Hammersmith Flyunder Tunnel Feasibility Study - Tunnel and Geotechnical Engineering

Mar 2014

Document: HGL/THXLGE003/482042/REP/001-Rev 3.0 Final (Draft)

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Document history

West London Link Tunnel Feasibility Study Tunnel and Geotechnical Engineering

This document has been issued and amended as follows

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1.0	20.12.2013	Draft for Comment	Hamidat Zerouati	Peter Wright	Martin Johnson
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This report is presented to Hammersmith and Fulham Borough Council in respect of preliminary feasibility for the provision of a new tunnel linking the A4 to Central London via Hammersmith as replacement to the existing flyover.

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Contents

Appendices:

List of Tables

List of Figures

Executive Summary

CH2MHILL-Halcrow has undertaken a preliminary feasibility study of a tunnelled by-pass at Hammersmith, to replace the Hammersmith Flyover. The tunnelled by-pass is popularly referred to as the Hammersmith “Flyunder”.

The purpose of this feasibility study is to consider possible conceptual route options for the Hammersmith Flyunder and to discuss whether and to what extent the considered route options are broadly feasible in terms of engineering and geotechnical considerations.

Three route options have been considered, and for each option a further sub-option with junctions to the existing route network have been considered. These proposed routes simply illustrate exemplar solutions to the brief given by H&F and should not be regarded as anything other than preliminary ideas illustrating possibilities.

The estimated works cost (including design fees) for the considered options are given in the body of the report, and vary from £0.25bn for a basic on-line replacement of the flyover to £2.2bn for a three lane twin-tunnel option with junctions and a tunnelled connection through the Hammersmith gyratory system. At this preliminary feasibility stage it is considered that these costs could vary by 50% depending on the detail of the individual routes.

At this stage considerable uncertainty remains in respect of existing and forecasted traffic movements, particularly origin-destination quanta, and in respect of utilities, particularly tunnelled utilities, of which some, but necessarily all are known. It is therefore recommended that these knowledge gaps are filled as soon as possible so that the engineering and economic feasibility can be firmed up. For this reason a preferred route is not identified.

The scope of this study has been to look at the replacement of Hammersmith Flyover by a tunnel, and it has not looked in detail at traffic mitigation in Hammersmith as a whole – this would need to be the result of a more extended study. In addition it is possible that longer tunnelled routes towards Hyde Park Corner in the east, to Heathrow and the M4 in the west could be more feasible than the options local to Hammersmith, and a separate strategic study for the A4 corridor is also recommended.

1 Introduction

1.1 Background

The Hammersmith Flyover is a 0.622Km long, 1960's era reinforced concrete elevated roadway in West London which carries the A4 arterial road over and to one side of the central Hammersmith gyratory system, and linking Talgarth Road with the start of the Great West Road.

The Hammersmith Flyover structure is one of West London's most important roadways. It is one of Central London's principal western connections to the M25 and the national highway system. The (2011) average traffic volume highlights its importance: 85,549 vehicles per day.

Figure 1-1 - View under Flyover Looking West

After 52 years of use, the Flyover structure is in poor condition and extensive structural deterioration has taken place. In 2011, The Flyover was considered to be at risk of collapse caused by deterioration of internal steel pre-stressing cables from de-icing salt water attack. Consequently the Flyover was closed to traffic for 5 months to carry out initial strengthening works prior to the London Olympics in 2012, and further strengthening works are continuing at present, as part of a £70m scheme to lengthen the service life of the structure. This has prompted many people to consider what possibilities will be available when the economic life of this structure expires.

Many people consider that the flyover divides the neighbourhoods that adjoin it, isolates the North Hammersmith, and blights South Hammersmith Road: darkening the streets, obstructing local traffic and devaluing local real estate.

On the other hand the removal of the flyover could transform the urban realm of central Hammersmith, enable the reconnection of severed communities either side of the A4, and re-connect Hammersmith with the river. The master-planning opportunities made possible could enable Hammersmith to develop into a more vibrant business, residential and leisure town centre.

1.2 The Hammersmith Flyunder Concept

As a result of the flyover closure and the continuing works to strengthen it, a group of local Architects, in association with Halcrow, started to campaign for the replacement of the flyover by a tunnel. This was supported publicly by H & F, and the media also reported that the Mayor of London was considering such a possibility. The local group of Architects, now called West London Links group, continued to campaign in 2012/2013, and produced a leaflet showing some of the possibilities for the regeneration of Hammersmith without the flyover. During 2013 the idea gained further traction, as the Mayor's aspirations in the 2020 Vison report further referred to a tunnelised alternative to the flyover, and TfL supported these sort of "bold" ideas in their response to the Roads Task Force Report. In March 2014 the idea of a tunnelled replacement continues to receive the enthusiastic support of Hammersmith and Fulham Council and London's Mayor.

Figure 1-2 – View of St Paul Church Looking Northwards

A growing number of the world's cities are solving such problems through a new generation of underground construction. Cities such as Seattle, Madrid, Paris, Lyons, Tokyo, Sydney, Singapore and Oslo have been finding that underground road systems provide bold solutions to the conflict between local urban interests and the need for modern, high capacity transportation infrastructure.

1.3 Commission

Subsequently Hammersmith & Fulham Borough Council have appointed, CH2MHILL-Halcrow to undertake an investigation into the provision of a new flyunder tunnel for the A4 at Hammersmith.

1.4 References

(1) Technical Proposal Report- V02/Final; dated 14 Oct 2013

(2) Meetings Held with Stakeholders held on 27 Sep 2013, and subsequent dates

(3) Boris Johnson, 2020 Vision, The Greatest City on Earth, Ambitions for London , June 2013

(4) Roads Task Force, The Vision and Direction for London Street and Roads, July 2013

(5) TfL, Delivering the Vision for Londons Streets and Roads, TfL's Response to the Roads Task Force

(6) West London Link Design, A Tunnel to Replace the Hammersmith Flyover - A Chain of Opportunities.

(7) Atkins, Traffic Flow Models

(8) Arup/WSP/EC Harris/Aedas, West London Link Feasibility Study, August 2012

1.5 Abbreviations

Table 1 List of Abbreviations

Terms	Definitions
TFL	Transport For London
H&F	Hammersmith & Fulham London Borough

2 Use of the Report:

This report is presented to Hammersmith and Fulham Borough Council in respect of a preliminary feasibility for the provision of a new tunnel linking the A4 to central London in replacement to the existing Hammersmith flyover.

3 Tunnel Considerations

3.1 Scope

The objectives of this study are to inform H&F Borough Council about feasible options and relative costs of the different forms of construction and lane configurations that are possible. This will enable the practicability of tunnelled alternatives to be reviewed with respect to the benefits that can be realised to the road network, and the overall effects on the local environment.

The scope of the study required three different tunnel route options as presented in Figure 3-1 below to be investigated. This includes

Option 1a (green) **–** On Line Cut and Cover replacement for the Flyover including portals

Option 1b – As Option 1a with additional North/South connections between Shepherds Bush Road and Fulham Palace Road

Option 2a (red) **–** Bored Tunnel between North End Road and the A4 Sutton Court Road (two lanes per tunnel).

Option 2b – Bored Tunnel between North End Road and the A4 Sutton Court Road (With Junctions, see below, three lanes per tunnel, and additional North/South connections between Shepherds Bush Road and Fulham Palace Road).

Option 3a (blue) – Bored Tunnel between Earls Court and the A4 Sutton Court Road (two lanes per tunnel).

Option 3b – Bored Tunnel between Earls Court and the A4 Sutton Court Road (With Junctions, see below, three lanes per tunnel and additional North/South connections between Shepherds Bush Road and Fulham Palace Road).

For options 2b and 3b, outline junction connections to be considered for:

- A316 Burlington Lane to Central London (both ways)
- Shepherds Bush Road to Heathrow (both ways)
- Fulham Palace Road to Heathrow (both ways)

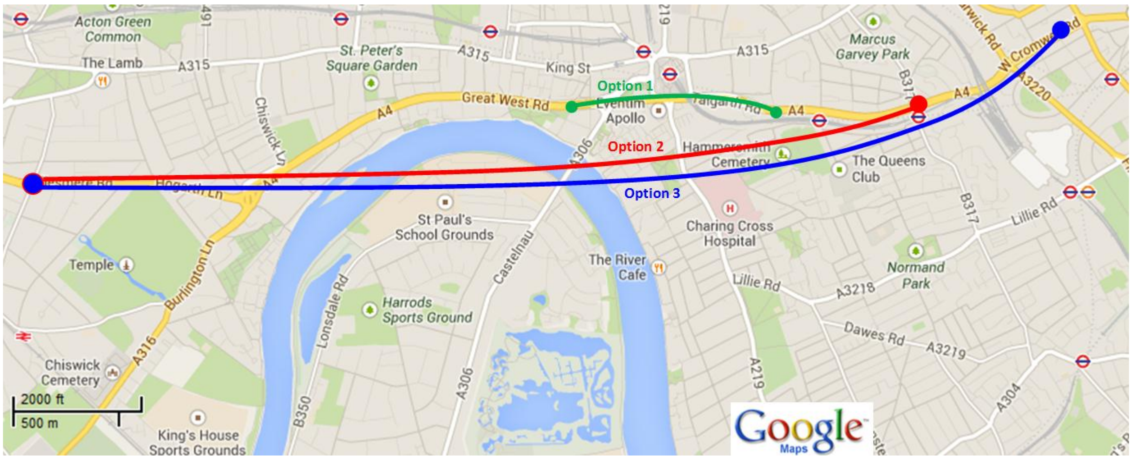


Figure 3-1 Initial Feasibility Route Options (Google 2013)

For each of the options, and subsequent junctions the following has been analysed and presented in this report:

- Horizontal and vertical alignments
- Various lane configurations
- Typical cross sections
- Impact of the existing geotechnical conditions
- Environmental considerations
- Constructability
- Construction Programme
- Cost estimate
- Risk assessment
- Obstructions

3.2 Master-Planning

During the development of the project H & F have put forward master-planning ideas that have a bearing on the tunnelling options. In particular Figure 3.3 shows the proposals for the central area of Hammersmith, a central tenet of which is the closure of the west side of the gyratory to traffic, and designating the north and east side of the gyratory as a bi-directional road. This is anticipated to result in a reduction of traffic capacity, for example for traffic movements between Fulham Palace Road and Shepherd Bush Road. Consequently options 1b, 2b and 3b include a north-south connection between Fulham Palace Road and Shepherds Bush Road.

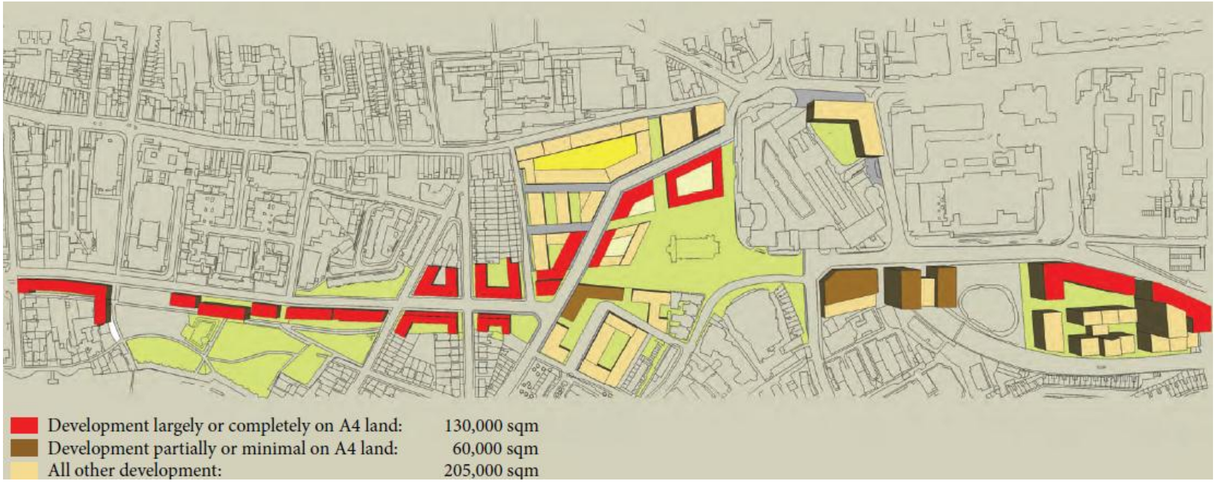


Figure 3-2 – Master-planning for Hammersmith

In addition the plans for the development of the Earls Court area are well in hand, and Figures 3-3 shows a plan of the development area. Work will soon start on the Exhibition Centre car park area, but it is understood that the development will be completed over the next decade.

Figure 3-2 – Master-planning for Earls Court

3.3 **Geology**

Evaluation of tunnelling feasibility requires information of sub-surface geological and groundwater conditions. This section provides a background from previous studies and existing records. A geotechnical long section profile can be found in Appendix B.

3.3.1 Regional Geology

The London Basin is an elongated, roughly triangular sedimentary basin approximately 250 kilometres (160 mi) long which underlies London and a large area of south east England, south eastern East Anglia and the adjacent North Sea. The basin formed as a result of extensional tectonics related to the Alpine orogeny during the Palaeogene period and was mainly active between 40 and 60 million years ago.

3.3.2 Site Profile

The Tunnel alignments considered in this study cover the area West of Central London between Earl's Court and Sutton Court Road/A4 Junction and crossing underneath the River Thames. The ground surface is generally level with a slight fall to the South towards the River Thames. The boundaries between the two portals and tunnel alignment are generally coincident with the Greater London Geology, characterised by relatively flat-lying strata, formed on top of the Late Cretaceous Chalk Group, which is exposed on the dip slopes of the Chilterns and North Downs. Within the centre of the basin the Chalk is mainly covered by Palaeocene, Eocene and younger rocks. The Chalk forms an artesian basin, with fresh water springs emerging on the bed of the Thames. In the greater part of the basin the surface rock is Eocene. London Clay, flanked at the margins by older deposits such as the Reading Beds. In large areas towards the western end the London Clay is overlain by rather younger deposits of the Bagshot Beds etc., forming sandy heaths.

3.3.3 Local Geology

The overall sequence at the Tunnel alignment site comprises Made Ground overlying Superficial Deposits (Alluvium and River Terrace Deposits), which in turn are underlain by the London Clay Formation. Borehole data, from the British Geological Survey (BGS), has been reviewed at regular intervals along all of the proposed routes. A sketch of the borehole locations can be found in Appendix B of this report.

The Made Ground through the alignment is of variable thickness with its heterogeneous composition reflecting historic development and redevelopment in the vicinity. The Alluvium is a predominantly clay material with localised organic pockets, silt and sand partings, and peat bands up to one metre thick. The Alluvium was absent in a number of boreholes within the site forming a north-east south-west trending tract. This apparent absence is likely to be the result of development in the area.

The River Terrace Deposits were encountered throughout the site and are typically between five and seven metres thick. There is considerable variation in the composition of these deposits throughout the footprint, with a trend of increasing sand and fines content towards the south; this variation is reflected in the corresponding permeability.

The layer of London Clay was encountered by all boreholes and it ranged from 55m to 70m thick. The London Clay is consistent over the route lengths but varies at depth from brown to blue to grey clay. It is stiff and becomes a hard and fissured silty clay at depth.

3.4 Ground Water

Information on the ground water level is only present in 6 of the 11 borehole logs. The borehole logs show across the Hammersmith area a ground water level that varies between approximately 4 and 7 m below ground level which would support the assumption that it is above the band of London Clay and in the River Terrace deposits. Two of the borehole records show a ground water level 20m below ground level, these are both located close to centre of Hammersmith near the Flyover.

3.5 Traffic Assessment

This traffic assessment is aimed to provide a rough order of magnitude as to the expected traffic volumes that will use any proposed tunnel. Estimations as to the amount of lanes required per direction of travel are based on these rough traffic estimates, with reference to BD 79/99 Road Tunnel Design standards. The traffic analysis performed at this stage is not intended to be a detailed travel demand forecasting exercise, or a traffic/transportation impact analysis typically performed at a later phase in a project.

A traffic flow model, developed by Atkins using Saturn software, was used to forecast traffic flows for the year 2031, based on 2009 values.

3.5.1 Scope and Limitations of the Traffic Analysis

The traffic modelling carried out was done for existing infrastructure conditions and did not account for any of the tunnelling options. Therefore, any interpretation made from this information is a best estimate. The flows of the main traffic corridors that are likely to be impacted due to the construction of the proposed tunnel have been considered. Origin – Destination survey information was not available at the time of assessment, and conservative traffic flows within the tunnel were considered as a result.

3.5.2 Traffic Flow Requirements

A study of the estimated traffic flows for the year 2031 was undertaken. These approximate traffic flow values were then assessed in terms of the proposed tunnelling options. An assessment of the traffic flow model data can be found in Appendix C of this report.

