Lower Thames Crossing

6.3 Environmental Statement Appendices
Appendix 10.2 – Stability Report

APFP Regulation 5(2)(a)

Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009

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Lower Thames Crossing

Appendix 10.2 – Stability Report

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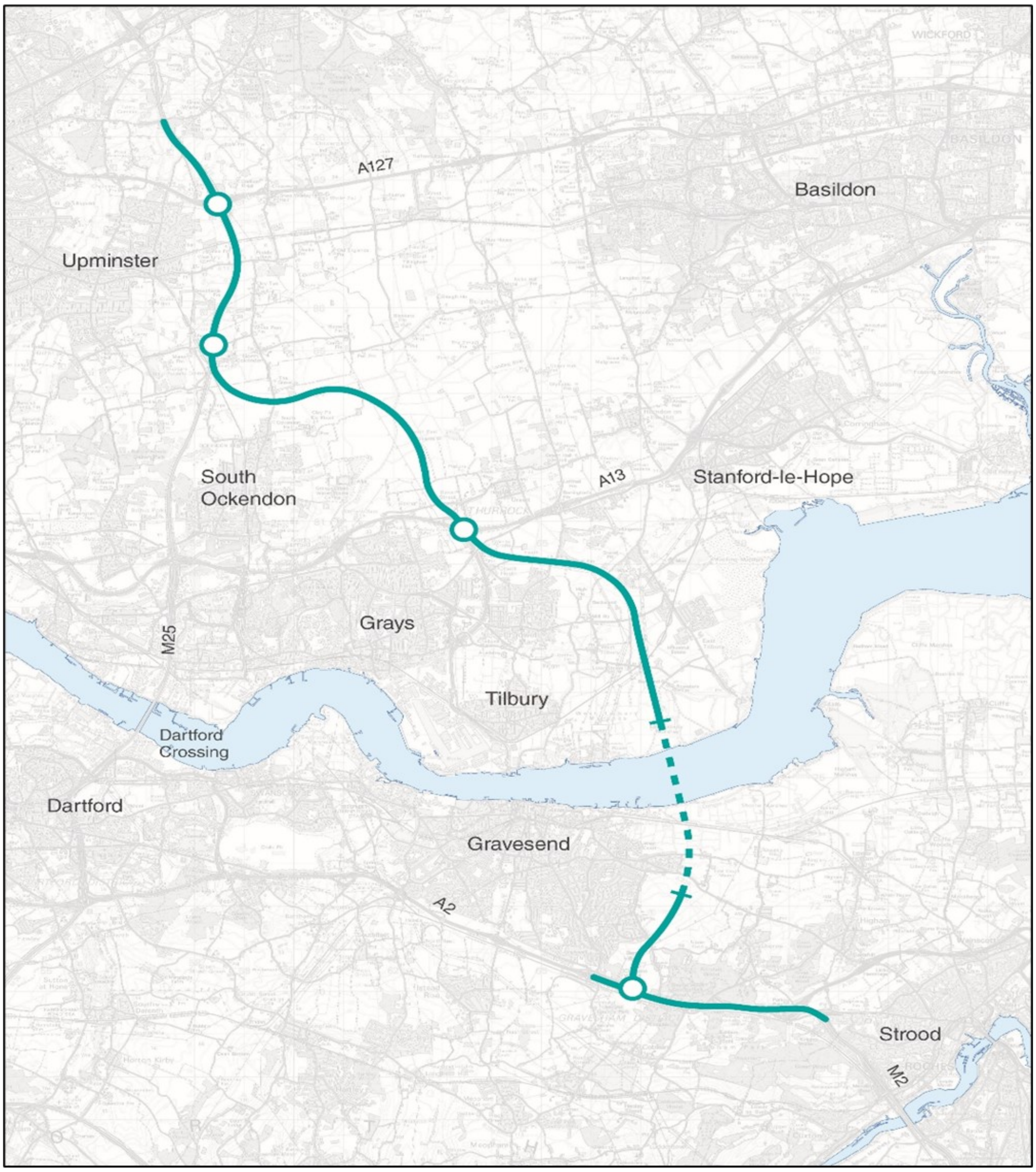
1 Introduction

1.1 Project description

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. The Project route is presented in Plate 1.1.

1.1.2 The Project 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.

Plate 1.1 The Project route



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1.2 Scope and objective of this Stability Report

Managing geotechnical risk

1.2.1 The identification and management of geotechnical risk is an essential part of an infrastructure project's lifecycle and is an ongoing process throughout the design, construction, operation and decommission of an asset.

1.2.2 Ground movements can be caused by a wide range of factors such as geology, construction methodology and quality and underground obstructions. It is essential to understand the potential ground movements associated with the construction of the Project in order to determine the technical feasibility of the construction methods and to determine appropriate mitigation strategies.

1.2.3 Geotechnical risks for the Project have been proactively managed in accordance with the Design Manual for Roads and Bridges (DMRB) CD 622 (Highways England, 2020). DMRB CD 622 adopts the guidance of BS EN 1997, Geotechnical Design.

1.2.4 In line with the requirements set out in DMRB CD 622, a geotechnical risk register would continue to be maintained and updated throughout the lifetime of the Project to inform and be informed by the ground investigation strategy, project and geotechnical design measures and construction methods.
A commitment to the continued management and monitoring of geotechnical risk during subsequent stages of the Project has been included in the Register of Environmental Actions and Commitments (REAC), which forms part of the Code of Construction Practice (Environmental Statement Appendix 2.2, Application Document 6.3). The REAC reference GS003 states the following:

REAC ref. No.	Name	Commitment
GS003	Managing geotechnical risks	To proactively manage the potential impacts from geohazards, such as land instability, during detailed design and construction activities the Contractors would carry out further ground investigation and establish a programme of instrumentation and monitoring in line with Section 7 of Appendix 10.2 (Application Document 6.3) [This Report]. A geotechnical risk register would continue to be maintained and updated throughout the development of the Project, in line with the requirements set out in DMRB CD 622.

1.2.5 In line with the requirements set out in paragraphs 5.116 to 5.119 of the National Policy Statement for National Networks (Department for Transport, 2014), this report provides a preliminary risk assessment of potential ground instability in relation to the Project by reviewing existing information on ground conditions to determine appropriate control measures and demonstrating the technical feasibility of the Project.

1.2.6 It should be noted that certain utility diversions required to deliver the Project would constitute a Nationally Significant Infrastructure Project (NSIP) in their own right when tested against section 20 of the Planning Act 2008, and therefore para 2.23.2 of the National Policy Statement for Gas Supply Infrastructure and Gas and Oil Pipeline (EN-4) has relevance to those pipeline/gas diversion NSIPs.

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1.2.7 Paragraph 2.23.2 of the National Policy Statement for Gas Supply Infrastructure and Gas and Oil Pipeline (EN-4) (Department of Energy and Climate Change 2011) states:

'*Applicants should assess the stability of the ground conditions associated with the pipeline route and incorporate the findings of that assessment in the ES* [Environmental Statement] *(see section 4.2 of EN-1) as appropriate. Desktop studies, which include known geology and previous borehole data, can form the basis of the applicant's assessment. The applicant may find it necessary to sink new boreholes along the preferred route to better understand the ground conditions present. The assessment should cover the options considered for installing the pipeline and weigh up the impacts of the means of installation.*

Where the applicant proposes to use horizontal directional drilling (HDD) as the means of installing a pipeline under a National or European Site and mitigating the impacts, the assessment should cover whether the geological conditions are suitable for HDD.'

1.2.8 By carrying out the preliminary risk assessment within the defined study area presented in Figure 1, the potential for ground instability has been considered in relation to the proposed method of installation of underground utility diversions including those works that qualify under EN-4. It should be noted that the Project is not proposing any HDD installation under a National or European Site.

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2 Structure of report

2.1.1 This Stability Report is structured as follows:

a. Section 3 presents the sources of information used for this document.

b. Section 4 summarises the ground conditions anticipated to be encountered along the Project alignment, based on desk study information and ground investigation works undertaken.

c. Section 5 presents the baseline for this report, in terms of works elements proposed to be constructed and geohazards likely to be present within and in close proximity to the Project footprint.

d. Section 6 reviews the possible impacts of geohazards and of the proposed Project works presented in Section 5.

e. Section 7 presents considerations for further works, in terms of instrumentation and monitoring as well as supplementary ground investigation works.

2.1.2 Several figures support this report as follows:

a. Figure 1: Assessment study area

b. Figure 2: Bedrock geology

c. Figure 3: Superficial geology

d. Figure 4: Distribution of landslide hazard

e. Figure 5: Distribution of karst hazard

f. Figure 6: Location of faults and structures

g. Figure 7: Distribution of shrink swell deposit hazard

h. Figure 8: Distribution of compressible deposit hazards

i. Figure 9: Distribution of collapsible deposit hazards

j. Figure 10 Distribution of running sand hazards

k. Figure 11: Distribution of possible deneholes

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3 Sources of information

3.1 Factual Project ground investigation information

3.1.1 A programme of intrusive ground investigation works was carried out in two phases to help develop the preliminary design and support the core assessments of the Development Consent Order (DCO) application.

3.1.2 Phase 1 was carried out between September 2017 and February 2018, and between September 2018 and January 2019. It was focused on the alignment of the tunnel and the areas surrounding the proposed North and South Portals.

3.1.3 Phase 2 of the ground investigation was carried out between July 2019 and June 2020 and included investigations along the whole Project route with a particular focus on the alignment of the road. Phase 2 also included further investigation works in the South and North Portal areas. The Phase 2 ground investigation works were split into the following work packages:

a. Package A covers the area of the route south of the River Thames. This includes the M2/A2/Lower Thames Crossing junction, South Portal and land north of the South Portal to the River Thames.

b. Package B covers the area of the route immediately to the north of the River Thames, around the North Portal and north to the Tilbury and Southend Railway line.

c. Package C covers the area of the route from the Tilbury and Southend Railway line in East Tilbury, northwards to the A13 junction in Orsett Heath.

d. Package D covers the area of the route from the A13 junction in Orsett Heath to the M25, north of junction 29 in Great Warley.

e. Package E covers 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.

3.1.4 Both phases of ground investigation included a range of intrusive and non-intrusive investigation, in situ testing, geotechnical and geo-environmental laboratory testing as well as hydrogeological testing.

3.1.5 The two phases of ground investigations are sufficient to develop robust conclusions on land stability.

3.1.6 In addition to the investigations supporting the highway and tunnel elements, ground investigation was carried out in September 2020 on behalf of the statutory undertaker to inform the third-party services (utility) diversions, including those gas diversion works that have been identified as NSIPs in their own right.

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3.1.7 The following factual ground investigation reports were used to inform the assessment of land stability:

a. Perfect Circle JV (2019) Phase 1 – main GI works

b. Perfect Circle JV (2020) Phase 1b – pumping test GI works

c. Perfect Circle JV (2020a) Phase 2 – Package A

d. Perfect Circle JV (2020b) Phase 2 – Package A Southern Valley Golf Course

e. Perfect Circle JV (2020c) Phase 2 – Package B

f. Perfect Circle JV (2020d) Phase 2 – Package C

g. Perfect Circle JV (2020e) Phase 2 – Package D1

h. Perfect Circle JV (2020f) Phase 2 – Package D2

i. Perfect Circle JV (2020g) Phase 2 – Package E

3.1.8 The following report has been used to inform the assessment of land stability for the NSIP gas diversion works:

a. Jacobs (2021) Lower Thames Crossing – Gas Pipeline Diversions Combined Ground Investigation Report and Geotechnical Design Report. Diversions Feeder 5 and Feeder 18

3.2 Assessments and publications

3.2.1 The following assessments and publications have been used as part of the preparation of this document:

a. British Geological Survey (BGS) (2019) Regional Structural Geology Technical Report

b. Ebor Geoscience Ltd (2018) Lower Thames Crossing Historical Aerial Photograph Interpretation

c. Cascade (2018) Lower Thames Crossing Historical Aerial Photograph and Preliminary Geomorphological Assessment: identification of potential geohazards and adverse ground conditions

d. Cascade (2019a) Stage 1 Damage Assessment Report – Permanent Works

e. Cascade (2019b) Third Parties Assets Damage Assessment Strategy

f. Cascade (2019c) Engineering Geomorphological Assessment

g. Cascade (2019d) Ground Movement Assessment (Stage 1) – Lower Thames Crossing A2 Junction Technical Note

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h. Cascade (2019e) Ground Movement Assessment (Stage 1) – Tilbury Junction

i. Cascade (2019f) A13 Junction Ground Movement Assessment Technical Note

j. Cascade (2019g) Ground Movement Assessment (Stage 1) – Lower Thames Crossing M25 Junction and M25 Junction 29 Technical Note

k. Cascade (2019h) Ground Movement Assessment (Stage 1) – A2 M2 Technical Note

l. Cascade (20019i) Ground Movement Assessment (Stage 1) – Ockendon Link Technical Note

m. Cascade (2019j) Ground Movement Assessment (Stage 1) – Chadwell St Mary Link Technical Note

n. Cascade (2019k) Ground Movement Assessment (Stage 1) – Main Crossing Technical Note

o. Cascade (2019l) Ockendon Link – Mardyke Ground Improvement Outline Assessment

p. Cascade (2020a) Assessment of Settlement of North Kent Railway due to Main Crossing tunnelling

q. Cascade (2020b) Options assessment for mitigating tunnelling effects on North Kent Railway

r. Cascade (2020c) Stage 1 Damage Assessment Report – Permanent Works

s. Cascade (2020d) Ground Movement Assessment (Stage 2) – A2 M2 Junction

t. Cascade (2020e) Ground Movement Assessment (Stage 2) – A13 Junction

u. Cascade (2020f) Technical Note – Ground Movement Assessment (Stage 2) Lower Thames Crossing M25 Junction

v. Cascade (2020g) Preliminary Ground Improvement Options for Tilbury Junction – Technical Note

w. Cascade (2020h) Technical Note: Stage 2 Damage Assessment for Ockendon Road Bridge – East Abutment

x. Cascade (2020i) Technical Note – Ground Movement Assessment (Stage 2) Main Crossing

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y. Cascade (2020j) Stage 2 Damage Assessment Report – Permanent Works

z. Construction Industry Research and Information Association (CIRIA) (2017) C760 Guidance on embedded retaining wall design.

aa. University of Portsmouth – Whitworth et al. (2020) Remote Sensing Geohazard Mapping: Final Mapping Results

bb. Zetica (2018) UXO Desk Study and Risk Assessment

3.3 Other factual information

3.3.1 Third-party data sources used to develop the Project's understanding of ground conditions are presented in Table 3.1.

Table 3.1 Other factual data sources

Data type	Source	Details
Soils, geology and geohazards	BGS	BGS 1:10,000 scale map – Artificial Ground BGS 1:10,000 scale map – Bedrock Geology BGS 1:10,000 scale map – Linear Features (faults) BGS 1:10,000 scale map – Mass Movement BGS 1:10,000 scale map – Superficial/Quaternary Deposits BGS 1:50,000 scale GeoSure mapping of adverse ground conditions (Collapsible Deposits, Compressible Ground, Landslides, Soluble Rocks, Running Sand deposits, Shrink/Swell Deposits) BGS National Landslide Database of historical events BGS BritPits mapping of past and present mines and quarries BGS 1:50,000 scale Bedrock and Quaternary deposits sheets for Romford (257), Southend and Foulness (258/259), Dartford (271) and Chatham (272)
Historical aerial photographs (1950, 1951, 1970, 1985, 1992)	Historic England	August 1992 – 1:6,000 scale July 1992 – 1:6,000 scale May 1985 – 1:5,400 scale November 1970 – 1:10,000 scale June 1951 – 1:7,900 scale May and June 1950 – 1:9,960 scale
Landmark geotechnical data	Project data catalogue	Geo-environmental data such as landfill sites
Digital Terrain Model with slope, aspect and hillshade derivatives: Light Detection and	Project data catalogue	0.5m resolution Project corridor-specific LiDAR digital elevation model resampled to 1m. Buildings and vegetation have been stripped out of the digital terrain model, which represents the bare earth.

