TRANSPORT FOR LONDON

RIVER CROSSINGS: SILVERTOWN TUNNEL

SUPPORTING TECHNICAL DOCUMENTATION

GROUND INVESTIGATION DESK STUDY – PRELIMINARY SOURCES STUDY REPORT

Mott MacDonald

May 2013

This report sets out in detail the Ground Investigation desk study at both Silvertown (for a bored tunnel from the Greenwich Peninsula (south of the River Thames) to Silvertown (north of the River Thames)) and Gallions Reach (for both a fixed link (either a bridge or immersed tube tunnel) and a ferry crossing between Thamesmead (south of the River Thames) and Gallions Reach (north of the River Thames).

This report is part of a wider suite of documents which outline our approach to traffic, environmental, optioneering and engineering disciplines, amongst others. We would like to know if you have any comments on our approach to this work. To give us your views, please respond to our consultation at www.tfl.gov.uk/silvertown-tunnel

Please note that consultation on the Silvertown Tunnel is running from October – December 2014.



TfL River Crossings - Ground Investigation Desk Study

Preliminary Sources Study Report

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Executive Summary

This report presents the Geotechnical Desk Studies for the Transport for London (TfL) River Crossings programme. The first site at Silvertown is being considered for a bored tunnel from the Greenwich Peninsula (south of the River Thames) to Silvertown (north of the River Thames). The second site at Gallions Reach is being considered for both a fixed link (either a bridge or immersed tube tunnel) and a ferry crossing between Thamesmead (south of the River Thames) and Gallions Reach (north of the River Thames).

The report presents a review of the available existing geotechnical data for the two project study areas in terms of:

- existing and historic land use;
- geological setting;
- ground and groundwater conditions;
- unexploded ordnance (UXO) risk;
- engineering assessment; and
- option comparison based on ground-related risks.

Preliminary Geotechnical Risk Registers have been prepared for both project study areas.

This report has been prepared in accordance with the Highways Agency document, HD22/08, 'Managing Geotechnical Risk'.

Silvertown Study Area

The proposed twin 12.1m outer diameter bored tunnels will provide a dual 2-lane connection between the A102 on the Greenwich Peninsula and the Tidal Basin Roundabout on Silvertown Way. The main bores are to be constructed using a TBM and will have a lining of reinforced pre-cast concrete segments. The segments will be bolted longitudinally and radially and are to be fitted with gaskets to render the lining nominally watertight. There are to be 3 No. pedestrian cross passages at typically 350m spacings along the line of the bored tunnel to facilitate intervention in an emergency. These 4.55m outer diameter cross passages are most likely to be formed using the sprayed concrete lining (SCL) technique. The tunnel approaches will be formed of cut and cover tunnels and retained cut ramps.

The desk study has revealed that the site has been in use since 1868 and has a legacy of industrial use. The two sides of the river have a similar industrial history. The northern part of the site encompasses the Royal Victoria Docks, including the historic Western Entrance to the docks which was closed in 1957. The land use on the northern side of the river is mixed with residential and recreational use around the perimeter of the Royal Victoria Docks and light commercial use to the south of the elevated Silvertown Way and the Docklands Light Rail (DLR). Waste management and cement/aggregate/concrete batching facilities dominate to the north and west of the proposed northern tunnel portal. The southern part of the site was dominated by a gasworks until 1987. Thereafter redevelopment of the site included extensive remediation to make it suitable for residential, commercial and industrial uses. The Emirates London Cable Car crosses the River Thames in close proximity to the proposed tunnel. The key aspects of the site development and the existing and historic structures which could potentially affect the proposed works are summarised in Sub-section 2.3.6.

No 'Sensitive Land Uses', for example Sites of Special Scientific Interest, have been identified near the footprints of the proposed tunnel, tunnel portals or highway interchange areas or within the greater study area as a whole.

The ground conditions across the site are expected to comprise of a variable mantle of Made Ground, Alluvium, River Terrace Deposits, London Clay, Harwich Formation (locally), the Woolwich and Reading Beds of the Lambeth Group, the Upnor Formation and Thanet Sand, all overlying the Upper Chalk. Made Ground is expected to be largely absent within the River Thames. The geology, including strata descriptions, and hydrogeology of the site has been summarised in Section 2.3. A geological profile along the proposed tunnel alignment is presented in Appendix A.3.

Groundwater is likely to be encountered as perched water in the Made Ground, as an 'upper aquifer' within the River Terrace Deposits, and a 'lower aquifer' in the granular Lambeth Group and underlying Thanet Sands and Chalk. The groundwater level in the River Terrace Deposits is likely to be connected to the River Thames. The lower aquifer water level may be depressed through historic (and continuing) groundwater abstraction.

Groundwater abstraction is undertaken at five locations in proximity to the site. It is not known whether groundwater is currently being abstracted from these wells. In addition, discharge consents have been granted to approximately five operators located within 100 metres of the Silvertown River Crossing project study area. The flood risk potential for the site has also been categorised; reference should be made to Sub-section 2.3.8 for further details.

A number of 'scour hollows', local, deep drift-filled hollows which exist in the surface of the London Clay (Berry, 1979) and represent localised zones in which the strata vary abruptly from the surrounding geology, have been identified within the vicinity of the proposed Silvertown River Crossing, most notably on the line of the Blackwall Tunnel beneath the River Thames. Two additional scour hollows are suggested by Berry (1979): a tube well at the mouth of the River Lea at Trinity Wharf and a feature near the Butane Store at East Greenwich Gas Works. Scour holes are generally characterised by poor geotechnical properties. However, the recently completed ground investigation for the London Cable Car project provided no evidence of such features within the footprint of the proposed works.

The potential for ground and groundwater contamination within the Silvertown project study area have been addressed in the Phase 1 Contaminated Land Assessment undertaken by Mott MacDonald as part of the Ground Investigation Desk Study commission. Overall the site has been given a MODERATE to HIGH risk rating. There are no sites determined as Contaminated Land under Part IIA of the Environmental Protection Act 1990 within 250m of the Silvertown site. However, landfills have been identified on both the northern and southern banks of the River Thames within the footprint of the project study area. Additionally, asbestos was encountered in the 'inert' backfill to the Western Entrance Lock to the Royal Victoria Dock during the ground investigation for the London Cable Car project.

The contamination assessment made the following recommendations:

- Undertake an intrusive site investigation and laboratory testing together with a programme of environmental monitoring to more fully understand the conceptualised pollutant linkages identified;

- The results of these investigations should be used to inform a quantitative risk assessment, and can also be used in materials management and site construction environmental management plans;

- The scope of any investigation that may be required for planning purposes should be discussed with the regulators (local planning authority environmental health and Environment Agency).

The Silvertown project study area is located in an area of East London which is known to have been heavily bombed during the Second World War (WWII). A Stage 2/3 Detailed UXO Threat Assessment of the project study area has been undertaken in accordance with the requirements of CIRIA C681 'Unexploded Ordnance (UXO) – A guide for the construction industry'. The assessment established that in the areas north and south of the River Thames, there is a 'Medium/High' risk of encountering UXO. However, in the River Thames, where bomb strikes are considered more likely to have gone unnoticed, the risk level is increased to 'High'.

It is recommended that once the scheme design and construction programme have been finalised, a detailed UXO risk mitigation strategy should be developed for the project. For the areas north and south of the River Thames, both non-intrusive and intrusive survey methods may be employed, in the first instance, to clear the site of any potential UXO threat in advance of any intrusive ground works. For the River Thames section, it has been recommended that a magnetometer survey should be employed to clear the site of any potential UXO threat. Where any intrusive ground works, such as ground investigation, piling or tunnelling are to be undertaken, a specialist UXO banksman should be present on site to identify the potential for any UXO threat.

A walkover survey of the Silvertown River Crossing project study area was undertaken during the preparation of this report. The key observations made during the walkover survey are summarised in Sub-section 2.2.1. On the basis of the site walkover it is anticipated that physical access for ground investigation purposes should not be a significant issue; exploratory holes have been completed successfully recently in the vicinity as part of the London Cable Car project ground investigation. However, access to the area will need to be negotiated with the respective third party stakeholders and there may be particular requirements with regards working in areas of historic contaminated land.

With the exception of those overwater boreholes sunk as part of the ground investigation for the London Cable Car Project, to date project-specific ground investigations have yet to be undertaken for the Silvertown River Crossing project. Details of the fieldworks and laboratory testing undertaken during this ground investigation are summarised in Sub-section 2.4.1. No other studies or fieldworks have been undertaken to date for the Silvertown River Crossing project.

The Preliminary Geotechnical Risk Register for the Silvertown River Crossing project is presented in Appendix A.11. The Geotechnical Risk Register will operate as a live document and will be reissued at key stages throughout the development of the project.

From a review of the pre-existing geotechnical data for the site it is concluded that to establish the ground and groundwater conditions and material properties along the proposed tunnel alignment a project-specific ground investigation would be required. To date only those boreholes sunk over water within the River Thames as part of the London Cable Car project ground investigation have been specifically constructed to inform the design of the Silvertown River Crossing project. In order for Transport for London to take the scheme design forward to construction, ground investigation to obtain a comprehensive understanding of the ground and groundwater conditions at the site is required; specific details of the preliminary ground investigation considered necessary are presented in Section 2.5.3.

Reducing the ground related risks associated with the scheme will have a considerable beneficial impact on the scheme construction costs. To achieve this ground investigation should be undertaken with its focus being to obtain specific information for the design and construction of particular elements of the proposed works such as the bored tunnels, and to reduce uncertainties associated with the existing information.

Gallions Reach Study Area

The proposed fixed link crossing between Gallions Reach and the Gallions Hill area of Thamesmead will be either a bridge or immersed tube tunnel. The river crossing is intended to be a local road network crossing scheme and as such the prescribed connections into the existing road network are at Gallions Roundabout/Royal Docks Road on the north side of the River Thames and at Thamesmead Roundabout/A2016 Western Way on the south side of the River Thames.

On the northern bank of the river at Gallions Reach the history of development (and re-development) is dominated by the now defunct Beckton Gas Works which occupied the site. More recently the Docklands Light Railway has influenced the development of the site. On the southern bank of the river the history of development is associated with the Woolwich Arsenal artillery range and, more recently, the Tripcock Point Registered Landfill Site to the northeast of Gallions Hill.

The ground conditions across the site are expected to comprise of a variable mantle of Made Ground, Alluvium, Peat, River Terrace Deposits, Lambeth Group and Thanet Sand overlying the Upper Chalk. Made Ground is expected to be largely absent within the River Thames. A possible fault, the ‘Greenwich Fault’, which is thought to extend from Dulwich to the mouth of the River Roding, crosses the route corridor in the vicinity of the Beckton Gas Works. Evidence obtained during the detailed site investigations for the East London River Crossing in the early 1980s suggested that this structure is a step-faulted monoclinic feature.

The historic ground investigations undertaken in the vicinity of the site encountered groundwater at approximately 0 mATD within the River Terrace Deposits. Groundwater can also be anticipated within the granular layers of the Lambeth Group and the Thanet Sand Formation.

The geology, including strata descriptions, and hydrogeology of the site have been summarised in Section 3.3. A geological profile along the proposed immersed tube tunnel alignment is presented in Drawing No. MMD-298348-TUN-603 included in Appendix B.2.

No records of groundwater abstraction wells located in close proximity to the site have been obtained. Discharge consents have been granted to three operators, one for cooling groundwater, located within the Gallions Reach River Crossing project study area. The flood risk potential for the site has also been categorised; reference should be made to Sub-section 3.3.8 for further details.

The potential for ground and groundwater contamination within the Gallions Reach River Crossing project study area have been addressed in the Phase 1 Contaminated Land

Assessment for this site undertaken by Mott MacDonald as part of the Ground Investigation Desk Study commission. Overall the site as a whole has been given a HIGH risk rating.

The contamination assessment made the following recommendations:

- Undertake an intrusive site investigation and laboratory testing together with a programme of environmental monitoring to more fully understand the conceptualised pollutant linkages identified;

- The results of these investigations should be used to inform a quantitative risk assessment, and can also be used in materials management and site construction environmental management plans.

- The scope of any investigation that may be required for planning purposes should be discussed with the regulators (local planning authority environmental health and Environment Agency).

The Gallions Reach River Crossing project study area is located in an area of East London which is known to have been heavily bombed during the Second World War (WWII). A Stage 2/3 Detailed UXO Threat Assessment of the study area has been undertaken in accordance with the requirements of CIRIA C681 'Unexploded Ordnance (UXO) – A guide for the construction industry'. The assessment established that in the areas north and south of the River Thames, there is a 'Medium/High' risk of encountering UXO. However, in the River Thames, where bomb strikes are considered more likely to go unnoticed, the risk level is increased to 'High'.

It is recommended that once the scheme design and construction programme have been finalised, a detailed UXO risk mitigation strategy should be developed for the project. For the areas north and south of the River Thames, both non-intrusive and intrusive survey methods may be employed, in the first instance, to clear the site of any potential UXO threat in advance of any intrusive ground works. For the River Thames section, it has been recommended that a magnetometer survey should be employed to clear the site of any potential UXO threat. Where any intrusive ground works, such as ground investigation, piling or tunnelling are to be undertaken, a specialist UXO banksman should be present on site to identify the potential for any UXO threat.

A walkover survey of the Gallions Reach River Crossing project study area was undertaken during the preparation of this report. The key observations made during the walkover survey are summarised in Sub-section 3.2.1. Of particular note is the deformation evident to the Armada Way road pavement. On the basis of the site walkover it is anticipated that physical access for ground investigation purposes should not be a significant issue; exploratory holes were completed successfully in the vicinity as part of the East London River Crossing ground investigation. However, access to the area will need to be negotiated with the respective third party stakeholders and there may be particular requirements with regards working in areas of historic contaminated land.

The Preliminary Geotechnical Risk Register for the Gallions Reach River Crossing project is presented in Appendix B.7. The Geotechnical Risk Register will operate as a live document and will be reissued at key stages throughout the development of the project.

To date the complete Factual Ground Investigation Report (Contract No.2) for the East London River Crossing project, particularly the results of the insitu and laboratory testing, undertaken within the Gallions Reach River Crossing project study area during the early to mid-1980s has not been obtained. In its absence a number of the borehole logs for the East London River Crossing ground investigation in the vicinity of the proposed route corridor have been obtained from the British Geological Survey.

In the first instance it is recommended that further efforts are made to obtain the complete Factual Ground Investigation Report (Contract No.2) for the East London River Crossing project. Obtaining this information will reduce the quantity of additional ground investigation that will be required to take either the bridge or immersed tube tunnel crossing options forward.

Whether or not this report is obtained the ground and groundwater conditions and material properties along the proposed route corridor will require verification through a project-specific additional ground investigation. A more extensive investigation will be required if the Factual Ground Investigation Report for the East London River Crossing project (Contract No.2) is not obtained. However, before any ground investigation is procured it would be prudent to select a preferred option rather than undertake ground investigation for all three potential options, i.e. bridge, immersed tube tunnel or Replacement for the Woolwich Ferry.

1. Introduction

1.1 Background

Mott MacDonald were commissioned by Transport for London (TfL) in February 2013 to undertake Geotechnical Desk Studies for potential projects known collectively as the River Crossings Programme which will provide new crossings of the River Thames in East London. The first site at Silvertown is being considered for a bored tunnel from the Greenwich Peninsula (south of the River Thames) to Silvertown (north of the River Thames). The second site at Gallions Reach is being considered for both a fixed link (either a bridge or immersed tube tunnel) and a ferry crossing between Thamesmead (south of the River Thames) and Gallions Reach (north of the River Thames).

The desk study is the first stage of a site investigation. BS EN 1997-2:2007 (Clauses 2.1 and 2.2 refer) requires a desk study to be carried out before a ground investigation programme is designed in order to evaluate the available existing information and data. The primary objectives of the desk study are to evaluate the ground and groundwater conditions based upon the available existing information, and to plan the scope of the subsequent stages of the investigation. The desk study and field reconnaissance/site inspection are the two essential components of a site investigation. On occasions other components (for example the ground investigation) may be omitted but these parts of the investigative process must always be carried out.

The desk study (or preliminary sources study as it is sometimes referred to) is the essential first link in the geotechnical project risk management chain (Hope, 2012); it identifies the likely ground-related hazards presented in the Preliminary Geotechnical Risk Register. Subsequent phases of the investigative process consider these hazards in relation to the proposed development and quantifies the risk associated with each hazard.

Interpretation is a continuous process, which should begin in the preliminary stages of data collection with the construction of the initial ground model; further interpretation of the ground conditions should proceed as information from the site investigation, for example the ongoing desk studies and walkover survey, becomes available.

1.2 Scope of Work

This report has been prepared by Mott MacDonald. The report presents a review of the project study areas based on the available existing factual information in terms of:

- existing and historic land use;
- geological setting;
- ground and groundwater conditions;
- unexploded ordnance (UXO) risk;
- engineering assessment; and
- option comparison based on ground-related risks.

1.3 Proposed Works

The options currently being considered by TfL are as follows:

- A tunnelled crossing at Silvertown;
- A replacement for the Woolwich Ferry (at Woolwich/Gallions Reach); and
- A fixed link (either a bridge or immersed tube tunnel) at Gallions Reach.

It is anticipated that each of the above options will comprise Geotechnical Category 2 structures as defined in Section 3 of the Highways Agency document, HD22/08, 'Managing Geotechnical Risk'. A decision on which options to progress will be made during 2013. An envisaged programme for delivery into service of the first two projects is 2021 and 2018 respectively. The programme for the third scheme is still in development but its completion date would be after 2021 irrespective. An application has been made for the Silvertown Tunnel to be developed via a Development Consent Order (DCO) application. The replacement for the Woolwich Ferry would be taken forward via a Transport and Works Act (TWA) Order.

1.3.1 Silvertown Tunnel

As shown on Drawing No. MMD-298348-TUN-201 in Appendix A.2 the proposed twin 12.1m outer diameter bored tunnels will provide a dual 2-lane connection between the A102 on the Greenwich Peninsula and the Tidal Basin Roundabout on Silvertown Way. The main bores are to be constructed using a TBM and will have a lining of reinforced pre-cast concrete segments. The segments will be bolted longitudinally and radially and are to be fitted with gaskets to render the lining nominally watertight. There are to be 3 No. pedestrian cross passages at typically 350m spacings along the line of the bored tunnel to facilitate intervention in an emergency. These 4.55m outer diameter cross passages are most likely to be formed using the sprayed concrete lining (SCL) technique. The tunnel approaches will be formed of cut and cover tunnels and retained cut ramps.

The approximate coordinates of the proposed tunnel portals are as follows:

- North tunnel portal: TQ 540137E 180673N; and
- South tunnel portal: TQ 539499E 179782N.

The embedded retaining walls will be formed using a combination of diaphragm and secant pile walling techniques with associated base slabs. Diaphragm walls will generally be the solution except for areas where there is a probability of obstructions beneath guide wall level (1.5 to 2m). Secant piles can be constructed in areas where obstructions are expected using a high torque rig with the casing coring through the obstruction.

The cut and cover box depths vary but at their shallowest they are approximately 10m deep. The temporary lateral ground loads during construction will be considerable. It is generally assumed that all boxes will be constructed bottom up although some may be constructed top down, but there will be sections which need to be left open to facilitate TBM operations and these will of necessity be constructed bottom up to allow craneage access during tunnelling. In these cases temporary steel props and/or ground anchors will be required.

At each end of the tunnel, it is proposed to undertake a redevelopment of the adjacent road junction and highway areas in order to accommodate the new tunnel.

That part of the site on the north bank of the River Thames is located within the London Borough of Newham; that part of the site on the south bank of the River Thames is situated within the London Borough of Greenwich. To the north of the River Thames, the study area includes the Thames and Clyde Wharves; the northern part of the site is bounded to the north by the Canning Town London Underground/DLR station, to the southeast by the West Silvertown DLR station and to the east by the Royal Victoria DLR station. The Royal Victoria Docks are located to the east between the two stations and are situated approximately 100m away from the proposed northern tunnel portal entrance.

On the south side of the River Thames, the project study area includes the area around Edmund Halley/Millennium Way and Cutter Lane, south of the O_2 arena on the Greenwich Peninsula, and extends south within the confines of the Blackwall Tunnel Approach and West Parkside.

The land on both sides of the River Thames at this location is gently undulating with ground levels generally between 1m AOD and 6m AOD. The bed of the Thames is anticipated to have a gentle transverse dip ranging from -3 m AOD to -10 m AOD.

1.3.2 Woolwich Ferry Replacement

Details of the proposed Woolwich Ferry Replacement scheme are described in the 'Woolwich Ferry Replacement and Gallions Reach Ferry Feasibility Study' report compiled by Halcrow in 2010. The study considered replacement crossings for the Woolwich Ferry in both the current location and at Gallions Reach. This report considers the Gallions Reach location only.

The new ferry crossing at Gallions Reach would be on the approximate alignment of the previously proposed Thames Gateway Bridge (TGB). Details of the proposed ferry terminal structures have not been developed to date; however, the scheme will require new connections to the existing principal road network. North of the River Thames the connection to the principal highway network would be via a combination of new and improved highways to Gallions Roundabout. Atlantis Avenue, which runs east from Gallions Roundabout, would be dualled on its south side and the existing signalised junction with Armada Way and Gallions Road would be modified. Atlantis Avenue currently terminates at a signalised T-Junction with Magellan Boulevard and it is proposed that this junction is modified to a crossroads with a new connection to the ferry continuing straight on from Atlantis Avenue.

South of the River Thames approximately 1.1km of new single carriageway highway will be required to connect the new ferry to the existing road network. This new highway will be located within the land safeguarded for the Gallions Reach River Crossing project. It has been proposed to connect this highway to Western Way, approximately 250m west of the Western Way/Eastern Way/Central Way roundabout. A drawing showing the indicative highway layout for the scheme is presented in Appendix B2.

1.3.3 Gallions Reach Fixed Link

The proposed fixed link crossing between Gallions Reach and the Gallions Hill area of Thamesmead is to take the form of either an immersed tube tunnel or bridge; outline details of these proposals are presented in Appendices B1.2 and B1.3 respectively. The river crossing is intended to be a local road network crossing scheme and as such the prescribed connections into the existing road network are at Gallions Roundabout/Royal Docks Road on the north side of the River Thames and at Thamesmead Roundabout/A2016 Western Way on the south side of the River Thames. The safeguarded area for the Gallions Reach River Crossing is shown in Drawing No. MMD-298348-TUN-401 in Appendix B.2.

2. Silvertown Study Area

2.1 Sources of Information

In October 2010, Mott MacDonald prepared a comprehensive geotechnical desk study to assist with the design of the London Cable Car scheme across the River Thames between Royal Victoria Dock on the north side of the river and the Greenwich Peninsula on the south side. Although the desk study was primarily carried out for the cable car project, the scope of the desk study was expanded to cover the proposed tunnel crossing scheme being developed at the same location (Silvertown). Ground investigation for the cable car project was subsequently undertaken. Therefore, an extensive database of existing geotechnical information for the Silvertown study area is available.

The sources of information which have been used in the preparation of this report are summarised in Table 2.1 below.

Table 2.1: Silvertown: Sources of information

Category	Sources of Information
Geology	▪ British Geological Survey, 1996. "London and the Thames Valley". ▪ Ellison, R.A. (Ed), "Geology of London: Special Memoir for 1:50 000 Geological sheets 256 (North London), 257 (Romford), 270 (South London) and 271 (Dartford) (England and Wales)" BGS, 2004.; ▪ England and Wales Sheet 256 North of London Solid and Drift Geology. 1:50 000 scale map, British Geological Survey 1981; ▪ England and Wales Sheet 270 South London Solid and Drift Geology, 1:50 000 scale map, British Geological Survey, 1981; ▪ England and Wales Sheet 271 Dartford Solid and Drift Geology. 1998. 1:50 000 scale map, British Geological Survey;
Non-Site Specific Geotechnical References	▪ A. F. Howland, 1991. "London Docklands: Engineering Geology" (Proceedings Institution of Civil Engineers, Part 1,1991, 90 Dec 1153-1178, paper 9659); ▪ A. W. Skempton, 1979. "Engineering in the Port of London 1789 – 1808"; ▪ BRE Special Digest 1:2005. "Concrete in aggressive ground". BRE/The Concrete Centre; ▪ British Construction Profile (London Docklands Development Supplement), 1986 "Royal Docks Drainage Scheme"; ▪ C.D. Warren and R.N. Mortimore, 2003. "Chalk Engineering Geology - Channel Tunnel Rail Link and North Downs Tunnel" Quarterly Journal of Engineering Geology and Hydrogeology, 36,17-34; ▪ D. Hay, M. Fitzmaurice, "The Blackwall Tunnel", Minutes of the Proceedings of the Institution of Civil Engineers Vol. cxxx session 1896-1897. Part iv.) ▪ D. K. Young, P. Rutty, "London's Docklands: a geotechnical perspective of the highways", (Proceedings Institution of Civil Engineers, Part 1,1991, 90 Dec 1203-1223, paper 9661); ▪ D. Kennedy, H. E. Aldington, 1936. "Royal Docks Approaches Improvement, London"; ▪ F.G. Berry, "Late Quaternary scour-hollows and related features in central London", Quarterly Journal of Engineering Geology and Hydrogeology 1979; v. 12; p. 9-29. ▪ G.B. Jamieson, 2000. "Greenwich peninsular – transport planning for the third millennium"; ▪ Hight, D. W., McMillan, F., Powell, J. J. M., Jardine, R. J. & Allenou, C. P. (2003) "Some characteristics of London Clay."; Characterization and Engineering Proprieties of Natural Soils-Tan et al (eds). Vol. II pp.851-907; ▪ J. B. Burland, J. R. Standing, F. M. Jardine, "Building response to tunnelling. Case studies from the Jubilee line Extension, London", 2001, CIRIA Special Publication 200. ▪ J. Kell, G. Ridley, "Blackwall Tunnel Duplication", (Proceedings Institution of Civil Engineers, Vol 35, October 1966, 253-274, paper 6954);

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Factual Ground Investigation Reports	■ "Blackwall Tunnel Southern Approach Route. New dual carriageway. Six volumes plus supplementary S.I. to locate fault position (unpublished report); ■ "Report on Ground Investigation for the Proposed Royal Docks Drainage in Royal Victoria Docks" (unpublished report); ■ "Silvertown – Cairn Mills Unilever Ltd – Messrs Loders and Nucoline Ltd" (unpublished report); ■ "Silvertown – North Woolwich Road North bank of Thames opposite Greenwich Marshes Redevelopment of Minerva Works for Courtaulds Technical Services" (unpublished report); ■ "Silvertown – North Woolwich Road. New Paint Store For Pinchen Johnson & Associates. Minerva Works" (unpublished report); ■ "Silvertown – Silvertown Way British Oil & Cake Mills" (unpublished report); ■ 6 Alpha Associates Limited. (2013). Detailed Unexploded Ordnance (UXO) Risk Assessment for Silvertown, London. Project Number: P3246. D. K. Young, P. Rutty, "London's Docklands: a geotechnical perspective of the highways", (Proceedings Institution of Civil Engineers, Part 1,1991, 90 Dec 1203-1223, paper 9661); ■ British Geological Survey database of historic boreholes; ■ Leamouth Area Study: Reclamation work at Limo and Thames Wharf, 1987. ■ Lower Lea crossing Geotechnical Interpretative Report, 1990. (Unpublished) ■ Mott MacDonald database of historic boreholes; ■ Mott MacDonald. (2010). Geotechnical Desk Study Report for the New Thames River Crossings. Report No. 265453/MNC/FNG/1. ■ Soil Mechanics. (2011). Cable Car for London – Ground Investigation: Factual Report on Ground Investigation. Report No. D1002-11/1.
OS Mapping/ Envirocheck	■ Landmark Information Group Service, Envirocheck Report for the site, March 2013; ■ Historical Ordnance Survey maps, for discrete years during the period 1850 to 2012;
Site Development	■ D. Ernest et al, "Port of London Authority: Development of Two Dock Areas", 1959 ICE Proceedings Vol 18 Issue 1, 97-109 paper 6436; ■ Docklands Light Rail (DLR) archive drawings; ■ Environment Agency (EA) archive drawings; North East London Polytechnic, 1986. "Dockland; An illustrated historical survey of life and work in east London"; ■ Port of London Authority (PLA) archive drawings; ■ R. J. M. Carr, D. Smith, J. Earl, A. Pearsall, C. Ellmers and P. Dean, 1984. "The Docklands History Survey"; ■ R. R. Liddell, "Improvements at the Royal Docks, Port of London Authority", January 1939, Journal

Category	Sources of Information
	of The Institution of Civil Engineers, No. 3 1938-39; ■ W. J. Kingsbury "Description of the Entrance, Entrance Lock, and Jetty Walls of the Victoria (London) Docks; with a detailed account of the Wrought-Iron Gates and Caisson, and remarks upon the form adopted in their construction", 19 April 1859, Minutes of the Proceeding of the Institution of Civil Engineers (with abstracts of the discussions) Vol 18 (Session 58-1859), No.1004;
Websites	■ ExCeL London *http://www.excel-london.co.uk/;* ■ Exploring 20th Century London *http://www.20thcenturylondon.org.uk/server.php?show=nav.481;* ■ Government Services and Information *http://www.gov.uk/;* ■ Ideal Homes: A History of South-East London Suburbs *http://www.ideal-homes.org.uk/greenwich/assets/histories/greenwich-peninsula;* ■ London Borough of Newham *http://www.newham.gov.uk/;* ■ London City Airport Consultative Committee *http://www.lcacc.org/;* ■ London Transport Museum *http://www.ltmuseum.co.uk/.* ■ London's Royal Docks *http://www.rodma.co.uk/;* ■ Museum of London Docklands *http://www.museumoflondon.org.uk/Docklands/;* ■ Royal Docks Trust (London) *http://www.royaldockstrust.org.uk/;* ■ The London Docklands Development Corporation *http://www.lddc-history.org.uk/;*

2.2 Field Studies

2.2.1 Site Inspection

The site reconnaissance (or walkover survey) of the Silvertown River Crossing project study area was undertaken by Mott MacDonald on 15 May 2013. The purpose of the walkover survey was to gather additional information on the geology, geomorphology and hydrogeology of the project study area in order to inform the preliminary ground model for the site, including potential construction problems and access constraints for any proposed ground investigation.