3.5.3 Estimated Flows for Options 1a and 1b

Option 1a is an online cut-and-cover replacement for the Fly-Over including portals. Option 1b, is similar to Option 1a, but with an additional North/South connection between Shepherds Bush Road and Fulham Palace Road.

The design flow for both options 1a and 1b has been based on the 2031 estimation for the existing Fly-Over. Table 2 below outlines the maximum hourly peak flow for the Fly-Over, and the design traffic flow (vehicle/hour/lane) as recommended by BD 79/99 Road Tunnel Design, Figure 4.1*.

Table 2 Vehicle Flows for Road Tunnels (Options 1a and 1b)

Option	Fly-Over Max Hourly Flow in one direction (2 lanes)	Max Hourly Flow in one direction Fulham Palace Road (one lane)	*Design Max hourly flow per lane
1a	3,025	-	2,000
1b	3,025	1,139	2,000

It is evident from Table 2 that a minimum requirement of 2 lanes per direction of travel are required for the proposed tunnel to meet current design standards and regulations. Initial estimations of the maximum junction flow suggest that one lane in each direction may be sufficient for the north-south connections. However, this analysis, as previously stated, does not account for driver habit or origin – destination surveys.

3.5.4 Estimated Flows for Options 2 and 3

Option 2a is a twin-bored tunnel running between North End Road and the A4 Sutton Court Road, Option 3a follows the same alignment as Option 2a but the eastern portal is located adjacent to Earls Court. Option 2b and 3b are similar to Options 2a and 3a, but with the addition of the north-south connections and junctions at the following locations.

- A316 Burlington Lane to Central London (both ways);
- Shepherds Bush Road to Heathrow (both ways); and
- Fulham Palace Road to Heathrow (both ways).

The traffic flow of the junctions has been estimated as a percentage of the current flows in the provided Saturn Model results –i.e. a best estimate of the traffic at the proposed junction locations that may choose to utilise the new Fly-Under.

A summary of the results for the year 2031 can be found in Table 3 below.

Table 3 Maximum Hourly Vehicle Traffic Flows and Estimated Junction Flows

Option	Fly-Over Max Daily Flow	Burlington Lane	Shepherds Bush Road	Fulham Palace Road
2a/3a	3,025	-	-	-
2b/3b	3,025	1,885	1,113	1,130

All traffic flows are best estimates of future flows. These values will help determine the size of the slip road junctions but a more rigorous and detailed assessment of these junctions is required, based on origin-destination surveys. However, based on the estimated maximum daily flow on the existing flyover, it seems that the proposed 2 lane design of the bored tunnel is adequate to meet the requirements of BD 79/99 Road Tunnel Design, shown in Table 3. However, with the incorporation of junctions to the design for Options 2b & 3b, it is recommended that a third lane be added to the tunnel to allow traffic to converge and diverge in a safe manner without impeding the traffic flow.

3.5.5 Construction Impact

It is expected that the traffic in the area will impacted during the construction of any of the 6 options proposed. A brief outline of possible implications for each option is discussed below.

3.5.5.1 Options 1a and 1b

Due to the nature of the cut-and-cover option the existing Hammersmith Fly-Over may have to be decommissioned and demolished prior to excavation works. Alternatively, a system of under-pinning may be utilised, which would be designed to keep the flyover in use as long as possible. However, in order to safely accomplish the underpinning some closures would probably be required. Major traffic issues in Hammersmith and its approach roads are to be expected as a result of construction, regardless of method. An appropriate traffic management plan would have to be put in place prior to any works taking place. Surrounding roads, such as Queen Caroline Street, will also be impacted upon due to cut-and-cover works.

Additionally, should junctions be required, construction works are likely to have a negative impact on the traffic flows on the Fulham Palace Road and Shepherds Bush Roads. Traffic restrictions will need to be applied.

3.5.5.2 Options 2 and 3

To allow for the construction of tunnel portals, at least four to six lanes will have to be acquired at both the western and eastern portals of the proposed twin bored tunnel. Traffic restrictions will almost certainly apply, with some lanes in both directions being closed.

However, although traffic flows will be affected, the existing Hammersmith Flyover will remain fully operational during the construction works.

Additional traffic restrictions will apply at the locations of the 3 junctions along Options 2b and 3b, should either option be chosen.

3.6 Ventilation and Fire Safety

3.6.1 Tunnel Ventilation System

The most cost-effective approach to ventilation for tunnels is using longitudinal ventilation, usually achieved through mechanical jet fans mounted on concrete linings along the tunnel. However, longitudinal ventilation is not ideal for queuing traffic because in the event of fire, traffic can be expected to be stopped on either side of the incident vehicle.

Due to the likelihood of vehicle queuing, the ventilation requirement for Hammersmith Flyunder will be achieved using a semi-transverse ventilation system whereby fans located within ventilation building at the portals supply or extract air transversally through an overhead ventilation duct (OHVD) that runs throughout the length of each tunnel. The smoke exhaust is operated through electrically actuated damper openings that are located at regular intervals within the OHVD. In order to maintain smoke free zones either side of the incident fire, dampers located within a certain distance upstream and downstream of the fire are opened, creating negatively pressurised area for smoke exhaust.

Benefits of using this system for tunnel ventilation are as follows:

- During an emergency fire in the tunnel, the fans are reversed providing high level smoke extracts which helps in creating smoke free zones either side of the incident.
- It provides a robust emergency ventilation response. In particular, it limits the decision process for the operator by having a simple operation which requires opening up dampers adjacent to the incident fire on either side.
- The ventilation plant system plant together with the control and power supply system will be located outside the tunnel, minimising both the electrical and mechanical plant and also the maintenance activities required within the tunnel.

Other features of the tunnel ventilation system include:

- 24 hour CCTV system
- Automatic incident detection system to rapidly identify the location of any fire
- 24 Hour manned control room
- Fire suppression system to control rapid heat release rates from large fire incidents

3.6.2 Tunnel Fire Ventilation Design

The emergency ventilation system is based upon compliance with BD78/79 and for a design fire of 100 MW, which reflects the proposed vehicles that will be allowed through the tunnels. The approach to estimating a design Heat Release Rates for vehicle fire is well documented within Road Tunnel design standards.

During an emergency fire, the fans at the portal extract smoke through the OHVD by opening the dampers located within adjacent to the fire. This can typically be within 50-100m either side of the incident fire. The mechanical capacity to be provided for the fans is such that back-layering is prevented by producing a longitudinal air velocity (incoming air through portals) that is greater than critical velocity. Back-layering is defined as "The reversal of movement of smoke and hot gases counter to the direction of the ventilation airflow". This longitudinal velocity which stops back-layering is termed critical velocity.

Hot smoke from a tunnel fire rises due to buoyancy. If the tunnel slopes, then buoyancy effects may be sufficient to cause the bulk flow in the tunnel to move upwards according to the tunnel gradient; smoke would also be carried along in this direction. Therefore, a higher critical velocity is required if longitudinal velocity is required against buoyancy.

The longitudinal profile of the Hammersmith Flyunder tunnel varies from 0% to 4%. Both these grades were considered in the analysis for Option 2A and 2B to account for an incident vehicle being stationary either at a flat section or at maximum grade.

3.6.3 Pollution Control

The ventilation system must be capable of maintaining acceptable conditions within the tunnel with regard to pollution and visibility. Limits are usually considered for Carbon Monoxide (CO), Nitrogen Oxides (NO) and particulates (usually measured in terms of visibility). For most tunnels it is appropriate to consider short-term exposure limits for public occupants of vehicles passing through the tunnel; a traffic management and ventilation strategy should be developed at a later stage for periods when there are workers in the tunnel.

The piston effect of the moving vehicles draws fresh air into the tunnel which dilutes pollutants and exhausts them from the tunnel portals. For short tunnels the piston effect is often sufficient to maintain acceptable conditions without the need to use mechanical systems. Some of the important parameters that impact the pollution levels within the tunnel are the gradients, the number of vehicles per hour, the speed of vehicles and the percentage of HGV vehicles which have higher emission levels.

One dimensional (1D) modelling has been used to determine the pollution levels within the tunnel. The IDA 1D code (www.equa.se) is used extensively and has been validated for design of road tunnel ventilation system. The features in the model include the vertical alignment of the tunnel, the geometry and cross section of the tunnel, traffic models with vehicles flowing through the traffic at different speeds and thrust provides by fans.

Traffic flow predictions for the year 2031 have been used for the purpose of the analysis. A HGV vehicle mix of 10% has been considered. Design traffic of 2031 has been used for the analysis because in later years after the opening of the tunnel, although the AADT may increase, it is expected that vehicle emissions will be substantially lower.

Bi-directional traffic is assumed to be operational only during off-peak hours. During these times, an off peak traffic mix 25% to that of peak travel times are assumed in each direction. Vehicle emissions have been obtained from PIARC 2012 document which outlines emission rates of three key parameters required to be controlled within the tunnel. Vehicles emission rates for NO2, CO and turbidity have been adopted for EURO 4, which is the European vehicle emission standard that was implemented in the year 2005. This suggests that all the road vehicles operational at 2031 are up to 26 years old thus accounting for further conservatism in the analysis. Table 4 outlines the maximum permissible short term levels that are acceptable within the tunnel.

Table 4 Design Limits of Pollution Levels

Pollutant	Maximum permissible short term level	Reference
NO2	1800 µg.m^3 / 1ppm	PIARC 2012
CO	80 µg/m^3 / 70ppm	PIARC 2012 / WHO
Extinction Coefficient	0.005/m	PIARC 2012(Fluid Traffic)

The simulation was carried out for both unidirectional and bi-directional traffic. Slow traffic (10km/h) was considered accounting for further conservatism in the calculation. The summary of the results for the option tunnels are shown in the discussion of the options respectively.

3.7 Utilities

Tunnel construction in this area is likely to encounter a number of services and underground utilities. The tunnel alignments may require some of the services to be redirected which will cause additional cost to the project. Additionally, potential ground movements induced by the construction of these tunnels needs to be evaluated, and where necessary controlled to avoid damage to the services and utilities.

Currently information on the services is limited to information from a recent project around the Flyover, which gives a plan view of utilities assets but does not give any indication as to the depths. While the depths are assumed to be relatively shallow in comparison with the depth of the tunnel alignments, they could have significant impact with cut and cover construction and also with portal construction. This information is important and will be necessary to fully appraise the options and potentially impact on the alignments, as acceptable settlement for a flexible cable tunnel may not be acceptable for a sewer. The table in Appendix D lists the information currently available with the further information required and a risk associated to each service.

As of February 2014 more comprehensive information has been received from Thames Water, and this is considered briefly below.

3.8 **Buried Obstructions**

In addition to the services and underground utilities there are a number of possible known interfaces with the tunnel options, these will influence the alignment and impact on the cost and feasibility of the options. This information has also been obtained the Capco study (ref 6) and from Halcrow archives, although what has been found is not considered to be an exhaustive list.

3.8.1 Thames Tideway Tunnel

The alignment of this tunnel runs south across the A4 around Eyot Gardens and under the river to Barnes where it bears East towards a pumping station on the North side of the river. Through this section of the alignment the external tunnel diameter is 6.5m and the tunnel crown is at a depth of 28m below ground level. This tunnel will have a large impact on the route and alignment of any tunnels that pass under the Thames and through Barnes. Any tunnel alignments in this area will have to ensure they do not compromise the alignment or function of the Thames Tideway project.

3.8.2 Hammersmith Flyover Foundations

Hammersmith Flyover has 16 spans which are supported on a central row of columns 4.9m tall, these transfer the load from the Flyover to its foundations. The foundations are deep pad foundations 8.3m x 8.3m which are founded on the River Terrace Gravels. The depth of the foundations vary, however the deepest foundation is believed to be at the same depth as the London Underground Cutting. The foundations are vital to the stability of the Flyover which is unlikely to be taken out of operation during the construction of a new tunnelled alternative. Therefore, all options will need to assess their effects on the Flyovers structural stability. In addition to this Pier N is integral to the structural stability of the London Underground Cutting and cannot be removed.

3.8.3 Lee Valley Water Tunnel

The Thames Water ring main runs approximately north south at an invert depth of 40m below ground level and a diameter of 5m.This should not affect any of the proposed alignments which should all have sufficient clearance to this sub-surface obstruction.

3.8.4 Thames Water Ring Main

The Thames Water Ring Main has an internal diameter of 2.54 m and a tunnel crown depth of 35m below ground level. The Ring Main consists of a wedge block lining and is very sensitive to ground movement. The tunnel runs east from Hogarth Roundabout under the Thames to Barnes before curving northwards towards Hammersmith.

3.8.5 London Underground Cutting

A London Underground cutting passes under one of the spans of the flyover (between Pier N and Pier O). Investigation has shown that Pier N of the Hammersmith Flyover is integral to the structural stability of the cutting and therefore cannot be removed. This cutting has both the District and Piccadilly Lines running between Barons Court and Hammersmith stations and is 7m below ground level. Information on any drainage structures below this level will be required to ascertain an appropriate level of cover for different tunnelling methods.

3.8.6 London Electricity Board Tunnel

A 2.44m diameter, expanded lining tunnel running from the Guinness Trust building grounds on the Fulham Palace Road in the direction of Willesden Junction. Most likely follows the path of local roadways, and passes underneath existing LUL infrastructure. Depth of asset unknown, but may be less than 15m below the ground surface level.

3.8.7 Storm Relief Sewers

An impressive number of storm relief sewers exist in Hammersmith, as shown in Figure 3.4. The North West Storm Relief Sewer, the Low Level No 1 Interceptor, and the Hammersmith Storm Relief Sewer are likely to be large sewers, which might have to be re-routed where the proposed tunnel clashes with the alignment of the sewers. Detailed information on these sewers has not been obtained for this project.

Figure 3-4 – Hammersmith Sewers

3.8.7.1 Storm Relief Sewers - Note after draft report submission.

A great deal of useful information on the Hammersmith Sewers was received after draft submission of the report. Details of these sewers have been added to Appendix D. However the following critical observations are made.

- *A storm relief sewer which flows directly under the town hall to an outfall at Furnival Gardens has an invert level of approximately 0.5m AOD, i.e. 4.7m below ground level. On the proposed alignment for Option 1 this would conflict with the open cut for the western portal.*
- *The Hammersmith Storm Relief Sewer (Stamford Brook Branch) has an invert level of approximately -6.7m AOD at the crossing of the flyover. This would conflict with the Option 1 tunnel vertical alignment.*
- *The Hammersmith Storm Relief Sewer (West Branch) has an invert level of approximately -3.6m AOD at the crossing of the flyover. This would be higher than the crown of the Option 1 tunnel vertical alignment.*

- *A major storm relief sewer along Hammersmith Bridge Road at an invert level of -7.2m AOD and outfalling at Queens Wharf would conflict with the Option 1 tunnel vertical alignment.*
- *Two other major branches of the Hammersmith Storm Relief Sewer cross the eastern end of the flyover, at invert levels of approximately -8.0m AOD and -7.3m AOD, and outfall at Chancellors Wharf. Both these sewers would conflict with the Option 1 tunnel vertical alignment.*
- *Others sewers appear to be at a higher level or are smaller sewers and don't significantly impact the proposed Option 1 tunnel alignment.*

3.9 Ground Movement Assessment

The construction of the Hammersmith Flyunder portals and tunnels will generate ground movements that have the potential to impact on the existing built environment, including LU and Thames Water infrastructures, overlying and adjacent buildings and structures, infrastructure, and utilities and services in the vicinity of the proposed tunnel alignment. The magnitudes of these movements will be dependent upon a number of factors including the ground and groundwater conditions, the construction methods, the quality of workmanship employed and the management and supervision of the construction. A preliminary ground level settlement assessment has been undertaken using CIRIA 2002 (C580) for portals. For tunnelling induced ground movement, the calculations adopt the conventional empirical Greenfield formulations, and provide a useful method based on well-established and widely accepted methods determined from the back analysis of case histories of short-term volume loss movements (O'Reilly and New (1982). The output of this ground movement assessment is presented in Appendix E, showing the maximum settlement predictions for options 1, 2 and 3 as well indicating the boundaries of ground movement for 1mm and 10mm ground level settlement contours. This study will allow a comparison between the different options proposed.

3.9.1 Categorisation of Buildings

Given predictions of ground movements it will often be necessary to quantify their potential effects on brick and masonry buildings and this problem has been considered by Burland (1995) and Mair, Taylor and Burland (1996). Broadly speaking their approach is to calculate the tensile strains in the building and to interpret these in terms of damage *degrees of severity* which are expressed in six categories ranging from *negligible* to *very severe*. Each category of damage is described and its ease of repair indicated.