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Data type	Source	Details
Ranging (LiDAR) data		
Worldview 2 A/B	Project data catalogue	0.5m resolution eight-band multispectral imagery
Colour infrared aerial imagery	Project data catalogue	50cm resolution infrared imagery
Google Earth aerial imagery	Google Earth	Various resolution aerial imagery from: 06/2019; 09/2018; 06/2018; 07/2017; 04/2015; 07/2014; 07/2013; 09/2012; 11/2011; 03/2011; 05/2007; 11/2006; 12/2003; 12/1990; 12/1960; 12/1940
ESRI World Imagery	Environmental Systems Research Institute (ESRI)	High resolution imagery available within ArcGIS
Study area and conceptual engineering	Project data catalogue	Engineering Geomorphological Assessment (EGA) study area and type and location of conceptual engineering
Base maps: Ordnance Survey (OS) raster mapping	Ordnance Survey	OS raster mapping at 1:10,000 and 1:25,000 scales, and large scale MasterMap vector mapping

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4 Summary of ground conditions

4.1 Published geology

4.1.1 A Preliminary Sources Study Report (PSSR) was prepared during the options assessment phase (Hyder-Halcrow, 2016) and was updated with an Addendum PSSR (Highways England, 2018). These reports provide geological and ground condition information across the study area presented in Figure 1, based on the available desk study data.

4.1.2 The generalised geological succession for the Order Limits is detailed in Table 4.1 to Table 4.3. For these tables, the stratigraphy and thicknesses quoted were extrapolated from available historical BGS borehole logs and the geological maps.

4.1.3 The distribution of the Quaternary/superficial and bedrock deposits is shown in Figures 10.6 and 10.7 (Application Document 6.2), which support ES Chapter 10: Geology and Soils (Application Document 6.1).

South of the River Thames

4.1.4 The land slopes downwards from the A2 in the south towards the River Thames and the marshes at Gravesend in the north.

4.1.5 Quaternary/superficial deposits (Head Deposits) are generally absent across much of the area south of the River Thames.

4.1.6 Made Ground is anticipated to be present associated with previously developed areas such as the North Kent Railway line, the Thames and Medway Canal and the former military airfield (Royal Air Force (RAF) Gravesend). Made Ground is also present in the area of the Filborough landfill site.

4.1.7 On high ground around the A2 connecting road from Cobham through the Shorne Woods Country Park to Higham, bedrock comprises the London Clay Formation underlain by the Harwich Formation at the highest parts which unconformably overlays the Lambeth Group and Thanet Formation. The published geological maps show that the Harwich Formation has been worked near Shorne Woods Country Park.

4.1.8 From geological maps, the bedrock geology underlying much of the area south of the River Thames comprises the White Chalk Subgroup (Seaford Chalk Formation and Newhaven Chalk Formation (to west) or Lewes Nodular Chalk Formation (to east)) which outcrops at the surface where superficial deposits are absent.

4.1.9 A summary of the geological succession to the south of the River Thames is provided in Table 4.1. The distribution of the Quaternary/superficial and bedrock deposits is shown in Figures 10.6 and 10.7 (Application Document 6.2).

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Table 4.1 General geological succession – south of the River Thames

Formation period/series/ group	General description	Estimated stratigraphical thickness
Made Ground	Likely to be associated with infrastructure earthworks and previously developed areas (e.g. the A2, former military airfield (RAF Gravesend), Southern Valley Golf Club, infilled quarries, North Kent Railway, Thames and Medway Canal and flood defences).	0.5–3m
Made Ground (landfill)	Made Ground associated with Filborough landfill.	6–8m
Head Deposits (Quaternary/Pleistocene)	Undifferentiated, pebbly sandy clay; some gravel.	1–10m
London Clay Formation (Palaeogene/Eocene/ Thames Group)	Dark bluish to brownish grey clay, containing variable amounts of fine-grained sand and silt.	1–10m
Harwich Formation (Palaeogene/ Eocene/ Thames Group)	Cross-bedded shelly sand (the Oldhaven Beds) with a basal pebble bed.	10–15m
Lambeth Group (Woolwich Formation) (Upnor Formation) (Palaeogene/Palaeocene/ Lambeth Group)	The upper beds are clay with shells, ferruginous sand, lignitic sand and lignite. The lower beds are coarse sand with pale grey clay partings and coarse gravel of black flint.	10–15m
Thanet Formation (Thanet Sand) (Palaeogene/Palaeocene/ Lambeth Group)	Greenish to brownish grey silty, fine-grained sand, clayey and siltier in the lower part, with a conglomerate of flint pebbles and nodular flints at the base.	10–30m
Seaford Chalk Formation (Cretaceous/ Upper Cretaceous/ White Chalk Subgroup)	Fossiliferous nodular chalk with bands of nodular flints, hardgrounds and marl seams.	Not proven, but estimated to be up to 70m thick
Newhaven Chalk Formation (Cretaceous/ Upper Cretaceous/ White Chalk Subgroup)	Soft to medium hard, smooth white chalks with numerous marl seams and flint bands, including abundant flints (notably at levels near the base). The Formation is known to contain distinct phosphatic chalks of limited lateral extent.	

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Formation period/series/ group	General description	Estimated stratigraphical thickness
Lewes Nodular Chalk Formation (Cretaceous/Upper Cretaceous/White Chalk Subgroup)	Hard to very hard nodular chalks and hardgrounds with interbedded soft to medium hard chalks (some grainy) and marls; softer chalks become more abundant towards the top. Nodular chalks are typically lumpy and iron-stained (usually marking sponges). First regular seams of nodular flint commence near the base and continue throughout.	

River Thames

4.1.10 In the low-lying marshes on either side of the River Thames and beneath the River Thames Channel, the geology consists of Alluvium overlying River Terrace Deposits overlying the Chalk (Seaford Chalk Formation and Newhaven Chalk Formation).

4.1.11 Thicknesses of the Alluvium have been found to range from 3 to 20m in the marshes on either side of the River Thames and approximately 3m within the river channel. Within the Alluvium, five distinct peat horizons have been described in the literature. The Geology of London special memoir (Ellison *et al*., 2004) notes that the total thickness of peat beds exceeds 2m in large areas between the confluence of the River Thames, River Lea and Tilbury Main.

4.1.12 River Terrace Deposits are present beneath the Alluvium in the marshes on either side of the River Thames and beneath the river channel. These are generally found to be 5–8m thick. The River Terrace Deposits typically comprise sand and gravel, but a bed of silty sand is commonly found towards the top of the unit, particularly south of the Thames.

4.1.13 A summary of the geological succession in the River Thames is provided in Table 4.2. The distribution of the Quaternary/superficial and bedrock deposits is shown in Figures 10.6 and 10.7 (Application Document 6.2).

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Table 4.2 General geological succession – River Thames

Formation period/ series/group	General description	Estimated stratigraphical thickness
Alluvium (Quaternary/Holocene)	Marine and Estuarine Alluvium. Silt and clay with lenses and beds of peat, and seams of sand and gravel.	3–20m
River Terrace Deposits (Taplow Gravel Formation) (Quaternary/Pleistocene)	Gravel, sandy and clayey in part.	5–8m
Seaford Chalk Formation (Cretaceous/ Upper Cretaceous/ White Chalk Subgroup)	Fossiliferous nodular chalk with bands of nodular flints, hardgrounds and marl seams.	Not proven, but estimated to be up to 70m thick
Newhaven Chalk Formation (Cretaceous/Upper Cretaceous/White Chalk Subgroup)	Soft to medium hard, smooth white chalks with numerous marl seams and flint bands, including abundant flints (notably at levels near the base). The formation is known to contain distinct phosphatic chalks of limited lateral extent.	

North of the River Thames

4.1.14 On the northern side of the River Thames, Made Ground (as a result of landfilling activities) of up to approximately 8m thickness has been encountered where it is associated with the Goshems Farm landfill area and the Tilbury Ash Disposal landfills, which contain pulverised fuel ash (PFA) from the power station. This coincides with the area of the proposed North Portal.

4.1.15 Made Ground is also anticipated to be present associated with previous and current developed areas and various light industrial activities. For example, the Low Street Brickworks historical landfill is present adjacent to the Tilbury Loop railway line. In this location, the Alluvium overlies River Terrace Deposits which overlie the White Chalk.

4.1.16 Further to the north between the Tilbury Loop railway line and the A13, the land slopes up from the River Thames valley and the East Tilbury Marshes. Here the Thanet Formation unconformably overlies the White Chalk Subgroup (Seaford Chalk Formation and Newhaven Chalk Formation).

4.1.17 Adjacent to the north of the A13 junction and east of Baker Street, there is Made Ground (landfill) associated with Miller’s sand and gravel pits historical landfill site. Around the A13, the topography reflects the underlying geology, with River Terrace Deposits overlying the Lambeth Group forming the higher ground. Underlying the Lambeth Group is the Thanet Formation which in turn is underlain by the White Chalk.

4.1.18 From Orsett northwards the geology comprises Head Deposits, Alluvium and River Terrace Deposits (Lynch Hill Gravel) overlying the London Clay Formation. Alluvium deposits lie along the route of the Mardyke River and various subsidiary channels and increase in width further north up the river valley to the A127.

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4.1.19 Head Deposits are the predominant superficial deposits in this area and are present on the gently sloping valley sides from the Romford/Upminster-Grays Railway line in the west, to beyond Bulphan in the east. River Terrace Deposits (Boyn Hill Gravel Member and Black Park Gravel Member) are present overlying the London Clay Formation in the North and South Ockendon area.

4.1.20 In localised areas no superficial deposits are present and there are outcrops of London Clay Formation at the ground surface.

4.1.21 There are many old clay pits within the London Clay Formation, shown on BGS maps as Worked Ground and Made Ground (described as wholly or partly backfilled pits). Between Ockendon and the A122 Lower Thames Crossing/M25 junction there is Made Ground/ landfill associated with the Ockendon Landfill complex and at Hall Farm and Groves Farm there are historical landfill sites.

4.1.22 A summary of the geological succession north of the River Thames is provided in Table 4.3. The distribution of the superficial deposits and bedrock is shown in Figures 10.6 and 10.7 (Application Document 6.2).

Table 4.3 General geological succession – north of the River Thames

Formation period/series/group	General description	Estimated stratigraphical thickness
Made Ground	Made Ground associated with developed or built-up areas.	0.5–2m
Made Ground (landfill)	Made Ground (landfill) on the northern side of the River Thames associated with historical and current landfill sites within the study area.	6–8m
Alluvium (Quaternary/Holocene)	Marine and Estuarine Alluvium. Silt and clay with lenses and beds of peat, and layers of sand and gravel.	1–20m
Head Deposits (Quaternary/Holocene and Pleistocene)	Undifferentiated, pebbly sandy clay; some gravel.	1–5m
River Terrace Deposits (Taplow Gravel, Lynch Hill Gravel, Boyn Hill Gravel, Black Park Gravel, Kempton Park Gravel) (Quaternary/Pleistocene)	River Terrace Deposits – gravel, sandy and clayey in part.	1–20m
London Clay Formation (Palaeogene/Eocene/ Thames Group)	Dark bluish to brownish grey clay, containing variable amounts of fine-grained sand and silt.	Up to 150m
Harwich Formation (Palaeogene/Eocene/ Thames Group)	Cross-bedded shelly sand (the Oldhaven Beds) with a basal pebble bed.	0–12m

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Formation period/series/group	General description	Estimated stratigraphical thickness
Lambeth Group (Woolwich Formation, Upnor Formation) (Palaeogene/Palaeocene/ Lambeth Group)	The upper beds are clay with shells, ferruginous sand, lignitic sand and lignite. The lower beds are coarse sand with pale grey clay partings and coarse gravel of black flint.	5–20m
Thanet Formation (Thanet Sand) (Palaeogene/Palaeocene/ Lambeth Group)	Greenish to brownish grey silty, fine-grained sand, clayey and siltier in the lower part, with a conglomerate of flint pebbles and nodular flints at the base.	Up to 32m
Seaford Chalk Formation (Cretaceous/Upper Cretaceous/ White Chalk Subgroup)	Fossiliferous nodular chalk with bands of nodular flints, hardgrounds and marl seams.	Up to 70m
Newhaven Chalk Formation (Cretaceous/Upper Cretaceous/ White Chalk Subgroup)	Soft to medium hard, smooth white chalks with numerous marl seams and flint bands, including abundant flints (notably at levels near the base). The formation is known to contain distinct phosphatic chalks of limited lateral extent.	

Summary

4.1.23 A map of the bedrock geology is provided in Figure 2 and a map of the Quaternary/superficial geology is provided in Figure 3.

4.2 Encountered geology

4.2.1 To illustrate the geology along the Project route, a ground model long-section was prepared based on the available data from the Phase 1 and Phase 2 ground investigations and supplemented with historical BGS borehole logs. The ground model is presented in Appendix 10.5 (Application Document 6.3).

4.2.2 This long-section shows that the geology encountered through the investigations is generally as anticipated by the published geological mapping and the description provided in Table 4.1 to Table 4.3. Project boreholes have revealed a more complex picture with regard to Alluvium deposits, with peat present either as discrete beds or isolated lenses at all depths within the Alluvium.

4.2.3 Further details of the geology encountered in the Phase 1 and Phase 2 investigations are included in Appendix 10.8: Generic Quantitative Risk Assessment Report for the Phase 1 Investigation (Application Document 6.3) and Appendix 10.9: Generic Quantitative Risk Assessment Report for the Phase 2 Investigation (Annex A–D) (Application Document 6.3).

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5 Baseline

5.1 Key elements of the Project

Tunnel section

5.1.1 The Project includes 4.25km of twin bored tunnels. The bored tunnels cross under the River Thames and terminate at two portals, north and south, with approach ramps connecting the tunnels with the highway sections of the Project.

Twin bored tunnels

5.1.2 The twin bored tunnels would be constructed with a tunnel boring machine (TBM), have an excavation diameter of approximately 16.4m and be connected by cross passages at set distances.

5.1.3 The twin bored tunnels would be lined using precast concrete segments, which are erected by the TBM. The internal diameter of the tunnel lining for the preliminary design is 14.94m.

Tilbury Fields landscaping

5.1.4 As part of the proposed landscape design, tunnel construction work arisings would be placed on top of the historic Goshems Farm Landfill to form Tilbury Fields.

5.1.5 The arisings are anticipated to predominantly comprise bored tunnel material including "chalk cake" (material resulting from the bored tunnel construction slurry treatment process). The arisings will also include other materials excavated from the North Portal, such as Alluvium to form the mounds and provide a cover of material over the “chalk cake” material that would support vegetation growth.

5.1.6 These arisings would be placed in a series of circular mounds ranging from 18 to 24m AOD in height to form the landscaping mounds. These mounds would not provide a structural function and are intended for landscaping purposes only.

North Portal

5.1.7 The North Portal is located to the south of the Tilbury Loop Railway line at Chainage 6+477 and represents a position where the structure transitions from cut and cover to open ramp. The North Portal design has been developed to facilitate the temporary activities associated with launching of the TBMs and servicing of the bored tunnel construction.

5.1.8 The design of the North Portal structure ensures that it can accommodate a TBM launch pit within the deepest section of the 300m-long cut and cover section. At preliminary design, sufficient space has been provided to enable the TBMs to be fully assembled before launch, with all the trailing gear installed. A 150m-long launch structure has been developed based on the assumed length of a fully assembled machine (approximately 120m in length), whilst providing additional space for flexibility, should the main works Contractor wish to use longer machines.

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South Portal

5.1.9 The South Portal location is to the south of the A226 at Chainage 2+230, allowing for the portal to be built in an open cut excavation with minimal temporary works.

5.1.10 The South Portal structure has been designed in the temporary case as a cutting with a cast in situ headwall to assist with the reception of the TBMs on completion of the tunnelling works.