The key observations made during the walkover survey of the Silvertown River Crossing project study area are summarised in the following sections.

2.2.1.1 North of the River Thames

The desk study for the Silvertown River Crossing project study area revealed that on the north side of the River Thames, access to the site area overlying the proposed tunnel alignment would be limited. Therefore, it was concluded that the site area was best viewed from the London Emirates Cable Car, which crosses above the proposed tunnel alignment.

The land on the north side of the River Thames within the Silvertown River Crossing project study area is occupied by a number of industrial units – concrete batching plants, aggregate processing yards, waste recycling and scrap metal yards, storage yards and warehouses, associated offices and car parking areas as well as quayside loading/unloading facilities for river-borne traffic. There are large, open expanses of hardstanding.

Between the A1011/A1020 interchange and Silvertown Way viaduct, and Dock Road there are an operational concrete batching plant, an aggregate storage area together with construction plant yard and car parking facilities. Between Dock Road and the Docklands Light Railway an aggregate processing facility occupies the majority of the land; the remaining land is either hardstanding/parking areas associated with the aggregate processing facility or scrubland bordering the DLR.

Between the DLR and river wall the project study area is occupied by a number of industrial units including a waste recycling facility and scrap metal yard, a cement works and plant storage yards with associated offices and warehousing for Laing O'Rourke and ES Global. The area is gently undulating and contains large areas of hardstanding/car parking. The northern towers (main and intermediate) of the London Emirates Cable Car are also within the vicinity.

The proposed Silvertown tunnel is to cross below the Laing O'Rourke/ES Global industrial units in a generally northern direction; the northern tunnel portal and associated cut and cover sections of tunnel traverse continue northwards traversing beneath the DLR; the northern tunnel approach is to share the alignment of the current Dock Road as it connects in to the existing highway network.

On the basis of the site walkover it is anticipated that physical access for ground investigation purposes should not be a significant issue; exploratory holes have recently been successfully completed in the vicinity as part of the London Cable Car project ground investigation. However, access to the area will need to be negotiated with the respective third party stakeholders and there may be particular requirements with regards working in areas of historic contaminated land.

2.2.1.2 South of the River Thames

On the south side of the River Thames the Silvertown River Crossing project study area is centred on Edmund Halley Way. Currently the project study area largely comprises areas of hardstanding, mainly car parking facilities for the adjacent O_2 Arena. The only significant structure along the proposed tunnel alignment is the Emirates Greenwich Peninsula London Cable Car terminal located to the east of the junction between Edmund Halley Way and East Parkside. At the southern extent of the study area, where the proposed road connects in to the existing highway network at the Blackwall Tunnel Southern Approach (A102), there is a traffic management storage yard and depot comprising a number of temporary structures; the land immediately adjacent to this unit is scrubland.

To the west and largely outwith the project study area there aggregate processing facilities and storage yards.

The proposed Silvertown tunnel and associated southern approaches are to be situated beneath and approximately parallel to Edmund Halley Way; the approaches then veer southwards to connect in to the existing highway network adjacent to the remaining operational gas holder on the peninsula. This gas holder formed part of the South Metropolitan Gas Works.

On the basis of the site walkover it is anticipated that physical access for ground investigation purposes should not be a significant issue; exploratory holes have been completed successfully recently in the vicinity as part of the London Cable Car project ground investigation. However, access to the area will need to be negotiated with the respective third party stakeholders and there may be particular requirements with regards working in areas of historic contaminated land.

2.3 Site Description

2.3.1 Site Location

The location of the Silvertown study area is highlighted in the site plan (Plan A) shown in Appendix A.1. The part of the site on the northern bank of the River Thames is located within the London Borough of Newham; the part of the site on the southern bank of the River Thames is located within the London Borough of Greenwich.

On the north side of the River Thames, the study area includes Thames and Trinity Buoy Wharves. It is bound to the north by the Canning Town London Underground and DLR station, to the south east by the West Silvertown DLR station and to the east by Royal Victoria DLR station. On the south side of the River Thames, the study area includes the area around Edmund Halley Way and Cutter Lane south of the O_2 arena on the Greenwich Peninsula and extends south within the confines of the Blackwall Tunnel Approach and West Parkside.

2.3.2 Current Land Use

The two sides of the river have a similar industrial history. The northern part of the site encompasses the Royal Victoria Docks, including the historic Western Entrance to the docks which was closed in 1957. The land use on the northern side of the river is mixed with residential and recreational use around the perimeter of the Royal Victoria Docks and light commercial use to the south of the elevated Silvertown Way and the Docklands Light Rail (DLR). Waste management and cement/aggregate/concrete batching facilities dominate to the north and west of the proposed northern tunnel portal.

The southern part of the site was dominated by a gasworks until 1987. Thereafter redevelopment of the site included extensive remediation to make it suitable for residential, commercial and industrial uses. The current land use is predominantly car parking (i.e. hardstanding) with the O_2 Arena and commercial buildings located to the northwest and a leisure facility to the southeast. To the west of the Blackwall Tunnel South Approaches there is a large aggregate distribution facility. An operational gas holder, which is known to have comprised part of the South Metropolitan Gas Works, is located directly south of the proposed southern tunnel portal adjacent to the southern end of the scheme. Additionally in this area to the west of the proposed tunnel portal entrance, there is a large aggregate distribution facility.

The Silvertown study area also includes the London Cable Car (Emirates Air Line), which provides a crossing between the Greenwich Peninsula on the south side of the River Thames and the Royal Docks on the north side of the River Thames for pedestrians, wheelchair users and cyclists.

2.3.3 Topography

The land on both sides of the River Thames at this location is gently undulating with ground levels in the region of 1mOD to 6mOD. The bed of the River Thames is anticipated to have a gentle transverse dip with levels ranging from -3 mOD to -10 mOD.

2.3.4 Geology

Background Information

A number of references to the geology of the site have been consulted (Table 2.1) in order to determine the stratigraphy and structural setting of the study area.

Historical ground investigation boreholes that are located in the immediate vicinity of the northern and southern tunnel portals and along the alignment of the bored tunnels have been selected and sourced from the British Geological Survey (BGS) by Mott MacDonald. This information has been used to support an understanding of the ground conditions. The historic borehole information includes data obtained for the design and construction of London Underground's Jubilee Line Extension tunnels that cross beneath the Thames and more recently, the London Cable Car crossing.

In addition, Mott MacDonald's experience of the ground and groundwater conditions in this part of London has been used to aid development of an understanding of the stratigraphy and develop the preliminary ground model (Figure 1) as shown in Appendix A.3.

Regional Geology

The 'Artificial Ground and Landslip' map (Envirocheck, 2013) contained in Appendix A.4 shows the presence of extensive Made Ground to the northeast and southeast of the proposed routes of the Thames river crossings. Superficial sediments exist around the docklands area comprising of alluvial deposits of the flood plain of the Thames which rests on the flood plain gravels (Thames River Terrace Deposits). These superficial sediments overlie solid geology which comprises London Clay, the Woolwich, Reading Beds and Upnor Formation of the Lambeth Group, Thanet Sand Formation and the Upper Chalk.

In addition to the above, the presence of Made Ground is also indicated around the perimeter of the Royal Victoria Dock, the Tidal Basin and the former Royal Victoria Dock Western Entrance. Mostly, and originally, Made Ground was placed to raise the level of the land above the original level of the marshes which formed the area. The marshes were prone to regular flooding, for example during construction of the Royal Victoria Dock. Subsequently Made Ground is likely to be associated with the demolition and re-development of sites in the area.

The stratigraphy of the site is summarised in Table 2.2.

Structural setting

Scour hollows

Local, deep drift-filled hollows, 'scour hollows', exist in the surface of the London Clay (Berry, 1979) and represent localised zones in which the strata vary abruptly from the surrounding geology; they are generally characterised by poor geotechnical properties. A number of these features have been identified beneath the Kempton Park Gravel in Central London, particularly in the area between Battersea and Greenwich.

Table 2.2: Regional Stratigraphy of the Silvertown site

Period	Epoch	Group	Formation
Quaternary	Holocene		Made Ground Alluvium
	Pleistocene		River Terrace Deposits
Tertiary (Palaeogene)	Eocene	Thames Group	London Clay
			Harwich
	Palaeocene	Lambeth Group	Woolwich Reading Upnor
			Thanet Sand
Cretaceous	Upper Cretaceous	White Chalk	Undivided Upper Chalk mainly Seaford Chalk Lewes Chalk

It is widely acknowledged that these hollows were formed in the late Quaternary under the prevailing periglacial climatic conditions. There are several mechanisms that can result in the formation of such local depressions, namely:

- local scale channel formation from periglacial rivers and streams;
- regional scale channel formation from the proto-Thames; or
- scour hollows of periglacial pingo origin.

The first two mechanisms result in an undulating surface at the top of the formation, with an amplitude of generally less than 5 metres, while the final mechanism may result in deeper hollows.

The characteristics of these features include:

- depths varying typically between 5m and 15m; the deepest depression recorded is 60 metres at Blackwall;
- in plan the depressions are irregular, roughly circular or 'boat shaped' and can vary between 90m and 475m in width;
- locally steep sides;
- infill deposits consisting mainly of sand and gravel (the overlying River Terrace Deposits) with some clayey beds. The deposits are usually stratified but can be disturbed by soft sediment deformation;
- upwards injections and gentle folding of London Clay and Lambeth Group material have also been recorded at the base of some of these depressions; and
- only a very small number of depressions have been identified that penetrate through the London Clay and Lambeth Group deposits into the underlying Thanet Sand and Chalk aquifer.

The locations of proven deep scour hollows within the vicinity of the Silvertown study area are shown in Figure 2.1.

It is known that the substantial thicknesses of soft alluvium and peats, and underlying gravels which characterise the area of the Greenwich Marshes conceal "numerous strongly formed channels which run athwart the main course of the modern Thames". As shown in Figure 2.1 there is a substantial scour hole present on the line of the Blackwall Tunnels (7a) with the deepest known part occurring within the River

Thames at approximately -30.5 mOD. London Clay in the scour hole is thin or locally absent. A survey in 1887 for the upstream tunnel revealed drift deposits to -29.3 mOD resting on 'green sand' (possibly the Upnor Formation, formerly called 'Bottom Bed', or the Thanet Sand Formation); the tunnelling in 1895-6 passed through a gravel and sand-filled hollow about 183 metres broad, at invert levels of about -20.4 mOD. The line survey for the second tunnel made in 1938, which is about 213 metres downstream, proved gravel to -27.7 mOD. Tunnelling in 1963 passed through a hollow of similar width to the upstream tunnel at invert levels of about -24.4mOD. The detailed tunnel record shows a complex series of strata within the hollow, which appear to consist of Pleistocene sands and gravels lying upon finer-grained deposits.

Two additional scour hollows are suggested by Berry (1979): a tube well at the mouth of the River Lea at Trinity Wharf (7b on Figure 3.1) and, based on the results of a trial hole drilled in 1974, a feature near the Butane Store at East Greenwich Gas Works (7c on Figure 2.1). The latter feature consisted of stratified sand and gravel to -16mOD, with the hole ending in gravel. The paper also notes that "The hollow was developed on Woolwich Beds". Gravel was recorded in the former feature to about -14.3mOD. It was considered that this hollow was likely to be related to the scour hole encountered by the Blackwall Tunnels. The Chalk surface at this location was found to be 15.3 metres below local trends at -67mOD, a vertical displacement also being apparent as a rise westward from this point of 30.5m in 366 metres. However, Berry (1979) notes that the older records should be treated with caution, especially as this is the only hollow in which strata of the underlying solid formations are shown to be depressed below adjacent levels.

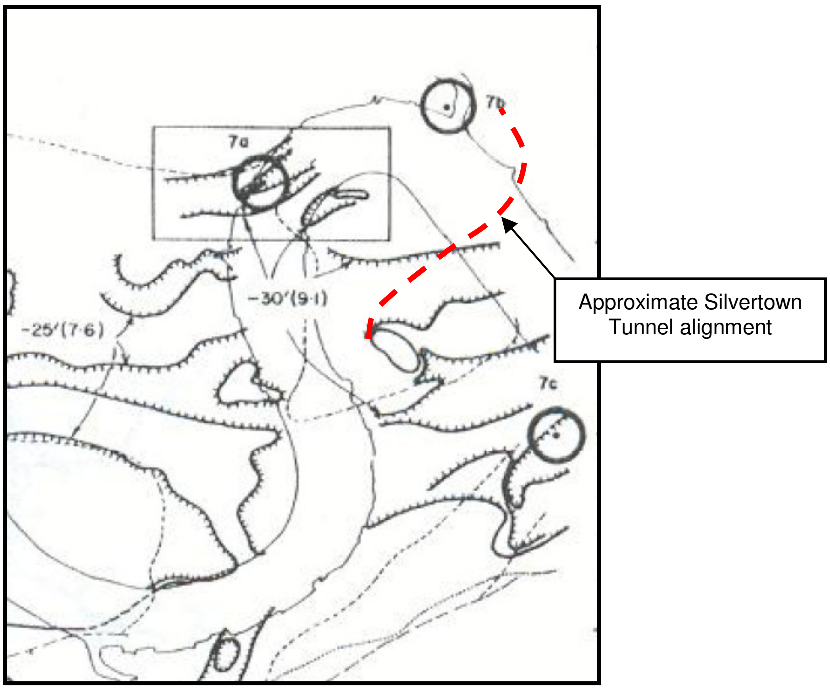


Figure 2.1: The location of deep scour hollows (Berry, 1979)

Hutchinson (1980) highlighted the area north of the River Thames as an area where the former flowing artesian area of the London Basin existed. It is possible that excavations will find remnants of open-pingos (scour hollows) in such former artesian areas.

Folds and faults

The proposed road tunnel route is located in close proximity to the southern edge of the London Basin, on the northern limb of a NE-SW trending anticline which forms the North Downs. No faults are shown in close proximity to the site on the published geological map. However, the Greenwich fault is located approximately 5 kilometres southwest of the proposed route and a northward plunging syncline called the Greenwich syncline is the dominant structural feature (Howland, 1991). A series of faults are understood to be present in the vicinity of Limmo Peninsula and may be related to the Lower Lea scour hollow at the confluence of the River Lea adjacent to East India Dock Basin.

2.3.5 Hydrogeology

The hydrogeological regime of the London Basin incorporates two key aquifers: a lower, deep (Major) aquifer within the granular units of the Lambeth Group, the Thanet Sand and Upper Chalk and an upper, shallow (Minor) aquifer within the Alluvium and River Terrace Deposits. The two aquifers are separated by an aquiclude formed by the less permeable London Clay and, where present, the cohesive deposits of the Lambeth Group. The London Clay is defined by the Environment Agency as unproductive strata and forms an aquitard between the upper and lower aquifer. The London Clay is thickest on the northern side of the River Thames; it is very thin (and may be locally absent) on the southern side. The minor aquifer is likely to be subject to tidal influence due to the close proximity of the River Thames. In addition, perched groundwater is likely to be present in the Superficial Deposits due to the presence of Alluvium. A local perched water table, possibly of limited extent and volume, may exist above low permeability layers in the Alluvium and Made Ground. Porous sandy units of the Made Ground and the pseudo fibrous peat within the Alluvium may retain water especially when sealed by a less permeable cohesive layer.

The Chalk is classified as a Principal aquifer and as all three strata of the lower aquifer are likely to be in hydraulic continuity; this classification applies to the whole of the lower aquifer. Additionally, the Lambeth Group in this area is predominantly granular, and as such there may be some connectivity between the two aquifers in this area.

Historic ground investigations undertaken in the vicinity of the site encountered groundwater at elevations between -1 m AOD and +1 m AOD within the River Terrace Deposits. This is consistent with the influence from the River Thames. During the ground investigation for the London Cable Car project in 2011, groundwater levels fluctuated between -0.67 and - 1.42m AOD. Groundwater can also be anticipated within the granular layers of the Lambeth Group and Thanet Sand Formation.

The proposed Silvertown Tunnel is to be situated within an area classed as a ‘Minor Aquifer’ with soils classified as having high leaching potential according to the groundwater vulnerability map (Envirocheck, 2013). However, the proposed tunnel crossing does not lie in close proximity to a source protection zone or source protection zone borehole (Envirocheck, 2013).

The nearest surface water features are the River Thames and the Royal Victoria Dock. In addition to these two surface water bodies, the River Lea joins the River Thames adjacent to the northern approaches for the proposed tunnel alignment.

2.3.6 Historical Development of the Site

Published historical records of the site area date from 1850 to 2012 and were obtained as part of the desk study. The historical development of the Silvertown site is summarised in Table A.1 included in Appendix

A.6. The key issues aspects of this development in relation to the proposed works are summarised in the following sections.

The two sides of the river have a similar industrial history. The northern part of the site encompasses the Royal Victoria Docks and the historic Western Entrance to the docks that was closed in 1957.

The southern part of the site was dominated by a gasworks until 1987. Thereafter redevelopment of the site included extensive remediation to make it suitable for residential, commercial and industrial uses.

2.3.6.1 North side of the Thames – Key Aspects

- the presence of contaminated ground/groundwater resulting from the former industrial uses of the site;
- the presence of historic jetties within the Tidal Basin and remnants of historic foundations, possibly piles;
- the presence of historic and current drainage infrastructure associated with the Royal Docks;
- existing transport infrastructure, including the DLR viaduct, in close proximity to the proposed works;
- infilling of the former channel (Western Entrance) to the Royal Victoria Docks connecting the Thames to the Tidal Basin;
- the presence of the dock entrance as a possible barrier to tunnel construction;
- the presence of the Royal Albert and Victoria Docks cut; and
- the presence of services, including hydraulic power systems within the Royal Docks.

2.3.6.2 South side of the Thames – Key Aspects

- the presence of ground contamination resulting from the former industrial use of the site;
- the potential presence of historic gas works infrastructure on the proposed tunnel approach alignment;
- existing transport infrastructure; and
- the presence of old services.

2.3.7 Existing and Historic Structures

There are a number of existing and historic structures, as noted in Sections 2.3.6.1 and 2.3.6.2, which could potentially affect and be affected by the proposed works. The following is a list of the key structures followed by a summary of what is currently known about them.

- Quay walls for the historic Tidal Basin/Royal Victoria Dock;
- Channel structure and lock between the former Tidal Basin and the Thames;

- Drainage infrastructure associated with the Royal Docks;
- Docklands Light Railway;
- Thames river walls; and
- Possible foundations of former gas works and associated infrastructure.

2.3.7.1 Royal Victoria Dock Tidal Basin

The following discussion on the tidal basin quay wall is deduced from Port of London Authority (PLA) drawings and supplementary information listed in Table 2.1.

The area in which the cable car station lies was previously a Tidal Basin for the Western Entrance Lock to the Royal Docks. The Western Entrance lay to its west and two jetties (usually names 'I' and 'M' jetties) bounded its eastern end. Between the two jetties lay a further gate to the main Royal Victoria Dock.

The depth of the main dock, the Tidal Basin and the inner sill of the Western Entrance Lock was 25 feet and 6 inches below Trinity High Water (see Section 2.3.7.9), which is -13 feet below Liverpool Ordnance Datum. As the depth of the water over the sill at neap tides was 24 feet, any vessel requiring more than this had to wait for spring tides before they could enter the dock. When the Royal Albert dock was opened, steam pumps were installed at the east end of the new dock to maintain the water of both docks at the level of Trinity High Water.

In 1911, a new intake-culvert and impounding station was completed. This included the installation of electric pumps to replace the steam pumps in order to raise and maintain the water level the Victoria and Albert docks to the increased height of 30 inches (or 2.5 feet) above Trinity High Water. The new Impounded Water Level was now 15 feet above Liverpool Ordnance Datum.

The cable car north 'Drive' station is located in the Tidal Basin. The dock adjacent the quay was dredged to 29 feet below THW between 1920 and 1938 (as described in Section 2.3.7.2). From this dredged area, the dock bottom then sloped at 1 in 5 rising up back to the 'existing level' away from the quay wall. The existing level was approximately 25.5 feet below THW. For further detail on the level of the base of the dock see PLA drawing 7620565, "Royal Victoria Dock North Side – Tidal Basin, Meat Accommodation, Site Plan & Section of Site No.1&2, Drawing No.1".

So whilst definitive details are not available, the documents indicate that the dock level near the cable car north 'Drive' station was dredged to approximately -5.4 mOD (Newlyn) between 1920 and 1938.

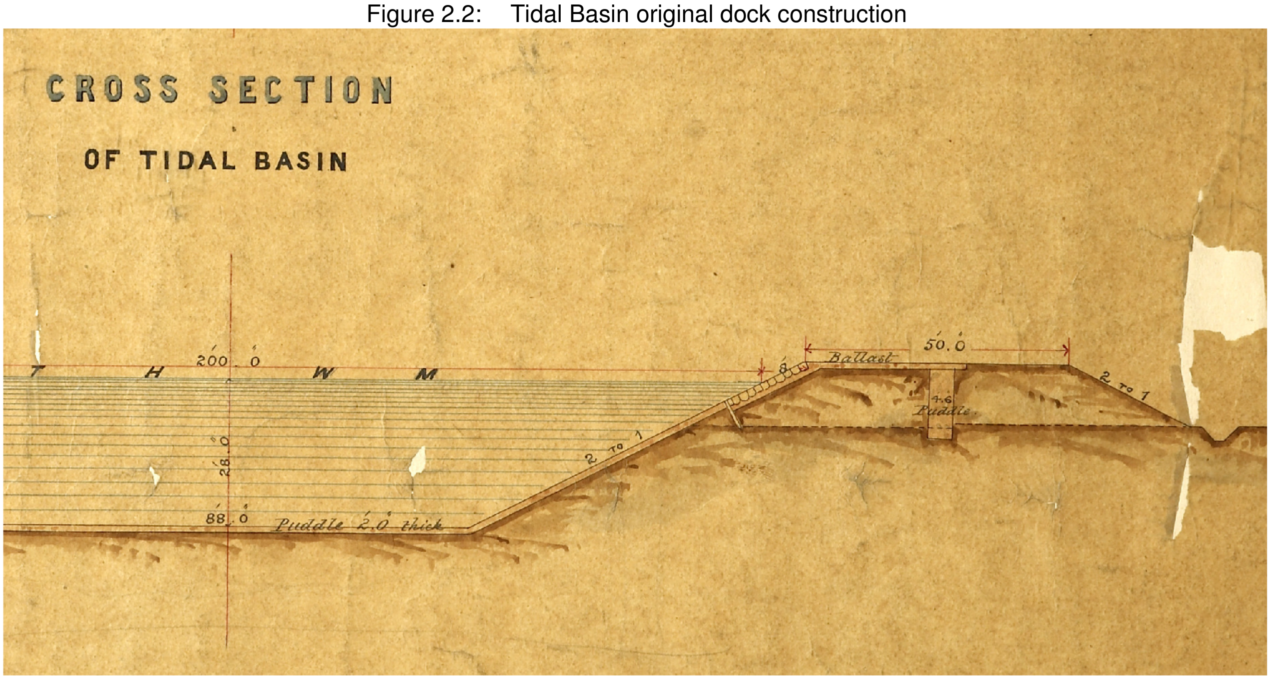
2.3.7.2 Royal Victoria Dock Quay Wall

The following discussion on the Royal Victoria Quay Wall has been extracted from the sources of information listed in Table 2.1.

The Victoria Dock was originally rather basic and was upgraded almost immediately following completion. "Dockland – An illustrated historical survey …" described the sides of the docks being "largely earthen banks". The Docks were opened by Prince Albert in 1855 and the prefix 'Royal' was bestowed in 1880 by the Duke of Connaught on behalf of Queen Victoria. The construction methods were radically different from those of the earlier docks which were built in stone for sailing ships. By the 1850s, a longer life for the docks was envisaged, so five finger jetties were constructed (two of which were in the Tidal Basin) to increase capacity.

A cross-sectional drawing received by the PLA in 1925 shows the Victoria (London) Dock before it was used for commercial use in this interim period (see PLA drawing 7700055 in Appendix A.7). Victoria Dock is shown to have a puddle (clay) layer which is 2'-0" thick throughout. The drawing shows one cross-section for the Tidal Basin (see Figure 2.2 for highlights) and one for the main dock (in the 300' cut).

Figure 2.2: Tidal Basin original dock construction

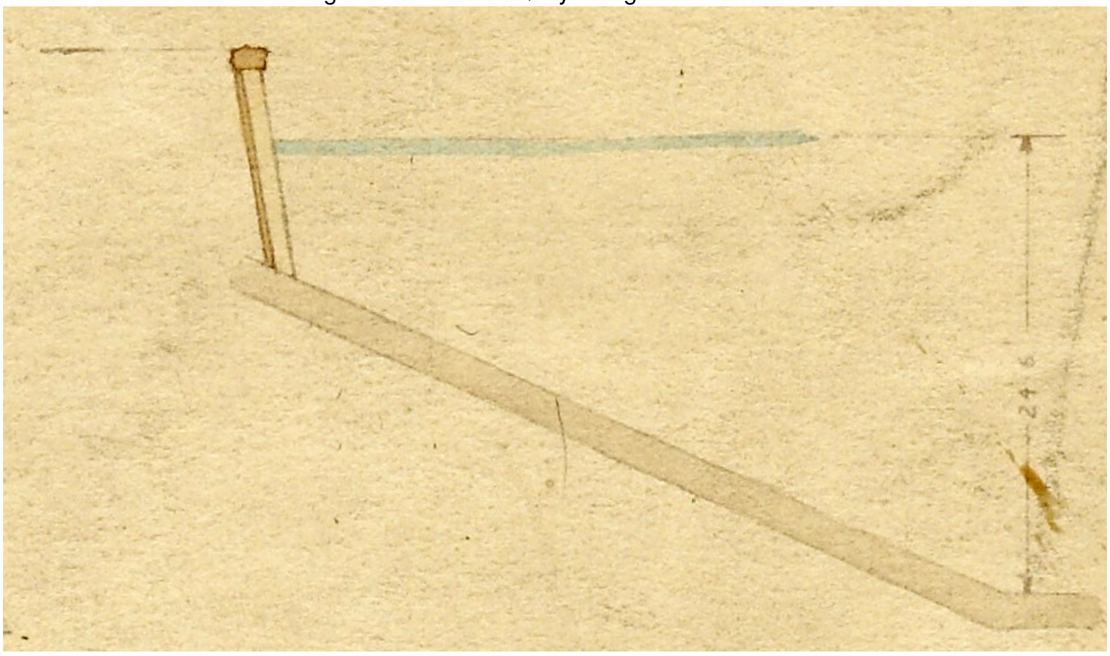


Source: PLA Drawing from Museum of London Docklands

The drawing shows that the dock was formed by constructing an embankment on top of the existing marsh, approximately 11'-0" above the previous marsh level and forming a cut for the dock, approximately 21' below marsh level. The embankment on the north side of the Tidal Basin extends 250'-0" and the embankment on the south side extends 50'-0". All slopes are shown as "2 to 1". The dockside upper slopes of the embankments are reinforced; however the type of construction is not specified. The vertical dimension of the reinforcing element is shown as 8 feet and therefore it extends 16 feet in plan, so the length is approximately 18'-11" (roughly 5.5m). At the lower extent of this reinforcing appears to be a pile. The pile is shown at 90° to the sloping dock base extending into the marsh material (3 feet vertically). Following this reinforcing, the 2'-0" puddle layer continues down the slope and along the base of the dock.

A drawing showing the construction of all Royal Victoria Dock quay walls was found in the archive. The drawing was in the index and has no PLA drawing number and no indication of the year of production, but the year of receipt by the PLA is stamped 1920 and 'N205' is also stamped on the drawings. The north quay wall in the Tidal Basin is shown as approximately vertical, with a slight tilt away from the water (see Figure 2.3). The water level is shown at roughly half way down the quay wall. The profile of the bottom of the dock at this point is shown as sloping away from the quay until the point at which the puddle is the 24'-6" (approx. 7.5m) below the drawn water level (see Figure 2.3 below).

