 113 Appendix A and comprises:

a. Step 1: establish the regional groundwater status

b. Step 2: develop a conceptual model of the surrounding area

c. Step 3: identify potential features that are susceptible

1.1.6 Sections 6.1 of Appendix 14.5 (Application Document 6.3) confirms the information used to inform the three steps. Section 6.3 provides further information on the matters considered in the simple assessment of embankments.

1.1.7 This annex presents the qualitative results of the assessment. This simple assessment has been based on the vertical alignment of the Project route and the proposed ground levels along the alignment, which comprise the following:

a. Engineered embankment comprising engineered fill earthworks which would support the highway above the existing ground level

b. Landscape embankments to be used for visual, noise and/or ecological benefit and which include ‘false cuttings’

1.1.8 The longest engineered embankments proposed are at Tilbury link, Chadwell St Mary link and the non-viaduct sections crossing the Mardyke floodplain at Ockendon link. The main areas of proposed landscape embankments are at the M2/A2/Project junction, Chadwell St Mary link, parts of the A13/A1089/Project junction and the southbound alignment at the Project/M25 junction.

1.1.9 This assessment focuses on three main types of potential impact on groundwater that could cause change to groundwater levels and flows:

a. Compression of soils causing locally reduced hydraulic conductivity of shallow aquifers

b. Permanent covering of the natural ground surface causing locally reduced rainfall recharge

c. Ground improvement measures, beneath the embankment, altering the local hydraulic conductivity of material above or within an aquifer

1.1.10 Groundwater-dependent receptors including licensed groundwater abstractions, source protection zones (SPZs), aquifer bodies, Water Framework Directive (WFD) groundwater bodies, groundwater and surface water abstractions, surface waters, Groundwater dependent terrestrial ecosystems (GWDTEs) and areas susceptible to groundwater flooding have then been identified near the main embankment areas.

1.1.11 As described in Chapter 4: EIA Methodology of the Environmental Statement (Application Document 6.1), the significance of environmental effects was determined taking into account the value (sensitivity) of the receptor and the potential magnitude of impact.

1.1.12 The value (sensitivity) of the identified receptors/resources was determined using the criteria shown in Table 3.70 of DMRB LA 113 (Highways England, 2020a). The magnitude of impacts on receptors/resources was determined using the criteria outlined in Table 3.71 and Table B.3 of DMRB LA 113. Significance of effect was then determined using the matrix approach shown in Table 4.3 of Chapter 4: EIA Methodology. Effects can be either beneficial or adverse. Where an impact magnitude is negligible, its overall significance of effect is classified as neutral, regardless of the sensitivity of the receptor.

1.1.13 The results of the simple assessment show that there is no potential significant impact on groundwater flow and levels as a result of the proposed embankments. This is due to the generally low compressibility of the soils present (e.g. medium dense to very dense Thanet Formation at Chadwell link); the small percentage of total footprint area of earthworks over the main recharge area of the South Essex and Thurrock Chalk aquifer; and the generally shallow proposed ground improvement measures. In addition, proposed embankments at Tilbury link and parts of the Mardyke floodplain overlie mostly clays, which are not aquifers. Therefore, no detailed assessment is required.

Table 1.1 Highway embankments – Simple assessment

Embankment general area	Underlying aquifer(s)	Proposed ground improvement method (elevation of deepest ground improvement depth)	Maximum groundwater level (mAOD) (approximate) (historical)	Proposed highway drainage	Earthworks, further information	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels
M2/A2/ Project junction Embankments	Thanet Formation (typically medium dense to very dense) and Chalk (weathered at outcrop)	'Dig and replace': removal of shallow Head Deposits, typically ≤2m thick, and replacing with engineered fill. Ground improvement generally not required in Chalk.	25mAOD (Chalk aquifer), i.e. tens of metres below proposed works	Infiltration basins on North Downs (Chalk outcrop areas) in same catchment	Junction would be a mixture of cuttings and embankments and some landscaping	• WFD North Kent Medway Chalk, (very high importance) • Thanet Formation aquifer (medium importance) • Ponds that may be fed by perched groundwater (medium/ ow importance)	Negligible impact as: - Chalk aquifer water table tens of metres below, so no direct impact on flows or levels. - Thanet Formation is unlikely to undergo significant settlement or change in permeability as it is typically medium dense to very dense. - Overall recharge volume	**(Very high to medium / low importance) x Negligible magnitude of impact =** **Slight to neutral or slight adverse**	**Not significant**

Embankment general area	Underlying aquifer(s)	Proposed ground improvement method (elevation of deepest ground improvement depth)	Maximum groundwater level (mAOD) (approximate) (historical)	Proposed highway drainage	Earthworks, further information	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels
							change would be insignificant due to the proposed highway drainage infiltration basins.		
North Portal approach to Tilbury Viaduct Embankments at the approach to the viaduct	Made ground (non-aquifer) over Alluvium (non-productive strata comprising mostly silty clays)	Piled reinforced platform: comprising deep piles into the Chalk to support embankment on Alluvium (maximum depth within structured Chalk). Surcharging the ground and installing band drains involves consolidating Alluvium (up to 13m thick).	1mAOD (approximate) Higher perched water where overlying made ground	Outfalls to surface watercourses	Not applicable	• WFD South Essex and Thurrock Chalk aquifer (very high importance) • Linford public water supply (very high importance) • Private local licensed groundwater abstractions (medium importance)	Negligible impact as no aquifer present directly beneath embankments. Consolidation of Alluvium would locally reduce permeability, but Alluvium is already an aquitard. Piles into the Chalk aquifer would not alter flow or levels due to alignment generally parallel to	**(Very high to medium importance) x Negligible magnitude of impact =** **Slight to neutral or slight adverse**	**Not significant**

Embankment general area	Underlying aquifer(s)	Proposed ground improvement method (elevation of deepest ground improvement depth)	Maximum groundwater level (mAOD) (approximate) (historical)	Proposed highway drainage	Earthworks, further information	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels
							groundwater flow.		
Chadwell St Mary link, northwards from Tilbury junction Engineered and landscape embankments and cuttings earthworks	Variable outcrop of River Terrace Deposits (Taplow Gravel member, south of Muckingford Road and Boyn Hill Gravel Member, west of Brook Farm (superficial aquifer). Majority of area is underlain by Thanet Formation (typically medium dense to	'Dig and Replace': local removal of soft of limited thickness (between Alluvium chainage 9400 and 9800, depth to be determined) and replacement with engineered fill. Surcharging the ground and installing band drains involves consolidating the Alluvium. Piled reinforced platform: comprising piles in Thanet Formation.	River Terrace Deposits, where present, potentially with perched water, if underlain by low permeability strata. Phase 2 groundwater level monitoring recorded RTD water levels up to 10.3mAOD at BH09011. 10.9mAOD at BH11007 (Thanet Fm.) (Oct 2019) where ground level is 16.5mAOD	Outfalls to surface watercourses, including Gobions Sewer	Area of all earthworks (engineered and landscape embankments and cuttings) are included for simplicity. Total area of all earthworks = 465,079m^2 Total area of unconfined or semiconfined Chalk aquifer catchment, south of Eocene margin ^{2} = 45,969,990m^2	• WFD Essex Gravels (medium importance) • WFD South Essex and Thurrock Chalk (very high importance) • WFD South Essex Lower London Tertiaries aquifer (medium importance) • Linford public water supply well (Chalk) (very high importance) • Orsett Golf Course well (Chalk)	Negligible impact as: - Thanet Formation is unlikely to undergo significant immediate settlement as it is typically medium dense to very dense. - ground improvement beneath embankments or false cuttings is currently assumed to be generally shallow.	**(Very high to medium importance) x Negligible magnitude of impact =** **Slight to neutral or slight adverse**	**Not significant**

Embankment general area	Underlying aquifer(s)	Proposed ground improvement method (elevation of deepest ground improvement depth)	Maximum groundwater level (mAOD) (approximate) (historical)	Proposed highway drainage	Earthworks, further information	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels
	dense) over Chalk (weathered and un-weathered strata) bedrock aquifers.		9mAOD [1] approximately (Environment Agency observation borehole at Brook Farm, Chalk aquifer)		Therefore, earthworks area = 1.0% of above Chalk aquifer unconfined and semi-confined area (of which some is cutting).	(medium importance) • Gobians Sewer watercourse may be partly groundwater fed (upper end including pond at (medium importance)	- recharge to unconfined and semi-confined Chalk aquifer would be insignificantly changed by footprint of earthworks At the existing pond, that will be largely removed by the Project, low permeability soils are anticipated. The requirement to replace soft (low permeability) Alluvium may be below the shallow water table here. Phase 3		

Embankment general area	Underlying aquifer(s)	Proposed ground improvement method (elevation of deepest ground improvement depth)	Maximum groundwater level (mAOD) (approximate) (historical)	Proposed highway drainage	Earthworks, further information	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels
							ground investigation is proposed here to inform the design. Impact after mitigation would be negligible.		
A13/A1089/ Project junction Embankments and earthworks	River Terrace Deposits overlying Lambeth Group., Thanet Formation. All underlain by Chalk Group.	Ground improvement is not anticipated, but any localised soft spots ≤2m in thickness encountered during construction would be excavated and replaced with granular fill.	River Terrace Deposits found generally to be dry (Phase 2 ground investigation) Phase 2 groundwater level monitoring shows high groundwater in the Lambeth Group and Thanet Formation (up to 17.80mAOD at BH13353 along the main	Mostly outfalls to a main river north of A13, but one infiltration basin and swales are proposed south of the Eocene margin[2] (with minor exception of some small swales on River Terrace Deposits but north of	Area of all A13 earthworks (engineered and landscape embankments and cuttings earthworks) estimated = 1.9% of Chalk aquifer unconfined/ semi-confined area (of which there is some highway drainage	• WFD Essex Gravels (medium importance) • WFD South Essex and Thurrock Chalk aquifer (very high importance) • WFD South Essex Lower London Tertiaries (medium importance) • Linford public water supply well (Chalk)	Negligible impact as: - ground improvement not anticipated - River Terrace Deposits, which outcrop over most of area, are mostly dry (Phase 2 ground investigation) - Thanet Formation is unlikely to	**(Very high to medium importance) x Negligible magnitude of impact =** **Slight to neutral or slight adverse**	**Not significant**

Embankment general area	Underlying aquifer(s)	Proposed ground improvement method (elevation of deepest ground improvement depth)	Maximum groundwater level (mAOD) (approximate) (historical)	Proposed highway drainage	Earthworks, further information	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels
			carriageway cutting, and 20.07mAOD at BH13015 to the east). Groundwater in the Lambeth Group and Thanet Formation are known to be connected (see Annex N). Groundwater in the Chalk aquifer is high at 18mAOD (BH13009).	Eocene margin[2]).	infiltration to ground).	(very high importance) • Orsett Golf Course well (Chalk) (medium importance) • Property at and near the proposed junction, of potential groundwater flooding[5] (no or low risk of flooding)	undergo significant settlement or change in permeability as it is typically medium dense to very dense - Negligible change to rainfall recharge that could affect Orsett Golf Course well due to the small footprint area of earthworks (<1%) in the up hydraulic gradient area of well radius of influence - Negligible impact on recharge to		

Embankment general area	Underlying aquifer(s)	Proposed ground improvement method (elevation of deepest ground improvement depth)	Maximum groundwater level (mAOD) (approximate) (historical)	Proposed highway drainage	Earthworks, further information	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels
							Chalk aquifer and Linford public supply well		
Mardyke area Embankments	Alluvium and Head Deposits (low permeability soils) underlain by London Clay Formation (non-aquifer)	Piled reinforced platform: comprising deep piles into the London Clay Formation to support embankment on Alluvium Surcharging the ground and installing band drains involves consolidating the Alluvium (up to 4m thickness anticipated)	Near ground level where there is low topography (groundwater level recorded in Alluvium at 3.6mAOD (0.35mbgl) in WS17006). Viaduct over shallow valley areas, so embankments proposed over low-lying interfluve areas. Shallow water levels, minor interflow and poor drainage in low permeability	Outfalls to surface water	Not applicable	• WFD Essex Gravels (Phase 2 ground investigation suggests this is not present here) (medium importance) • Local agricultural wells (probably screened in Harwich Formation aquifer, beneath London Clay Formation) (medium importance) • Property in mapped area	Negligible impact on groundwater flows and levels as no aquifer is present within depth of proposed works.	**(Medium importance) x No change to negligible magnitude of impact =** **Neutral to slight adverse**	**Not significant**

Embankment general area	Underlying aquifer(s)	Proposed ground improvement method (elevation of deepest ground improvement depth)	Maximum groundwater level (mAOD) (approximate) (historical)	Proposed highway drainage	Earthworks, further information	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels
			soils is anticipated.			of potential groundwater flooding[5] (mostly medium risk of flooding)			
Project/M25 junction Embankment	River Terrace Deposits and Head Deposits (British Geological Survey mapping shows mostly Head Deposits) (Alluvium at the Mardyke West) crossing)	'Dig and Replace': removal of shallow Head Deposits and localised soft spots, typically ≤2m thick, and replacing with engineered fill.	Phase 2 ground investigation indicates deep groundwater near the base of River Terrace Deposits (see Annex L)	Outfalls to surface water	The landscape embankment (chainage 19200 to 20600) borders the proposed southbound carriageway. The landscape embankment would be parallel to the northbound proposed M25 cutting widening.	• Agricultural surface water abstractions from streams that may receive groundwater baseflow (medium importance) • WFD Essex Gravels (medium importance) • Mardyke West (mostly high to medium importance (Chapter 14: Road Drainage and	Negligible impact on groundwater flows and levels as only shallow ground improvement proposed. Environment Agency–mapped Essex Gravels comprise isolated areas of which the embankment would cross the eastern edge of one area. Negligible impact to	**(High to medium importance) x Negligible magnitude of impact =** **Slight to neutral or slight adverse**	**Not significant**

Embankment general area	Underlying aquifer(s)	Proposed ground improvement method (elevation of deepest ground improvement depth)	Maximum groundwater level (mAOD) (approximate) (historical)	Proposed highway drainage	Earthworks, further information	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels
						the Water Environment)) • SILC sites which are potentially GWDTEs (low to moderate importance) • Cranham Local Nature Reserve (moderate importance as a GWDTE) • Mapped area of potential groundwater flooding[5], near the Mardyke West (mostly low risk of flooding)	recharge of the Essex Gravels is likely.		

Embankment general area	Underlying aquifer(s)	Proposed ground improvement method (elevation of deepest ground improvement depth)	Maximum groundwater level (mAOD) (approximate) (historical)	Proposed highway drainage	Earthworks, further information	Key potential groundwater receptors within 3km (value)	Magnitude of groundwater impact (groundwater levels and flows)	Significance of environmental effect	Significance of impact to groundwater flows and levels
M25 including north of M25 junction 29 Embankments	River Terrace Deposits, Head Deposits	'Dig and Replace': removal of Head Deposits and localised soft spots, typically ≤2m thick, and replacing with engineered fill.		Outfalls to surface water		Small, mapped area of potential groundwater flooding[5] north of junction (small area of mostly low risk of flooding, distant from the Project) (low importance).	Negligible impact on groundwater flows and levels as only shallow ground improvement proposed.	**(Low importance) x Negligible magnitude of impact =** **Neutral or slight adverse**	**Not significant**

Notes:
[1] Environment Agency Brook Farm observation (Chalk aquifer) borehole historical maximum assessed as 8.8mAOD (Feb 2015), data 1997 to 2017 inclusive. Recorded maximum historical water level is approx. 14.78mAOD (0.52mbgl) on 26/08/2015 but appears erroneous as outside of range of all other data (6m higher than next maximum).
[2] Eocene margin – southern outcrop limit of the London Clay Formation. North of this boundary, the Chalk aquifer is confined by the London Clay Formation.
[3] mAOD – metres above ordnance datum.
[4] mbgl – metres below ground level.
[5] Groundwater flood risk is shown in Drawing HE540039-CJV-EFR-SZP-GNZZZZZZZZ-DR-LF-00151-00153 Groundwater Flood Risk – Groundwater Flooding Susceptibility. This is based on GeoSmart Groundwater Flood Risk Map, GW5 version 2.3 (GeoSmart, 2019).

Annex J Ground protection tunnel and main tunnels groundwater model – technical note

Lower Thames Crossing

Annex J Ground Protection Tunnel and Main Tunnels Groundwater Model – Technical Note

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1 Introduction

1.1 Background

1.1.1 The A122 Lower Thames Crossing (the Project) would provide a connection between the A2 and M2 in Kent, east of Gravesend, crossing under the River Thames through a tunnel, before joining the M25 south of junction 29.

1.1.2 The A122 road would be approximately 23km long, 4.25km of which would be in tunnel. On the south side of the River Thames, the Project route would link the tunnel to the A2 and M2. On the north side, it would link to the A13 and junction 29 of the M25. The tunnel entrances would be located to the east of the village of Chalk on the south of the River Thames and to the west of East Tilbury on the north side.

1.1.3 The South Portal is above the maximum recorded groundwater level and no aquifer dewatering is anticipated. On this basis, the South Portal itself is not included in this assessment.

1.1.4 A detailed description of the Project is provided in Chapter 2: Project Description (Application Document 6.1) and Appendix 2.1: Construction Supporting Information (Application Document 6.3).

1.1.5 Ground treatment is necessary to allow for below ground servicing of the tunnel boring machine (TBM); this would require the placement of grout blocks at intervals along the main tunnel line. To facilitate this, a ground protection tunnel would be constructed above the alignment of the main tunnel. The ground treatment would mitigate the risks from groundwater inflows that may happen when support pressure is allowed to reduce in the TBM cutter head.

1.1.6 The ground protection tunnel would launch from a shaft located to the south of Lower Higham Road, whilst its egress shaft would be located north of the Thames and Medway Canal and North Kent Railway line. Groundwater control measures have the potential to cause drawdown and changes to the direction of groundwater flow at South Thames Estuary and Marshes Site of Special Scientific Interest, Shorne Marshes Royal Society for the Protection of Birds Reserve and the Thames Estuary and Marshes Ramsar site. These are sensitive receptors. The underlying Chalk formation itself is a Principal aquifer (Highways England, 2017) and therefore a sensitive receptor.

1.1.7 The ground protection tunnel has a mid-line elevation of -6.7m above ordnance datum (AOD) and each shaft has a bottom elevation of -11.6m AOD. The main tunnels have centreline elevations of -42m AOD to 21m AOD.

1.1.8 Watertight retaining structures, such as caissons, would be used when constructing the portals to control groundwater ingress. This would remove the need for large-scale dewatering during the excavation of the launch and reception shafts (Cascade, 2019).

1.1.9 The following are key components of the ground protection tunnel that are included in the model (Cascade, 2019):

a. Launch shaft: 9m internal diameter (ID) (approx. 9.7m outside diameter (OD)) pre-drilled clutched sheet piles 16m deep with a 2m concrete base plug, plus 2m toe in depth

b. Reception shaft: 9m ID (approx. 9.7m OD) caisson shaft, 16m deep with a 2m concrete base plug

c. Ground protection tunnel: concrete segmentally lined, 5.8m OD.

d. Grouting:

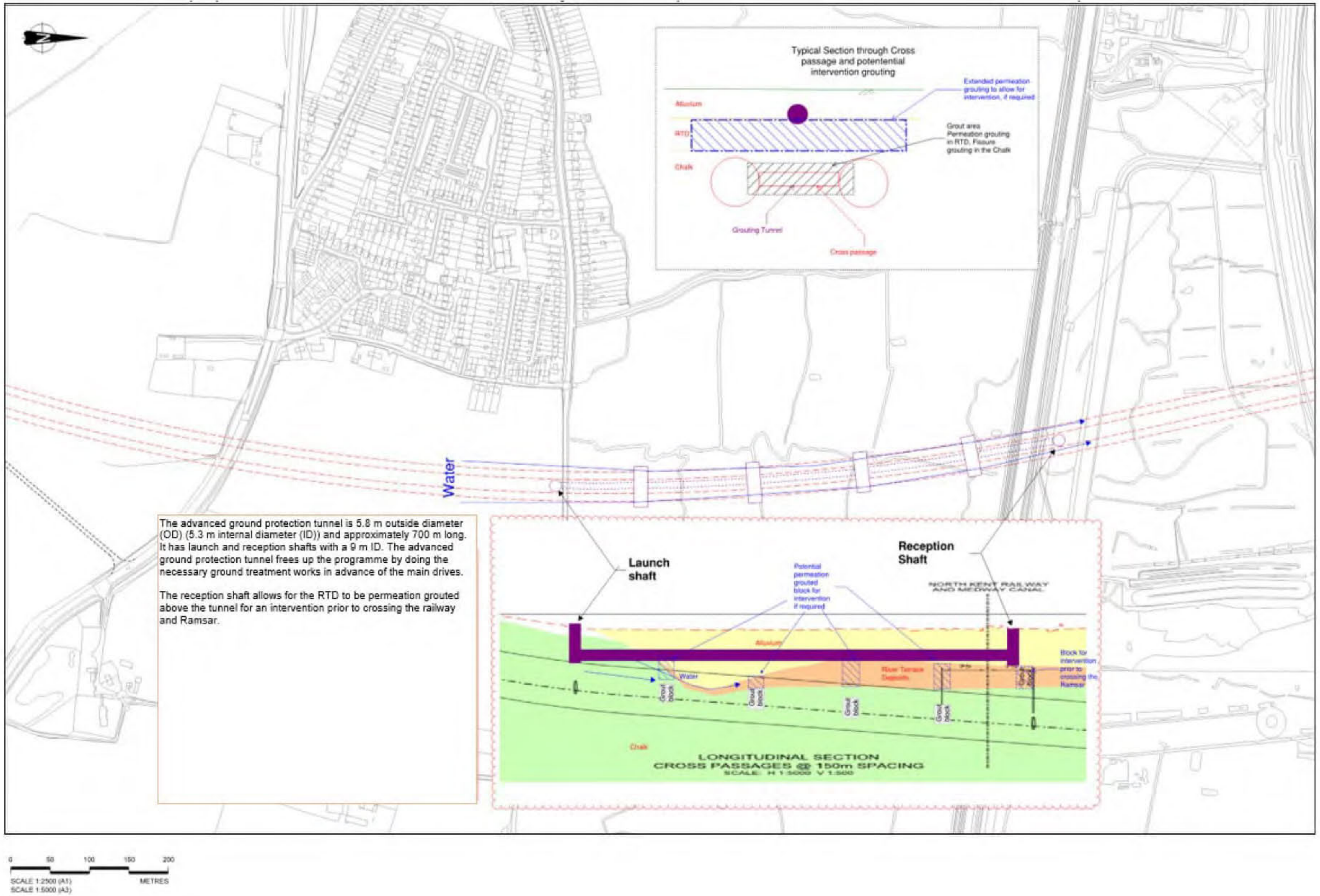
  i. Cementitious permeation grouting from reception shaft of River Terrace Deposits (RTD) for intervention prior to crossing Ramsar site. Half a diameter wider than the main bores.

  ii. Cementitious permeation grouting of RTD at four locations, 150m apart for interventions (same as cross-passages, half a diameter wider than the main bores).

  iii. Cementitious fissure grouting at four cross-passage locations that sit below the intervention tunnel (8.6x20m block).

1.1.10 Plate 1.1 provides a sketch of the layout of the components of the ground protection tunnel. The TBM would be launched from the upstream launch shaft.

Plate 1.1 Sketch of the proposed ground protection tunnel and the layout of its components. The tunnel would be launched from the upstream launch shaft



1.2 Report and modelling objectives

1.2.1 This report focuses on the modelling of groundwater flows for the construction of the ground protection tunnel and main tunnels, which is located beneath the Ramsar site to the south of the River Thames. This model incorporates information from the Phase 1 and Phase 2 ground investigation, as follows:

a. Inclusion of site-specific data from Phase 1 and Phase 2 ground investigations

b. Calibration against site-specific data, including a time-variant calibration of tidal response in the Chalk

1.2.2 Modelling of the groundwater flows has included:

a. Simulation of the groundwater inflow into the excavation during construction of the ground protection tunnel and main tunnelling operations

b. Simulation of drawdown

c. Simulation of saline/freshwater interface movement

d. Modelling scenarios for:

i. ground protection tunnel shafts only

ii. ground protection tunnel shafts and tunnels

iii. main tunnels (operation)

1.3 Assumptions and limitations

1.3.1 The following additional assumptions and limitations apply:

a. The infrastructure modelled and model simulations are in steady state.

b. The models simulate saturated conditions only. This means it is not possible for perched water tables to be computed. This is a limitation for computing the water table within non-aquifers, such as in the Alluvium in which the Ramsar site is situated.

c. Construction techniques (such as caisson methods) would be used that would avoid major dewatering during the excavation of the launch and reception shafts for the ground protection tunnel. No active dewatering has been included in the model for such structures. Mitigation measures include the following:

i. Use of pressurised TBM method that inhibits groundwater inflow during tunnelling

ii. Stopping the TBM within grout blocks for TBM maintenance

iii. Use of caisson methods and pre-grouting of ingress and egress shafts to inhibit groundwater inflow

iv. Specification of the maximum leakage rates based on the British Tunnelling Society (British Tunnelling Society and Institution of Civil Engineers, 2010) prescribed leakage rates for tunnels.

2 Methodology

2.1 Software

2.1.1 The model uses MODFLOW 2005, which is an industry standard software, developed and maintained by the United States Geological Survey (USGS) (Harbaugh, 2005). The model has been created using FloPy (Bakker *et al.*, 2016). FloPy contains a set of Python scripts enabling the building, running and postprocessing MODFLOW, MT3D, SEAWAT and other MODFLOW-related groundwater programs. Visualisation and MODPATH simulations are completed in Groundwater Vistas 7, produced by Environmental Simulations International (ESI) (Rumbaugh and Rumbaugh, 2017).

2.2 Model geometry

Model grid geometry

2.2.1 Table 2.1 shows the model grid geometry.

Table 2.1 Model grid extent

Top-left easting (m)	564250
Top-left northing (m)	175500
Bottom-right easting (m)	572500
Bottom-right northing (m)	169030
Delr (cell height)	60
Delc (cell width)	60
nCol (number of columns)	109
nRow (number of rows	137
Layers (no.)	46
Layer bottom depths (m below ground level (bgl))	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,22,24,26, 30,32,36,38,40,45,50,55,60,65,70,75,80,85,90,95,100, 105,110,115,120,130,150,170

2.2.2 The groundwater model uses a block model approach. In a block model the model layers are pre-defined and are independent of the geological layers. The geology is ascribed to the model by changing the material parameters of the individual cells to represent the geology. This approach differs from a standard approach whereby the top and bottom of model layers represents the top and bottom of geological surfaces. Advantages of this approach are as follows:

d. Rapid convergence often resulting in shorter run-times although more memory intensive. This allows for more vertical discretisation, especially in contaminant transport models.

e. Avoidance of pinched-out layers inside the model or at the top surface.

f. A more consistent representation of groundwater flow velocity within a layer. This can be beneficial if modelling a saline interface or contaminant transport where solute dispersion is influenced by upstream and downstream velocities.

g. Better modelling of infrastructure features such as diaphragm walls and tunnels. These features are often independent of or do not fully penetrate geological layers. In a block model these changes can be incorporated without changing the model layer structure, making the results comparable.

h. Good and consistent vertical resolution around boundary conditions, thereby minimising model errors.

i. The numerical model is a block-centred finite difference model. A 60m cell size is ideal to simulate a tunnel of 17m diameter, as it is approximately three times the size of the tunnel (Zaidel *et al*., 2010).Within 20m of the ground surface the thickness of the model layers is 1m. The top layer has the elevation of the topographic surface.

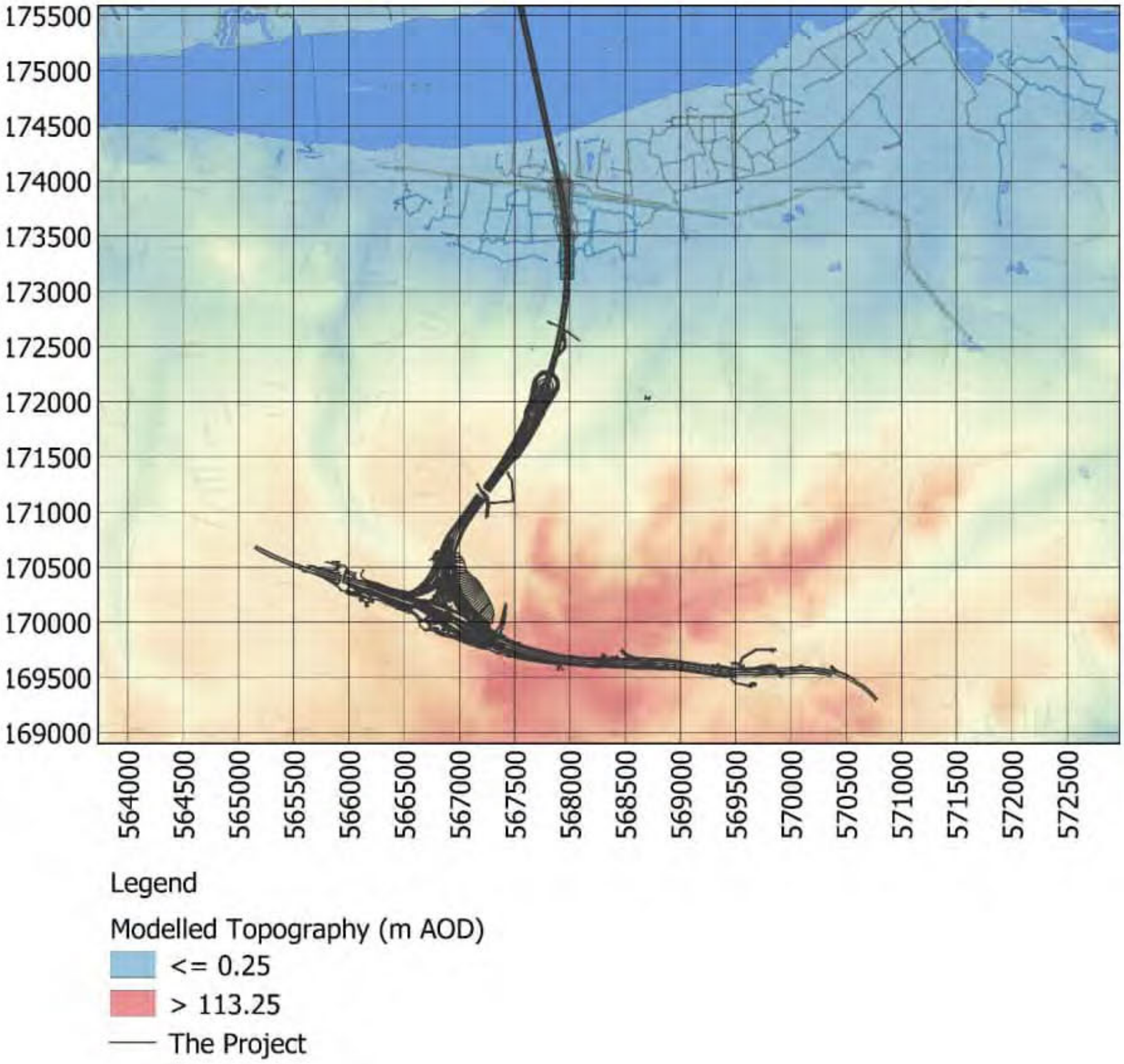
j. The bottom layer has a bottom elevation set to 170m below the topography. In total there are 46 layers in the model. Model layers are thinner in the top 30m to include for the increased geological data and project infrastructure in this zone. The top 20 layers have a thickness of 1m, between 20m and 30m bgl the layers are 2m thick, and between 30m bgl and 105m bgl the layers are 5m thick. Beneath this, the layer thickness is set to 10m.

MODFLOW layer setup

2.2.3 Layer 1 (the uppermost layer) is set as unconfined (Laycon Type 1), so the transmissivity of the layer varies depending on the saturated thickness and hydraulic conductivity. All remaining layers are able to switch between confined and unconfined conditions (Laycon Type 3). The transmissivity of these layers also varies and is calculated from the saturated thickness and hydraulic conductivity. Specific yield or specific storage are used if the layer is unconfined or confined, respectively. This is the default setting in MODFLOW. Rewetting is disabled for all layers.

2.2.4 Plate 2.1 shows the top elevation of the model; this is coincident with the current topography (*Ordnance Survey*, 2019).

Plate 2.1 Topography (m AOD)



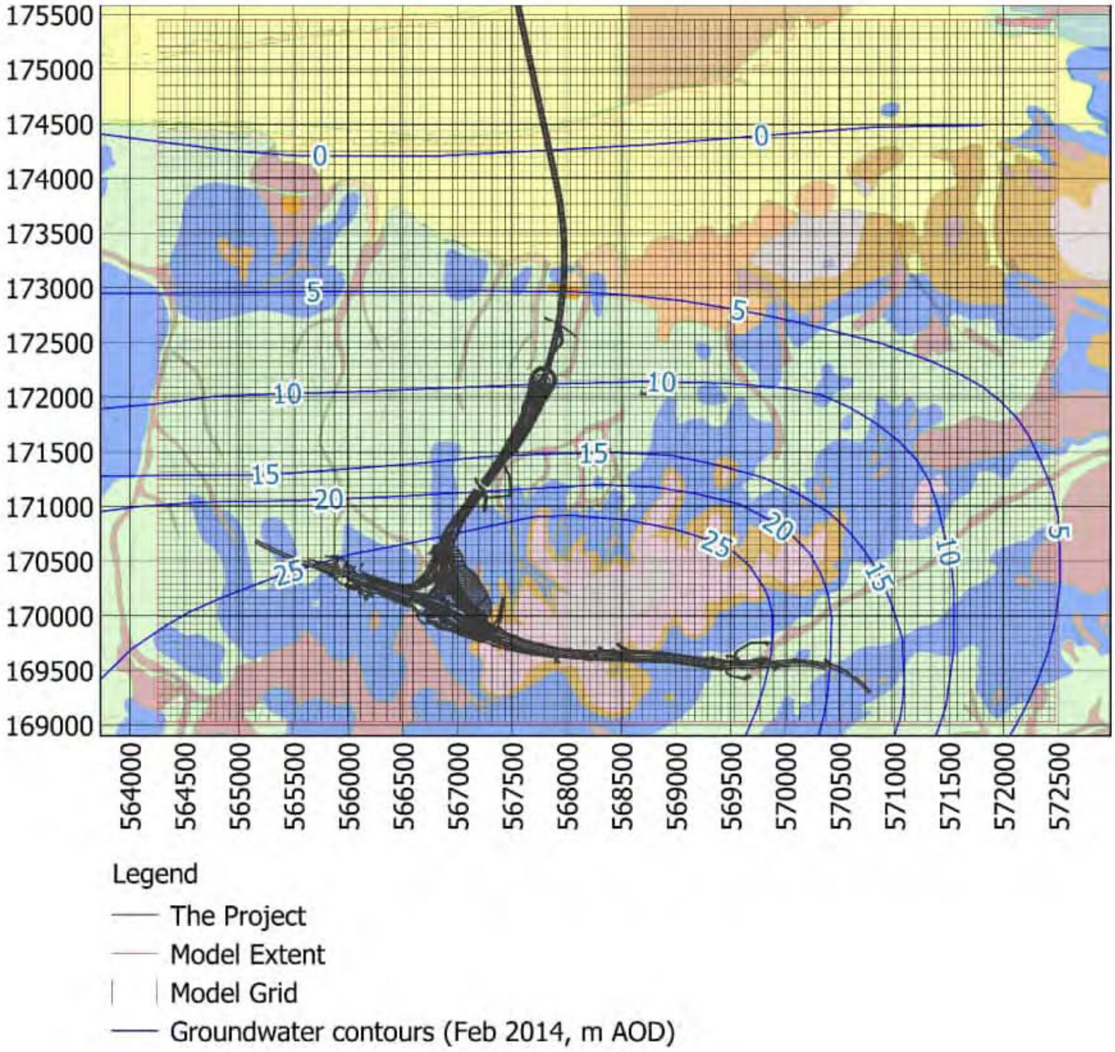
British Geological Survey (BGS) geological model

2.2.5 A lithostratigraphic geological model purchased from the British Geological Survey (BGS) (2017) is used for the geological model. This geological model is a checked and peer reviewed baseline. Results of the Project Phase 1 and Phase 2 ground investigations (Perfect Circle, 2018) have been included in the model by the BGS.