5.1.11 A 130m-long temporary reception pit is proposed to allow the machines to be pushed clear of the headwall and facilitate access to the southern end of the tunnel for subsequent ‘fit-out’ activities. This pit has been assumed to be of the same depth as the North Portal assembly pit. A minimal clearance of 5m from the TBM shield to the surrounding slopes has been safeguarded to assist with the removal process.

5.1.12 A bottom-up constructed cut and cover structure to form the portal and local service building would be built within the temporary cutting.

Approach ramps

5.1.13 The approach ramps are non-enclosed, open-air structures that extend beyond the tunnel portals leading the traffic from tunnel level to ground level.

5.1.14 The approach ramps would retain the same carriageway configuration as the bored and the cut and cover elements of the tunnels and would each accommodate three traffic lanes.

5.1.15 The approaches to the North and South Portal are different due to geology, topography and relationship to the local network. The approach to the South Portal is all within a large cutting with the inclusion of emergency and maintenance access from ground level down to road level.

5.1.16 The North Portal approach ramp and approach road are within a retaining structure up to Chainage 6+854 where the road alignment rises above the assumed long-term groundwater level of +4m Above Ordnance Datum. Beyond this chainage the road is within flood bunds which form man-made false cuttings.

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Piled and retaining wall structures

5.1.17 A number of piled structures are proposed across the Project. In addition, several retaining walls are proposed to be constructed, to retain slopes in the vicinity of the Project or enable the construction of certain Project elements. On the north side, a total length of retaining wall of approximately 8km is proposed, with a maximum retained height of approximately 11m. On the south side, a total length of retaining wall of approximately 6.5km is proposed, with a maximum retained height of approximately 16m.

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Cuttings

5.1.18 Cuttings are proposed to be constructed with a maximum depth of approximately 16m (within the A122 Lower Thames Crossing/M25 junction section) to the north of the Thames, and approximately 28m at the approach to the South Portal. Preliminary assessment has been carried out to determine safe side slopes to reduce the risk of instability of the cutting slopes.

Embankments

5.1.19 Embankments are proposed to be constructed to a maximum height of approximately 11m (within A13/A1089/A122 Lower Thames Crossing junction) to the north of the Thames, and approximately 16m (within the M2/A2/Lower Thames Crossing junction section) to the south of the Thames. Preliminary assessment has been carried out to determine safe side slopes to reduce the risk of instability.

Third-party services

5.1.20 Along the route of the proposed Project there are a number of existing utilities including underground, high-pressure gas pipelines, electric cables and gas mains, water pipes, sewers and fibre-optic and telecoms cables. To construct the new road safely, protect existing supplies and enable future maintenance, numerous existing utilities, owned by the respective statutory undertakers, would require diversion or protection to allow the Project to be built in accordance with the design and to avoid the impact of the construction works on these assets.

5.1.21 The works necessary for these utilities would vary depending on how the assets are affected by the Project main works and the appropriate treatment of the asset, whether diversion or protection of it, has been determined with the relevant asset owner who has assessed the ability to operate and maintain their network during construction and operation of the A122, including a compliance check with their own industry standards, to minimise risk to their asset, their customers and to the Project workforce.

5.1.22 The construction of relatively shallow underground utility services uses an open trench excavation or trenchless technique, depending on factors such as location, ground and groundwater conditions, burial depth required, presence of nearby assets, utility characteristics (type, size, etc.). An open trench excavation is a supported open excavation in which the utility is installed. A trench support system ensuring the stability of the excavation and surrounding ground is employed during these works. These are routine construction works and an approach normally used for relatively shallow utility installation depths, and therefore result in a low risk to land instability.

5.1.23 For greater depths, or where the utility alignment crosses the path of another asset, trenchless techniques are typically employed. There are several commonly-used systems, the selection of which depends on the factors mentioned previously, but generally these subsurface construction techniques involve pushing a pipe from the launch area to the reception area. The construction may be completed wholly at surface level, or the pipe may be pushed from a shaft constructed for this purpose.

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5.1.24 These trenchless systems are also well-established techniques, and the significant experience accumulated by the utility construction industry ensures that these works can be robustly implemented without any detrimental stability effects on nearby land or assets. The trenchless techniques would not be used under any National or European protected sites as referenced in Paragraph 2.23.2 of NPS EN-4.

5.1.25 For protection works, a three-stage damage risk assessment, such as presented by Mair et al. (1996), would be undertaken to ascertain the likelihood of a failure of an asset. This would consider both the permanent and temporary indirect impacts to existing assets during and post construction.

5.1.26 The design and implementation of the protection methodology for all protection works would be undertaken as part of initial utility construction works and may involve the construction of slabs, rafts or piles to prevent damage/impact to the services resulting from the Project's construction and/or operation activities.

Gas pipeline diversion NSIPs

5.1.27 Three gas pipeline works, located to the north of the M2/A2/Lower Thames Crossing junction (Work numbers G2, G3 and G4), qualify as NSIPs under section 20(3) of the Planning Act 2008. Further information on why these works quality as NSIPs is provided in the Explanatory Memorandum (Application Document 3.2), whilst Appendix 1.3: Assessment of proposed gas pipeline works for the purposes of section 20 of the Planning Act 2008 (Application Document 6.3).

5.1.28 Two National Grid gas transmission pipelines would need to be diverted. One of the pipelines would be diverted in two separate locations. These would consist of approximately 0.12km in length at the Claylane Wood area (Work number G2) and 2.7km from the west of Thong Lane to the A226 (Work number G4). Work number G4 extends into construction Section B.

5.1.29 The other pipeline diversion would be approximately 1.6km in length and run from the east of Claylane Wood to Shorne Ifield Road, passing beneath Thong Lane and the A122 (Work number G3).

5.1.30 The majority of the pipeline diversion works associated with G2, G3 and G4 would be installed using normal open cut trenching techniques. However, due to the small footprint of land to the west of Thong Lane and the depth of the pipelines relative to the existing ground level, each of the pipelines (Work numbers G3 and G4) would be installed under the A122 by the construction of two shafts (approximately 17–20m in depth) and a joining tunnel (approximately 200m in length). The section under Thong Lane will be installed using trenchless techniques at a shallower depth of approximately 3–6m. To construct the tunnels, extended working hours would be required.

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5.2 Geohazards

Overview

5.2.1 Geohazards are defined as geological and geomorphological processes, landforms and ground materials that may pose a hazard to proposed engineering works during design, construction or operation.

5.2.2 The Project is exposed to geohazards that may adversely affect construction or operation of structures if not recognised and mitigated during design. Early recognition, avoidance or management of these is necessary to mitigate the potential for project delays during design and construction, rising project costs, reduced asset life and performance, and reputational harm. Early recognition and management of geohazards also mitigates the risk of the Project itself causing geohazards that affect the wider environment and third-party assets.

Geohazard assessment

5.2.3 In 2017 to 2018 Ebor Geoscience Ltd and Cascade undertook historical aerial photographic and preliminary geomorphological assessments (Cascade, 2018; Ebor Geoscience Ltd, 2018) to appraise the potential for geohazards in the study area. These were desk-based studies using archive historical aerial photographs, LiDAR elevation data, soil/geology/ landform maps, Google Earth imagery and other published data sources.

5.2.4 Several geohazards, including karst, faults, slope instability and adverse ground conditions were identified as possibly being present and a detailed EGA was undertaken to fully evaluate their distribution and significance. The EGA comprised a comprehensive appraisal of geohazards to identify severity, potential impacts on the Project design, construction and operation, and to provide recommendations for mitigation, avoidance or further assessment.

5.2.5 The principal geohazards identified on site comprise the following:

a. Slope instability

b. Chalk solution hollows

c. Running sand deposits

d. Materials susceptible to shrink/swell

e. Compressible deposits

f. Collapsible deposits

5.2.6 A wide study area was selected during the early stages of the Project to inform the development of the preliminary design. The study area was defined by applying a 500m buffer to the Project route presented at Statutory Consultation in 2018. This has given an assessment corridor of over 1km width and has allowed subsequent changes to the alignment of the Project route to be accommodated without compromising the robustness of the assessment. The main objective of this study is the Project route itself, due to the key elements noted in Section 5.1. It was determined that the 1km-wide study area would cover the reasonable worst case for impact pathways from geohazards.

5.2.7 The study area is presented on Figure 1.

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Geohazard inventory

5.2.8 The desk study work undertaken provided an inventory of all potential geohazards that could affect the study area. A summary of the inventory, including related adverse engineering impacts, is provided in Table 5.1.

Table 5.1 Inventory of potential geohazards

Geohazard	Underlying geological/man-made process(es)	Potential engineering impact
Faults	Tectonism, resulting from the Alpine orogenic event/mid-Atlantic spreading	Variable ground conditions for construction, potential for tunnel collapse and loss of support.
	Glacio-isostatic rebound	Unknown/variable depth to rockhead.
	Diapirism of Chalk into overlying sediments along weaker faulted sections	Preferential flow of water along fault systems, subsequent corrosion and corrosive contamination.
Karst: solution hollows and piping	Solution of calcium carbonate in Chalk Group geology by groundwater Diapirism of Chalk into overlying sediments	Undulating contact between Chalk and overlying sediments.
		Potential for sinkhole cover collapse and sudden loss of support.
		Unknown/variable depth to rockhead and variable infilling.
		Preferential pathways for groundwater or contaminants.
Man-made cavities	Deneholes	Potential for cover collapse and sudden loss of support and unforeseen ground conditions.
	Bomb craters	Unknown/variable depth to rockhead and variable infilling.
Chalk erosion and disturbance	Cryoturbation and solifluction of Chalk geology during periglacial climates of the Pleistocene	Inconsistent conditions: weaker geology and greater depth than expected to rockhead. Possible relict shear surfaces.
	Fluvial erosion during past climatic regimes, particularly meltwater scouring	Presence of drift-filled hollows infilled with significant thicknesses of water-bearing sand and gravel.
	Periglacial patterned ground: ground that has been fractured by changes in temperature, or layered due to resorting of sediment	Variable ground conditions and depth to rockhead.
Slope failure in over-	Reactivation of relict shear surfaces in clay with buried soils resulting from periglacial solifluction	Slope failure of very low-angle slopes, unforeseen ground

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Geohazard	Underlying geological/man-made process(es)	Potential engineering impact
consolidated clays	First-time failures in London Clay Formation and clay-derived Head slopes	conditions, debris runout, loading, settlement and shearing. Loss of support to and displacement of infrastructure.
Adverse/ differential ground conditions	Compression of peat/Alluvium from overburden	Differential ground response to loading and unloading; and variable ground conditions for construction.
	Swell and heave of expansive clays Shrink and cracking of expansive clays	
	Differential settlement of superficial sediments	
	Collapsible deposits (loess)	Loss of support, rapid subsidence.
	Running sand deposits	Saturated sandstone bedrock and loosely packed sands have the potential to lose strength and stiffness in response to stress conditions. This can cause slope instability and inundation of excavations.

5.2.9 A summary of the geohazards associated with the bedrock geology throughout the study area is provided in Table 5.2.

Table 5.2 Bedrock geology and geohazards

Formation	Description (BGS; Ellison *et al.*, 2004)	Potential engineering impacts
London Clay Formation	Bioturbated, slightly calcareous, silty clay to very silty clay	Clay shrink/swell; settlement and heave; instability and failure of low-angle slopes.
Harwich Formation	Variable; glauconitic fine-grained sand and pebble beds are principal lithologies.	Variable ground conditions due to changes in lithology.
Lambeth Group	Woolwich Formation; Lower Shelly Clay – dark grey to black clay	Variable ground conditions due to rapid changes in lithology; clay with irregular water-bearing sand bodies; hard bands; flint gravel beds which are water bearing.
	Reading Formation; unbedded mottled silty clay and clay	
	Upnor Formation; fine to medium grained sand	
Thanet Formation	Coarsening upwards sequence, dominantly fine-grained sand, but clayey and silty in the lower part	Running sands where saturated sandstone bedrock and loosely packed sands have the potential to lose strength and stiffness in response to stress conditions.
	Intensely bioturbated, so primary sedimentary structures are lacking	

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Formation	Description (BGS; Ellison *et al.*, 2004)	Potential engineering impacts
Chalk Group: Lewes Nodular Chalk Formation and Seaford Chalk Formation	Seaford Chalk Formation – Fossiliferous nodular chalk with bands of nodular flints, hardgrounds and marl seams Lewes Nodular Chalk Formation – White chalk with hard nodular beds	Dissolution weathering, karstic voids and infill of solution features by later pebbly sandy clay or fine-grained sand deposits, depending on the overlying materials; flint beds.

5.2.10 A summary of the geohazards associated with Quaternary/superficial geology in the study area is provided in Table 5.3.

Table 5.3 Superficial geology and geohazards

Superficial deposit	Description (Bridgland, 1994; Ellison *et al.*, 2004)	Potential engineering impacts
Alluvium	Olive-green to blue-grey silt and or clay interbedded with up to five peat layers in the Thames Valley and possibly Mardyke Valley.	Settlement Variable ground conditions
Head Deposits	Remobilised London Clay in the Mardyke Valley and Clay Downland regional terrain units. May contain landslides or low-angled shear surfaces.	Shrink/swell Settlement and heave Instability and failure of low-angle slopes
Langley Silt Member	0.5m veneer overlaying some terrace gravel deposits.	Collapsible ground
Shepperton Gravel Member	Sand and gravel underlain by Chalk and underlying Alluvium.	Variable ground conditions
Kempton Park Gravel Member	Sand and gravel underlain by Chalk and Thanet Sands, overlying Alluvium.	Variable ground conditions
Taplow Gravel Member	Stratified gravel and sand.	Variable ground conditions
Lynch Hill Gravel Member	Sand and gravel, locally with lenses of silt, clay or peat overlain by 0.5m of Langley Silt.	Variable ground conditions
Boyn Hill Gravel Member	Sand and gravel, with possible lenses of silt, clay or peat overlain by 0.5m of Langley Silt.	Variable ground conditions
Black Park Gravel Member	Sand and gravel, with possible lenses of silt, clay or peat. Oldest post-diversionary Thames terrace that may include oversized glacial material.	Variable ground conditions

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6 Assessment of results and evaluation of impacts

6.1 Engineering implications of geohazards

Introduction

6.1.1 The following section provides an overview of how the Project has managed the potential risks arising from geohazards within the development of the preliminary design.

6.1.2 As described in Section 1, the identification and management of geotechnical risk is an essential part of an infrastructure project's lifecycle and is an ongoing process throughout the design, construction, operation and decommission of a Project.

6.1.3 Geotechnical risks for the Project have been proactively managed in accordance with DMRB CD 622 (Highways England, 2020). In line with the requirements set out in DMRB CD 622, a geotechnical risk register would continue to be maintained and updated throughout the lifetime of the Project. A commitment to the ongoing management of geotechnical risk has been included in the REAC via GS003:

REAC ref. No.	Name	Commitment
GS003	Managing geotechnical risks	To proactively manage the potential impacts from geohazards, such as land instability, during detailed design and construction activities the Contractors would carry out further ground investigation and establish a programme of instrumentation and monitoring in line with Section 7 of Appendix 10.2 (Application Document 6.3) [This Report]. A geotechnical risk register would continue to be maintained and updated throughout the development of the Project, in line with the requirements set out in DMRB CD 622.

6.1.4 The main works Contractors would carry out further ground investigation to inform the detailed design and construction delivery alongside a programme of instrumentation and monitoring (described in Section 7) as part of the ongoing management of geotechnical risk.

Landslide hazard

6.1.5 The results of the desk study work and the geomorphological assessment indicate that there are a number of pre-existing landslides within the study area as shown on Figure 4. However, none of these pre-existing landslides intersect the alignment and therefore will not cause risk to the Project. Furthermore, construction works or operation activities of the Project itself are not expected to have any effect on these pre-existing landslides.