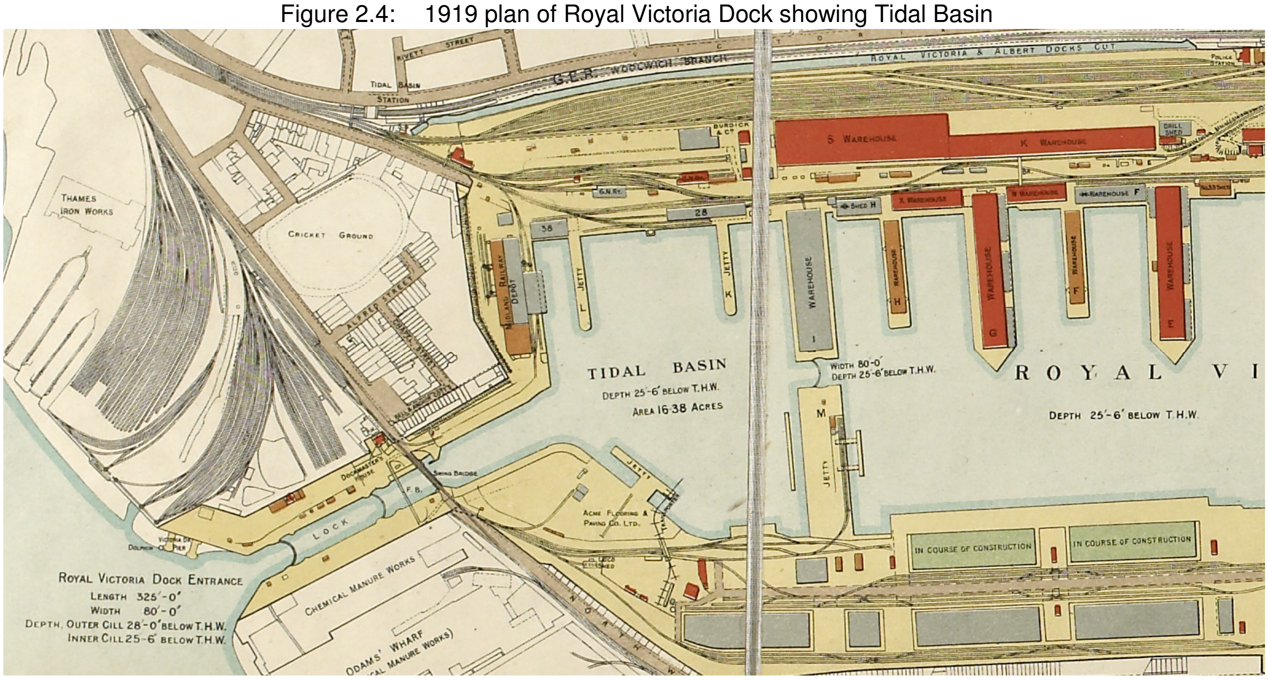
Figure 2.3: North Quay – original construction



Source: PLA Drawing from Museum of London Docklands

The drawing also shows the construction of the jetties which extended into the Tidal Basin, which is different to the small jetties which extended into the main dock. Although there is no indication of material in the drawing, the “Improvements at the Royal Docks” paper refers to the main dock small jetties as being constructed of timber. Other archive documentation refers to the westernmost jetty as ‘L’ and easternmost jetty as ‘K’ (see Figure 2.4 for plan).

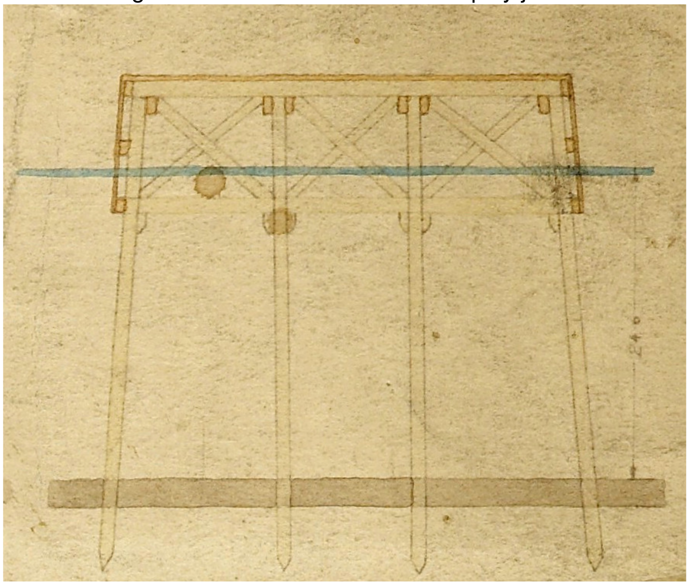
Figure 2.4: 1919 plan of Royal Victoria Dock showing Tidal Basin



Source: PLA Drawing from Museum of London Docklands

The construction of the two jetties is shown as the same in the drawing - four piles in cross section (see Figure 2.5 for end on section).

Figure 2.5: Tidal Basin – north quay jetties



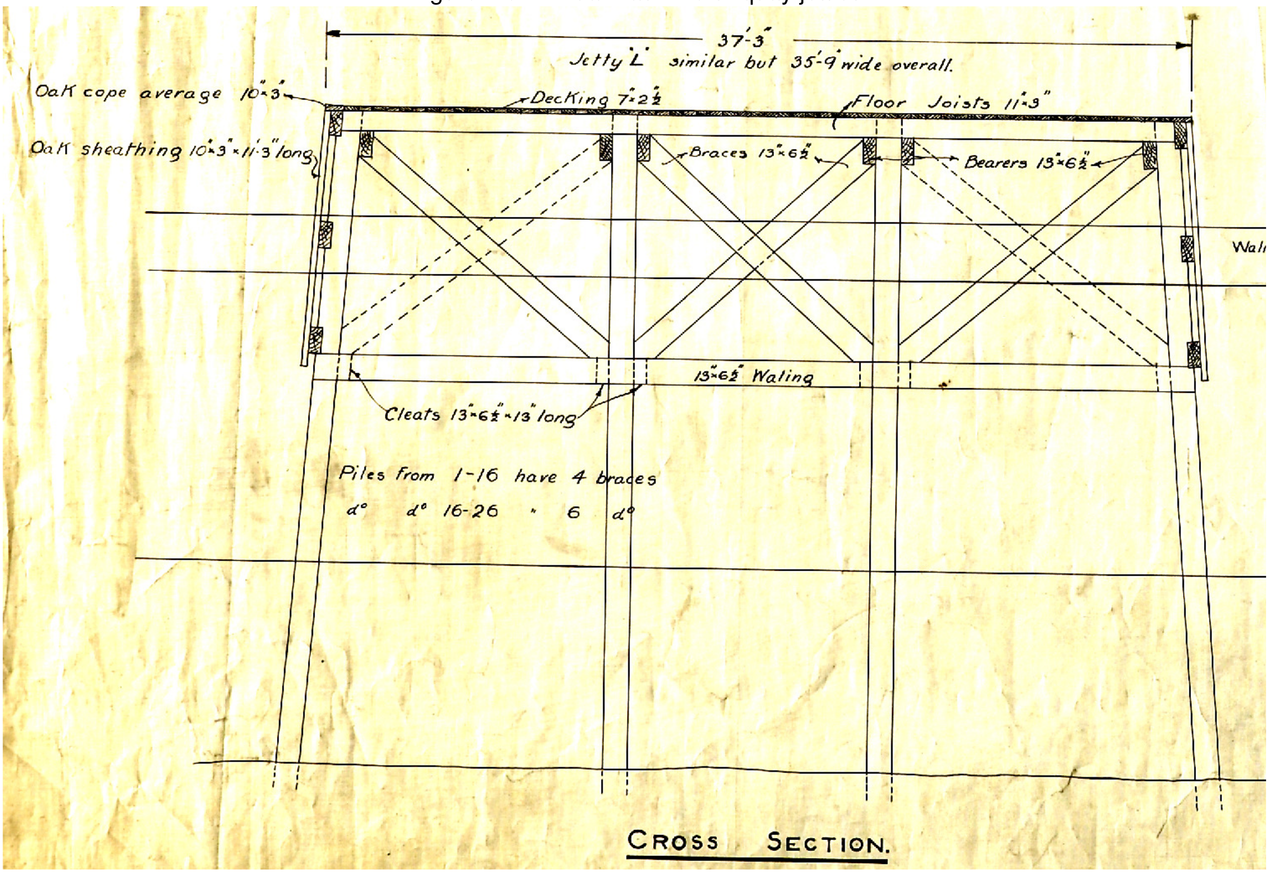
Source: PLA Drawing from Museum of London Docklands

The depth of the water (to the 'puddle' material) is shown to be 24'-6" (approximately 7.5m). No information on the width or length of the jetty is provided in this drawing. Other jetties of similar construction are shown to be 9.1m and 14m long from the jetty surface (see drawing 'N205' shown in Appendix A.7), however, the variation in forms of construction of the jetties is great, so this is unlikely to be representative.

With regard to water levels, it may be worth noting that the distance between water level and the base of the dock adjacent to the large jetties separating the Tidal Basin from the main dock is 23'-6". It should be noted that due to the drawing showing only one side of the jetty this may represent the dimensions in the main dock. However, cross-sections for the main dock small piers show a water level above base of dock to be 26'-0".

PLA drawing 7430087 (see Appendix A.7) shows details of K and L jetties. It is consistent with drawing N205 (see Figures 2.5 and 2.6). The naming of the structural elements suggested timber construction and the cross-section has the similar 4 pile arrangement. The width of the K jetty is 37'-9" (11.5m) and L jetty is 35'-9" (10.9m). The 'Part Elevation' view shows the elevation along the length of the jetty. The piles are shown at 12'-0" (3.7m) centres. The 'Plan of Jetty' view shows the jetty extending 300' into the Tidal Basin and the regular equidistant grid of the piles denote an average of 12'-0" centres. The drawing also denotes that "piles average 13" x 13" ". A note in pencil on the drawing says "demolished", which is consistent with the historical maps which suggest the jetties are demolished between 1920 and 1938. Timber piles may not have been removed and may remain embedded below dock bed level.

Figure 2.6: Tidal Basin north quay jetties



Source: PLA Drawing from Museum of London Docklands

Comparison of the 1920 and 1938 historic maps show that the profile of the north quay of the dock has changed. A set of seven drawings show the “Royal Victoria Dock, North Side – Tidal Basin, Meat Accommodation” circa 1920. The Meat Accommodation is the building occupying the land on the north side of the Tidal Basin. The drawings are marked as traced from the originals in July 1923 and some are marked as drawn on the same date. It is possible that this reconstruction was planned to take place prior to the demolition of the ‘I’ jetty (and thereby the major reconstruction of the rest of the north quay). This is supported by figure 1 from “Improvements at the Royal Docks, Port of London Authority" by Liddell which shows “Blocked-in areas of new work”. This shows that the works described in the paper modified only the eastern corner of the Meat Accommodation quay.

Drawing No.1 (PLA drawing number 7620563) appears to show the “Main Shed”, the “Barge Berth Shed and the quay superimposed on earlier infrastructure including the L and K jetties and the earlier line of the quay. From this main drawing, seven cross-sections of the quay are drawn and presented some at the bottom of drawing No.1 and the remaining section on drawing No. 2 (PLA drawing number 7620566). The cross-sections on drawings No. 1 and No.2 show that the Impounded Water Level (IWL) is +15.0 feet above Ordnance Datum (AOD), the Trinity High Water (THW) is +12.5 feet AOD and the Lowest Water Level (LWL) is 11.0 feet AOD. Note that Ordnance Datum is likely to be related to Liverpool not Newlyn as current day (see section 5.3). Drawing No.1 also shows spot levels in the Tidal Basin adjacent to the quay. Level range between 21.75 feet in the western part and 25.6 feet roughly at the centre of the area. An area in front of the quay is highlighted as “to be dredged 29’-0” below T.H.W.”, which would be

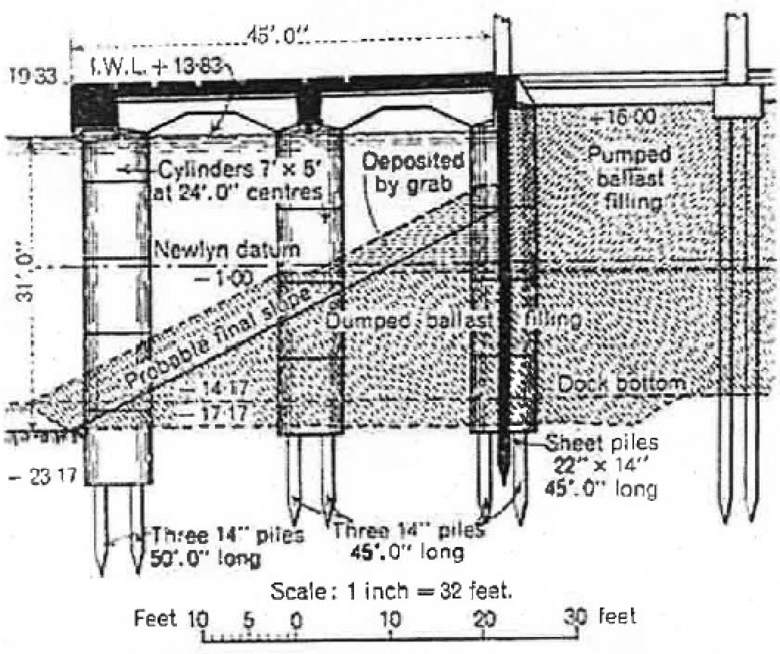
-16.5 feet AOD as highlighted in the cross-section drawings. An aerial photograph shows a large vessel at the 'Tidal Basin' north quay which supports that this dredging went ahead.

The barge berth shed is supported on one set of piles in front of the quay sheet pile wall, extending approximately 20 feet into the dock. The main quay extends approximately 50 feet into the dock (see Drawing No. 4, PLA drawing number 7620568). Three sets of piles of similar construction to those in front of the barge berth shed extend from the quay sheet pile wall. Each set of piles which supports the quay consists of a reinforced 5'-6" diameter concrete cylinder containing two, three or four square 14 inch by 14 inch reinforced concrete piles (see Drawing No.7 for precise layout of 4 pile arrangement). The cylinder shell was installed in 8'-0" sections and those not at the front of the quay extend down to the assumed ballast level. The front of the front cylinder in the dock was embedded "not less than 2'-0" " below approximate ballast level (see Drawing No.7). Drawing No. 5 (PLA drawing 7620569) notes that the 14" x 14" piles should be driven 10'-0" into the ballast layer. It also notes that the 14" x 14" square reinforced concrete sheet piles at the land side of the quay and barge berth should be driven 5'-0" into the ballast. The assumed ballast level is not provided on any of the drawings, however, the bar schedule on Drawing No. 6 (PLA drawing 7620570) shows that the 14" square piles were taken as 40'-0" long and the sheet piles were taken as 35'-0". Reinforced concrete piles may not have been removed and may remain embedded below dock bed level.

Further details of the piles and cylinder rings are provided in Drawing No.6. The toe of the shoe for the main piles is 3'-0" long which tapers to a point. It is unclear what material is used for the toe. The detail shows that steels straps are cast into the shoes and the toe extends a further 6 ¾". A 1 ½" tube is provided from the upper end of the pile to the tip. "4 No. 5/4" dia. cored holes. The purpose of this tube is not shown on the drawings, however, there remains a possibility that it was used to grout around the toe of the pile at installation depth (of 10 feet below ballast level). So in addition to the piles embedded into the dock, there may be surrounded by grout.

During the redevelopment of the Royal Docks between 1920 and 1938, the eastern (and major) section of the northern quay wall construction comprised a suspended deck founded on three rows of driven piles up to around 15m below bed level, upon which concrete or stone cylinders are founded. Each cylinder is founded on three 350mm diameter driven piles. The depth of piles is listed as 45' or 50' (13.7m to 15.2m) long. A figure extracted from the references above showing a cross section through the quay wall is provided as Figure 2.7.

Figure 2.7: Section through (main dock) north quay



Source: "Improvements at Royal Docks .." by Liddell

The eastern section is well documented by Liddell, but much less information is provided on the western end of the north quay wall adjacent to the north 'Drive' station. The paper by Liddell describes work carried out in 1937;

"At the west end [of the north quay], cylinders were sunk and the small recess decked over for the extension of "Z" shed and quay 120 feet eastward to "I" jetty, where pre-cast sheeting piles were driven along the west side of the jetty prior to forming a false quay on one row of cylinders.".

The "I" jetty in the paper refers to the northern 'barrier' jetty between the Tidal Basin and the main dock. The 120 feet (roughly 37 metres) does not correspond with the entire length of the jetty shown in the historical maps. This distance corresponds to the distance between the eastern end of the Meat Accommodation quay and the "I" jetty. This small distance can be seen in PLA drawing 7620568 split into 50 feet of tapering at the end of the quay and 70 feet of dock wall. The extension mentioned in the paper can be seen in the London Docklands Development Corporation drawing CE 0004/04/C/00 names "Royal Victoria Dock Low Level Sheet 3, Actual Trial Pit Layout". There is no date on the drawing, but the Ordnance Survey plan used as a base states that it is a "Copy of revised field sheet made on 11-10-82". Again piles used for this re-development may not have been removed and may remain embedded below dock bed level.

The area below the newly formed quay was filled with the dredged material from the dock. Demolition material was also used as fill for the area under the quay, which agrees with PLA drawing 7620569.

Following the closure of the dock in 1982 to commercial activity, further redevelopment work was carried out. Historical Ordnance Survey plans again show a change of alignment. These changes were carried out under LDDC and no PLA drawings cover this redevelopment.

The records viewed at the Museum of London Docklands were only from the PLA archive as the LDDC documents held were corporate documents. The remaining LDDC records were held by the Homes and Communities Agency (who took over the role from English Partnerships), but subsequently the majority of the records were distributed to the Royal Docks Management Authority (RoDMA), British Waterways, the London Borough of Newham and the London Metropolitan Archives. The London Metropolitan Archives have confirmed that they have no construction plans, so the LDDC construction plans are likely to be held by either the London Borough of Newham or British Waterways.

2.3.7.3 Channel and lock structure (Western Entrance)

Historically, entrance to the Royal Docks was via the Western Entrance. A lock was provided along with a Tidal Basin to allow entry to the docks throughout the majority of the tidal vicissitudes. The lock had two lock gates often referred to as the upper dock gates and the lower dock gates, which is the terminology used in the following text (The gate between the Tidal Basin and the main dock was often referred to as the "inner gate"). The total length of the lock is approximately 135m for the straight sided length. The lock varies in width, but is around 24m wide. The coping level of the entrance and the entrance lock walls was built to match the historic bank level of the Thames at this location (5 feet above THW). London Clay was found at 37 feet below THW, so the brickwork for the upper and lower gate cill were laid at 37'-6" below THW.

The depth of the channel at its western entrance adjacent to the Thames is likely to be at around 2.9mOD and 3.6mOD for the inner lock. This is taken from Locke who writes that the levels of the base of the dock and lock are as follows;

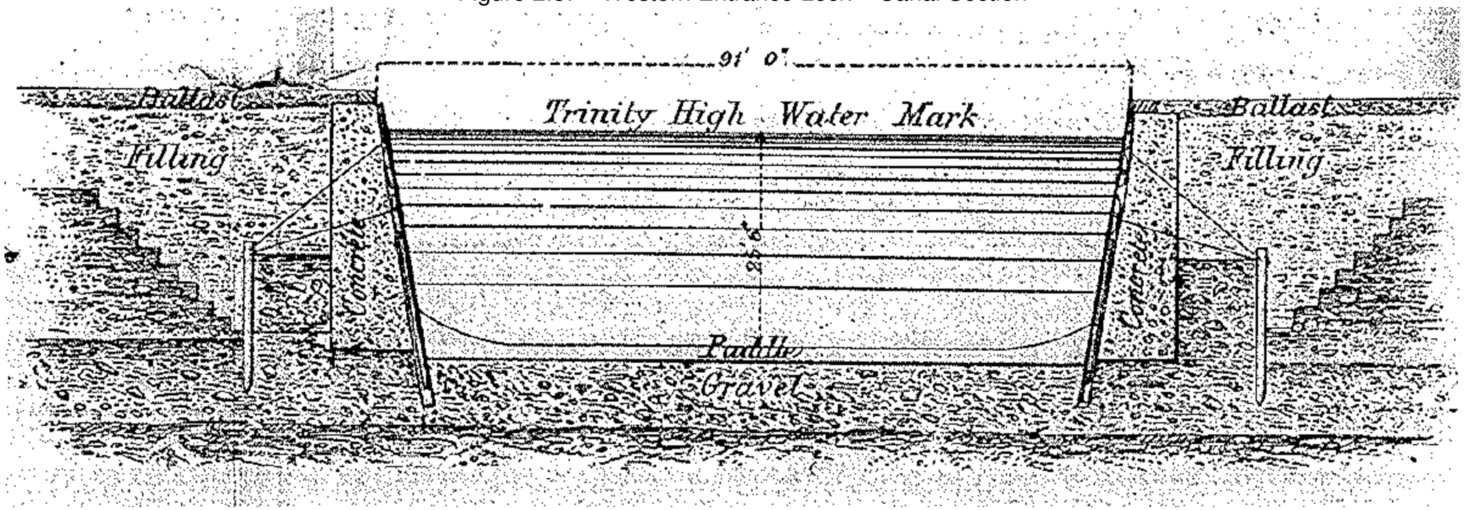
- Tidal Basin and main dock = 24'-0" below THW
- Channel leading to the lock from the Tidal Basin = 25'-8" below TWH
- Cill of the upper gates = 25'-6" below THW
- Lock, cill of lower gates, channel toward river = 28'-0" below THW

Shortly after construction it was remarked that at the Trinity low water mark, the depth of water was 10 feet on the lower cill and 7 feet 6 inches on the upper gate cill.

The available records indicate that the channel was originally constructed from brickwork, concrete and cast-iron. The channel is formed from mainly of cast-iron piling and plates backed with concrete side walls. This side wall construction is interrupted in two places, for the brickwork of the gates.

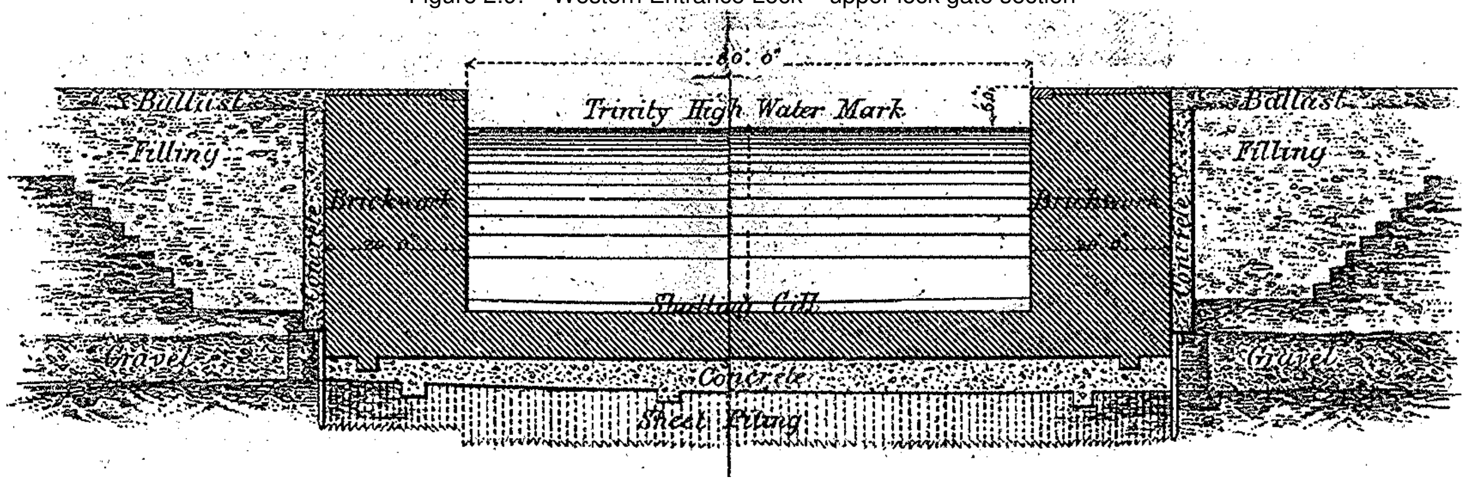
There are five distinct sections along the Western Entrance (see Figures 2.8 – 2.11 for cross sections of the first four sections). The cast-iron piling is similar to a king post wall and has a batter of 2 inches in a foot. This construction commences in the trapezoidal "canal" leading from the Tidal Basin to the upper gate. The upper lock gate has brick side walls which are approximately 6m thick and vertical. The non-vertical cast-iron sheet pile walls recommence for a further 256 feet 10 inches until the lower lock gate structure which again has vertical brick side walls (itself 73 feet 3 inches in length). Following the second gate, the piled and concrete side walls recommence, running parallel for 85 feet, then widening out in trapezoidal form for approximately 200 feet in the northerly direction and 160 feet in the southerly direction.

Figure 2.8: Western Entrance Lock – Canal Section



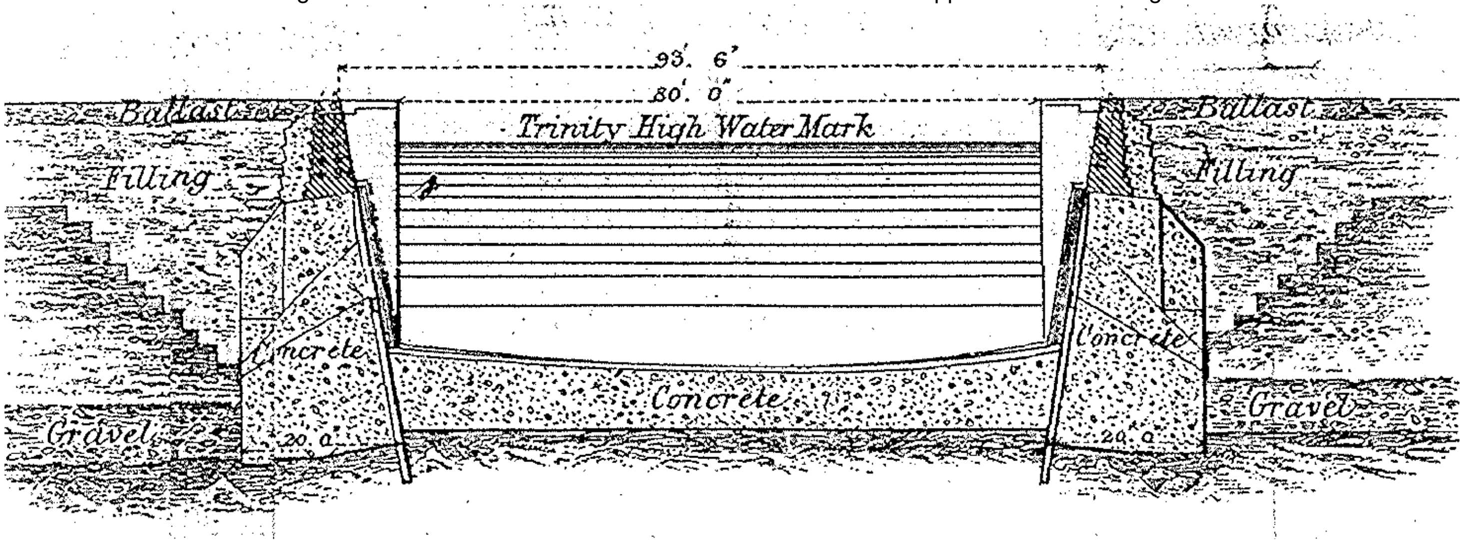
Source: PLA Drawing from Museum of London Docklands

Figure 2.9: Western Entrance Lock – upper lock gate section



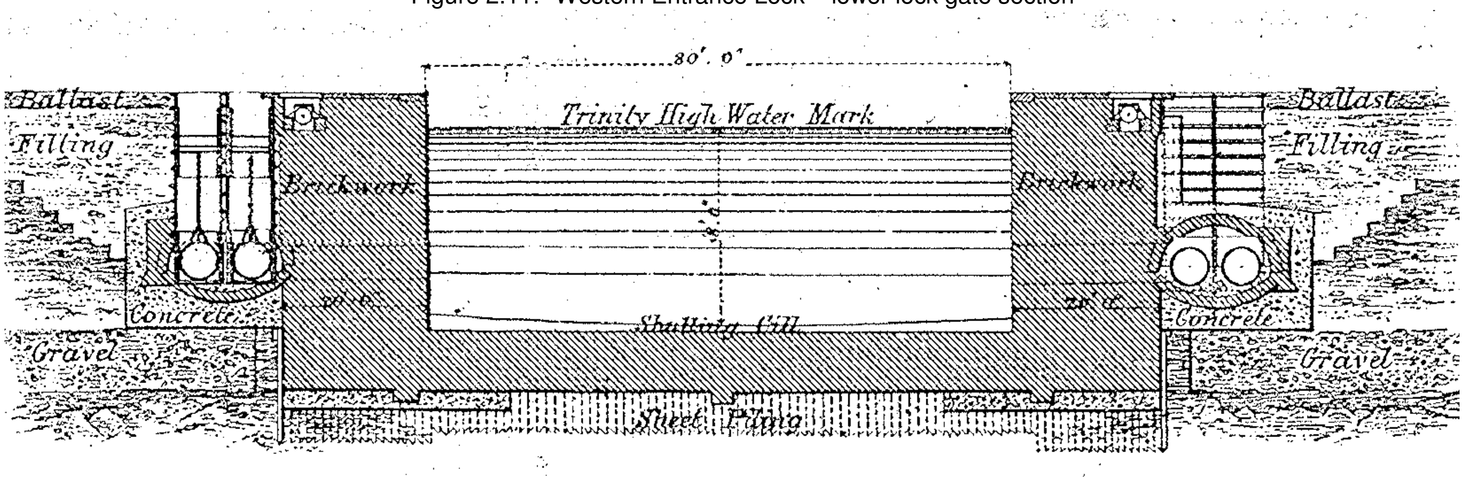
Source: PLA Drawing from Museum of London Docklands

Figure 2.10: Western Entrance Lock – Section between the upper and lower lock gates



Source: PLA Drawing from Museum of London Docklands

Figure 2.11: Western Entrance Lock – lower lock gate section



Source: PLA Drawing from Museum of London Docklands

The cast-iron piles are formed in bays (like king-posts) and are placed 7 feet 1 inch centre to centre. Each main pile is split into two sections totalling 37 feet and 8 inches (joint occurs 12 feet 8 inches from the top). In the top 15 feet, the intervening space is filled by three cast-iron plates with back feathers (each plate 5 feet in height, length 5 feet 11 inches), retained laterally by the main piles which stand in front of them. The lower intervening space contains four cast-iron sheet piles (each 20 feet in height). The front edge of the stone coping of the wharf, which is 18 inches in thickness, is carried by the upper plate.