2.2.6 The BGS geological model provides the skeleton of the groundwater model layers. The BGS model is assigned to the groundwater model layers by comparing the model layer elevations with the geological surfaces.

2.2.7 Plate 2.2 shows a plain view of the outcrop geology overlaid on the model grid for the model area. The blue contour lines represent the Chalk hydraulic head contours for February 2014. The contours have been digitised and interpolated from the Environment Agency regional network of observation boreholes.

Plate 2.2 Model domain (6.5x8.3km), cross-section location plan and outcrop geology



2.2.8 The BGS geological model contains many layers; however, there are four key surfaces/layers, described below:

a. Made Ground. The topography (Ordnance Survey, 2019) forms the top surface of the model. The base of the Made Ground surface is provided by the BGS. Made Ground in the model area includes areas alongside the River Thames, the Thames and Medway Canal and industrial land east of Gravesend.

b. Superficial deposits at outcrop including Alluvium, Head Deposits and RTD. RTD underly the Alluvium. Assigned using elevation data from the BGS model for the bottom of the layer.

c. Eocene deposits, such as the London Clay and the Lambeth Group and the Thanet Formation. These outcrop south of the South Portal capping the Chalk at higher elevations and above the water table.

d. Chalk. The top of the Chalk is defined from the BGS model.

2.2.9 The BGS geological model includes many ASCII format grids. The grids include a top elevation, bottom elevation and thickness for each different stratum identified by the BGS. FloPy (Section 2.1) imports all these as TIF files using the Geospatial Data Abstraction Library (GDAL) module. The raster band value of the TIF file is the elevation. The TIF files are re-gridded by GDAL (Warmerdam, 2019) to match the model grid arrays. A comparison is done in Python whereby each BGS elevation grid is checked against the elevation of a model cell. The BGS layer with the least residual from this comparison is assigned to the cell and the suitable parameters are then applied to the cell. This builds up a block model and overcomes many of the problems that can occur with complex geological models.

2.2.10 The groundwater model includes all 31 geological layers supplied in the BGS data.

Site-specific geological information

2.2.11 Site-specific geological data is gained from the site investigation and includes the following:

a. Material type at depth intervals as described in the Association of Geotechnical and Geo-environmental Specialists (AGS) dataset.

b. Construction Industry Research and Information Association (CIRIA) Chalk grade. This is split between types A, B and C (structured chalk) and type D (structureless Chalk) within AGS datasets.

c. Rock Quality Designation (RQD). A low value of RQD of less than 0.1 can indicate very fractured Chalk rock materials. These areas of Chalk are often not able to be screened for hydraulic pressure testing and are likely to include the highest hydraulic conductivity zones.

d. Variable head pressure tests completed during fieldwork.

e. Pumping tests.

2.2.12 The geology listed in the AGS data is represented in the model using by changing the hydraulic conductivity of the model cells to match parameters for the material found.

AGS data

2.2.13 A Python module adds the AGS data into the model using the borehole location, sample interval and geological code, and this new information overwrites the BGS model. Table 2.2 shows how the block model parameters were altered to represent the AGS data. A radius of influence of 300m was given for each borehole site. At 300m distance, the BGS model information is used, whilst at 0m distance the AGS data used. In between, and/or where the radius of influence of multiple samples overlap, the average is given to the model cell.

2.2.14 Table 2.2 provides a summary of the AGS material included.

Table 2.2 Summary of AGS material included

Geological code recorded in AGS file	Conceptualisation	K_h, K_y(horizontal hydraulic conductivity) (m/s)	K_z (vertical hydraulic conductivity) (m/s)	Sy	Ss
Oth	Made Ground	As per bulk Made Ground value	As per bulk Made Ground value	As per Made Ground value	As per bulk Made Ground value
CL	Clay superficial deposits	As per bulk Alluvium calibrated value	As per bulk Alluvium calibrated value	As per bulk Alluvium calibrated value	As per bulk Alluvium calibrated value
SA	Sand superficial deposits	$1x10^{-4}$	$0.3x10^{-4}$	0.1	1e-5
SI	Silt superficial deposits	As per bulk Alluvium calibrated value	As per bulk Alluvium calibrated value	As per bulk Alluvium calibrated value	As per bulk Alluvium calibrated value
GR	Gravel superficial deposits	As per bulk RTD calibrated value	As per bulk RTD calibrated value	As per bulk RTD calibrated value	As per bulk RTD calibrated value
AZCL/CKD or RQD <0.1 (in LECH/WHCK)	Unstructured or karstic Chalk situated under the Thames or under RTD	Calibrated value based on High Speed 1 (HS1) findings	Calibrated value based on HS1 findings	Calibrated value	Calibrated value
CKABC	Structured Chalk	Calibrated parameter for the Chalk above the Belle Tout Formation	Calibrated parameter for the Chalk above the Belle Tout Formation	Calibrated parameter for the Chalk above the Belle Tout Formation	Calibrated parameter for the Chalk above the Belle Tout Formation

2.2.15 As there are over 50,000 lines of AGS data included in the model, this dataset is not presented in the report.

Packer and variable head tests

2.2.16 Packer and variable head tests are imported using the same approach as for material type data. The radius of the area of rock tested by a packer test or variable head test is likely just a few meters up to 10m. However, extrapolation is needed to use the information within a conceptual and groundwater model in a meaningful way. For packer and variable head tests, the radius of influence is set to 120m (two model cells) and 60m (one model cell), respectively. The hydraulic conductivity is applied to all cells within the screen interval and radius of influence, overwriting previous information, based on proximity. Packer and variable head tests data included in the model are presented in Annex A.

Pumping tests

2.2.17 Table 2.3 provides details for the completed pumping tests at the test wells PW03001 and PW04001A, which are included in the model. The hydraulic conductivity field results were applied to all model cells within a radius of influence of 500m from the boreholes, within the screened zone. Pumping tests data included in the model are presented in Table 2.3.

Table 2.3 Pumping test results included within the model

Test site	Easting, northing	Screen interval (m bgl)	Horizontal hydraulic conductivity (m/s)	K_v/K_r	Specific storage
PW03001	568046,172651	-29, -49.5	$1.3x10^{-4}$	0.1	$2.0x10^{-5}$
PW04001A	568108,173703	-29, -49.5	$3.6x10^{-5}$	0.1	$1.2x10^{-6}$

Cross-sections and conceptual model

2.2.18 Plate 2.3 shows a typical cross-section through the BGS skeleton geology along the Project route (colours presented are arbitrary); this runs through model column 62 (Easting 567856). Plate 2.4 shows the same section after inclusion of the site-specific information. The sections in Plate 2.4 is colour flooded by the hydraulic conductivity of the material.

2.2.19 Within the Chalk, the site-specific information has shown evidence for the following:

a. A highly fractured zone of Chalk gravels (CKD and AZCL) at the top of the Chalk sequence underlying the RTD.

b. A thicker zone of low RQD and CKD at depth beneath the River Thames with areas of missing core (AZCL).

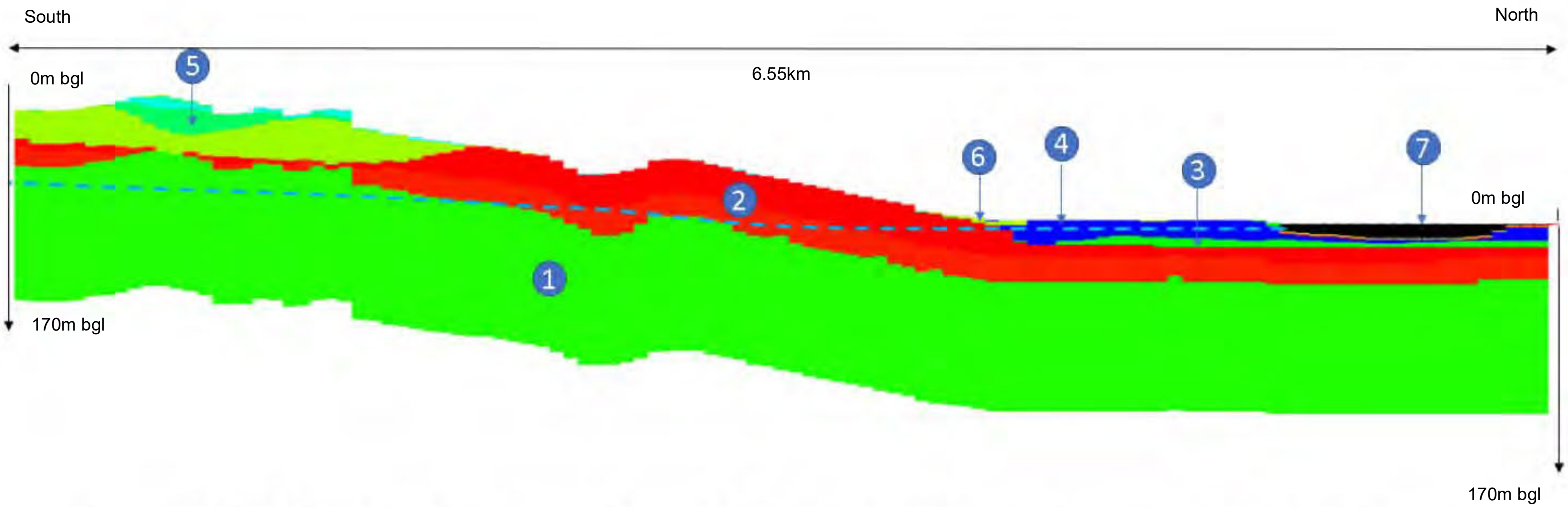
c. A thick zone of low RQD, CKD and AZCL straddling and below the water table at the southern periphery of the Alluvium and RTD deposits.

d. Along the central part of the Thames, the Chalk rises up towards the channel bottom. There is no low permeability barrier between the River Thames and the top of the Chalk.

2.2.20 Adjacent to the southern limit of the Alluvium, the site-specific information has shown that there are thin layers of gravel and sand of limited northward extent. The sands and gravels are on-lapping (draping) onto the RTD or Chalk at the southern periphery of the Alluvium deposits and may be Head or RTD deposits.

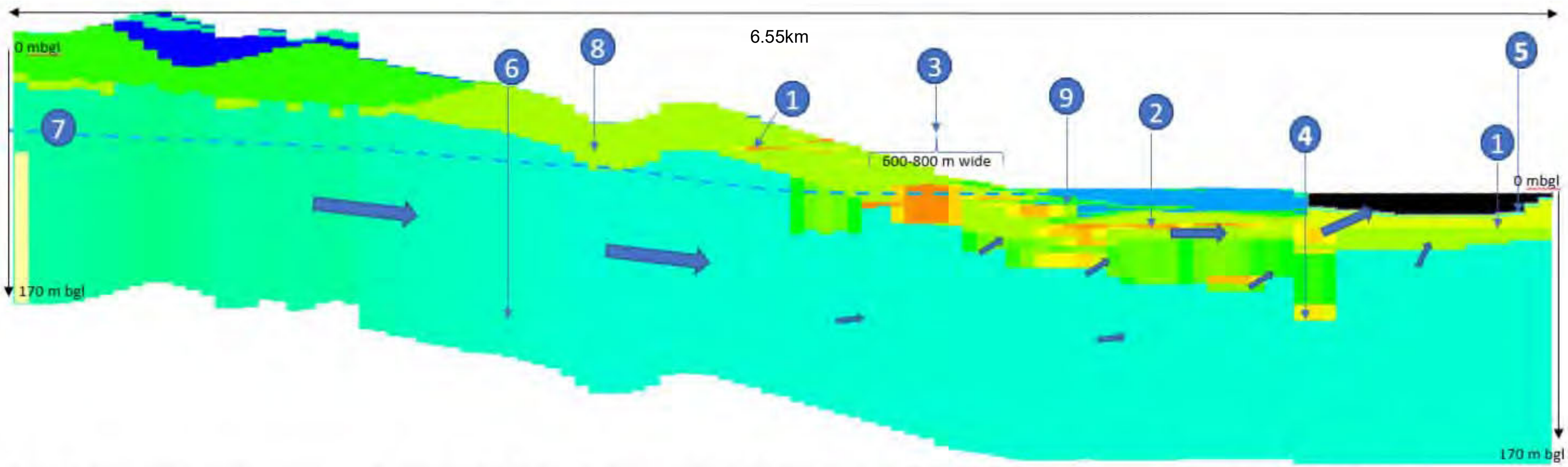
2.2.21 The site-specific data corresponds well with the BGS model, particularly regarding the elevations of the Alluvium, RTD and top of the Chalk.

Plate 2.3 Geological structure using the BGS skeleton along British National Grid Easting 567856. Vertical exaggeration 10x.



1. Deep Chalk; 2. Chalk from 20 m above the base of the Seaford Formation; 3. RTD 4. Alluvium; 5. Thanet Formation, Lambeth Group, London Clay; 6. Head deposits; 7. River Thames

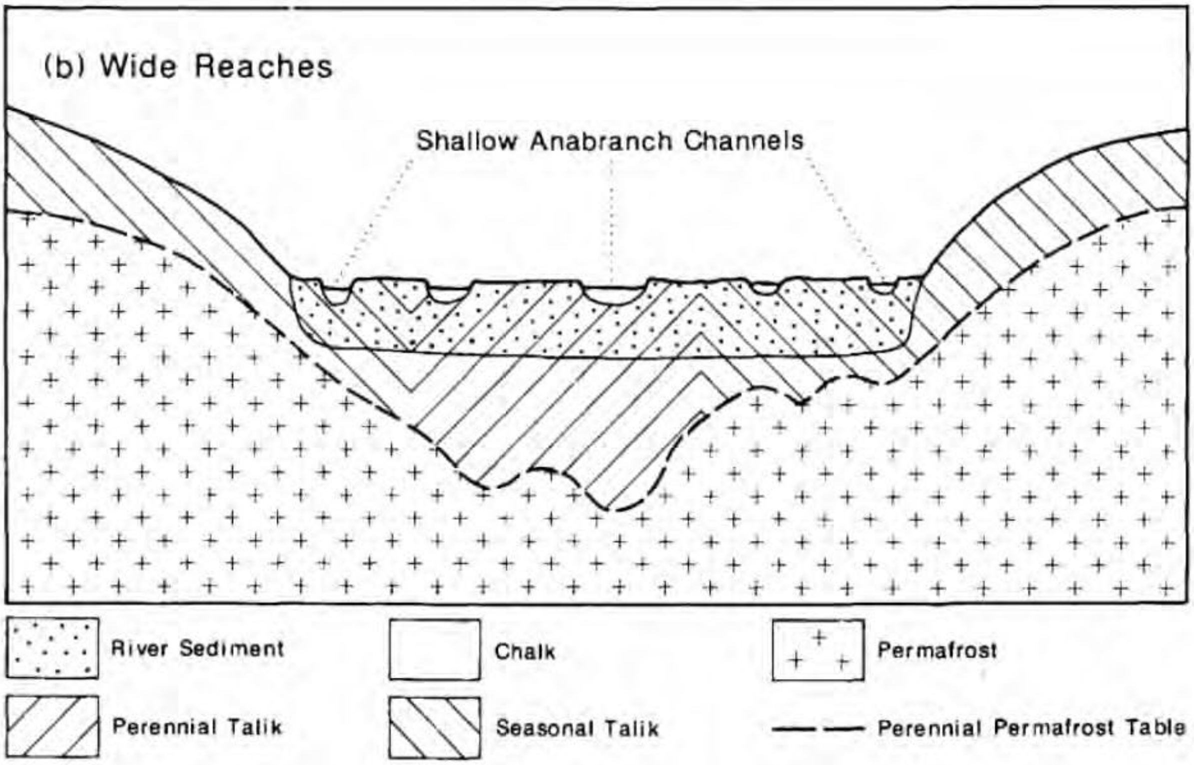
Plate 2.4 Geological structure including AGS information in the model along cross-section through British National Grid Easting 567856. Vertical exaggeration 6x.



1. High transmissivity zone corresponding to top of Belle tout Beds, approximately 20 m above the base of the Seaford Formation. Populated with higher K where marked as CKD/RQD<0.1 in AGS data
2. Very high transmissivity Chalk corresponding with CKD or RQD <0.1, in a thin zone underlying the RTD. Highly confined, karstic, low storage. Ratio of K to Ss as well as connection to Thames allows for a high Tidal response.
3. Very high transmissivity Chalk corresponding with CKD or RQD <0.1, along the margin of the ALV and RTD. Corresponds to very flat hydraulic gradient
4. Deeper zones of higher transmissivity Chalk corresponding with CKD or RQD <0.1 at depth beneath the Thames
5. Conceptualised high transmissivity zone, providing high transmissivity connection with Chalk (tidal response)
6. Deeper Chalk, simplified to total 100 m in thickness with uniform transmissivity below the water table
7. Water table – Steeper hydraulic gradient with higher altitude as the occurrence of higher transmissivity deposits below water table is less frequent
8. Flow paths – 'dry' valleys correspond with dips in the topography. Where the high transmissivity zone dips below the water table the groundwater velocity is rapid. These channels point towards the Thames (north)
9. Thin lens' of sand and gravel with limited extend at the margins

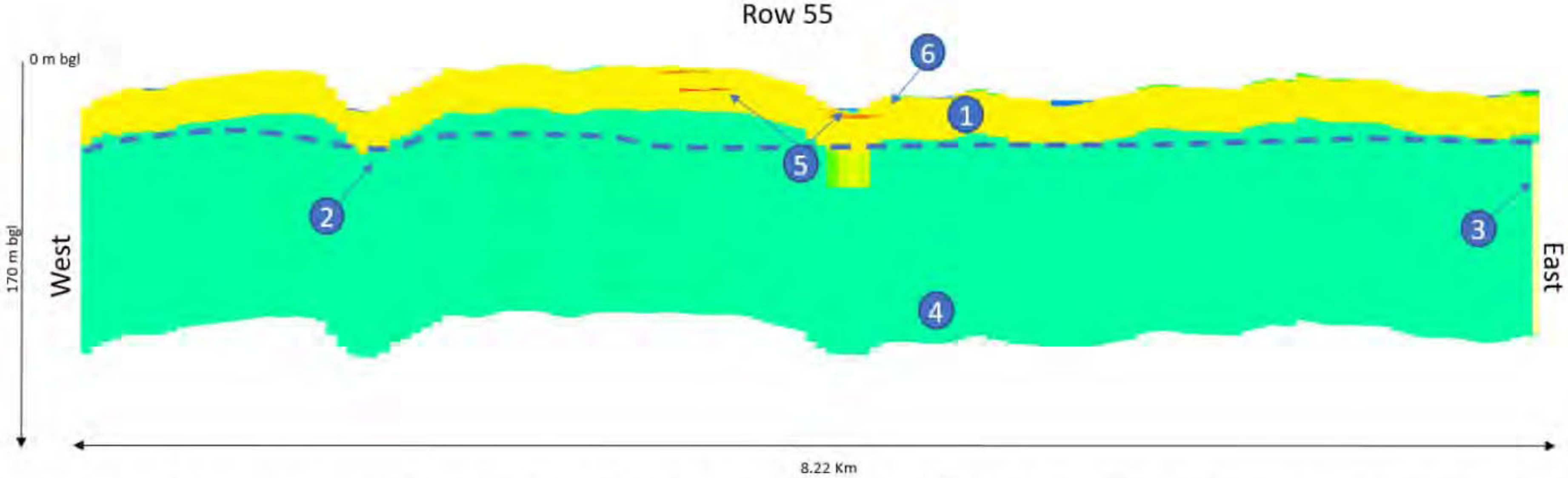
2.2.22 The position of the high transmissivity Chalk around the River Thames is similar to that described in Younger (1989). Plate 2.5 shows the conceptual cross-section developed by Younger. It describes areas of higher permeability development within the Chalk around Shallow Anabranch Channels. For the Thames area, repetitive tidal action and deeper scoured channel has caused increased dissolution of the Chalk in the area of the water table and beneath the river sediments (RTD).

Plate 2.5 Cross-section proposed in Younger (1989)



2.2.23 Plate 2.6 shows a west–east trending cross-section through the hinterlands south of the Ramsar site and south of the main tunnels. In this area, the hydraulic gradients can be reproduced reasonably well, by allowing the Chalk water levels to be controlled by drainage within higher transmissivity zones along north–south orientated topographical depressions, typically mapped with Head Deposits at the surface.

Plate 2.6 Conceptualisation of the hydrogeology and geology south of the Project on the Chalky hillside



1. Higher hydraulic conductivity in the upper part of the Chalk potentially due to weathering, dissolution from recharge or water table movement. Potentially associated with the Belle Tout beds within the Seaford Formation.
2. Water levels in the Chalk may be controlled by higher transmissivity zones beneath 'dry' stream channels. In these zones dissolution may have occurred in the past.
3. The water level dips to the east, though groundwater flow is likely dominated by flows beneath 'dry' river channels towards the north. The eastern boundary must be controlled with a boundary condition.
4. The deeper Chalk is bulked into a single unit for simplicity as there is little data on it.
5. Some boreholes indicate the presence of weathered zones within the near surface chalk area.
6. Superficial deposits are limited in thickness and the Chalk is at outcrop.

2.3 Hydraulic conductivity

2.3.1 The model hydraulic conductivity (or permeability) ranges are derived from site investigations (Perfect Circle, 2018), the Thames Cable Tunnel Project (Haswell, 1969) and the Addendum Preliminary Sources Study Report (Tables 36–38, pages 130–139 (Highways England, 2017)). Table 2.4 provides parameter ranges for the model calibration. Plate 2.2 shows the hydraulic conductivity mapped to the outcrop geology in Layer 1 of the model. Plate 2.3 and Plate 2.4 show the hydraulic conductivity in cross-section.

Table 2.4 Summary of hydraulic conductivity ranges

Geological unit	Hydraulic conductivity minimum (m/s)	Hydraulic conductivity maximum (m/s)	Hydrogeological behaviour and influences
Made Ground	-	Variable, approximately $1x10^{-5}$ to $1x10^{-4}$	Variable – depends on material content. Acknowledged to be cohesive in places but assuming higher values for worst-case.
Head Deposits	-	Variable, $1x10^{-8}$ to $1x10^{-6}$	Variable – depends on underlying geology
Alluvium	-	k_h = $1x10^{-7}$ k_v = $1x10^{-8}$ [1]	Aquitard or aquifer – depending on whether predominantly clay or granular material in the field but mapped as a single unit with an equivalent bulk permeability.
RTD	Lower values where clayey	$2x10^{-5}$ [1] to $1x10^{-3}$	Aquifer – depends on lateral extent and thickness
London Clay	Non aquifer	Non aquifer	This is a confining unit and has very limited potential to supply a water resource. On a broader scale may support underlying aquifers through slow leakage.
Harwich Formation	$1.1x10^{-5}$ [2]	$1.1x10^{-3}$ [2]	Aquifer
Lambeth Formation (Reading and Woolwich Formation)	$3.5x10^{-8}$ [2]	$2.3x10^{-3}$ [2]	Variable hydro-stratigraphy but generally not considered to be an aquifer
Thanet Formation	$2x10^{-5}$ [2]	$4x10^{-5}$ [2]	Aquifer
Chalk	May vary with Chalk weathering grade and site-specific ground conditions. See Table 2.5 and Table 2.6.		Aquifer

References:
[1] Bevan *et al.* (2010)
[2] The Physical Properties of Minor Aquifers in England and Wales (Jones *et al.*, 2000).

Table 2.5 Chalk weathering grade and hydraulic conductivity range

CIRIA grade	Munford grade	Chalk type*	Approximate hydraulic conductivity range (m/s)
A	I and II	Structured with bedding and/or jointing.	Highly variable because of presence of fissures
B and C	III and IV	Structured with bedding and/or jointing.	$1x10^{-5}$m/s to $1x10^{-3}$m/s
Dc	V and VI	Structureless, clast dominated.	$1x10^{-5}$m/s to $1x10^{-3}$m/s in relatively harder Chalk with chalk 'bearings' or frost shattered chalk evidenced
Dm	V and VI	Structureless, matrix dominated.	$1x10^{-7}$m/s to $1x10^{-9}$m/s

References:
*Spink (2002) and Preene and Roberts (2017).

Table 2.6 Project-specific hydraulic conductivity results

Location	Chalk lithology	Reported Chalk hydraulic conductivity (m/s)
Thames Cable Tunnel (North Shaft), Tilbury, East London	Upper 9m of Chalk of high permeability. Permeability reduced significantly at depths greater than 15m below top of the Chalk. During the shaft sinking, the upper 6m of the Chalk appeared to be completely disintegrated. Similar to CKDc (unstructured Chalk) reported in Project AGS data. Also likely to have significant core loss (AZCL).	$1x10^{-3}$m/s to $4x10^{-6}$m/s in upper zones of Chalk from *in situ* permeability tests. $2x10^{-5}$m/s to $2x10^{-6}$m/s below 15m from top of Chalk, from Lugeon tests.
Medway Crossing, Chatham, Kent	Upper 2m to 5m of Chalk was noted to be structureless (Mundford grade VI to V) with grade III to IV structured Chalk below. Similar to CKDc (unstructured Chalk) reported in Project AGS data. Also likely to have significant core loss (AZCL).	$1x10^{-3}$m/s to $1x10^{-5}$m/s in structured Chalk (Mundford grade III to IV) estimated from *in situ* and laboratory tests $9x10^{-4}$m/s back-analysed from dewatering system flow rate. $1x10^{-7}$m/s to $1x10^{-9}$m/s in structureless Chalk (Mundford grade VI to V) estimated from *in situ* and laboratory tests.
HS1 Thames Tunnel, south side, Swanscombe, Kent	Upper Chalk. Implied that a high-permeability zone exists at the top of the Chalk beneath the RTD and at the edge of the Alluvium outcrop.	$2x10^{-6}$m/s to $1x10^{-4}$m/s from borehole packer tests. Numerical modelling to back analyse the dewatering system implied that a high-permeability zone of the order of $3x10^{-2}$m/s to $7x10^{-2}$m/s may have existed in Chalk in part of the excavation.

2.3.2 Plate 2.7 illustrates how the hydraulic conductivity of the Chalk reduces with its depth (Highways England, 2017). The ability to include this in the model is gained by subdividing the Chalk into CKD (unstructured Chalk), Belle Tout and Chalk.

Plate 2.7 Chalk horizontal hydraulic conductivity results from double packer testing carried out in boreholes located to the north and south of the River Thames in lowland areas

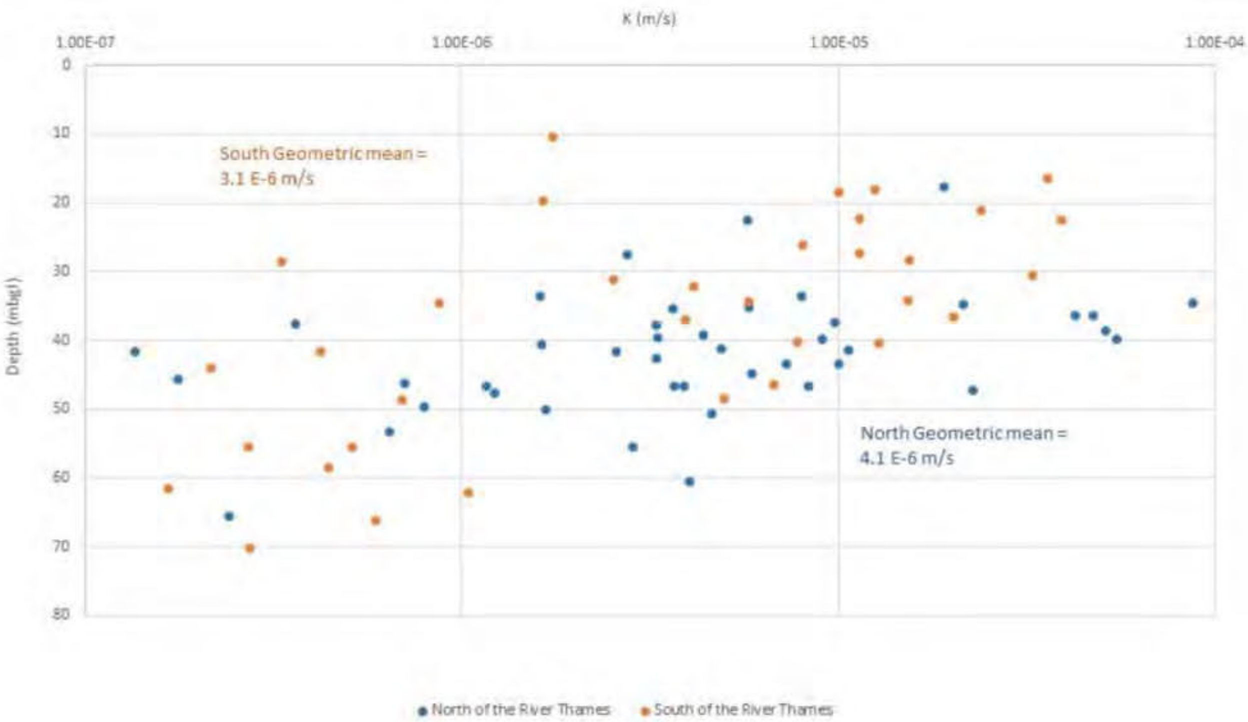
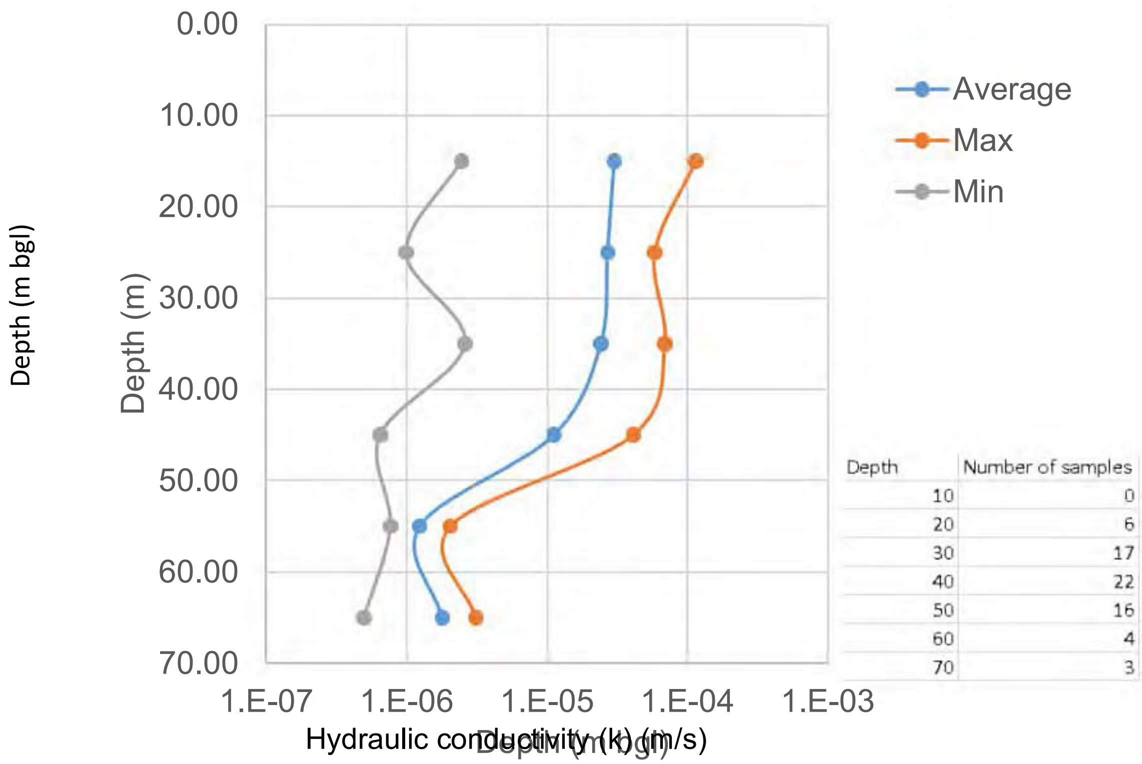


Plate 2.8 Packer test results against depth (2019–2020 AGS/SI packages)



Depth	Number of samples
10	0
20	6
30	17
40	22
50	16
60	4
70	3

2.3.3 Plate 2.8 shows the relationship of depth and hydraulic conductivity results from packer tests completed during Project Phase 2 ground investigation packages A to E. The reduction in hydraulic conductivity at between 50m AOD and 60m AOD may correspond with the base of the Seaford Chalk Formation. A trend to lower hydraulic conductivity within the Chalk is present from around 35m bgl, possibly coinciding with the top of the Belle Tout Formation, present from approximately 15m above the base of the Seaford Formation.

2.3.4 There are various mechanisms by which this depth-trend may occur, such as the following:

a. Enhancement of discontinuity apertures by groundwater flows around the water table resulting in an increase in hydraulic conductivity. This enhancement may also occur at greater depths of burial where there has been an ancient water table.

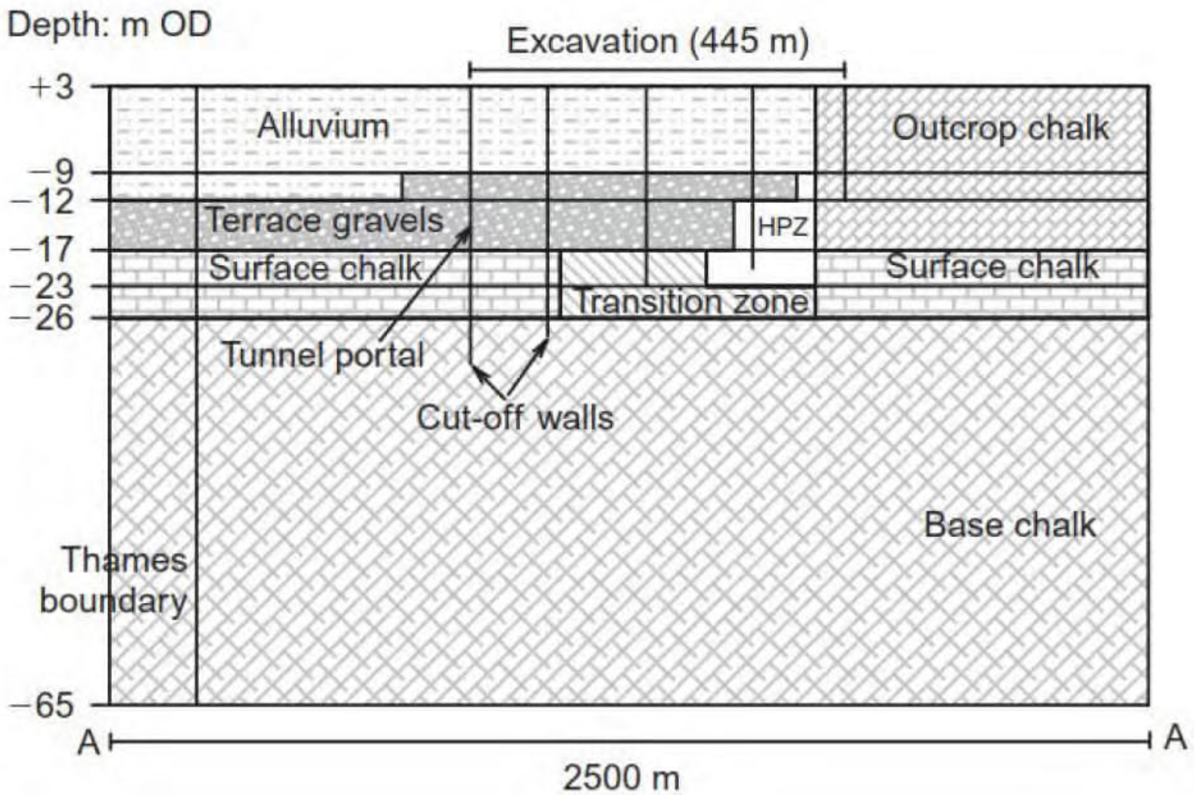
b. Historical frost-thaw weathering of the near-surface Chalk during pre-glacial conditions (Younger, 1989).

c. Closing of fractures due to burial, resulting in a decrease in hydraulic conductivity with depth.

d. Presence of marl or shale beds at depth causing lower hydraulic conductivity horizons and likely reducing vertical hydraulic conductivity significantly.