Table 5 Classification of Visible Damage

Category of Damage	Normal Degree of Severity	Description of Typical Damage	Limit Tensile Strain (%)
0	Negligible	Hairline cracks less than about 0.1mm	0 - 0.05
1	Very Slight	Fine cracks which are easily treated during normal decoration. Damage generally restricted to internal wall finishes. Closes inspection may reveal some cracks in external brickworks or masonry. Typical crack widths up to 1mm.	0.05 - 0.075
2	Slight	Cracks easily filled. Re-decoration probably required. Recurrent cracks can be masked by suitable linings. Cracks may be visible externally and some repointing may be required to ensure weathertightness. Doors and windows may stick slightly. Typical crack width up to 5mm.	0.075 - 0.15
3	Moderate	The cracks require some opening up and can be patched by mason. Repointing of external brickwork and possibly a small amount of brickwork to be replaced. Doors and windows sticking. Service pipes may fracture. Weathertightness often impaired. Typical crack widths are 5 to 15 mm or several up to 3mm.	0.15 - 0.3
4	Severe	Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows. Windows and door frames distorted, floor sloping noticeably. Walls leaning or budge noticeably, some loss of bearing in beams. Service pipes disrupted. Typical crack widths are 15 to 25 mm but also depends on the number of cracks.	>0.3
5	Very Severe	This require a major repair job involving partial or complete rebuilding. Beams lose bearing, wall lean badly and require shoring. Windows broken with distortion. Danger of instability. Typical crack widths are greater than 25mm but depends on the number of cracks.	
Notes:			

1. Crack width is only one factor in assessing category of damage and should not be used one its own as a direct measure of it.
2. Local deviation of slope, from the horizontal or vertical, or more than 1/100 will normally be clearly visible. Overall deviations in excess of 1/150 are undesirable.
3. Boscardin & Cording (1989) describe the damage corresponding to the tensile strain in the range 0.015 - 0.3% as "moderate to severe". However, none of the case quoted by them exhibit severe damage for this range of strains. There is therefore no evidence to suggest that tensile strains up to 0.3% will result in severe damage

References: • *Relation between category of damage and limiting tensile strain (after Boscardin & Cording, 1989 and Burland (1995))*
• *Classification of visible damage to walls with particular reference to ease of repair of plaster and brickwork masonry (after Burland, 1995)*

3.9.2 Ground Movement Results

Based on the settlement results, shown in Appendix E, option 2a is likely to induce the lowest ground movements, with a maximum settlement of 48mm at chainage 4850m. Although the options 1a and 1b will have a smaller zone of influence, the magnitude of the settlement in option 2a is likely to be approximately four times less than the maximum settlement of 196 mm predicted at the chainage 1160m of options 1a and 1b.

Although settlement for option 3a is less than option 1a and 1b, with maximum settlement of 70mm, however its magnitude is approximately 50% higher than the maximum predicted settlement for the option 2a.The use of two 12.8 m diameter bored tunnels appears to be the options with a least impact on the existing surrounding assets.

3.9.3 Preliminary Impact Assessment of key Structures

Given the predicted ground movements induced by the various options for the Hammersmith Flyunder, the table in Appendix E indicates how sensitive some of the significant assets along the project route are likely to be to settlement. Using categorisation identified in section 3.9.1 to assess the likely damage on each structure, mitigation measures were recommended.

Along the proposed project route, twelve buildings with of at least six storeys and deep foundations have been identified, including nine Grade II listed buildings. Among them, two buildings were found to expect a degree of severity on the Burland *et al*. (1977) scale of *Moderate to Severe* (Appendix E).

3.10 **Environmental Considerations**

3.10.1 Noise

The surrounding area of the A4 and specifically Hammersmith Town Centre is a mix of residential, office and commercial buildings and public areas. During construction, at Portal areas and along the route for the Cut and Cover options there is likely to be an increase in noise due to excavation, operation of machinery and additional site vehicle movements. This can be mitigated against by using temporary noise barriers. However due to the displacement of traffic from this route into local back roads there will also be an increase in noise disturbance from this additional traffic to the surrounding area. A comprehensive traffic management plan should be used to mitigate the effects of displaced traffic and minimise the impact of site vehicles and traffic. For the bored options once the TBM is in operation noise at the surface will be negligible. The proposed worksite on playing fields in Barnes would also experience an increase in noise through construction and deliveries however this could be managed with well-planned site organisation to reduce noise impact during school hours.

Once in operation it is assumed that for all options noise levels along the routes will not exceed the noise threshold limits. With the Flyover being replaced with a Flyunder, there will be a notable and significant reduction in traffic related noise levels in the centre of Hammersmith. However, the extent of remaining noise levels will now be concentrated at the proposed tunnel portals – sound walls or use of materials with good acoustic absorption should be used to reduce the noise impact at these locations. Accordingly, all other necessary measures should be taken to reduce the noise impact on the local environment also (e.g. noise barriers and regular surface cleaning). Limiting noise levels and mitigation measures can be found in highways agency standard HD 213/11 Part 7.

3.10.2 Air Quality

The introduction of construction works is likely to reduce air quality due to an increase in dust and also through diesel powered site equipment which will have to be managed within allowable levels. As mentioned previously the construction works could lead to a large displacement of traffic causing congestion on the local back roads. This could lead to reduced air quality and would need to be monitored along with a more detailed investigation into the impacts of reduced traffic flow on the A4 on the surrounding area. A comprehensive travel management plan will be required to limit the effects of displaced traffic

Similarly with removal of traffic underground, it may improve the air quality along the majority of the route, however air quality at the tunnel portals and shafts will be reduced as this is the point at which the air is exhausted from tunnel. For all options a ventilation shaft would be difficult to accommodate, but is often disguised in a portal structure. Mitigation measures should be introduced to minimise the local environmental impact of gasous pollutants and atmospheric pollutant particles. Inevitably, because of the urban location of ventilation outlets some form of air cleaning system may well be required to ensure the air quality at the portals is within safe limits. Air pollutions should not exceed the recommendations of the Air Quality (Standard) Regulations 2010.

3.10.3 Vibration

Increased vibration due to traffic and construction works is a possibility. This can be mitigated against by limiting the load of construction vehicles where possible and implementing the measures recommended in the highways agency standard HD 213/1 Part 7.

3.10.4 Spoil Removal

The process and available options for spoil removal are detail for the different tunnelling methods below. It is likely that the spoil will be put to further use in a similar manner to Crossrail and Thames Tideway.

Due to the extent of all tunnel options, it is possible that an interface with contaminated land may occur. Appropriate mitigation measures should be in place for handling and removing any spoil from brown-field sites (e.g. soil washing etc.). At this time, no brown-field sites have been identified along any of the proposed alignments.

Table 6 Volumes of Spoil to be disposed and to be stored

Option	Volume of Spoil to be disposed (m^3)	Volume of Spoil to be stored and reinstated (m^3)
1a	432,712	231,067

1b	492,282	303,517
2a	1,030,148	42,188
2b	1,660,000	194,638
3a	1,138,239	42,188
3b	1,768,091	194,638

3.10.4.1 Option 1

The excavated soil mass will need to be disposed of, or stored correctly. A traffic management plan should be in place to deal with the additional demands on the local road networks. Very limited spoil bunding storage will be available on site. Heavy vehicle movements should be limited where reasonably practicable, possibly by utilising rail or river means to further transport the spoil.

3.10.4.2 Options 2 and 3

Options 2 & 3 propose the use of a TBM tunnel, with a TBM construction shaft/box most likely on the existing playing fields in Barnes. Accordingly, spoil may be removed via the river Thames on barges. Sufficient space is available on site to stock-pile a reasonable amount of material on site if required, thus limiting river transports to the least disruptive times (high tide, night-time etc.) and to facilitate its use as an amenity.

3.10.5 Construction Site Locations

Public consultation should be considered prior to final location of portals and shafts. Temporary construction sites will impact on the local environment through increased noise, pollution, traffic etc. and adequate planning and mitigation measures should be considered to reduce this impact. For permanent works, environmental screening should be considered as a measure to limit the visual impact of any proposed works.

3.10.6 Carbon Footprint

A large construction project of this nature is likely to produce a large carbon footprint through vehicular movements, construction materials and ground excavations. Accordingly, methods should be explored to offset or limit this impact. Mitigation measures may consist of spoil removal strategies, green concrete, maintaining traffic speed within the tunnel etc.

3.10.7 Construction Traffic

Traffic will increase in the locality due to the construction of the tunnel. Traffic management plans should be implemented at the tunnel construction sites to minimise the impact on the local flow. Heavy loads will be required and motorist and pedestrian safety should be considered as a result.

3.11 **Programme**

Due to this being a phase 1 feasibility study it is difficult to try and predict a programme for each of the options in their early stages. For the bored tunnel options we have looked to the average advancement rates for projects in London (Crossrail) and similar cross-section (Sparvo) which were approximately 100m/week to give an indication for the potential duration relative to their length.

We are able to draw on some of the information from the SPONS costing books, which were used to develop an initial cost estimate, estimating construction gang hours for the major Civil engineering tasks for Cut & Cover tunnelling. This provided an estimate for the duration of entire activity for one team, obviously on a project of this size it would be necessary to have multiple teams operating to reduce the construction time. With this and the logistics of the number of teams working we were able to estimate project duration for the cut and cover options.

Table 7 Estimated Project Durations for Project Options

Option	Est. Duration (yrs)	Option	Est. Duration (yrs)
Option 1a	3	Option 2b	3-4
Option 1b	4	Option 3a	2-3
Option 2a	2-3	Option 3b	3-4

3.12 **Risk Register**

A Risk Register has been completed for this project looking at various risks associated with activities involved in all options. This risk register can be found in the Appendix G, it should be noted that this is not a definitive list and as the options are developed the risk register should be reviewed and amended as appropriate.

4 Assessment of options

4.1 Option 1a – On Line Cut and Cover replacement for the Flyover including portals

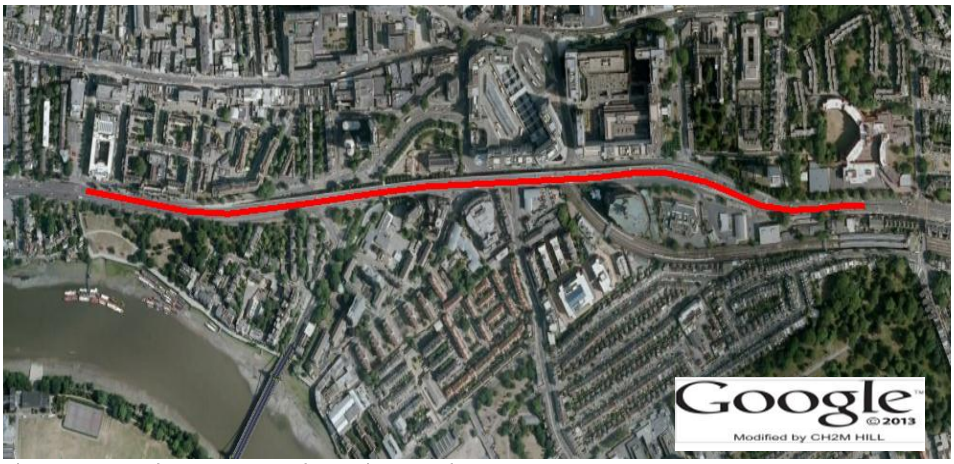


Figure 4-1 Option 1a Route (Google, 2013)

Option 1a is a 'Cut-and-Cover' tunnel link along the existing alignment of the Flyover, with the aim of providing an alternative route for traffic travelling to and from Central London and the West. This also allows the possible decommissioning and removal of the existing Flyover.

4.1.1 Horizontal and Vertical Alignment

The horizontal alignment of the tunnel follows the existing alignment of the Flyover and the A4, with open cut portal sections extending beyond the current ramps. The open cut sections are each approximately 230m long. A maximum vertical gradient of 4% has been used from the East and West portals; this is less than the Maximum 5% gradient stipulated in for new tunnels (Clause 2.2.2, Directive 2004/54/EC). This gradient allows the necessary clearance from other sub-surface obstructions (tunnel roof approximately 9m below ground level). Both horizontal and vertical gradients have been developed for a design speed of 80kph as supported by the current and forecast traffic assessment and the wishes of H & F. This is the shortest option and is 1.7km in length.

4.1.2 Portal Locations

This option was devised as direct replacement tunnelled option and as such the length and position of the portals is governed predominantly by the required depth and gradient of the tunnel. The western Open Cut begins 340m from the start of the west Flyover ramp, this point on the A4 Great West Road has 3 lanes in each direction which offers enough room to construct the portal while keeping a lanes open to aid traffic flow. The eastern Open Cut is 360m from the start of the east Flyover ramp; this point on Talgarth Road also has 3 lanes in each direction allowing space for the portal and a lane in each direction for traffic. The portals will consist of an open cut section from the current road level and leading to a depth of the portal approximately 270m. The current roadway is limited in width and the open cut will take the majority of the roadway and is likely to cause disruption to traffic.

4.1.3 Lane Configuration and Tunnel Cross Section

The feasibility study considered a number of options to provide the required 2 lane capacity in each direction while complying with the relevant design standards for both roads and tunnels. The Cut-and-Cover tunnel box dimensions will be 25m x 10.6m with a central service gallery splitting the box into separate running tunnels. Similar sized Cut & Cover boxes have been constructed in tunnelling projects in London at Gallions Reach. Each tunnel will accommodate a 7.3m dual carriageway with 1.2m walk ways on either side. This lane arrangement will match the current road layout for the Flyover (shown in Figure 4-2).

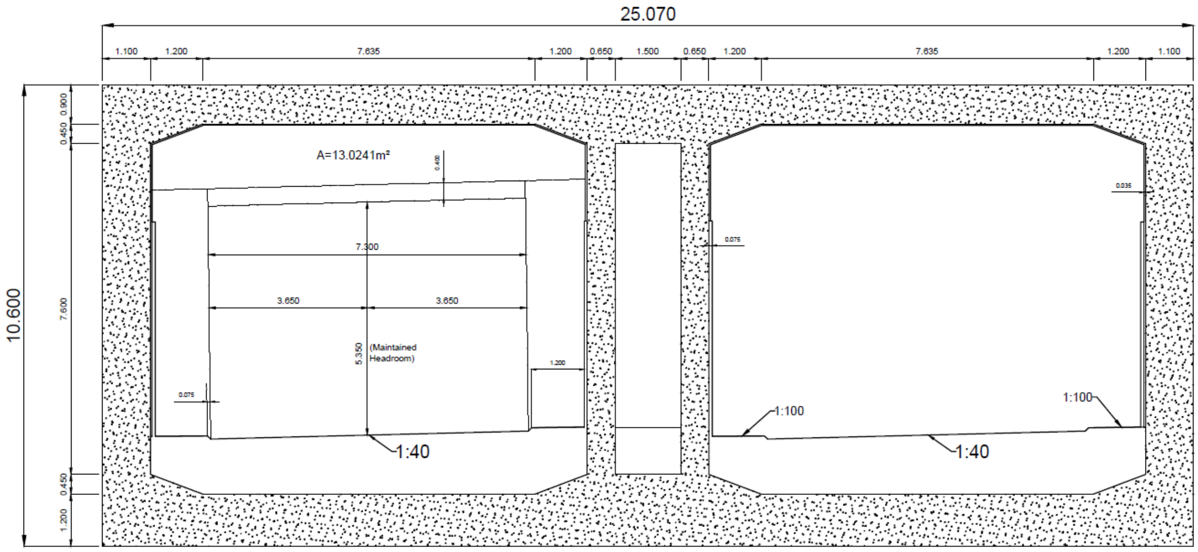


Figure 4-2 Two Lane Cut and Cover Cross-Section

4.1.4 Impact of existing Geotechnical Conditions

The available information from boreholes along the existing Flyover route suggests the Cut and Cover box will be in a deep band of London Clay which is suitable for this type of construction. The ground water level is currently believed to at the top of the band of London Clay or higher with some shallow ground water within the overlying the River Terrace deposits. Given the high permeability of the River Terrace Gravel, any excavation in this band of soil is likely to be the subject of water ingress. Therefore groundwater control measures will be required for this option.

4.1.5 Construction Methods

The tunnel would be constructed using Cut-and-Cover (top down) tunnelling which is broadly completed in the following 4 stages as shown in figure.

1. a) Secant piles are installed along the route to support the excavation and form the permanent walls of the tunnel box.

   b) Dewatering within the excavation limits if required.

2. a) Excavation to the depth of the bottom of the tunnel roof slab.

   b) Construction and waterproofing of the tunnel roof slab, tying it into the supporting secant pile wall.

3. a) Backfilling the excavation above the roof slab and reinstating the roadway

   b) Continued excavation of the tunnel interior with bracing as required.

   c) Construction of the tunnel floor and tying into the supporting tunnel walls.