A timber land pile is connected to each main cast-iron pile. Each pile is 18 feet from the pile wall, 20 feet long and driven to the same depth as the pile wall. The pile is connected to the pile wall via two wrought-iron rods, each 2 inches in diameter. One rod is connected to the upper end of the lower section of the main pile and the other rod is connected to the upper main pile, at a distance of 8 feet above the former.

In the 'canal' section, the channel was excavated to a depth of 27 feet and 8 inches below THW and 2 feet of clay puddle was placed bringing the level of the bottom on the channel to 25'8" as noted above. The main piles were driven 5 feet into the gravel, the sheet piles were driven 2 feet 6 inches into it and the concrete wall was carried to the bottom of the clay puddle. The space between the concrete wall and the land ties was filled in with "well rammed" gravel.

In the vicinity of the lock gates, the gravel in the bottom was taken out down to the clay. A portion of the gravel on each side of the channel was left in place. The main piles were driven into this gravel and the concrete forming the toe to the wall was laid on the gravel. In between the walls above the London Clay, clay puddle was laid "to the proper level". It is noted that timber (elm) sheet piles are identified extending into the ground beneath the lock cill structures.

Beyond the lower gate platform the concrete walls extend to the land tie piles. Above this level the thickness of the concrete walls gradually decreased until they were about 10 feet (due to the batter of the piles, this works out as roughly 6 feet at the top). The coping stone is 18 inches thick and 3 feet "on the bed". The concrete was composed of clean gravel, containing two-thirds coarse gravel and one-third sharp grit, and Halling lime in the proportion of 6:1. It was reported that "The lime was not ground, but used hot, and the concrete was found to set very hard".

Due to the competent layer of London Clay, ordinary brickwork in level courses was laid directly onto the ground. The upper gate platform was 120'-0" wide and 83'-3" long and the lower gate platform was 120'-0" wide and 73'3" long. Around each of the platforms a single row of elm sheet piles, 16 feet in length and 8 inches thick, was driven close, to a depth of 6 or 7 feet into the solid clay. The heads of the piles are levelled and secured by walings. The aim of this was to cover the horizontal joints in the brickwork. For the lower gate, the brickwork was laid 8 feet 6 inches thick to the underside of the shutting cill and 9 feet 6 inches thick to the top of the shutting cill. For the lower gate, 4 feet 6 inches of concrete was laid followed by 6 feet 6 inches of brickwork to the underside and a further foot to the top of the shutting cill. Upon these platforms, the side walls were carried up in brickwork, including the copings, to heights above the cills of 33 feet for the lower gate platform and 30 feet 6 inches for the upper gate platform. The breaks in the coping to allow for the roller frames when the gates are opened back are covered with a cast-iron plate.

The associated plate also shows the presence of tie bars and anchor blocks to the channel side walls on the eastern side of the channel. Whilst these are not shown on the western side of the channel they may well be present. The tie bars are approximately 6m long.

PLA drawing 7762015 shows "Royal Victoria Dock – Western Entrance – Strengthening Inner and Outer Gate Platforms" and is dated "1/1/29". The plan shows that this refers to the upper and lower gate platforms as described earlier. The drawing shows the strengthening works including additional reinforced concrete and cast steel roller paths. The following note is included on the drawing to describe the proposed strengthening works;

"Add re-inforced apron over Gate Platform;
Raise gates bodily 7'-0";
Fit new granite Sill;
Replace existing cast steel roller paths (if found in satisfactory condition); and
Fit new steel casting to take bottom heel pintles.
…[ ]"

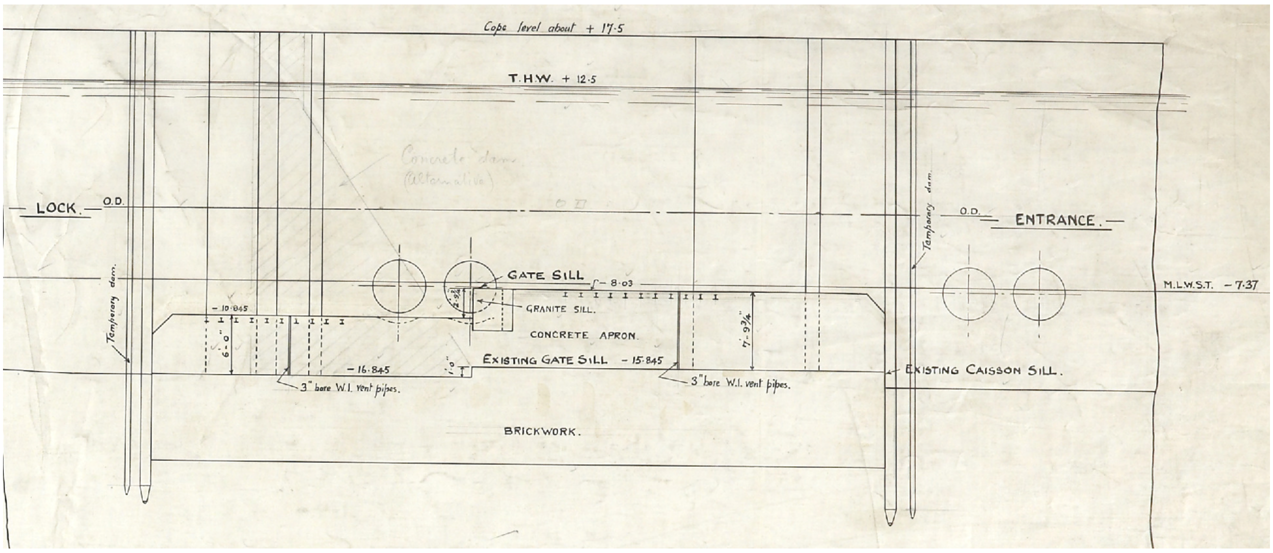
The following note is provided on the reinforced concrete apron:

"Whole top surface of concrete apron to be re-inforced with old 75 lbs flat bottomed rails, at 18" centres, these rails should be each in 3 lengths, lapped 8'-6" at joints, and where necessary must be kept low enough to pass under roller paths.

The whole area of concrete apron must be studded with 3" bare wrought iron pipes spaced 10'-6" apart, passing down through whole thickness of new concrete."

The details of the lower platform are shown on the drawing in plan and elevation and can be found in Appendix A.7. Figure 2.12 shows a cross section along the platform detailing the iron in the concrete apron.

Figure 2.12: Western Entrance Lock – lower lock gate section showing gate sill details



Source: PLA Drawing from Museum of London Docklands

Drawings of a proposed redevelopment of the Western Entrance Lock show various proposed details. PLA Drawing 7762346 shows two dams within the lock containing both lock gates. The 'existing dredged level' at the dock end of the lock is labelled, ” T.H.W. -21.4’ ”. The dimension shown between the gate platforms and the water level is 32 feet.

PLA drawing number 7762347G, from 1962, with a proposed reconstruction scheme showing a temporary inner dam, a temporary proposed outer dam and the creation of a new outer gate. The area at the top of the inner dam is labelled “Original position of demolished swing bridge”. The eastern end of the level area of the inner dam is labelled “sheet piles”. The inner dam is immediately adjacent to the “Silvertown Viaduct” and directly below the demolished swing bridge. Existing cope level is shown as T.H.W. +4.6’ and existing invert level is shown as 28 feet below THW. The distance between the two existing gates is 99m (325 feet) as expected. The plan shows a concrete apron on the river side of the new outer gate. However, the profile is oriented in the opposite direction (riverward) to the profile seen today (away from the river at the centre of the point), so it may not have been built in this format.

PLA drawing 7762492, dated 1962, is entitled “Royal Victoria Dock, Reconstruction of Western Entrance Plan showing existing construction”. It shows 2 No. 3 ½ “ dia. tie rods extending from each side of the outer gate held back by a 10”x10”x10” concrete anchor blocks on “4 No. 9” SQ. piles” 14’ long. However, the same is not shown for the inner gate. The drawing shows a number of items around the inner gate that may be of interest. The foundations of the demolished swing bridge and a demolished footbridge are shown just east of the inner gate. On the north side, a disused machinery pit is also shown which is likely to be associated with the swing bridge. A PLA footbridge and the London Electricity Board (LEB) cable bridge to the east of Silvertown Viaduct are also shown.

PLA drawing number 7762493 is entitled “Royal Victoria Dock, Reconstruction of Western Entrance, Longitudinal Section As Existing” and is dated 14/8/62. This shows the walls of the lock and the river wall within the PLA boundary. It is quite detailed and shows relevant details. The northern extent of the PLA boundary is just south of Thames Wharf and shows a concrete facing with a concrete coping. Below “Original Ground Level”, it notes cast iron plates and piles at 7’-0” crs. Further towards the lock, a timber jetty is shown including a life ladder, followed by a substantial section of timber fendering. Following a knuckle, the fendering continues until the Western Entrance outer lock gate. The cross section of the lock shows that composite timber piles with cast iron sheet piling extends below the concrete. Within the lower gate section, reinforced concrete is shown as extending to between 90.9m and 82.4mATD. The reinforced concrete also shows 3” bore wrought iron vent pipes as expected from the 1929 PLA drawing. A note reports “Both gate platforms reinforced top and bottom with 75 lb bullhead rails”. Below the reinforced concrete platform lies brickwork then timber sheet piling. Further along the lock, the cast iron plates and piles at 7’-1” centres with cast iron sheet piles below the plates recommence. Just south of the upper gate platform a short timber scour platform exists with has 2’-0” concrete below the timber decking. The upper gate platform is similar to the lower gate platform with the additional concrete shown below the brickwork and above the timber sheet piling. Further along the lock the hardcore dam is shown. The services tunnel is approximately below the alignment of the swing bridge and the level section at the top of the dam. The steel sheet piling is also shown, but no toe depth is detailed. Further along the lock, the concrete foundation to the Silvertown Way bridge abutments are shown extending below the clay puddle. The concrete piles are shown as 16” x 16”. On the cross section showing the southern wall, the brick abutment to the demolished swing bridge is detailed on the drawing at the eastern of the hardcore dam.

It may be worth noting that in observing the western lock location using Google maps satellite feature, the car park above the dock appears to have white lines demarking notable features of the dock below it. The extrusions from the white lines are in the likely position of the two lock gates and infrastructure.

The current proposed tunnel alignment appears to pass below the inner gate and the cable car tower is likely to lie within the lock between the hardcore dam and the inner lock gate system. Locations should be checked using overlaying of appropriate drawings of the final alignments so that piles locations can be planned relative to the lock walls. Note also the possible presence of further lock infrastructure behind the lock walls.

As for details of the Royal Victoria Dock, the Museum of London Docklands retains records for both the Port of London Authority and some information from the London Docklands Development Corporation. This includes drawings of the Royal Victoria Docks Western Entrance and the many schemes that were proposed to improve it. Although additional information may reside in the museum archive, limited materials were found by the archivist. Due to the fragility of the archive material, the only method of capturing the data is to take photographs without a flash.

Other sources have also provided some information on the history of the Western Entrance lock. “Dockland – An illustrated historical survey …” suggests that repair and strengthening works, including the fitting of new lock gates, were carried out in 1928 during the renovation of the docks. Silvertown Way has its foundations within the lock; its construction meant that ships could no longer use the entrance. However, “unsoundness necessitated rebuilding anyway by the 1930s”. The lock was reconstructed by Mowlem in 1963-67.

2.3.7.4 Drainage infrastructure associated with the Royal Docks

The drainage infrastructure of the Royal Victoria Docks was found to be generally at capacity when it was assessed for redevelopment in the 1980s and a comprehensive new sewerage system was designed. This included a northern surface water sewer from a pumping station running close to the northern boundary station parallel to the Victoria and Albert Docks, a southern sewer running south from the new pumping station under the closed Western Entrance lock to serve the south western and southern portion of the development area. The river outfall was completed in autumn 1986. It is located just to the north of the former Western Entrance lock to the Royal Victoria Dock, and is sited within several generations of old river walls. The structure has to maintain the existing tidal defences, which is achieved via a weir overflow for the main flood discharge.

The historic drainage infrastructure named “Royal Albert and Victoria Cut” was identified in the Thames Wharf area in the historical maps. A drawing was located that shows a sluice and culvert “for River Inlet in Boundary Ditch”. The boundary ditch discharges into both a pipe “for clearing mud” and a culvert. Both of these then discharge into the Thames. Drawings from the Environment Agency for the Thames Wharf area identified the ditch as a V shaped cutting. The drawing suggests that it was mainly used as a surface drainage system potentially draining directly into the River Thames. Previous visual survey of the cut during the development of the Limmo and Thames Wharf area in 1987 revealed that the channel had timber clad sloping walls, and was at that time described as being in poor conditions. The cut was shown divided in half by the piled DLR embankment in the DLR archive drawings (see Appendix A.10). DLR as-built drawing TBDLCE-HA-GEO-S01-DRG-41000 shows a Victoria Cut culvert at approximately 0+590 chainage, however drawing TBDLCE-HA-GEO-S01-DRG-41011 shows the culvert crossing the embankment at an angle. The latter drawing also shows the culvert to be 1m wide, with a 0.5m RC slab over it extending 2m beyond each edge of the culvert. No further details have been found with respect to this cut. Any tunnels, pipes or culverts that feed this cut may be of concern to the tunnel construction.

A pipe subway is shown immediately west of the swing bridge. The 4’ pipe contains a 12” gas main, a 3” hydraulic main, telephone cables, “West Ham cables” and a G.P.O cable. (Of note, a “fly bridge” is also shown on this plan, which is possibly associated with the upper lock gate. Although this is now demolished, the foundations for this structure may remain.) This pipe subway is also shown as disused on a 1962 'existing' drawing. Another 1962 plan shows the pipe subway being along the level of the puddle layer associated with the lock.

Other, now disused, drainage infrastructure may also be present.

2.3.7.5 Docklands Light Railway

DLR archive records for the Silvertown extension, including as-built drawings of the Silvertown viaduct, were interrogated.

The viaduct commences just to the north of the Royal Docks Western Entrance. A piled embankment is shown (possibly provision for a Thames Wharf Station) following which the viaduct commences. Piers 1 and 2 are to the north of the infilled lock, Pier 3 is within the lock and Pier 4 is to the south of the lock. The piers have piled foundations. Details of the sizes and locations of the piles/pile caps are provided in drawing HA-BRG-PWD-DRG-15000 rev X0 and summarised in the Table 2.3 below. The piles are indicated to be 900mm diameter 'CFA' piles.

Table 2.3: Details of DLR viaduct substructure

Pier	Easting	Northing	Pile cap type	Pile cap depth (mm)	Number of piles	Top of Pile Cap (mAOD)	Pile toe level (mAOD)
1	539904	180475	4	1500	8	2.50	-26.5
2	539960	180462	11	1500	12	3.70	-24.6
3	540002	180442	1	1500	6	4.5	-22.8
4	540029	180422	3	1500	4	2.65	-26.0

Source: HA-BRG-PWD-DRG-15000 (DLR archive drawing)

Pile layout drawings (Drawing Nos. HA-BRG-PWD-DRG-15005 and HA-BRG-PWD-DRG-15006) can be found in Appendix A.10.

2.3.7.6 Thames River Walls

The Environment Agency archive drawings of the Thames river walls were reviewed (see Appendix A.8 and A.9).

North River Wall

The 1978 drawing (ref no TF 146/1987) shows works executed in raising the river bank fronting Clyde Wharf and the Minerva Works to the south of the Western Entrance lock. The river wall appears to have been constructed for the majority of this length from Larssen sheet piles. The northernmost section of the wall is shown as Section No. 2 Larssen sheet pile with a 4'-6" 'R.C. Capping' and a mass concrete parapet (possibly 3' high). Further south along this frontage, the wall is shown as Section No.3 sheet Larssen steel sheet piles with a reinforced concrete parapet (but no mass concrete section). This section also shows a tie rod. The cross-sections state that the northernmost section is 193' long and the southern section is 245' long. The length of the sheet piles and the toe elevation are not shown on this drawing.

Drawing TF64/1966 shows the proposed steel sheet piled frontage at Union Mills in Silvertown which is approximately equivalent to the southern section of the wall described above. The section shown is approximately 270' long in total. "Existing Steel Sheet Piled Frontage (Section No.2 Larssen)" is shown to extend north from the section shown on the drawing (which would correspond with the northernmost section as described above). The southernmost section is described as being 38' long (assumed to refer to the depth of the sheet pile) for the entire length. The tie rods are described as 2 ¾" diameter and 32' long (approximately 10 metres). The tie rods lead to an 'R.C.' anchor block which is 2'-0" by 7'-6" in cross-section. The tie rod is shown as being 2'-6" below ground level adjacent to the parapet. The "Enlarged detail of the steel sheet pile anchorage" shows that 4 No. 12'-0'' long Section No. 1A Frodingham Sheet piles are on the front and back of the anchor block. The anchor block is shown as 2'-0" below ground and the tie is shown as falling to 4'-0" deep at the anchor block. In addition, in this section reinforced concrete beams are shown running perpendicular to the frontage connecting piled foundations to the old concrete river wall frontage. It is not clear if these structures are foundations associated with onshore structures, or have been used as structural support for the river wall or both.

Drawing No. TF 174/96 of the river wall around the Thames Wharf area to the north of the Western Entrance lock shows a concrete edge along with sub-vertical piled timber fenders supported by horizontal steel beams placed at similar intervals along the length of the wall (see Appendix A.8). The actual construction of the wall can be determined from two sections. One section depicting a typical king pile shows the king piles with a wood pattern and another section shows the king piles extending into stoney gravel with horizontal cast iron plates spanning between the king piles. The height of the wall varies along the section, but is shown as 7.0m typically. To the west of this wall is existing sheet piling and to the east is a brick wall. The title of this drawing is "Defective River Wall"; however there is no indication on this drawing of anything unsatisfactory. A later drawing (Drawing No. 723/97 N465) showing a proposed new river wall indicates that the penetration into the river bed is less than 3.0 metres.

Drawing No. TF 615/99 from June 1997 indicates a new river wall constructed in front of the historical river wall. Frodingham steel sheet piles, which have a minimum 19.5 metres penetration into the river bed, are tied back with 60 mm diameter steel rods at generally 1.7 metres centres (see Appendix A.8). The new Frodingham steel sheet section was welded to the existing steel edge at both ends. The anchor bearing plates are fastened to the river-facing line of the sheet piles and the anchor rods are driven through the existing wall and tied back to similar steel anchorage piles approximately 15 metres behind the new Frodingham sheet piling. Each tie rod is attached to an anchor plate at approximately 2.5 metres below ground level; the top of the anchor block is approximately 1.2 metres below ground level. The space between the new sheet piles and existing wall appears to have been infilled with granular fill along the majority of the section and with concrete backfill behind the splayed sections. A new quay slab appears to have been constructed at the top of the newly installed sheet piles. The existing flap valve outlet in the previous face has been extended out by a 10mm thick fabricated box to the new sheet piles.

South River Wall

The drawings from the Greenwich Peninsula site enabling works (Contract 1.2) from c.1997 show the section of river wall adjacent to the O_2 arena towards the location of the historic Greenwich Gas Works and the Powerhouse Jetty further south (see Appendix A.9). This section of the river wall is of interest in relation to the proposed tunnel alignment.

The 1997 drawing of the river wall (Drawing No. TF125/98) shows the existing Larssen sheet piled wall with mass concrete coping at the top with a reduced level of approximately +2.70mOD. The sheet piled wall toes into the river bed at a level of -7.50mOD and has an approximate height of 10m. A new Larssen sheet piled wall is indicated approximately 1.5m in front of the existing sheet piled wall. The top of the new wall is at a reduced level of +5.5mOD and has a toe level of -8.5mOD into the riverbed. The new sheet piled wall has an approximate height of 14m and has been tied back with anchor plates and rods at a level of +3.5mOD to an anchor wall (Larssen sheet piled wall) located approximately 17m behind this new sheet piled wall. The top of the anchor wall is at a level of +3.7mOD (1.8mbgl) with a toe level of +0.1mOD.

Drawing No. TF238/98, showing the plan and section of the new river wall and slurry wall for the peninsula remediation works, indicates the presence of timber cladding on the existing sheet piled river wall in the vicinity of the O_2 arena and demolished Phoenix and Hovercraft Jetties. The top of the existing sheet piled wall ranges from +2.3mOD to + 0.2mOD along this section of the river wall. The drawing indicates a new high level retaining structure for the walkway and cycleway at approximately 7m from the existing sheet piled wall with an elevation of +5.3mOD to +4.8mOD along this section of the river wall. A 0.75 metre wide bentonite slurry wall is indicated approximately 11 metres behind the retaining wall along the entire length of this section of the river wall as part of the river wall development remediation works. Previous GI works around the River Lea Crossing to the north of the River Thames indicated a similar quay wall configuration of tied back steel sheet piles around the River Lea frontage.

2.3.7.7 Foundations of Gas Works and Associated Structures

The edge of one of the main Gas Works buildings was present above the proposed alignment of the tunnel. No records have been found detailing the demolition of this building. Nor have records been found detailing the surface remediation of the Greenwich Peninsula. Therefore it is unknown whether the foundations of the Gas Works building or any of its infrastructure remains underground. The previous infrastructure through which the proposed route passes includes overhead railways, conveyors, hoppers, a travelling crane and tanks.

2.3.7.8 Hydraulic machinery

Hydraulic machinery associated with ship mooring, manoeuvring and cranes within docks is likely to be present around Royal Victoria Dock. William Cory and Sons installed their own hydraulic network in Victoria Dock in 1857 to operate eight hydraulic coal derricks. (Dockland – An illustrated historical survey …). William Cory and Sons coal depot is reputed to be adjacent to the entrance of Victoria Dock, so it is possible that the depot is that alongside the Tidal Basin. The same source also reports that Victoria Dock had “large scale application at new dock” of hydraulic machinery. However, it is not known where such machinery was located. It should be noted that a crane is shown in the centre of the quay north of the Tidal Basin in the earliest historic maps. This crane location coincides with the protrusion in the current day quay profile.

Liddell (1939) writes “It [Royal Victoria Dock] was the first in the port to have railway facilities, and also the first to be equipped with hydraulic power”. In this part of the text it is referring to the ‘fragile’ original 5 jetties in the main dock, so it is possible that hydraulic power was installed throughout the dock.

Fourteen Strothert and Pitt cranes were located in pairs along the north and south docksides of Royal Victoria Dock, three pairs to the north, four to the south. The westernmost pair on the south side are the earliest, possibly 1920s; the rest date from 1962. The cranes are Grade II listed (ref: 251/0/10091 Royal Victoria Dock).

2.3.7.9 Historical Water Levels

There are many references to Trinity High Water throughout the historic records consulted. "Improvements at the Royal Docks, Port of London Authority" lists the following relationships which are reproduced for convenience;

- Trinity High Water (THW.) is 11.4 feet (3.48m) above Ordnance datum at Newlyn (present day OD)
- Newlyn datum (ND) is 1.1 feet below Ordnance datum (Liverpool), so THW is 12.5 feet above ordnance datum (Liverpool)
- Impounded Water level is 15 feet above Ordnance datum (Liverpool)
- Low water spring tides (LWST) is 8.75 feet below Ordnance datum (Liverpool)

Between 1844 and 1921, Ordnance Datum was taken from the level of a tidal pole at the Victoria Dock in Liverpool. So drawings between these dates that include 'O. D.' will refer to the Liverpool Ordnance Datum. The different between Liverpool and Newlyn Ordnance datum varies throughout the country and the Ordnance Survey website has a facility for determining the correction based on the kilometre square in their grid system. Their website listed the correction for TQ395813 is -1.3 feet. This does not agree with the Liddell paper, so this does not give confidence to either value, but the Liddell paper has been given preference in this report due to the possibility that the value is more location specific.

2.3.8 Potential Ground and Groundwater Contamination

The potential for ground and groundwater contamination within the Silvertown project study area has been addressed in the Phase 1 Contamination Assessment undertaken by Mott MacDonald as part of the Ground Investigation Desk Study commission. Overall the site has been given a MODERATE to HIGH risk rating.

The principal contamination sources in the Silvertown area comprise former land uses including rail land (including coal and goods depots), manure works, chemical works, garages and an engineering works as well as those associated with continued use for industrial activities. On the Greenwich Peninsula the principal contamination source relates to the former South Metropolitan Gasworks which dominated this area between the 1860s and 1980s. A single remaining gas holder is the only above ground remnant of this former facility. Site wide remediation of the gasworks was undertaken during the late 1990s by British Gas and English Partnerships. It is understood that key sources of contamination, such as tar tanks and known contamination hot spots, were removed, groundwater remediation was undertaken and near surface soils were removed or cleaned prior to landscaping. However, it is understood that contaminated materials remain at depth beneath much of the site. Additionally, asbestos was encountered in the 'inert' backfill to the Western Entrance Lock to the Royal Victoria Dock during the ground investigation for the London Cable Car project.

There are no sites determined as Contaminated Land under Part IIA of the Environmental Protection Act 1990 within 250m of the Silvertown site.

Asbestos

During the ground investigation for the London Cable Car project, asbestos was encountered within the Made Ground used to infill the former Western Entrance to the Royal Victoria Dock. Laboratory testing undertaken as part of the London Cable Car ground investigation revealed that the onsite asbestos contained fibres of Chrysotile, Crocidolite, and Amosite. Details of the extent of the asbestos within the study area are not known.

Landfill

Landfills have been identified on both the northern and southern sides of the Thames. Landfill materials can potentially be contaminated and very variable in nature. On the northern side of the river the landfill is associated with the infilling of the former Western Entrance lock to the Royal Victoria Dock.

On the southern side of the Thames, landfill is designated in an area adjacent to the south portal of the tunnel crossing. Within this zone, south of Edmund Halley Way, there is a registered waste treatment or disposal site. The site has surrendered a completion certificate.

The contamination assessment made the following recommendations:

- Undertake an intrusive site investigation and laboratory testing together with a programme of environmental monitoring to more fully understand the conceptualised pollutant linkages identified;
- The results of these investigations should be used to inform a quantitative risk assessment, and can also be used in materials management and site construction environmental management plans;
- The scope of any investigation that may be required for planning purposes should be discussed with the regulators (local planning authority environmental health and Environment Agency).

Reference should be made to the report, 'Phase 1 Contamination Assessment, Silvertown to Greenwich Peninsula' (Document No. 320530/MNC/TUN/03) for further details.

2.3.9 Environmental Considerations

Sensitive land uses

No 'Sensitive Land Uses' have been identified along the proposed tunnel alignment.

Surface water bodies

As noted previously there are three surface water bodies either along or immediately adjacent to the alignment of the road tunnel, namely:

- River Thames;
- Royal Victoria Dock; and
- River Lea.

Flood risk susceptibility

On the northern side of the Thames, the flood risk potential is categorised as 'Flooding from Rivers or Sea without Defences (Zone 3)' along the proposed tunnel alignment.