2.3.5 Bevan *et al*. (2010) found that a zone of hydraulic conductivity in the range of $1x10^{-2}$m/s to $5x10^{-2}$m/s was present. The conceptual model was that this zone extended beneath the RTD and at the margins of the RTD deposits (Plate 2.9). Beneath the RTD the zone was labelled the ‘Transition Zone’, while at the margin of the RTD it was labelled the ‘Highly Productive Zone’ (HPZ). The performance of their dewatering system could not be explained without these zones. This distribution has similarities with the distribution of high transmissivity zones shown in Plate 2.4 and Plate 2.5, caused by the presence of CKD and Chalk RQD of less than 0.1.

Plate 2.9 Extract from Bevan *et al*. (2010)

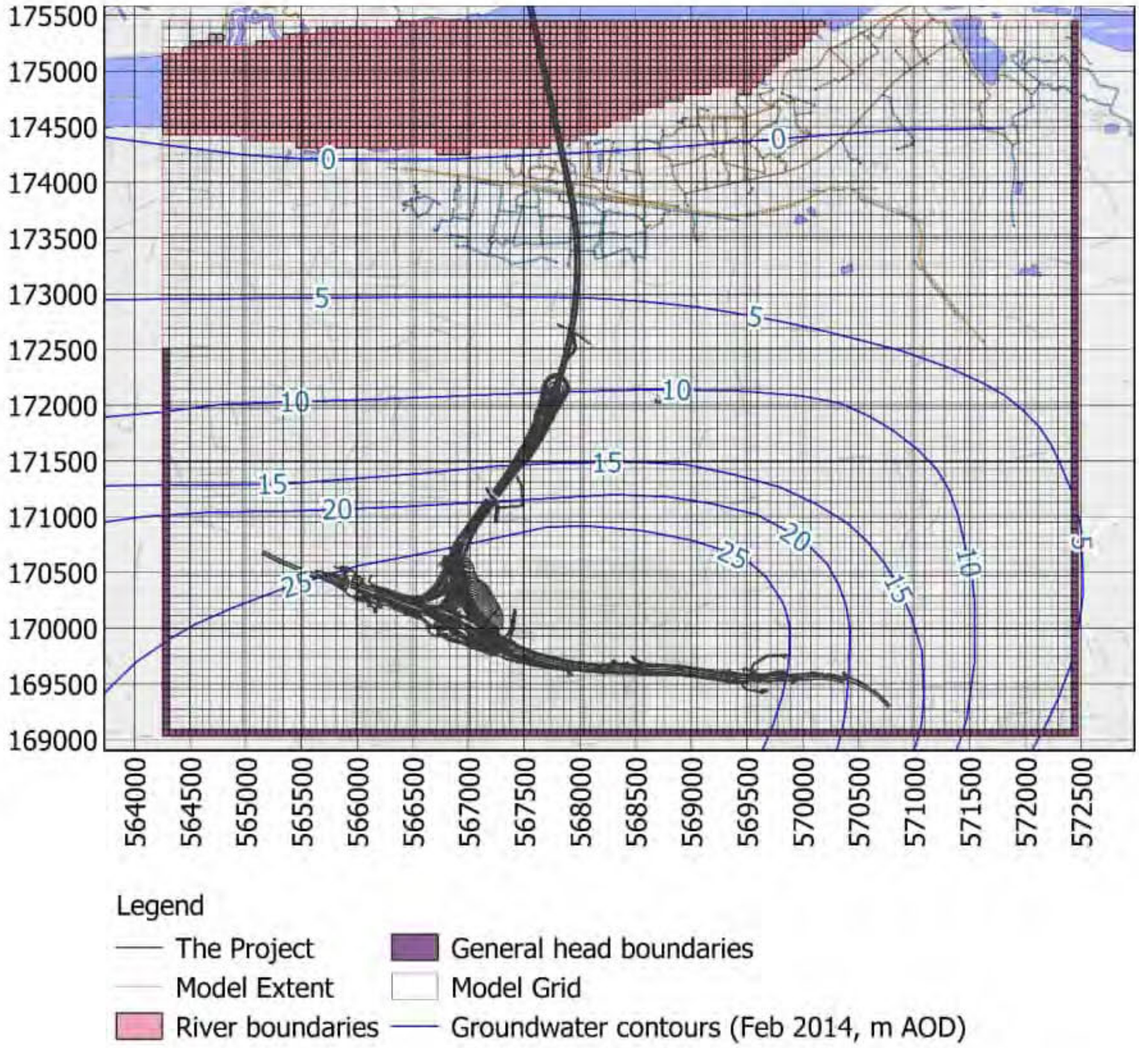


2.4 Boundary conditions

River Thames

2.4.1 Plate 2.10 shows the location of the river boundary conditions. The Thames Estuary is on the northern model boundary. This is a river boundary condition with a river bottom elevation, stage and conductance. The river boundary conditions allow for water to move out or into the boundary from the aquifer.

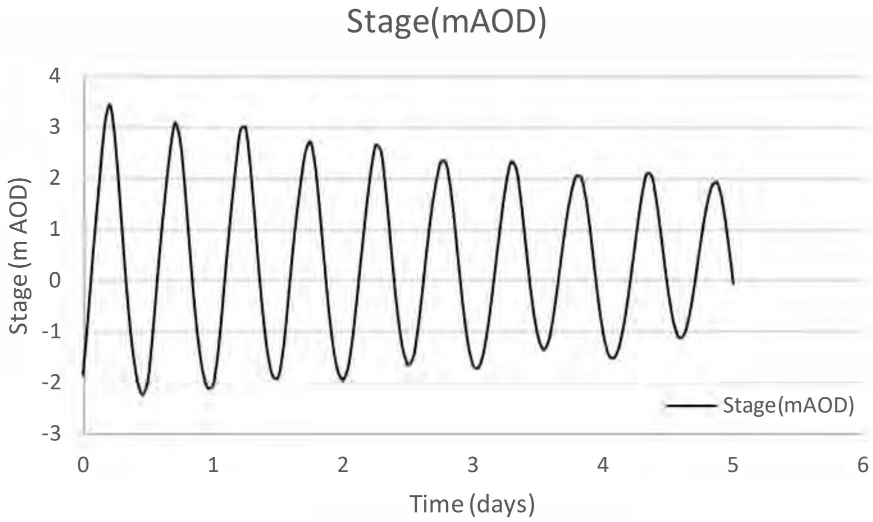
Plate 2.10 River and general head boundaries, with the February 2014 hydraulic head contours



2.4.2 The boundary is assigned into the single layer that encompasses the river bottom elevation. Layers above this are made inactive.

2.4.3 The stage is 0m AOD in steady state conditions. The time-variant simulation starts at 09:50 on 1 November 2019, and the stage follows the Thames tide at one-hour stress periods.

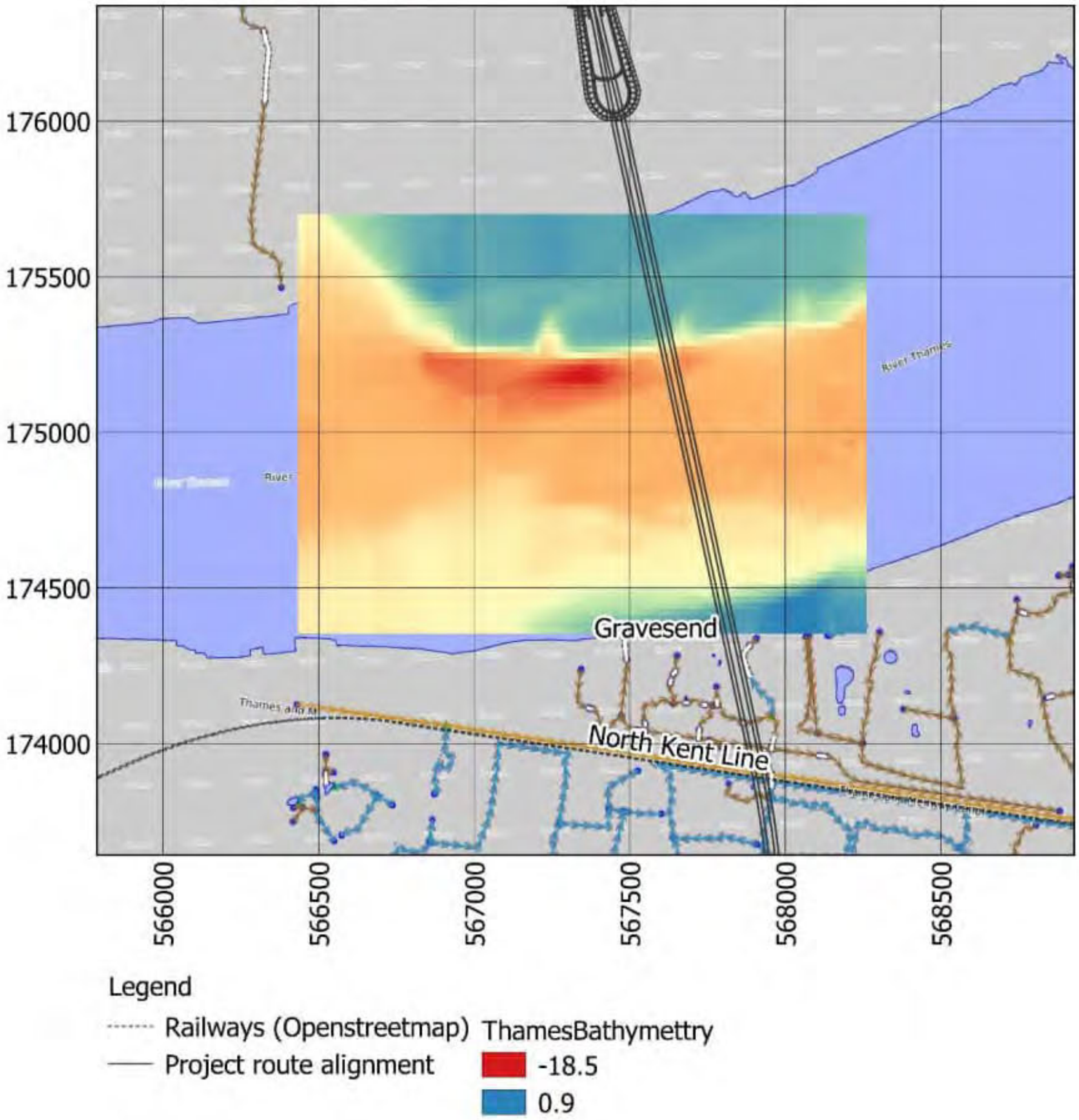
Plate 2.11 Stage for the Thames tide time-variant model



2.4.4 The rate of flow (per metre length of boundary) depends on the conductance of the boundary and a river 'stage'. The conductance is a function of the hydraulic conductivity, cell size and thickness of the riverbed in which the boundary resides. In practice, this is often a calibrated value as riverbed information is not known. For this model, the riverbed conductance is the hydraulic conductivity of the river boundary model cell multiplied by the area of the cell.

2.4.5 Plate 2.12 shows the Thames bathymetry data collected for the Project. The riverbed elevation is matched to bathymetry information where it is available. The riverbed elevation is set to -13m AOD where it is not known. This is an approximation inferred from river geophysical survey results. The river bottom elevation is checked against the model layer elevations during assignment to avoid errors.

Plate 2.12 Thames bathymetry data



2.4.6 During the model build process, the river bottom is checked against the minimum stage in the tidal range simulated. River cells are not applied where the minimum stage is less than the river bottom. This scenario may occur when modelling a tidal scenario at the river edges.

2.4.7 For the easternmost 2km of the northern boundary, the Thames Estuary is not present in the model. Here, the boundary is assumed to be no-flow. This boundary is on the easternmost 2,400m of the northern model edge (30%) over 3,300m from the Project. In the area the hydraulic gradient is low and the River Thames is just north of the model boundary. The area is instead drained into the general head boundary on the eastern edge of the model (see below).

General head boundaries

2.4.8 The model simulates a part of the broader Chalk aquifer and so the aquifer continues out of the model to the north and east. A general head boundary (GHB) represents a constant head at a distance from the boundary cell. The amount of flow from or into the cell depends on:

a. the head difference between the model and the GHB

b. the GHB head value

c. the conductance of the cell

2.4.9 The GHB is useful where boundary effects are possible. The boundary assignment uses the MODFLOW-GHB module. A GHB is defined using a head and a conductance. The conductance is a combination of the hydraulic conductivity of the cell, boundary cell area and the distance to the conceptual source of recharge.

2.4.10 Plate 2.10 shows the locations of the GHB in the groundwater model. A GHB is assigned to the eastern and southern edges of the model domain. This is used to represent the coast and Medway channels east of the model domain and the continuation of the aquifer in the south. It is assigned with a hydraulic head that matches the February 2014 water level observed data. The western boundary does not reach all the way to the River Thames to avoid numerical instability caused by adjacent boundary conditions.

Infrastructure – portals and tunnel outflows

2.4.11 The DRN (drains) and WEL packages are used to create the infrastructure boundary conditions.

2.4.12 The drain boundaries simulate:

a. the shafts of the ground protection tunnel.

2.4.13 The WEL boundaries simulate the prescribed inflow rates into the:

a. ground protection tunnel

b. main tunnel

2.4.14 The hydraulic conductivity for infrastructure cells must be altered to include for the presence of the infrastructure.

2.4.15 Table 2.7 provides details of the infrastructure boundaries used in the model.

Table 2.7 Infrastructure boundary conditions

Feature simulated	Drain elevation	Boundary
Ground protection tunnel shafts (2 no.)	-11.6m AOD Diameter 9.7m	The DRN package is used. The drain conductance is a factor of the area of the shaft within the cell, the interface hydraulic conductivity (1x10^{-7}m/s) and the thickness of the caisson (0.5m). For the shaft, this is the surface area of the portal shaft. For the bottom of the tunnel shaft, an additional conductance is added representing the area of the base of the shaft. Plate 2.13 shows a plan view of the boundary conditions relating to the ground protection tunnel. Annex B provides the locations of the ground protection tunnel boundary conditions in cross-section.
Ground protection tunnel (1 no.)	-9.7m AOD. The centreline is at -6.8m AOD, but the tunnel is 5.8m in diameter.	The WEL package is used. A single well is included in every cell encompassing the tunnel. The flow rate is calculated in advance, based on a prescribed inflow rate of 0.1L/d/m^2. It is a calculated using the prescribed inflow rate and the area of the circumference of the tunnel within the model cell, considering cells size and height. The calculated inflow rate to the grouting tunnel is calculated to be just 1.16m^3/d (0.01L/s) in total. If a rate of 0.5L/d/m^2 were used, the flow rate is proportionately larger. Plate 2.13 shows a plan view of the boundary conditions relating to the ground protection tunnel. Annex B provides the locations of the ground protection tunnel boundary conditions in cross-section. The ground protection tunnel is in the Alluvium and RTD.
Main tunnels (2 no.)	Variable elevation 16.8m diameter	The WEL package is used. A single well boundary per model cell with tunnel. The flow rate is calculated in advance, based on an inflow rate of 0.1L/d/m^2. It is a factor of the prescribed inflow rate and the area of the circumference of the tunnel within the model cell, considering the cell thickness. Using a 60m cell size, each tunnel is located in a single cell. The total flow calculated for the main tunnels within the model area is 18.4m^3/d (0.2L/s). If a rate of 0.5L/d/m^2 were used, the flow rate is proportionately larger. The tunnel is to be surrounded by a concrete perimeter (lining) made up of sheet piles, which is assumed to have a low hydraulic conductivity (1x10^{-7}m/s). The tunnels make up a large part of the volume of a model cell. It is necessary to reduce the hydraulic conductivity of the cell, to determine any mounding impact of the tunnel. This is calculated by comparing the volume of the tunnel in each cell with the remaining volume of the cell. With a 60m grid spacing, the two tunnels are across two model cells. There is one tunnel per cell width, but multiple model layers cross the tunnels.

Feature simulated	Drain elevation	Boundary
		Plate 2.14 shows a plan view of the boundary conditions relating to the main tunnel. Annex C shows the locations of the main tunnels in cross-section.

Plate 2.13 Ground protection tunnel portal (shafts) boundary conditions

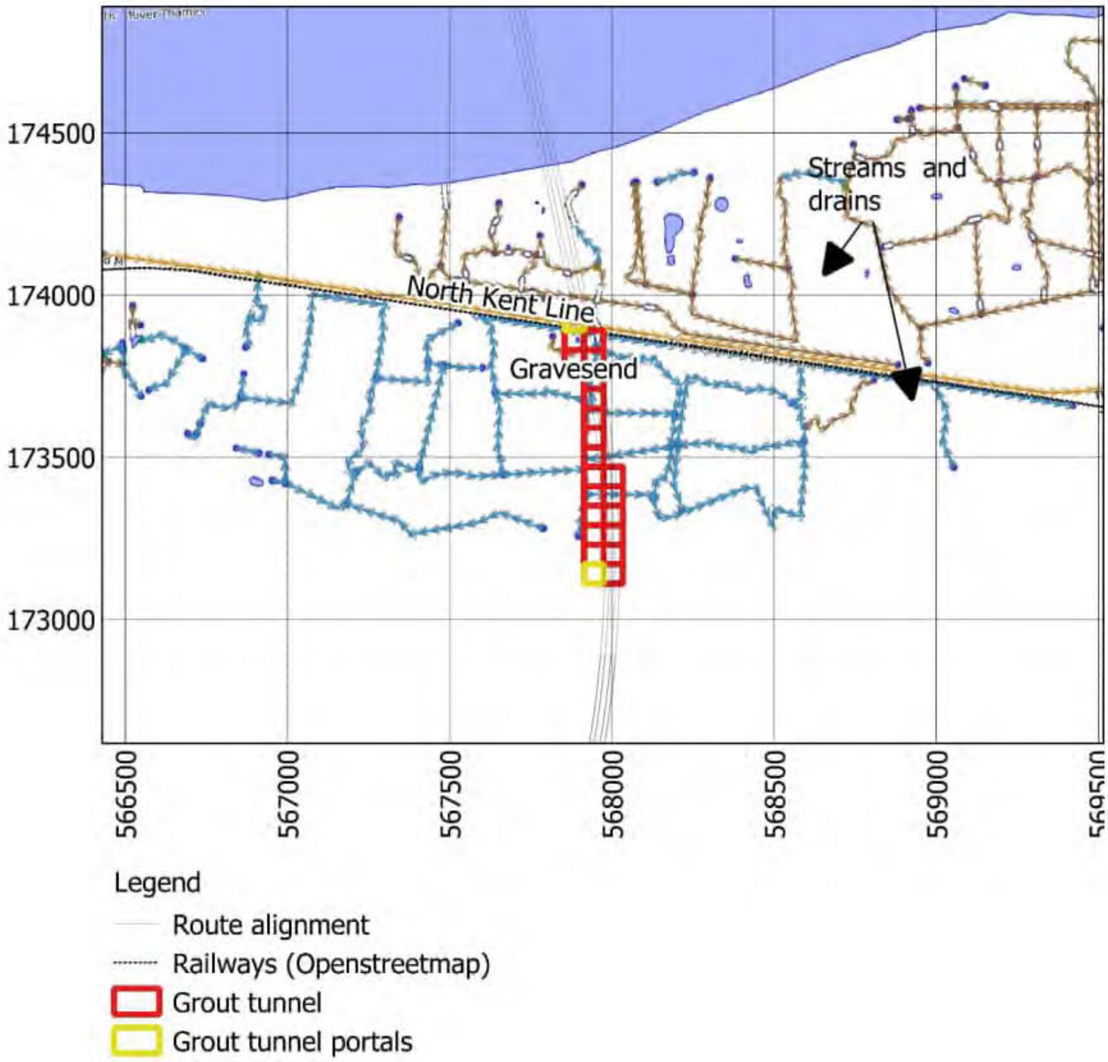
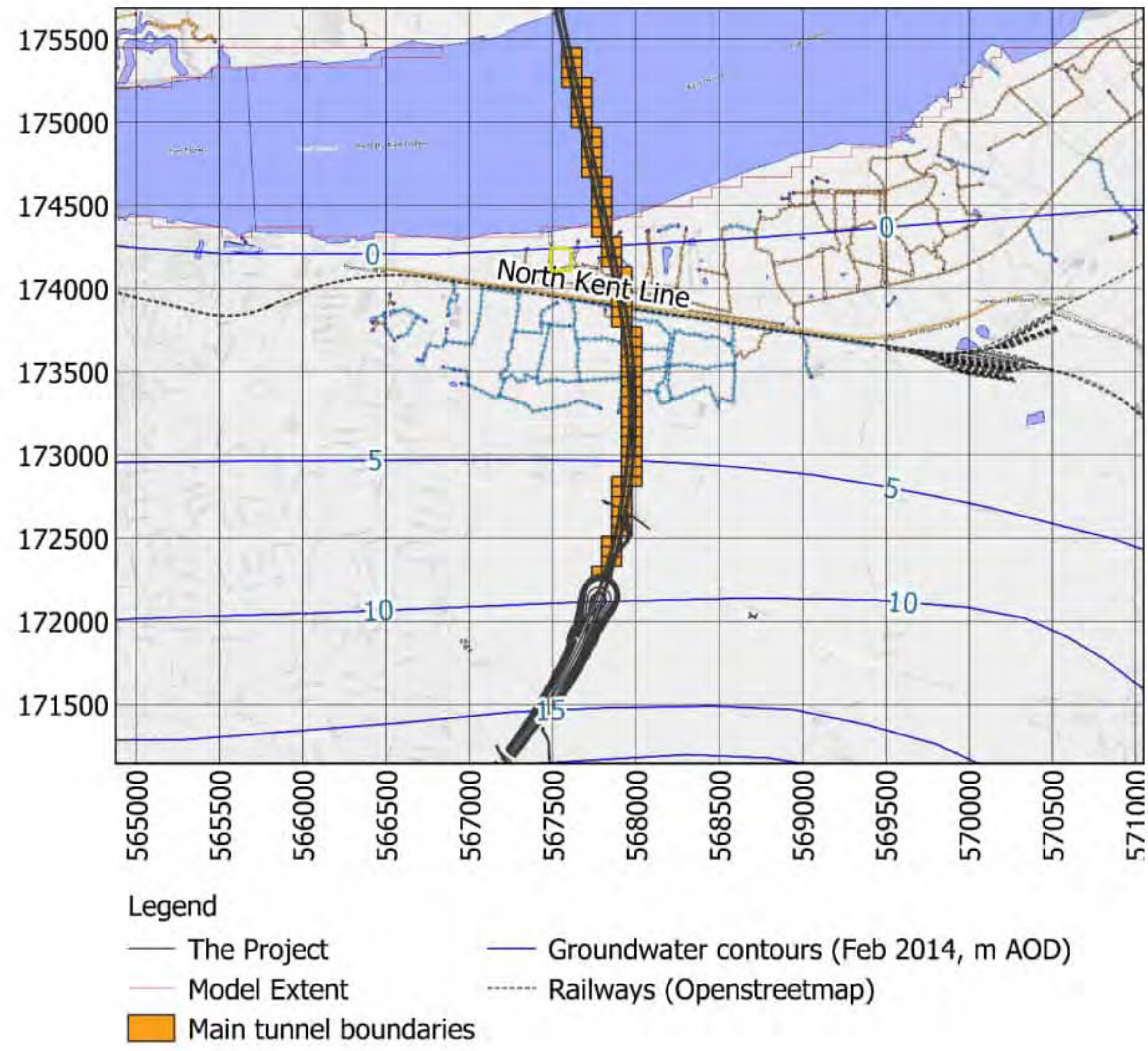


Plate 2.14 Main tunnel boundary conditions



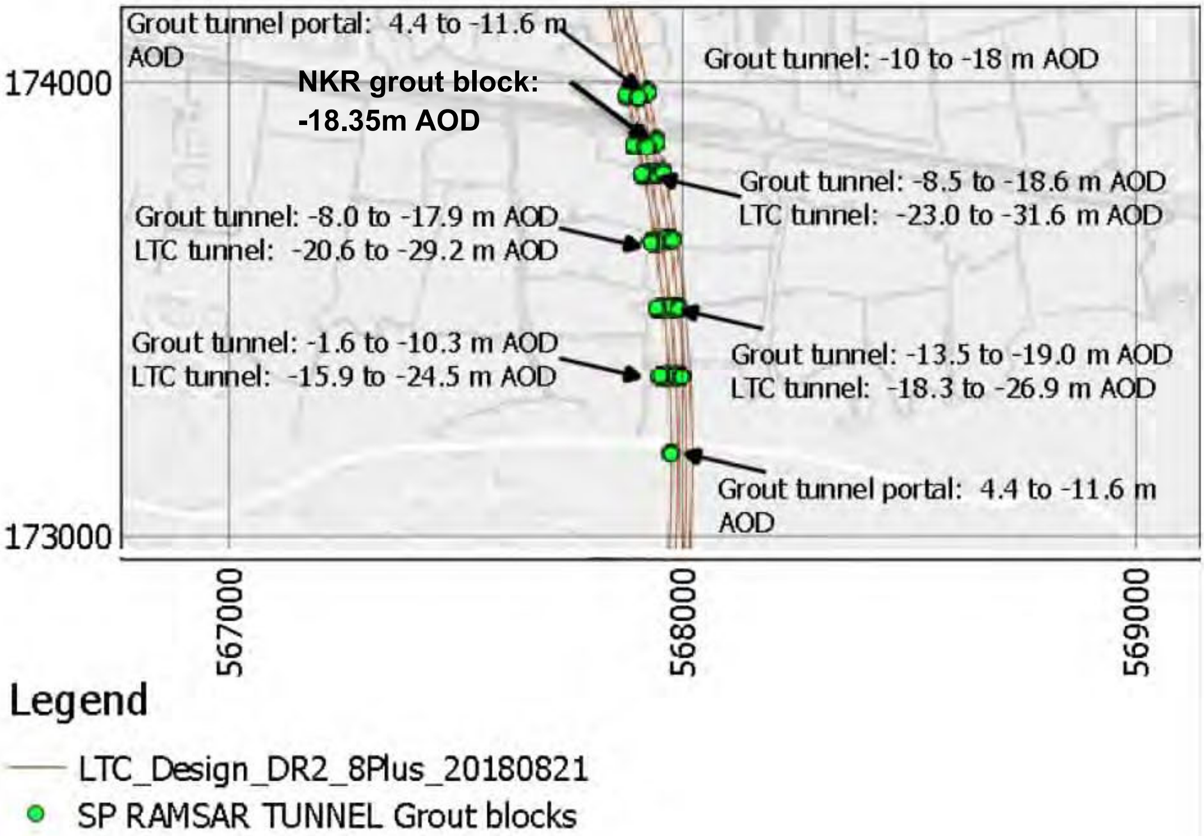
Infrastructure – grout blocks

2.4.16 Plate 2.15 shows the location and elevation of the grout blocks for the ground protection tunnel and main tunnels. The grout block locations are identified by vertices coordinates with an elevation (Highways England, 2019). The grout blocks span multiple layers of the groundwater and geological models. The purpose of the grout blocks is to provide a very low permeability zone in which maintenance of the TBM or switching of parts or systems can occur without significant groundwater inflow. The assignment is done using the top and bottoms of the grout wall.

2.4.17 The hydraulic conductivity of the grout blocks is $1x10^{-7}$m/s. The grout blocks for the ground protection tunnel are 20m wide and therefore do not fill the entire 60m wide model cell.

2.4.18 The grout blocks are included in the model as there is potential for groundwater mounding. The grout blocks also act to reduce drawdown as they have lower hydraulic conductivity than the surrounding aquifer.

Plate 2.15 A location plan showing the grout blocks for the ground protection tunnel, cross tunnels and tunnel, including their elevations



Aquifer recharge

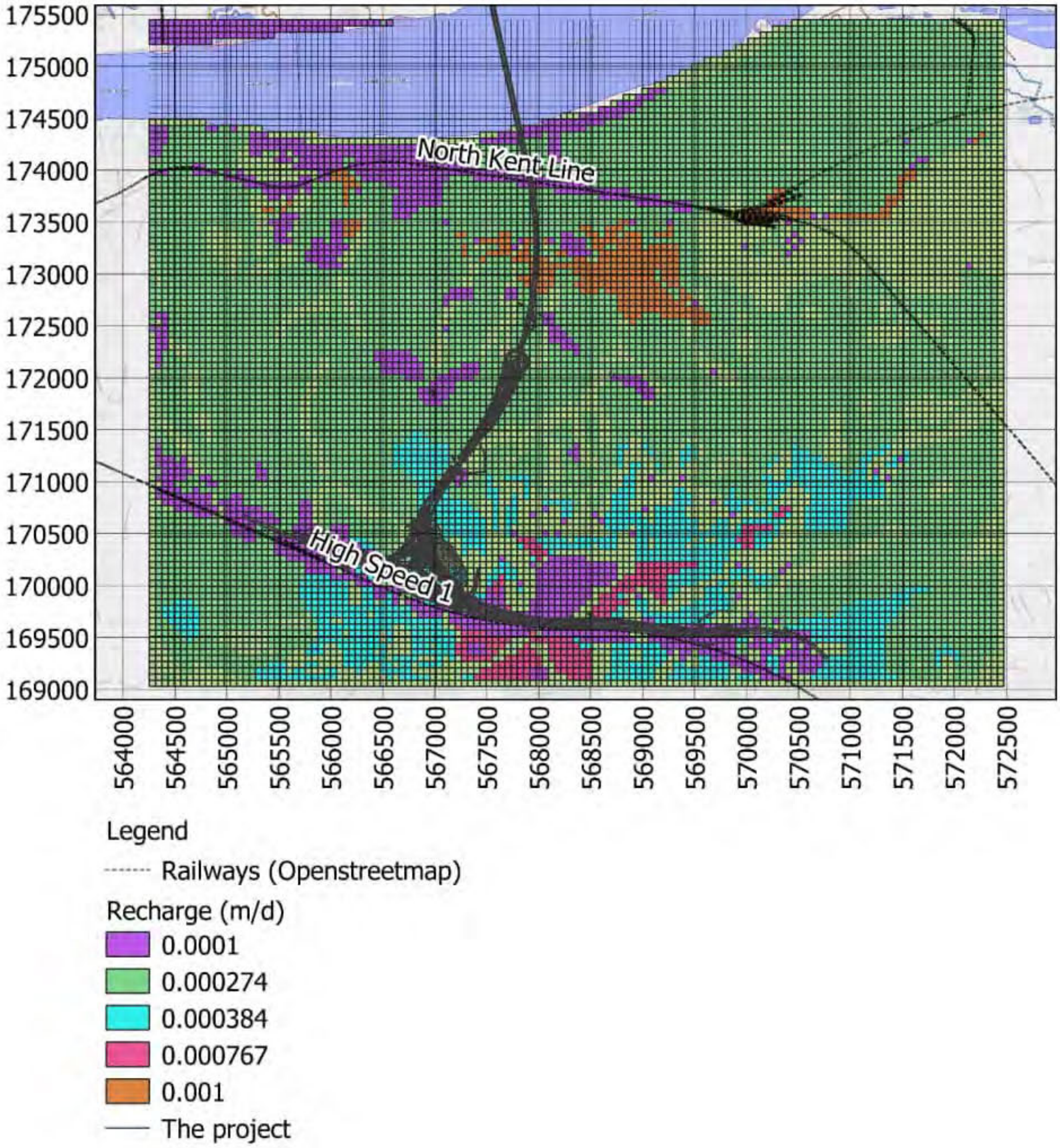
2.4.19 BGS (2008) states that 'values [of aquifer recharge] of 100mm/a (millimetres per annum) were found for the north coast of Kent and values of over 280mm/a to central and southern Kent'. In the model, the recharge is applied to the top-most active model cell, excluding cells with river or drain boundary conditions.

2.4.20 Plate 2.16 and Table 2.8 describe the expected distribution of recharge in the groundwater model, with topographical change. The recharge rates are defined based on the material type as well as the topographical elevation.

Table 2.8 Aquifer recharge values implemented in the groundwater model

Recharge rate (m/d)	Potential upper recharge rate (mm/a)	Distribution	Geological units	Conceptualisation
0.000767	280	Where the topography is above 100m AOD	Harwich Formation Lambeth Group Thanet Formation London Clay Chalk	Influenced by the amount of rainfall and the elevation. Recharge through lower permeability formations may be increased due to prolonged release from storage into unconfined Chalk.
0.000384	140	Where the topography is between 70m AOD and less than 100m AOD		
0.000274	100	Where the topography is less than 70m AOD		
0.000274	100	By outcrop type	Alluvium Tidal Flat Deposits Interglacial Deposits Head Deposits	Low elevation, with lower average rainfall and low hydraulic conductivity. Reasonable storage, but underlying Chalk is confined.
0.001	365	RTD at outcrop	RTD Gravels (Boyn Hill; Black Park; Taplow; Lynch Hill, Kempton Park; Glacio-fluvial Deposits; Stanmore; Hackney) Bagshot Formation	Highly permeable allowing for rapid infiltration of rainfall into the ground where these deposits are at ground surface.

Plate 2.16 Recharge applied to the model based on elevation and material type



2.5 Calibration

Steady state calibration

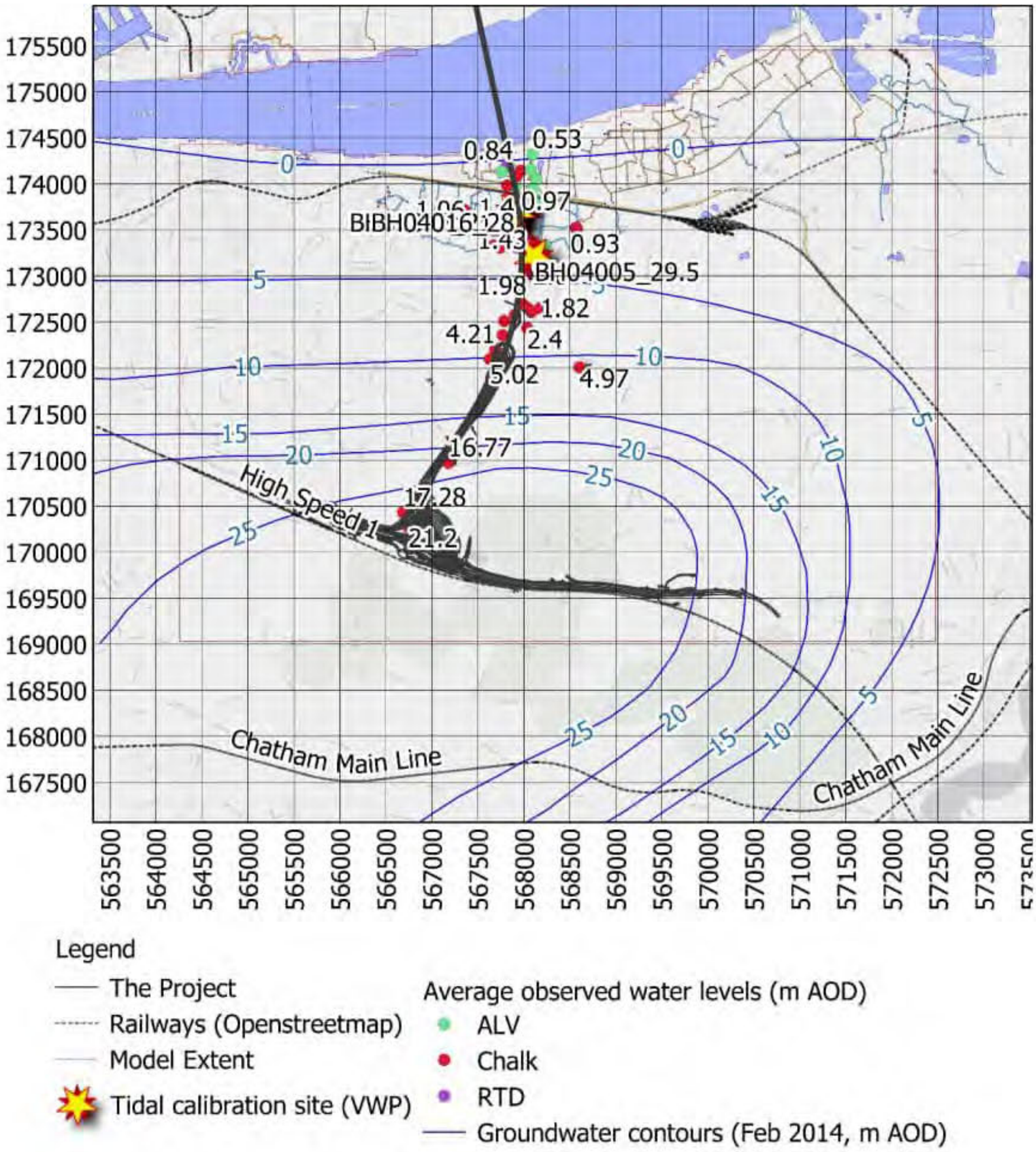
2.5.1 The hydraulic head steady state model calibration was obtained by means of a manual iterative approach, by comparing the model output with the following:

a. The February 2014 groundwater contours (baseline model) shown in Plate 2.17. These are interpolated from the Environment Agency regional monitoring network in the Chalk aquifer and provide a grid across the whole model domain for calibration.

b. The maximum observed water levels from selected Project boreholes, also shown in Plate 2.17. The use of the maximum data is to be more compatible with the February 2014 water levels.