6.1.6 The EGA shows that the combination of particular landform and geology assemblages provide the conditions for first-time failures in clay slopes and/or reactivation of relict periglacial shear surfaces on extreme low-angle slopes. In both cases, instability can be triggered if slopes are cut, loaded or saturated with water as part of the engineering process.

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6.1.7 Figure 4 shows the areas with the potential for first-time failures and reactivation of periglacial shears in the study area, represented by yellow and orange colouring (ground conditions conducive to slope instability are present/possibly present, respectively).

6.1.8 Cuttings and tunnel portals, where buried relict shear surfaces may be present, or where clay or deeply weathered parent materials are present, have the potential to cause slope instability. However, satisfactory management of this risk has been achieved through routine earthworks design and engineering design. This includes design of slopes to a stable angle, providing physical support to or stabilisation of the slope, and drainage measures to reduce groundwater pressures on the slope.

Karst hazard

6.1.9 The assessment of karst hazard reveals the potential for the widespread presence of infilled solution cavities or voids in the chalk. Figure 5 shows the distribution of karst hazards in the study area. Solution cavity features are potentially widespread in the chalk of the North Downs south of Lower Higham Road, and below the River Thames and its alluvial deposits.

6.1.10 There are large areas of the study area where karst cannot be detected due to urban developments at Chalk, Thong and Shorne, in the woodland south of Thong and Shorne, and at Southern Valley Golf Club where landscaping has taken place.

6.1.11 Karstic solution pipes and cavities are typically filled with unconsolidated sediment, but underground voids are possible. Karstic conditions give rise to adverse ground conditions, such as variable depth to rockhead, settlement or collapse, and groundwater ingress.

6.1.12 There is a large amount of industry experience dealing with karst geohazards, including in the tunnelling sector. There are standard construction practices to minimise the impact of karst hazards, and these would not result in any additional significant adverse environmental effects.

6.1.13 It is anticipated that the main works Contractors would undertake additional targeted investigations at detailed design phase, ahead of construction works, to complement the extensive ground investigation campaign already completed [REAC GS003]. Techniques can be employed to detect possible karst features ahead of the TBM, directly through probing or indirectly via the use of geophysical investigation. Typical measures employed during construction activities, upon encountering a karst feature, can include localised ground treatment such as grouting, or adjustments to the works such as modifying a structure’s proposed foundation type, depth and layout.

Fault hazard

6.1.14 The desk study and geomorphological assessment found no evidence of capable faulting (i.e. faulting with a significant potential for displacement at or near the ground surface) in the study area. However, faults may still pose hazards relating to unforeseen or variable ground conditions. Figure 6 shows all faults marked on the BGS 1:50,000 sheet, those inferred by others as reported in published papers, and zones of possible faulting inferred through interpretation of project ground investigation.

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6.1.15 The evidence for active faulting in the London Basin is presently inconclusive, and even if proven, displacement rates are anticipated to be very low. It is therefore unlikely that active faulting is a significant risk to the Project's design, construction or operation.

6.1.16 Unforeseen ground conditions and variable depth to rockhead may be encountered at faults due to preferential formation of hollows, diapirism of chalk into overlying sediments at weaker faulted sections and the unexpected movement of water along fault systems with subsequent corrosion and corrosive contamination.

6.1.17 In the instances where faults intersect with the Project, there are standard construction practices to mitigate the associated risks. These practices, for example advance probing and ground treatment, would not result in any significant adverse environmental effect and would be implemented at a very localised extent.

Other geohazards arising from adverse natural ground conditions

6.1.18 The BGS GeoSure datasets and the assessment of landforms, geology and superficial materials have highlighted a number of other adverse natural ground conditions within the study area.

a. Shrink/swell deposits: expansive clays can swell and shrink considerably, causing differential ground response to loading and unloading. Figure 7 shows the distribution of shrink/swell deposit hazards in the study area.

b. Compressible deposits: Alluvium and peat have the potential to cause uneven settlement and/or sudden loss of support when cut, loaded, wetted or drained. Figure 8 shows the distribution of the compressible deposits hazard in the study area. These are associated with the Thames Valley, and to a lesser extent the Mardyke Valley.

c. Collapsible deposits: wind-blown loess has the potential to collapse suddenly under loading or saturation. Figure 9 shows the distribution of the collapsible deposits hazard in the study area. While collapsible deposits are not thought to affect the Project, small areas may be present.

d. Running sand deposits: areas with loosely packed sands have the potential to lose strength and stiffness in response to stress conditions. Figure 10 shows the distribution of the running sand hazard in the study area.

6.1.19 These adverse natural ground conditions may in particular affect transitions between areas of soft compressible soils and coarse-grained materials of better properties, or transitions between engineering type (e.g. embankment to cutting, earthworks to structure), for example through the development of differential settlement. The geohazards have been taken into account in the development of the preliminary design, in particular through the design of the proposed works in the Tilbury and Mardyke area influencing the adoption of piled embankment solutions in the preliminary design.

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6.1.20 The above geohazards are well understood through extensive past industry experience. In line with REAC GS003, it is anticipated that the main works Contractors would undertake additional targeted investigations to complement the extensive ground investigation campaign already completed by the Project. This would enable the main works Contractors to confirm the presence or absence of these geohazards at detailed design phase ahead of construction works starting and delineate their extent to develop element-specific ground models.

6.1.21 It is also anticipated that the main works Contractors would allow, in particular in their detailed design and construction programme, for encountering the above geohazards during construction activities. These can be mitigated by routine construction techniques and approaches, such as but not limited to, appropriately sequencing earthworks activities, adjusting earthworks slopes or providing slope retention or stabilisation measures, employing ground treatment and improvement measures, using ground and surface water control measures, excavating materials of unsatisfactory engineering properties and replacing these with materials of better characteristics, and modifying structure foundation proposals. These are standard design and construction practices to minimise the risks associated with the above hazards and these would not result in any significant adverse environmental effect.

Man-made hazards

6.1.22 There is also the possibility of World War II (WWII) bomb craters and deneholes in the chalk. These features should be considered in the same way as described for the karst geohazard.

WWII bomb craters

6.1.23 The possible locations of craters caused by WWII bombs may be inferred from available sources of information, in particular the detailed desk study report commissioned for the Project (Zetica, 2018) (Appendix 10.10, Application Document 6.3). Other evidence of possible bomb craters may be collected from site observations or data (e.g. mottled white/dark soils along the runways at RAF Gravesend and in the adjacent fields, visible in the historical aerial photographs, and shallow depressions in the LiDAR data).

6.1.24 However, as many of the potential bomb sites correspond with locations considered to have high karst hazard potential, it is likely that chalk dissolution or patterned ground are responsible for at least some of the mottled white/dark soils. Consequently, it is not possible to differentiate bomb craters from solution hollows. Also, shallow depressions associated with bomb damage or karst may have been ploughed out of fields or obscured by urban development.

6.1.25 Where a bomb crater may still exist, the effect on ground conditions and engineering challenges associated with exploded WWII bombs would resemble those associated with solution features such as karst geohazards as described above.

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Deneholes

6.1.26 Deneholes are chalk and flint extraction pits dating from Medieval times. Characteristically they comprise a narrow shaft, commonly in the order of two to three metres wide, with chambers radiating from the base. The depth of these deneholes reflects the depth to a specific chalk or flint horizon. Once they had reached their limits, deneholes were commonly capped, using for example upturned trees or brick arching. Records pertaining to the distribution of deneholes are incomplete, but if detectable in the field they may be visible as shallow depressions.

6.1.27 The locations of possible deneholes have been mapped in this assessment using the BGS Dartford sheet (none were identified within the study area); and the Peter Brett Associates man-made cavity dataset (10 identified within the study area) (Landmark, 2010). The accuracy of this dataset is stated to be 100m, and consequently the mapped features have been plotted with a 100m diameter buffer to indicate their range of possible locations (Figure 11 – note this shows the seven possible deneholes features closest to the Project alignment, the other three are quite distant and hence not shown on Figure 11).

6.1.28 The ground conditions and engineering challenges created by deneholes resemble those common to karstic features described above.

6.2 Evaluation of impacts – tunnel section

6.2.1 The tunnels are driven below a number of assets and an area of environmental designation that could be affected by the tunnelling works. These include the North Kent Railway, the Thames and Medway Canal, the A226 and Lower Higham Road, the Metropolitan Police firing range and the Thames Estuary and Marshes Ramsar site, all to the south of the River Thames.

Potential sources of ground movement

Tunnel construction

6.2.2 During the TBM tunnelling excavation there would be some induced ground settlements at the surface due to the volume loss inevitably caused at tunnel level. An initial (Stage 1) assessment of these movements has been undertaken in line with the three-stage approach presented by Mair et al. (1996) for the whole of the tunnel alignment considering the geological, geotechnical, geometrical and mechanical parameters of the bored tunnels.

6.2.3 The Project has also undertaken a more detailed (Stage 2) assessment of the possible ground settlement under the North Kent Railway, due to the high sensitivity of the asset and the possible significance of the impact on rail traffic (Cascade, 2020a).

6.2.4 A Stage 2 assessment was not undertaken for other assets because there is significantly less concern about the impact the predicted movements may have over their performance, given the asset type and criticality, and the anticipated movement profile vertically and laterally. Nonetheless, it is expected that the main works Contractors would undertake a full assessment of these assets during detailed design as part of the continued process for managing geotechnical risks in line with REAC GS003.

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6.2.5 The Stage 2 assessment undertaken for the North Kent Railway included induced ground movements analyses which have been conducted using the industry standard specialist XDisp software. Absolute and differential movements between adjacent rails have been considered, as well as the ‘cant’ and ‘twist’ of adjacent rails. The sequential tunnel ring build process has also been assessed.

6.2.6 Drawings with settlement contours have been produced to present the results of the different scenarios, and these movements have been compared with the maximum limits allowed by the asset owner, Network Rail, to locate the areas where potential mitigation measures may be required.

6.2.7 It is to be noted that a certain degree of conservativeness is included in the above assessments for the preliminary design. It is normal practice and anticipated that the main works Contractors would undertake more detailed sophisticated numerical analyses to estimate the settlements that may occur during the tunnelling works, based on their selected equipment and methodology and a detailed review of all information collected [REAC GS003].

6.2.8 In addition, extensive consideration has been given to options for mitigating tunnelling-induced ground movements and their effect on this asset (Cascade, 2020b).

6.2.9 For this asset and other assets along the alignment of the tunnels which may experience ground movements, the actual methodology employed to reduce and control these ground movements would be selected by the main works Contractors. It is anticipated that a combination of measures would address this issue and allay stakeholders' concerns, such as the following:

a. Use of well-established TBM technology that can control volume loss and limit ground disturbance to as low as reasonably practicable

b. Development of suitably robust protocols and procedures to manage tunnel construction to required criteria

c. Design and installation of a state-of-the-art ground, groundwater and asset instrumentation and monitoring system to inform the main works Contractor team of changes during tunnelling, including the collection of baseline monitoring data, as described in Section 7 and as per REAC GS003

d. Undertake permeation grouting in the vicinity of the asset(s), to ‘strengthen’ the ground ahead of tunnelling works

e. Undertake compensation grouting during tunnelling works to counter settlement induced by the passage of the TBM

f. Discuss and agree with asset owner, and put in place asset usage restrictions, monitoring and remedial works measures, during the passage of the TBM

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Retaining walls and cuttings

6.2.10 Construction of retaining walls and cuttings in the approach ramps is another source of potential ground movements.

6.2.11 Retaining walls and cuttings are conventional works which have been designed following standard industry procedure to ensure their stability during construction and long-term operation. This also ensures that the impact of these works on nearby land and assets in terms of ground movements is minimal.

6.2.12 This would be re-evaluated by the main works Contractors during detailed design, as the magnitude and timing of movements is dependent on the actual proposals adopted, including construction methodology proposed, type of equipment employed and construction sequencing assumed.

6.2.13 In addition, instrumentation is typically used to monitor the performance of such major structures during and following their construction and alert the Project of developing ground movements.

Tilbury Fields landscaping

6.2.14 As introduced in Section 5.1, the arisings which would form the Tilbury Fields landscaping mounds are anticipated to predominantly comprise bored tunnel material ("chalk cake" material resulting from the bored tunnel construction slurry treatment process). Industry experience from the use of “chalk cake” indicates that this material would be appropriate to ensure long term stability of the landscaping mounds.

6.2.15 The ground conditions underlying the majority of the footprint of the proposed mounds are considered geotechnically poor due to the presence of peat layers and sand lenses within the underlying Alluvium, as well as the heterogeneity of Made Ground overlying the Alluvium.

6.2.16 The placement of large quantities of material to form the landscaping mounds will result in settlement occurring over the extent of their footprint. Whilst the magnitude of this settlement cannot be reliably estimated with precision, there is substantial industry experience of construction of fills over soft ground. Best practice earthworks construction approaches, such as those set out in Manual of Contract Document for Highway Works Volume 1 Series 600 of the Specification for Highway Works (Highways England, 2016), would be adopted to ensure that the development of settlement is managed and allowed for, and that no failure develops in the man-made or natural materials underlying the landscaping mounds.

6.2.17 Through the detailed design, an earthworks construction sequence would be designed, which would likely include elements such as progressively depositing materials in layers of a maximum defined thickness uniformly over the footprint of the mounds, applying hold periods before deposition of subsequent layers and adjusting earthworks thicknesses to allow for settlement. Installing and monitoring earthwork control instrumentation and in situ testing would also be carried out in line with Section 7: Instrumentation and monitoring. In addition the detailed design would determine the best approach to manage surface water run-off and control pore pressure within the underlying ground.

6.2.18 As above, the main works Contractors would manage geotechnical risks associated with the construction of the Tilbury Fields landscaping mounds in line with REAC GS003.

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6.3 Evaluation of impacts – highways

6.3.1 Potential ground movements and ground instability due to the underlying ground conditions and proposed highway permanent works include the following:

a. Ground movements due to piling and retaining wall construction

b. Heave and settlement due to earthworks (cuttings and embankments)

Structures, piling and retaining wall construction

6.3.2 The construction of retaining walls and subsequent excavation of surrounding soils could lead to horizontal and vertical ground movements, caused by possible deflection of the retaining walls.

6.3.3 A robust preliminary design has been undertaken for such retaining walls where proposed, following industry guidance and standards such as CIRIA 760 (CIRIA, 2017) and BS 8002:2015 (British Standards Institution, 2015). This ensures that the risk of ground movements resulting from the construction of retaining walls is mitigated and that the impact of retaining wall construction on nearby land and assets is minimised.

6.3.4 The Project ground investigation has targeted the locations of proposed piling and retaining walls. This information would assist the main works Contractors with their detailed design and inform their analyses and predictions of associated ground movements and deflections.

6.3.5 The main works Contractors would adopt good construction techniques, including, where deemed needed as added precautions, measures such as supporting retaining walls with ground anchors or tiebacks. This would reduce the likelihood of significant wall deflections and ground movements occurring and minimise the impact on surrounding land and assets. Such measures would not give rise to any additional significant adverse environmental effects.

Ground movements due to earthworks

Earthworks slopes

6.3.6 Preliminary assessments have been carried out in line with industry practice to determine safe side slopes for the cuttings and embankments proposed to be formed. These safe side slopes form part of the preliminary design proposals. Together with the implementation of an appropriate drainage design such as that developed for the Project, this ensures that slope instability is designed out and hence movements that may affect surrounding land due to earthworks slope instability are very unlikely to occur.

Earthworks settlement and heave

6.3.7 There is a risk of ground movements (heave at the base of the cutting and settlement at the crest) at deep cuttings proposed over consolidated clays north of the River Thames, mainly in the vicinity of the A13/A1089/A122 Lower Thames Crossing junction. There is also a risk of ground movement (settlement) where embankments are built on compressible ground.

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6.3.8 The potential impact of these ground movements on nearby land, infrastructure, utilities and structures has been assessed in line with the three-stage approach presented by Mair et al. (1996). This approach is generally accepted industry-wide and has been adopted on other major infrastructure projects.