On the southern side of the Thames, immediately adjacent to the Thames the flood risk is categorised as 'Extreme Flooding from Rivers or Sea without Defences (Zone 2)', whilst further inland on the Greenwich Peninsula the flood risk is defined as 'Flooding from Rivers or Sea without Defences (Zone 3)'. The proposed area of works is upstream of the Thames Barrier and is expected to be protected from a 1 in 1,000 year event.

Groundwater abstraction

Groundwater abstraction is undertaken at several locations in proximity to the proposed works. On the northern side of the River Thames, adjacent to the north quay of the Royal Victoria Dock, there is an abstraction well operated by Meadowshire Limited.

On the south side of the Thames, there are three groundwater abstraction points in proximity to the proposed works. One is situated close to the London Underground North Greenwich underground station; there is a second abstraction point operated by Greenwich Peninsula N0204 Block A Nominee 1 & 2 Limited.

There are two groundwater abstraction points along the southern approaches alignment. One is operated by the Urban Regeneration Agency from a borehole in Boord Street and the other is operated by "Hanson Quarry Prod Europe Ltd" from a borehole in Victoria Deep Water Terminal, Tunnel Ave, Greenwich. The latter abstraction point is at a quarry producing crushed rock and marine sand and gravel.

It is not known whether groundwater is currently being abstracted from these wells. Design for buried structures will need to consider the full range of groundwater pressures that might occur as a result of the recovery of groundwater levels, or by increased groundwater abstraction.

Cooling groundwater discharge consents

Cooling groundwater discharge consents have been granted to approximately five operators located less than 100 metres southwest and northwest of the site of the proposed works.

Industrial archaeology

Both north and south of the proposed crossing, structures are located in areas of historic industrial development. Consequently, there are potentially features of industrial archaeological importance. This may however be less of an issue on the southern side of the Thames, given the more recent ground remediation works.

2.3.10 Unexploded Ordnance (UXO)

The Silvertown study area is located in an area of east London which is known to have been heavily bombed during the Second World War (WWII). As part of the London Cable Car works, an Unexploded Ordnance (UXO) assessment was undertaken as part of the ground investigation; however, its extent was limited to the exploratory hole locations. Therefore, a Stage 2/3 Detailed UXO Threat Assessment of the study area was commissioned in accordance with the requirements of CIRIA C681 'Unexploded Ordnance (UXO) – A guide for the construction industry'.

Detailed UXO Risk Assessment

The findings of the UXO assessment are detailed in the report, ‘Detailed Unexploded Ordnance (UXO) Risk Assessment’, prepared by 6 Alpha Associates. For the purposes of the assessment the site was divided into three areas:

- The area north of the River Thames;
- The River Thames; and
- The area south of the River Thames.

The assessment established that in the areas north and south of the River Thames, there is a ‘Medium/High’ risk of encountering UXO. However, in the River Thames, where bomb strikes are considered more likely to go unnoticed, the risk level is increased to ‘High’. This is highlighted in the WWII High Explosive (HE) bomb strike location plan (Figure 6) shown in Appendix A.5.

6 Alpha have recommended that once the scheme design and construction programme has been finalised, a detailed UXO risk mitigation strategy should be developed for the project. For the areas north and south of the River Thames, 6 Alpha have recommended that, in the first instance, both non-intrusive and intrusive survey methods may be employed to clear the site of any potential UXO threat in advance of any intrusive ground works.

For the River Thames section, 6 Alpha have recommended that a magnetometer survey should be employed to clear the site of any potential UXO threat. Where any intrusive ground works, such as ground investigation, piling or tunnelling are to be undertaken, 6 Alpha have advised that a specialist UXO banksman should be present on site to identify the potential for any UXO threat.

2.4 Ground Conditions

2.4.1 Previous Ground Investigations

This section provides a description of the anticipated ground and groundwater conditions at the Silvertown study area based upon the available factual geotechnical information obtained from previous ground investigations undertaken within the study area. A summary of the previous ground investigation undertaken at the Silvertown study area is provided in Table 2.4.

Table 2.4: Previous ground investigations undertaken at Gallions Reach

Ground Investigation	Date	Scope
London Cable Car	2011	36 No. boreholes (7 No. overwater); 14 No. trial pits; 9 No. dynamic sampling; 6 No. concrete coring; Pressuremeter testing in 4 No. boreholes.
Blackwall Tunnel Southern Approach Route	1965	130 No. boreholes; 2 No. trial pits.

2.4.1.1 Cable Car for London Ground Investigation (2011)

In August 2010, Mott MacDonald were commissioned by TfL to undertake a geotechnical desk study to assist with the design of a proposed cable car scheme across the River Thames between Royal Victoria Dock on the north side of the River Thames and the Greenwich Peninsula on the south side of the River Thames. In September 2010, the scope of the desk study was expanded to cover a proposed tunnel crossing scheme being developed at the same location.

The ground investigation for the London Cable Car was undertaken by Soil Mechanics in January 2011 and comprised cable percussion and rotary core boreholes, trial pits, dynamic sampling and concrete coring. The exploratory holes were positioned at five distinct sites, within the vicinity of the key structures associated with the proposed cable car scheme:

- The North Station (NS);
- The North Intermediate Tower (NIT);
- The North Tower (NT);
- The South Tower (ST); and
- The South Station (SS).

The names of each exploratory hole were prefixed with NS, NIT, NT, ST, TU or SS to denote the work site. There were two boreholes, prefixed TU, which were sunk along the alignment proposed Silvertown Tunnel. A summary of the London Cable Car ground investigation is provided in Table 2.5. The locations of boreholes located within the vicinity of the proposed Silvertown Tunnel alignment are shown in the geological long section (Figure 1) contained in Appendix A.3.

There was a significant amount of in situ and laboratory testing undertaken as part of the London Cable Car ground investigation.

Table 2.5: Summary of the London Cable Car ground investigation

Exploratory Hole	Quantity	Maximum Depth (m)
Cable percussion boreholes	17	25.00
Cable percussion boreholes extending using rotary core drilling	13	61.07
Rotary open hole drilling	6	9.20
Trial pits	14	4.00
Dynamic sampling	9	5.00
Concrete coring	6	1.50

2.4.1.2 Blackwall Tunnel Southern Approach Route (1965)

The ground investigation for the proposed dual carriageway Blackwall Tunnel Approach was carried out between March and August 1965. The fieldwork initially comprised 128 No. boreholes along the current alignment of the Blackwall Tunnel Approach (A102) between the Blackwall Tunnel and Shooters Hill Road (A2).

There were 2 No. additional boreholes sunk in September 1965 as part of a geophysical survey undertaken to prove the location of a suspected fault close to the junction of Tunnel Avenue and Glenforth Street, south of the Silvertown study area. The results of the geophysical survey did not support the Geological Survey supposition that there is a fault present in the area.

2.4.2 Made Ground

Made Ground can be anticipated to exist on both the northern and southern sides of the Thames as a result of historic redevelopments. The thickness and nature vary across the site and depends on previous development and land use. In addition, the presence of Made Ground within the River Thames, adjacent to the southern mast tower, cannot be discounted given the presence of the former jetty structure. The nature of the Made Ground used as fill within the entrance lock would be different to that outside the lock which may have undergone compaction over time and due to recent redevelopment works.

The descriptions of Made Ground in the area consist of loose to medium dense dark grey slightly clayey, silty fine to medium SAND with angular to rounded fine to medium size fragments of flint and concrete and fairly compact mixtures of ash, bricks and concrete rubbles. Typical secondary constituents include fragments of polythene, chalk and flint fragments, traces of peat, timber, tile, bone, and cinder. Made ground is likely to be variable, and possibly soft/loose and weak.

2.4.3 Alluvium

The published geological map indicates Alluvium to be present along the tunnel crossing and across the cable car routes. The Alluvium rests unconformably on the Thames River Terrace Deposits. It comprises of river deposits of primarily silts and clays with seams of sands and gravel. Pockets and beds of peat and organic material are also present which may include gases from decomposition of the organic matter. These deposits were laid down in the valley floors in the Holocene era and formed the original marsh deposits in the area prior to 19th century industrial development.

A typical Alluvium description comprises of soft and firm mottled dark brown mottled black silty CLAY with occasional small pocket of peat and very soft dark brown clayey PEAT.

Distinct peat layers with thicknesses ranging from 0.8 metres to 4.5 metres were encountered in boreholes both north and south of the River. No peat was encountered within the over water boreholes within the Thames.

Within the alluvial clay moisture contents are within the range of 37% to 77%, averaging 55%. The Plasticity Index varies between 23% and 57% and Liquid Limits from 40% to 126% indicating that the material is medium to extremely high plasticity and essentially normally consolidated. The results are illustrated in Figure 2.13. The undrained shear strengths for the Alluvium range from 4 kPa to 63 kPa (averaging 22kPa) representing extremely low to medium strength clay.

Within the Peat the moisture contents are in the range of 82% to 239%. The Plasticity Index varies between 28% and 131% and Liquid Limits from 58% to 237%. The Peat can be expected to be highly compressible and subject to long term creep.

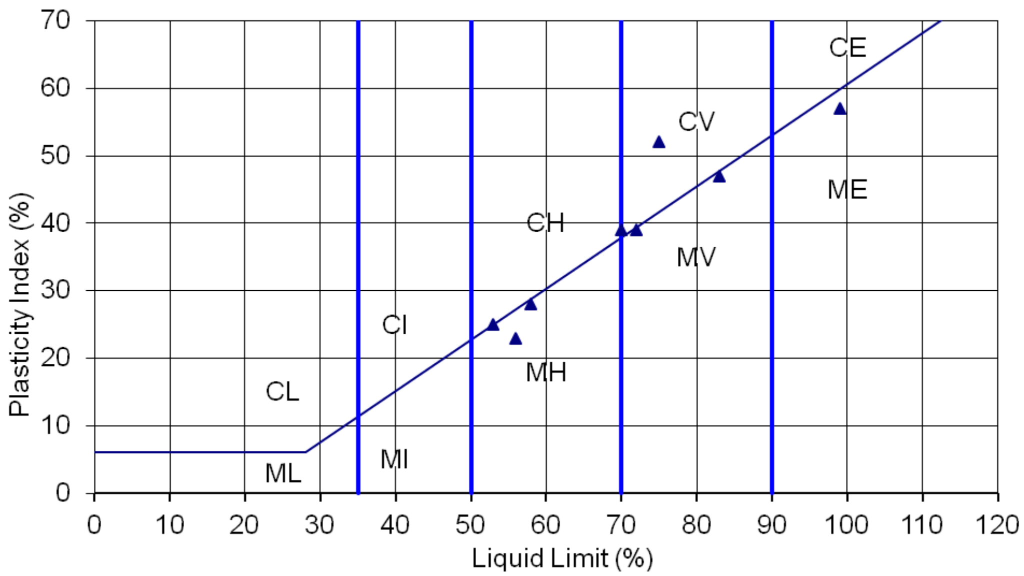


Figure 2.13: Plasticity chart for samples taken within the Alluvium

2.4.4 River Terrace Deposits

The published geological map indicates Thames River Terrace Deposits to be present across much of the docklands area. The River Terrace Deposits are described on the published geological map as gravels with pockets of sands and clays with an estimated thickness of 2.0 metres to 5.0 metres. They were mainly deposited during the colder climatic periods of the Pleistocene formed in response to heavy snow-melt run-off which formed a series of braided channels that interlinked within the wider flood plain to form the Thames River Terrace Deposits.

Typical descriptions of the River Terrace Deposit are ‘medium dense to dense grey brown sandy GRAVEL’ and ‘loose coarse sandy fine to coarse subangular to well rounded flint GRAVEL’ where potential reworking with the alluvium above has occurred. Standard Penetration Test (SPT) results vary between 6 and 49 (loose to dense gravels), averaging 21. Using correlations between SPT N-vales and the effective angle of friction suggested by Peck et al (1974), the effective angle of friction (φ’) of the River Terrace Deposits can be taken to be 33°.

These descriptions are supported by the available particle size distribution tests which indicate that the materials are predominantly fine to coarse very sandy fine to coarse GRAVEL. The grading curves are summarised in Figure 2.14.

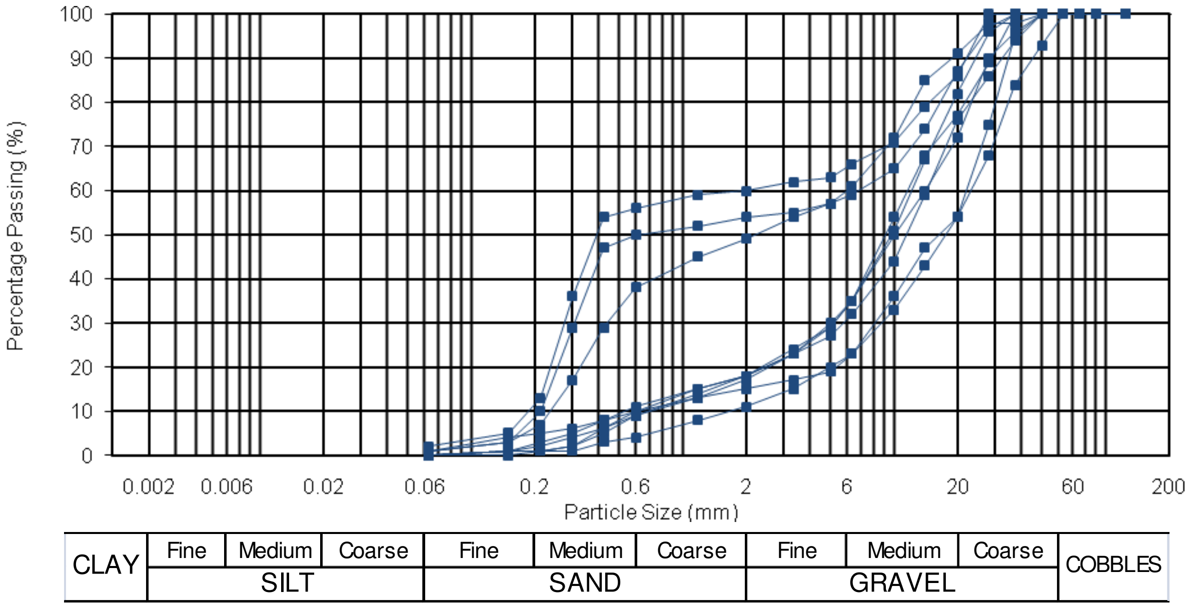


Figure 2.14: Particle Size Distribution plots for samples taken in the River Terrace Deposits

2.4.5 London Clay

The published geological map shows London Clay Formation being present across the site beneath the Made Ground, Alluvium and River Terrace Deposits. The London Clay conformably overlies the Harwich Formation and underlies the River Terrace Deposits. The unweathered profile is described as mainly grey to blue-grey, stiff, fissured, becoming increasingly stiffer with depth silty to very silty CLAY.

The weathering profile is brown in colour and is often extensively bioturbated and occasionally calcareous in nature. Silty fine grained sand of quartzitic origin is often present in the formation and glauconitic grains in the more clayey beds form marker horizons. The top of the unweathered profile of the London Clay and bottom part of the weathered profile often contain very thin pyritised algae tubes, white mica flakes and carbonate concretions.

Within the London Clay the moisture contents are within the range of 16% to 33%, averaging 24%. The Plasticity Index varies between 23% and 53% and Liquid Limits from 40% to 84% indicating that the material is high to very high plasticity. The results are plotted in Figure 2.15. The undrained shear strengths range from 21 kPa to 301 kPa and can be represented broadly by a strength profile of:

$$c_u = 50 + 6z$$

Where *z* is the depth from the top of the London Clay.

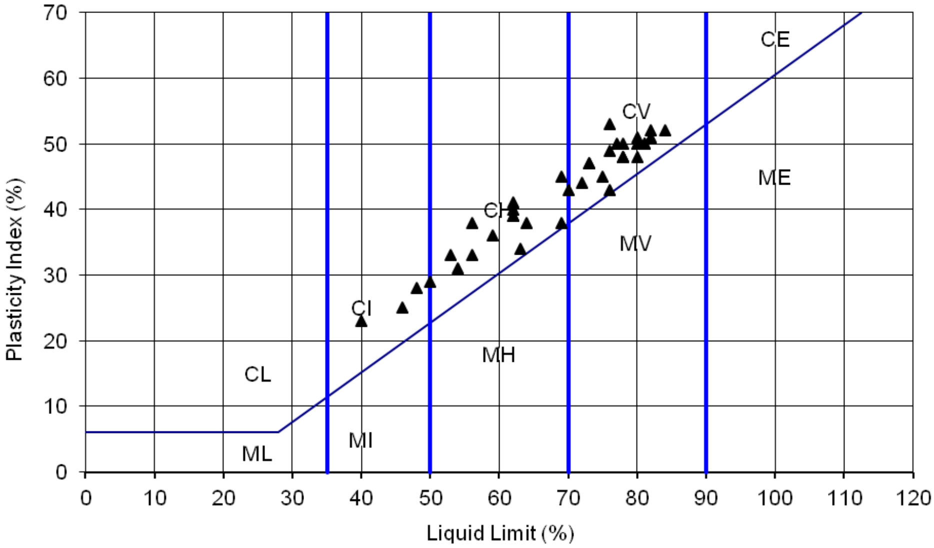


Figure 2.15: Plasticity chart for samples taken within the London Clay

2.4.6 Harwich Formation

The published geological map shows Harwich Formation occurs at isolated locations around the London docklands area. In the London district area, the formation was formerly mapped as the Blackheath Beds and can be referred to as the basement beds of London Clay (Ellison, 2004).

There are numerous descriptions of former exposures recording very variable thicknesses over very short distances. This may be an indication of an irregular base (Ellison, 2004).

The borehole records indicate that the Harwich Formation extends up to 6.5m and an average thickness of approximately 3.5 metres and has a sharply defined base which forms an erosive contact on the Lambeth Group. Glauconitic fine grained sand and pebble beds of rounded black flints are the main lithologies.

However, broken shells of marine to brackish fauna can also be evident. The proportion of the pebbles varies considerably. Calcareous, ferruginous and siliceous cements occur locally in beds massing up to several metres.

Harwich Formation is typically described as ‘very dense fine to coarse flint and chert GRAVEL with some fine sands and cobbles.

Limited in-situ or laboratory testing is available for the Harwich Formation.

2.4.7 Lambeth Group

The published geological map indicates that the Lambeth Group conformably overlies the Thanet Sand and unconformably underlies the Harwich Formation. The Lambeth Group comprises the Woolwich Formation and Reading Beds and the Upnor Formation.

Woolwich Formation

The Woolwich Formation comprises of several distinct lithological units which include lower shelly clay unit, laminated beds and upper shelly clay. The lower Shelly clay which occurs in south east of London comprises typically of fine shell fragments in clay soil matrix. The Laminated beds unit is equivalent to the "laminated sands and silts," Ellison (1991). Thin beds of colour mottled clay and silt, interpreted as Upper Mottled Clay of the Reading Formation, occur within the laminated beds between Docklands and Stratford. The upper Shelly beds are often classified as Shelly basal beds of London Clay. It includes weakly cemented shell beds (up to 0.43 m thick) containing Ostrea, bioturbated sand beds, sands and silts with rip-up clay clasts (less than 5 mm) and clays and silts with sand-filled burrows.

Reading Formation

The Reading Formation consists of lower and upper mottled clay units. The most accessible exposure of the Lambeth Group in the London district is the Charlton Sand Pit (east of Woolwich) at Maryon Park an area now preserved as SSSI (Daley and Balson, 1999 in Ellison 2004). Large and extensive sand units of the Lambeth Group with consistent thickness may be encountered along the route. In London, the formation divides into two units separated by Woolwich Formation and where the Woolwich Formation does not exist, it is not possible, using lithological criteria, to identify the two units. The Lower Mottled Clay contains carbonate nodules up to 0.5 m in diameter particularly in the top part. They may be hard and splintery or softer and powdery.

Upper Mottled Clay is identified mainly as an upper leaf of the Formation lying above the Lower Shelly Clay. In cores in central and east London it consists largely of mottled clays, silty clays and silts with colours similar to those of the Lower Mottled Clay

Upnor Formation

The Upnor Formation occurs at the base of the Lambeth Group. The thickness of the Upnor Formation within the London Basin in a regional context is often less than 3m; however, thickness often ranges from between 6m to 7m within central London and northern Kent.

The Upnor Formation consists of fine to medium-grained sand with a variable proportion of glauconitic, beds and stringers of well rounded flint pebbles, and minor amounts of clay.

Bioturbation, cross lamination and small scale ripple marks often characterise the Upnor Formation. The Upnor Formation was described as green brown silty fine to medium SAND becoming very dense to coarse GRAVEL to base.

In the central and eastern parts of the London Basin some of the sandy beds contain up to 25 per cent glauconite. The clay content of the Upnor Formation is variable with beds up to 300 mm thick, and laminae, of grey clay common in the east of the basin and in London. The Upnor Formation is overlain by the Reading Formation.

SPT N-values varied between 30 and 66, averaging 49, indicative of the material being dense to very dense.

In addition, cemented bands of limestone and siltstone were encountered within the Woolwich and Reading Beds.

2.4.8 Thanet Sand

Thanet Sand unconformably overlies the erosional surface of the Chalk. It is anticipated to be present across the site and is regionally a coarsing upward sequence of fine grained grey to brownish grey sand.

A conglomeratic band of dark greyish black flint pebbles usually occurs at the base of the Thanet Sand known as the Bullheads Beds. The sediments are often bioturbated and may lack general primary sedimentary structures such as lamination.

The basal Bullheads are a conglomerate up to 0.5 metres thick. It is variable with sporadic rounded flint pebbles up to 50 mm in diameter. The units occasionally contain pellets of glauconite up to 1 mm in diameter.

The typical descriptions Thanet Sand include: 'Dense dark greenish grey silty fine to medium SAND' in an unweathered state and 'dense grey occasionally yellowish brown slightly gravely silty fine to medium SAND' in a weathered state.

The dense to very dense nature will likely provide substantial end bearing capacity for piled foundations associated with the tunnel portal excavations. Laboratory tests carried out on samples obtained during the London Cable Car ground investigation indicate that the effective angle of friction (φ') ranges from 29° to 33°, with an average of 31°.

2.4.9 Upper Cretaceous Chalk

The published geological map of the area of interest shows the White Chalk unconformably underlies the Thanet Sand. The base of the Chalk as indicated on structural contour map (Ellison, 2004) around the vicinity of the proposed site is approximately 200 metres below ground level.

Flints can also be expected within the Chalk and represent very strong brittle inclusions in the Chalk.

The level of the Chalk was encountered during the London Cable Car ground investigation at levels ranging from -48.20mOD to -53.97mOD. The Chalk on site was found to have a saturated moisture content ranging from 25% to 29%, with an average of 27%.

SPT N-values in the Chalk ranged from 46 to 99, with an average of 63. Laboratory unconfined compressive strength (UCS) tests were carried out on 3 No. Chalk samples, with an average of 4.5MPa.

2.4.10 Ground Profiles

North of the River Thames

The location plan of the previous ground investigation exploratory holes and the anticipated stratigraphic profile along the proposed tunnel alignment (Figure 1) is contained in Appendix A.3 .

A broad summary of the profile of the ground conditions identified from the historic ground investigations applicable for the works on the northern side of the River Thames around vicinity of the proposed tunnel north portal adjacent to the Tidal Basin roundabout are presented in Table 2.6.

This information is based upon the findings of the investigations obtained from both the British Geological Survey and Mott MacDonald's database of historic information.

Table 2.6: Typical strata boundary around the vicinity of Tidal Basin Roundabout for the Tunnel North Portal

Formation	Soil Description	Top (mOD)		Bottom (mOD)		Top (mbgl)		Bottom (mbgl)		Thickness (m)	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Made Ground	Brick rubbles, ash, sand	1.35	5.28	-9.22	1.76	0.0	0.0	1.0	14.50	1.0	14.50
Alluvium	Silty Clay	-3.23	1.76	-5.95 (EOH)	-1.1	1.0	8.1	3.2	10.3	1.45	7.7 (EOH)
River Terrace Deposits	Sandy Gravel silty	-5.84	-1.1	-8.74	-4.43	3.2	10.3	6.6	13.9	1.6	4.4
London Clay	Stiff silty Clay	-9.22	-4.43	-22.3	-16.54	6.6	14.5	18	26.04	9	17.9 (P)
Harwich Formation	Very dense Gravels	-20.76	-19.48	-25.48	-20.54	14.5	26.04	15.02	30.64	0.52	5.17
Lambeth Group	Very Dense pale green blue SAND	-25.48	-20.15	-40.08 (EOH)	-27.83	15.02	30.64	30.85	45.24 (EOH)	5	15.83
Upnor Formation	Silty fine to medium SAND	-38.97	-36.37	-40.47	-39.33	30.85	44.25	33.81	45.25	1.5	2.96
Thanet Sand	Very dense grey silty fine SAND	-40.47	-39.33	-52.52	-50.44	33.81	45.75	47.0	56.88	10.02	13.19
Chalk		-52.52	-50.44	N/A	N/A	47.0	56.88	N/A	N/A	N/A	N/A

EOH End of hole

P Proven

River Thames Section

A broad summary of the profile of the ground conditions identified from the historic ground investigations applicable for the works within the Thames are presented in Table 2.7. This information is based upon the findings of the investigations obtained from both the British Geological Survey and Mott MacDonald's database of historic information.

Table 2.7: Typical strata boundaries across the Thames River

Formation	Soil Description	Top (mOD)		Bottom (mOD)		Top (mbgl)		Bottom (mbgl)		Thickness (m)	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Alluvium	Silty Clay	-9.3	-1.4	-8.9	-4.5	0.0	2	0.3	3.5	0.3	3.5
River Terrace Deposits	Sandy Gravel silty	-8.4	-4.5	-11.3	-7.4	0.0	3.5	1.6	9.0	1.2	6.1
London Clay	Stiff silty Clay	-11.3	-7.4	-18.6	-11.9	0.4	9.0	6.6	14.7	2.65	9.6
Harwich Formation	Very dense Gravels	-17.45	-11.9	-20.36	-16.95	6.6	14.7	8.55	17.5	0.7	5.95
Lambeth Group	Very Dense pale green blue SAND	-20.36	-16.95	-38.33	-25.3	8.0	17.5	20	31.33	8.8	17.97
Upnor Formation	Silty fine to medium SAND	-35.2	-30.9	-37	-31.06	25.09	30.3	27.43	32.8	0.16	2.35
Thanet Sand	V dense grey silty fine SAND	-38.33	-25.3	-50.6	-33.4	24.7	32.8	25	46.1	0.3	14.77
Chalk		-50.6	-45.9	N/A	N/A	40.19	46.3	N/A	N/A	N/A	N/A

South of the River Thames

A broad summary of the profile of the ground conditions identified from the historic ground investigations applicable for the works on the southern side of the Thames are presented in Table 2.8. This information is based upon the findings of the investigations obtained by from both the British Geological Survey and Mott MacDonald's database of historic information.

Table 2.8: Typical strata boundaries on the southern side of the Thames

Formation	Soil Description	Top (mOD)		Bottom (mOD)		Top (mbgl)		Bottom (mbgl)		Thickness (m)	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Made Ground	Brick rubbles, ash, sand	2.13	5.72	-0.91	2.57	0.0	0.0	0.91	6.2	0.91	6.2
Alluvium	Silty Clay with pockets of peat	-0.91	2.57	-3.95	-0.48	0.91	6.2	3.66	9.45	1.22	4.5
River Terrace Deposits	Sandy Gravel silty	-3.95	-0.48	-10.96	-6.88	3.66	9.45	10.36	16.0	5.95	8.38
London Clay	Stiff silty Clay	-10.96	-6.88	-16.93	-11.86	11.58	16.0	14.02	22.65	0.9	6.8
Harwich Formation	Dense black Pebbles	-16.93	-14.48	-22.76	-15.39	17.53	22.65	18.44	28.48	1.02	5.83
Lambeth Group	Very Dense pale green blue SAND	-22.76	-6.88	-35.26	-18.8	10.36	28.48	24.3	40.6	8.9	14.8
Upnor Formation*	Silty fine to medium SAND	-35.26	-	-37.41	-	40.6	-	42.75	-	2.15	-
Thanet Sand	Very dense silty fine SAND	-37.41	-18.8	-45.9	-29.5	24.3	42.75	35	49.38	10.7	12.5 (P)
Chalk*		-45.9	-	N/A	N/A	49.38	-	N/A	N/A	N/A	N/A

* only encountered in one borehole.

P Proven

2.4.11 Groundwater Conditions

As noted previously the historic ground investigations indicate that groundwater is likely to be encountered in the following materials:

Superficial sediments

Local perched water table, possibly of limited extent and volume may exist above low permeability layers in the Alluvium and Made Ground. Porous sandy units of the made ground and the pseudo fibrous peat within the Alluvium may retain water especially when sealed in by a less permeable cohesive layer.

River Terrace Deposits – upper 'Minor Aquifer'

The minor aquifer is understood to be in hydraulic connectivity with the River Thames and is recharged by rainwater, leakages from drains and sewers and the River Thames. It is expected to have a regional flow pattern towards the River Thames. Ground water levels and flow pattern may be affected by buried or near surface structures such as the river quay wall, dock structures, basements, tunnels, retaining wall etc.