2.5.2 These are two very different datasets and are only partially compatible. There is quite poor correlation between the borehole data and Environment Agency gridded data, though the trends are similar. The borehole data shows a flatter hydraulic gradient within the Chalk at low elevations and around the areas of outcrop Alluvium and RTD. The contour data is more useful for calibrating the wider domain, whilst the borehole data is more useful for the Project.

Plate 2.17 Water level data from boreholes used for calibration



2.5.3 The Standardized Root Mean Square Error (SRMSE) is calculated for the February 2014 grid compared to the model domain as well as for observations within subzones for the Alluvium, RTD and Chalk. Table 2.9 presents the quality criteria according to which the calibration has been obtained, i.e. the relative importance (weighting) assigned to the different zones of the modelled domain for the calculation of the SMRS.

Table 2.9 Weighting for steady state calibration

Subzone/zone	Data	Weighting	Justification
Whole domain Chalk water level	February 2014	45%	Reflects wider water balance and recharge/transmissivity ratio. Compensating for fact Project data is very linear in extent
Project – Chalk	Project borehole water level monitoring data	45%	Important for controlling inflows into the Project. Very sensitive to changes.
Project – RTD	Project borehole water level monitoring data	8%	Potentially important to Project inflows, but largely controlled by Chalk transmissivity
Project – Alluvium	Project borehole water level monitoring data	2%	Low conductivity and largely insensitive in steady state. High scatter due to very local inhomogeneities and perching, land drainage.

Time-variant calibration

2.5.4 Plate 2.18 shows the locations of the vibrating wire piezometer (VWP) sites. Table 2.10 provides the screen elevations and representative aquifer unit for the observation sites, BH04005 and BH0416, which were used for time-variant calibration. Plate 2.18 shows the water levels at these sites at various screen intervals. Of all the Project VWP sites, these boreholes provided the best spatial distribution and had data over the same time-period.

Plate 2.18 VWP observations of tidal response in the chalk (BH04005 and BH04016)

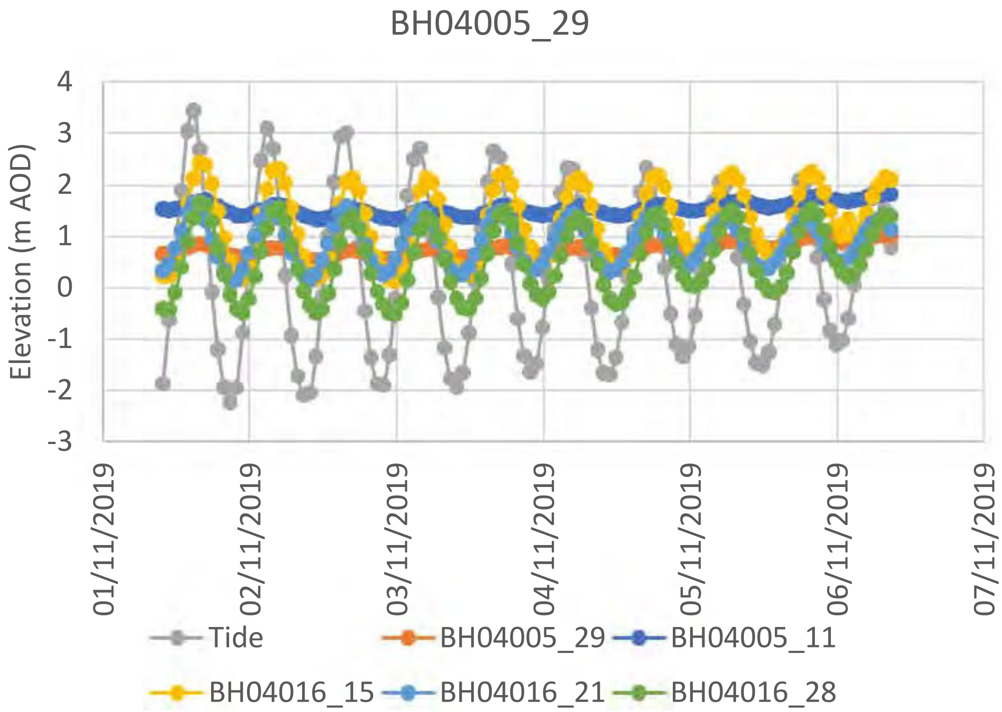


Table 2.10 Screen elevation and lithology for observation sites

Name	Representative screen depth (m bgl)	Lithology
BH04005_11	11	Chalk
BH04005_29	29	Chalk
BH04016_15	15	RTD
BH04016_21	21	Chalk
BH04016_28	28	Chalk

2.5.5 The MODFLOW 'Hobs' package was used to extract data from the model at the correct times, matching the observed data. A stress period of one hour was used to simulate the changing of the tide over a period of five days.

Manual calibration and changes to the conceptual model

2.5.6 A manual iterative approach to calibration was used to adjust the conceptual model to better fit the observed groundwater level data. Plate 2.19 shows plots of the predicted water level and the highest water level recorded from the Project boreholes. Plate 2.20 shows a plan view of the water table and the observed water level in the chalk for February 2014. The SRMSE for the chalk boreholes is 8.19% and for the February 2014 levels is 7.8%. Findings from the calibration were as follows:

a. The observed tidal response is very large. Such a tidal response can be achieved if there is a very high transmissivity, low storage and strongly confined aquifer with the Chalk. This aquifer must be well connected to the

River Thames. Reviews of the nearby HS1 scheme showed that a thin but high transmissivity zone was present beneath RTD. After review of the AGS data for Chalk grade and core loss in the Chalk, this same zone of high transmissivity was included in the model. To obtain the high tidal response, the hydraulic conductivity of this area was calibrated to be in the order of $1x10^{-2}$m/s and to be isotropic. Though the zone is only less than 5m thick in general, this high hydraulic conductivity determines the Chalk's large transmissivity. The high value has been previously reported during excavation in this locality (Bevan *et al*., 2010). It was also necessary that the RTD vertical hydraulic conductivity (k_z) was low so that the amplitude of the response was not dissipated.

b. The BGS model of the Chalk does not match with site derived data well beneath the centre of the Thames. The BGS model has a layer of Alluvium and RTD present, when the Project borehole information shows the Chalk rising and outcropping at the river base. A modification was required beneath the Thames to improve the connectivity with the Chalk.

c. A near surface layer of Chalk approximately 35m thick allows for draining of the hinterlands through intersection of the water table with 'dry' streambeds. These streambeds are conceptualised to have increased transmissivity due to increased groundwater flows and dissolution effects. The location of the 'dry' channels can be approximated to topographical dips filled with Head Deposits, trending from south to north towards the River Thames. This structure was built into the model by applying a layer with an elevation matching the Seaford Formation base (approximately 55m bgl beneath the Thames) plus 20m. This elevation approximately matches the Belle Tout beds. The calibration was found to be quite sensitive to the thickness of this high permeability layer; too deep and the groundwater levels would be too low in the hinterlands. This zone was found to have a calibrated horizontal hydraulic conductivity of about $5x10^{-4}$m/s.

d. The horizontal hydraulic conductivity of the deeper, 'bulk' chalk is lower than that of the shallow or weathered chalk. Mapping by the Environment Agency suggests that the transmissivity of the Chalk in the hinterland areas north of the River Thames is between 20 and 100m^2/d. This was assumed to be similar for the south side and a calibrated value of 35m^2/d was found (a hydraulic conductivity of approximately $1x10^{-5}$m/s to $5x10^{-6}$m/s) when distributed across the saturated thickness beneath the Thames area and hinterlands respectively.

e. The Alluvium horizontal bulk hydraulic conductivity was calibrated to be $7x10^{-7}$m/s and found not to be very sensitive. During time-variant simulations of the tidal effect, a cycling upwards and downwards gradient develops between the Alluvium and Chalk. With such low hydraulic conductivity, recharge causes a local mounding of the water table.

2.5.7 This initial calibration was used to provide the starting point for a stochastic Monte Carlo assessment.

Plate 2.19 Steady state manual calibration with Project boreholes: Calculated vs. Observed groundwater levels.

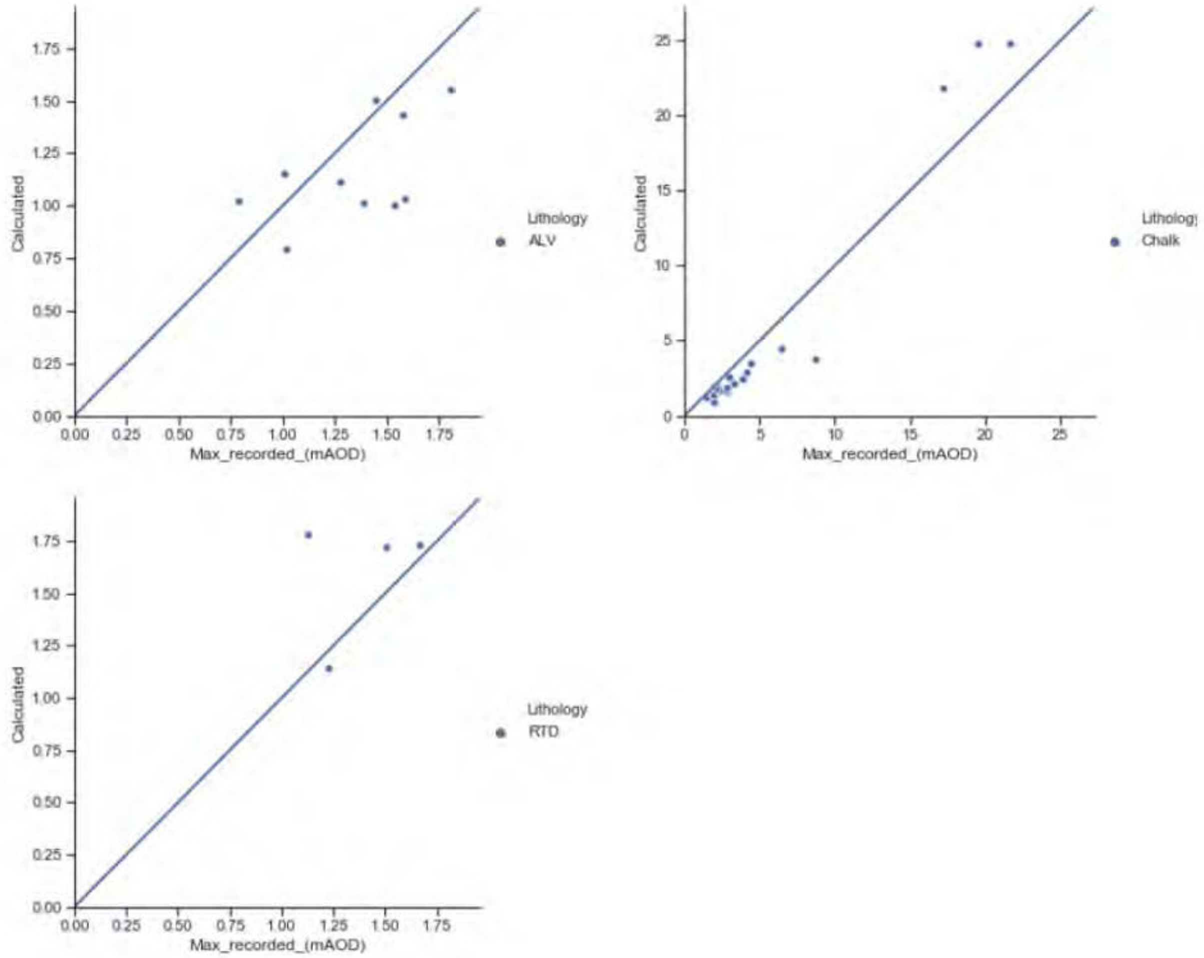
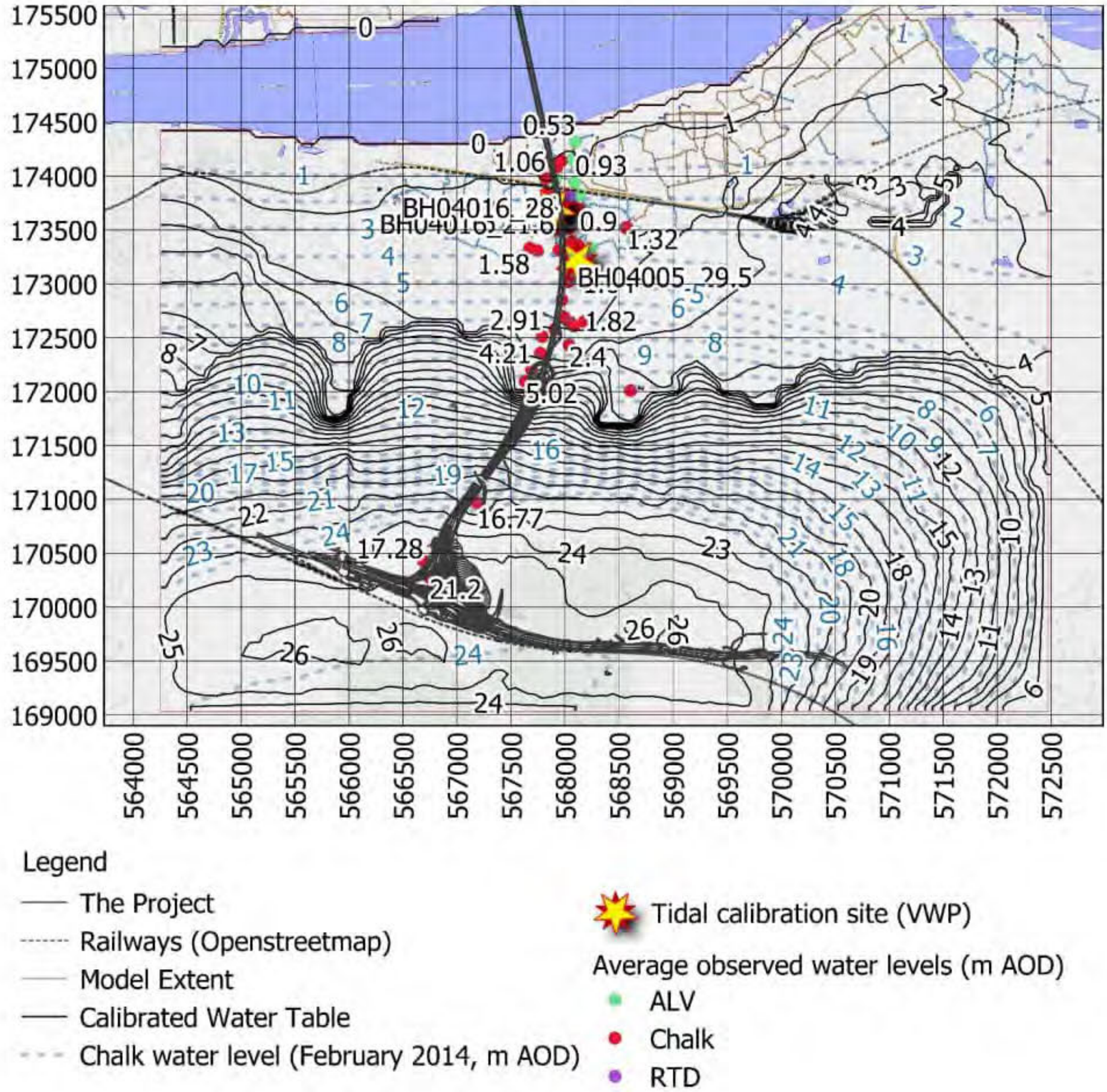


Plate 2.20 Steady state manual calibration: calibrated water table Monte Carlo assessment



2.5.8 It can be the case that a single calibration is fixed upon during groundwater modelling by manual iteration, when many may be available within the pre-defined parameter ranges. A Monte Carlo analysis tested 1,600 model calibration parameter (horizontal and vertical hydraulic conductivities) combinations. Each simulation included a steady state and time-variant calibration assessment, followed by the Project infrastructure scenario if the calibration was suitable. The assessment was completed using FloPy. For each simulation, the SRMSE and parameters applied were recorded and assessed for the calibration data.

2.5.9 The recharge was 'fixed' at the values discussed in paragraph 2.4.5. Parameters varied in the analysis included the horizontal and vertical hydraulic conductivity (in a pre-defined ratio) for the following:

a. Alluvium (ratio of k_z(vertical) / k_h(horizontal) = 0.1)

b. RTD (ratio of k_z(vertical) / k_h(horizontal) = 0.1)

c. CKD (unstructured granular chalk/core loss zones ($k_z = k_h$)

d. Belle Tout Chalk (a zone within approx. 35m bgl, ratio of k_z(vertical) / k_h(horizontal) = 0.02)

e. Bulk Chalk – deeper chalk, making up the saturated chalk in the hinterlands (ratio of k_z(vertical) / k_h(horizontal) = 0.02)

2.5.10 Table 2.11 provides the stochastic distribution statistics from which the parameters were selected at random. The initial mean values were created from the manual calibration results.

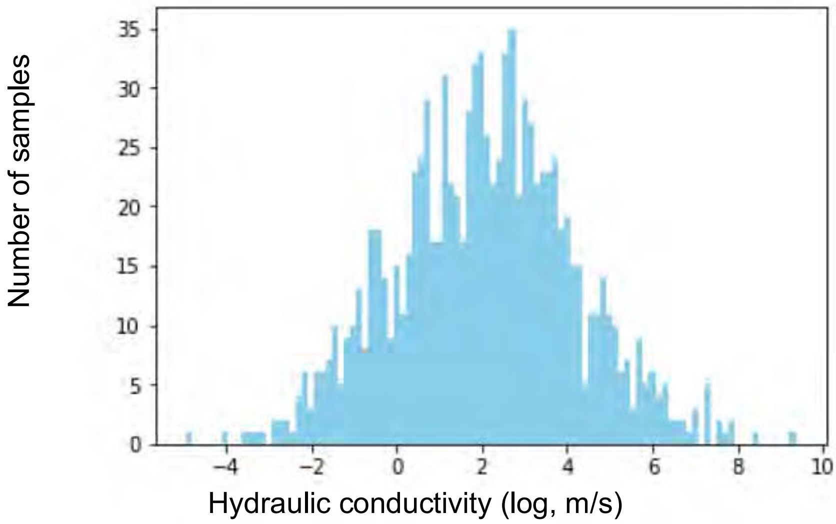
Table 2.11 Log-normal distributions of hydraulic conductivity for the Monte Carlo simulations

Geological Unit	Hydraulic conductivity (m/s)		
	Mean	Standard deviation	Max and min tested
Alluvium	$7x10^{-7}$	1.25	$1.29x10^{-8}$ to $9.95x10^{-5}$
RTD	$7.30x10^{-4}$	1	$5x10^{-5}$ to $2x10^{-3}$
Unstructured Chalk (CKD/AZCL)	$1x10^{-2}$	0.1	$6.93x10^{-3}$ to $1.39x10^{-2}$
Belle Tout Formation	$5x10^{-4}$	0.25	$1.00x10^{-3}$ to $5.40x10^{-2}$
Bulk Chalk Transmissivity	$35m^2/d$	0.25	[1]

[1]Bulk Chalk is matched to a transmissivity zone of between $20m^2/d$ to $100m^2/d$ (Figure 3.17 of Environment Agency (2016))

2.5.11 Plate 2.21 shows an example, randomly generated distribution with a mean of log ($1x10^{-4}$m/s) and standard deviation of log ($0.5x10^{-4}$m/s).

Plate 2.21 An example normal distribution for a mean of log ($1x10^{-4}$m/s) and standard deviation of log ($0.5x10^{-4}$m/s).

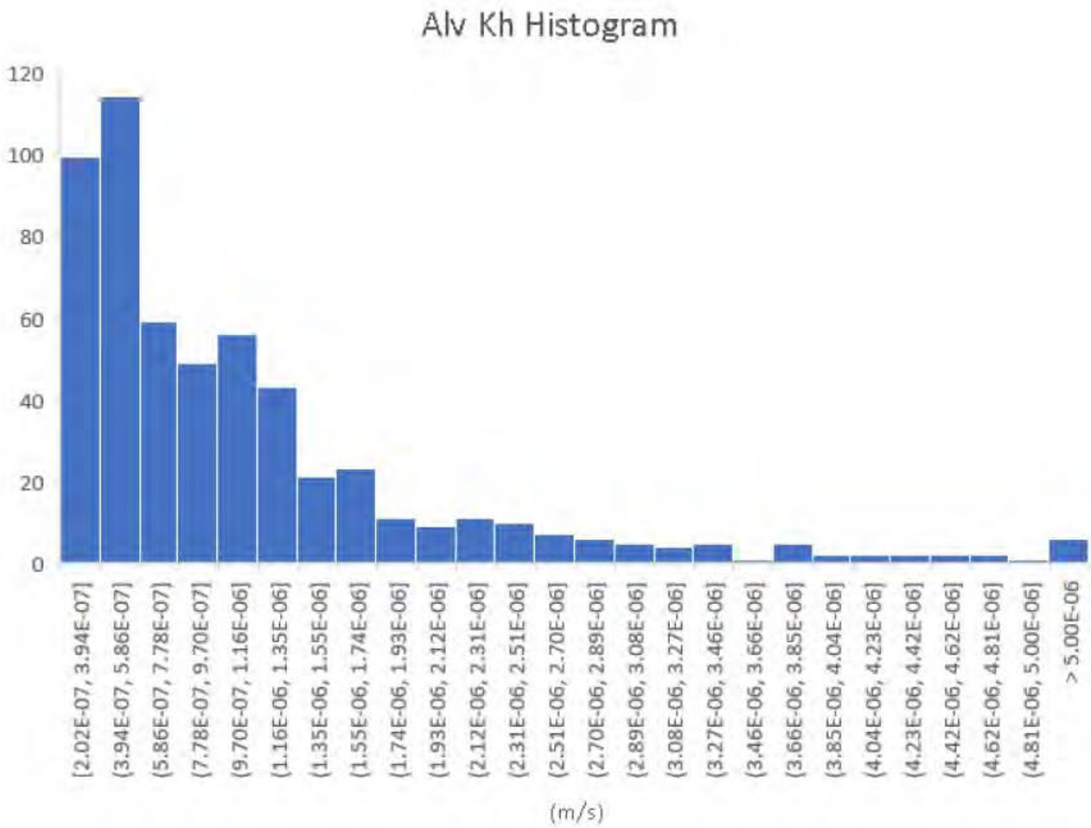


2.6 Results of the Monte Carlo simulations

Alluvium

2.6.1 Plate 2.22 shows a histogram for Alluvium k_h (horizontal hydraulic conductivity). The result shows that most calibrated Alluvium models have a low hydraulic conductivity. The hydraulic conductivity tends towards the lowest values simulated, in the order of $1x10^{-7}$m/s.

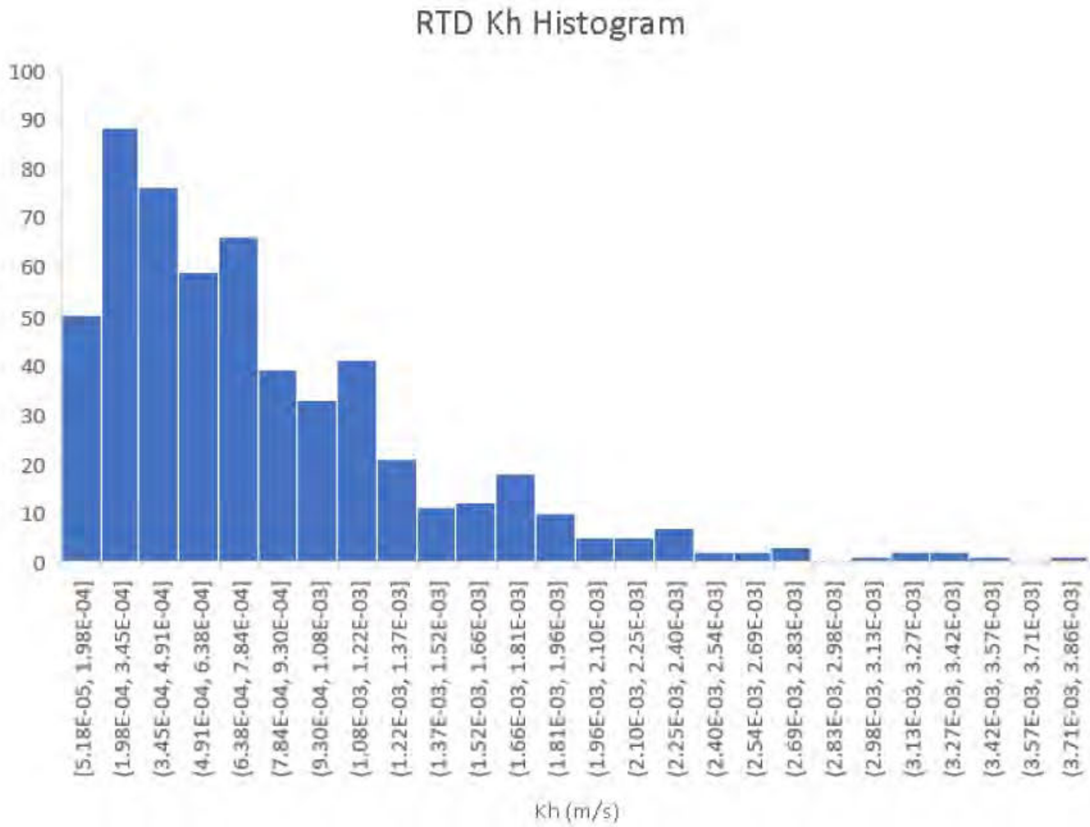
Plate 2.22 Alluvium k_h



River Terrace Deposits (RTD)

2.6.2 Plate 2.23 shows a histogram of the results for the RTD. The results are skewed towards the lower end of the tested range, generally less than 7x10^{-4m}/s.

Plate 2.23 Monte Carlo results for the RTD k_h



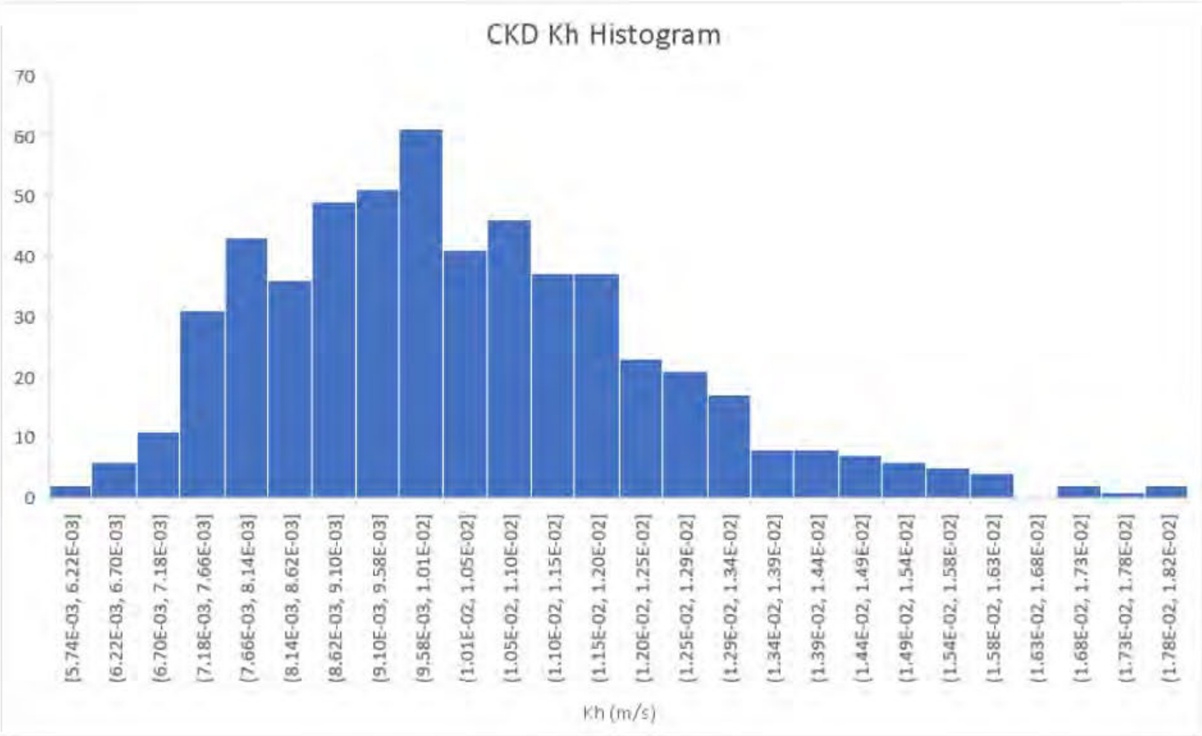
Unstructured Chalk (CKD, AZCL or RQD <0.1)

2.6.3 Plate 2.24 shows that the extremes of the range tested for the CKD (unstructured or karstic Chalk situated under the Thames or under RTD) are much less likely to occur than the central range of between 8.8x10^{-3}m/s and 1.12x10^{-3}m/s. Once in the central range of parameters, there is little additional sensitivity. In practice:

a. lower hydraulic conductivity values cause the tidal response to be too small

b. higher values cause both model instability and too much flattening of the water table in steady state

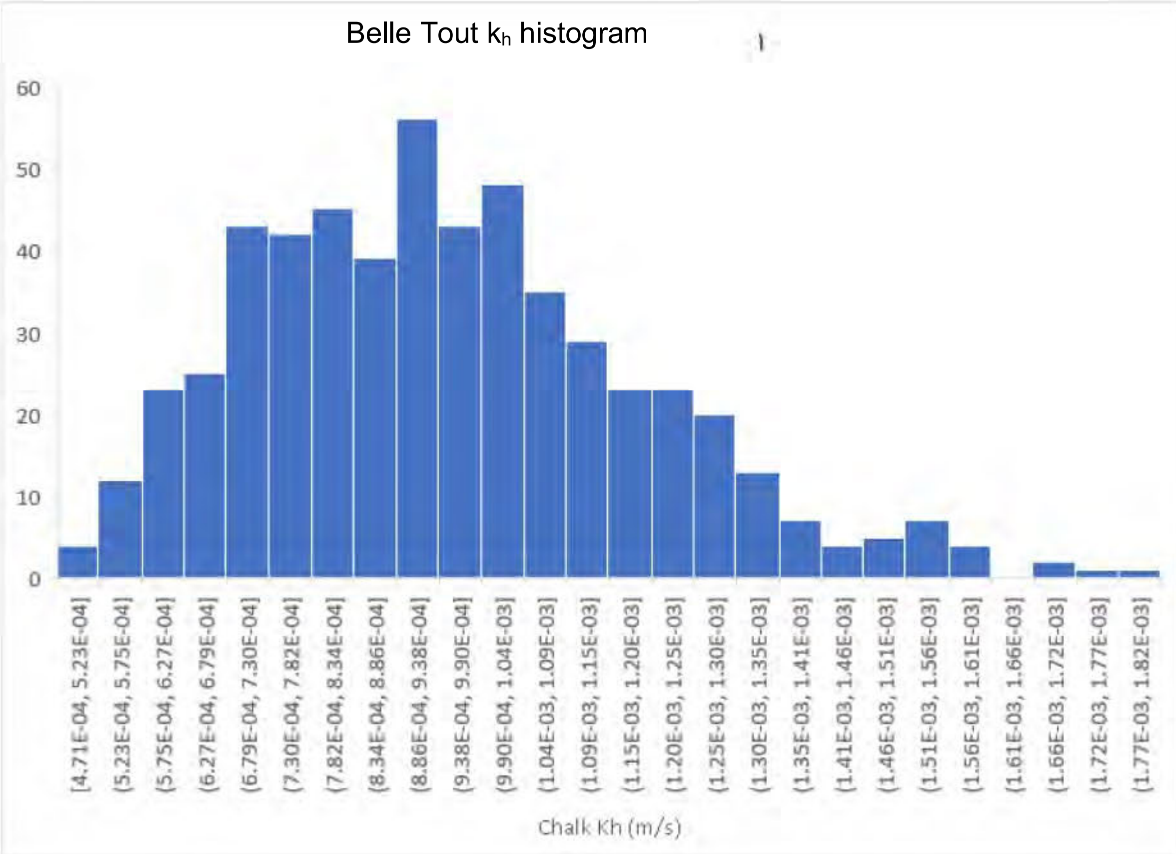
Plate 2.24 Monte Carlo results for the unstructured Chalk – (CKD, AZCL or RQD <0.1)



Belle Tout (upper part of Chalk)

2.6.4 Plate 2.25 shows that the calibrated values for the Belle Tout layer that forms the upper part of the Chalk, form a log-normal distribution with a skew to higher values. The peak bin is for a hydraulic conductivity of approximately 9.5x10^{-3}m/s. Lower hydraulic conductivities cause hydraulic gradient between the River Thames and the hinterlands to become too steep. This causes the calibration of the observed Chalk water levels in borehole to become poorer. Higher hydraulic conductivity values do not affect the observed Chalk water levels but cause the hinterland regions to drain too freely. This causes the steady state calibration against the February 2014 regional water levels to fail.