6.3.9 Stage 1 and Stage 2 of this approach are considered adequate for the preliminary design of the Project, while Stage 3 is reserved for detailed design. The scope of the Stage 1 and Stage 2 assessments is detailed in the Project's Third Parties Assets Damage Assessment Strategy (Cascade, 2019b) and Stage 1 Damage Assessment Report – Permanent Works (Cascade, 2019a) documents.

6.3.10 Stage 1 includes the prediction of ground movements to identify assets within the ‘zone of influence’ of construction (i.e. lateral limits of the 1mm ground movement surface contour). The assessment assumes ‘greenfield’ site conditions and ignores any positive contribution or mitigation from existing structures. Ground settlement contours produced are used to identify assets to be carried forward to Stage 2.

6.3.11 The Stage 1 preliminary assessment undertaken for the earthworks within the A122 Lower Thames Crossing/M25 junction, the A13/A1089/Lower Thames Crossing junction sections and the M2/A2/Lower Thames Crossing junction sections of the Project, where earthworks heights and depths are the greatest, predicts a zone of influence extending some distance from the edge of the earthworks.

6.3.12 Stage 2 includes an assessment of the impact or response of selected existing assets to the ground movements predicted in Stage 1.

6.3.13 Based on the findings of the Stage 1 assessment, more detailed Stage 2 assessments have been undertaken for the assets listed in Table 6.1 below.

Table 6.1 Stage 2 assessments – highways

Asset	Reason for Stage 2 assessment	Outcome
Ockendon Road Bridge over M25 (Ockendon South) (adjacent to LTC Mainline 21 +100)	Proposed M25 widening works in the vicinity of the overbridge to accommodate a Lower Thames Crossing southbound slip	Anticipated maximum vertical displacement – 8mm Anticipated maximum differential movement – 4mm
Upminster to Grays Railway (OB) (adjacent to LTC Mainline Ch 20+100 to Ch 20+300)	Proposed embankment (up to 10m in height) around the railway	Anticipated maximum vertical displacement – 20mm Maximum cant – 5mm Maximum twist – <1mm
Upminster to Grays Railway (adjacent to LTC Mainline Ch 20 +400 to Ch 21 +400)	Proposed cutting (up to 10m in depth) around the railway	Anticipated maximum vertical displacement – 22mm Maximum cant – 5mm Maximum twist – 4mm
Ockendon Rail Bridge (adjacent to LTC Mainline 20 +600)	Jacked box tunnelling adjacent to the existing Ockendon Rail Bridge	Anticipated maximum vertical displacement – 8mm

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Asset	Reason for Stage 2 assessment	Outcome
Nurture Landscape Ltd buildings (adjacent to LTC Mainline 20 +700)	Cuttings up to 10.0m	Structures out of zone of influence
Ockendon Road Rail Bridge (adjacent to LTC Mainline 21 +100)	Cuttings up to 10.0m and excavation in front of a proposed retaining wall	Anticipated maximum vertical displacement – 2mm
Cast iron main water 27’’ (adjacent to M25 4 +000)	Proposed LTC Works	Anticipated maximum vertical displacement – 30mm Maximum stress acting on pipe – 3.50kPa Maximum strain – 0.60 * 10-3
Shoeburyness Railway Line (Frank’s Farm Rail) (adjacent to M25 4 +550)	Proposed cutting (up to 11.7m in depth) around the railway	Anticipated maximum vertical displacement – 37mm Maximum cant – 6mm Maximum twist – 1mm
HS1 Railway near Park Pale Overbridge	Proposed cuttings (up to 5m in depth) around the railway	Anticipated maximum vertical displacement – 1mm Maximum cant – 0.20mm Maximum twist – 0.13mm
HS1 Railway opposite Park Pale Overbridge	Proposed embankment widening (up to 4m in height) around the railway.	Anticipated maximum vertical displacement – <2mm Maximum cant – <1mm Maximum twist – <1mm
HS1 Crib Wall	Proposed cutting widening (up to 3.3m in depth) around the crib wall.	Anticipated maximum vertical displacement – 2mm
HS1 Assets near Thong Lane	Proposed embankment widening (up to 5m in height) around the railway	Anticipated maximum vertical displacement – <2mm Maximum cant – <1mm Maximum twist – <1mm
HS1 Assets near Henhurst Road	Proposed embankment widening (up to 6m in height) around the railway	Anticipated maximum vertical displacement – <1mm Maximum cant – <1mm Maximum twist – <1mm
HS1 Brewers Road overbridge	Replacement of the existing Cobham Flyover	Less than 10% difference between resultant and existing forces in structural elements of existing HS1 structure Anticipated maximum calculated settlement – 7mm (total) and 4mm (differential)

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Asset	Reason for Stage 2 assessment	Outcome
HS1 Halfpence Lane Cut and Cover Tunnel	Realignment of roads connecting to the Halfpence Lane roundabout	Calculated forces and bending moments in structural elements of base slab within existing limits Anticipated maximum calculated settlement – 17mm (total) and 4mm (differential)
Kempsters Bridge	Construction of a proposed overbridge near the asset	Anticipated maximum differential settlement of 4mm predicted between bridge abutment and piers
Five Chimney Cottages	Proposed A13 earthworks	Anticipated maximum calculated settlement less than 1mm (corresponding to negligible to very slight impact according to published approach by Burland (1995))

6.3.14 In parallel with the above, more specific assessments have been carried out in the Mardyke and Tilbury areas, which have been identified as being likely underlain by a substantial thickness of compressible soils. Ground improvement measures have been considered, developed and incorporated into the preliminary design to reduce the risk of settlement and movement of the surrounding ground. These include piled embankments and ground improvement in the form of surcharging and band drains.

6.3.15 The findings from the Stage 2 assessments indicate that the anticipated impact of the construction of the Project earthworks on nearby assets is generally relatively minimal. However, further detailed assessments that consider the possible impact of predicted ground movements on nearby assets, and adequate measures to manage this possible impact would be developed by the main works Contractors as part of the development of their detailed design proposals for the Project and in line with the requirements of DMRB CD 622 [REAC GS003]. Such measures would likely comprise relatively minor works to and in the immediate vicinity of the asset, for example strengthening and support. These would not result in any significant adverse environmental effects.

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6.4 Evaluation of impacts – gas pipeline diversion NSIPs

6.4.1 The following subsections provide an evaluation of the impacts associated with the major excavations required for the NSIP gas diversion works (Work Nos. G2, G3 & G4) to the north of the M2/A2/Lower Thames Crossing junction sections of the Project.

Trench and pit excavations

6.4.2 It is anticipated that trench and pit excavations associated with Works No G2, G3 and G4 will be formed within Made Ground or reworked ground, Head Deposits, Thanet Formation and Chalk.

a. Made Ground (excluding reworked topsoil) may be located in localised areas such as Thong Lane and may be removed if unsuitable for trench side slopes.

b. Reworked ground may be encountered in areas where past ground investigation or archaeological investigation works have been undertaken (trial pits, trenches).

c. The Thanet Formation is anticipated to be encountered predominantly to the south of Thong Lane in the vicinity of Claylane Wood.

d. Head Deposits may be encountered across site.

e. The majority of trench and pit excavations will be within Chalk.

6.4.3 Significant amounts of groundwater are not anticipated to be encountered during excavation and groundwater control is unlikely to be required for trench and pit excavations. However, there is still potential for perched groundwater conditions in strata overlying Chalk, which may require localised small-scale drainage measures.

6.4.4 The Contractors would adopt good design and construction techniques for temporary and permanent works, including, where deemed needed as added precautions, measures such as battering where space allows or excavation support elsewhere, and siting construction equipment at a safe distance away from excavations. Such measures would not give rise to any additional significant adverse environmental effects.

Trenchless crossing of the A122 alignment

6.4.5 The pipeline diversion for Works No G3 and G4 crosses beneath the Project route, which is in a cutting at this location. The depth of the excavations for the launch and reception shaft and the trenchless excavation is anticipated to be between 17m and 20m approximately.

6.4.6 Shallow excavations are anticipated to encounter Head Deposits, Thanet Formation and structureless chalk. The ground conditions for the majority of the shaft excavations and the pipe jack are anticipated to comprise structured chalk.

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6.4.7 Shaft support may be required for the shallow depths of the shaft excavation due to cohesive material in the overlying strata. Localised sidewall support may be required for the deeper sections of excavation depending on the main works Contractor's preferred temporary works approach and the anticipated characteristics of the chalk.

6.4.8 Although encountering groundwater is considered unlikely, it should be noted that Chalk can have a relatively high permeability and groundwater ingress into excavations is possible. Furthermore, there is the potential for karst features to be encountered.

6.4.9 As mentioned in 6.1 above, there is a large amount of industry experience dealing with these geohazards, which it is anticipated will be informed by the undertaking by the main works Contractor of additional targeted investigations at detailed design phase ahead of construction works starting. There are standard construction practices to minimise the impact of groundwater ingress and karst hazards, and these would not result in any additional significant adverse environmental effects.

Thong Lane crossing

6.4.10 The proposed pipeline diversion associated with Works No G3 and G4 crosses beneath the existing Thong Lane using trenchless techniques. The depths of the pipeline would be approximately 3-6m bgl to the base of the excavation. The west launch pit would be approximately 6m bgl and the reception pit at approximately 4m bgl.

6.4.11 Anticipated geohazards are the same as those presented above in Section 6.4. Hence, it is similarly anticipated that additional targeted investigations will be undertaken by the main works Contractor at detailed design phase ahead of construction works starting, and that the main works Contractor will employ standard construction practices to minimise the impact of hazards present, which would not result in any additional significant adverse environmental effects.

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7 Further work

7.1 Instrumentation and monitoring

General ground movement monitoring

7.1.1 A programme of ground movement monitoring would be established where Project construction works have an interface with a third party asset. Due to the scale of the works associated with the Project, the main works Contractors would develop and implement a programme of asset monitoring in line with REAC GS003. Typically, the monitoring planning would be required to include the following phases:

a. Monitoring scope development

b. Instrumentation and monitoring design

c. Procurement and commissioning

d. Monitoring and analysis of results

e. Decommissioning

f. Continuation of structural health monitoring

7.1.2 The working hypothesis for potential behaviour of the area or asset to monitor, must be outlined prior to developing any monitoring programme.

Monitoring scope development

7.1.3 The scope of the monitoring would define the required the objectives. The scope of the monitoring may differ between construction workstreams, as outlined below:

a. Pre-construction monitoring: monitoring carried out on existing assets in advance of the commencement of the works that could lead to an impact. This would:

   i. Help to develop an understanding of the existing condition of the existing asset.

   ii. Reduce risks which may arise from poor knowledge of the current conditions and/or behaviour of the assets.

   iii. Reduce the potential risks to the construction works programme which could result from additional requirements for monitoring. For example, potential long lead times for instrument and monitoring design development, design approval from third parties, difficult installations, access issues, uncertainties around the applicability and/or the performance of the instrument and monitoring systems.

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b. Asset protection monitoring: monitoring carried out on third-party assets during the execution of the Project construction works. This would assess the behaviour of these assets under the extent and the scope of the works.

c. Design and construction verification monitoring: geotechnical and structural performance monitoring of the works in respect of the behaviour expected in the design.

d. Structural health monitoring: monitoring the performance of structures, especially the ones that may be vulnerable to processes that may have an influence in their material and geometric properties.

Instrumentation and monitoring design

7.1.4 The instrument and monitoring design would include the following:

a. Parameters of interest to be monitored, and associated expected range of values

b. Instrumentation type

c. Instruments' location

d. Data acquisition frequencies

e. Applicable trigger levels and associated action plans

f. Monitoring specifications

g. Monitoring data dissemination system requirements and specifications (including specifications for monitoring database and associated periodic backup)

h. Reporting requirements and specifications

i. Redundancy levels (instruments and data)

Procurement and commissioning

7.1.5 The procurement and commissioning of the monitoring system would include instruments, datalogging and data dissemination system. This phase would include the mobilisation of the monitoring programme and installation of the instrumentation to the required location and/or assets.

Monitoring stages

7.1.6 This would include the following:

a. Pre-construction monitoring, including review and evaluation of data, definition of baseline values and reporting

b. Monitoring during the works

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c. Post-construction monitoring

d. Handover and novation procedures between the different monitoring stages, including the associated data

Decommissioning

7.1.7 Where applicable the monitoring system would be decommissioned.

Continuation of structural health monitoring

7.1.8 Where applicable, some structural health monitoring of a third-party asset would be continued beyond the completion of the works.

Project ground movement monitoring proposals

7.1.9 An outline baseline monitoring strategy has been developed as part of the preliminary design and to inform the requirements for enabling works associated with the Project. The final list of assets and plans would be determined as part of the detailed design by the main works Contractors as secured via REAC GS003.

7.1.10 The installation of the baseline monitoring instrumentation would be required prior to construction commencing, with the collection of baseline monitoring information continuing for a number of months following completion of installation.

7.2 Ground investigation

7.2.1 To proactively manage the potential impacts from geohazards during the detailed design and construction activities, the main works Contractors would carry out further targeted ground investigation. The findings of the targeted ground investigation would be used to support the development of the detailed design and finalise construction methods. A geotechnical risk register would continue to be maintained and updated throughout the development of the Project, in line with the requirements set out in DMRB CD 622 [REAC GS003].

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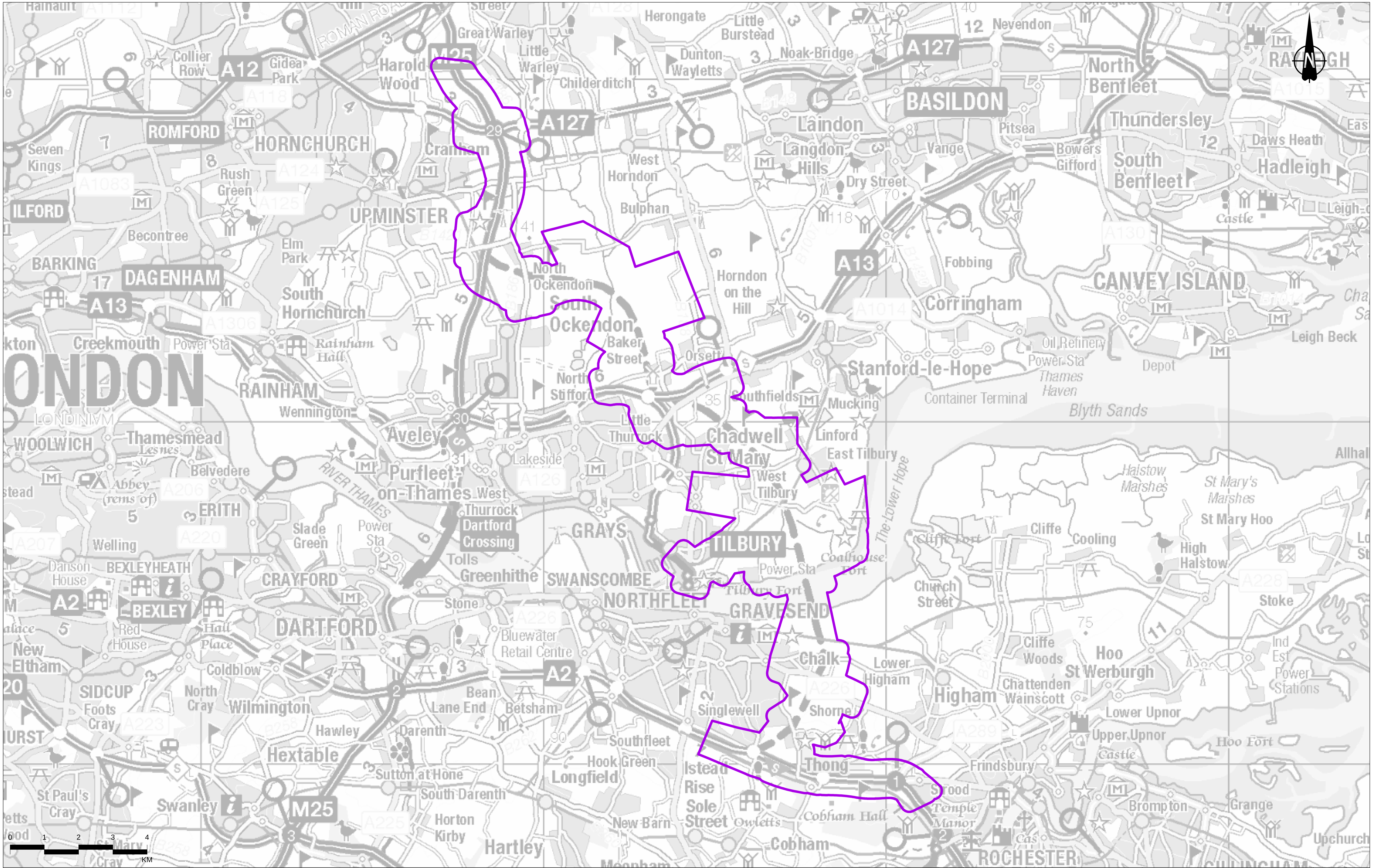