Upnor Formation, Thanet Sand and Chalk – lower 'Major Aquifer'

The main body of water in the Chalk is understood to be in hydraulic connectivity with the overlying Thanet Sand and Upnor Formation. A decline in ground water abstraction in the 20th century has resulted in gradual recovery of the deep aquifer levels. The main aquifer is expected to be separated from the minor aquifer by less permeable London Clay and Lambeth Group encountered around the area proposed for work, however, these aquifers are expected to behave as a single unit where the less permeable cohesive strata are absent.

2.5 Preliminary Engineering Assessment

2.5.1 Engineering Considerations

This desk study was initiated as part of the feasibility studies for a proposed new Thames River Crossing between Silvertown Way on the north side of the river and the Greenwich Peninsula on the south side. The desk study has revealed that the site has been in use since 1868 and has a legacy of industrial use.

The northern part of the site encompasses the Royal Victoria Docks and the historic western entrance to the docks that was subsequently closed in 1957. The adjacent area has also been subject to a history of industrial, residential and railway development, much of which is now very different to what existed when the Royal Victoria Dock was fully operational. Industrial development included manure works, chemical works, Peruvian guano works, sugar refining works, soap works and oil works.

Today the land use on the northern side of the river is mixed with residential and recreational use around the perimeter of the Royal Victoria Docks and light commercial use to the south of the elevated Silvertown Way and the Docklands Light Rail (DLR). Waste management and cement/aggregate/concrete batching facilities dominate to the north and west of the proposed northern tunnel portal. The locations of the remains of any old foundations and services left beneath the ground are also unknown.

The southern part of the site was dominated by a gasworks until 1987. Thereafter redevelopment of the site included extensive remediation to make it suitable for residential, commercial and industrial uses. The current land use is predominantly car parking (i.e. hardstanding) with the O_2 Arena and commercial buildings located to the northwest and a leisure facility to the southeast. To the west of the Blackwall Tunnel South Approaches there is a large aggregate distribution facility. An operational gas holder, which is known to have comprised part of the South Metropolitan Gas Works, is located directly south of the proposed southern tunnel portal adjacent to the southern end of the scheme. Additionally in this area to the west of the proposed tunnel portal entrance, there is a large aggregate distribution facility.

The ground conditions across the site are expected to comprise of a variable thickness of Made Ground, Alluvium, River Terrace Deposits, London Clay, Harwich Formation, Woolwich and Reading Beds of the Lambeth Group and Thanet Sand overlying the Upper Chalk. Made Ground is expected to be absent within the River Thames.

Groundwater is likely to be encountered as perched water in the Made Ground, as an 'upper aquifer' within the River Terrace Deposits, which is likely to be separated from a 'lower aquifer' in the granular Lambeth Group and underlying Thanet Sands and Chalk. The groundwater level in the River Terrace Deposits is likely to be connected to the River Thames. The lower aquifer water level may be depressed through historic (and continuing) groundwater abstraction.

2.5.2 Preliminary Geotechnical Design Parameters

A considerable amount of in situ and laboratory testing was undertaken as part of the London Cable Car ground investigation carried out in 2011. Using this data it is possible to derive preliminary geotechnical parameters, as summarised in Table 6.1. The values in this table do not take account of particular limit states and thus cannot be considered 'characteristic' values in accordance with BS EN 1997-1: 2004 *Incorporating Corrigendum February 2009*.

Table 2.9: Summary of the preliminary geotechnical parameters

Formation	Unit Weight (kN/m³)	Undrained Shear Strength, c_u (kPa)	Undrained Elastic Modulus, E_u (MPa)	Effective Angle of Friction, φ' (°)	Effective Elastic Modulus, E' (MPa)	Unconfined Compressive Strength (MPa)
Made Ground	19	-	-	-	-	N/A
Alluvium	19	22	TBC	17	TBC	N/A
River Terrace Deposits	19	N/A	N/A	33	15	N/A
London Clay	20	50 + 6*z*	TBC	27	TBC	N/A
Harwich Formation	20	N/A	TBC	TBC	TBC	N/A
Lambeth Group - Cohesive	20	TBC	TBC	27	TBC	N/A
Lambeth Group - Granular	20	N/A	N/A	29	TBC	N/A
Upnor Formation	20	TBC	TBC	32	TBC	N/A
Thanet Sand	19	N/A	N/A	31	TBC	N/A
Chalk	TBC	N/A	N/A	35	TBC	4.5

2.5.3 Recommendations for Further Investigation

Ground Investigation

It is recommended that the ground conditions and material properties along the proposed tunnel alignment are established through a project-specific ground investigation. To date only those boreholes sunk over water within the River Thames as part of the London Cable Car project ground investigation have been specifically constructed to inform the design of the Silvertown River Crossing project. In order for Transport for London to take the scheme design forward to construction, ground investigation to obtain a comprehensive understanding of the ground and groundwater conditions at the site is required.

Reducing the ground related risks associated with the scheme will have a considerable beneficial impact on the scheme construction costs. To achieve this ground investigation should be undertaken with its focus being to obtain specific information for the design and construction of particular elements of the proposed works such as the bored tunnels, and to reduce uncertainties associated with the existing information.

At all on-land locations there is a requirement to undertake geotechnical investigations to support the design of the new tunnel. There are no historic investigations with particular focus on the location of the proposed new structures nor is testing to establish material properties available from previous investigations. The scope of the investigations should encompass both cable tool and rotary drilling as well as CPT testing. In situ testing to establish material stiffnesses and in situ stresses should also be considered (e.g. pressuremeter testing, or the use of in situ geophysical techniques).

Additional specialist (for example CPT) and advanced field testing (for example pressuremeter), together with routine sampling and laboratory testing over and above that currently available from previous investigations should be undertaken; the laboratory testing will include both standard classification tests and more sophisticated advanced testing. This is to enable the characterisation of the soil behaviour thus enabling more economic design and construction as well as more realistic estimates of ground movements. This level of information is not currently available within the existing geotechnical data.

Instrumentation, for example standpipes/standpipe piezometers, will also be required to provide information on groundwater levels and pore pressures. The tidal influence on groundwater levels may also have to be investigated.

Given the paucity of information on the existing foundations, intrusive investigations should be undertaken to identify whether or not existing historic structures will be a hindrance to excavations associated with the construction of the tunnel portals.

For the tunnel structures the following preliminary additional ground investigation requirements have been identified:

- 12 No. Cable percussive boreholes with rotary follow-on to a maximum depth of 40m below existing ground level (begl);
- 12 No. CPTs to a maximum depth of 20m begl;
- 12 No. Standpipes/standpipe piezometers installed in each borehole;
- 3 No. Machine excavated trial pits to a maximum depth of 3.5m begl.

For the highway interchanges the following preliminary additional ground investigation requirements have been proposed by W S Atkins:

- 8 No. Machine excavated trial pits to 3.5m below existing ground level (begl);
- 15 No. Window sample boreholes to 6.5m begl;
- 4 No. Cable Percussive boreholes to 12m begl;
- 9 No. Cable percussive boreholes with rotary follow on to 25m begl.

As part of the investigations disturbed and undisturbed samples should be collected for laboratory testing. The testing should encompass routine classification and strength testing and more advanced testing for verification of the stiffness of the materials through which foundations are to be installed. The aggressivity of the ground and groundwater to concrete should be assessed as part of this process. At present there is limited geotechnical testing information available. Planning of the investigations should be undertaken in accordance with the requirements of parts 1 and 2 of Eurocode 7 (BS EN 1997-1 & 2), including the UK National Annex and relevant execution codes.

Investigations of Existing Structures

Given the limited information available concerning the existing foundations, consideration should be given to undertaking intrusive investigations in order to identify whether or not existing historic structures will be a hindrance to excavations associated with the construction of the tunnel portals.

2.6 Comparison of Project Options

2.6.1 Ground Engineering Risks

The key geotechnical risks that are envisaged for the Silvertown study area are detailed in the Geotechnical Risk Register contained in Appendix A.11. The Geotechnical Risk Register will operate as a live document and will be reissued as part of the Ground Investigation Report (GIR) and at subsequent stages throughout the development of the project.

The key structures for the tunnel scheme are the south and north tunnel portals and approaches, bored tunnel section and associated ancillary structures of the tunnel crossing. The key risks associated with the respective aspects of the tunnel are summarised in the following sections:

North Tunnel portal and primary substation structure

At the north tunnel portal, the tunnel will connect to Silvertown Way roundabout in the north. The extent and construction of the approach structures is unknown at this point, but the length between the portal and the TBM launch structure is likely to be cut and cover. The TBM launch site is likely to be immediately north of the start of the DLR viaduct. The launch structure is likely to be a piled box structure. The key ground related risks and considerations associated with the north tunnel portal, ventilation chimney and primary substation include:

- Excavation induced ground settlement will take place due to construction, in the soft soil environment, of the large diameter twin bored tunnels and cut and cover structures. This may result in large strains being induced in overlying structures and adjacent subsurface structures and services resulting in unacceptable damage. Key overlying structures include the DLR piled bridge viaduct, north River Thames quay wall structures, surface road network e.g. Dock Road and Silvertown Way viaduct, buildings (shallow and piled) used for commercial and residential purposes. In addition, underlying structures including third party underground services/utilities infrastructure may also be affected, e.g. drainage from Royal Victoria Dock, telecommunications and electricity supply ducts and Jubilee Line tunnel structures.

- Encountering residual ground contamination due to historic or current use of the site works may be a hazard to site operatives during construction. There is also a risk that contamination might be enabled to migrate to deeper strata during construction, for example during pile construction.

- Natural ground gas such as methane with explosive potential from clayey peat in the Alluvium could be a hazard during excavation works associated with sub-surface structures.

- Potential aggressive ground/groundwater conditions (for example, sulphate attack due to the oxidisable pyrite in the London Clay or elevated chloride levels in the superficial soils) could present aggressive conditions for the reinforced concrete used in the construction of the tunnel and associated substructures.

- Presence of natural ground obstructions such as granular and cemented beds of the Blackheath member and cemented beds of siltstone of the Lambeth Group, and manmade ground obstructions such as deep buried foundation remains could obstruct piling works.

- Potential basal heave/swelling due to excavation in the London Clay for the cut and cover portal structure and substation may require relevant design mitigation measures such as thicker slabs.

- Uplift pressures at the base of the slabs of the tunnel structures due to significant pore water pressure in the granular units of the Lambeth Group may require a programme of dewatering to be instigated during construction.

Bored/running tunnel section – River Thames

The main risks for the bored section of tunnel passing beneath the river Thames are as follows:

- Mixed face ground conditions (sands and clays) may be encountered during excavation through the Lambeth Group soils.

- Difficult tunnelling conditions might be encountered in the Blackheath Member (Harwich Formation) or Lambeth Group where hard bands of cemented/siliceous material are found.

- Ground improvement techniques applicable to the bored tunnel section under the River may be limited due to environmental or construction constraints.

- Tunnel face instability due to water ingress during tunnel construction.

- Possible deep periglacial scour hollows infilled with saturated gravels.

- Obstructions from deep buried foundations e.g. piled foundations (possibly those of now redundant structures), or sheet piles and walls of the infilled entrance to the Royal Victoria Dock.

- Tunnelling induced settlement of over-lying structures and services, such as river walls.

South tunnel portal cut and cover structure, ventilation chimney and secondary substation

The area around the vicinity of Edmund Halley Way, Greenwich is likely to serve as the TBM reception and dismantling site. The key ground related risks and considerations associated with the south tunnel portal, ventilation chimney, secondary substation and associated approach structures include:

- Encountering residual ground contamination due to historic or current use of the site works may be a hazard to site operatives during construction. There is also a risk that contamination might be enabled to migrate to deeper strata during construction, for example during pile construction.

- Natural ground gas such as methane with explosive potential from clayey peat in the Alluvium will be a hazard during excavation works associated with sub-surface structures.

- Potential aggressive sulphate attack due to the oxidisable pyrite in the London Clay or chloride in the superficial soils could present aggressive conditions to reinforced concrete used in the construction of the tunnel and associated substructures.

- Presence of natural ground obstructions such as granular and cemented beds of the Blackheath member and cemented beds of siltstone of the Lambeth Group, and manmade ground obstructions such as foundation remains could obstruct piling works.

- Potential basal heave/swelling due to the excavation in the London Clay for the cut and cover portal structure may require relevant design mitigation measures such as thicker slabs.

- Uplift pressures at the base of the slabs of the tunnel structures due to significant pore water pressure in the granular units of the Lambeth Group may require a programme of dewatering to be instigated during construction.

- Excavation induced ground settlement will take place due to construction, in the soft soil environment, of the large diameter twin bored tunnels and cut and cover structures. This may result in large strains being induced in overlying structures and adjacent subsurface structures and services resulting in unacceptable damage. Key overlying structures include the south River Thames quay wall structures, surface road network surface road network e.g. Millennium Way, A102, Edmund Halley Way around the proposed south tunnel portal, Tunnel House listed building around A102 road, buildings (shallow and piled) used for commercial and residential purposes within Greenwich Peninsula and adjacent subsurface structures such as the Blackwall Tunnel and other third party services/utilities and Infrastructure.

2.6.2 Other potential ground related risks and considerations

In addition to the items discussed above the following are more general ground related risks and considerations that should be reviewed during design:

- Archaeology – given the historic development of the site and in particular for the works on the northern side of the Thames there is the potential to encounter features of importance with respect to industrial archaeology;

- Buried services/utilities – buried services/utilities are likely to be present adjacent to all the structures. Previous reclamation works around the Limmo and Thames Wharf areas indicate the presence of a buried electricity cable (132kV), overhead cables and pylons (132kV &400kV) and 12'' gas main in the vicinity of Thames Wharf adjacent to the proposed north tunnel approach. Consequently buried services/utilities searches will be required to ensure both ground investigations and construction works do not damage existing buried services/utilities;

- Unexploded ordnance - the location of the site was subject to the direct impact of bombs during the world war two and whilst the site area has undergone extensive redevelopment following world war two there remains the potential for unexploded ordnance to exist;

- Disposal of arisings - excavated spoil from either ground investigation or construction, particularly within the Made Ground or superficial deposits may be classified as contaminated waste and consequently require disposal at licensed disposal sites. Reference should be made to the report, 'Phase 1 Contamination Assessment, Silvertown to Greenwich Peninsula' (Document No. 320530/MNC/TUN/03) for further details.

2.7 Drawings

Drawings relating to the proposed Silvertown Tunnel scheme are contained in Appendix A.2 and listed in Table 2.10 below.

Table 2.10: Silvertown Tunnel design drawings

Drawing Number	Drawing title
MMD-298348-TUN-101	Safeguarded Area
MMD-298348-TUN-102	Constraints
MMD-298348-TUN-103	Borehole Data
MMD-298348-TUN-201	Scheme Layout Plan
MMD-298348-TUN-202	Geological Long Section
MMD-298348-TUN-203	Plan and Longitudinal Section Sheet 1
MMD-298348-TUN-204	Plan and Longitudinal Section Sheet 2
MMD-298348-TUN-205	Plan and Longitudinal Section Sheet 3
MMD-298348-TUN-206	Bored Tunnel Cross Section
MMD-298348-TUN-207	Emergency Escape Cross Passages
MMD-298348-TUN-208	Cross Passage & Sump
MMD-298348-TUN-209	Precast Concrete Segmental Lining - Right Hand Taper Ring
MMD-298348-TUN-210	Greenwich Approach Structures Plan
MMD-298348-TUN-211	Greenwich Approach Structures Sections Sheet 1
MMD-298348-TUN-212	Greenwich Approach Structures Sections Sheet 2
MMD-298348-TUN-213	Silvertown Approach Structures Plan Layout
MMD-298348-TUN-214	Silvertown Approach Structures Sections Sheet 1
MMD-298348-TUN-215	Silvertown Approach Structures Sections Sheet 2
MMD-298348-TUN-216	Greenwich Vent Station, GA, Sections and Details
MMD-298348-TUN-217	Silvertown Vent Station, GA, Sections and Details
MMD-298348-TUN-218	Tunnel Services Building Greenwich, Primary Substation
MMD-298348-TUN-219	Tunnel Services Building Silvertown, Secondary Substation
MMD-298348-TUN-220	Greenwich Worksite Layout
MMD-298348-TUN-221	Silvertown Worksite Layout
MMD-298348-TUN-222	Greenwich Temporary Diversion

3. Gallions Reach

3.1 Sources of Information & Desk Study

The Gallions Reach River Crossing Project study area includes the earlier East London River Crossing/Thames Gateway Bridge (TGB) Project study areas and as such much work has been undertaken previously. Information compiled as part of the TGB project has been provided by TfL from their project archives. However, on review it has been established that significant amounts of the ground investigation data is missing, most notably associated with the East London River Crossing ground investigations.

The main ground investigations for the East London River Crossing, comprising a total of 243 boreholes, were procured by Sir William Halcrow & Partners in 1983 on behalf of the Department for Transport. The ground investigation was implemented as two separate contracts. Contract No. 1 was carried out by Wimpey Laboratories Limited and comprised 137 boreholes located south of the River Thames between Thamesmead and the A2 at Falconwood. The ground investigation factual report for Contact No. 1 consists of five parts; only three of these parts have been made available at the time of writing.

Contract No. 2 was carried out by Foundation Engineering Limited and comprised 106 boreholes located between Thamesmead and the A13 interchange near Barking Creek. The corresponding factual ground investigation report has not been reviewed as part of the current desk studies. As Contract No. 1 covers the area safeguarded for the Gallions Reach River Crossing project, the ground investigation information obtained during this ground investigation is of particular relevance. Halcrow/CH2M Hill have been approached to establish whether they have records of the missing ground investigation information. At the time of writing, this information had not been made available.

The sources of information which have been utilised in the preparation of this report are summarised in Table 3.1 below.

Table 3.1: Gallions Reach: Sources of information

Category	Sources of Information
Geology	▪ Ellison, R.A. (Ed), “Geology of London: Special Memoir for 1:50 000 Geological sheets 256 (North London), 257 (Romford), 270 (South London) and 271 (Dartford) (England and Wales)” BGS, 2004; ▪ England and Wales Sheet 271 Dartford Solid and Drift Geology. 1998. 1:50 000 scale map, British Geological Survey; ▪ England and Wales Sheet 270 South London Solid and Drift Geology, 1:50 000 scale map, British Geological Survey, 1981; ▪ England and Wales Sheet 256 North of London Solid and Drift Geology. 1:50 000 scale map, British Geological Survey 1981; ▪ England and Wales Sheet 257 Romford Solid and Drift Geology. 1:50 000 scale map, British Geological Survey 1996; ▪ British Geological Survey, 1996. “London and the Thames Valley”.
Non-Site Specific Geotechnical References	▪ C.D. Warren and R.N. Mortimore, 2003. “Chalk Engineering Geology - Channel Tunnel Rail Link and North Downs Tunnel” Quarterly Journal of Engineering Geology and Hydrogeology, 36,17-34; ▪ F.G. Berry, “Late Quaternary scour-hollows and related features in central London”, Quarterly Journal of Engineering Geology and Hydrogeology 1979; v. 12; p. 9-29. ▪ BRE Special Digest 1:2005. “Concrete in aggressive ground”. BRE/The Concrete Centre; ▪ Stone, K., Murray, A., Cooke, S., Foran, J. & Gooderham, L. (2009) “Unexploded Ordnance (UXO) – A guide for the construction industry”. CIRIA C681

Category	Sources of Information
Factual Ground Investigation Reports	■ 6 Alpha Associates Limited. (2013). Detailed Unexploded Ordnance (UXO) Risk Assessment for Gallions Reach, London. Project Number: P3247. ■ British Geological Survey historic boreholes; ■ Foundation Engineering Limited. (1980). East London River Crossing. Factual Report on Preliminary Site Investigation. CF669/2029. ■ Halcrow. (1992). East London River Crossing. Supplementary Interpretative Geotechnical Report. ■ Halcrow. (2005). Thames Gateway Bridge. Contaminated Land Desk Study. P1-P-R005. ■ Mott MacDonald database of historic boreholes; ■ Mott MacDonald. (2012). Gallions Reach River Crossing Study. Document No.: 298348/MNC/TUN/001. ■ Scott Wilson. (2003). Thames Gateway Bridge. Contamination Survey: Factual Report. D101265. ■ Sir William Halcrow and Partners. (1985). East London River Crossing. Site Investigation – Interpretative Report. ■ Soil Mechanics. (2007). Thames Gateway Bridge Site Investigation – Location 1. Factual Report on Ground Investigation. Report No A7028-1. ■ Soil Mechanics. (2007). Thames Gateway Bridge Site Investigation – Location 2. Factual Report on Ground Investigation. Report No A7028-2. ■ Soil Mechanics. (2007). Thames Gateway Bridge Site Investigation – Location 3. Factual Report on Ground Investigation. Report No A7028-3. ■ Soil Mechanics. (2007). Thames Gateway Bridge Site Investigation – Location 4. Factual Report on Ground Investigation. Report No A7028-4. ■ Symonds. (2001). Gallions Roundabout: Environmental Due Diligence Report. ■ White Young Green. (2002). Ground Conditions Assessment of the Site 3, Gallions Approach, Beckton, London. E02532/CG/November 02/GCA/V1. ■ White Young Green. (2003). Ground Conditions Assessment of the Armada 1/1A Site, Beckton, London. REPORT/E03410/E03672/MLOCT03/GCA/V2 ■ White Young Green. (2004). Japanese Knotweed Assessment Report of the Site at Gallions Approach – Site 3. REPORT\E02532\EMT\AUG03\JKASSESS\V1. ■ White Young Green. (2008). Greenwich Waterfront Transit Project. Ground Investigation Report. Report No. GWT043. ■ Wimpey Geotech Limited. (1990). East London River Crossing. Supplementary Ground Investigation. S/28296. ■ Wimpey Laboratories Limited. (1983). East London River Crossing A13 to A2. Contract No. 1: Factual Report on Site Investigation. S/20055.
OS Mapping/ Envirocheck	■ Landmark Information Group Service, Envirocheck Report for the site, March 2013; ■ Historical Ordnance Survey maps, for discrete years during the period 1850 to 2012; ■ Lord, J.A., Clayton, C.R.I. and Mortimore, R.N. 2002. “Engineering in Chalk” C574. CIRIA, London;

3.2 Field Studies

3.2.1 Site Inspection

The site reconnaissance (or walkover survey) of the Gallions Reach River Crossing project study area was undertaken by Mott MacDonald on 15 May 2013. The purpose of the walkover survey was to gather relevant additional information on the geology, geomorphology and hydrogeology of the project study area in order to inform the preliminary ground model for the site, including potential construction problems and access constraints for any proposed ground investigation.

The key observations made during the walkover survey of the Gallions Reach River Crossing project study area are summarised in the following sections.

3.2.1.1 North of the River Thames

On the north side of the River Thames in the vicinity of the project study area there are areas of scrubland, the Beckton DLR rail maintenance depot, the Beckton branch of the DLR, the (derelict) remains of the Beckton gas works, a concrete works (the Byrne Group) and large commercial units on Atlantis Avenue.

The northern bank of the River Thames was accessible at the eastern extent of Atlantic Avenue, at the southern extremity of the proposed river crossing. At this location there is a communications mast and an electricity substation located close to the river wall. The river wall includes reinforced concrete, timber and steel sheet pile wall construction; the sheet piles were locally raised to accommodate a sewer outfall in the vicinity of the proposed Gallions Reach River Crossing.

The current alignment of the proposed river crossing at Gallions Reach traverses a large area of scrubland to the south of the Beckton DLR rail maintenance depot, bisected by Armada Way. Although access to the area was not available, this former gas works land appears to be derelict, heavily vegetated and contains stockpiles of waste materials. The area is gently undulating and it is not anticipated that access for ground investigation purposes will be an issue once agreement is reached with the landowner/leaseholder. Given its former use, however, there may be issues concerning the contaminated nature of the ground to be investigated.

To the east of the Beckton DLR rail maintenance depot, a series of undulations were noted along the alignment of Armada Way. There is reflective cracking in the tarmac which appears to have been caused by localised subsidence. This is anticipated to have been caused by consolidation in the underlying peat and soft clay deposits. Similar undulations in the road pavement were observed further along Armada Way, north of the gas works.

To the east of Armada Way and north of the concrete works, a series of what appeared to be gas monitoring wells were noted within a part of the former gas works site. It is assumed that these wells are being used to monitor ground gas within the underlying made ground as well as the peat and soft clay as the organic material contained therein decomposes.

3.2.1.2 South of the River Thames

On the south side of the River Thames, the Gallions Reach project study area is occupied by a landfill site (the Tripcock Point Registered Landfill site) to which public access is denied. A walkover survey of the

Gallions Reach River Crossing project study area, carried out by Mott MacDonald in March 2012, established that the study area south of the River Thames can only be viewed from the Thames River Path which runs along the southern bank of the River Thames.

Although the walkover survey did not extend to the south side of the River Thames due to access difficulties, the southern extent of the project study area was visible from the northern bank of the River Thames. Since the study area south of the River Thames is largely undeveloped, it is not anticipated that there will be significant issues with regards access for ground investigation purposes. It should also be noted that there has been little change in land use within the project study area south of the River Thames since the East London River Crossing ground investigations were undertaken along a similar corridor of land in the early 1980s. However, there may be issues concerning the contaminated nature of the ground to be investigated.

3.3 Site Description

3.3.1 Site Location

The location of the Gallions Reach study area is highlighted in the site plan (Plan B) contained in Appendix B.1. The northern side of the site is located within the London Borough of Newham and the southern side is located within the London Borough of Greenwich.

On the north side of the River Thames, the site is located within an area known as Gallions Reach. The study area is bound to the north by the Beckton Sewage Treatment Works, to the south by Gallions Point Marina and to the west by Woolwich Manor Way (A117) and Royal Docks Road (A1020).

On the south side of the River Thames the study area includes an area of Thamesmead which is largely undeveloped. The study area is bound to the south by Western Way (A2016) and by two large residential areas to the east and west.

3.3.2 Current Land Use

North side of the River Thames

The current land use on the northern side of the River Thames is a mix of industrial, commercial and residential use. The north of the site area is dominated by Gallions Reach Shopping Park, the former Beckton Gas Works and the Beckton DLR depot. To the south, the study area is occupied by large warehouse/commercial units and residential developments.

The Beckton branch of the DLR network runs along the western perimeter of the study area from Gallions Reach DLR station. Other major infrastructure within the site area includes Woolwich Manor Way (A117) and Royal Dock Road (A2016) which are aligned along the western perimeter of the site.

South side of the River Thames

On the south side of the River Thames, there are three landfill site entries: two are located approximately 400m to the northeast of the safeguarded zone (historic and Local Authority recorded landfills). In addition, there is a Licensed Waste Management Facility (the Tripcock Point Registered Landfill site) which occupies a large portion of the study area/safeguarded zone. There are also two large commercial units located within the site area south of Western Way.

3.3.3 Topography

The land on both sides of the River Thames is gently undulating with ground levels in the region of 5mOD and 7mOD on the north side of the River Thames and in the region of 3mOD and 7mOD on the south side of the River Thames.

The bed of the River Thames is anticipated to have a gentle transverse dip ranging from 0mOD to -12mOD.

3.3.4 Geology

Background Information

A number of references to the geology of the site have been consulted in order to determine the stratigraphy and structural setting of the study area. The references are summarised in Table 3.1.

Historical ground investigation boreholes that are located within the Gallions Reach study area have been selected and sourced from the British Geological Survey (BGS) by Mott MacDonald. This information has been used to support an understanding of the ground conditions gained from ground investigations undertaken as part of the East London River Crossing/TGB projects.

As highlighted in Section 3.1, a majority of the of the ground investigation data for the obtained as part of the East London River Crossing/TGB projects is currently unavailable. However, much of the borehole information obtained as part of the East London River Crossing/TGB projects is presented in the geological long section produced by Halcrow in 2005.

Regional Geology

The 'Artificial Ground and Landslip' map (Envirocheck, 2013) contained in Appendix B.4 shows the presence of extensive Made Ground over a majority of the study area both north and south of the River Thames. Superficial sediments exist around the docklands area comprising of alluvial deposits of the flood plain of the River Thames which rests on the flood plain gravels (Thames River Terrace Deposits). These superficial sediments overlie solid geology which comprises London Clay, the Woolwich, Reading Beds and Upnor Formation of the Lambeth Group, Thanet Sand Formation and the Upper Chalk.

The regional geology of the area essentially comprises a gentle synclinal basin flanked by chalk escarpments which form the Chiltern Hills to the north and northwest and the North Downs to the south. The basin, which is formed by Upper Chalk of the Cretaceous period, is overlain by Eocene sediments. Within the safeguarded corridor at Gallions Reach the Eocene sediments flanking the present course of the River Thames are overlain by alluvial deposits, which consist of the Flood Plain Gravel, the most recent of Thames Valley terrace succession, and overlying modern to recent alluvium and very recent river bed sediments. Within the existing channel of the River Thames and on the adjacent banks immediately bordering the river these alluvial deposits rest directly on the chalk.