4. The internal partitions and fit out of the tunnel is completed.

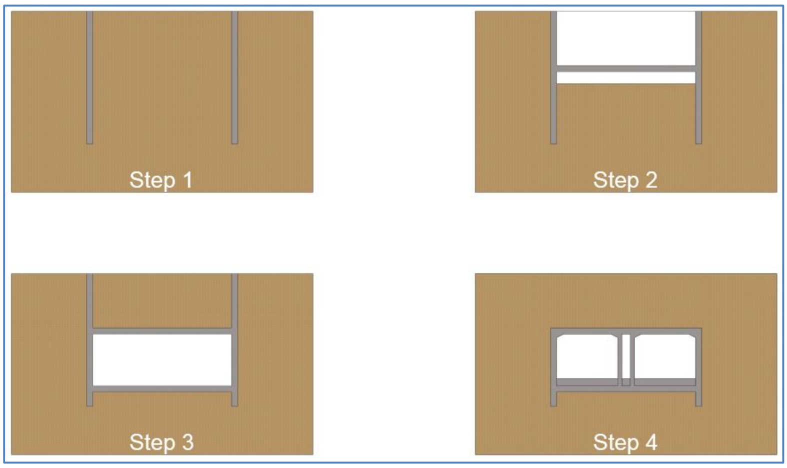


Figure 4-3 Showing the Construction Steps of 'Top Down Cut & Cover' Method

This 'Top-Down Cut and Cover' method is chosen to reduce the impact of construction on the local traffic as the roadway can be reinstated sooner than other methods reducing the amount of time required for road closures. Due to this sequence it is important to ensure the waterproofing of the tunnel is completed correctly.

4.1.6 Constructability

Cut and Cover construction is a fairly intrusive tunnelling method as it requires space above ground, along the entire route, to carry out excavation and construction. It is likely that a cut and cover tunnel along the route of the Flyover would cause extensive traffic disruption even with construction mitigation as above, ie the Top Down construction method and completing half at a time to maintain some traffic flow. Access and space for plant will also be an issue as this area is heavily built up and congested, finding a location for a site concrete plant will be difficult. The construction process will require closures of a number of roads for both the initial piling and the more extended excavation. Underpinning of the Flyover pier foundations will be necessary to maintain stability and traffic flow during the excavation phases. Initial designs suggest that a series of 4 deep beams spanning the 25m between the secant piles forming the permanent walls of the cut and cover box could provide a solution to this. The excavation will produce a large amount of spoil, some of which will be used to backfill above the tunnel box. This will require a storage area during the excavation. The spoil that is not reused will need to be removed, most likely in the first instance via the local road network, adding to the congestion around the site.

An estimated 65,000 lorry movements would be required for the removal of excavated spoil from the site. It is assumed that some of the excavated material will be retained on site and used to backfill above the tunnel, and lorry movements associated with this are not considered. A further estimated 25,000 movements will be associated with delivery of concrete and other materials.

4.1.7 Cost Estimate

A cost estimate has been calculated using initial option design information and applying unit costs for the major civil engineering activities, this has then been scaled using common percentages for the proportion of project activities.

Table 8 Option 1a Cut and Cover Tunnel Cost Estimate

Item	Cost	%
Preliminaries	£41.3m	25
Design	£11.6m	7
Roadworks	£2.1m	1
Earthworks Handling	£23.2m	14
Tunnelworks – C/C	£29.2m	18
M&E Facilities	£33.0m	20

Risk Allowance	£24.8m	15
TOTAL	£165.4m	100
plus 45% TfL Management Contingency	£240m	

The cost estimate for this option is compared in Table 9 to an estimate from the Earls Court Development (ref 8) assessing the viability of this project and its impact on their development.

Table 9 Comparison of Cost Estimates - Option 1a

Source	Length (m)	Price	Price – Scaled to Option 1a tunnel length
Estimated Quantities	1700	£240m	£240m
E C Harris/Arup (2013)	1100	£200	£309m

This is an estimate for the purposes of feasibility; a more accurate estimate should be performed once the design allows using the work breakdown structure. A number of items have not been fully accounted for in the estimate however they may pose a significant increase in the cost of the tunnels and should be considered to match the level of design and information available in the future:

- Compensation/Land payments
- Temporary Works
- Enabling Works
- Re-routing of services
- Cost of the impact of traffic disruption
- Drainage and Ventilation
- Demolition of the existing flyover
- Operation and Maintenance Cost – See Appendix H

4.1.8 Alternative Construction Technique

Although not covered in the scope of the original study, on further consideration it is considered feasible to construct Option 1 using a *mechanised tunnelled and Sprayed Concrete Lined (SCL) construction. While there are risks associated with this methodology, particularly where the cover of London Clay is less than 5m, twin alignments could be constructed each side of the piers for the existing flyover and could go deeper enough to avoid the storm relief sewers described in Section 3.8.7.1. The construction time and cost could both increase, but the disruption in central Hammersmith would be greatly reduced, although there would still be considerable disruption at the eastern and western portal locations.*

The estimated costs for an SCL tunnel in Table 10 below are based on the methodology used for Options 2 and 3, assuming a tunnel construction cost of £45m per km for 2 x 2 lane twin bore.

Table 10 Alternative SCL Construction Method - Option 1a

Item	Cost	%
Preliminaries + Ins + Profit	£incl	0
Design	£10m	4
Roadworks	£3m	1
Open Cut/C & C	£50m	20
Tunnelworks SCL	£113m	45
M&E Facilities	£37m	15
Risk Allowance	£37m	15
TOTAL	£250m	100
plus 45% TfL Management Contingency	£363m	

4.2 Option 1b – Cut and Cover Tunnelled Solution & North-South junction

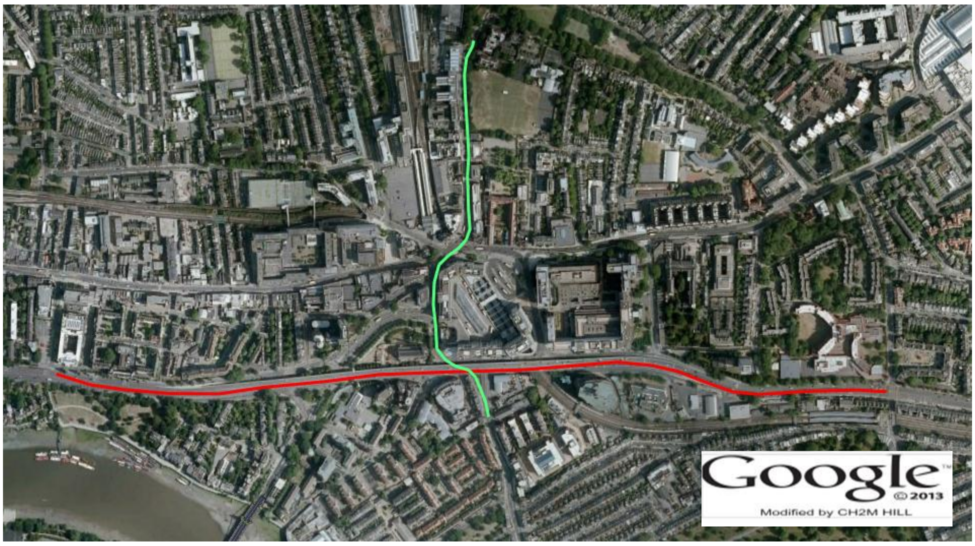


Figure 4-4 Option 1b Route (Google, 2013)

Option 1b is also a Cut and Cover replacement for the existing Flyover, with the same East-West Cut and Cover Tunnel as in option 1a with the addition of a North-South tunnel to reduce congestion around the Hammersmith Gyratory system. As such the following headings will only address the additional or different points of note to avoid repetition.

4.2.1 Horizontal and Vertical alignments

The North-South tunnel connects Shepherds Bush Road to the north of Hammersmith and Fulham Palace Road to the south and follows the road layout via Queen Caroline St. It is possible for this additional tunnel to cross above the flyover replacement tunnel between two of the piers to limit the effect on the previous alignment. Similarly to option 1a the tunnel requires clearance under the London Underground Piccadilly and District Lines. The vertical alignment negotiates these to obstructions with a maximum gradient of 3.6%, which is less than the desirable maximum of 4%. Initial routes suggest the additional North-South tunnel would be approximately 1.12 km.

4.2.2 Portal Locations

Both Shepherds Bush Road and Fulham Palace Road are narrower than the A4 and range from 2-3 lanes along their route. As such portal locations are limited, there is potential for a Northern Portal approximately 600m from the gyratory system at Hammersmith Station where there are three lanes and a small area of land that could be utilised to create a portal and also allow traffic flow to be maintained. The opportunities for the Southern Portal are more limited and as such construction may require significant road closures and traffic disruption in that area and also purchasing of certain properties.

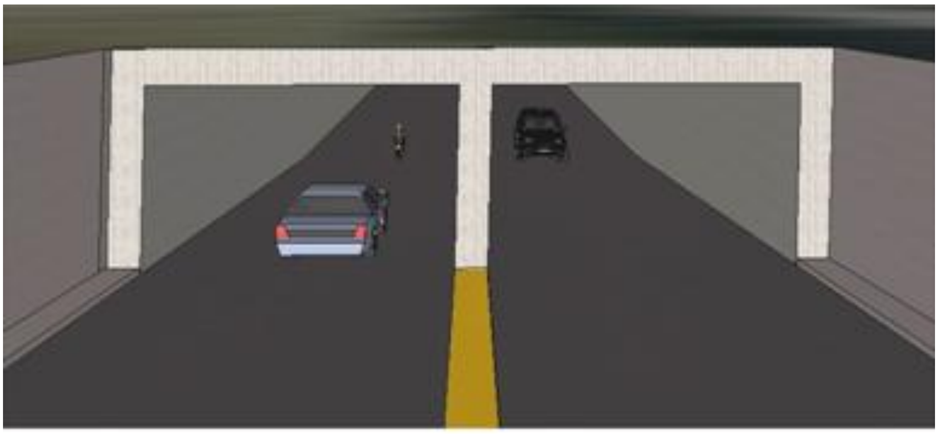


Figure 4-5 Proposed Portal Interface for North-South Tunnel option 1b

4.2.3 Lane Configuration and Cross Sections

The North-South tunnel would be constructed in Cut and Cover (top down) but would have a smaller cross-section than option 1a. The tunnel would be for light vehicles only and as such has a reduced height providing the benefits of reduced approach lengths excavation depth. This could also be reduced to one lane with a hard shoulder for breakdowns allowing more space for continued traffic flow.

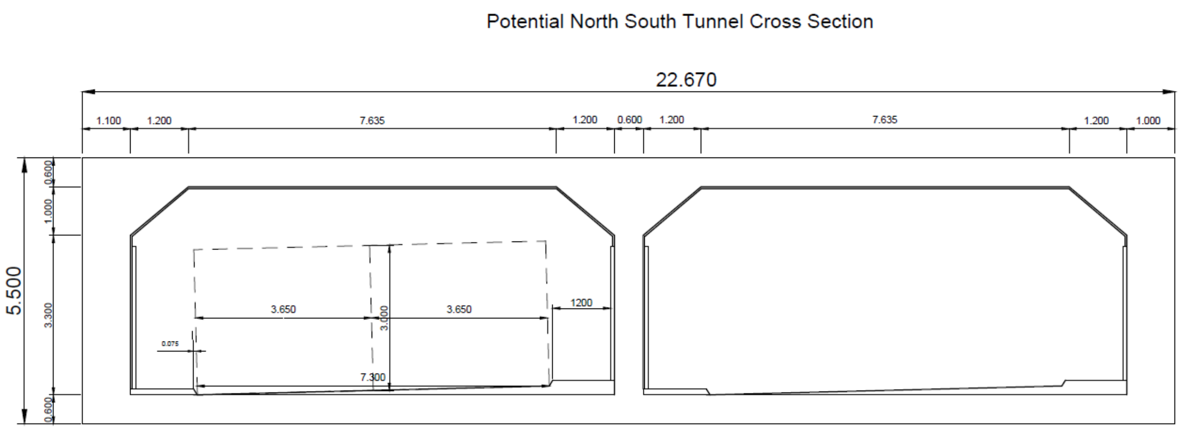


Figure 4-6 Two Lane Cut and Cover Cross-Section (Light Vehicles Only)

4.2.4 Impact of existing Geotechnical Conditions

Due to the shallower nature of the North-South tunnel the majority of the tunnel will be constructed in the band of River Terrace Gravels with only a small section of tunnel in the more suitable London Clay. Again due to the high permeability of the River Terrace Gravels ground water control measures are likely to be needed.

4.2.5 Construction Methods

The tunnel would be constructed using Cut-and-Cover (top down) tunnelling, see section 4.1.5. The construction of the two tunnels one on top of the other could cause some issues with construction at the point where they cross.

An estimated 100,000 lorry movements would be required for the removal of excavated spoil from the site. It is assumed that some of the excavated material will be retained on site and used to backfill above the tunnel, and lorry movements associated with this are not considered. A further estimated 40,000 movements will be associated with delivery of concrete and other materials.

4.2.6 Constructability

Additional disruption to traffic will be caused by with the North-South tunnel as this runs through the centre of Hammersmith and the gyratory system.

4.2.7 Cost Estimate

As Option 1b is the addition of a North-South Cut and Cover tunnel to Option 1a the cost estimate will be an addition of this tunnel to the estimate form 1a.The additional project cost for the North-South tunnel has been calculated in the table below.

Table 11 Option 1b (North-South Tunnel) Cut and Cover Cost Estimate

Item	Cost	%
Preliminaries	£15.3m	25
Design	£4.3m	7
Roadworks	£1.6m	3
Earthworks Handling	£6.2m	10
Tunnelworks – C/C	£12.4m	20
M&E Facilities	£12.2m	20

Risk Allowance	£9.2m	15
Total	£61.1m	100
Option 1a	£166m	
TOTAL Option 1b	£226.5m	
plus 45% TfL Management Contingency	£328	

This would give a combined estimate for option 1b of £328m. However it is assumed that there would be some efficiency born out of constructing both tunnels and as such the estimate may be reduced. The same assumptions have been made for Option 1b that were used in the estimation of option 1a. The same limitations apply to this estimation; a more comprehensive estimate should be performed when the project is more developed to include omitted items listed in option 1a.

4.3 Option 2a – TBM Tunnel (A4/Sutton Court junction to North End road)

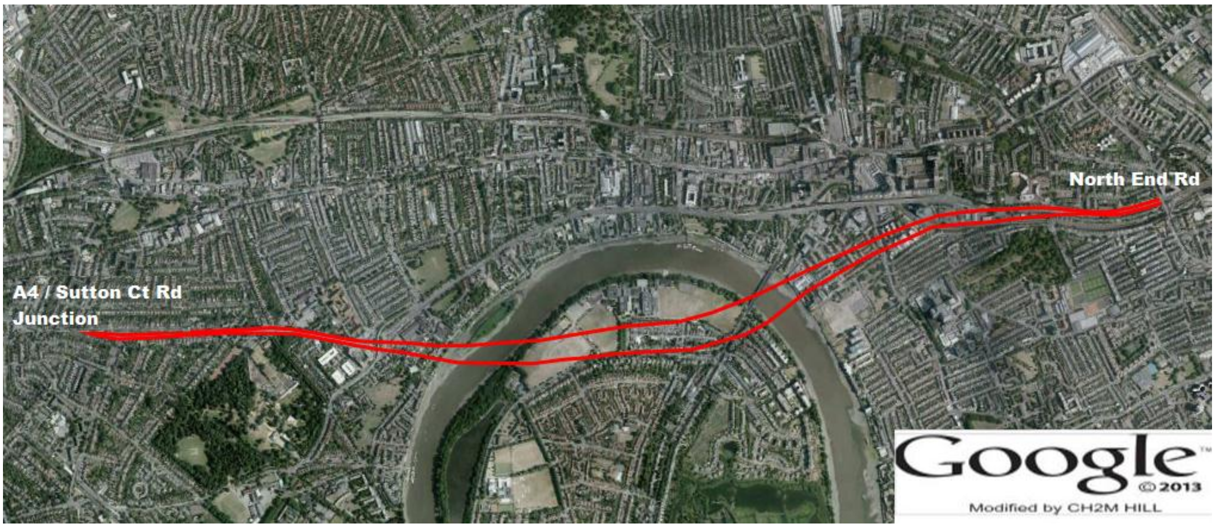


Figure 4-7 Option 2a Route (Google, 2013)

Option 2a is an East-West tunnel link from the Great West Road – West of Hogarth Roundabout (western portal) to North End Road (eastern portal) with the aim of removing traffic from the centre of Hammersmith.