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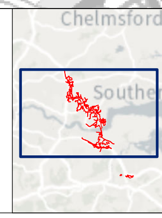
Legend

Geohazards assessment study area

Rev	Status	Rev. Date	Purpose of revision	Drawn	Chck'd	Apprv'd
P01	S8	03/10/2022	DCO Application	SW	MW	BF



Client: national highways

Project: LOWER THAMES CROSSING

Status: DCO APPLICATION

Original Size: A3

Revision: P01

Application Document Number: TR010032/APP/6.3

Scale: 1:100,000

Drawing Title: Figure 1 - Geohazards Assessment Study Area

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

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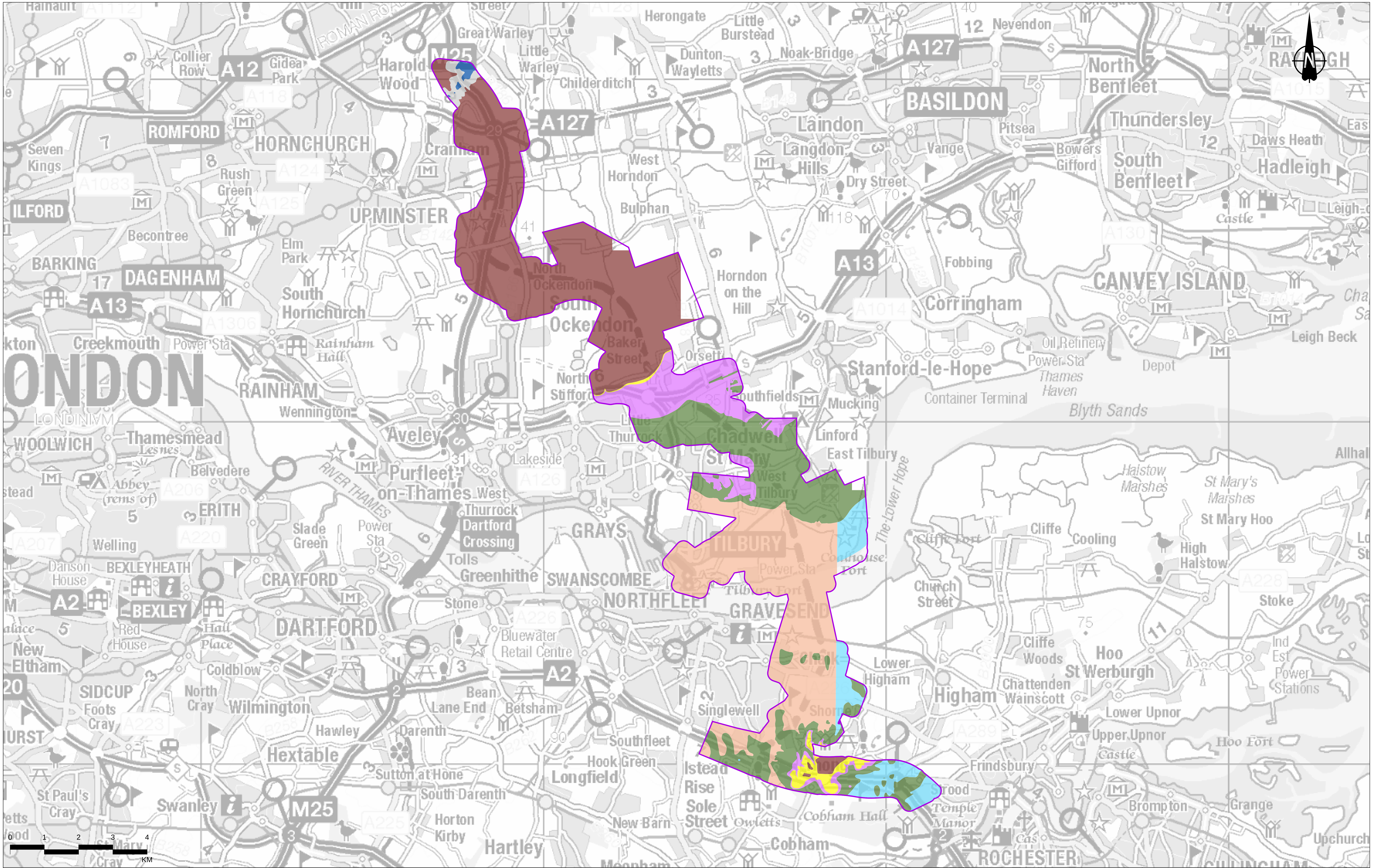

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Legend

- Geohazards assessment study area
- Bagshot Formation
- Claygate Member
- Harwich Formation
- Lambeth Group
- Lewes Nodular Chalk Formation, Seaford Chalk Formation and Newhaven Chalk Formation (Undifferentiated)
- London Clay Formation
- Seaford Chalk Formation and Newhaven Chalk Formation (Undifferentiated)
- Thanet Formation

Rev	Status	Rev. Date	Purpose of revision	Drawn	Chck'd	Appr'd
P01	S8	03/10/2022	DCO Application	SW	MW	BF

Client: national highways

Project: LOWER THAMES CROSSING

Status: DCO APPLICATION

Original Size: A3 | Revision: P01

Application Document Number: TR010032/APP/6.3

Scale: 1:100,000

Drawing Title: Figure 2 - Bedrock Geology

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

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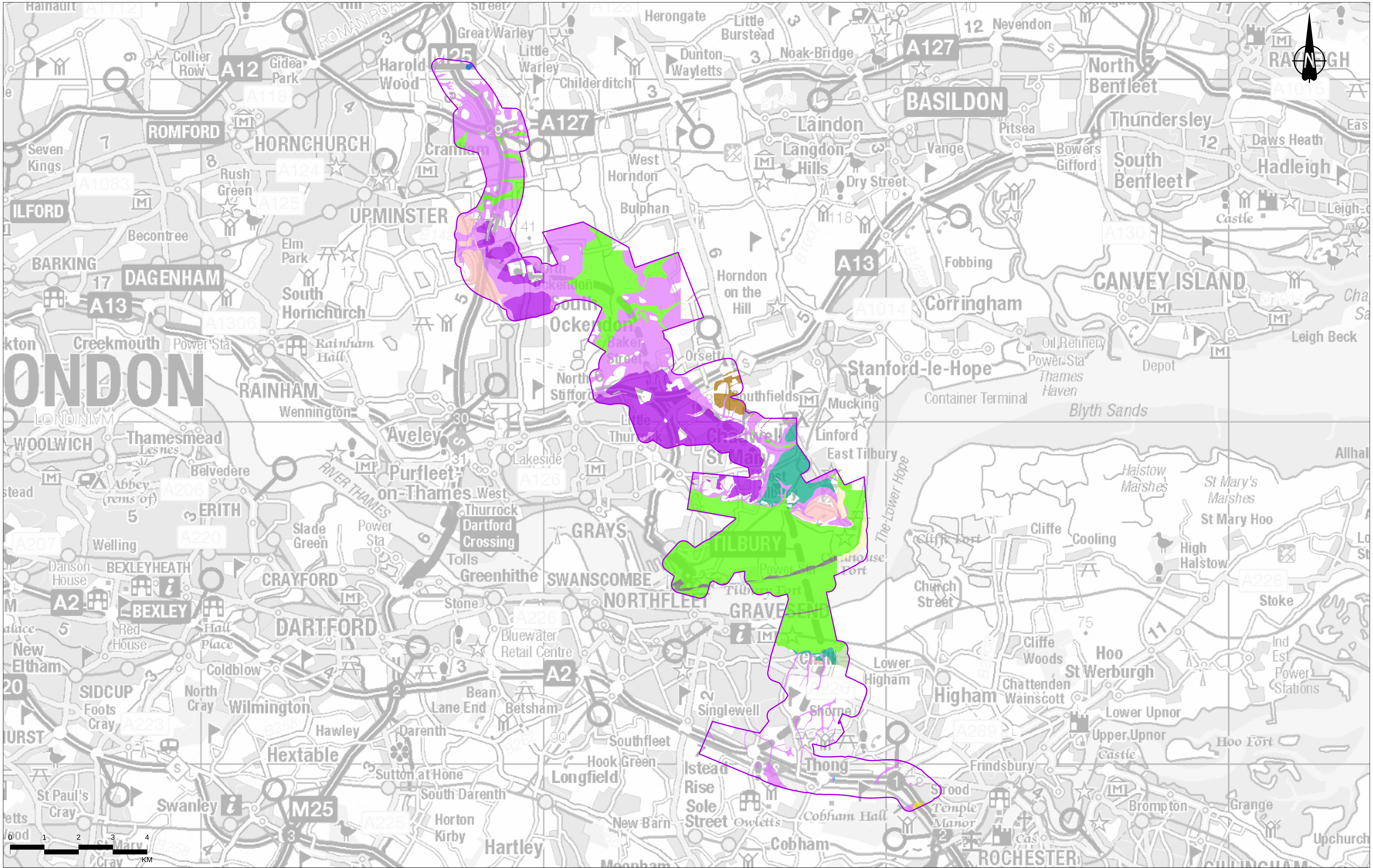

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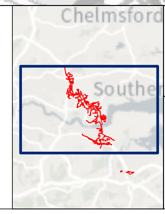
Legend

- Geohazards assessment study area
- Alluvium
- Beach and Tidal Flat Deposits (Undifferentiated)
- Black Park Gravel Member
- Boyn Hill Gravel Member
- Clay-with-flints Formation
- Glaciofluvial Deposits, Mid Pleistocene
- Head
- Lynch Hill Gravel Member
- Peat
- River Terrace Deposits (Undifferentiated)
- River Terrace Deposits, 1
- River Terrace Deposits, 2
- Stanmore Gravel Formation
- Taplow Gravel Formation
- Tidal River Or Creek Deposits

Rev	Status	Rev. Date	Purpose of revision	Drawn	Chck'd	Apprv'd
P01	S8	03/10/2022	DCO Application	SW	MW	BF



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Project: LOWER THAMES CROSSING

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Application Document Number: TR010032/APP/6.3

Original Size: A3

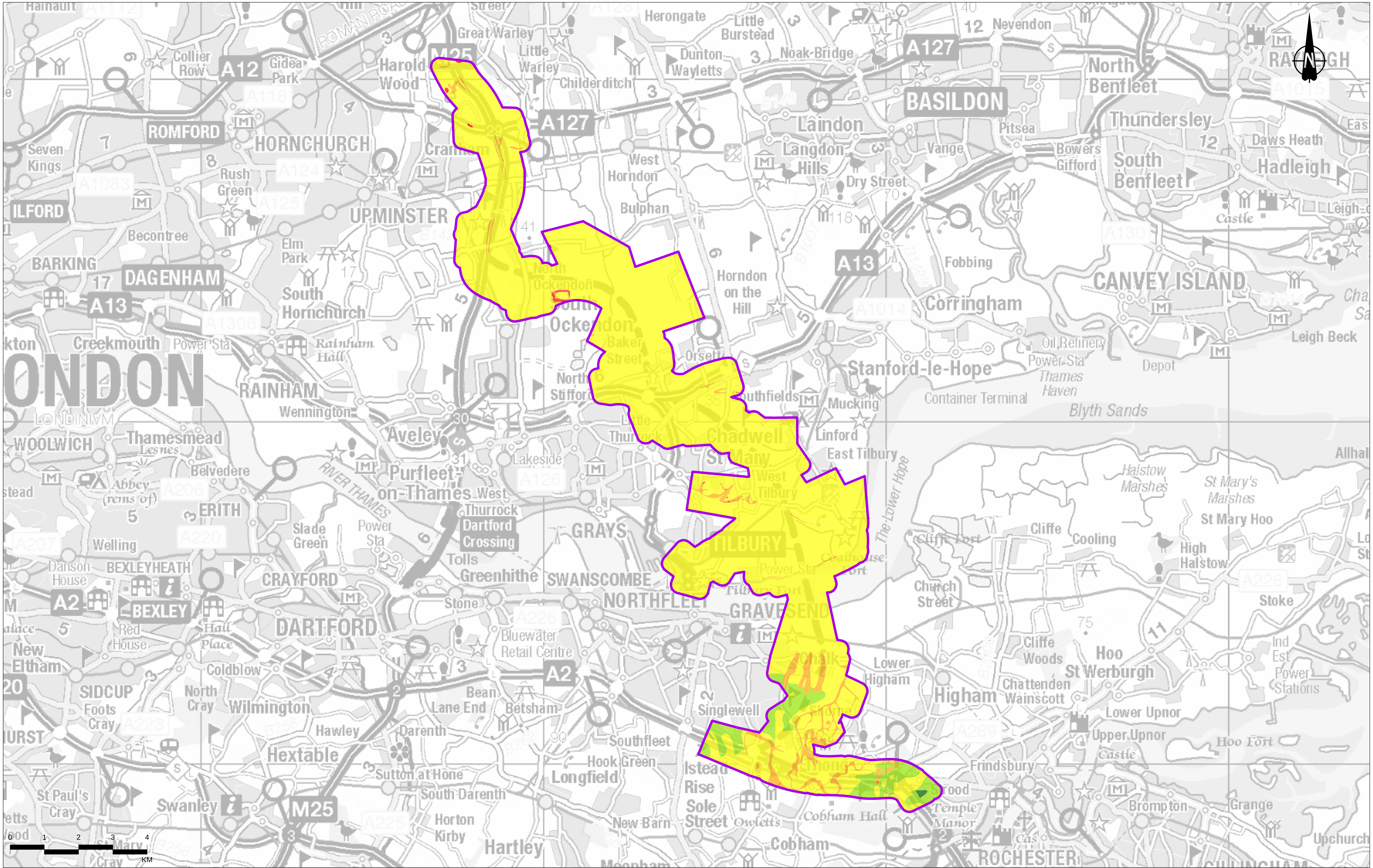
Revision: P01

Scale: 1:100,000

Drawing Title: Figure 3 - Superficial Geology

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

Z:\Environment\Environmental Statement\10. Geology and Soils\Appendix 10.2new\Figure 3 - Superficial Geology.aprx



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P01	S8	03/10/2022	DCO Application	SW	MW	BF

Legend

- Geohazards assessment study area
- Ground conditions conducive to slope instability are believed not to be present
- Ground conditions conducive to slope instability are unlikely to be present
- Ground conditions conducive to slope instability are possibly present
- Ground conditions conducive to slope instability are present
- Slope instability issues are known to be present