Structurally the site and surrounding area are comparatively free from tectonic features; the syncline referred to above excepted. Although a number of minor folds and faults have been observed in the middle of the London Basin their identification is made difficult because of their small size. In addition, human activity, as well as the weathering features of surface chalk and alluvial deposits conceal their true nature. However, it is accepted that they generally trend to the north-east, approximately parallel to the synclinal axis.

The stratigraphy of the site is summarised in Table 3.2.

Table 3.2: Regional Stratigraphy of the Gallions Reach site

Period	Epoch	Group	Formation
Quaternary	Holocene		Made Ground Alluvium
	Pleistocene		River Terrace Deposits
Tertiary (Palaeogene)	Eocene	Thames Group	London Clay
			Harwich
	Palaeocene	Lambeth Group	Woolwich Reading Upnor
			Thanet Sand
Cretaceous	Upper Cretaceous	White Chalk	Undivided Upper Chalk mainly Seaford Chalk
			Lewes Chalk

Folds and Faults

A possible fault, the 'Greenwich Fault', which is thought to extend from Dulwich to the mouth of the River Roding, crosses the route corridor in the vicinity of the Beckton Gas Works. Evidence obtained during the detailed site investigations for the East London River Crossing in the early 1980s suggested that this structure is a step-faulted monoclinic feature.

3.3.5 Hydrogeology

The hydrogeological regime of the London Basin incorporates two key aquifers: a lower, deep (Major) aquifer within the granular units of the Lambeth Group, the Thanet Sand and Upper Chalk and an upper, shallow (Minor) aquifer within the Alluvium and River Terrace Deposits. The two aquifers are separated by an aquiclude formed by the less permeable London Clay and, where present, the cohesive deposits of the Lambeth Group. The London Clay is defined by the Environment Agency as unproductive strata and forms an aquitard between the upper and lower aquifer. The minor aquifer is likely to be subject to tidal influence due to the close proximity of the River Thames. In addition, perched groundwater is likely to be present in the Superficial Deposits due to the presence of Alluvium. A local perched water table, possibly of limited extent and volume, may exist above low permeability layers in the Alluvium and Made Ground. Porous sandy units of the Made Ground and the pseudo fibrous peat within the Alluvium may retain water especially when sealed by a less permeable cohesive layer.

With the exception of the northern extremity of the Gallions Reach project study area the London Clay is absent from the site; the geological succession at the site is expected to comprise the Seaford Chalk, the Thanet Sand Formation and the Lambeth Group. The Lambeth Group is predominantly granular in nature at the site and as such there may be some connectivity between the upper and lower aquifers in the area.

The historic ground investigations undertaken in the vicinity of the site encountered groundwater at approximately 0 mATD within the River Terrace Deposits. Groundwater can also be anticipated within the granular layers of the Lambeth Group and the Thanet Sand Formation.

That part of the Gallions Reach project study area on the north bank of the River Thames is classed largely as a 'Minor Aquifer' with the underlying soils classified as having high leaching potential according to the groundwater vulnerability map (Envirocheck, 2013); that part of the Gallions Reach project study area on the south bank of the River Thames is classed largely as a 'Major Aquifer' with the underlying soils classified as having high leaching potential according to the groundwater vulnerability map (Envirocheck, 2013). However, the proposed river crossing does not lie in close proximity to a source protection zone or source protection zone borehole (Envirocheck, 2013).

The nearest surface water features are the River Thames and the Royal Albert Dock. In addition to these two surface water bodies, the River Roding joins the north side of the River Thames approximately 800m east of the study area. There is also a small surface water feature to the east of the DLR maintenance depot.

3.3.6 Historical Development of the Site

Published historical records of the site area were obtained as part of the Envirocheck Report. The maps and photographs consulted date from 1850 to 2012. The history of the site and surrounding areas as indicated in available records are summarised in Table B.1 in Appendix B.6. The key issues arising from the historical development of the site are summarised in the following sections.

3.3.6.1 North side of the Thames – summary key issues from historic maps

On the basis of foregoing discussion of the historic maps, the following key issues have been identified with respect to the proposed development:

- The presence of ground contamination resulting from the former industrial use of the site i.e. Beckton Gas Works;
- The presence of historic jetties and the remains of piers associated with the former gas works;
- The presence of historic foundations associated with the former land use;
- The interface between the proposed works and the DLR viaduct;
- The interface between the proposed works and the northern river wall; and
- The presence of buried services.

3.3.6.2 South side of the Thames – summary key issues from historic maps

On the basis of foregoing discussion of the historic maps, the following key issues have been identified with respect to the proposed development:

- The presence of ground contamination resulting from the former use of the site i.e. artillery ranges and industrial use;
- The presence of historic foundations associated with the former land use;
- The interface between the proposed works and the southern river wall; and
- The presence of buried services.

3.3.7 Existing and Historic Structures

There are a number of existing and historic structures, as noted in Sections 3.3.6.1 and 3.3.6.2, which could potentially affect the proposed schemes.

3.3.8 Potential Ground and Groundwater Contamination

The potential for ground and groundwater contamination within the Gallions Reach River Crossing project study area have been addressed in the Phase 1 Contamination Assessment for this site undertaken by Mott MacDonald as part of the Ground Investigation Desk Study commission. Overall the site as a whole has been given a HIGH risk rating.

The principal contamination sources to the north of the River Thames at this location include rail land (including a large DLR depot), warehousing, paint works, sewage treatment works, Beckton Gasworks, a pumping station, industrial warehousing units and a tar and liquor works. The area south of the River Thames comprises largely undeveloped land and previously was the location of a number of artillery ranges (part of the Royal Woolwich Arsenal). Historically, a large section of the site, in the Gallions Hill area, was designated as a “Tip”. Additionally, the Tripcock landfill site is located by Gallions Hill and encroaches within the footprint of the safeguarded area for the proposed crossing route.

Asbestos

Asbestos was encountered within the Made Ground during a ground investigation at the Armada 1/1A site, north of Armada Way. During the ground investigation, undertaken by White Young Green, asbestos was identified within the two Made Ground samples; and organic/inorganic contamination was also encountered within the perched water groundwater samples taken from the Alluvium, River Terrace Gravels and Thanet Sand Formation.

Landfill

Landfills have been identified on both the northern and southern sides of the River Thames (Landmark, 2013). Landfill materials can potentially be contaminated and very variable in nature. On the north side the landfill is likely to be associated with the removal of the Beckton Gas Works.

On the south side of the River Thames, there are three landfill site entries: two are located approximately 400m to the northeast of the safeguarded zone (historic and Local Authority recorded landfills). Additionally on this side of the River Thames, there is a Licensed Waste Management Facility which occupies a large portion of the study area, the Tripcock Point Registered Landfill site. The waste authorised for disposal at this site includes ‘difficult’ and ‘inert’ waste; ‘difficult’ waste (Waste Category E) is also disposed of at the site. Records indicate that the landfill is operational.

The contamination assessment made the following recommendations:

- Undertake an intrusive site investigation and laboratory testing together with a programme of environmental monitoring to more fully understand the conceptualised pollutant linkages identified;
- The results of these investigations should be used to inform a quantitative risk assessment, and can also be used in materials management and site construction environmental management plans;
- The scope of any investigation that may be required for planning purposes should be discussed with the regulators (local planning authority environmental health and Environment Agency).

Reference should be made to the report, 'Phase 1 Contamination Assessment, Gallions Reach to Thamesmead Crossing' (Document No. 320530/MNC/TUN/04) for further details.

3.3.9 Environmental Considerations

Sensitive land uses

No 'Sensitive Land Uses' have been identified within the study area.

Surface water bodies

There are a number of surface water bodies either within, or within the vicinity of, the study area. These are listed as follows:

- River Thames;
- Royal Albert Dock;
- A small reservoir east of Armada Way; and
- River Roding.

Flood risk

The scheme is located predominantly within Flood Zone 3. However, the site benefits from defenses along the banks of the River Thames which effectively remove it from the Flood Risk Zone and locate it within the residual risk floodplain. The exception is area adjacent to the River Thames on the southern side of the river which is not regarded by the Environment Agency (EA) as being at risk from flooding.

The proposed safeguarded area is outside the area of London protected by the Thames Barrier.

It is assumed that reliance is placed on the existing flood protection and no tunnel specific protection works are required or will be provided as part of the scheme and normal tunnel design good practice for intercepting water flows at the cut and cover tunnel portals will be followed. It is noted that the existing Blackwall Tunnels have flood protection gates installed. The intention of these gates is to provide protection to London in the event of a breach of the tunnel linings. The perceived risk arises primarily because of the extremely low ground cover beneath the river in particular with regards to the northbound Blackwall Tunnel. The ground cover to the proposed for the tunnel is more secure and floodgates are not deemed necessary. In addition, protection above the tunnel crown could be provided.

Where works are undertaken in close proximity to the flood defenses along the banks of the River Thames consent from the Environment Agency for works affecting watercourses and/or flood defenses will be required prior to undertaking the works.

In addition to the risk of flooding from the River Thames the EA also indicated that the area immediately adjacent to the north of Royal Albert Way and west of Woolwich Manor Way is within the maximum extent of risk of flooding from the King George V and William Girling Reservoirs.

Groundwater abstraction

The Site Sensitivity Maps contained within the Envirocheck Report for the Gallions Reach study area show that there are no known groundwater abstraction points located within the study area.

Cooling groundwater discharge consents

Cooling groundwater discharge consent has been granted at one location within the study area and a further two discharge points located within 250m of the site boundary. Within the study area, the discharge consent has been granted at the small reservoir located to the east of Armada Way on the north side of the River Thames.

Industrial archaeology

The study area on both the north and south sides of the River Thames are located in areas of historic industrial development. Consequently, there are potentially features of industrial archaeological importance.

Japanese Knotweed

As reported in Section 3.4.1.3, Japanese knotweed has previously been encountered within the study area and the associated risks should be considered in any scheme proposals for the Gallions Reach study area.

Japanese knotweed was introduced to the UK in the mid-nineteenth century as an ornamental plant for gardens. It has since escaped its domestic setting and is a thriving weed found in many natural environments. It is commonly found in abundance at roadsides, on riverbanks and on derelict land. Japanese knotweed is considered to be a problematic, invasive plant for a number of reasons. Japanese knotweed is very vigorous and can grow through hard surfacing, retaining walls and most industrial surfaces.

The occurrence of Japanese knotweed at brownfield sites is often associated with fly-tipping and from the incidental transfer of viable portions of vegetation.

3.3.10 Unexploded Ordnance (UXO)

The Gallions Reach study area is located in an area of east London which is known to have been heavily bombed during the Second World War (WWII). Therefore, a Stage 2/3 Detailed UXO Threat Assessment of the study area was commissioned in accordance with the requirements of CIRIA C681 'Unexploded Ordnance (UXO) – A guide for the construction industry'.

Detailed UXO Risk Assessment

The findings of the UXO assessment are detailed in the 'Detailed Unexploded Ordnance (UXO) Risk Assessment' report, prepared by 6 Alpha Associates. For the purposes of the assessment the site was divided into three areas:

- The area north of the River Thames;
- The River Thames; and
- The area south of the River Thames.

The assessment established that in the areas north and south of the River Thames, there is a 'Medium/High' risk of encountering UXO. However, in the River Thames, where bomb strikes are considered more likely to go unnoticed, the risk level is increased to 'High'. This is highlighted in WWII High Explosive (HE) bomb strike location plan (Figure 6) shown in Appendix B.5.

6 Alpha have recommended that once the scheme design and construction programme has been finalised, a detailed UXO risk mitigation strategy should be developed for the project. For the areas north and south of the River Thames, 6 Alpha have recommended that, in the first instance, that both non-intrusive and intrusive survey methods may be employed to clear the site of any potential UXO threat in advance of any intrusive ground works.

For the River Thames section, 6 Alpha have recommended that a magnetometer survey should be employed to clear the site of any potential UXO threat. Where any intrusive ground works, such as ground investigation, piling or tunnelling are to be undertaken, 6 Alpha have advised that a specialist UXO banksman should be present on site to identify the potential for any UXO threat.

3.4 Ground Conditions

3.4.1 Previous Ground Investigations

This section provides a description of the anticipated ground and groundwater conditions at the Gallions Reach study area based upon the available factual geotechnical information obtained from previous ground investigations undertaken within the study area. A summary of the previous ground investigation undertaken at the Gallions Reach study area is provided in Table 3.3.

Table 3.3: Previous ground investigations undertaken at Gallions Reach

Ground Investigation	Date	Scope
North Bank of River Thames		
ELRC Preliminary GI	1980	9 No. Boreholes to 50m depth.
ELRC Detailed GI Contract No.2	1982/83	106 No. Boreholes; 112 No. Static CPTs; 4 No. Trial Pits.
Armada Sites 1/1A GI	2003	10 No. Boreholes; 28 No. Trial Pits.
Gallions Approach Site 3 GI	2002	15 No. Boreholes; 45 No. Machine excavated Trial Pits.
Gallions Roundabout GI	2000	6 No. Boreholes; 6 No. Trial Pits.
Thames Gateway Bridge GI Location 2	2007	2 No. Boreholes; 1 No. Trial Pit.
Greenwich Waterfront Transit Development GI	2008	16 No. Trial Pits.
River Thames		
ELRC Preliminary GI	1980	Nine Boreholes to 50m depth.
ELRC Detailed GI Contract No.2	1982/83	106 No. Boreholes; 112 No. Static CPTs; 4 No. Trial Pits.
ELRC Supplementary GI	1990	8 No. Boreholes.
Thames Gateway Bridge GI Location 1	2007	6 No. Boreholes; 10 No. Static CPTs.
Thames Gateway Bridge GI Location 4	2007	2 No. Boreholes; 30 No. Static CPTs.
South Bank of River Thames		
ELRC Preliminary GI	1980	Nine Boreholes to 50m depth.
ELRC Detailed GI Contract No.2	1982/83	106 No. Boreholes; 112 No. Static CPTs; 4 No. Trial Pits.
Thames Gateway Bridge GI Location 3	2007	2 No. Boreholes.

3.4.1.1 East London River Crossings

In 1980 the Department of Transport appointed Sir William Halcrow & Partners to prepare a technical appraisal for a proposed East London River Crossing (ELRC) in the Gallions Reach area. The scheme was to link the A2 to the south with the A13 to the north via a crossing of the River Thames.

Preliminary Ground Investigation (1980)

As part of this appraisal a preliminary site investigation was carried out by Foundation Engineering Limited during August and September 1980. The preliminary site investigation comprised nine boreholes situated between Beckton in the north and Plumstead in the south including Gallions Reach; the boreholes extended to depths of between 15m and 50m below existing ground level, and were advanced by a combination of cable percussion and rotary coring techniques; five of the boreholes were extended into the Chalk. Two of the boreholes (Nos. 8 and 9) were sunk within the River Thames. Representative disturbed and undisturbed samples of the superficial deposits were obtained during the preliminary site investigations. Standard Penetration Tests (SPT) were undertaken in the granular deposits and the Chalk. The laboratory testing undertaken as part of the investigations included classification testing (for example Atterberg Limits, Particle Size Distributions, single stage 'Quick' Undrained Triaxial Tests and basic chemical tests (ph and sulphate content)). The preliminary site investigation was planned, supervised and administered by Sir William Halcrow & Partners on behalf of the Department of Transport.

Detailed Site Investigation (1982 – 1983)

Having defined a preferred route for the crossing the Department of Transport appointed Sir William Halcrow & Partners in 1982 to progress the scheme. The ELRC was to begin at Falconwood on the A2 passing northwards crossing Shooters Hill and then on to Plumstead. The route was to cross the Thames flood plain on embankment before crossing the River Thames on a new cable stayed bridge; the main piers of the bridge were to be in the river with the approaches on viaduct/embankment. North of the Thames the road was to be on embankment through the Beckton Gas works before joining the A13 via a three-level interchange.

As part of this scheme development a detailed site investigation was carried out in 1982/83. The site investigation was divided into separate contracts; Contract No.1, which was undertaken by Wimpey Laboratories Limited, ran from Falconwood on the A2 to the Thamesmead Spine Road; Contract No.2, which was carried out by Foundation Engineering Limited, ran north from the Thamesmead Spine Road to the proposed interchange with the A13 near Barking Creek and included the River Thames Bridge Crossing. The site investigations were planned, supervised and administered by Sir William Halcrow & Partners on behalf of the Department of Transport. A summary of the site investigations is provided in Table 3.4.

Table 3.4: Summary of the East London River Crossing detailed site investigation

Fieldwork Item	Contract No.1	Contract No.2	Total
Boreholes – on land	137	84	221
Boreholes – over water	Nil	22	22
Static Penetrometer Probes	41	112	153
Trial Pits	27	4	31

Contract No.2 is of particular interest to the current geotechnical desk studies as it was located within the current Gallions Reach project area. Unfortunately, the Factual Ground Investigation Report prepared by Foundation Engineering Limited has not been obtained to date during the current geotechnical desk studies.

The boreholes were advanced by light cable percussion boring methods (shell and auger) through the superficial deposits; a number of the boreholes were extended into the Chalk employing rotary core drilling techniques. Representative disturbed and undisturbed samples of the superficial deposits were obtained during the site investigations; piston samples were also taken in the very soft soils within the Thames flood plain. Cores were obtained from those boreholes extended into the Chalk.

Insitu testing included SPTs, vane tests, permeability tests, static Cone Penetrometer Tests (CPT) and pressuremeter testing. SPTs were carried out in granular deposits and the Chalk. Falling head permeability tests were undertaken in a select number of boreholes. On Contract No.2 pressuremeter tests were undertaken within the chalk in boreholes sunk both on land (2No.) and overwater (4No.); on Contract No.1 pressuremeter testing was carried out within the superficial deposits (sand and gravels) encountered (2No. boreholes). To monitor and establish the groundwater within the various strata encountered during the investigations Casagrande type piezometers were installed in a number of boreholes on Contract No.2. In addition, slotted casing was installed in two boreholes, one on each bank of the River Thames, and monitored hourly over a 24-hour period to establish the tidal response over a full cycle. The static CPTs were undertaken in order to determine the depth and extent of the soft alluvium; this work was undertaken by Osiris-Cesco for Foundation Engineering Limited.

The laboratory testing undertaken as part of the investigations included classification testing (for example Atterberg Limits, Particle Size Distributions, single stage 'Quick' Undrained Triaxial Tests and basic chemical tests (ph and sulphate content)).

Supplementary Ground Investigation

Due to the close proximity of the proposed East London River Crossing to London City Airport a redesign of the form of the bridge was undertaken in the early 1990s; the towers of the original cable stayed design were considered a hazard to aircraft navigation. The alternative design required piers at locations closer to the centre of the river. In order to verify, or otherwise, that the ground conditions were similar to those proved at the locations of the piers for the original cable stayed design in 1983, a supplementary ground investigation was undertaken.

This investigation was undertaken by Wimpey Geotech Limited during March and April 1990; eight boreholes were sunk over water employing cable percussion and rotary drilling techniques to a depth of 50m below existing riverbed level. Representative disturbed and undisturbed samples of the superficial deposits were obtained; rock core was recovered from the rotary drilled sections. SPTs were undertaken in the granular deposits and the Chalk. The laboratory testing undertaken as part of the investigations included classification testing of samples of both the superficial deposits and the chalk (for example Atterberg Limits, Particle Size Distributions and basic chemical tests (ph and sulphate content) on the superficial deposits and dry density and porosity determinations on samples of the chalk) as well as strength (triaxial) and consolidation (oedometer) tests. The site investigations were planned, supervised and administered by Sir William Halcrow & Partners on behalf of the Department of Transport.

It should be noted that some 7 .7m of 200mm diameter casing was left between river bed level and 12.8m depth in the vicinity of borehole 8. If this material remains insitu it could constitute an obstruction to site operations during subsequent construction of a fixed link.

3.4.1.2 Armada 1/1A Site, Beckton Ground Investigation

As shown in the location plan (Drawing No. SK. 17) contained in Appendix B.3, the Armada site comprises two individual pockets of land designated Armada 1 and Armada 1A situated north of Armada Way, Beckton. The Docklands Light Railway (DLR) Beckton Extension, which runs in a generally north-south direction, dissects the two sites; the Gallions Reach DLR Station is located to the south of the sites. A 2m high fence surrounds the DLR track. The DLR Station consists of ticketing facilities on the ground floor, with the platform and passenger waiting areas suspended approximately 5m above site level. The brownfield Armada 1 site lies to the east of the DLR track, covering a total area of approximately 4.3ha while the Armada 1A site is a narrow verge situated between the DLR Beckton Extension and Royal Docks Rd, covering an area of about 1.2ha.

The DLR Maintenance Depot and various commercial warehouses bound the Armada 1 site to the northeast. The Beckton Gas Works are located 300m northeast of the site. Land east of the Armada 1 site was vacant during the ground investigations.

A large 5-way gyratory is located immediately south of the Armada 1A site. Situated within this roundabout is the Gallions Reach Pumping Station. Royal Docks Road forms the western border of the Armada 1A site and consists of a dual-carriageway. A vacant lot is situated further west beyond this road, which appears to be covered by relatively thick, established vegetation. The residential areas of Cyprus lie approximately 120m further west of the site. An unfinished overpass crosses the site to the north, beyond which is a smaller landscaped verge.

Ground investigations were carried out at the Armada sites as part of their development during August and September 2003; the ground investigations were planned, supervised and administered by White Young Green on behalf of the London Development Agency. The ground investigation in the Armada 1 site comprised six boreholes and 14 trial pits; the investigation in the Armada 1A site consisted of four boreholes and 14 trial pits.

The six boreholes sunk within the Armada 1 site extended to depths varying between 23.4 and 26.5m below existing ground level. The 14 mechanically excavated trial pits undertaken within the site extended to depths varying between 3.0 and 5.0m below existing ground level.

The four boreholes sunk within the Armada 1A site extended to depths varying between 20.5 and 25.0m below existing ground level. The 14 mechanically excavated trial pits carried out within the site extended to depths varying between 0.8m and 4.9m below existing ground level.

In-situ geotechnical testing, comprising penetration resistance testing (SPT) and falling head permeability tests, was undertaken in the boreholes sunk at each site. Representative disturbed and undisturbed samples of the superficial deposits were obtained during the site investigations.

The geotechnical laboratory testing undertaken as part of the investigations included standard classification testing (for example Atterberg Limits, Particle Size Distributions, single stage ‘Quick’ Undrained Triaxial Tests and basic chemical tests (ph and sulphate content)).

Dual-purpose 50mm diameter land gas and groundwater monitoring standpipes installed in all boreholes on completion. Monitoring of groundwater levels over a complete tidal phase was also carried out.

A previous investigation of the Armada 1 site by WSP Environmental established twelve boreholes using cable percussive methods. This information has not been made available during the current work.

The general geological sequence consists of Alluvial drift deposits underlain by Thanet Beds, which in turn are underlain by Chalk at depth. Made Ground was encountered at all exploratory hole positions with the thickness ranging from 3.2m to 6.5m; it was highly variable in composition and consistency. A thin layer of topsoil was noted across the entire Armada 1A site. The soil sequence encountered across both Armada 1 and 1A was broadly consistent between investigation locations and compared well with that identified in published literature and the 1999 WSP site investigation. In summary ground conditions comprised Made Ground, overlying Alluvium, overlying River Terrace Deposits that in turn overlay the Thanet Sands Formation to the full extent of this investigation.

The intrusive site investigation encountered the presence of significant contamination within the Made Ground and to a lesser extent within the natural strata. Asbestos was encountered in two locations within the Made Ground. Inorganic and organic contaminants were encountered within the perched water groundwater samples taken from the Alluvium, River Terrace Deposits and Thanet Sand Formation. Given the encountered geological profile and proven permeability of the Thanet Sand Formation, it was concluded that it was possible that the contamination had impacted the Chalk aquifer underlying the site. Elevated concentrations of CH_4, CO_2 and VOCs were encountered in several exploratory positions.

3.4.1.3 Gallions Approach Site 3 GI

As part of the development of Site 3 at Gallions Approach a ground investigation was undertaken during October 2002; the ground investigation was planned, supervised and administered by White Young Green Environmental on behalf of the London Development Agency. As shown in the borehole location plan (Drawing No. SK.02) in Appendix B.3 the site, which covers an area of approximately 7.8ha, is located northeast of the Royal Albert Dock in Beckton, East London. The site is bounded to the east by the River Thames and to the north by the Beckton Gasworks. Adjoining the southern boundary are recently built offices and warehousing facilities; the western boundary is formed by an access road leading to a roundabout linking to Armada Way midway along the boundary. The underground Gallions Outfall Sewer also runs east-west across the site.

The investigation consisted of 15 boreholes, sunk to depths varying between 15m and 30m below existing ground level, and 45 trial pits, machine excavated to depths varying between 2.3m and 5.8m below existing ground level. In situ geotechnical testing, comprising penetration resistance tests and falling head permeability tests, was undertaken in the boreholes sunk at the site during the fieldworks. Representative disturbed and undisturbed samples of the superficial deposits were obtained during the ground investigation.

The geotechnical laboratory testing undertaken as part of the investigations included standard classification testing (for example Atterberg Limits, Particle Size Distributions, single stage 'Quick' Undrained Triaxial Tests and basic chemical tests (ph and sulphate content)).

Dual-purpose 50mm diameter land gas and groundwater monitoring standpipes were installed in all the boreholes on completion of drilling. Monitoring of groundwater levels over a complete tidal phase was also carried out.

Additional ground investigation works were carried out in conjunction with the above as specified by Hyder in relation to the installation of a sewer outfall and comprised one borehole (BH1) drilled to a depth of 10.0m below existing ground level with 50mm diameter landgas and groundwater monitoring standpipe installed upon completion. Two machine excavated trial pits (TP1 & TP2) extending to depths of 5.0m and 4.6m below existing ground level respectively were also carried out for the sewer outfall.

The soil sequence encountered across the site was broadly consistent between investigation locations and in summary comprised Made Ground, underlain by Alluvium, overlying River Terrace Deposits that in turn overly the Upper Chalk Formation. This was generally the case for the whole site excepting BH16 where Thanet Sands were encountered below the River Terrace Deposits.

Japanese Knotweed

As part of the development of Site 3 at Gallions Approach, an assessment of the Japanese knotweed was also carried out by White Young Green. The assessment established the presence of Japanese knotweed at a number of locations across the site, covering a total area of 113m² at the time the survey was undertaken. The area of the contaminated soil, including the root system, was estimated to be close to 3,301m² and to a depth of approximately 3m.

3.4.1.4 Gallions Roundabout GI

The Gallions Roundabout site is situated 360m north of the eastern end of the Royal Albert Dock and is approximately 160m long and about 65m wide giving an overall area of 1.16Ha. It is bounded to the north by a sliproad; to the east by the Royal Docks Road (the Gallions Reach DLR Station is situated further east); to the south by the Gallions Roundabout and pumping station; to the west by Woolwich Manor Way.

A ground investigation was carried out by Soils Ltd as part of the development of the site during January and February 2000; it was planned, supervised and administered by the Symonds Group on behalf of the London Development Agency. The fieldworks comprised six boreholes, three extending to a depth of 25m below existing ground level and three extending to a depth of 15m below existing ground level; and six mechanically-excavated trial pits extending to depths of the order of 4m below existing ground level. In situ geotechnical testing, comprising penetration resistance tests and falling head permeability tests, was undertaken in the boreholes sunk at the site during the fieldworks. Representative disturbed and undisturbed samples of the superficial deposits were obtained during the ground investigation. Dual-purpose 50mm diameter land gas and groundwater monitoring standpipes were installed in all the boreholes on completion of drilling.

The geotechnical laboratory testing undertaken as part of the investigations included standard classification (for example Atterberg Limits, Particle Size Distributions, single stage 'Quick' Undrained Triaxial Tests and basic chemical tests (ph and sulphate content)) and deformation (for example oedometer consolidation tests) testing.

The soil sequence encountered across the site was broadly consistent between investigation locations and in summary comprised Made Ground, underlain by Alluvium, overlying River Terrace Deposits that in turn overly the Thanet Sand Formation. A perched water table was observed in the Made Ground.

3.4.1.5 Greenwich Waterfront Transit Development GI

A ground investigation was carried out as part of the Greenwich Waterfront Transit Development in 2008; the ground investigation was planned, supervised and administered by White Young Green Environmental on behalf of Parsons Brinckerhoff/Transport for London.

As shown in the borehole location plan (Figure 1) in Appendix B.3 the fieldworks, which were carried out during August and September 2008, comprised:

- 16No. mechanically-excavated trial pits extending to depths of up to 5.1m below existing ground level;
- 16No. land rover mounted CBR tests;
- 16No. density tests using nuclear method;
- 17No. 2D Resistivity Imaging Profiles;

- 30No. Seismic Refraction Profiles;
- Laboratory contamination testing; and
- Laboratory geotechnical testing

The geotechnical laboratory testing undertaken as part of the investigations included standard classification testing (for example Atterberg Limits, Particle Size Distributions, single stage 'Quick' Undrained Triaxial Tests and basic chemical tests (ph and sulphate content)).