4.3.1 Horizontal and Vertical Alignment

The horizontal alignment of the tunnels, from the western portal 450m west of Sutton Court Road, follows the A4 towards Hogarth Roundabout. This gives the tunnel an appropriate distance to pass below the Fullers Brewery and the Thames with suitable cover at the maximum 4% gradient. The tunnel must have a minimum of one tunnel diameter cover when underneath the Thames; this requires a depth of 36m below the level of the river bed (approximately 6m below ground level (bgl)). Therefore the portal must be a minimum distance of 900m to comply with 4% maximum gradient.

Once under land the invert level of the tunnel rises to 24m bgl as it passes above the Thames Tideway Tunnel; this provides 4m of cover to the Thames Tideway Tunnel. Once passed the Tideway Tunnel the tunnels will drop to a level of approximately 36m bgl to gain the required clearance for crossing under the River Thames. They will continue to the eastern portal at North End Road; the eastbound tunnel follows the alignment of Talgarth Road and the westbound tunnel follows the alignment of the London Underground Lines. The proposed alignment does not conflict with the minimum horizontal radii governed by the proposed design speed of 70 km/h.

Twin tunnels would need to maintain a minimum horizontal separation of approximately one tunnel diameter along the alignment to prevent over stressing of the soil between the two tunnels and redistribution of ground loads during excavation. The maximum allowable gradient in tunnels is 4% and is the main constraint on the vertical and subsequently the horizontal alignment. Due to the proximity of the Western Portals' location to the Thames Tideway Tunnel and the River Thames the alignment is governed by the tunnel depth at these obstacles.

4.3.2 Portal Locations

As both east and west portals are on the A4, which has 3 lanes in both directions, it was important to select portal locations that would allow for the continuation of traffic flow during construction. The location for the Western Portal was more constrained due to the road layout and the need to have it within close proximity to Hogarth Roundabout without making the alignment overly long and costly. The Western Portal, located 450m west of the junction between the A4 and Sutton Court Road, is 3 lanes in each direction and has a broad central reservation and crossing area allowing space for the portal and lanes in both directions for traffic flow. This location is also the required distance from the Fullers Brewery and the River to allow the tunnel to reach a suitable depth before the obstructions at a gradient of 4% or less.

The Eastern Portal will be located at the junction between the A4 and North End Road to avoid having to cross under another active railway line. The portal construction may include a variety of tunnelling methods, beginning with Open Cut, Cut and Cover and SCL before entering the bored section. This will allow the roads to separate underground to enable the correct distance between the bores and limit the width of road at the surface which is required without overly disrupting traffic flow.

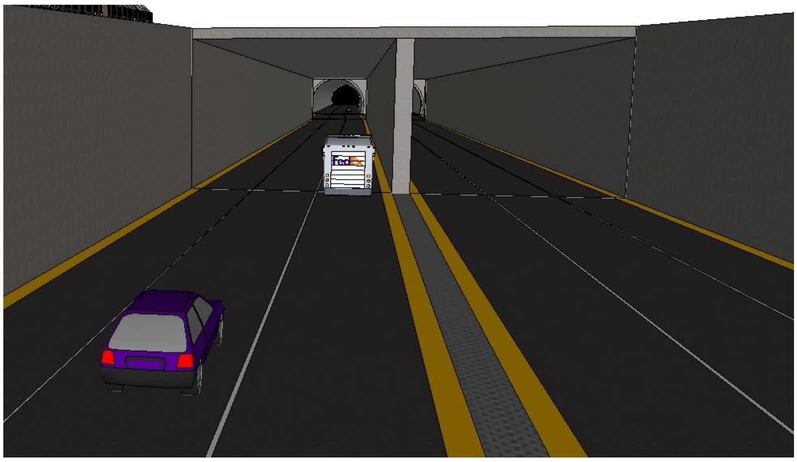


Figure 4-8: View from proposed Cut-and-Cover Portal of Option 2a, to SCL and Bored Sections

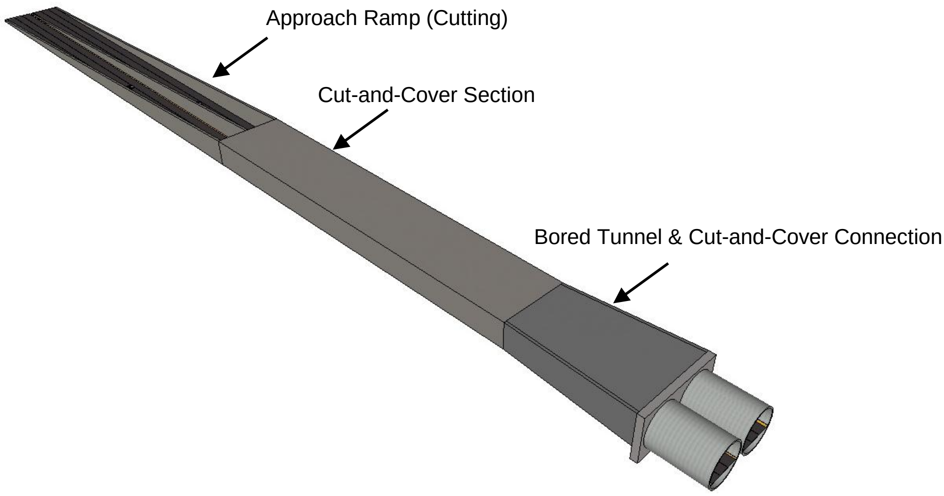


Figure 4-9: Long Section View of Option 2a
(Open Cut, Cut & Cover, SCL and Bored Tunnel Section)

4.3.3 Lane Configuration and Cross Section

According to the review of traffic analysis from Atkins Saturn Model and the BD 79/99 Road Tunnel Design any tunnel constructed would require a minimum of two lanes per tunnel bore. With this information a tunnel diameter of 12m was been chosen as shown above in Figure 4-10. This cross section would allow for two lanes of 3.65m in each bore with additional walkways (0.6m) on either side and achieves the minimum maintained headroom of 5.35m. The tunnels will be connected by cross passages, at regular spacing (estimated to be 100m), for use in the case of fire and emergencies.

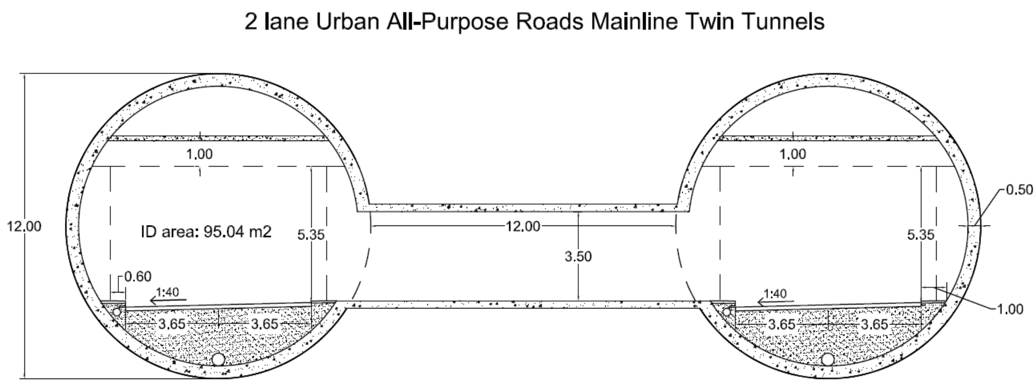


Figure 4-10 Two lane 12m Diameter Bored Tunnel Cross Section

However on consultation with the Fire and Ventilation team it was found that the tunnel layout and cross section was not suitable as the roof area for ventilation was insufficient. Following the analysis of the geometry by the Fire and Ventilation it was found that for the 2-lane option would require a minimum duct area of 21m^2. A tunnel diameter of 12.8m is required to satisfy the fire and ventilation standards as shown in Figure 4-11.

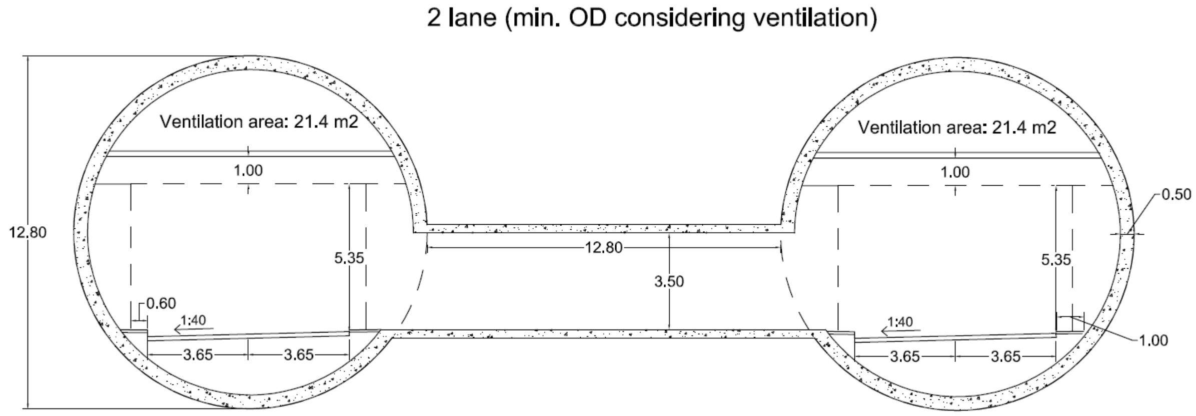


Figure 4-11 Two Lane 12.8m Diameter Bored Tunnel Cross Section

4.3.4 Impact of existing Geotechnical Conditions

The initial available borehole information suggests the tunnel will be in a deep band of London Clay which is the ideal material for bored tunnelling. The portal sections are likely to span the London Clay and the layer above of River Terrace Gravels.

4.3.4.1 Fire and Ventilation

For a minimum tunnel diameter required for a 2 lane unidirectional traffic, the available duct area on each tunnel is 11.5m^2. Preliminary calculations for achieving critical velocity for smoke control suggests that a minimum flow rate of approximately 350m^3/s is required; this accounts for a flow velocity within the ducts of ~15m/s. The pressure drop associated with this flow speed is in excess of ~1500 Pa and is likely to cause leakage of smoke through closed dampers. To limit pressure drop and any potential leakage across the ducts, a limiting velocity of 8m/s is proposed. Therefore a minimum duct area of 21m^2 is to be provided to meet ventilation control. This can be only be achieved by increasing the diameter of the tunnel. The Table below shows the results of the analysis.

Table 10 Overhead duct size estimation for emergency ventilation (Option 2)

Option 2A (EB/WB)	Grade 0%	Grade 5%
No. of Lanes	2	2
Internal Diameter(m)	11	11
Upstream critical Velocity(m/s)	2.74	3.19
Downstream critical Velocity(m/s)	1.5	1.5
Available Duct Area (m^2)	11.5	11.5
Total Flow Rate (m^3/s)	307	341
Average Velocity through ducts(m/s)	13.3	14.8
Pressure Drop across ducts (Pa)	2000	1400
Limiting Velocity (m/s)	8	8
Minimum required Duct Area (m/s)	19	21

The results for Option 2a show that for both unidirectional and bi-directional traffic, mechanical ventilation is required for either tunnel. For Unidirectional flow, the jet fans mounted at either portal can be used to supply fresh air and promotes mixing of air to maintain acceptable conditions. However during bi-directional traffic, due to the asymmetry in air mixing, the jet fans may not provide the required longitudinal air flow. In these conditions, the mechanical ventilation will have to be provided transversally through the overhead ducts supplying clean air from above. Monitoring systems for CO, NO2 and visibility can be used to activate mechanical ventilation to maintain acceptable conditions.

Table 11 Calculated Pollution Levels for Option 2a

Traffic Direction (EB/WB)	Number of Lanes	Mechanical Ventilation	No of fans	CO mg/m^3	NO_2 mu g/m^3	Extinction/ m
Unidirectional	2	No	N/A	70	2860	0.0045
Unidirectional	2	Yes	4 fans at each portal	42	1680	0.0026
Bi-Directional	2	No	N/A	82	3100	0.007
Bi-Directional	2	Yes	OHVD	33	1290	0.002

4.3.5 Construction Method

Due to the length and depth of this tunnel alignment cut and cover construction would be difficult and time consuming therefore a Tunnel Boring Machine (TBM) is preferred. Of the various types of TBM an Earth Pressure Balance (EPB) TBM has been chosen because of its ability to minimise ground loss at the cutting face and also surface settlement – an important factor in minimising the impact on structures at the surface.

The EPB TBM requires a site to launch, with open space in Barnes being identified as a suitable indicative drive location. This space also offers the potential benefit of removing spoil via barge on the Thames. A shaft would need to be constructed here to allow the assembly at the correct depth. The TBM would then be launched from this site and proceed to the portal locations. The cutting wheel of the TBM operates in a chamber filled with excavated ground; the Face Pressure is balanced by controlling the rate of advance of the face and the discharge of the excavated spoil via a screw convey to be removed. Some additives may be added to the excavated soil to make it better suited to for removal. It will be necessary to construct the areas near the portals due to the minimal cover that where the alignment rises to meet the ground.

Behind the TBM a series of precast concrete ring segments will be used to provide stability of the excavation for the life of the structure. These will be bolted together and will have rubber gaskets along the joints to eliminate any water ingress.

4.3.6 Constructability

Due to the size of the TBM it will have to be delivered to site in a number of sections most likely via the Thames River as this could cause the least disruption. The TBM will need to be turned at each portal to bore in the opposite direction. This will be a difficult operation due to the size of the TBM and will cause a large amount of disruption to traffic at the portals as the turning operation could take as long as two weeks.

Due to the required size of the portals it may only be possible to keep one lane open for traffic; this would cause significant disruption to traffic. This could be minimised either by constructing the portals in two phases closing half the road at a time. This could also be achieved through top down cut and cover construction, where by the roadway could be reinstated during construction to reduce adverse impacts on traffic. It is possible to provide diversions around the open cut sections of the tunnel to re-join the route around Sutton Court Road junction where the cut and cover section begins.

An estimated 150,000 lorry movements would be required for the removal of excavated spoil from the site. It is assumed that some of the excavated material will be retained on site and used to backfill above the tunnel, and lorry movements associated with this are not considered. It is likely that this spoil could be removed by river transport. A further estimated 40,000 movements will be associated with delivery of tunnel segments, concrete and other materials.

4.3.7 Cost Estimate

Due to the nature of this report the construction cost provided for this option is an estimate. This estimate does not account for the fact that this project is not likely to be constructed for a number of years or the following issues which could add significant costs to the project:

- Design Fees
- Compensation/Land payments
- Temporary Works
- Enabling Works
- Re-routing of services
- Cost of the impact of traffic disruption
- Drainage and Ventilation
- Demolition of existing flyover
- Operation and Maintenance Cost

Bored Tunnel projects by their nature tend to be larger and higher profile than Cut and Cover and as such information on their costs are more widely known. The British Tunnelling Society (BTS) published a report in 2010 investigating the cost of a selection of tunnelling projects undertaken in the UK and Europe. This included a range of tunnelling methods, lengths, locations, end use, lining types and ground conditions. Their drivers for this investigation were to identify the factors that impact tunnel construction costs and to investigate the claim that construction costs were greater in the UK than comparable parts of Europe.

This investigation has provided us with cost information and tunnel data for number of tunnelling projects and an understanding of the factors affecting construction costs. It will form the basis for the cost estimate for the Bored tunnel options in this report. Only TBM-Bored tunnels have been used for this estimate.