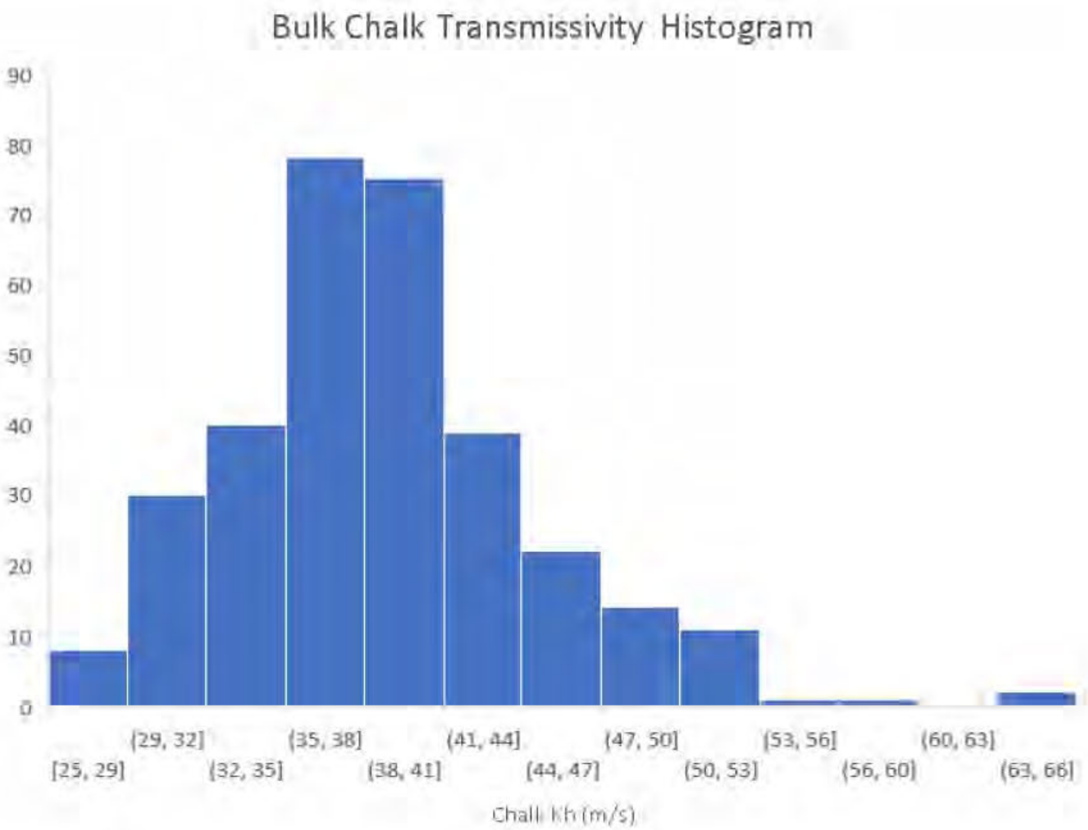
Plate 2.25 Monte Carlo results for the Belle Tout k_h



Bulk Chalk (buried structured chalk)

2.6.5 Plate 2.26 shows the calibrated values for the Chalk layer that forms the remaining aquifer beneath the Belle Tout layer (approx. 35m bgl) to the base of the model (170m bgl). This has been done by varying the transmissivity of the aquifer. If the base of the Belle Tout layer was above the water table, then the February 2014 water table was used as the top of the aquifer to derive the thickness. The results showed a normal distribution with a mean of 37.6m^2/d. This is within the expected range and corresponds to a hydraulic conductivity of approximately 3x10^{-6}m/s for a 135m thick aquifer.

Plate 2.26 Monte Carlo results for the bulk Chalk rock



Representative 50^{th} percentile model

2.6.6 Table 2.12 presents the results for the 50^{th} and 95^{th} percentile parameters from the Monte Carlo assessment.

Table 2.12 Material hydraulic conductivity for different percentiles

<table>
<tr><th>Material</th><th>Hydraulic conductivity[2] 50^{th} percentile (m/s)</th><th>Hydraulic conductivity[2] 5^{th} percentile (m/s)</th><th>Hydraulic conductivity[2] 95^{th} percentile (m/s)</th></tr>
<tr><td>[1]Made Ground</td><td colspan="3">1.00×10^{-5}</td></tr>
<tr><td>[1]Head Deposits</td><td colspan="3">5.00×10^{-7}</td></tr>
<tr><td>Alluvium</td><td>7.90×10^{-7}</td><td>2.83×10^{-7}</td><td>3.35×10^{-6}</td></tr>
<tr><td>RTD</td><td>6.55×10^{-4}</td><td>1.63×10^{-4}</td><td>2.0×10^{-3}</td></tr>
<tr><td>[1]London Clay</td><td colspan="3">1.00×10^{-7}</td></tr>
<tr><td>[1]Lambeth Group</td><td colspan="3">1.00×10^{-7}</td></tr>
<tr><td>[1]Harwich Formation</td><td colspan="3">1.00×10^{-5}</td></tr>
<tr><td>[1]Thanet Sands</td><td colspan="3">1.00×10^{-4}</td></tr>
<tr><td>CKD (unstructured Chalk, Channel Tunnel Rail Link Transition and</td><td>1.00×10^{-2}</td><td>7.40×10^{-3}</td><td>1.39×10^{-2}</td></tr>
</table>

Material	Hydraulic conductivity[2] 50th percentile (m/s)	Hydraulic conductivity[2] 5th percentile (m/s)	Hydraulic conductivity[2] 95th percentile (m/s)
Highly Productive Zone)			
Belle Tout Chalk layer	9.30×10^{-4}	6.00×10^{-4}	1.39×10^{-3}
Material	**Transmissivity 50th percentile (m^2/d)**	**Transmissivity 5th percentile (m^2/d)**	**Transmissivity 95th percentile (m^2/d)**
Bulk Chalk transmissivity (m^2/d)	37.61	29.46	49.84

[1] Manual calibration and not varied in assessment
[2] Horizontal

2.6.7 Plate 2.27 shows the prediction of the groundwater level in the chalk for the 50th percentile parameter set given in Table 2.12. The SRMSE statistics for the simulation are as follows:

a. February 2014 water levels – 8.5%

b. Chalk observations – 6.9%

c. Against all observations – 5.7%

d. Against tidal observations – 15.8%

2.6.8 The calibration statistics for the February 2014 regional water levels reflect the difficulty in finding a solution that works for both datasets. The site-specific chalk observations from Project boreholes have been prioritised. The February 2014 water levels have the following limitations:

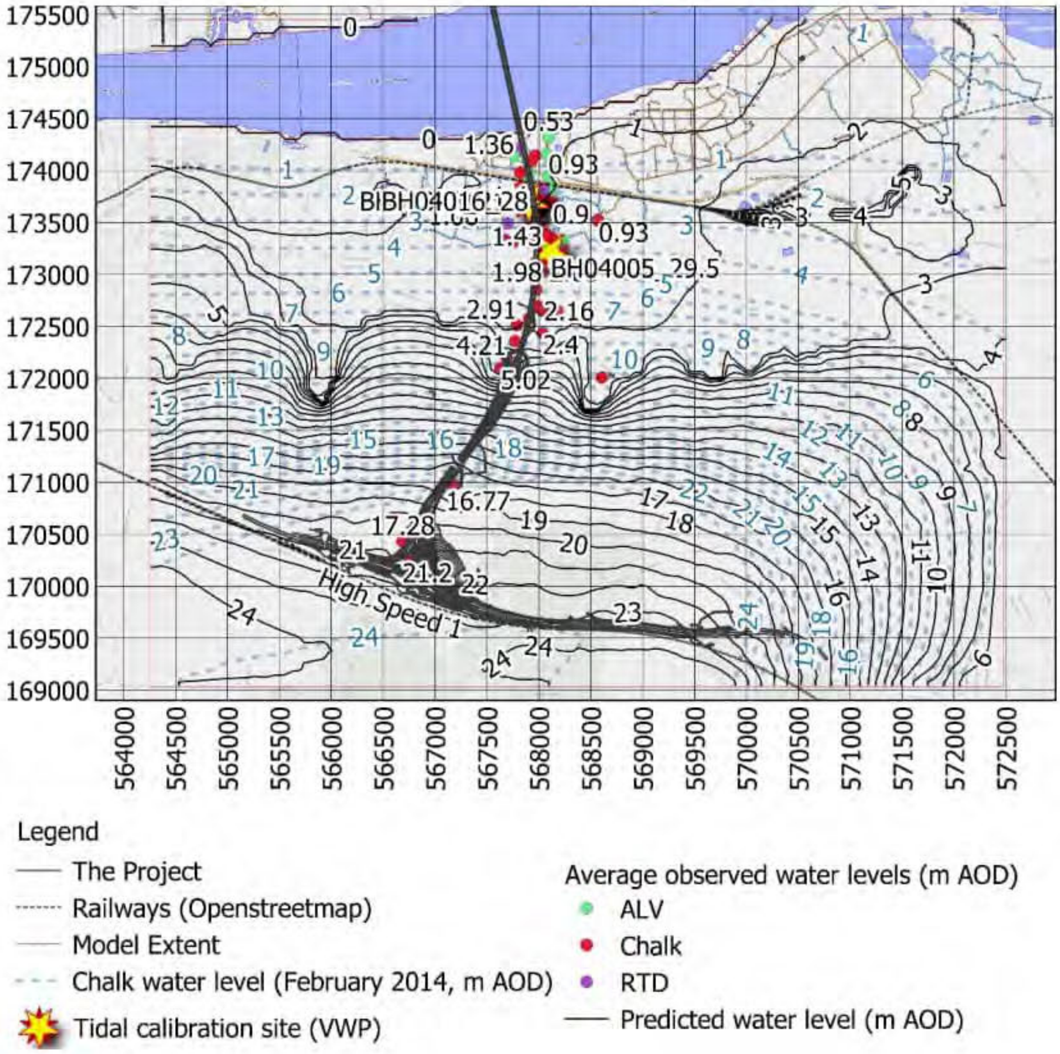
a. The February 2014 grid is produced from a relatively small number of water level observations distributed over a wide area (wider than the model).

b. The February 2014 grid does not include information about the influence of local topography (valleys, interfluves).

c. The February 2014 represents winter levels, rather than summer or average conditions. The Project borehole monitoring data was obtained in summer and autumn conditions.

d. The February 2014 grid does not match well the observed data at Project boreholes. It is still useful as a guide to the regional calibration.

Plate 2.27 Predicted water table from the steady state baseline model using the 50th percentile parameter setup



2.6.9 The SRMSE of the calculated and observed tidal variation of the 50th percentile scenario is calculated to be 16%, but a good fit is observed with the data. Achieving the full range of tidal variation in the model is difficult with parameters within the expected ranges of hydraulic conductivity. The observed tidal range at BH04016 is from +2m AOD to -0.2m AOD. This borehole is approximately 450m from the River Thames. The tidal range within the Chalk causes an alternating upwards and downwards gradient between the Chalk in which it is measured, the underlying Chalk and overlying RTD and Alluvium. The response is indicative of:

a. a level of confinement that is not achievable

b. a lower storage than the expected range allows

c. a very direct hydraulic connection to the River Thames

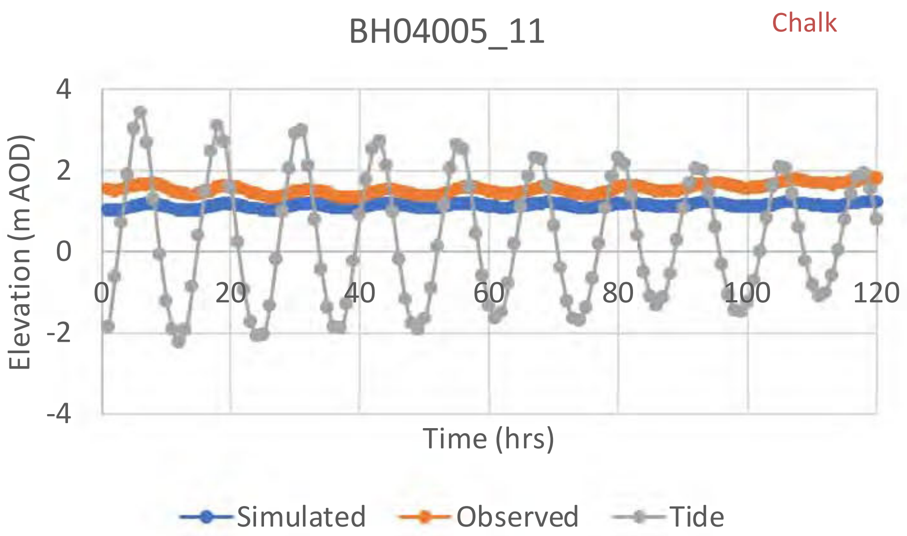
2.6.10 To obtain the degree of hydraulic response observed (Plate 2.28 and Plate 2.29), the following modifications were necessary:

a. Inclusion of Clay layers from AGS data within the bulk Alluvium is necessary to confine the RTD. The clay was assigned a hydraulic conductivity of 1/10th the bulk Alluvium.

b. A zone with a hydraulic conductivity of at least $1x10^{-3}$m/s (k_h=k_z) was required beneath the Thames to connect the river with the Chalk.

c. RTD gravel and Chalk storage coefficient set to $1x10^{-6}$m/s.

Plate 2.28 Predicted and observed tidal variation for BH04005



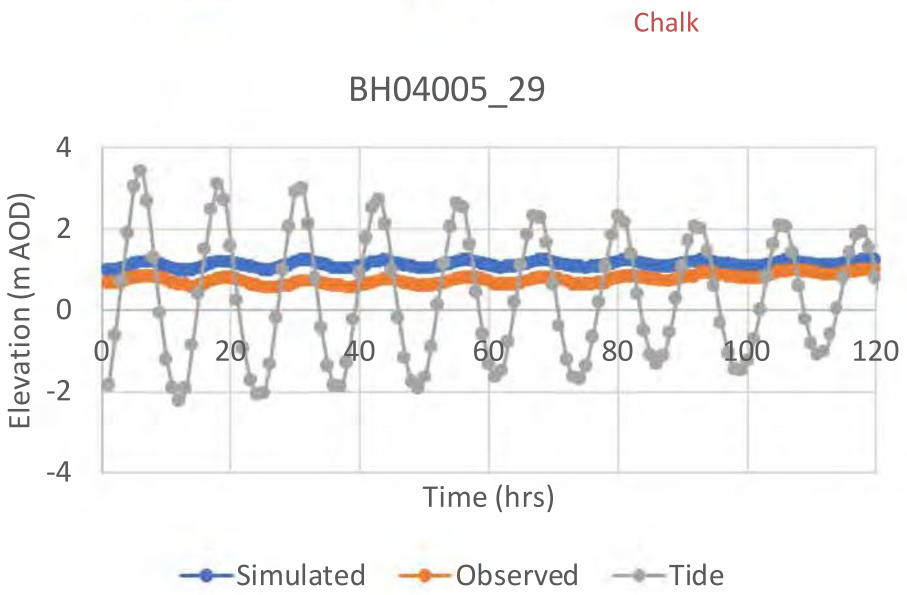
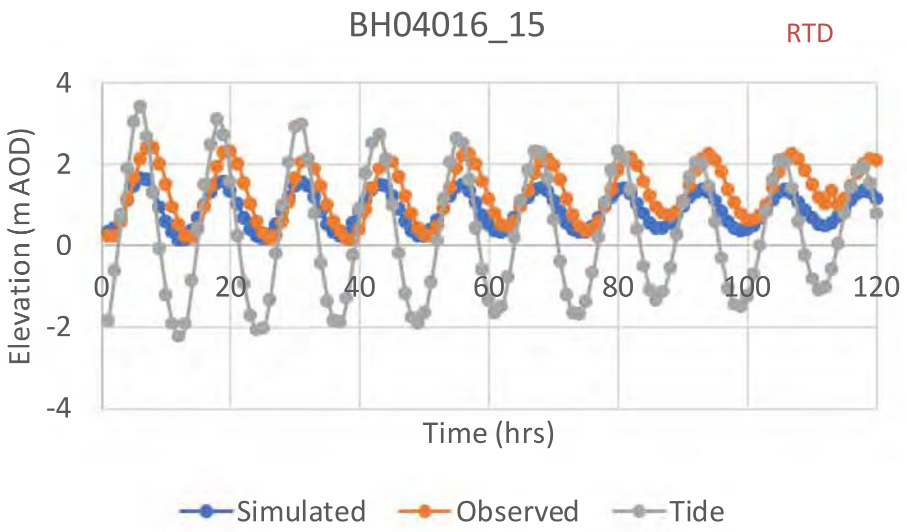
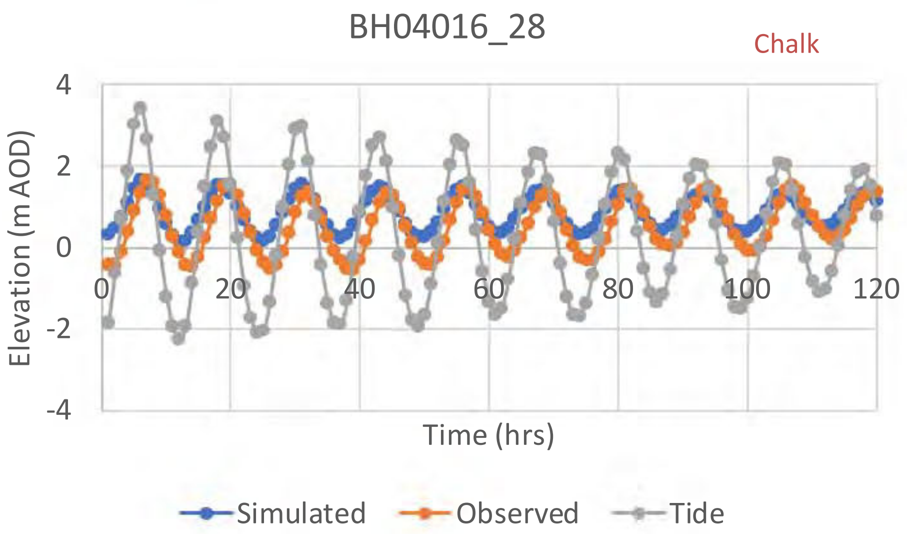
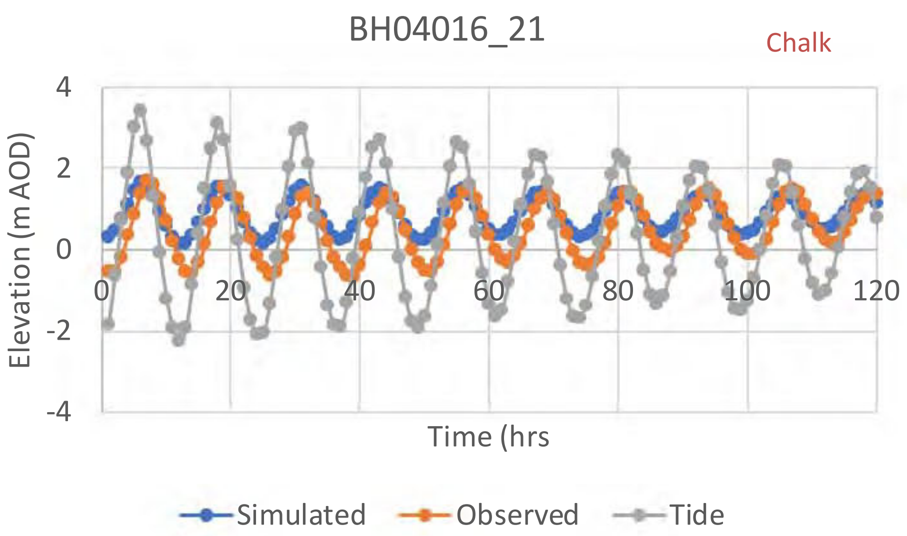


Plate 2.29 Predicted and observed groundwater levels for BH04016







3 Results with the Project

3.1 Ground protection tunnel shafts only (construction)

3.1.1 The ground protection tunnel shafts are modelled using a drain boundary condition. This simulates the caisson and clutch sheet piles, forming a relatively watertight cylindrical column. Excavation is to be performed by a grab excavator within this column. As such, the shaft inflow is dependent on the conductance and the geological formation parameters.

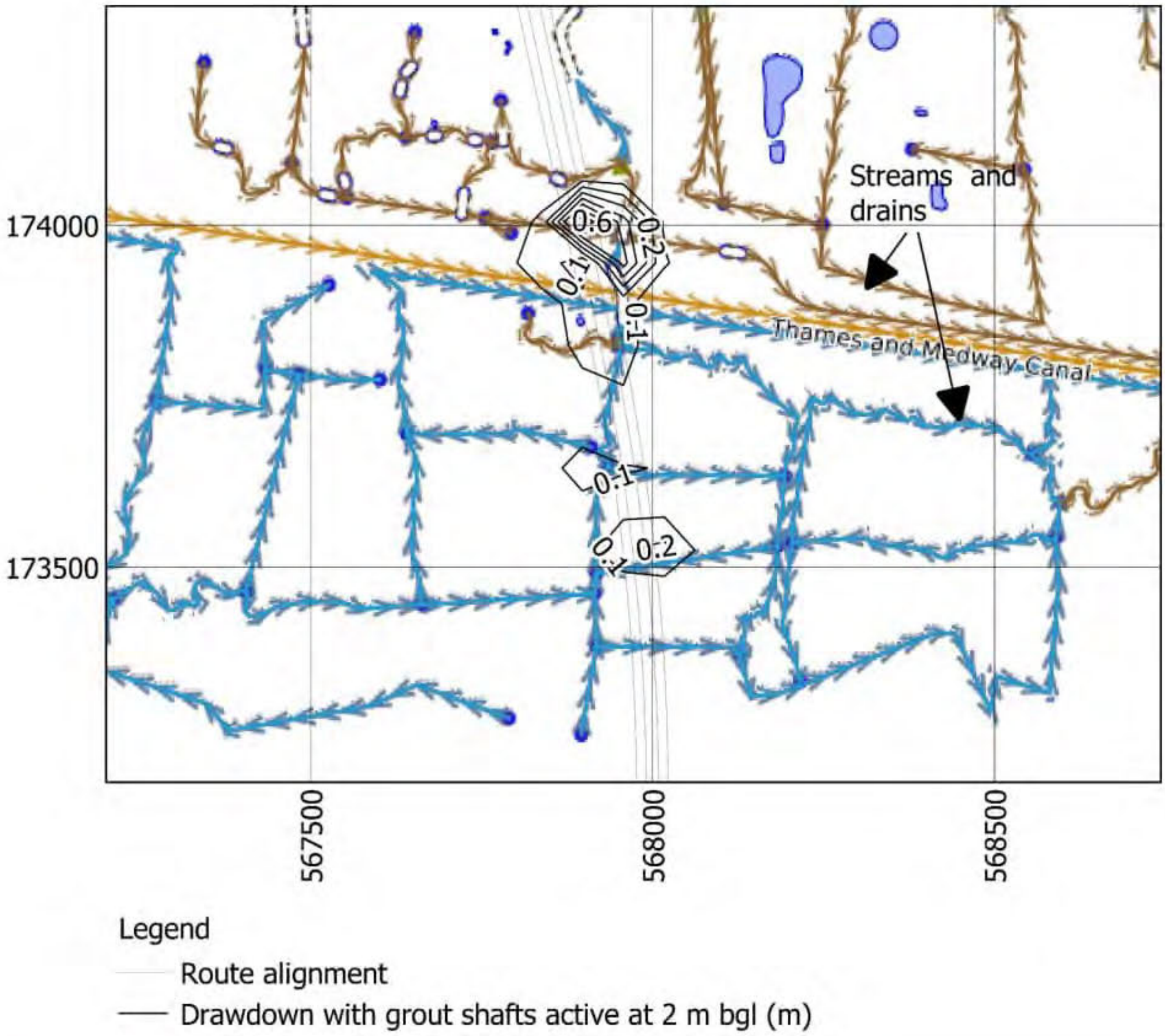
3.1.2 The predicted combined flow rate to the two ground protection tunnel shafts for the 50th percentile scenario is 3.3L/s (284m^3/d). This is worst case as it assumes:

a. both are constructed simultaneously

b. a steady state

c. no recharge above the Project footprint

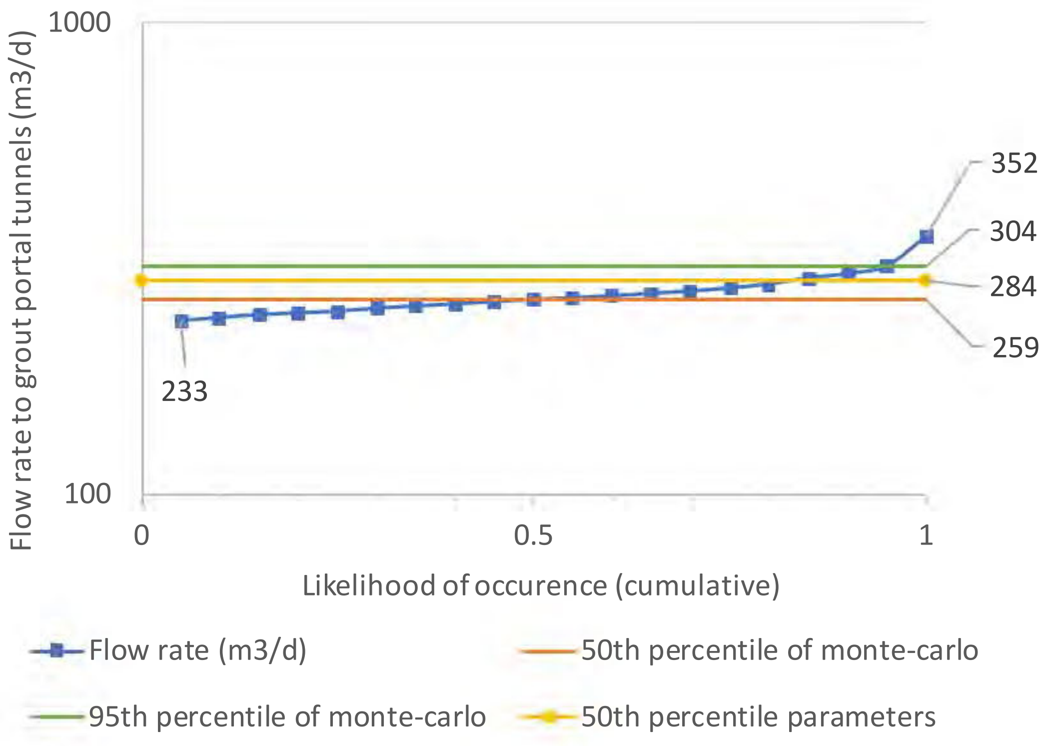
Plate 3.1 Drawdown of the water table with ground protection tunnel shafts active



3.1.3 The extent and magnitude of drawdown is quite limited as the inflows are restricted by the low conductance of the drains making up the shafts (Plate 3.1). Because of this, the water level in the cell with the shaft inside does not drawdown to the base of the shaft and represents the water level in the aquifer immediately next to the sheet piles. Annex D shows that the extent of drawdown decreases within the RTD. In the RTD, the flow rate is so small that drawdown is negligible. Drawdown is larger in magnitude within the Alluvium as recharge and hydraulic conductivity is low, but the extent is very limited.

3.1.4 The Monte Carlo assessment included a steady state simulation for inflow to the shafts for each calibrated parameter set. Plate 3.2 shows the inflow rate to the shafts from the Monte Carlo assessment. The inflow rate does not vary significantly as it is well controlled by the low conductivity caisson and the grout base of the ground protection tunnel shaft.

Plate 3.2 Monte Carlo assessment of inflow to ground protection tunnel shafts

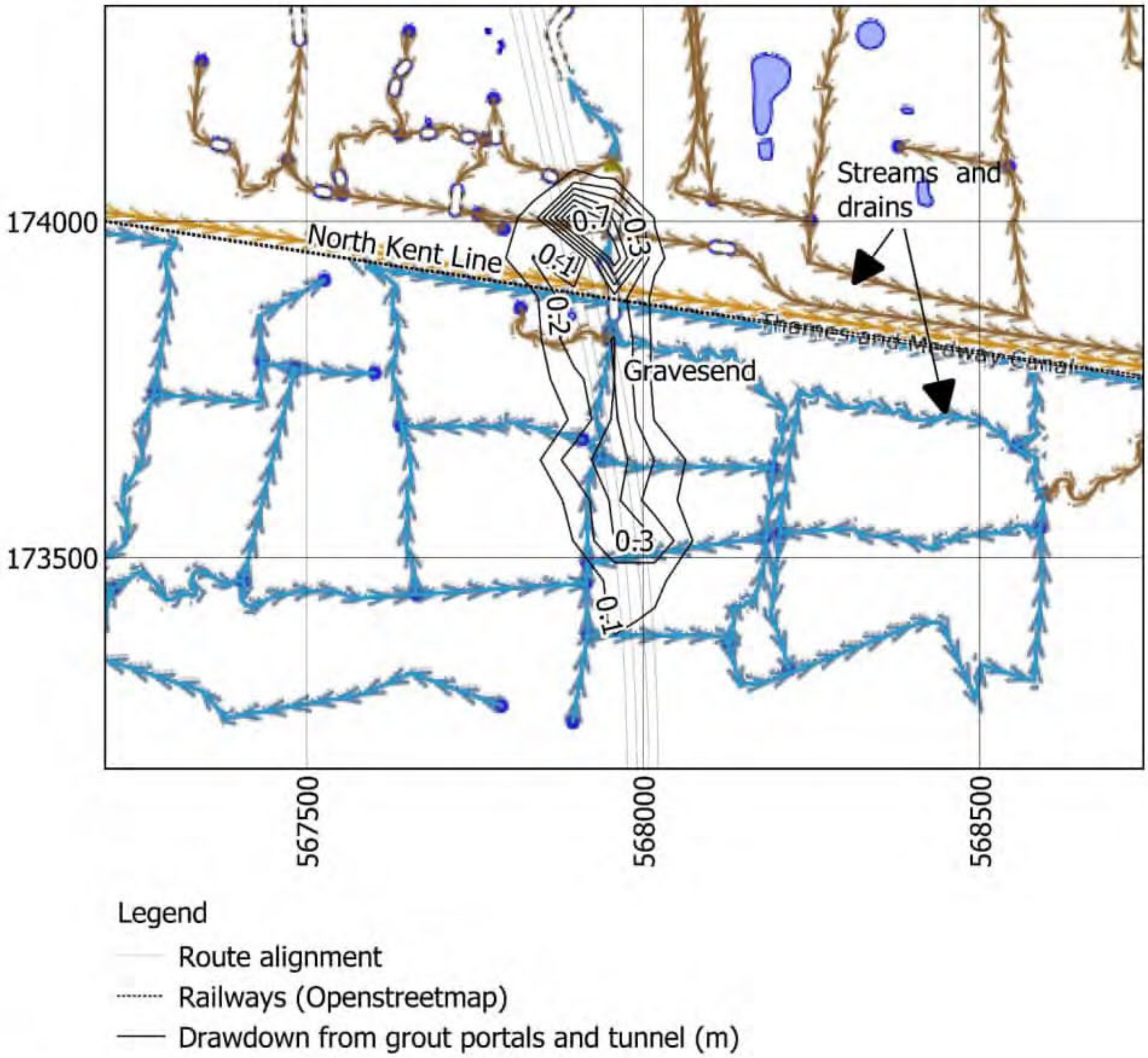


3.2 Ground protection tunnel shafts and tunnel (construction)

3.2.1 The calculated inflow for the ground protection tunnel is 0.013L/s (1.16m^3/d). This is low because the prescribed flow rate is restricted to 0.1L/d/m^2. Plate 3.3 shows the predicted drawdown of the water table in the Alluvium. There is little additional drawdown. As the total inflow rate to the ground protection tunnel is very low, the drawdown is mainly caused by the shafts. The presence of the ground protection tunnel has caused the drawdown cone to be extended across the top of the ground protection tunnel. This is because it acts as a local flow barrier and drawdown increases when there is a flow barrier close to an abstraction. Annex E illustrates the extent of the drawdown at different depths.

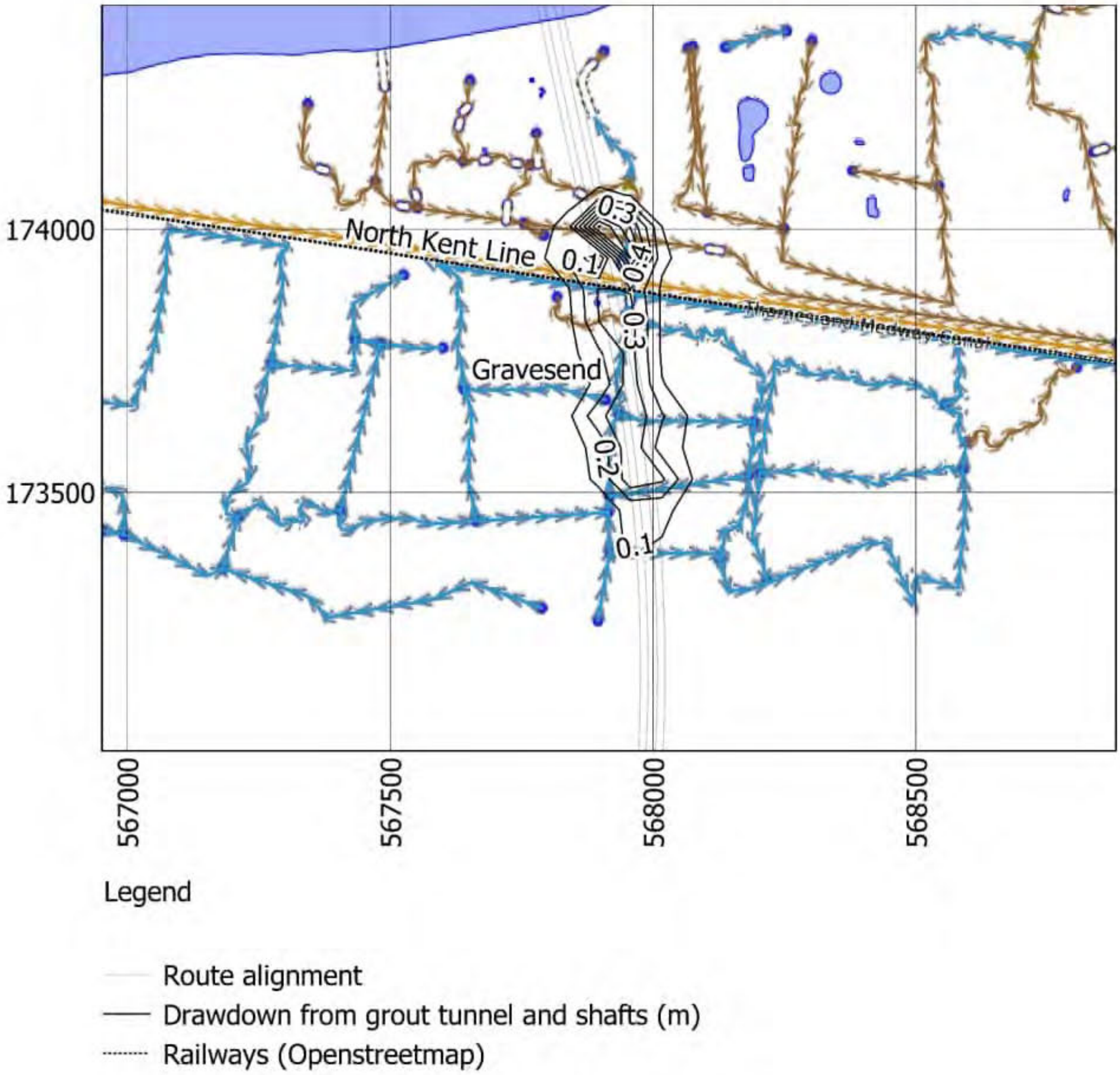
The drawdown from the tunnel reduces to non-detectable with depth. This is because seepage supported by the high transmissivity RTD rather than the low hydraulic conductivity Alluvium.

Plate 3.3 Drawdown of the water table from the ground protection tunnel with inflow rate of 0.1L/s/m^2



3.2.2 In a worst-case scenario, the inflow rate to the tunnel could be 0.5L/s/m^2 of tunnel surface area. Plate 3.4 shows the drawdown predicted in this scenario at 2m bgl. The calculated drawdown remains very small; this is because the prescribed flow rate into the tunnel remains very small.