Client: national highways

Project: LOWER THAMES CROSSING

Status: DCO APPLICATION

Original Size: A3

Revision: P01

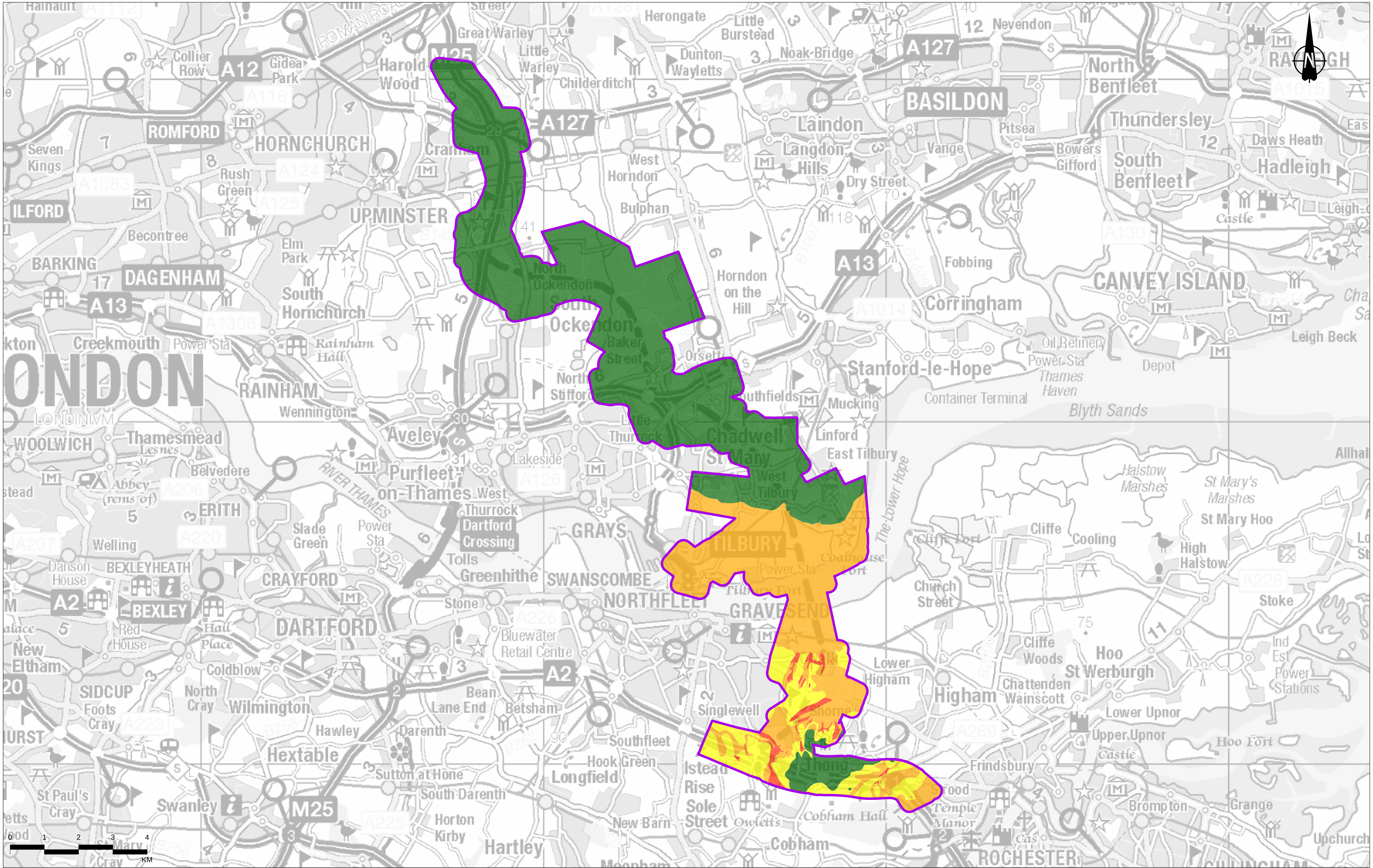
Application Document Number: TR010032/APP/6.3

Scale: 1:100,000

Drawing Title: Figure 4 - Distribution of Landslide Hazard

Drawing Number: HE540039-CJV-EGT-SZP_EGNE00000000-DR-LE-50157

Z:\Environment\Environmental Statement\10. Geology and Soils\Appendix 10.2new\Figure 4 - Distribution of Landslide Hazard.aprx



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Legend

- Geohazards assessment study area
- Soluble rocks are believed not to be present. Karst hazards are believed not to be present
- Soluble rocks are believed not to be present. Karst hazards such as cover collapse of sinkholes are unlikely
- Soluble rocks are possibly present in places. Karst hazards such as cover collapse of sinkholes are possible
- Soluble rocks are present. Karst hazards such as cover collapse of sinkholes are likely
- Karst hazards such as cover collapse of sinkholes are known to be present

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Project: LOWER THAMES CROSSING

Status: DCO APPLICATION

Original Size: A3

Revision: P01

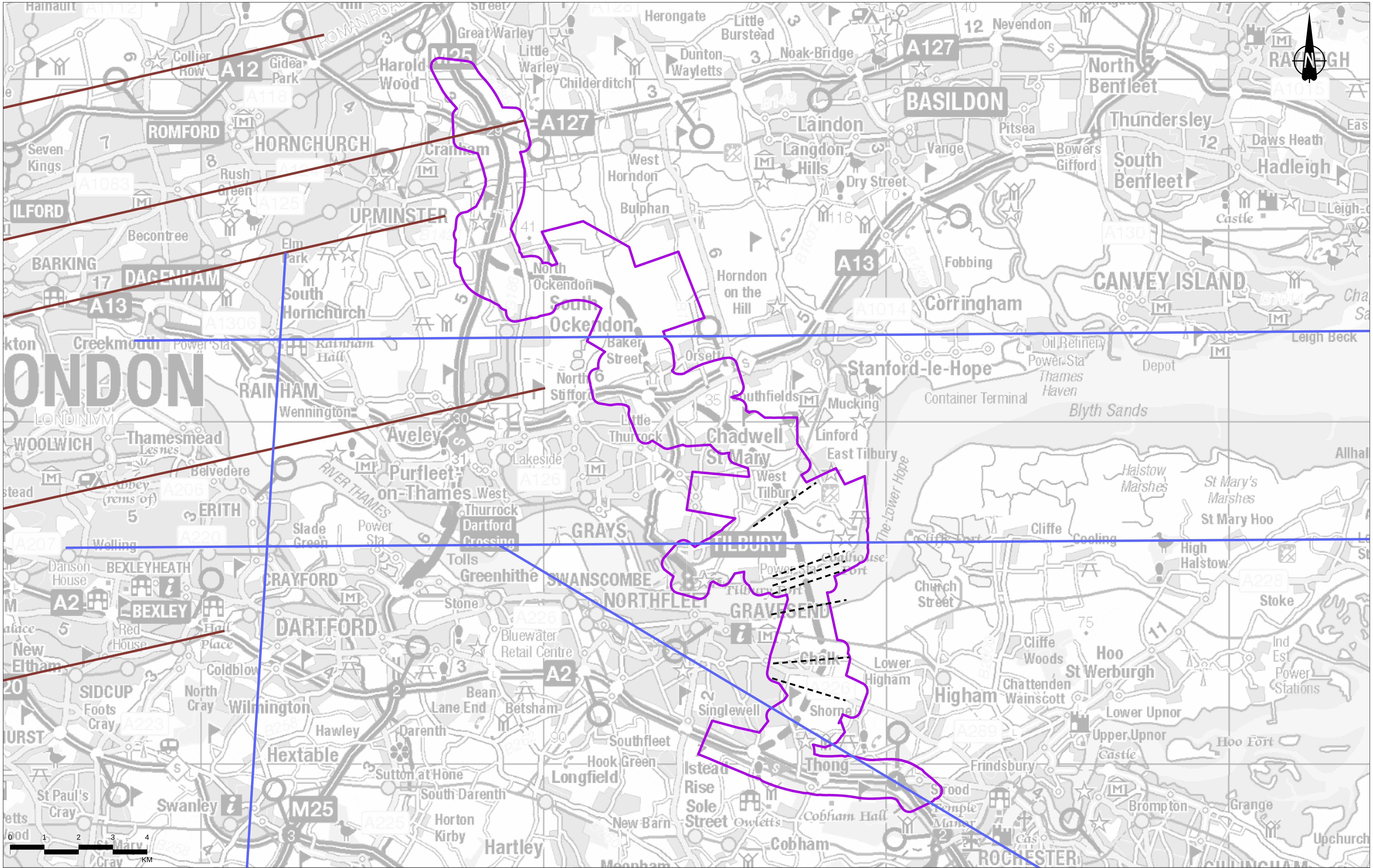
Application Document Number: TR010032/APP/6.3

Scale: 1:100,000

Drawing Title: Figure 5 - Distribution of Karst Hazard

Drawing Number: HE540039-CJV-EGT-SZP_EGNE00000000-DR-LE-50158

Z:\Environment\Environmental Statement\10. Geology and Soils\Appendix 10.2new\Figure 5 - Distribution of Karst Hazard.aprx



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Legend

- Geohazards assessment study area
- Indicative location of fault hazard (lateral extent unknown)
- Known near-vertical structure
- Normal fault

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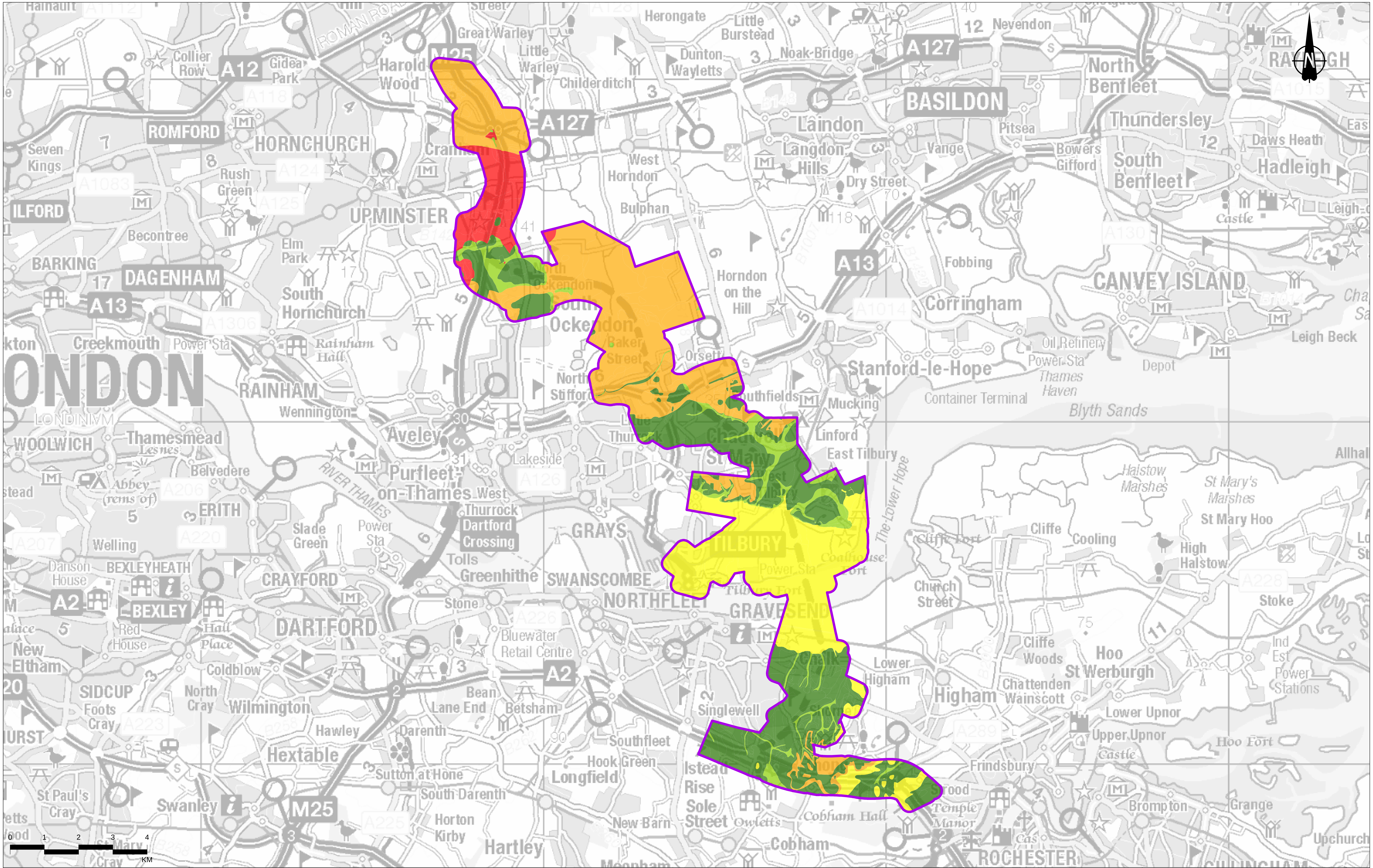
Application Document Number: TR010032/APP/6.3

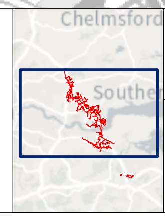
Original Size: A3 | Revision: P01 | Scale: 1:100,000

Drawing Title: Figure 6 - Location of faults and structures mapped by BGS and inferred from Lower Thames Crossing GI data

Drawing Number: HE540039-CJV-EGT-SZP_EGNE00000000-DR-LE-50159

Z:\Environment\Environmental Statement\10. Geology and Soils\Appendix 10.2new\Figure 6 - Location Faults And Structures.aprx





Legend

- Geohazards assessment study area
- Deposits with potential to shrink/swell are believed not to be present
- Deposits with potential to shrink/swell are believed unlikely be present
- Deposits with potential to shrink/swell are possibly present in places
- Deposits with potential to shrink/swell are present
- Deposits with potential to shrink/swell are widespread

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Revision: P01

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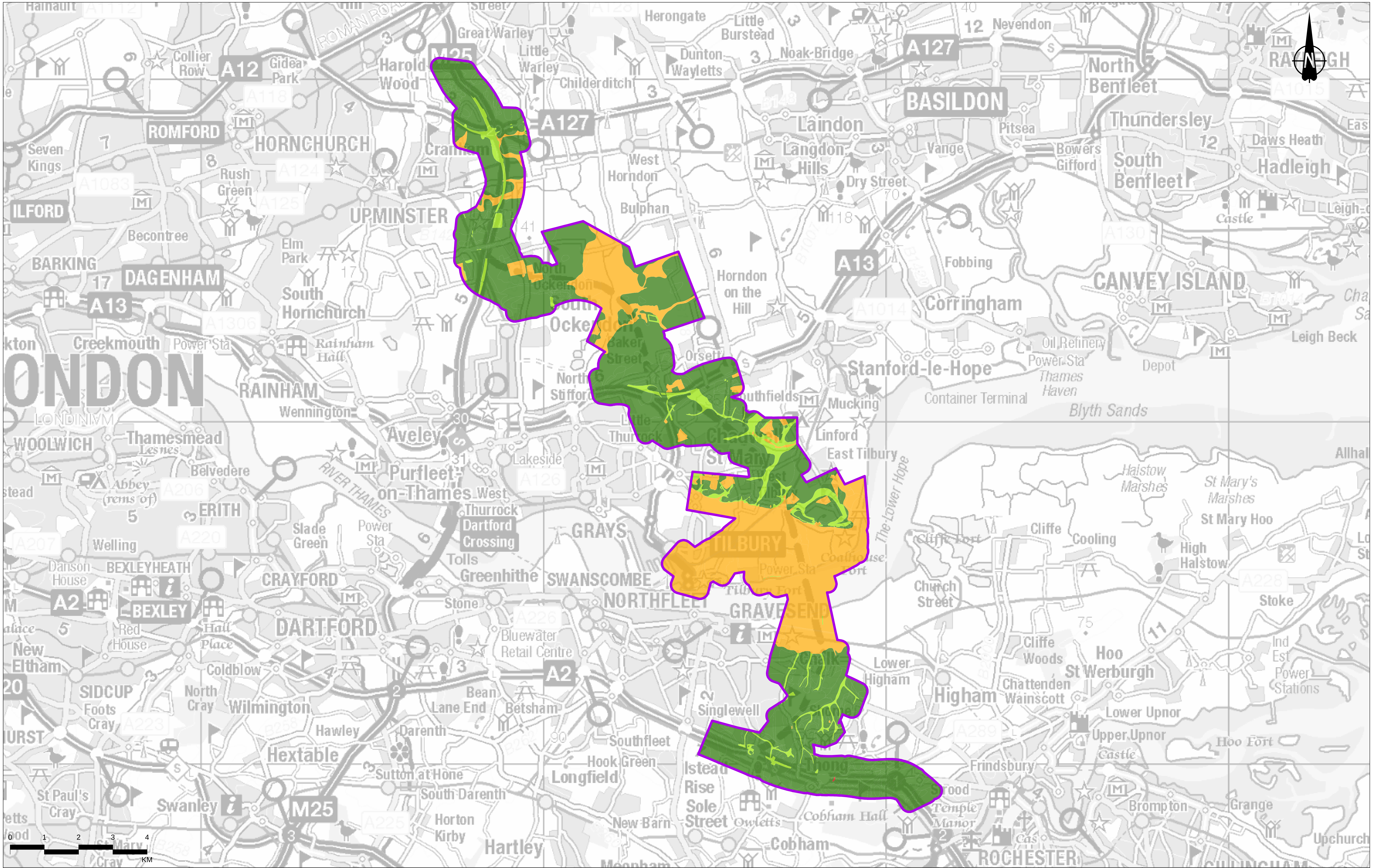
Scale: 1:100,000