Table 12 Proposed Option 2 Hammersmith Flyunder details

Total Alignment Length	Outer Diameter	Lining Type	Ground Conditions
9.2km	12.8m	Pre-cast Concrete Segments	London Clay

Table 13 Comparison of Tunnelling Project Costs (Taken from BTS Infrastructure UK Cost Study Tunnels)

Input Sheet Name	Country	Location	End Use	Tunnelling Method	Tunnel Alignment Length (Total Tunnelled Length)	Tunnel OD (m)	Lining Type (Primary and Secondary)	Ground Conditions	Total Cost of Tunnelling (Including Shafts and Features	Overall Scheme Cost (Original Value)	Tunnel Cost/km	Current Value (1Q2010) of Tunnel Cost/km (£)	Current Value (1Q2010) of Tunnel Cost/m³ (£)
UK Tunnel 1	UK	Urban	Rail	Bored - TBM (EPB)	15,000	8.15	Steel fibre and polypropene reinforced concrete segments	Sand and Gravel	£151,995,000	£157,431,000	£10,133,000	£11,961,311	£229
UK Tunnel 2	UK	Urban	Rail	Bored - TBM (Slurry)	5,000	8.15	Pre-cast concrete tunnel segments manufactured in a specially built factory on site	Chalk	£165,000,000	£165,000,000	£33,000,000	£38,954,234	£747
UK Tunnel 3	UK	Urban	Rail	Bored - TBM (EPB)	9,400	8.15	Steel fibre and polypropene reinforced concrete segments	Sand and Gravel	£131,084,000	£136,668,000	£13,945,106	£16,461,240	£316
UK Tunnel 4	UK	Urban	Rail	Bored - TBM (EPB)	10,600	8.15	Steel fibre and polypropene reinforced concrete segments	Sand and Gravel	£131,308,000	£150,000,000	£12,387,547	£14,622,649	£280
UK Tunnel 5	UK	Rural	Highway/Road	SCL - sequential excavation	3,660	11	SCL and cast in-situ concrete	Soft rock	£109,718,000	£152,475,000	£29,977,596	£28,808,468	£303
UK Tunnel 7	UK	Urban	Rail	Bored - TBM (EPB)	3,600	6	Precast concrete	Alluvium, with organic silt and clay and peat bands,	£112,000,000	£180,000,000	£31,111,111	£33,446,102	£1,183
UK Tunnel 8	UK	Urban	Water	Bored - TBM	5,100	6.5	Precast concrete	Chalk	£53,000,000	£0	£10,392,157	£15,172,053	£457
UK Tunnel 9	UK	Urban	Water	Bored - TBM (EPB)	3,300	2.8	Precast concrete	Clay and gravels	£22,884,000	£56,000,000	£6,934,545	£6,800,716	£1,104
UK Tunnel 10	UK	Suburban	Power	Bored - TBM (EPB) (Lovat)	10,000	3.6	Precast fibre reinforced concrete trapezoidal segmental lining	Chalk with flint and mixed gravel	£75,500,000	£75,500,000	£7,550,000	£7,752,292	£762
UK Tunnel 12	UK	Urban	Water	Bored - TBM (EPB)	9,400	2.1 - 4.0m	Precast concrete	Clay, sand and rock	£120,000,000	£160,000,000	£12,765,957	£12,268,085	N/A
UK Tunnel 13	UK	Rural	Highway/Road	Prevault	800	12	Shortcrete	Chalk	£16,804,725	£21,589,725	£21,005,907	£27,600,858	£244
UK Tunnel 14	UK	Urban	Power	Bored - TBM	6,030	4.1	Precast concrete	Cohesive	£60,000,000	£60,000,000	£9,950,249	£10,216,852	£774
UK Tunnel 15	UK	Urban	Power	Bored - TBM	6,890	3.05	Precast concrete	Cohesive	£61,000,000	£61,000,000	£8,853,411	£9,090,626	£1,244
UK Tunnel 17	UK	Urban	Water	Bored - TBM (EPB) (Lovat)	10,700	4.1	Precast concrete	Glacial tills, alluvial sands, silts, sands and gravels	£107,606,000	£0	£10,056,636	£13,213,987	£1,001
European Tunnel 1	Norway	Undersea	Highway/Road	Drill and blast	7,776	10	SCL	Hard rock	kr 500,000,000	kr 846,000,000	kr 64,300,412	£7,696,895	£98
European Tunnel 2	Spain	Urban	Metro	Bored - TBM (EPB)	7,432	9.38	Trapezoidal reinforced concrete segments	Soft rock	€ 160,090,230	€ 277,934,100	€ 21,540,666	£27,359,419	£396
European Tunnel 3	Netherlands	Rural	Rail	Bored - TBM (Slurry Shield)	7,160	14.87	Reinforced precast concrete segments	Soft rock	€ 426,553,200	€ 426,553,200	€ 59,574,469	£55,125,985	£317
European Tunnel 4	Austria	Suburban	Highway/Road	NATM with conventional blast advance method	2,967	9.6	In-situ concrete lining	Schrattenkalk, Drusberg layers, marl and	€ 30,000,000	€ 47,250,000	€ 10,111,223	£10,333,268	£143
European Tunnel 5	Portugal	Rural	Highways/Road	Drill and Blast	21,385	12	SCL	Hard Rock	€ 0	€ 480,000,000	€ 22,445,639	£19,909,282	£176
European Tunnel 6	Germany	Rural	Highways/road	SCL sequencial	3,449	11.6	SCL	Hard Rock	€ 85,000,000	€ 0	€ 24,644,825	£23,406,697	£221
European Tunnel 7	Spain	Urban	Highway/Road	EPB TBM	56,000	15	Precast concrete	Clay and gypsum	€ 2,785,714,286	€ 3,900,000,000	€ 49,744,898	£50,878,015	£288
European Tunnel 8	Switzerland	Urban	Highway/Road	Bored - TBM pilot and sequential excavation	8,800	14	SCL and cast in-situ concrete	Moraine and molasse rock	SFr. 466,270,000	SFr. 1,120,000,000	SFr. 52,985,227	£34,754,990	£226
European Tunnel 9	Switzerland	Suburban	Highway/Road	Bore - TBM, road header with TBM pilot	2,500	11	SCL and cast In-situ concrete	Soft Rock	SFr. 107,040,000	SFr. 0	SFr. 42,816,000	£30,329,825	£319
European Tunnel 10	France	Suburban	Highway/Road	Single bore	3,000	10.4	SCL	Soft rock	€ 273,571,429	€ 383,000,000	€ 91,190,476	£103,028,983	£1,213
European Tunnel 11	Spain & France	Urban	Highway/Road	Drill and blast	8,602	10.4	Reinforced Concrete	Hard Rock	€ 275,000,000	€ 0	€ 31,969,309	£37,966,452	£447
European Tunnel 12	Greece	Mountain	Highway/Road	NATM/SCL	1,385	11	SCL	Flysch with clay schist, sandstones and siltstones	€ 45,705,000	€ 0	€ 33,000,000	£35,027,302	£369
European Tunnel 13	Germany	Rural	Highway/Road	Drill and blast	1,740	10.5	SCL and cast In-situ concrete	Hard rock	€ 25,000,000	€ 0	€ 14,367,816	£14,683,336	£170
European Tunnel 14	Luxembourg	Rural	Highway/Road	NATM/SCL	5,876	11.4	SCL and cast In-situ concrete	Soft rock	€ 170,000,000	€ 0	€ 28,931,246	£26,474,523	£259
European Tunnel 15	Greece	Urban	Highway/Road	Drill and blast	9,140	12.5	SCL and cast In-situ concrete	Siltstone flysch of the Ionian zone	€ 115,000,000	€ 0	€ 12,582,057	£13,355,015	£109
European Tunnel 16	Greece	Urban	Highway/Road	Drill and blast	3,300	11.5	SCL	Limestone Ionian flysch	€ 164,000,000	€ 0	€ 54,666,667	£61,216,386	£589
European Tunnel 17	France/Switzerland	Rural	Scientific	Roadheader	2,600	3.8	SCL and cast In-situ concrete	Hard rock	SFr. 100,000,000	SFr. 100,000,000	SFr. 38,461,538	£27,042,418	£2,384
European Tunnel 18	France/Switzerland	Rural	Scientific	Bored - TBM	2,500	3.6	SCL and cast In-situ concrete	Soft Rock	SFr. 23,000,000	SFr. 23,000,000	SFr. 9,200,000	£6,468,546	£635
European Tunnel 19	Spain	rural	Rail	Bored - TBM	48,296	10	Precast concrete	Hard Rock	€ 1,379,032,831	€ 1,379,032,831	€ 28,553,769	£30,343,144	£386
European Tunnel 20	Spain	rural	Rail	Bored - TBM	56,825	9.5	Precast concrete	Hard Rock	€ 1,219,000,000	€ 1,219,000,000	€ 21,451,826	£21,940,468	£310
European Tunnel 21	Netherlands	Urban	Highway/Road	Bored - TBM	13,200	11.3	Single pass lining with passive fire protection	Sand and clay	€ 300,000,000	€ 690,000,000	€ 22,727,273	£27,854,062	£278

The costs for the tunnels in the BTS report were all factored to Q1 2010 prices and so these will have been bought in line with 2013 prices using inflation indices. The relationship between Cost/m3 and tunnel diameter has been used to produce a cost estimate. It should be stated that this does not take into account other variables that affect the tunnel cost such as tunnel overall length, ground conditions and setting, whether urban or

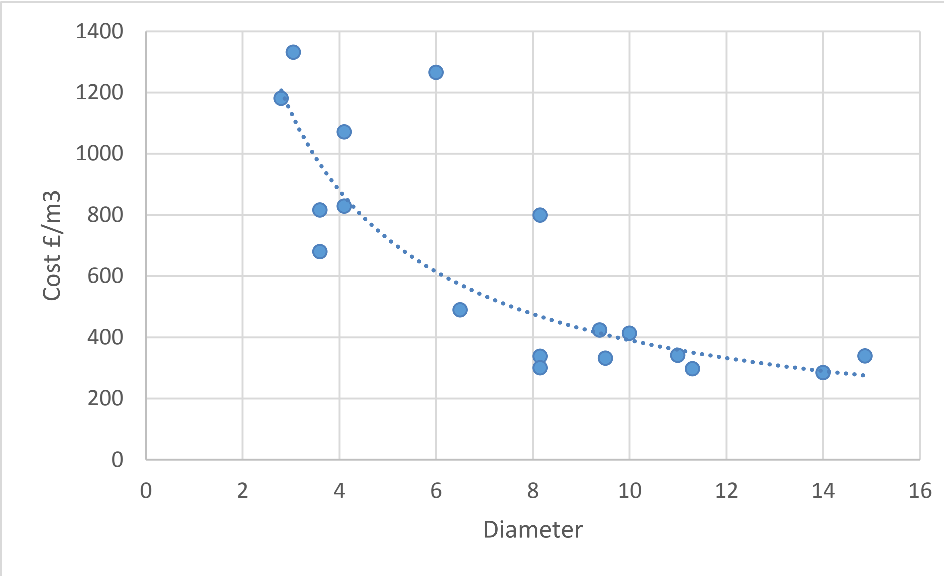


Figure 4-12: Graph Showing the Relationship between TBM Tunnel Cost/m3 excavated and Tunnel Outside Diameter adjusted to 2013 prices

rural. Neither is it assumed to include M & E works and design, but it is assumed to include preliminaries, insurances and profit.

Using the relationship between the tunnel diameter and the cost per m3 for the bored options, from the data it is assumed that the tunnel cost for the large diameter tunnels we are considering would be £350/m3 giving a rate of £45m/km for a 12.8m external diameter. A bored tunnel of 9.2km would therefore cost approximately £414m. Using the work done previously in this report the approximate cost of both Open Cut/Cut and Cover ramps at portals is £50m.

Table 14 Option 2a Cost Estimate

Section	Length (km)	Cost/km (£m)	Total Cost
Bored Tunnel	9.2 km	£45m	£414m
Portal Sections (Cut & Cover/Open Cut)	0.99km	£50m	£50m

Item	Cost	%
Preliminaries + Ins + Profit	£incl	0
Design	£29m	4

Roadworks	£7m	1
Open Cut/C & C	£50m	7
Tunnelworks (TBM)	£414m	58
M&E Facilities	£107m	15
Risk Allowance	£107m	15
TOTAL	£714m	100
plus 45% TfL Management Contingency	**£1035m**	

4.4 Option 2b – TBM Tunnel (A4/Sutton Court junction to North End Road) with Junctions

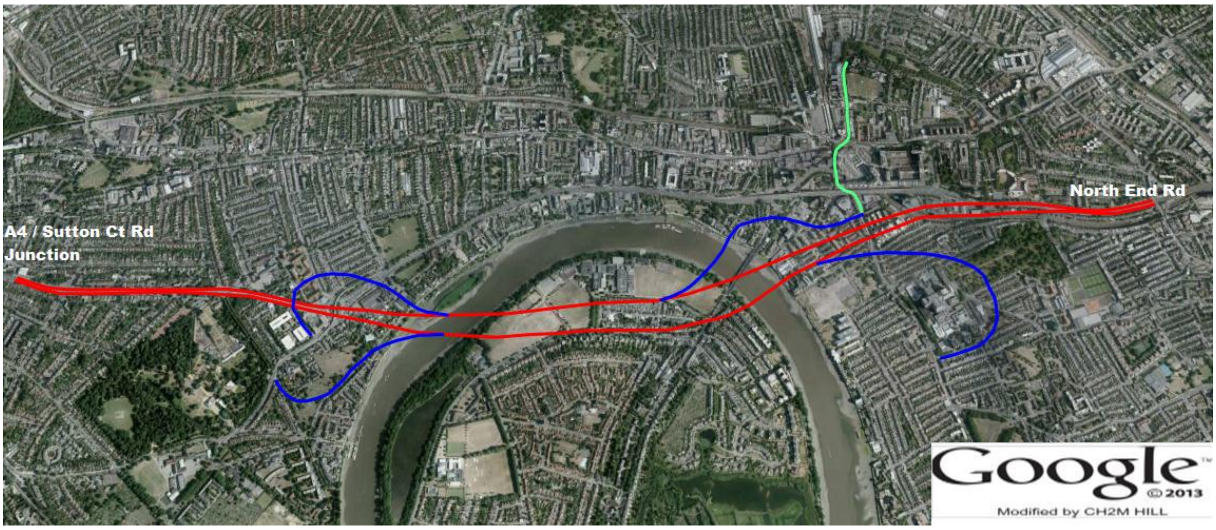


Figure 4-13: Option 2b Route (Google, 2013)

Option 2b is an East-West tunnel link from the Great West Road – West of Sutton Court Road (Western Portal) to North End Road (Eastern Portal) with the aim of removing traffic from the centre of Hammersmith.

4.4.1 Horizontal and Vertical Alignment

The horizontal alignment of the main running tunnels in option 2b are the same as that in option 2a with the addition of the junctions facilitating North-South traffic. The alignment of these additional junction tunnels are dependent on the depth of the main running tunnels, as such the horizontal alignments are complex to provide enough length to achieve the depth to intersect with the main tunnels.

4.4.2 Portal Locations

The main tunnel portal locations are as stated in option 2a. Additional portals will be located in the following locations to accommodate the junctions linking the tunnel with North and South links:

- A316 Burlington Lane to Central London (both ways)
- Shepherds Bush Road to Heathrow
- Fulham Palace Road to Heathrow

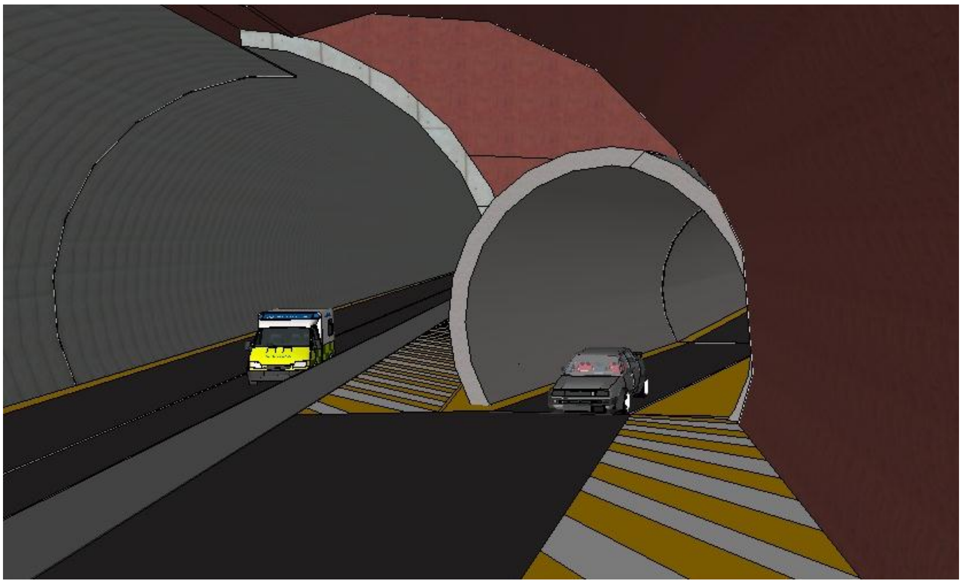


Figure 4-14: Proposed SCL Junction Connection (Options 2b and 3b)

4.4.3 Lane Configuration and Cross Section

According to BD 79/99 Road Tunnel Design constructing a 3-lane tunnel would require a minimum of tunnel diameter of 15m. This cross section would allow for three lanes of at least 3.65m in each bore with additional walkways (0.6m) on either side and achieves the minimum maintained headroom of 5.35m. The tunnels will be connected by cross passages, at regular spacing (estimated to be 100m), for use in the case of fire and emergencies.