Plate 3.4 Drawdown in the Alluvium from the ground protection tunnel with inflow rate of 0.5L/s/m²



3.3 Main tunnels (operation)

3.3.1 A separate scenario was completed that included the main tunnels only. In operation, the ground protection tunnel will no longer be drained of groundwater. The main tunnels boundary conditions are shown in Annex C. The scenario included the following features:

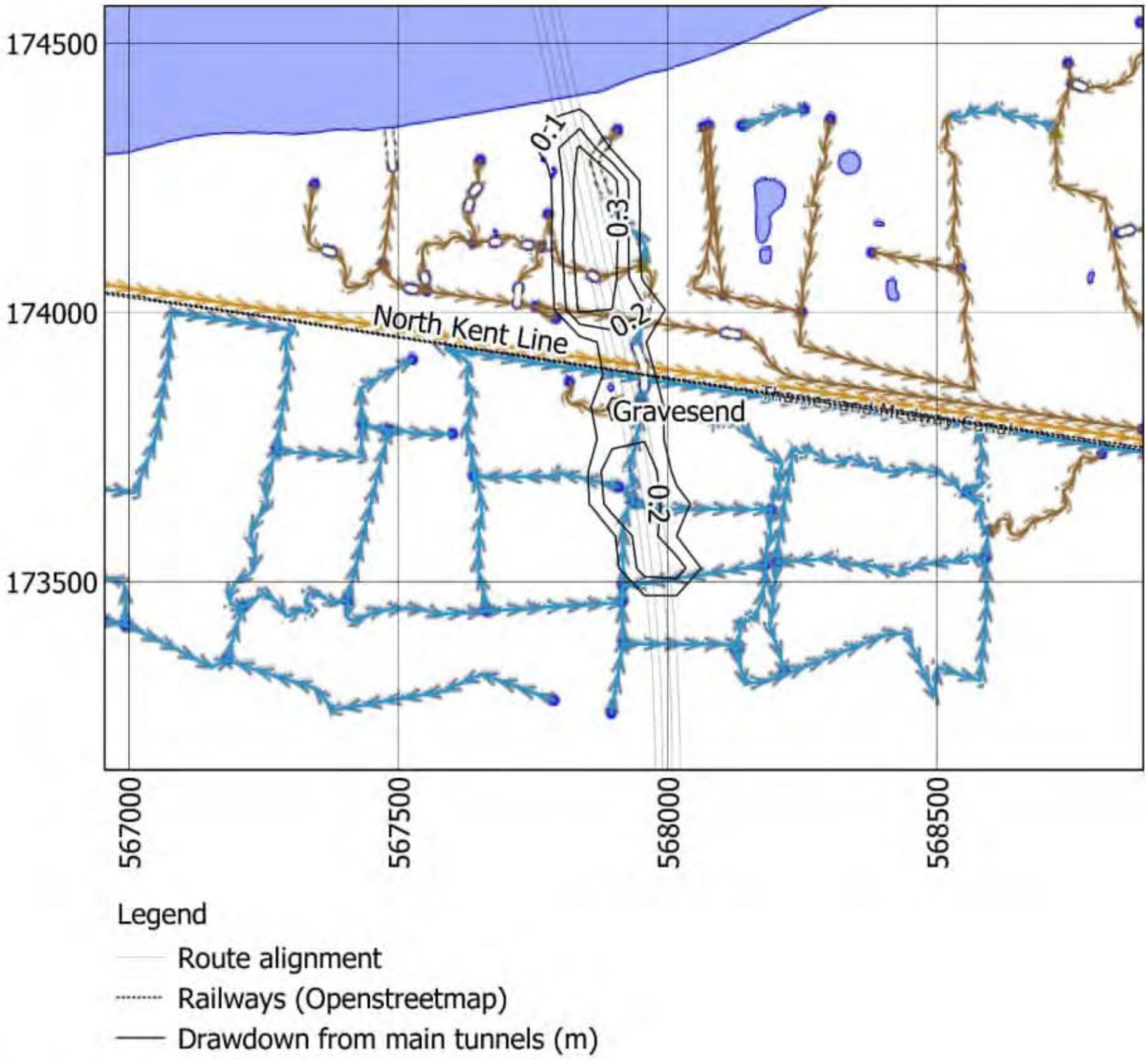
a. Main tunnel TBM maintenance grout blocks

b. Main tunnels prescribed drainage

3.3.2 The water extracted from the main tunnels in the model was 0.2L/s (18.4m^3/d). Plate 3.5 shows the predicted drawdown in the Alluvium for this scenario. The drawdown is predicted to be less than 0.3m and is likely to be within the numerical accuracy of the calibrated model. The drawdown along the length of the tunnel is because of the worst-case assumption that recharge will not occur along its length. The drawdown would likely only manifest as a change in pore pressure within the alluvial clay and would not be distinguishable in the field.

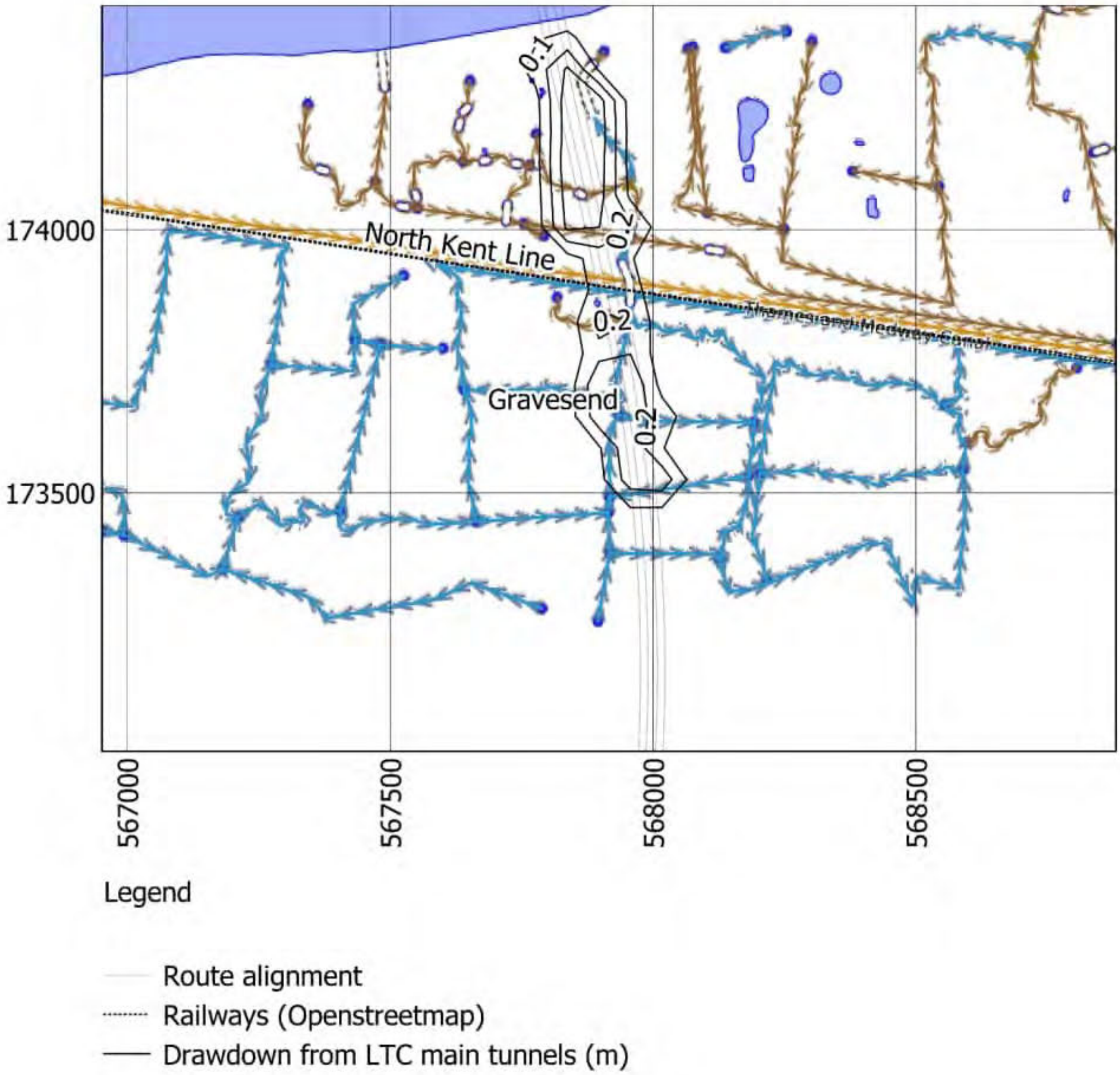
3.3.3 There is no drawdown predicted within the Chalk or RTD. This is because the inflow rate to the tunnel is so small.

Plate 3.5 Drawdown in the Alluvium from the main tunnels with an inflow rate of 0.1L/s/m²



3.3.4 In the worst-case scenario, the inflow rate to the main tunnels could be 0.5L/d/m² of tunnel surface area. Plate 3.6 shows the drawdown predicted in this scenario at 2m bgl, within the Alluvium. The difference between the two scenarios is negligible. This is because the total inflow rate is very low in comparison to the aquifer hydraulic conductivities. The predicted drawdown within the Chalk is nil, due to the high transmissivity of the Chalk and low flow rates into the tunnel.

Plate 3.6 Drawdown of the water table within the Alluvium from the main tunnels with an inflow rate of 0.5L/s/m²



4 Movement of the fresh-saline interface

4.1 Method

4.1.1 SEAWAT V4 (USGS, 2008) is used via the FloPy interface to carry out the saline interface modelling. SEAWAT is a coupled version of MODFLOW and MT3DMS designed to simulate three-dimensional, variable density, saturated ground-water flow. The model is solved using a finite difference approximation.

4.1.2 The SEAWAT models have been completed in steady state.

4.1.3 Table 4.1 provides the additional parameters that are implemented for SEAWAT for the baseline model.

Table 4.1 SEAWAT specific parameters

Applied to all models	Parameter	Value	Unit
Dt0	Timestep length	Unspecified (determined by solver)	d
dmcoef	Molecular diffusion coefficient	0.57	m^2/d From Henry Problem
al	Longitudinal dispersivity	K_h*3	m
trpt	Transverse dispersivity	0.1*longitudinal dispersivity	m
trpv	Vertical dispersivity	0.05*longitudinal dispersivity	m
River boundary concentration		20	g/l
denseref	Reference density of water	1,000	g/l
denseslp	The slope of the linear equation of state that relates fluid density to solute concentration	0.7143	From Henry Problem
iwtable	Flag	0	Water table correction for density not applied
densemin densemax	Flag	0	No limitation
Sconc	Initial concentration	Initial distribution concentration calculated based on Ghyben-Herzberg approximation, with a maximum of 20 g/l	g/l

Applied to all models	Parameter	Value	Unit
InitHds	Initial Heads	Topography	m AOD
Perlen	Length of simulation	Steady state	d
nstp	Number of stress periods	1	
dt0		5,000	days per time period

4.2 Results of SEAWAT modelling

4.2.1 Plate 4.1, Plate 4.2 and Plate 4.3 provide a cross-section through model column 62 (Easting 567856) for the baseline, ground protection tunnel and main tunnel scenarios. This is the cross-section through which the conceptual model was drawn (see 'cross-sections and conceptual model' in Section 2).

4.2.2 Plate 4.4 and Plate 4.5 show the concentration change at 20m bgl in the Chalk between the baseline, ground protection tunnel and main tunnel scenarios, respectively. The chloride concentration change is less than 0.2g/l. The plates show that there is a small increase where the Project crosses beneath the River Thames, as expected. Similar magnitude changes occur elsewhere in the layer, at considerable distance from the Project. This suggests that the changes are potentially within the error of the model solution accuracy and can be considered as negligible. This is to be expected as the volume of groundwater drained to the Project is very small.

4.2.3 The steady state solution does not include the natural impacts of the tidal flushing of the upper part of the Chalk aquifer with saline water from the River Thames. The impact of this is likely to be significantly larger that the impact of the Project.

4.2.4 Overall, the modelling results indicate that there would be no measurable movement of the saline interface due to the Project. This is due to the construction methodology and materials used in construction, which together cause the inflow to the Project to be negligible in terms of the wider water balance, as well as the existing large scale impact of the River Thames tidal fluctuation.

Plate 4.1 Position of the saline interface in the baseline scenario. Vertical exaggeration approximately 10x.

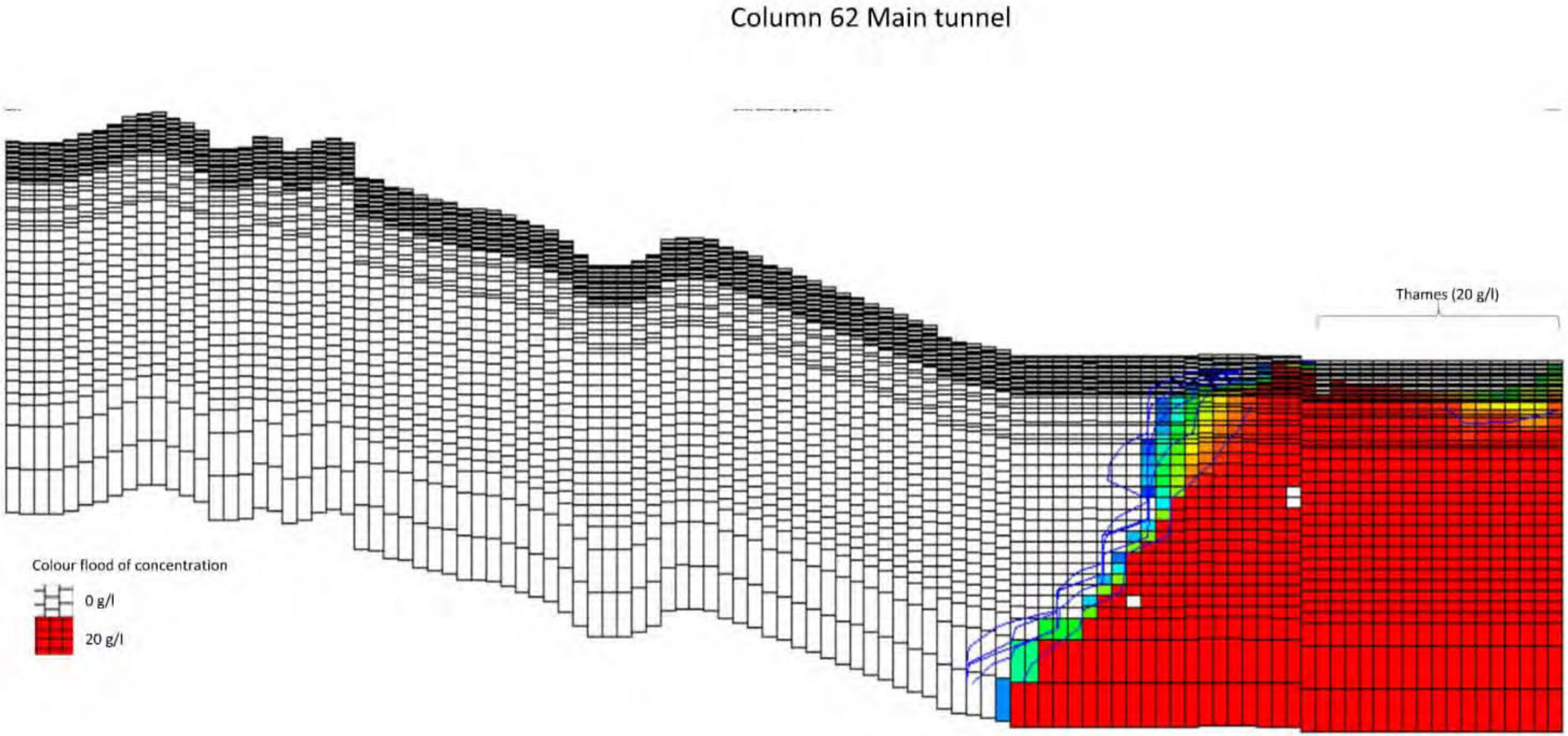


Plate 4.2 Position of the saline interface in the ground protection tunnel shafts and tunnel scenario. Vertical exaggeration approximately 10x.

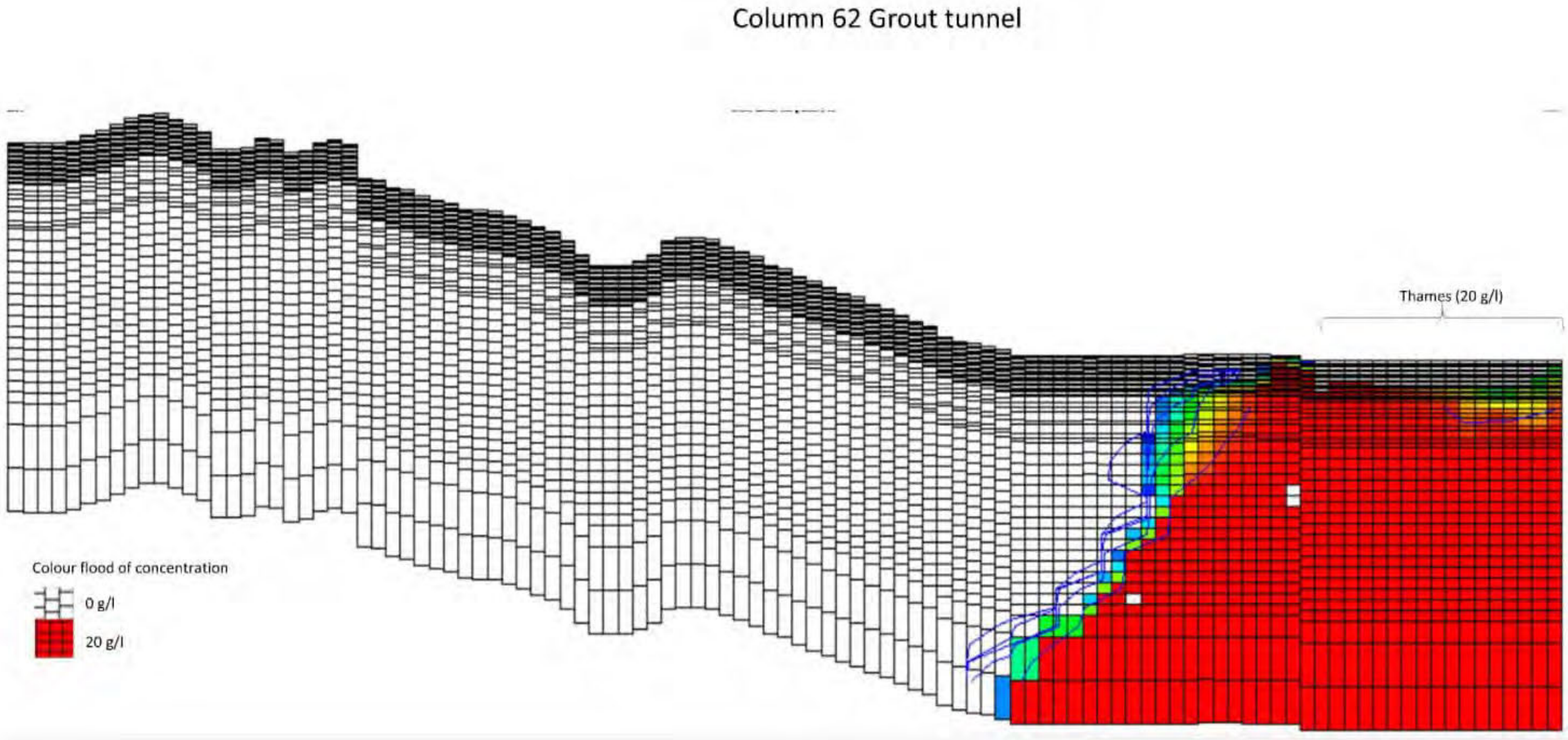


Plate 4.3 Position of the saline interface in the main tunnels scenario. Vertical exaggeration approximately 10x.

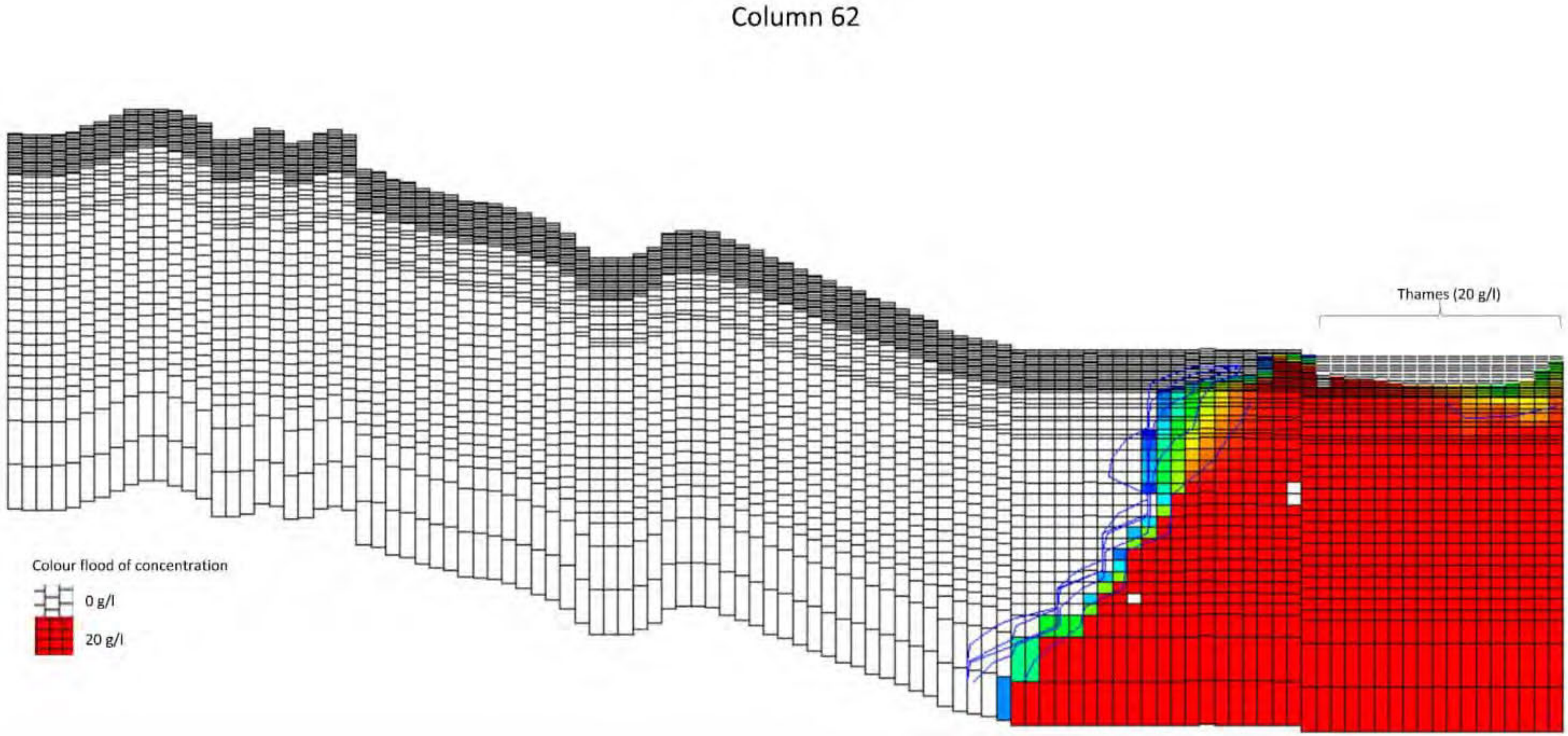


Plate 4.4 Concentration change between baseline and ground protection tunnel scenario at 20m bgl

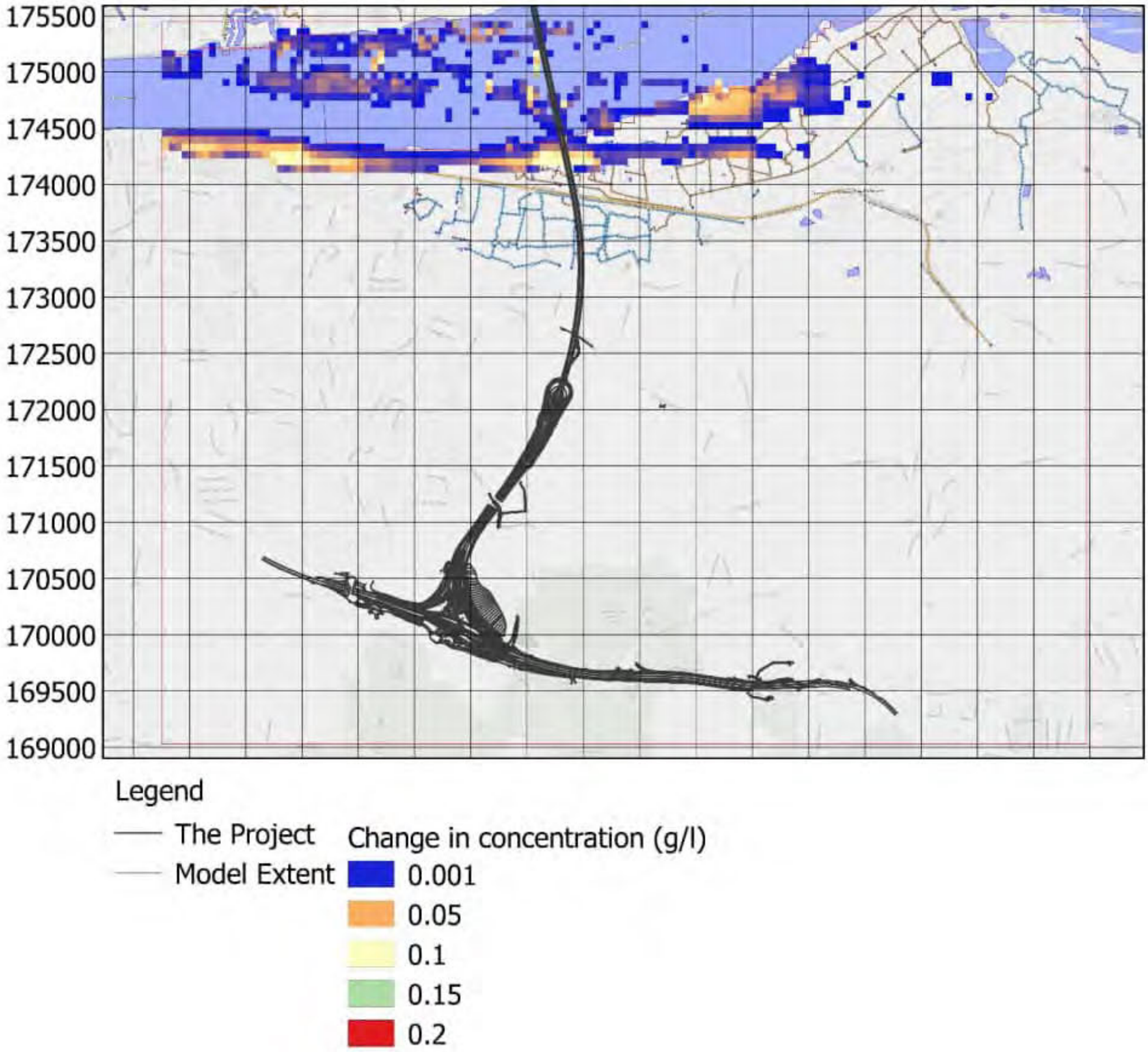
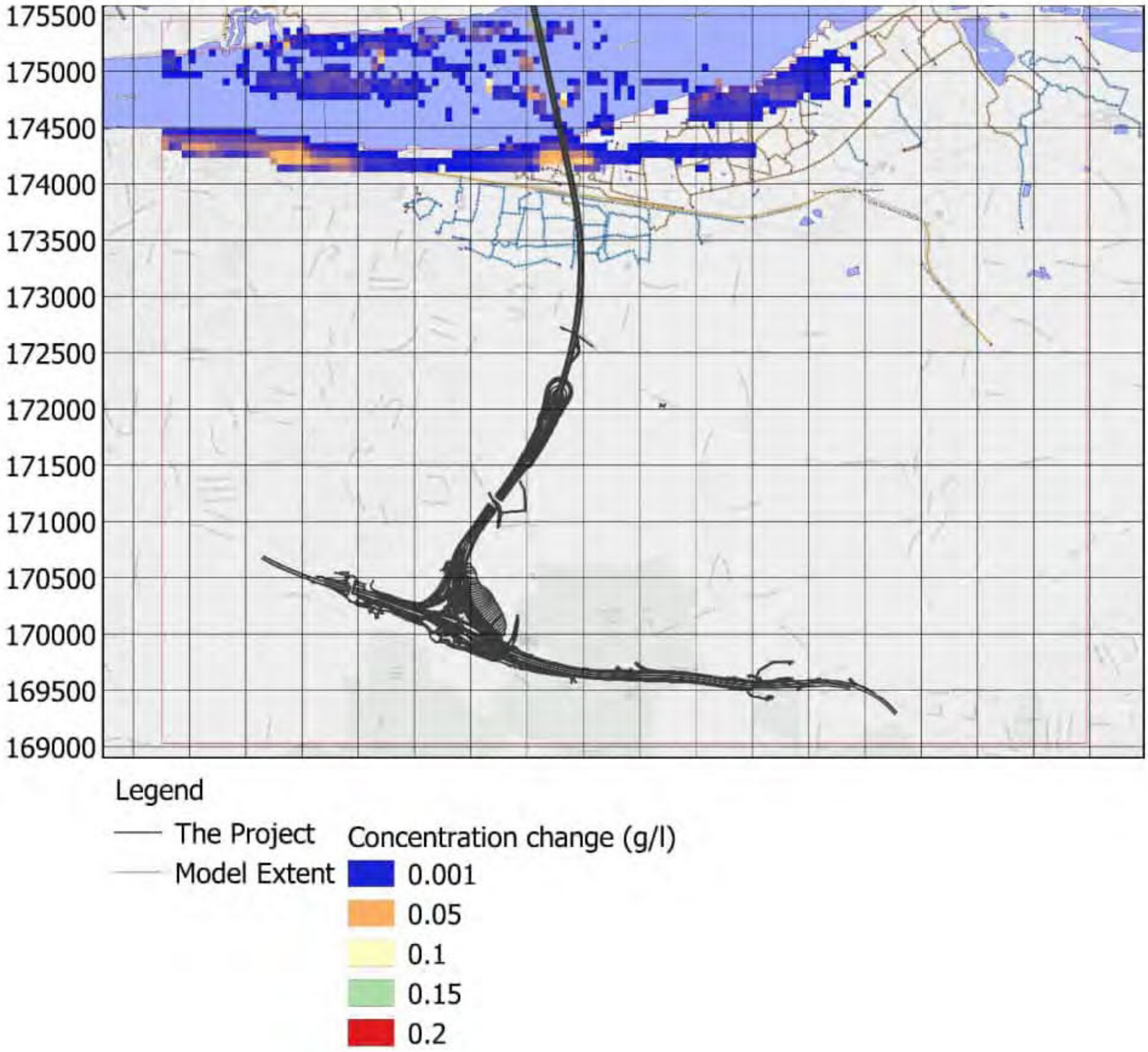


Plate 4.5 Concentration change between baseline and Project main tunnels scenario at 20m bgl



5 Summary

5.1.1 Groundwater modelling has been completed for the proposed ground protection tunnel and main tunnels which would pass under the Ramsar site area, south of the River Thames.

5.1.2 The groundwater model included a 3D geological model supplied by the BGS, supplemented with site-specific information obtained from Project ground investigations. This data included material type, stratigraphy and RQD information from boreholes, packer test, variable head test and pumping test data.

5.1.3 Groundwater level data from boreholes was used to calibrate the steady state model and a time-variant tidal response model. As a result of calibration to the new data, adjustments were made to the conceptual model. These included a zone of high transmissivity associated with RQD of less than 0.1, zones of core loss and Chalk weathering of CIRIA grade D. This zone enables a strong hydraulic, confined response within the Chalk to the River Thames tide. These high transmissivities exist at a shallow elevation within the Chalk, in a relatively thin layer beneath the RTD as well as a thicker zone at the edge of the Alluvium. Their position is similar to those found in other projects local to this area.

5.1.4 A manual calibration was completed, followed by a Monte Carlo assessment. In both, parameters were varied within suitable ranges to determine the ranges that maintain a reasonable calibration.

5.1.5 Prediction of drawdown was completed using the 50th percentile results of the Monte Carlo assessment. These are the most realistic parameter set.

5.1.6 The modelling scenarios completed included the following:

a. Ground protection tunnel shafts only

b. Ground protection tunnel shafts and tunnels

c. Main tunnels (operation)

5.1.7 The following mitigation measures act to reduce the groundwater inflow to the Project

a. Use of pressurised TBM method that inhibits groundwater inflow during drilling

b. Stopping the TBM within grout blocks for TBM maintenance

c. Use of caisson methods and pre-grouting of ingress and egress shafts to inhibit groundwater inflow

5.1.8 The inflow to the ground protection tunnel and main tunnels was simulated at both prescribed inflow rates of 0.1L/d/m^2 (British Tunnelling Society and Institution of Civil Engineers, 2010) and 0.5L/d/m^2, the latter being considered the worst case. Both sets of simulations gave a very similar result. The results for the worst case were as follows:

a. Ground protection tunnel shafts:

   i. The predicted total inflow to the shafts, simulated as drains in the model, is 3.2L/s (284m^3/d). This prediction assumes that shafts are fully surrounded by a hydraulic barrier 0.5m thick with a hydraulic conductivity of 1x10^{-7}m/s.

   ii. The southern shaft is not predicted to cause drawdown of more than 0.1m.

   iii. The northern shaft is predicted to cause drawdown of 0.7m immediately adjacent to it. This reduces to less than 0.1m at a distance of 120m from the shaft.

b. Ground protection tunnel:

   i. Drawdown of over 0.1m extends from Northing 173374 to Northing 174081 in the Alluvium. Drawdown extends 60m or less from the grouting tunnel and reaches a maximum of 0.3m above the tunnel. This is most likely due to the assumption that recharge would be reduced above the tunnel.

   ii. Drawdown within the RTD is nil and cannot be presented for this reason. The calculated inflow rates are too low to cause notable drawdown.

c. Main tunnels:

   i. Over 0.1m drawdown extends from Northing 176465 to Northing 174377 within the Alluvium. The maximum drawdown is predicted to be 0.3m along a line immediately above the main tunnels within this area. This is considered to be within the model accuracy limits and negligible, or undetectable in the field.

   ii. Drawdown in the Chalk is predicted to be nil, due to the low flow rate and high transmissivity of the Chalk.

   iii. The extent of the drawdown is limited to the model cells above the main tunnels, forming a channel approximately 120m wide.

5.1.9 The SEAWAT models show that there would be no increase in salinity below the Ramsar site because of the underground infrastructure. The model predicts no significant movement of the saline/freshwater interface, either during construction or operation. This is the same for both prescribed leakage rates.

5.1.10 Overall, the model indicates that the measures set out above are effective at minimising the groundwater drainage to the infrastructure below groundwater level and so also at minimising the amount of drawdown caused by the Project.