3.4.1.6 Thames Gateway Bridge Investigations

Ground investigations associated with the Thames Gateway Bridge project were undertaken at four locations in 2007 by Soil Mechanics. The investigations were planned, supervised and administered by Sir William Halcrow & Partners on behalf of Transport for London.

Location 1

The Location 1 Ground Investigation was situated in the River Thames. Six boreholes were sunk over water to a maximum depth of approximately 35.7m together with ten static Cone Penetration Tests to a maximum depth of almost 13.2m during March and April 2007. The locations of the exploratory holes are shown in Drawing No. E2 in Appendix B.3. Insitu testing in the boreholes consisted of SPTs/CPTs in the superficial deposits and underlying Chalk. The Static Cone Penetration Tests were undertaken by Geocone, a division of Soil Mechanics. The locations of the exploratory holes are shown in Drawing No. E2 in Appendix B.3.

The laboratory testing undertaken as part of the investigation comprised routine classification testing (for example Atterberg Limit, Particle Size Distribution determinations for soil samples recovered and Unconfined Compression Strength, Point Load and Saturation Moisture Content testing of Chalk samples).

Location 2

The Location 2 Ground Investigation was situated at the proposed Eastern Gateway Grade Separation Bridge, Beckton. The two boreholes constructed were each sunk to a depth of 40m; one trial pit was excavated to a depth of 4.2m. Standpipes were installed in both boreholes. In addition, geophysical surveys were undertaken to investigate the existing piled foundations of Pier No.5. The fieldworks were carried out during April and May 2007; the locations of the exploratory holes are shown in Drawing No. G2 in Appendix B.3.

The laboratory testing undertaken as part of the investigation included basic classification testing (for example Atterberg Limits and Particle Size Distributions) as well as strength tests (i.e. 'Quick' undrained triaxial tests).

The geophysical surveys undertaken by Pelorus Surveys, a division of Soil Mechanics, in an attempt to determine the lengths of the existing piled foundations to Pier No.5.

Location 3

The Location 3 Ground Investigation was situated on the south bank of the River Thames in the Royal Arsenal Woolwich Conservation Area and comprised two boreholes. One of the boreholes was sunk to a depth of approximately 15.5m (by shell and auger only); the other borehole was sunk to a depth of approximately 39.90m (shell and auger with rotary follow-on).

The fieldworks were carried out during April 2007; the locations of the exploratory holes are shown in Drawing No. F2 in Appendix B.3.

Location 4

The Location 4 Ground Investigation was also situated in the River Thames. It comprised two boreholes (each sunk by cable percussion with rotary follow-on to a maximum depth of approximately 25.3m) and 30 CPTs (advanced to a maximum depth of approximately 13.4m); the CPTs were carried out by Geocone, a division of Soil Mechanics Limited.

The fieldworks were carried out during March 2007 and April 2007; the locations of the exploratory holes are shown Drawing No. E2 in Appendix B.3.

3.4.2 Made Ground

Made Ground can be anticipated to exist on both the northern and southern sides of the Thames as a result of historic redevelopments. The thickness and nature vary across the site and depends on previous development and land use.

3.4.3 Alluvium

The Alluvium rests unconformably on the Thames River Terrace Deposits. It comprises of river deposits of primarily soft silty clays, peat and medium dense silty fine sands. Pockets and beds of peat and organic material are also present which may include gases from decomposition of the organic matter. These deposits were laid down in the valley floors in the Holocene era and formed the original marsh deposits in the area prior to 19th century industrial development.

On the north side of the River Thames the Alluvium contains pockets of peat and organic material up to 5m thick. On the south side of the River Thames, there is a distinct band of peat within the Alluvium which ranges between 1.5m and 5m thick.

3.4.4 River Terrace Deposits

The published geological map indicates Thames River Terrace Deposits to be present across much of the docklands area. The River Terrace Deposits are described on the published geological map as gravels with pockets of sands and clays. They were mainly deposited during the colder climatic periods of the Pleistocene formed in response to heavy snow-melt run-off which formed a series of braided channels that interlinked within the wider flood plain to form the Thames River Terrace Deposits.

Within the study area, the River Terrace Deposits typically comprise medium dense to dense multicoloured well rounded and angular well graded flint gravel and silt/sand, becoming finer with depth. The thickness of River Deposits could be expected to be between 4m and 8m on the north side of the River Thames, decreasing to between 1m and 4m beneath the River Thames. To the south of the River Thames, the River Terrace Deposits could be expected to be between 4m and 10m.

3.4.5 London Clay

The London Clay Formation is present on the northern and southern margins of the safeguarded route corridor, covering the Lower Tertiary succession. In the northern extremity of the project study area near the Beckton Gas Works, the London Clay is overlain by Holocene and Upper Pleistocene alluvial deposits and is underlain by the Harwich Formation.

3.4.6 Harwich Formation

The published geological map shows Harwich Formation occurs at isolated locations around the London docklands area. In the London district area, the formation was formerly mapped as the Blackheath Beds and can be referred to as the basement beds of London Clay (Ellison, 2004).

There are numerous descriptions of former exposures recording very variable thicknesses over very short distances. This may be an indication of an irregular base (Ellison, 2004).

The Harwich Formation could be expected in varying thicknesses in the northern extremity of the study area, overlain by the London Clay.

3.4.7 Lambeth Group

The Lambeth Group comprises a variable series of sands, silts, clays, pebble beds and loams. Within the current Gallions Reach project study area the Lambeth Group consist of estuarine deposits overlying the Thanet Sand Formation; they are confined to an area north of the Greenwich Fault.

3.4.8 Thanet Sand

The Thanet Sand Formation is marine in origin and was deposited following a period of erosion of the Upper Chalk. With the exception of the crossing of the River Thames the Thanet Sand Formation is likely to be present throughout the current Gallions Reach project study area, resting unconformably on the Upper Chalk surface; alluvial erosion and deposition has removed the Thanet Sand Formation within the Thames Estuary. On the flanks of the Thames Estuary the Thanet Sand Formation has formed ‘wedges’ of material of the order of 15m to 17m thick.

During the detailed ground investigations for the East London River Crossing in the early 1980s the Thanet Sand Formation was recovered as a pale yellow, off-white, green, grey and pale brown loosely cemented silt, sand and sandy silt with occasional flint gravel bands. The junction with the Upper Chalk was often marked by a 0.2m to 0.5m thick green or brown clayey gravel basal layer commonly referred to as the Bullhead Beds; this basal layer was absent over much of the central part of the 1980s East London River Crossing project study area suggesting that this material had been reworked locally and redeposited.

Within the vicinity of the Greenwich Fault the Thanet Sand Formation appears to have been downthrown some 5m to 8m to the northwest; the fault defines the boundary with the Lambeth Group which overlies the downthrown Thanet Sand Formation on heading north. Thereafter the surface profile of the Thanet Sand Formation is essentially parallel to the chalk substrate.

Insitu testing indicates that the Thanet Sand Formation is a very dense material; a slight reduction in SPT ‘N’ value was recorded in the top 3m to 5m of the formation where it was overlain by alluvial deposits of the

River Thames flood plain; this reduction may reflect marginal disturbance associated with reworking of surface material.

With the exclusion of colour variations, the Thanet Sand Formation was considered to be fairly uniform in character. Although the proportion of fines increased marginally with depth at some locations this was not a consistent feature of the deposits as a whole.

3.4.9 Upper Cretaceous Chalk

The published geological map of the area of interest shows the White Chalk unconformably underlies the Thanet Sand. The base of the Chalk as indicated on structural contour map (Ellison, 2004) around the vicinity of the proposed site is approximately 200 metres below ground level.

Chalk is present across the whole of the Gallions Reach study area. It is anticlinal, dipping steeply to the north-west (see notes on faulting below) and somewhat more gently to the south-east. The chalk is moderately to highly weathered, friable, soft to medium soft and very weak containing some medium to large nodular flints.

Chalk is a relatively pure white limestone which is normally considered to have been deposited in a shallow sea; the enveloping land environment is considered to have comprised desert thus explaining the lack of other constituents. Flint bands, a characteristic feature of the Upper Chalk are generally believed to have formed from solutions associated with decomposition of siliceous fossil skeletons.

The soft nature of the near surface chalk, which reflects the extent of the weathered zone, is apparent in the SPT N values recorded. Excluding the effect of flint bands on the SPT results, a general increase in strength (i.e. N value) with depth was observed within the weathered chalk layer during the detailed ground investigations for the East London River Crossing until competent chalk was encountered; thereafter, consistently high N values (i.e. greater than 50) were recorded.

No evidence of solifluction sheets was observed in the current project study area during the detailed ground investigations for the East London River Crossing in the early 1980s.

The chalk encountered during the detailed ground investigations for the East London River Crossing in the early 1980s was off-white to cream in colour and contained abundant irregularly shaped find gravel to cobble-sized flints, which frequently resulted in poor core recovery. Sub-vertical, horizontal and oblique fractures comprising joints and bedding planes were evident in the core recovered of the more competent chalk strata. These fracture planes surfaces were often slightly weathered and displayed ferruginous coatings and, occasionally, organically stained surfaces.

In most of the boreholes sunk during the detailed ground investigations sound and relatively unweathered chalk was encountered at depths of 8m to 10m below the rockhead surface; this material corresponded to Grade II on the Mundford Classification (Ward et al., 1968). Occasionally, impersistent pockets of Grade IV to V chalk (Mundford Classification) were apparent in the chalk cores at depth. The chalk surface typically comprised Grade V material (Mundford Classification); chalk quality marginally improved to Grade III/IV (Mundford Classification) at depths approaching 5m below rockhead level.

It was noted that the depth and type of superficial cover overlying the chalk did not appear to have a marked effect on the chalk quality regime described above. In addition, the competence of the chalk in the vicinity of the Greenwich Fault was considered consistent with that found elsewhere in the project study area; on this basis it was concluded that the fault had not influenced chalk quality.

Solution cavities often associated with chalk and limestone formations were not encountered during the detailed ground investigations for the East London River Crossing in the early 1980s, nor are they indicated on geological maps or evident at the surface within the project study area. Whilst this suggests that the existence of such features in the project study area is unlikely it was not discounted entirely.

The information obtained during the detailed ground investigations for the East London River Crossing indicated that within the confines of the River Thames the Flood Plain gravels rest directly on the chalk; elsewhere the Thanet Sand Formation/Lambeth Group/London Clay Formation (i.e. Eocene deposits) overly the chalk and in turn are overlain by the Quaternary deposits.

3.4.10 Mining Subsidence

Rockliff Gardens to the south of the current Gallions Reach project study area is a known area of mining subsidence and was studied in detail during the geotechnical investigations for the East London River Crossing in the early 1980s. No areas of mining subsidence are known of in the current project study area.

3.4.11 Ground Profiles

A summary profile of the ground conditions identified from the historic ground investigations applicable for the works on the northern side of the River Thames, within the River Thames and on the southern side of the River Thames are presented in Tables 3.5, 3.6 and 3.7 respectively. The anticipated ground profiles have predominantly been derived from the findings of the East London River Crossing ground investigations which broadly correspond to the alignment of the proposed fixed link crossing at Gallions Reach. The anticipated ground profile along the proposed immersed tube tunnel alignment is shown in the long section drawing (Drawing No. MMD-298348-TUN-603) included in Appendix B.2.

Table 3.5: Typical strata boundary north of the River Thames

Formation	Soil Description	Top (mOD)		Bottom (mOD)		Top (mbgl)		Bottom (mbgl)		Thickness (m)	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Made Ground	Brick rubbles, ash, sand	2.0	7.72	0.52	3.94	0.0	0.0	1.0	7.2	1.0	7.2
Alluvium	Silty Clay with pockets of Peat	0.0	3.94	-10.1	-2.57	1.0	7.2	6.0	15.3	2.6	10.9
River Terrace Deposits	Sandy Gravel silty	-10.1	-2.08	-12.6	-7.81	6.0	15.3	10.4	17.8	1.8	7.8
Lambeth Group	Very Dense pale green blue SAND	-11.91	-5.97	-20.74	-10.73	9.8	18.0	16.0	28.5	0.0	11.5
Thanet Sand	Very dense grey silty fine SAND	-20.74	-10.02	-42.05	-16.22	15.4	28.5	21.6	49.8	0.0	21.3
Chalk		-42.04	-7.0	N/A	N/A	12.3	49.8	N/A	N/A	N/A	N/A

Table 3.6: Typical strata boundaries across the River Thames

Formation	Soil Description	Top (mOD)		Bottom (mOD)		Top (mbgl)		Bottom (mbgl)		Thickness (m)	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Alluvium	Silty Clay	-7.95	2.80	-10.6	-8.0	0.0	0.0	0.5	9.0	0.0	9.0
River Terrace Deposits	Sandy Gravel silty	-10.6	-8.0	-13.85	-10.35	0.0	9.0	2.25	13.3	0.85	4.5
Chalk		-14.15	-10.35	N/A	N/A	3.0	13.3	N/A	N/A	N/A	N/A

Table 3.7: Typical strata boundaries on the south side of the River Thames

Formation	Soil Description	Top (mOD)		Bottom (mOD)		Top (mbgl)		Bottom (mbgl)		Thickness (m)	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Made Ground	Brick rubbles, ash, sand	1.18	6.94	-1.77	3.84	0.0	0.0	0.3	6.45	0.3	6.45
Alluvium	Silty Clay with layer of peat	-1.77	3.84	-6.85	-3.89	0.3	6.45	4.5	13.4	4.2	10.3
River Terrace Deposits	Sandy Gravel silty	-7.71	-3.89	-16.9	-10.41	4.5	13.4	11.5	22.1	3.7	10.2
Thanet Sand	Very dense silty fine SAND	-16.6	-10.41	-20.45	-16.32	11.5	20.75	17.5	21.7	0.0	6.75
Chalk		-22.05	-9.93	N/A	N/A	14.4	23.3	N/A	N/A	N/A	N/A

3.5 Preliminary Engineering Assessment

3.5.1 Engineering Considerations

The desk study has revealed that the site on the northern side of the Thames has been in use since 1870. The site has a legacy of industrial use, including Beckton Gas Works. The northern part of the site encompasses parts of the DLR Beckton Depot and the Royal Albert Docks.

The adjacent area has also encompassed a history of industrial, residential and railway development. The area is currently occupied by residential and commercial buildings and infrastructure. The extent to which contamination from previous industrial uses has been remediated is partially unknown and is covered in a separate report. The locations of remains of any old foundations and services left beneath the ground are also unknown.

The southern side of the Thames was developed from marshland in the 1960s. Today, the study area is underdeveloped and largely unoccupied with residential areas to the east and west. There are two large commercial units located within the site area south of Western Way. The proximity of the proposed alignment to the Tripcock Point Landfill should also be taken into account and further investigations made to identify the hazardous material contained in the site.

The ground conditions across the site are expected to comprise of a variable thickness of Made Ground, Alluvium, Peat, River Terrace Deposits, Lambeth Group and Thanet Sand followed by the Upper Chalk. Made Ground is expected to be absent within the River Thames.

For cost effectiveness and sustainability it is essential to check the possibility of re-using material that is excavated from the works. For an immersed tunnel there are large volumes of material arising and large volumes required for backfilling, but there may also be significant volume of arisings from the piles for the bridge option. There is therefore a great benefit if materials can be re-used in the construction. Both dredged and land excavated material should be considered.

Both the south and north approach tunnels will be excavated through Alluvium, Terrace Gravels down to the top of the chalk. The Terrace Gravel layer is expected to be approximately 4m to 6m thick in this vicinity and with careful excavation methods this material could be stockpiled for re-use in the works.

Within the river, the materials that will arise from the dredging operation will be primarily Alluvium, Terrace Gravels and Chalk. It is not expected that this material can be re-used in the works and is will be disposed of at a licensed site for beneficial use, such as Wallasea Island/Rainham.

3.5.1.1 Engineering considerations for the Immersed Tube Tunnel

For the immersed tube options, short lengths of cut and cover tunnel are required at each shoreline and beyond them an open ramp section through which the road will descend to the tunnel portal. Given the presence of the permeable strata it is most likely that these will be constructed using embedded walls such as diaphragm walls for the primary retaining structure. Ground conditions are suitable for the construction of diaphragm walls. The excavation within the walls will need to be accompanied by ground water lowering in order to keep the excavations dry and allow the construction of the tunnel base slab.

Some temporary piling will be necessary at the river banks to enable the bank to be excavated and the immersed tunnel to be connected to the cut and cover tunnels at each side. The type of piling used is generally heavy sections such as combi-piled walls. At the river banks the piles will need to be driven through the alluvium and terrace gravels and into the top of the chalk. This is expected to be achievable.

The immersed tunnel will be founded predominantly in the chalk which will offer a good bearing stratum. Settlement should not be significant for the bearing pressures that might be expected beneath the immersed tunnel structure.

Some ground investigation will be required to determine the quality and hardness of the chalk material. It is expected that it will be possible to dredge the chalk with the use of a back-hoe dredger. It should be possible to achieve reasonable steep side slopes for the dredge trench through the chalk, at a gradient of approximately 1:1, although these will relax for the overlying alluvium layers, to a gradient of approximately 1 vertical to 4 horizontal. Dredging of the alluvium can be carried out using the same equipment as for the chalk. However, Alluvium does provide greater choice of dredging equipment and therefore more flexibility for the dredging contractor.

Casting Basin

If a casting basin were to be constructed on site for the tunnel elements it would be in the order of 15m deep over an area of 150m x 200m. With the earthworks slopes required to form the excavation this area would become approximately 250m x 300m. The preferred geology for a casting basin is to have impermeable strata beneath the base of the basin, and if possible, in the 15m depth of soil around the perimeter of the basin. This avoids the need to install perimeter ground water cut-off walls and to treat the base of the trench by grouting or installing dewatering to lower the ground water and enable the excavation to be made dry.

A large area of open ground is available to the north of the alignment on the southern Thamesmead approach. This has sufficient area but only has a thin layer of alluvium quite close to the surface that could be considered cohesive and therefore watertight. The material at the base of the excavation is expected to be Chalk or Thanet Sand. Both of these formations will be permeable and require a dewatering system to control the ground water. Perimeter ground water cut-off walls will also be required, probably slurry walls some 25m to 30m deep.

More significantly however is that this area is currently in use as a landfill site and is expected to contain hazardous material. Thus, the possibility of using this area for a casting basin is somewhat doubtful and will have to be confirmed based on survey and sampling of the ground in that area.

Space is more limited on the northern approach but the ground conditions are similar and would require the same measures to create a dry excavation suitable for building the tunnel elements. The founding properties of the chalk and Thanet sands are expected to be good, such that settlement during construction of the tunnel elements is unlikely to be a problem.

A casting basin with extensive dewatering and cut-off walls is likely to be expensive. It may be more cost effective to consider off-site solutions.

3.5.2 Recommendations for Further Investigation

Ground Investigation

To date the complete Factual Ground Investigation Report for the East London River Crossing project, particularly the results of the insitu and laboratory testing, undertaken within the Gallions Reach River Crossing project study area during the early to mid-1980s has not been made available. In its absence a number of the borehole logs for the East London River Crossing ground investigation in the vicinity of the Gallions Reach River Crossing project study area have been obtained from the British Geological Survey. In addition, the recommendations of the corresponding interpretative report prepared by Sir William Halcrow and Partners in 1985 have been largely relied upon in the formulation of preliminary geotechnical parameters for use in design.

In the first instance it is recommended that further efforts are made to obtain the complete Factual Ground Investigation Report for the East London River Crossing project undertaken within the Gallions Reach River Crossing project study area. Obtaining this information will reduce the quantity of additional ground investigation that will be required to take either the bridge or immersed tube tunnel crossing options forward.

Whether or not the Factual Ground Investigation Report for the East London River Crossing project undertaken within the Gallions Reach River Crossing project study area is obtained the ground and groundwater conditions and material properties along the proposed route corridor will require verification through a project-specific additional ground investigation. The scope of this ground investigation will be largely dependent upon whether the Factual Ground Investigation Report for the East London River Crossing project, particularly the results of the insitu and laboratory testing, undertaken within the Gallions Reach River Crossing project study area during the early to mid-1980s is obtained. A more extensive investigation will be required if the Factual Ground Investigation Report for the East London River Crossing project (Contract No.2) is not obtained.

In addition, the Phase 1 Contamination Assessment made the following recommendations:

- Undertake an intrusive site investigation and laboratory testing together with a programme of environmental monitoring to more fully understand the conceptualised pollutant linkages identified. The aggressivity of the ground and groundwater to concrete should be assessed as part of this process;

- The results of these investigations should be used to inform a quantitative risk assessment, and can also be used in materials management and site construction environmental management plans;

- The scope of any investigation that may be required for planning purposes should be discussed with the regulators (local planning authority environmental health and Environment Agency).

Investigations of Existing Structures

Given the paucity of information on the existing foundations, intrusive investigations should be undertaken to identify whether or not existing historic structures will be a hindrance to excavations associated with the construction tunnel and tunnel portals or bridge piers and approaches.

3.6 Comparison of Project Options

3.6.1 Ground Engineering Risks

The key geotechnical risks that are envisaged for the Gallions Reach study area are detailed in the Geotechnical Risk Register contained in Appendix B.7. The Geotechnical Risk Register will operate as a live document and will be reissued as part of the Ground Investigation Report (GIR) and throughout the development of the project.

The key structures for the proposed schemes are:

- Southern and northern tunnel portals and approaches, immersed tunnel section and associated ancillary structures (including a casting basin) for the immersed tube tunnel option and;
- Southern and northern approach viaducts, south and north abutments and associated piers for the bridge option.

The key risks associated with the respective aspects of the tunnel and bridge schemes are summarised in the following sections:

Tunnel approach structures

- Dewatering will be required during the construction of the excavation of the open ramps for the tunnel approaches as they will be founded in the alluvium overlying the terrace gravels. Due to the lack of boreholes for this site, the difficult piling conditions associated with the Blackheath Member (Harwich Formation) or the hard bands of cemented/siliceous associated with the Lambeth Group remain a potential risk

- The open ramps may need to be piled down to the chalk to control settlements due to the thickness of the soft superficial deposits. In the long term, the piles may be in an uplift condition as the alluvium is unlikely to be of sufficient quality to provide any tension pile resistance. Gravity structures may be necessary.

- Ground improvement techniques may be limited due to environmental constraints, for example, the past uses of the site as landfills, construction within the riverbed.

- Excavation induced ground settlement will take place due to construction, in the soft soil environment, of the cut and cover structures. This may result in large strains being induced in nearby structures and adjacent subsurface structures and services resulting in unacceptable damage. Key overlying structures include the River Thames quay wall structures, surface road network, buildings (shallow and piled) used for commercial and residential purposes. In addition, underlying structures including third party underground service utilities/infrastructures may also be affected, e.g. drainage from Royal Albert Dock, telecommunications and electricity supply ducts.

- Presence of manmade ground obstructions such as foundations or old pier structures remains could obstruct piling works. Piling may be required at the river banks to enable the bank to be excavated and the immersed tunnel to be connected to the cut and cover tunnels at each side.

- Encountering residual ground contamination due to historic or current use of the site works may be a hazard to site operatives during construction, especially around Tripcock Point Landfill on the southern side of the Thames. There is also a risk that contamination might be enabled to migrate to deeper strata during construction, for example during pile construction.

- Natural ground gas such as methane with explosive potential from clayey peat in the Alluvium will be a hazard during excavation works associated with sub-surface structures.

- Potential aggressive ground/groundwater conditions (for example, elevated sulphate or chloride levels in the superficial soils) could present aggressive conditions for the reinforced concrete used in the construction of the tunnel approach structures.

Immersed Tube Tunnel

- Presence of manmade ground obstructions such old pier structures remains (possibly those of now redundant structures) or sunken vessels could obstruct dredging works. These will be a hindrance to tunnel construction and may need to be removed.

- Differential settlement at the interface between immersed tunnel and cut and cover tunnel. In this instance the interface occurs at the horizon between the chalk and the terrace gravels. Whilst there is a change in materials at this point both materials offer good bearing capacity and differential settlement is not expected to be problematic.

- Saline intrusion into the underlying Chalk aquifer following dredging. The groundwater is generally separated from the brackish water of the River Thames by a layer of alluvium/clay. When the river is put into hydraulic continuity with the river there is a risk of saline intrusion into the aquifer. During construction, this might be tolerated but long term the river should be separated again. This can be achieved either through the use of selectively placed cohesive backfill material or by use of ground membranes within the tunnel backfill.

- Release of fine material into the water column will need to be controlled during dredging.

- Undermining or destabilising river walls on either side of the Thames due to dredging operations.

- Possible periglacial scour hollows infilled with saturated gravels.

Bridge Approach Structures

- Encountering residual ground contamination due to historic or current use of the site works may be a hazard to site operatives during construction, especially around Tripcock Point Landfill on the southern side of the Thames. There is also a risk that contamination might be enabled to migrate to deeper strata during construction, for example during pile construction. The design should avoid positioning support columns on or undertaking construction works through the landfill site.

- Viaducts founded on Alluvium will have to be piled to reduce settlement. The alluvium is unlikely to be of sufficient quality to provide any tension pile resistance. The potential uplift condition within this material may require deep piles or gravity structures to reduce this effect.

- Presence of manmade ground obstructions such as redundant foundations or the remains of old pier structures could obstruct construction, for example any piling works.

- Potential aggressive ground/groundwater conditions (for example, elevated sulphate or chloride levels in the superficial soils/groundwater) could present aggressive conditions for the reinforced concrete used in the construction of the bridge approach structures.

- Excavation induced ground settlement may take place due to construction, in the soft soil environment, of a large number of piles. This may result in strains being induced in overlying structures and adjacent subsurface structures and services resulting in unacceptable damage. Key overlying structures include the southern river wall structures, surface road network, buildings (shallow and piled) used for commercial and residential purposes.

Bridge

- Presence of manmade ground obstructions such old pier structures remains (possibly those of now redundant structures) or sunken vessels could obstruct construction of the bridge support columns in the river Thames. These will be a hindrance to foundation construction and may need to be removed.

- Piling works within the Thames have the potential to create preferential pathways for contaminants to migrate to the underlying Chalk aquifer. Any large scale, long duration piling activity would be of concern to the EA who are increasingly concerned about the potential negative impact of piling activity within the river. Mitigation techniques will be required to reduce the impact of the work on fish in this stretch of the River Thames.

- Piling works may create excess, potentially contaminated, soil at the surface or may drag shallow contaminated soils/riverbed sediments down to deeper previously un-affected horizons. In addition the scheme may also lead to contaminants within the river bed being mobilised during the construction of any support columns situated in the river and consequently result in the deterioration in water quality within the River Thames or lead to an uptake of contaminants by ecological receptors.

- Differential settlement at the interface between immersed tunnel and cut and cover tunnel. In this instance the interface occurs at the horizon between the chalk and the terrace gravels. Whilst there is a change in materials at this point both materials offer good bearing capacity and differential settlement is not expected to be problematic.

- Release of fine material into the water column will need to be controlled during dredging.

- Possible periglacial scour hollows infilled with saturated gravels.

3.6.2 Other potential ground related risks and considerations

In addition to the items discussed above the following are more general ground related risks and considerations that should be reviewed during design:

- archaeology – given the historic development of the site and in particular for the works on the northern side of the Thames there is the potential to encounter feature of importance with respect to industrial archaeology;

- buried services – buried services/utilities are likely to be present adjacent to all the structures. Utility searches will be required to ensure both ground investigations and construction works do not damage existing buried services/utilities;
- unexploded ordnance - the location of the site was subject to the direct impact of bombs during WWII and whilst the site area has undergone extensive redevelopment subsequently there remains the potential for unexploded ordnance to exist; and
- disposal of arisings - excavated materials from either ground investigation or construction, particularly within the Made Ground or superficial deposits, may be classified as contaminated waste and consequently require disposal at licensed disposal sites.

3.7 Drawings

Drawings relating to the proposed fixed link are contained in Appendix B.2 and listed in Table 3.8 below.

Table 3.8: Gallions Reach scheme drawings

Drawing Number	Scheme Option	Drawing Title
MMD-298348-TUN-401	General	Safeguarded Area and Constraints
MMD-298348-TUN-601	Immersed Tunnel Option	Plan and Longitudinal Section Sheet 1 of 2
MMD-298348-TUN-602	Immersed Tunnel Option	Plan and Longitudinal Section Sheet 2 of 2
MMD-298348-TUN-603	Immersed Tunnel Option	Geological Long Section
MMD-298348-TUN-604	Immersed Tunnel Option	Typical Cross Sections - Lane Configurations
MMD-298348-TUN-605	Immersed Tunnel Option	Cross Section at Ventilation Fan Niche
MMD-298348-TUN-606	Immersed Tunnel Option	Worksite Layout
MMD-298348-TUN-701	Bridge Option	Plan and Longitudinal Section Sheet 1 of 3
MMD-298348-TUN-702	Bridge Option	Plan and Longitudinal Section Sheet 2 of 3
MMD-298348-TUN-703	Bridge Option	Plan and Longitudinal Section Sheet 3 of 3