3 lane Urban All-Purpose Roads Mainline Twin Tunnels

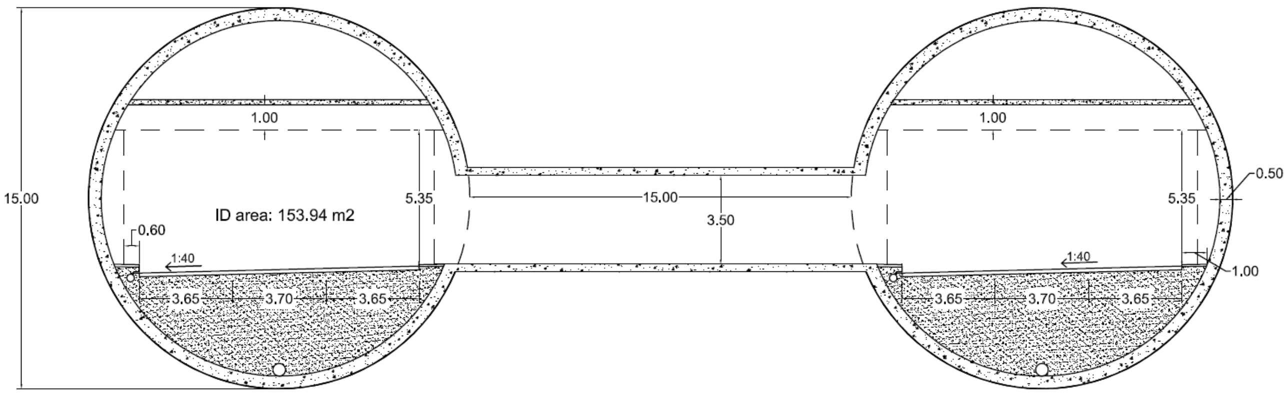


Figure 4-15: Three Lane 15m Diameter Cross-Section

4.4.4 Geotechnical Conditions

The main bored running tunnels will be in a deep band of London Clay as in option 2a. The additional junction tunnels will have some sections of Open Cut and Cut and Cover in the River Terrace Gravel the layer above the London Clay and will require some ground water measures needed to prevent infiltration.

4.4.5 Fire and Ventilation

For a 3 lane unidirectional traffic tunnel, the available overhead duct area in each tunnel is 25.7 m^2. Preliminary calculations for critical velocity for smoke control suggest that a minimum flow rate of ~450m^3/s is required; this accounts for a flow velocity of ~8.5m/s within the ducts. The pressure drop associated with this flow speed is ~550 Pa and is unlikely to cause significant leakage of smoke through the closed dampers. However, it is desired to limit the velocity within the ducts to 8 m/s for which a minimum duct area of 27m^2 is required.

Table 15: Overhead duct size estimation for emergency ventilation (Option 2b)

Option 2B (EB/WB)	Grade 0%	Grade 5%
No. of Lanes	3	3
Internal Diameter(m)	14	14
Upstream Critical Velocity(m/s)	2.61	3.03
Downstream critical Velocity(m/s)	1.5	1.5
Available Duct Area (m/s)	25.7	25.7
Total Flow Rate(m^3/s)	392	435
Average Velocity through ducts(m/s)	7.6	8.5
Pressure Drop across ducts (Pa)	429	528
Limiting Velocity (m/s)	8	8
Minimum required Duct Area (m/s)	25	27

The results for Option 2b (Table 15) show that no mechanical ventilation is required for either a unidirectional and/or bi-directional traffic. Due to the large tunnel diameter available, the piston effect of the vehicles draw in enough air through the portals to keep the tunnel sufficiently vented. However, like for Option 2a, mechanical ventilation can be used to lower down pollution levels even further.

Table 16: Pollution Levels for Option 2b

Traffic Direction (EB/WB)	Number of Lanes	Mechanical Ventilation	No of fans	CO mg/m3	NO2 mu g/m3	Extinction
Unidirectional	3	NO	N/A	44	1030	0.0015
Bi-directional	3	NO	N/A	50	1220	0.003

Pollutions Control for receptors around the portal building has not been carried out in this study. Further ventilation plant can be provided at the portal buildings to minimise the impact of pollutions within areas near the portals. This can be in the form of filtering plants that dilute the pollutant air or through a controlled vertical discharge of the pollutants through the portal shaft at higher levels.

4.4.6 Construction Method

The method of tunnelling would be consistent with option 2a, EPB TBM dual bored tunnels. However this option would also have the addition of junctions and additional portal locations. These portals will be a combination of open-cut, cut and cover and SCL, some widening of the main tunnels may be required to satisfy the slip on/off lane distances.

4.4.7 Constructability

The additional constructability issues with 2b arise from the junction locations and portals. The roads linking to the main tunnels are generally narrower and so portal locations are limited.

An estimated 250,000 lorry movements would be required for the removal of excavated spoil from the site. It is assumed that some of the excavated material will be retained on site and used to backfill above the tunnel, and lorry movements associated with this are not considered. It is likely that most of this spoil could be removed by river transport. A further estimated 50,000 movements will be associated with delivery of tunnel segments, concrete and other materials.

4.4.8 Cost Estimate

It is likely due to the narrow roadways that some properties will need to be purchased to make room to accommodate the junction portals. The cost of this option will be the addition on the junction costs to the cost of option 1a. The junction tunnels that connect to the main running tunnels are an additional 3.545km. Due to the variety in tunnelling methods and complexity of constructing junctions in tunnels the additional junction lengths have been added to the overall alignment lengths of the bored tunnels to provide a cost estimate. The North-South tunnel discussed in option 1b is a discrete component of this and will also be added to the cost estimate.

The same method to obtain a cost/km, as in option 3a, has been used for the following cost estimate of option 3b. Due to the larger diameter a cost of £300 per m3 excavated is used and so the cost per km is £53m

Table 17: Option 2b Cost Estimate

Section	Length (km)	Cost/km (£m)	Total Cost
Bored Tunnel	9.2 km	£62m	£488m
Junction Tunnels	3.7 km	£45m	£166m
Portal Sections (Cut & Cover/Open Cut)	0.99km	£50m	£50m
North-South Cut & Cover Tunnel	0.765	-	£146m

Item	Cost	%
Preliminaries + Ins + Profit	£incl	0
Design	£52m	4
Roadworks	£13m	1
Open Cut/C & C	£50m	4
N-S Cut and Cover	£146m	11
Tunnelworks Main	£488m	37
Tunnelworks Junctions	£166m	13
M&E Facilities	£196m	15
Risk Allowance	£196m	15

TOTAL	£1308m	100
plus 45% TfL Management Contingency	£1896m	

4.5 **Option 3a – TBM Tunnel (A4/Sutton Court junction to Earls Court)**

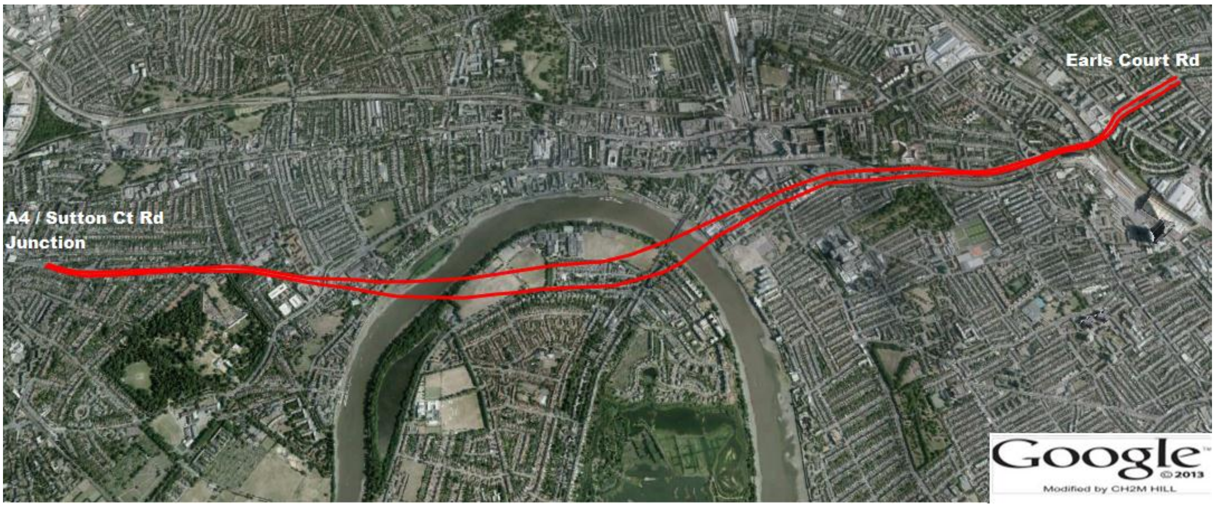


Figure 4-16: Option 3a Route (Google, 2013)

Option 3a is an East-West tunnel link from the Great West Road – West of Hogarth Roundabout (western portal) to Earls Court (eastern portal) with the aim of removing traffic from the centre of Hammersmith.

4.5.1 Horizontal and Vertical Alignment

The horizontal alignment for option 3a is the same as that of option 2a but extends beyond the proposed North End Road towards Earls Court following the road alignment with a portal on West Cromwell Road. The vertical alignment is also the same however it maintains a level gradient eastward beyond the London Underground Piccadilly and District Line Cuttings before climbing at 4% towards the eastern portal.

4.5.2 Portal Locations

The Western Portal will remain in the same place the as option 2a. The Eastern Portal is located on West Cromwell Road where there is an island in the middle of the roadway which will allow enough space for portal construction and allowing a road to remain open in each direction. There will be 220m of open cut leading to the portal which will be a minimum 29m wide. The portal construction may include a variety of tunnelling methods, beginning with Open Cut, Cut and Cover and SCL before entering the bored section. This will allow the roads to separate underground to enable the correct distance between the bores and limit the width of road at the surface which is required without overly disrupting traffic flow.

4.5.3 Lane Configuration and Cross Section

The cross section for option 3a is the same as the 12.8m diameter tunnel from option 2a.

4.5.4 Geotechnical Conditions

From the information provided form the boreholes there is no significant variation in geotechnical conditions due to the extended route alignment from option 2.

4.5.5 Fire and Ventilation

As option 2a.

4.5.6 Construction Method

As option 2a.

4.5.7 Constructability

As option 2a.

4.5.8 Cost

The cost estimate follows the same framework calculated from the BTS Tunnel Cost works

Table 18: Proposed Option 3 Hammersmith Flyunder details

Total Alignment Length	Outer Diameter	Lining Type	Ground Conditions
11.2km	12.8m	Pre-cast Concrete Segments	London Clay

Using the same framework as used for option 2a a TBM-bored tunnel of 11.2km at £45m per km would result in a cost of approximately £504m for the bored sections and £142m for the Cut and Cover/Open Cut and the total cost for option 3a would be as follows in the next Table.

Table 19: Option 3a Cost Estimate

Item	Cost	%
Preliminaries + Ins + Profit	£incl	0
Design	£40m	4
Roadworks	£10m	1

Open Cut/C & C	£142m	14
Tunnelworks – C/C	£504m	51
M&E Facilities	£149m	15
Risk Allowance	£149m	15
TOTAL	£994m	100
plus 45% TfL Management Contingency	£1441m	

4.6 Option 3b – TBM Tunnel (A4/Sutton Court junction to Earls Court) with Junctions

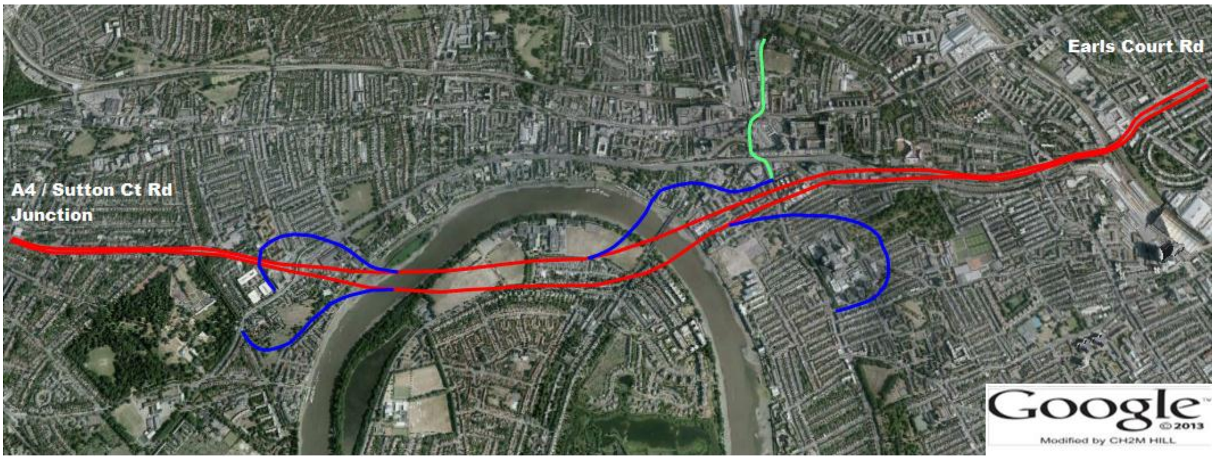


Figure 4-17: Option 3b Route (Google, 2013)

Option 3b is an East-West tunnel link from the Great West Road – West of Hogarth Roundabout (western portal) to Earls Court (eastern portal) with the aim of removing traffic from the centre of Hammersmith.

4.6.1 Horizontal and Vertical Alignment

The horizontal alignment of the main running tunnels in option 2b are the same as that in option 2a with the addition of the junctions facilitating North-South traffic. The alignment of these additional junction tunnels are dependent on the depth of the main running tunnels, as such the horizontal alignments are complex to provide enough length to achieve the depth to intersect with the main tunnels.

4.6.2 Portal Locations

The main tunnel portal locations are as stated in option 3a. Additional portals will be located in the following locations to accommodate the junctions linking the tunnel with North and South links as in option 2b:

- A316 Burlington Lane to Central London (both ways)
- Shepherds Bush Road to Heathrow
- Fulham Palace Road to Heathrow

4.6.3 Lane Configuration and Cross Section

As option 2b

4.6.4 Geotechnical Conditions

From the information provided form the boreholes there is no significant variation in geotechnical conditions due to the extended route alignment from option 2.

4.6.5 Fire and Ventilation

As option 2b

4.6.6 Construction Method

As option 2b

4.6.7 Constructability

As option 2b

4.6.8 Cost

It is likely due to the narrow roadways that some properties will need to be purchased to make room to accommodate the junction portals. The cost of this option will be the addition on the junction costs to the cost of option 1a. The junction tunnels that connect to the main running tunnels are an additional 3.545km. Due to the variety in tunnelling methods and complexity of constructing junctions in tunnels the additional junction lengths have been added to the overall alignment lengths of the bored tunnels to provide a cost estimate. The North-South tunnel discussed in option 1b is a discrete component of this and will also be added to the cost estimate.

The same method to obtain a cost/km, as in option 3a, has been used for the following cost estimate of option 3b.

Table 20: Option 3b Cost Estimate

Section	Length (km)	Cost/km (£m)	Total Cost
Bored Tunnel	11.2 km	£53m	£594m
Junction Tunnels	3.7 km	£45m	£166m
Portal Sections (Cut & Cover/Open Cut)	1.78 km	£50m	£89m
North-South Cut & Cover Tunnel	0.765	-	£146m

Item	Cost	%
Preliminaries + Ins + Profit	£incl	0
Design	£62m	4
Roadworks	£16m	1
Open Cut/C & C	£89m	6
N-S Cut and Cover tunnel	£146m	10
Tunnelworks Main	£594m	39
Tunnelworks Junctions	£166m	11
M&E Facilities	£230m	15
Risk Allowance	£230m	15
TOTAL	£1531m	100
plus 45% TfL Management Contingency	£2220m	

5 Comparative Discussion of Options

5.1 Option 1a

Option 1a is the minimum option considered, it a like for like replacement of the Flyover in tunnelled form. As such it is the cheapest of the options detailed in this report, however it is also likely to be cause massive construction disruption due to the Cut and Cover method of construction and the required depth of the excavation due to sub surface obstructions. It is likely that this is cause long term disruption and traffic congestion for the duration of its construction. In addition to this option 1a does not relieve traffic on the gyratory, only the east-west traffic along the A4.

5.2 Option 1b

The addition of a North-South tunnel to option 1a will cause even more construction disruption in central Hammersmith and potentially remove some of the routes to mitigate traffic disruption from the previous option. The North-South tunnel significantly increases the cost of this option by over 50%, and though it addresses the congestion in the Hammersmith gyratory, we are not sure that a significant amount of traffic would use the North-South tunnel.

5.3 Option 2a

The most economic bored tunnel option, with least ground settlement effects. More expensive than central Hammersmith options however, and traffic use will be limited to non-local traffic that will still have to use the existing roads. Air qualities at portals are an issue, and construction disruption at portals. The open space in Barnes, currently playing fields, would be temporarily lost during construction. The major construction disruption for this option will be focused around the portal locations which will have sections of Open Cut (220m) and Cut and Cover (225m) at each portal, in addition to this the TBM will need to exit the tunnel and be turned during construction at the portal locations which will cause greater disruption to traffic movements.