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Annexes

Annex A Packer and variable head tests included in the model

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
BH2322	2.28	-13.32	2.40E-06	567883.4	173842.1	0.5	562289_V9-Final AGS2-Phase1A	Rising head	15.6	15.6
BH2322	2.28	-13.32	2.80E-05	567883.4	173842.1	0.5	562289_V9-Final AGS2-Phase1A	Falling head	15.6	15.6
BH2384	8.79	-18.11	8.00E-07	567348.3	176334.8	0.5	562289_V9-Final AGS2-Phase1A	Falling head	27.15	26.65
BH2384	8.79	-24.19	1.50E-06	567348.3	176334.8	0.5	562289_V9-Final AGS2-Phase1A	Falling head	33.23	32.73
BH2384	8.79	-22.86	2.00E-06	567348.3	176334.8	0.5	562289_V9-Final AGS2-Phase1A	Falling head	31.9	31.4
BH2385	7.14	-18.28	9.70E-07	567407.8	176463.1	0.5	562289_V9-Final AGS2-Phase1A	Falling head	25.67	25.17
BH2392A	5.36	-16.64	4.90E-06	567363.5	176631.4	0.5	562289_V9-Final AGS2-Phase1A	Falling head	22	22
BH2392A	5.36	-16.64	5.60E-04	567363.5	176631.4	0.5	562289_V9-Final AGS2-Phase1A	Rising head	22	22

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
BH2384	8.79	-2.61	2.20E-06	567348.3	176334.8	0.6	562289_V9-Final AGS2-Phase1A	Falling head	11.7	11.1
BH2385	7.14	-20.46	3.50E-07	567407.8	176463.1	0.6	562289_V9-Final AGS2-Phase1A	Falling head	27.9	27.3
BH2385	7.14	-22.81	6.50E-07	567407.8	176463.1	0.6	562289_V9-Final AGS2-Phase1A	Falling head	30.25	29.65
BH2308	2.2	-1.7	6.00E-06	568082.9	173268.7	1	562289_V9-Final AGS2-Phase1A	Rising head	4.4	3.4
BH2308	2.2	-6.8	2.70E-05	568082.9	173268.7	1	562289_V9-Final AGS2-Phase1A	Rising head	9.5	8.5
BH02002	48.6	-6.9	5.08E-07	567807.4	171508.1	1.5		Packer		
BH02002	48.6	29.1	1.63E-06	567807.4	171508.1	1.5		Packer		
BH02002	48.6	38.35	1.73E-06	567807.4	171508.1	1.5		Packer		
BH2301	9.17	-39.28	4.97E-06	568028	173026.3	1.5		Packer		
BH2301	9.17	-9.28	1.00E-05	568028	173026.3	1.5		Packer		
BH2301	9.17	-27.28	2.02E-05	568028	173026.3	1.5		Packer		
BH2301	9.17	-21.28	3.27E-05	568028	173026.3	1.5		Packer		
BH2301	9.17	-13.28	3.89E-05	568028	173026.3	1.5		Packer		

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
BH04009	5.8	-12.2	1.20E-05	567926	173142.8	1.5	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	18.75	17.25
BH04009	5.8	-12.2	1.25E-05	567926	173142.8	1.5		Packer		
BH04009	5.8	-12.2	1.30E-05	567926	173142.8	1.5	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	18.75	17.25
BH04009	5.8	-12.2	1.40E-05	567926	173142.8	1.5	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	18.75	17.25
BH04009	5.8	-12.2	1.50E-05	567926	173142.8	1.5	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	18.75	17.25
BH04009	5.8	-12.2	1.60E-05	567926	173142.8	1.5	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	18.75	17.25
BH04009	5.8	-12.2	1.80E-05	567926	173142.8	1.5	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	18.75	17.25
BH04009	5.8	-15.2	2.40E-05	567926	173142.8	1.5		Packer		
BH04009	5.8	-15.2	2.40E-05	567926	173142.8	1.5	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	21.75	20.25
BH04009	5.8	-15.2	3.00E-05	567926	173142.8	1.5	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	21.75	20.25

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
BH04009	5.8	-15.2	3.10E-05	567926	173142.8	1.5	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	21.75	20.25
BH04009	5.8	-15.2	3.20E-05	567926	173142.8	1.5	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	21.75	20.25
OH07022	7.24	-36.01	9.30E-06	567341	176009	1.5	B-AGSF-X-X-X-D-X-X-X-0003-02012083	Water Pressure	44	42.5
OH07022	7.24	-36.01	9.70E-06	567341	176009	1.5	B-AGSF-X-X-X-D-X-X-X-0003-02012082	Water Pressure	44	42.5
OH07022	2.33	-36.01	1.00E-05	567341	176009	1.5		Packer		
OH07022	7.24	-36.01	1.00E-05	567341	176009	1.5	B-AGSF-X-X-X-D-X-X-X-0003-02012081	Water Pressure	44	42.5
OH07022	7.24	-36.01	1.00E-05	567341	176009	1.5	B-AGSF-X-X-X-D-X-X-X-0003-02012084	Water Pressure	44	42.5
OH07022	7.24	-36.01	1.10E-05	567341	176009	1.5	B-AGSF-X-X-X-D-X-X-X-0003-02012080	Water Pressure	44	42.5
OH07022	7.24	-29.01	3.00E-05	567341	176009	1.5	B-AGSF-X-X-X-D-X-X-X-0003-02012075	Water Pressure	37	35.5

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
OH07022	7.24	-29.01	3.30E-05	567341	176009	1.5	B-AGSF-X-X-X-D-X-X-X-0003-02012076	Water Pressure	37	35.5
OH07022	7.24	-29.01	4.40E-05	567341	176009	1.5	B-AGSF-X-X-X-D-X-X-X-0003-02012077	Water Pressure	37	35.5
OH07022	7.24	-29.01	4.50E-05	567341	176009	1.5	B-AGSF-X-X-X-D-X-X-X-0003-02012078	Water Pressure	37	35.5
OH07022	2.33	-29.01	4.73E-05	567341	176009	1.5		Packer		
OH07022	7.24	-29.01	5.30E-05	567341	176009	1.5	B-AGSF-X-X-X-D-X-X-X-0003-02012079	Water Pressure	37	35.5
OH07022	2.33	-32.51	5.48E-05	567341	176009	1.5		Packer		
OH07021	7.64	-57.86	1.60E-07	567530	176062	1.5	B-AGSF-X-X-X-D-X-X-X-0003-02012072	Water Pressure	66.25	64.75
OH07021	7.64	-57.86	1.60E-07	567530	176062	1.5	B-AGSF-X-X-X-D-X-X-X-0003-02012074	Water Pressure	66.25	64.75
OH07021	7.64	-57.86	2.30E-07	567530	176062	1.5	B-AGSF-X-X-X-D-X-X-X-0003-02012073	Water Pressure	66.25	64.75
OH07021	2.33	-57.86	2.40E-07	567530	176062	1.5		Packer		

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
OH07021	7.64	-57.86	3.30E-07	567530	176062	1.5	B-AGSF-X-X-X-D-X-X-X-0003-02012070	Water Pressure	66.25	64.75
OH07021	7.64	-57.86	4.90E-07	567530	176062	1.5	B-AGSF-X-X-X-D-X-X-X-0003-02012071	Water Pressure	66.25	64.75
OH07040	2.33	-35.52	7.24E-06	567379	176105	1.5		Packer		
OH07040	2.33	-32.02	9.00E-06	567379	176105	1.5		Packer		
OH07040	2.33	-28.52	4.24E-05	567379	176105	1.5		Packer		
BH1306	7.4	-27.8	3.61E-06	567449.8	175700.3	1.6		Packer		
BH1306	7.4	-33.8	4.89E-06	567449.8	175700.3	1.6		Packer		
BH1306	7.4	-39.8	2.27E-05	567449.8	175700.3	1.6		Packer		
OW06016	26.21	-45.7	2.65E-06	567608.5	175545.6	2		Packer		
OW06016	26.21	-41.7	2.76E-06	567608.5	175545.6	2		Packer		
OW06016	26.21	-33.7	1.52E-05	567608.5	175545.6	2		Packer		
BH13002	23.66	9.16	4.20E-07	564805.2	180074.9	2	C-AGSF-X-X-X-D-X-X-X-0004-02012064	Falling Head	15.5	13.5
BH01003	68.85	-1.15	2.60E-07	570033	169729.1	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	71.5	68.5
BH01003	68.85	-1.15	2.70E-07	570033	169729.1	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	71.5	68.5

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
BH01003	68.85	-1.15	2.72E-07	570033	169729.1	3		Packer		
BH01003	68.85	-1.15	2.80E-07	570033	169729.1	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	71.5	68.5
BH01003	68.85	-1.15	2.90E-07	570033	169729.1	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	71.5	68.5
BH01003	68.85	2.85	5.40E-07	570033	169729.1	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	67.5	64.5
BH01003	68.85	2.85	5.60E-07	570033	169729.1	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	67.5	64.5
BH01003	68.85	2.85	5.86E-07	570033	169729.1	3		Packer		
BH01003	68.85	2.85	5.90E-07	570033	169729.1	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	67.5	64.5
BH01003	68.85	2.85	6.00E-07	570033	169729.1	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	67.5	64.5
BH01003	68.85	2.85	6.40E-07	570033	169729.1	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	67.5	64.5
BH01003	68.85	6.85	8.90E-07	570033	169729.1	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	63.5	60.5

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
BH01003	68.85	6.85	9.90E-07	570033	169729.1	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	63.5	60.5
BH01003	68.85	6.85	1.04E-06	570033	169729.1	3		Packer		
BH01003	68.85	6.85	1.10E-06	570033	169729.1	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	63.5	60.5
BH01025	70.9	9.4	1.20E-07	567177.8	170977.2	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	63	60
BH01025	70.9	15.4	1.20E-07	567177.8	170977.2	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	57	54
BH01025	70.9	9.4	1.65E-07	567177.8	170977.2	3		Packer		
BH01025	70.9	9.4	2.10E-07	567177.8	170977.2	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	63	60
BH01025	70.9	15.4	2.60E-07	567177.8	170977.2	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	57	54
BH01025	70.9	9.4	2.70E-07	567177.8	170977.2	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	63	60
BH01025	70.9	15.4	2.70E-07	567177.8	170977.2	3		Packer		

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
BH01025	70.9	9.4	2.90E-07	567177.8	170977.2	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	63	60
BH01025	70.9	15.4	2.90E-07	567177.8	170977.2	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	57	54
BH01025	70.9	15.4	3.10E-07	567177.8	170977.2	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	57	54
BH01025	70.9	12.4	4.10E-07	567177.8	170977.2	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	60	57
BH01025	70.9	12.4	4.30E-07	567177.8	170977.2	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	60	57
BH01025	70.9	12.4	4.40E-07	567177.8	170977.2	3		Packer		
BH01025	70.9	12.4	4.60E-07	567177.8	170977.2	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	60	57
BH01025	70.9	12.4	4.70E-07	567177.8	170977.2	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	60	57
BH02002	48.6	20.1	3.30E-07	567807.4	171508.1	3		Packer		
BH02002	48.6	7.1	4.20E-07	567807.4	171508.1	3		Packer		
BH02002	48.6	0.1	6.90E-07	567807.4	171508.1	3		Packer		
BH02002	48.6	14.1	8.65E-07	567807.4	171508.1	3		Packer		

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
BH04009	5.8	-25.2	2.30E-06	567926	173142.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	32.5	29.5
BH04009	5.8	-25.2	2.50E-06	567926	173142.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	32.5	29.5
BH04009	5.8	-25.2	2.52E-06	567926	173142.8	3		Packer		
BH04009	5.8	-25.2	2.60E-06	567926	173142.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	32.5	29.5
BH04009	5.8	-25.2	2.70E-06	567926	173142.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	32.5	29.5
BH04009	5.8	-20.2	7.50E-06	567926	173142.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	27.5	24.5
BH04009	5.8	-20.2	8.00E-06	567926	173142.8	3		Packer		
BH04009	5.8	-20.2	8.50E-06	567926	173142.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	27.5	24.5
BH04009	5.8	-20.2	8.60E-06	567926	173142.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	27.5	24.5
BH04009	5.8	-20.2	9.20E-06	567926	173142.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	27.5	24.5

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
BH04009	5.8	-20.2	9.60E-06	567926	173142.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	27.5	24.5
BH04015	1.95	-42.05	2.10E-07	568028.6	173521.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	45.5	42.5
BH04015	1.95	-42.05	2.15E-07	568028.6	173521.8	3		Packer		
BH04015	1.95	-42.05	2.20E-07	568028.6	173521.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	45.5	42.5
BH04015	1.95	-42.05	2.40E-07	568028.6	173521.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	45.5	42.5
BH04015	1.95	-42.05	2.60E-07	568028.6	173521.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	45.5	42.5
BH04015	1.95	-42.05	2.90E-07	568028.6	173521.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	45.5	42.5
BH04015	1.95	-34.85	3.90E-06	568028.6	173521.8	3		Packer		
BH04015	1.95	-34.85	3.90E-06	568028.6	173521.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	38.3	35.3
BH04015	1.95	-30.05	3.90E-06	568028.6	173521.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	33.5	30.5

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
BH04015	1.95	-30.05	4.10E-06	568028.6	173521.8	3		Packer		
BH04015	1.95	-30.05	4.30E-06	568028.6	173521.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	33.5	30.5
BH04015	1.95	-34.85	4.40E-06	568028.6	173521.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	38.3	35.3
BH04015	1.95	-30.05	4.80E-06	568028.6	173521.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	33.5	30.5
BH04015	1.95	-30.05	5.00E-06	568028.6	173521.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	33.5	30.5
BH04015	1.95	-34.85	5.20E-06	568028.6	173521.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	38.3	35.3
BH04015	1.95	-30.05	5.90E-06	568028.6	173521.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	33.5	30.5
BH04015	1.95	-34.85	6.60E-06	568028.6	173521.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	38.3	35.3
BH04015	1.95	-34.85	7.90E-06	568028.6	173521.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	38.3	35.3

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
BH04015	1.95	-25.25	8.80E-06	568028.6	173521.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	28.7	25.7
BH04015	1.95	-25.25	1.10E-05	568028.6	173521.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	28.7	25.7
BH04015	1.95	-25.25	1.14E-05	568028.6	173521.8	3		Packer		
BH04015	1.95	-25.25	1.20E-05	568028.6	173521.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	28.7	25.7
BH04015	1.95	-25.25	1.30E-05	568028.6	173521.8	3	A-AGSF-X-X-X-D-X-X-X-0001-02012020	Double packer test	28.7	25.7
BH2316	2.18	-16.32	7.00E-07	568038.2	173653.4	3	562289_V9-Final AGS2-Phase1A	Falling head	20	17
BH2316	2.18	-29.82	1.70E-06	568038.2	173653.4	3	562289_V9-Final AGS2-Phase1A	Falling head	33.5	30.5
BH2316	2.18	-37.97	7.78E-06	568038.2	173653.4	3		Packer		
BH2316	2.18	-31.97	1.53E-05	568038.2	173653.4	3		Packer		
BH2316	2.18	-25.97	1.54E-05	568038.2	173653.4	3		Packer		
OW05002	-7.72	-29.02	6.70E-06	567742.3	174496.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	22.8	19.8

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
OW05002	-7.72	-29.02	6.90E-06	567742.3	174496.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	22.8	19.8
OW05002	-7.72	-29.02	7.10E-06	567742.3	174496.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	22.8	19.8
OW05002	26.21	-29.02	7.12E-06	567742.3	174496.4	3		Packer		
OW05002	-7.72	-29.02	7.30E-06	567742.3	174496.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	22.8	19.8
OW05002	-7.72	-47.32	7.40E-06	567742.3	174496.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	41.1	38.1
OW05002	26.21	-47.32	7.40E-06	567742.3	174496.4	3		Packer		
OW05002	-7.72	-29.02	7.60E-06	567742.3	174496.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	22.8	19.8
OW05002	-7.72	-41.32	8.30E-06	567742.3	174496.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	35.1	32.1
OW05002	-7.72	-47.32	8.40E-06	567742.3	174496.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	41.1	38.1
OW05002	-7.72	-47.32	9.10E-06	567742.3	174496.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	41.1	38.1

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
OW05002	-7.72	-41.32	9.50E-06	567742.3	174496.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	35.1	32.1
OW05002	-7.72	-47.32	1.00E-05	567742.3	174496.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	41.1	38.1
OW05002	-7.72	-41.32	1.10E-05	567742.3	174496.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	35.1	32.1
OW05002	26.21	-41.32	1.10E-05	567742.3	174496.4	3		Packer		
OW05002	-7.72	-47.32	1.20E-05	567742.3	174496.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	41.1	38.1
OW05002	-7.72	-35.32	1.90E-05	567742.3	174496.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	29.1	26.1
OW05002	26.21	-35.32	1.90E-05	567742.3	174496.4	3		Packer		
OW05002	-7.72	-35.32	2.20E-05	567742.3	174496.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	29.1	26.1
OW05002	-7.72	-35.32	2.50E-05	567742.3	174496.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	29.1	26.1
OW05007	-12.22	-54.12	1.10E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	43.4	40.4

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
OW05007	-12.22	-54.12	1.30E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	43.4	40.4
OW05007	-12.22	-54.12	1.50E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	43.4	40.4
OW05007	-12.22	-54.12	1.60E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	43.4	40.4
OW05007	26.21	-54.12	1.60E-06	567781.6	174776.4	3		Packer		
OW05007	-12.22	-39.26	1.80E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	28.54	25.54
OW05007	-12.22	-54.12	1.90E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	43.4	40.4
OW05007	-12.22	-39.26	1.90E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	28.54	25.54
OW05007	-12.22	-32.96	1.90E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	22.24	19.24
OW05007	26.21	-39.26	1.98E-06	567781.6	174776.4	3		Packer		
OW05007	-12.22	-39.26	2.00E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	28.54	25.54

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
OW05007	-12.22	-32.96	2.10E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	22.24	19.24
OW05007	-12.22	-39.26	2.30E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	28.54	25.54
OW05007	-12.22	-32.96	2.30E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	22.24	19.24
OW05007	-12.22	-32.96	2.50E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	22.24	19.24
OW05007	26.21	-32.96	2.53E-06	567781.6	174776.4	3		Packer		
OW05007	-12.22	-32.96	2.80E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	22.24	19.24
OW05007	-12.22	-48.12	4.60E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	37.4	34.4
OW05007	26.21	-48.12	4.60E-06	567781.6	174776.4	3		Packer		
OW05007	-12.22	-48.12	4.90E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	37.4	34.4
OW05007	-12.22	-48.12	5.40E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	37.4	34.4

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
OW05007	-12.22	-48.12	5.50E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	37.4	34.4
OW05007	-12.22	-32.96	6.30E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	22.24	19.24
OW05007	26.21	-32.96	6.30E-06	567781.6	174776.4	3		Packer		
OW05007	-12.22	-48.12	6.80E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	37.4	34.4
OW05007	-12.22	-32.96	9.70E-06	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	22.24	19.24
OW05007	-12.22	-32.96	1.10E-05	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	22.24	19.24
OW05007	-12.22	-32.96	1.30E-05	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	22.24	19.24
OW05007	-12.22	-32.96	1.50E-05	567781.6	174776.4	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	22.24	19.24
OW06001	-13.15	-32.99	3.90E-07	567659.3	174856.3	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	21.34	18.34

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
OW06001	-13.15	-32.99	4.10E-07	567659.3	174856.3	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	21.34	18.34
OW06001	-13.15	-32.99	4.30E-07	567659.3	174856.3	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	21.34	18.34
OW06001	-13.15	-32.99	4.70E-07	567659.3	174856.3	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	21.34	18.34
OW06001	-13.15	-32.99	4.80E-07	567659.3	174856.3	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	21.34	18.34
OW06001	26.21	-32.99	9.00E-06	567659.3	174856.3	3		Packer		
OW06001	-13.15	-39.55	9.30E-06	567659.3	174856.3	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	27.9	24.9
OW06001	-13.15	-39.55	9.90E-06	567659.3	174856.3	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	27.9	24.9
OW06001	-13.15	-39.55	1.00E-05	567659.3	174856.3	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	27.9	24.9
OW06001	26.21	-39.55	1.00E-05	567659.3	174856.3	3		Packer		
OW06001	-13.15	-45.55	1.10E-05	567659.3	174856.3	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	33.9	30.9

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
OW06001	-13.15	-39.55	1.10E-05	567659.3	174856.3	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	27.9	24.9
OW06001	-13.15	-51.55	1.40E-05	567659.3	174856.3	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	39.9	36.9
OW06001	-13.15	-45.55	1.40E-05	567659.3	174856.3	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	33.9	30.9
OW06001	-13.15	-51.55	1.50E-05	567659.3	174856.3	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	39.9	36.9
OW06001	26.21	-51.55	1.52E-05	567659.3	174856.3	3		Packer		
OW06001	-13.15	-51.55	1.60E-05	567659.3	174856.3	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	39.9	36.9
OW06001	-13.15	-45.55	1.60E-05	567659.3	174856.3	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	33.9	30.9
OW06001	-13.15	-51.55	1.70E-05	567659.3	174856.3	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	39.9	36.9
OW06001	-13.15	-45.55	1.70E-05	567659.3	174856.3	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	33.9	30.9
OW06001	26.21	-45.55	1.70E-05	567659.3	174856.3	3		Packer		

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
OW06001	-13.15	-45.55	1.80E-05	567659.3	174856.3	3	E-AGSF-X-X-X-D-X-X-X-0002-02012020	Packer Test	33.9	30.9
OW06006	26.21	-41.8	3.76E-06	567692.3	175144	3		Packer		
OW06006	26.21	-47.84	4.72E-06	567692.3	175144	3		Packer		
OW06006	26.21	-41.8	5.48E-06	567692.3	175144	3		Packer		
OW06006	26.21	-35.8	7.43E-06	567692.3	175144	3		Packer		
OW06016	26.21	-37.7	9.18E-06	567608.5	175545.6	3		Packer		
OH07022	7.24	-40.26	1.10E-06	567341	176009	3	B-AGSF-X-X-X-D-X-X-X-0003-02012086	Water Pressure	49	46
OH07022	7.24	-40.26	1.10E-06	567341	176009	3	B-AGSF-X-X-X-D-X-X-X-0003-02012087	Water Pressure	49	46
OH07022	7.24	-40.26	1.20E-06	567341	176009	3	B-AGSF-X-X-X-D-X-X-X-0003-02012088	Water Pressure	49	46
OH07022	7.24	-40.26	1.20E-06	567341	176009	3	B-AGSF-X-X-X-D-X-X-X-0003-02012089	Water Pressure	49	46
OH07022	2.33	-40.26	1.22E-06	567341	176009	3		Packer		
OH07022	7.24	-40.26	1.50E-06	567341	176009	3	B-AGSF-X-X-X-D-X-X-X-0003-02012085	Water Pressure	49	46

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
OH07021	7.64	-52.86	3.10E-07	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012066	Water Pressure	62	59
OH07021	7.64	-52.86	3.30E-07	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012065	Water Pressure	62	59
OH07021	7.64	-47.86	1.30E-06	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012060	Water Pressure	57	54
OH07021	7.64	-47.86	1.80E-06	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012061	Water Pressure	57	54
OH07021	7.64	-47.86	2.30E-06	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012062	Water Pressure	57	54
OH07021	7.64	-47.86	2.40E-06	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012063	Water Pressure	57	54
OH07021	7.64	-47.86	2.60E-06	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012064	Water Pressure	57	54
OH07021	2.33	-47.86	2.83E-06	567530	176062	3		Packer		
OH07021	7.64	-52.86	3.20E-06	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012067	Water Pressure	62	59

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
OH07021	7.64	-52.86	3.20E-06	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012068	Water Pressure	62	59
OH07021	7.64	-38.86	3.50E-06	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012058	Water Pressure	48	45
OH07021	7.64	-38.86	3.60E-06	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012057	Water Pressure	48	45
OH07021	7.64	-38.86	3.60E-06	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012059	Water Pressure	48	45
OH07021	2.33	-38.86	3.65E-06	567530	176062	3		Packer		
OH07021	7.64	-38.86	3.90E-06	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012056	Water Pressure	48	45
OH07021	2.33	-52.86	4.00E-06	567530	176062	3		Packer		
OH07021	7.64	-52.86	4.00E-06	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012069	Water Pressure	62	59
OH07021	7.64	-34.86	4.00E-06	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012052	Water Pressure	44	41
OH07021	7.64	-34.86	4.10E-06	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012051	Water Pressure	44	41

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
OH07021	7.64	-34.86	4.50E-06	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012050	Water Pressure	44	41
OH07021	7.64	-34.86	4.50E-06	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012053	Water Pressure	44	41
OH07021	2.33	-42.86	4.58E-06	567530	176062	3		Packer		
OH07021	7.64	-34.86	5.20E-06	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012054	Water Pressure	44	41
OH07021	7.64	-38.86	5.50E-06	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012055	Water Pressure	48	45
OH07021	7.64	-30.86	4.70E-05	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012045	Water Pressure	40	37
OH07021	7.64	-30.86	4.90E-05	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012048	Water Pressure	40	37
OH07021	7.64	-30.86	5.00E-05	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012047	Water Pressure	40	37
OH07021	7.64	-30.86	5.10E-05	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012046	Water Pressure	40	37
OH07021	2.33	-30.86	5.12E-05	567530	176062	3		Packer		

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
OH07021	7.64	-30.86	5.90E-05	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012049	Water Pressure	40	37
OH07021	7.64	-26.86	8.00E-05	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012041	Water Pressure	36	33
OH07021	7.64	-26.86	8.40E-05	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012040	Water Pressure	36	33
OH07021	7.64	-26.86	8.40E-05	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012042	Water Pressure	36	33
OH07021	2.33	-26.86	8.70E-05	567530	176062	3		Packer		
OH07021	7.64	-26.86	8.80E-05	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012043	Water Pressure	36	33
OH07021	7.64	-26.86	9.90E-05	567530	176062	3	B-AGSF-X-X-X-D-X-X-X-0003-02012044	Water Pressure	36	33
OH07040	2.33	-38.77	3.88E-06	567379	176105	3		Packer		
OH07012	7.45	-34.05	1.10E-07	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012033	KPO	43	40
OH07012	7.45	-34.05	1.40E-07	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012032	KPO	43	40

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
OH07012	7.45	-34.05	1.60E-07	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012034	KPO	43	40
OH07012	7.45	-38.05	1.70E-07	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012039	KPO	47	44
OH07012	2.33	-38.05	1.75E-07	567559	176233	3		Packer		
OH07012	7.45	-38.05	1.80E-07	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012035	KPO	47	44
OH07012	7.45	-34.05	1.80E-07	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012031	KPO	43	40
OH07012	7.45	-34.05	1.90E-07	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012030	KPO	43	40
OH07012	7.45	-30.05	3.40E-07	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012027	KPO	39	36
OH07012	2.33	-30.05	3.60E-07	567559	176233	3		Packer		
OH07012	7.45	-30.05	3.60E-07	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012028	KPO	39	36
OH07012	7.45	-30.05	3.80E-07	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012026	KPO	39	36

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
OH07012	7.45	-30.05	4.80E-07	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012025	KPO	39	36
OH07012	7.45	-30.05	4.90E-07	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012029	KPO	39	36
OH07012	7.45	-38.05	6.60E-07	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012036	KPO	47	44
OH07012	7.45	-38.05	1.20E-06	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012038	KPO	47	44
OH07012	7.45	-38.05	1.50E-06	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012037	KPO	47	44
OH07012	7.45	-26.05	7.40E-06	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012023	Water Pressure	35	32
OH07012	2.33	-26.05	7.97E-06	567559	176233	3		Packer		
OH07012	7.45	-26.05	8.00E-06	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012021	Water Pressure	35	32
OH07012	7.45	-26.05	8.50E-06	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012022	Water Pressure	35	32

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
OH07012	7.45	-26.05	1.10E-05	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012020	Water Pressure	35	32
OH07012	7.45	-26.05	1.10E-05	567559	176233	3	B-AGSF-X-X-X-D-X-X-X-0003-02012024	Water Pressure	35	32
BH09002	3.38	-1.62	1.20E-04	567046.2	177958.1	3	C-AGSF-X-X-X-D-X-X-X-0004-02012021	Falling Head	6.5	3.5
BH09002	3.38	-1.62	6.60E-04	567046.2	177958.1	3	C-AGSF-X-X-X-D-X-X-X-0004-02012020	Rising Head	6.5	3.5
BH09006	12.37	-2.63	1.60E-06	566928	178336.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012023	Rising Head	16.5	13.5
BH09006	12.37	-2.63	1.70E-06	566928	178336.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012022	Falling Head	16.5	13.5
BH10003	6.64	-33.86	1.40E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012046	Packer	42	39
BH10003	6.64	-33.86	1.40E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012047	Packer	42	39
BH10003	6.64	-33.86	1.60E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012048	Packer	42	39

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
BH10003	6.64	-26.86	1.60E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012042	Packer	35	32
BH10003	6.64	-26.86	1.60E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012043	Packer	35	32
BH10003	6.64	-33.86	1.70E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012045	Packer	42	39
BH10003	6.64	-26.86	1.70E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012041	Packer	35	32
BH10003	6.64	-26.86	1.70E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012044	Packer	35	32
BH10003	6.64	-26.86	1.80E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012040	Packer	35	32
BH10003	6.64	-33.86	2.00E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012049	Packer	42	39
BH10003	6.64	-20.86	2.70E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012036	Packer	29	26
BH10003	6.64	-20.86	2.70E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012037	Packer	29	26

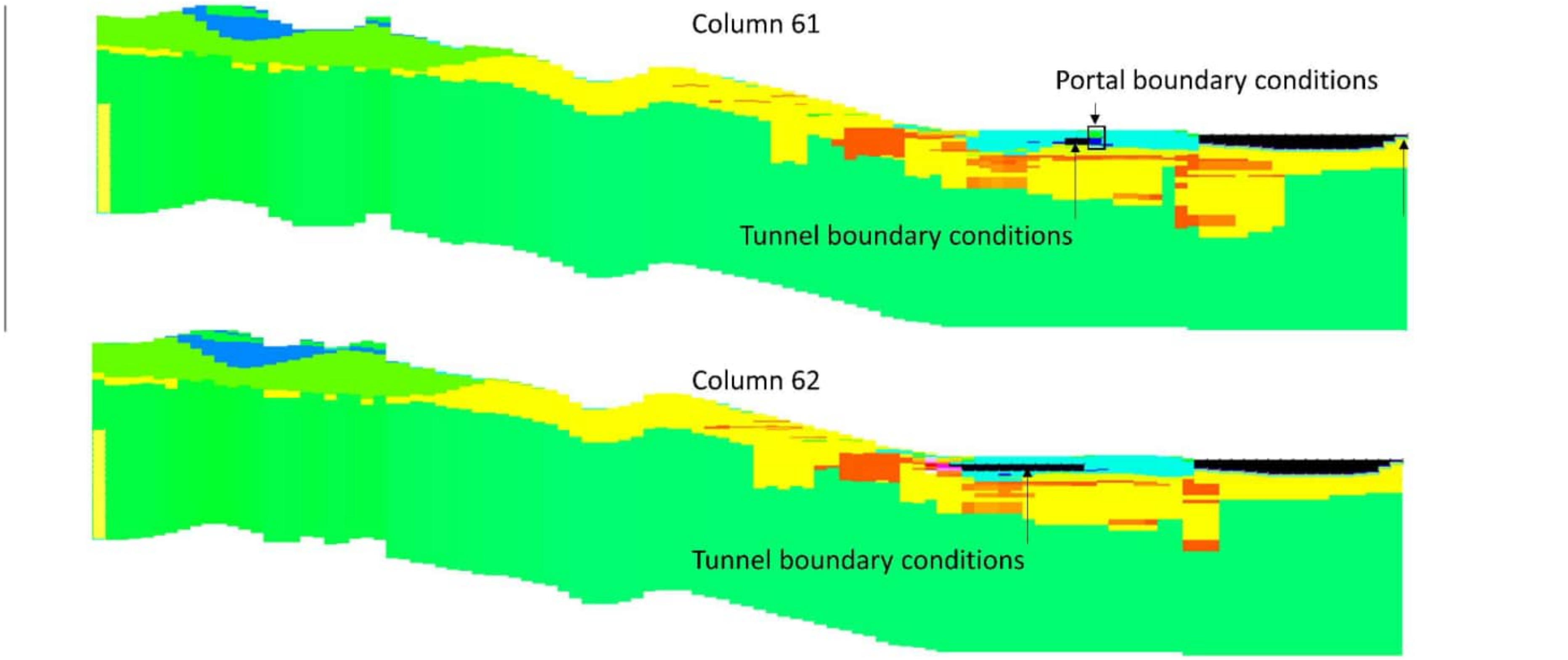
Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
BH10003	6.64	-20.86	2.70E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012038	Packer	29	26
BH10003	6.64	-20.86	2.80E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012035	Packer	29	26
BH10003	6.64	-20.86	2.80E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012039	Packer	29	26
BH10003	6.64	-15.86	5.70E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012032	Packer	24	21
BH10003	6.64	-15.86	6.00E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012033	Packer	24	21
BH10003	6.64	-39.86	6.10E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012050	Packer	48	45
BH10003	6.64	-39.86	6.10E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012051	Packer	48	45
BH10003	6.64	-15.86	6.20E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012031	Packer	24	21
BH10003	6.64	-15.86	6.50E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012034	Packer	24	21

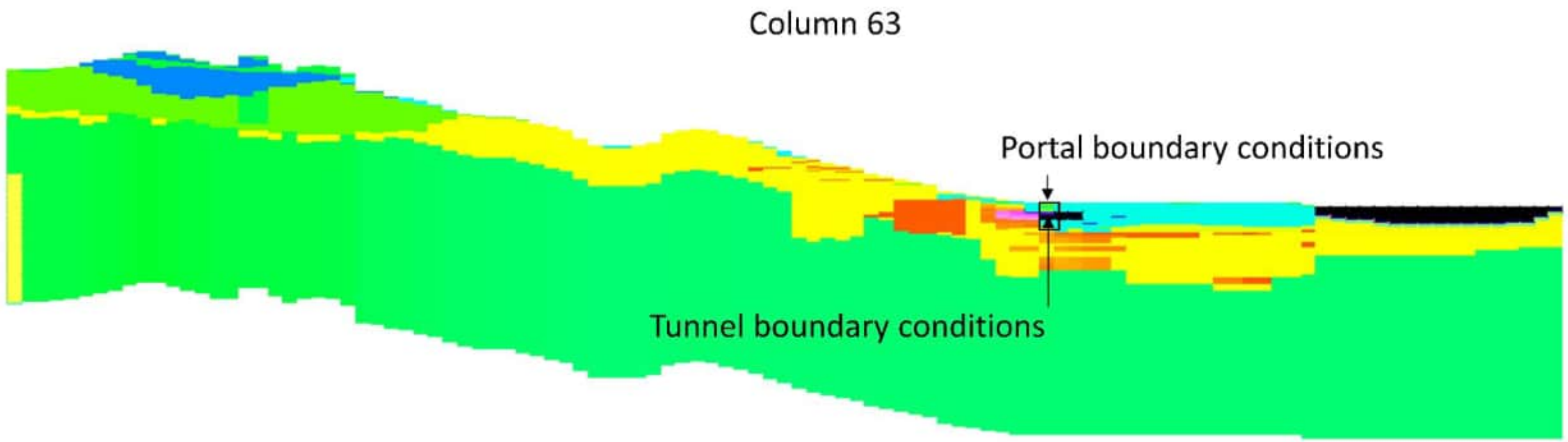
Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
BH10003	6.64	-15.86	6.70E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012030	Packer	24	21
BH10003	6.64	-39.86	6.90E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012052	Packer	48	45
BH10003	6.64	-39.86	7.30E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012053	Packer	48	45
BH10003	6.64	-39.86	8.30E-06	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012054	Packer	48	45
BH10003	6.64	-10.86	1.80E-05	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012026	Packer	19	16
BH10003	6.64	-10.86	1.90E-05	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012025	Packer	19	16
BH10003	6.64	-10.86	1.90E-05	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012027	Packer	19	16
BH10003	6.64	-10.86	2.00E-05	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012028	Packer	19	16
BH10003	6.64	-10.86	2.00E-05	566824.3	179204.7	3	C-AGSF-X-X-X-D-X-X-X-0004-02012029	Packer	19	16

Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
BH10004	7.63	2.13	2.70E-07	566645.5	179312.2	3	C-AGSF-X-X-X-D-X-X-X-0004-02012056	Rising Head	7	4
BH10004	7.63	2.13	2.80E-07	566645.5	179312.2	3	C-AGSF-X-X-X-D-X-X-X-0004-02012055	Falling Head	7	4
BH11004	20.3	2.3	2.50E-07	566276	179707	3	C-AGSF-X-X-X-D-X-X-X-0004-02012058	Rising Head	19.5	16.5
BH11004	20.3	2.3	2.60E-07	566276	179707	3	C-AGSF-X-X-X-D-X-X-X-0004-02012057	Falling Head	19.5	16.5
BH11007	17.88	4.38	1.00E-07	565801.6	179927.6	3	C-AGSF-X-X-X-D-X-X-X-0004-02012060	Rising Head	15	12
BH11007	17.88	4.38	4.10E-07	565801.6	179927.6	3	C-AGSF-X-X-X-D-X-X-X-0004-02012059	Falling Head	15	12
BH2302	3.77	-30.53	5.77E-06	568094.5	173178.4	3.2		Packer		
BH2302	3.77	-42.53	6.74E-06	568094.5	173178.4	3.2		Packer		
BH2302	3.77	-18.53	1.14E-05	568094.5	173178.4	3.2		Packer		
BH2302	3.77	-36.53	1.28E-05	568094.5	173178.4	3.2		Packer		
BH2302	3.77	-12.53	3.58E-05	568094.5	173178.4	3.2		Packer		
BH2374	8.51	-38.09	1.16E-06	567426.1	175994.4	3.2		Packer		
BH2374	8.51	-41.39	1.66E-06	567426.1	175994.4	3.2		Packer		