Drawing Title: Figure 7 - Distribution of Shrink/Swell Deposits Hazard

Drawing Number: HE540039-CJV-EGT-SZP_EGNE00000000-DR-LE-50160

Z:\Environment\Environmental Statement\10. Geology and Soils\Appendix 10.2new\Figure 7 - Shrink Swell Hazards.aprx



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Legend

- Geohazards assessment study area
- Deposits with potential to compress and settle unevenly are believed not to be present
- Deposits with potential to compress and settle unevenly are unlikely to be present
- Deposits with potential to compress and settle unevenly are present
- Deposits with potential to compress and settle unevenly are widespread

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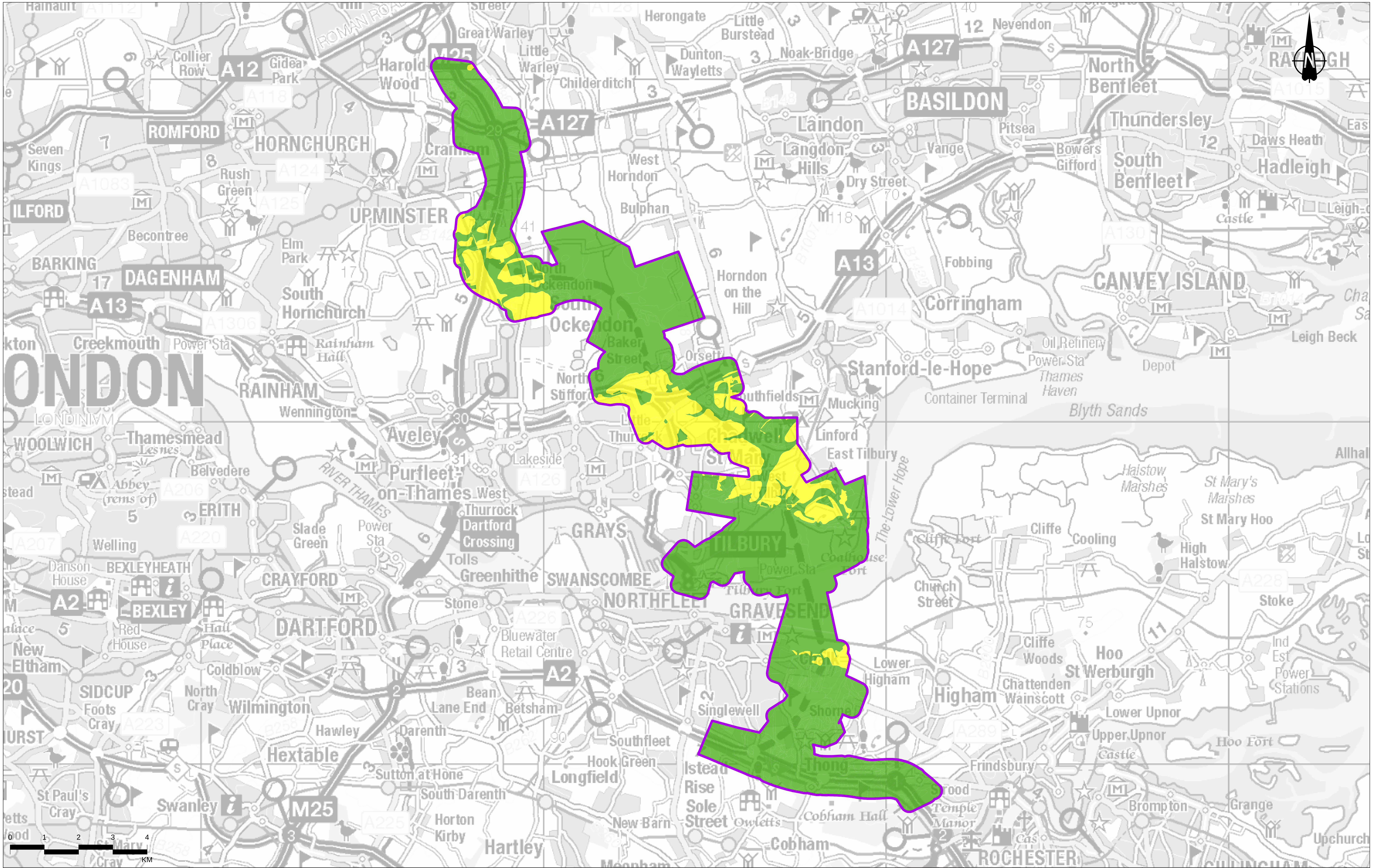
Application Document Number: TR010032/APP/6.3

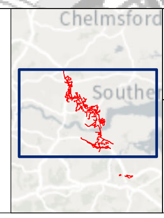
Original Size: A3 | Revision: P01 | Scale: 1:100,000

Drawing Title: Figure 8 - Distribution of Compressible Deposits Hazards

Drawing Number: HE540039-CJV-EGT-SZP_EGNE00000000-DR-LE-50161

Z:\Environment\Environmental Statement\10. Geology and Soils\Appendix 10.2new\Figure 8 - CompressibleDepositsHazards.aprx





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Legend

- Geohazards assessment study area
- Collapsible deposits are possibly present
- Collapsible deposits are unlikely to be present

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Revision: P01

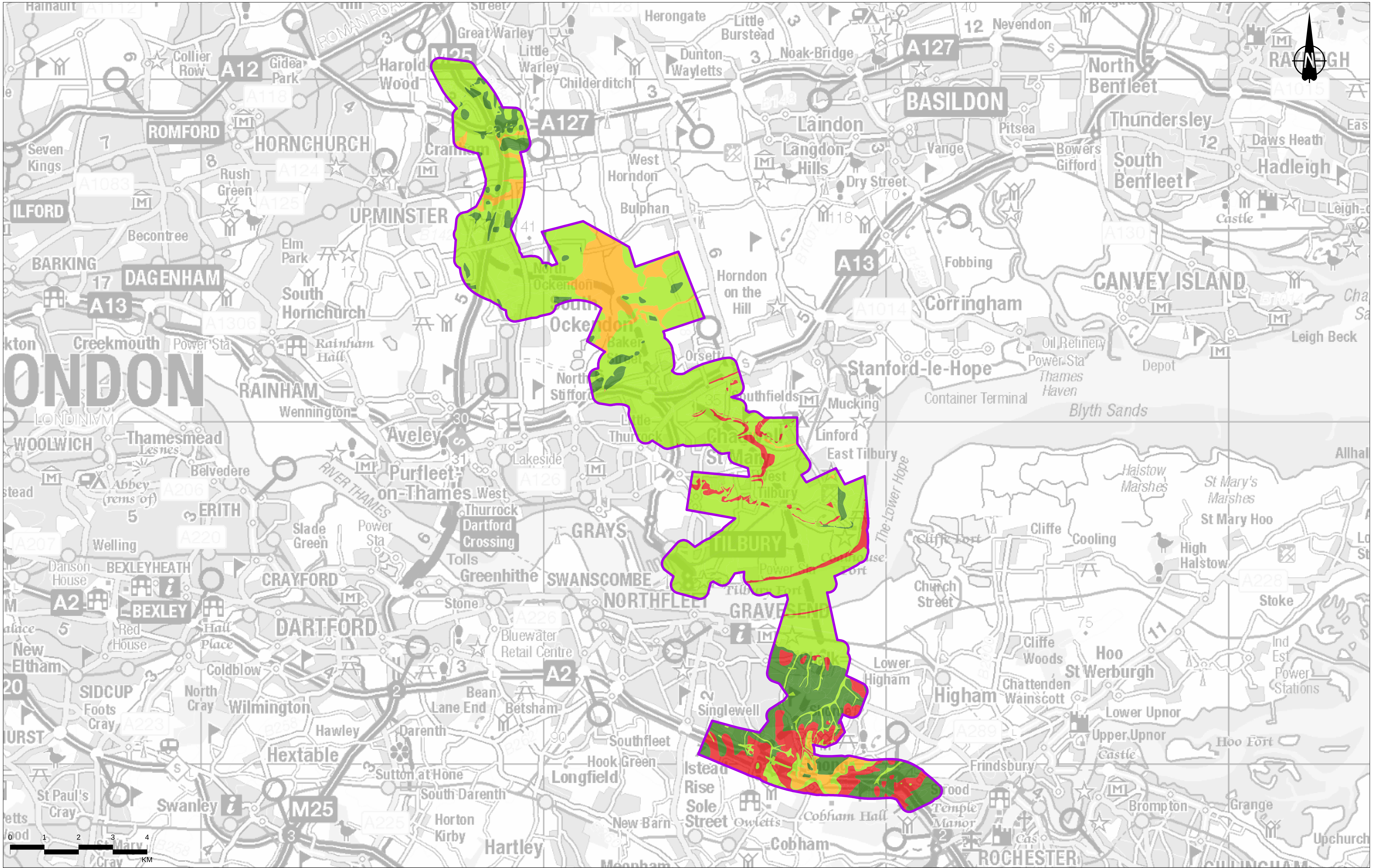
Application Document Number: TR010032/APP/6.3

Scale: 1:100,000

Drawing Title: Figure 9 - Distribution of Collapsible Deposits Hazard

Drawing Number: HE540039-CJV-EGT-SZP_EGNE00000000-DR-LE-50162

Z:\Environment\Environmental Statement\10. Geology and Soils\Appendix 10.2new\Figure 9 - CollapsibleDepositsHazards.aprx



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Legend

- Geohazards assessment study area
- Deposits conducive to running sand conditions are believed not to be present
- Deposits conducive to running sand conditions are unlikely to be present
- Deposits conducive to running sand conditions are present
- Deposits conducive to running sand conditions are widespread

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Status: DCO APPLICATION

Application Document Number: TR010032/APP/6.3

Original Size: A3

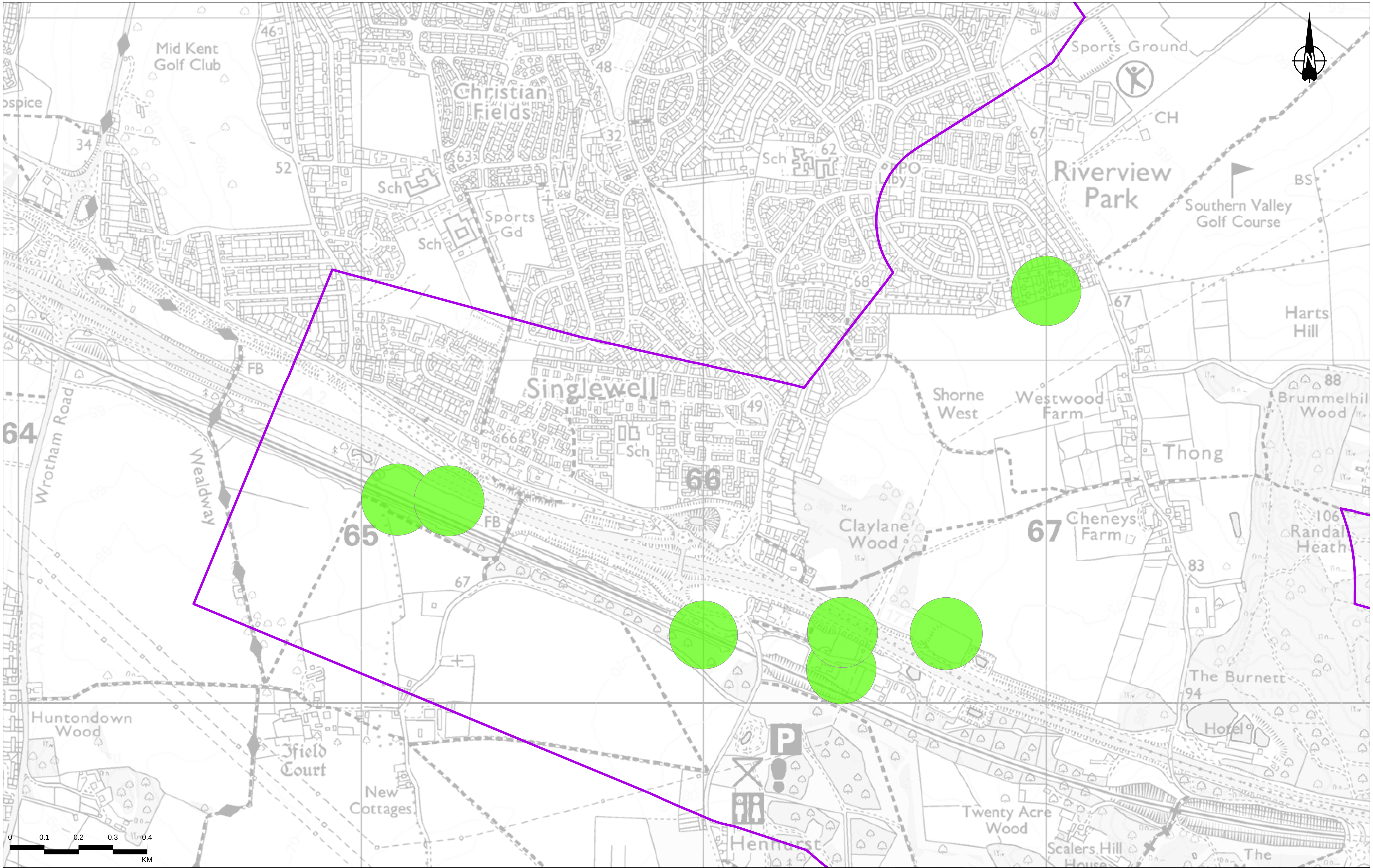
Revision: P01

Scale: 1:100,000

Drawing Title: Figure 10 - Distribution of Running Sand Hazard

Drawing Number: HE540039-CJV-EGT-SZP_EGNE00000000-DR-LE-50163

Z:\Environment\Environmental Statement\10. Geology and Soils\Appendix 10.2new\Figure 10 - RunningSandHazards.aprx



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Legend

- Geohazards assessment study area
- Possible deneholes (identified by Peter Brett Associates)

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Revision: P01

Application Document Number: TR010032/APP/6.3

Scale: 1:10,000

Drawing Title: Figure 11 - Distribution of Possible Deneholes

Drawing Number: HE540039-CJV-EGT-SZP_EGNE00000000-DR-LE-50164

Z:\Environment\Environmental Statement\10. Geology and Soils\Appendix 10.2new\Figure 11 - Distribution of Possible Deneholes.apr

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