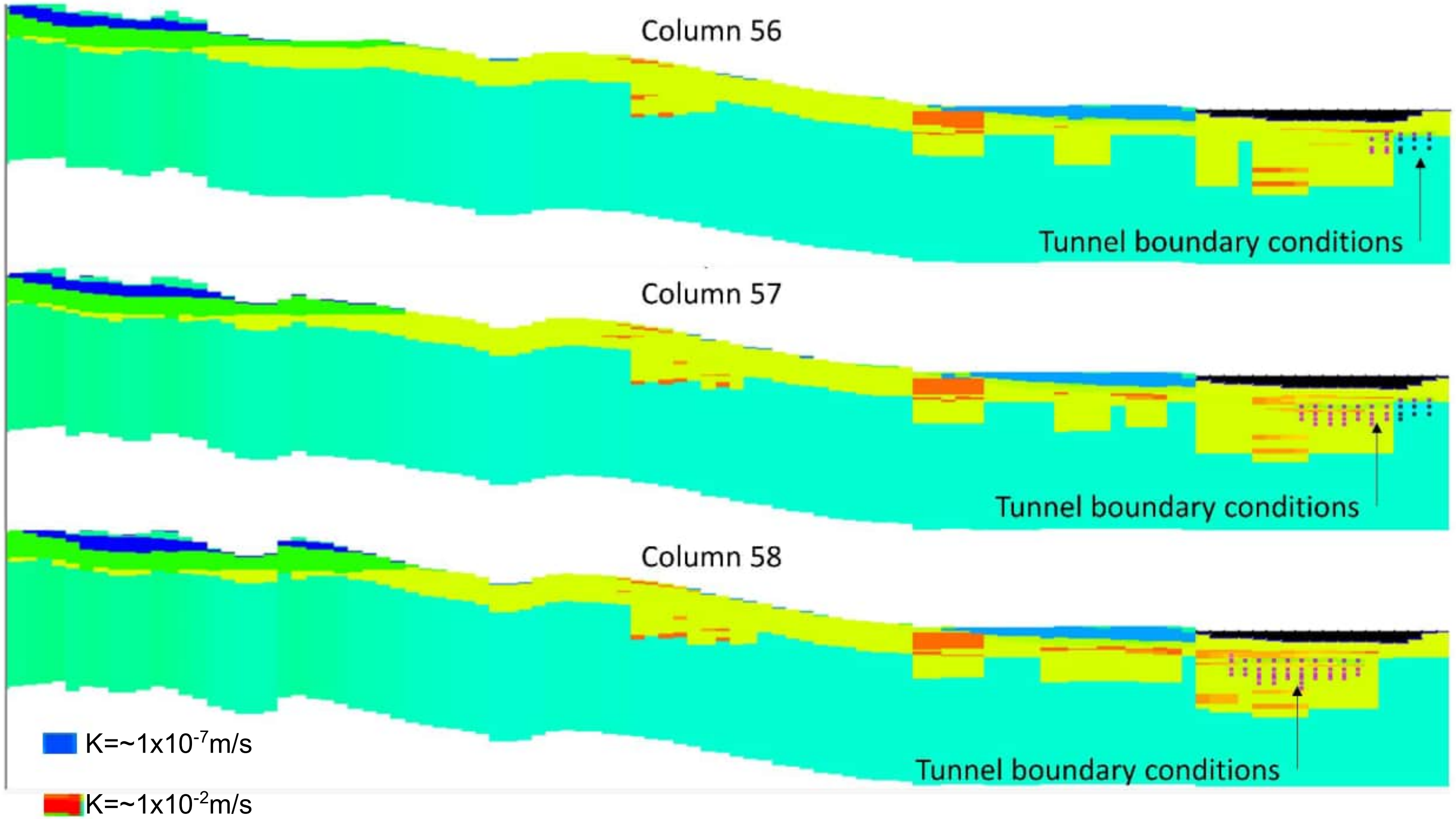
Borehole ID	Elevation (m AOD)	Screen (m AOD)	Hydraulic conductivity (m/s)	Easting	Northing	Screen length (m)	Ground investigation phase	Type (from AGS record)	Screen bottom (m bgl)	Screen top (m bgl)
BH2374	8.51	-33.09	2.56E-06	567426.1	175994.4	3.2		Packer		
BH2374	8.51	-31.09	3.29E-06	567426.1	175994.4	3.2		Packer		
BH2374	8.51	-28.59	9.78E-06	567426.1	175994.4	3.2		Packer		
BH2374	8.51	-26.09	2.15E-05	567426.1	175994.4	3.2		Packer		
BH2385	7.14	-45.96	6.39E-07	567407.8	176463.1	3.2		Packer		
BH2385	7.14	-38.96	6.99E-07	567407.8	176463.1	3.2		Packer		
BH2385	7.14	-42.46	7.87E-07	567407.8	176463.1	3.2		Packer		
BH2385	7.14	-35.46	3.28E-06	567407.8	176463.1	3.2		Packer		
BH2385	7.14	-31.96	4.36E-06	567407.8	176463.1	3.2		Packer		
BH2385	7.14	-27.96	5.76E-06	567407.8	176463.1	3.2		Packer		
OH07012	2.33	-34.05	1.35E-07	567559	176233	4		Packer		
BH12005	23.82	-3.18	2.50E-06	564462.1	180123.4	6	C-AGSF-X-X-X-D-X-X-X-0004-02012062	Rising Head	30	24
BH12005	23.82	-3.18	4.30E-06	564462.1	180123.4	6	C-AGSF-X-X-X-D-X-X-X-0004-02012061	Falling Head	30	24

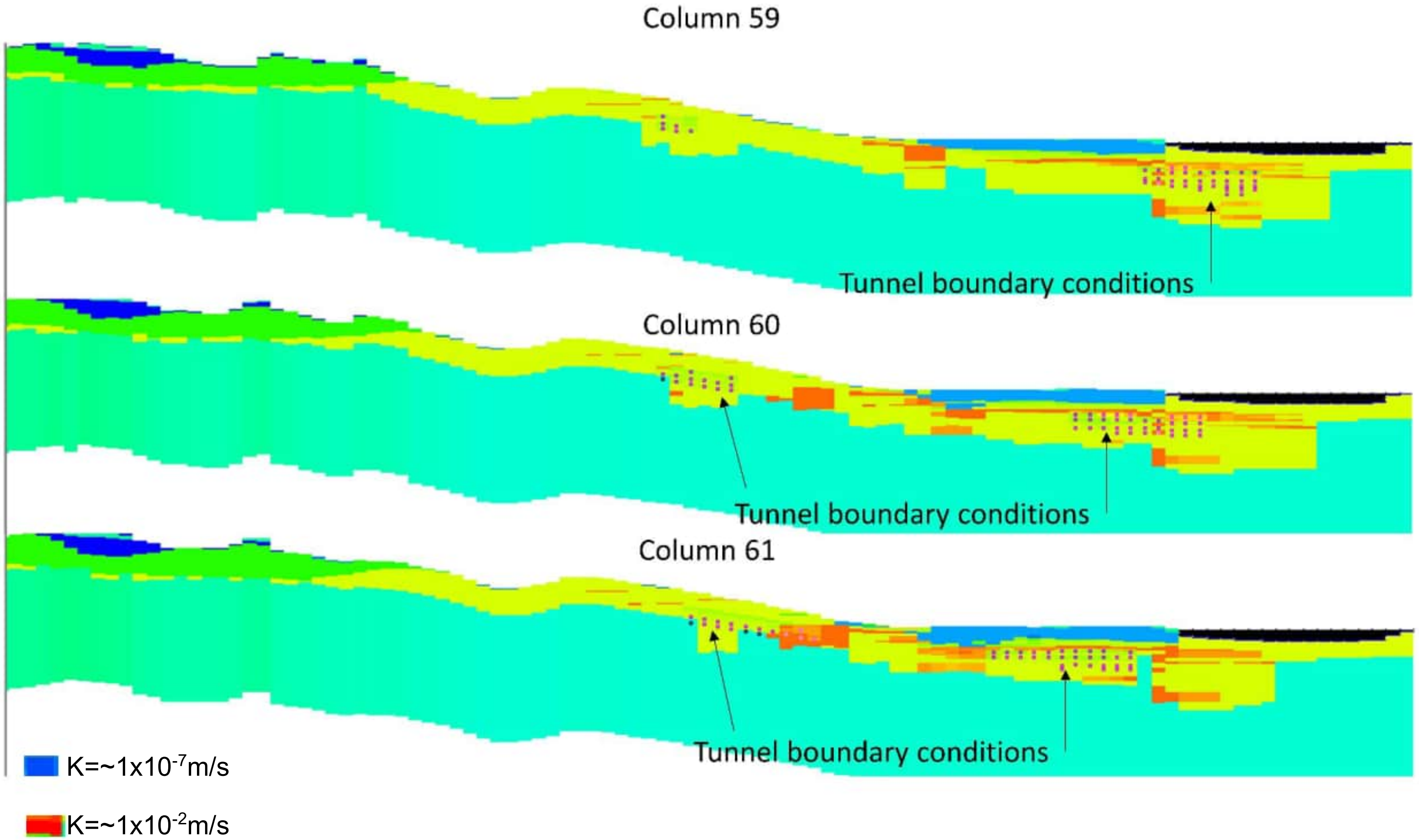
Annex B Ground protection tunnel boundary conditions



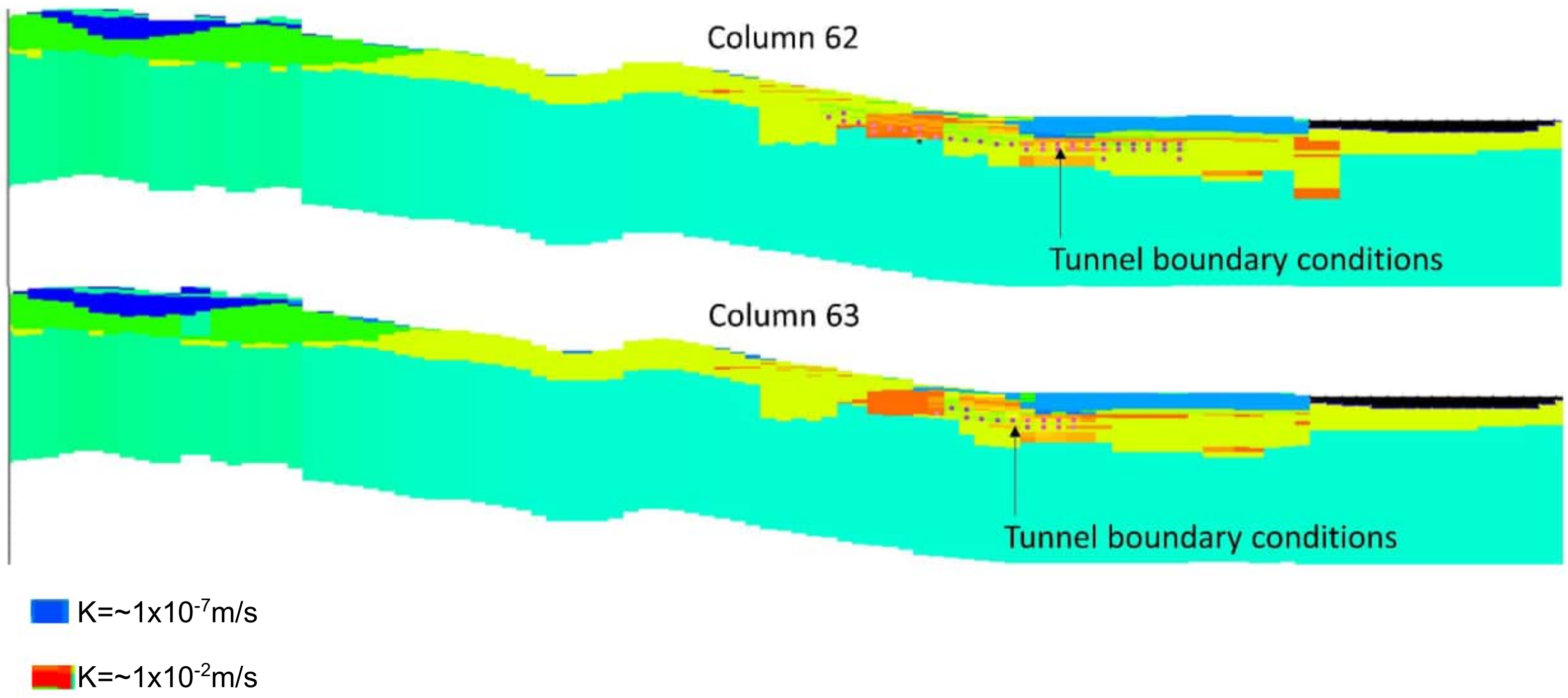

Column 63
Portal boundary conditions
Tunnel boundary conditions

Annex C Main tunnel boundary conditions

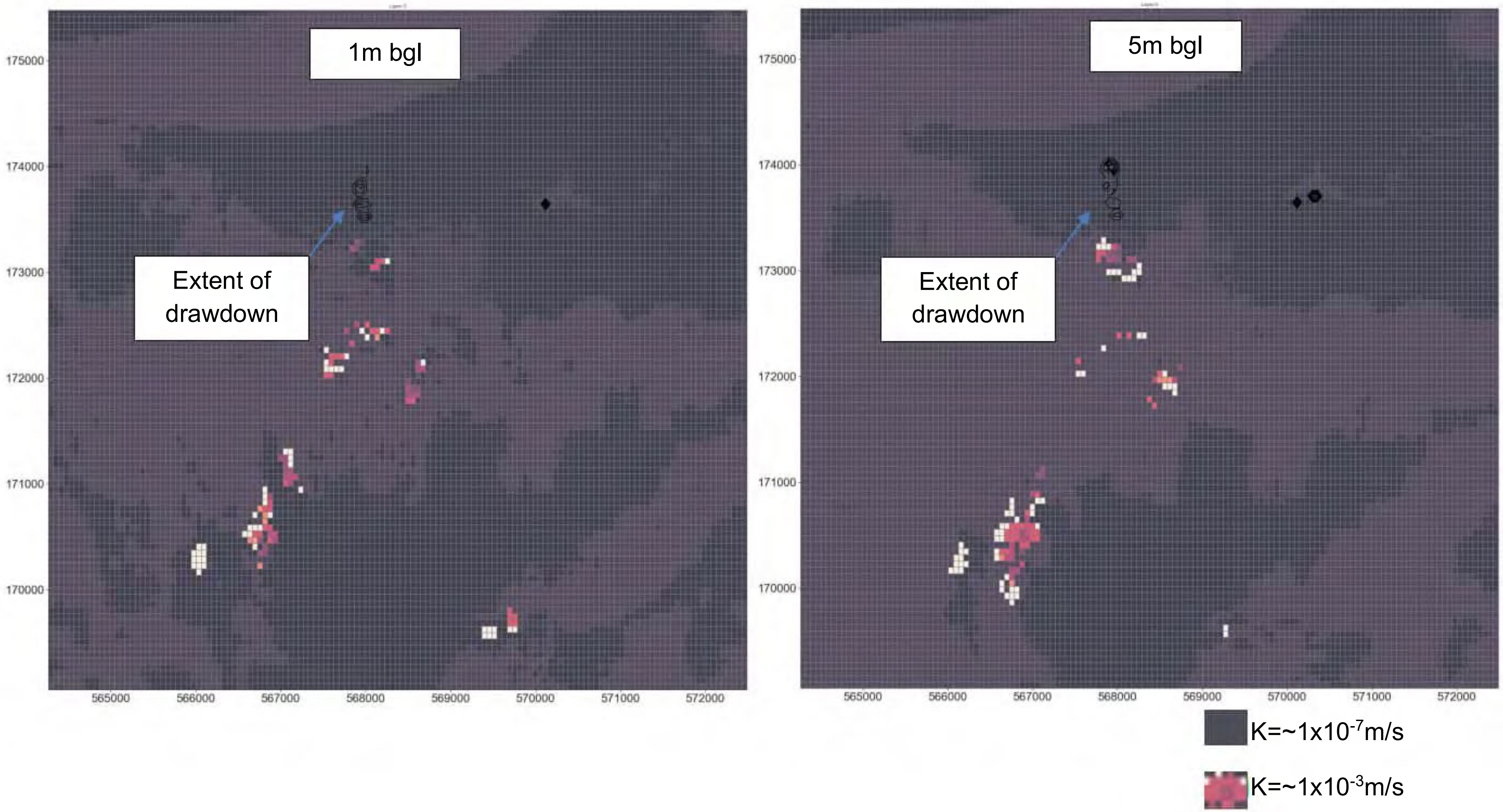


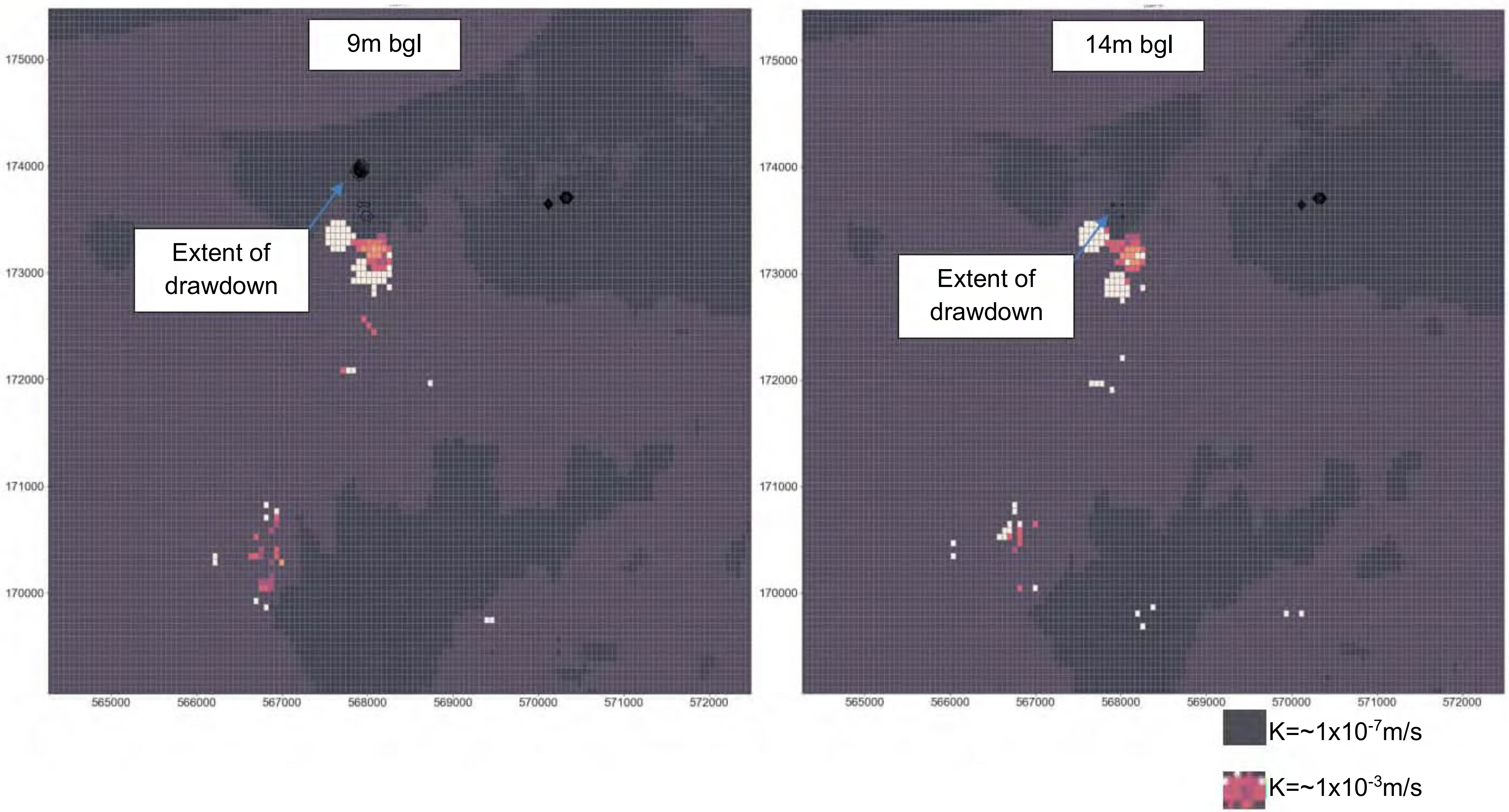

Column 59
Tunnel boundary conditions
Column 60
Tunnel boundary conditions
Column 61
Tunnel boundary conditions
K=~1x10-7m/s
K=~1x10-2m/s

`

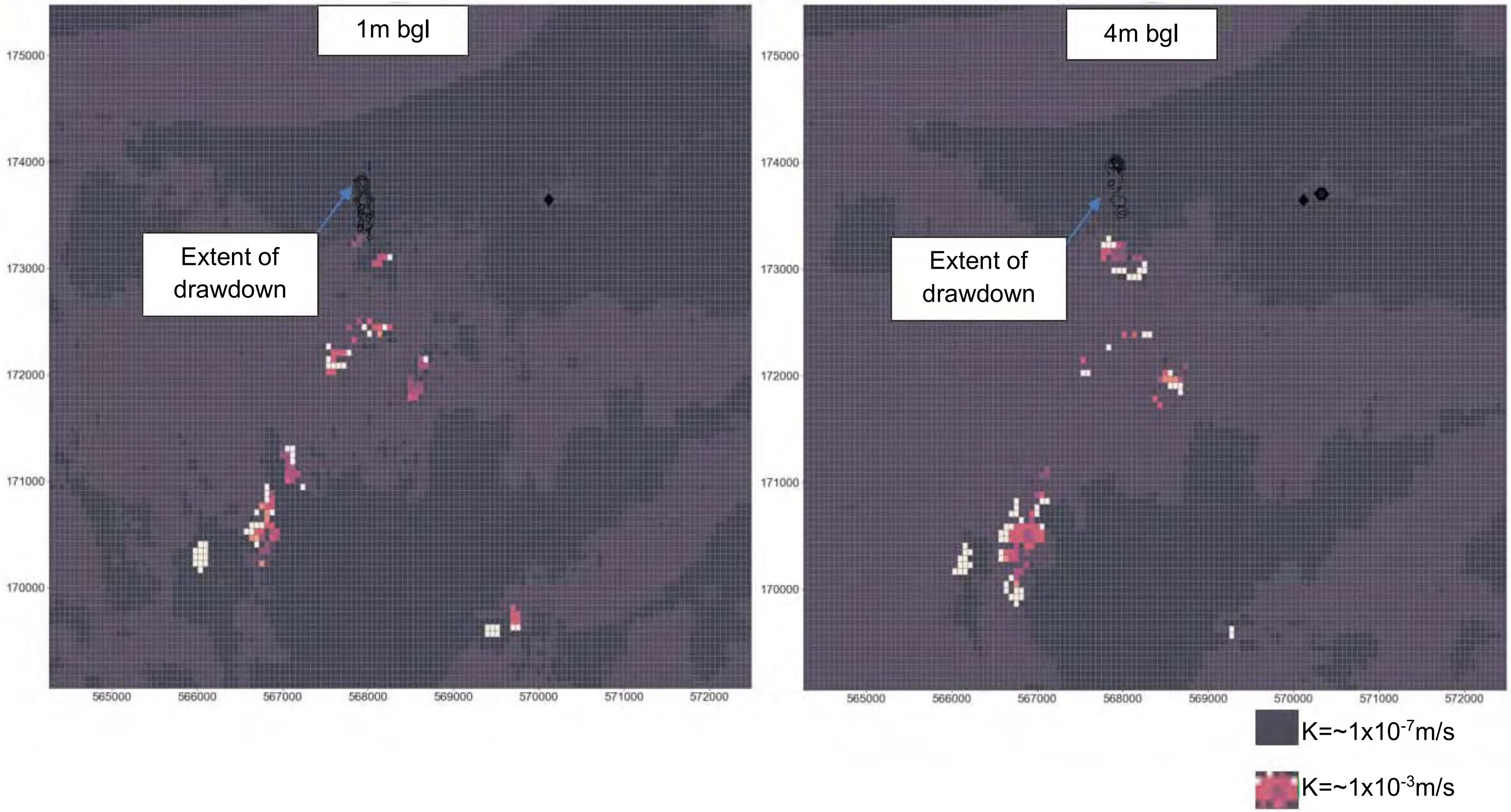

Column 62
Tunnel boundary conditions
Column 63
Tunnel boundary conditions
K=~1x10^{-7}m/s
K=~1x10^{-2}m/s

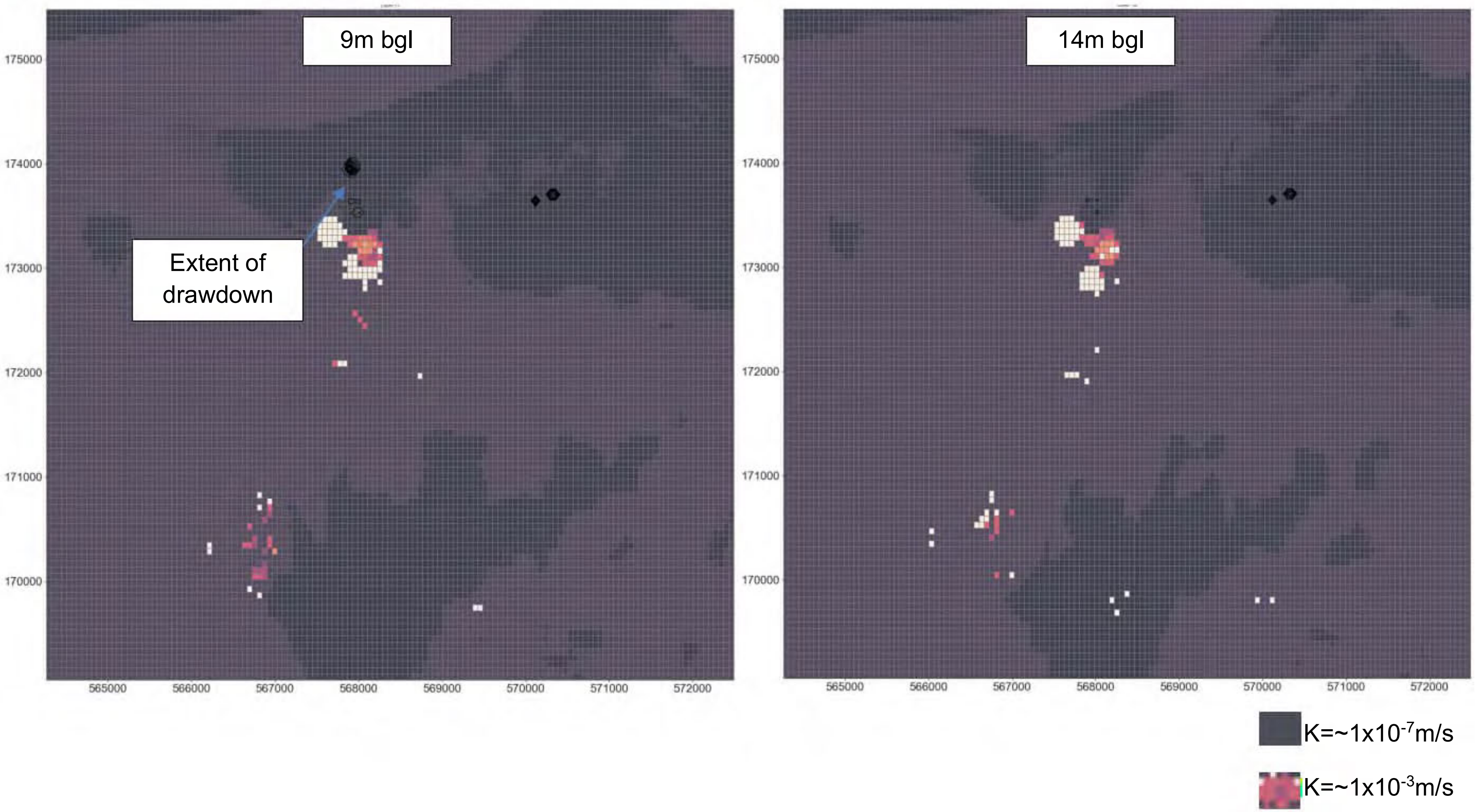
Annex D Drawdown for ground protection tunnel portals



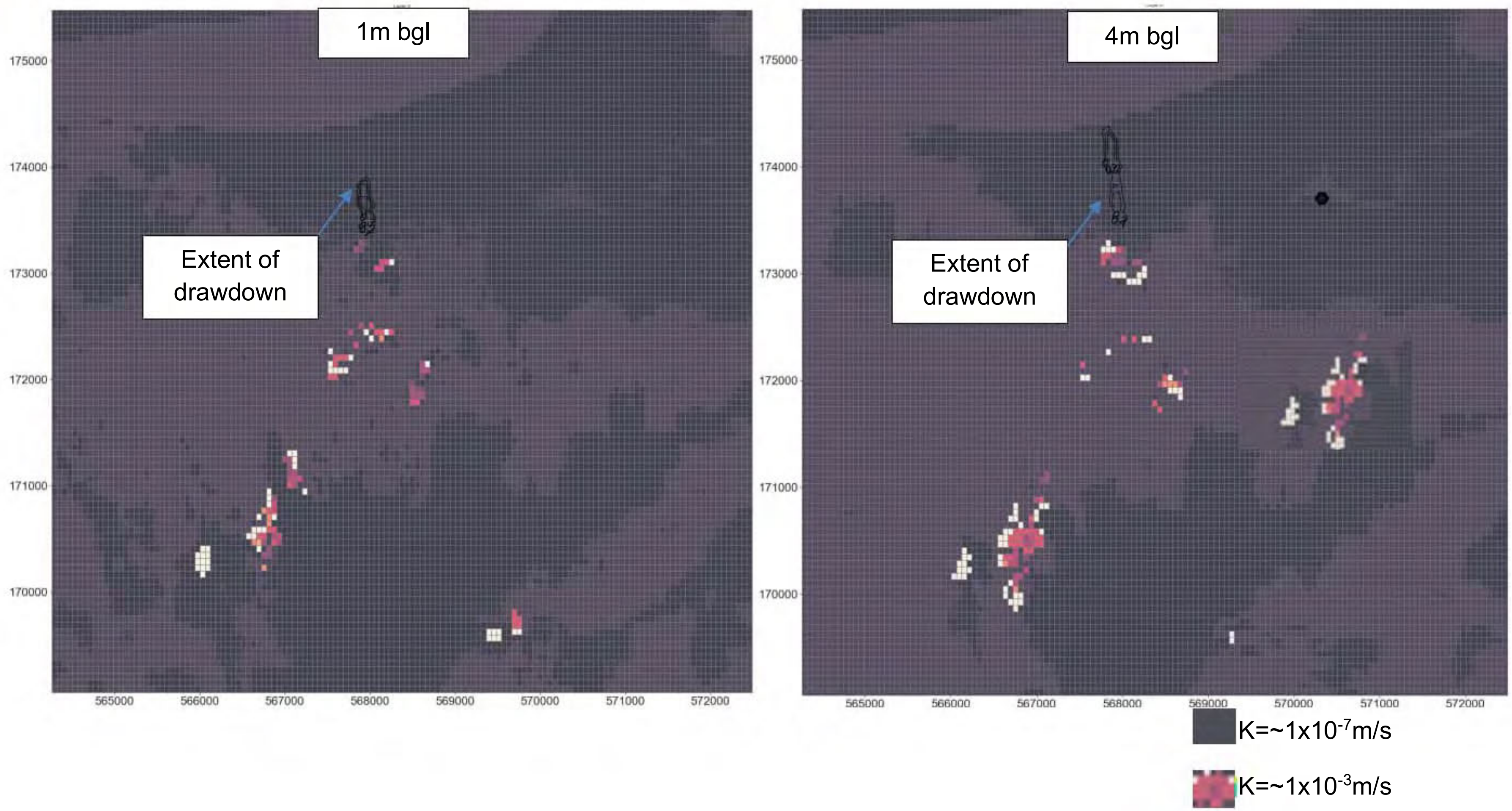

9m bgl
14m bgl
Extent of drawdown
Extent of drawdown
175000
174000
173000
172000
171000
170000
565000
566000
567000
568000
569000
570000
571000
572000
K=~1x10-7m/s
K=~1x10-3m/s

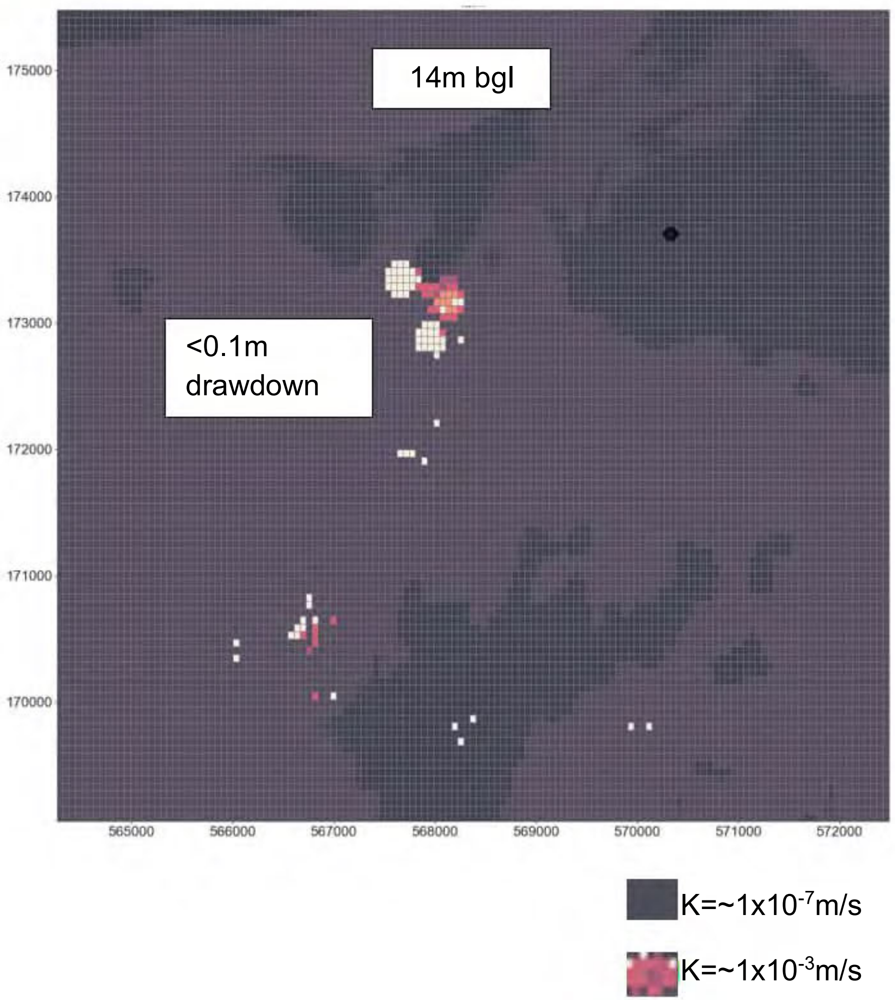
Annex E Drawdown for ground protection tunnel shafts and tunnel




9m bgl
14m bgl
Extent of drawdown
175000
174000
173000
172000
171000
170000
565000
566000
567000
568000
569000
570000
571000
572000
K=~1x10-7m/s
K=~1x10-3m/s

Annex F Drawdown for Main tunnels




14m bgl
<0.1m drawdown
175000
174000
173000
172000
171000
170000
565000
566000
567000
568000
569000
570000
571000
572000
K=~1x10-7m/s
K=~1x10-3m/s

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