5.4 Option 2b

Option 2a with junctions therefore takes more traffic, and removes more traffic from Hammersmith Centre. However traffic from Hammersmith Road and Shepherds Bush Road still goes through Hammersmith gyratory. Again portal locations will be the focus of the construction disruption; however this is likely to be increased with the additional junction locations to accommodate the North-South traffic flows. Junctions are very disruptive and expensive, with 150m portal plus another 150m of cut and cover.

5.5 Option 3a

This is an extended version of option 2a. May have even less traffic than 2a, as it won’t take traffic from the North End Road area.

5.6 **Option 3b**

This is the most expensive option and is an extended version of option 2b, again traffic volumes may be less as it won't accommodate traffic from North End Road.

Principal Features							Traffic Flow		Highway Alignment									
Option	Approx Dimensions	Length of route / *tunnel length* (Km)	Open ramp/*Cut and Cover* (each portal)	Approx Construction Cost (£)/Time(yr)	Main Const Method	Ventilation	Maximum Design Traffic Flow	Requirement for Traffic Control	Horizontal	Gradient	Visual Environment	Waste Management Volume of Spoil Disposal (m^3)	Waste Management Volume of Spoil to be stored & reinstated (m^3)	Air Quality and Noise	Highway connections (TBC)	Traffic Impact	Approx Lorry Movements Spoil Disposal/*Other*	Maximum Ground Movements
Option 1a On Line Cut and Cover replacement for the Flyover including portals	10.6 x 25.07m	1.7	230	£243m 3y £363m (SCL alt)	Top Down Cut and Cover and/or SCL	Semi Transverse, local extraction	2000	For emergency only	80km/h design speed	Maximum vertical gradient of 4% has been used from the East and West portals	Vent towers should be above roof level	432,712	231,067	High	A4 only	Extensive traffic disruptions expected in Hammersmith and its approach. Robust traffic Management Plan to be put in place	65,000 *25,000*	Moderate
Option 1b As Option 1a with additional North/South tunnel from Shepherds Bush Road to Fulham Palace Road	10.6 x 25.07m 5.5 x 22.670m	2.7	230 130	£328m 3y	Top Down Cut and Cover and/or SCL	Semi Transverse, local extraction	2000	For emergency only	80km/h design speed	Maximum vertical gradient of 4% has been used between the portals	Vent towers should be above roof level	492,282	303,517	Air quality and noise worst case	A4 and A219	Extensive traffic disruptions expected in Hammersmith and its approach. Robust traffic Management Plan to be put in place	100,000 *40,000*	Moderate
Option 2a Bored Tunnel between North End Road and the A4 Sutton Court Road (two lanes each way twin bore)	12.8m ext dia	4.6 *9.2*	225 *220*	£1.04bn 3y	EPB TBM, and C & C	Semi Transverse, local extraction	3731	For emergency only	80km/h design speed	Maximum vertical gradient of 4% has been used between the portals	Vent towers should be above roof level	1,030,148	42,188	Medium as localised only at theportals	A4 only	Minimum impact on traffic with the existing Hammersmith Fly-Over remaining fully operational. Significant disruption at portals.	150,000 *40,000*	Slight to Moderate
Option 2b Bored Tunnel between North End Road and the A4 Sutton Court Road (With Junctions - three lanes per bore)	15m ext dia	4.6 *12.9*	225 *220*	£1.90bn 3y	EPB TBM, C & C and SCL	Semi Transverse, local extraction	3731	For emergency only	100km/h design speed proposed in main tunnel	Maximum vertical gradient of 4% has been used between the portals	Vent towers should be above roof level	1,660,000	194,638	Medium as localised only at theportals	A4, A216 and A219	Minimum impact on traffic with the existing Hammersmith Fly-Over remaining fully operational. Significant disruption at portals. Significant property demolition at junction portals.	250,000 *50,000*	Slight to Moderate
Option 3a Bored Tunnel between Earls Court and the A4 Sutton Court Road (two lanes each way twin bore)	12.8m ext dia	5.6 *11.2*	225 *220*	£1.44bn 3y	EPB TBM, and C & C	Semi Transverse, local extraction	3731	For emergency only	80km/h design speed	Maximum vertical gradient of 4% has been used between the portals	Vent towers should be above roof level	1,138,239	42,188	Medium as localised only at theportals	A4 only	Minimum impact on traffic with the existing Hammersmith Fly-Over remaining fully operational. Significant disruption at portals.	175,000 *50,000*	Slight to Moderate
Option 3b Bored Tunnel between Earls Court and the A4 Sutton Court Road (With Junctions - three lanes per bore)	15m ext dia	5.6 *14.9*	225 *220*	£2.22bn 3y	EPB TBM, C & C and SCL	Semi Transverse, local extraction	3731	For emergency only	100km/h design speed proposed in main tunnel	Maximum vertical gradient of 4% has been used between the portals	Vent towers should be above roof level	1,768,091	194,638	Medium as localised only at theportals	A4, A216 and A219	Minimum impact on traffic with the existing Hammersmith Fly-Over remaining fully operational. Significant disruption at portals. Significant property demolition at junction portals.	275,000 *60,000*	Slight to Moderate

Table 21 Hammersmith Flyunder Option Comparison Framework

6 Conclusions and Recommendations:

Surveys of the public have determined that the most popular end points for a tunnel would be between Earls Court and Sutton Park Road, *i.e.* option 3. However it is by no means certain whether options 2a or 3a (two lanes without junctions) would cater for sufficient traffic to enable Talgarth Road to be reduced to a lightly trafficked single carriageway. An unintended result may also be a greater volume of traffic on the gyratory. On the other hand options 2b and 3b (3 lane tunnel with junctions), while likely to divert the majority of traffic away from Talgarth Road, is considerably more expensive, not just because of the larger diameter, but because of the junctions, which involve significant lengths of disruptive open-cut and cut and cover, in populated areas.

The on-line replacement of the flyover is a much cheaper option, albeit with a lot of disruption during construction. Together with the proposed remodelling of the gyratory system, this would provide the main benefits in central Hammersmith, with an open plaza between the Apollo Theatre and St Pauls church, and the opportunity for redevelopment in the central area. The downside would be that the Talgarth Road east and west of central Hammersmith would remain as it is at present.

In Hammersmith town centre the proposed master-planning, assumed to be implemented for all options, involves the closure of part of the gyratory, and a return to bi-directional traffic. While the traffic details are not known, it is considered that this remodelling will reduce the traffic capacity of the gyratory system significantly. The proposed north-south tunnel for light/low vehicles may not appreciably reduce the congestion on the gyratory, if origin-destination surveys show there are not significant traffic movements between Fulham Palace and Shepherds Bush Road.

Clearly this report is a preliminary one, and considers some basic ideas for the flyunder. However a more comprehensive analysis is necessary, once origin-destination surveys allow us to understand better where traffic is currently moving. In addition the effects of new developments planned for Earls Court and elsewhere need to be factored in.

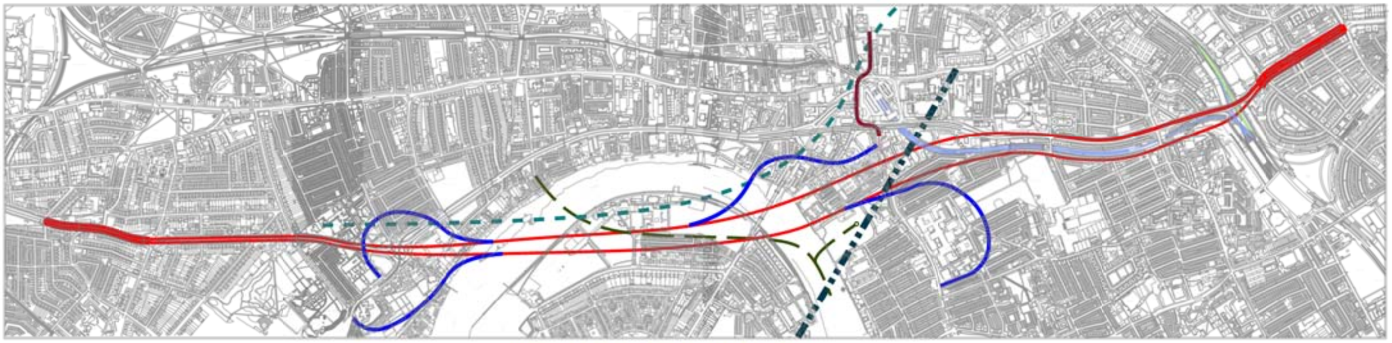
There is still scope for a more detailed study of vertical and horizontal alignments, looking in detail at the implications on existing utilities, in particular the large sewers that run through Hammersmith. Such a follow-on study could also consider the constructability of each option and the management of traffic during construction.

It should be noted that this study has considered the replacement of the flyover only, and has not seriously considered mitigating traffic around the Hammersmith gyratory system.

Finally the study has been confined to the Hammersmith area, and it may be that more feasible strategic options are available to construct a tunnel over a longer length, towards Hyde Park corner in the east and Heathrow/M4 in the west.

List of Appendices

Appendix A – Alignment and Cross-Sectional Drawings



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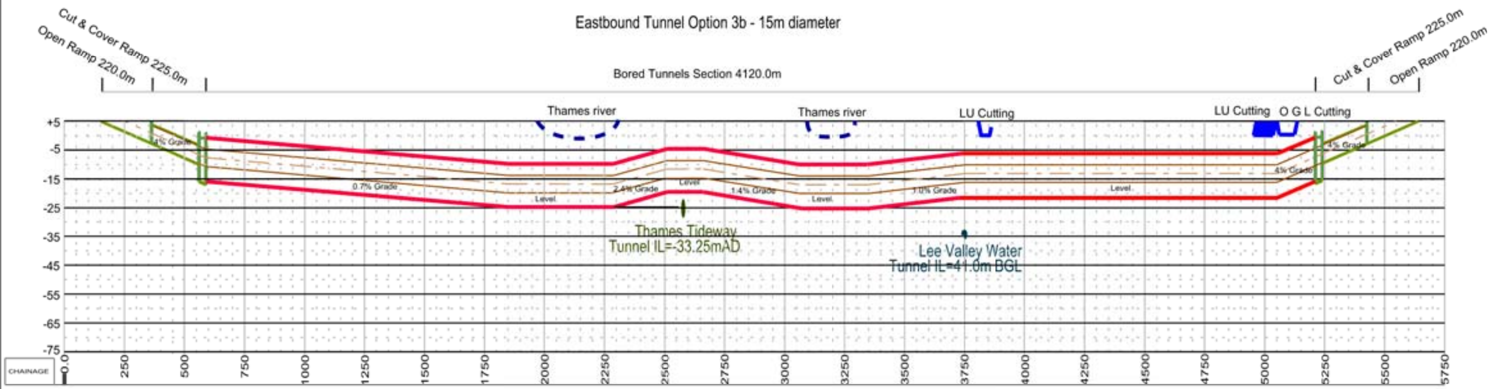

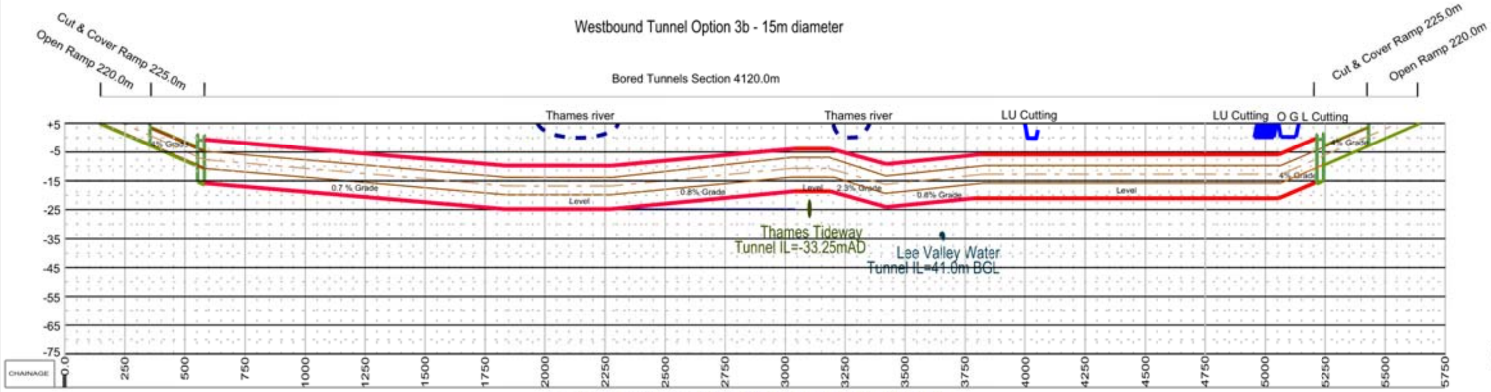

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NOTES:
1. LEVELS ARE TO ORDINANCE DATUM
2. ALL DIMENSIONS ARE IN METERS UNLESS NOTED OTHERWISE.

Key to Symbols;

- Proposed Main Bored Tunnels Route Section
- Cut & Cover and Open Cut Sections
- Existing Thames Lee Valley Water Tunnel
- Proposed Thames Tideway Tunnel
- Existing Thames Lee Valley Water Tunnel
- Proposed Thames Tideway Tunnel
- Existing Thames Water Ring Main
- London Underground Lines (LUL) Cuttings
- London Overground Lines (OGL)
- Proposed North /South Tunnels Route Section
- Proposed Slips in/out Tunnels Section

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Bored Tunnel Option 3b Plan
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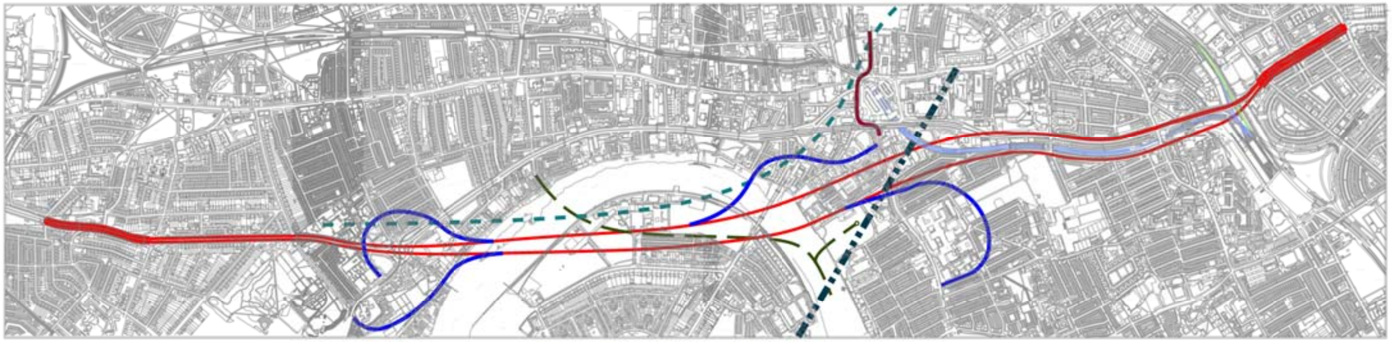

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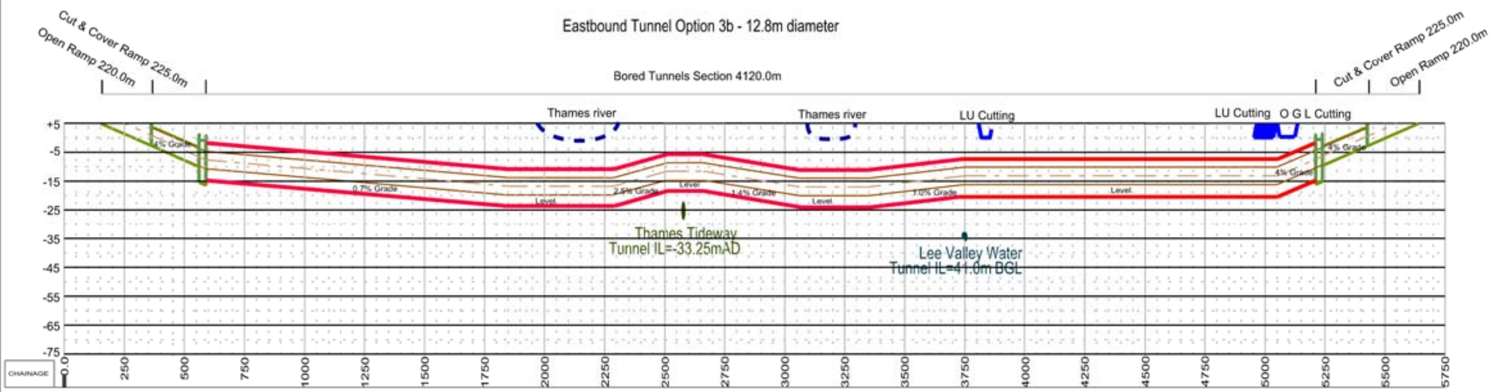

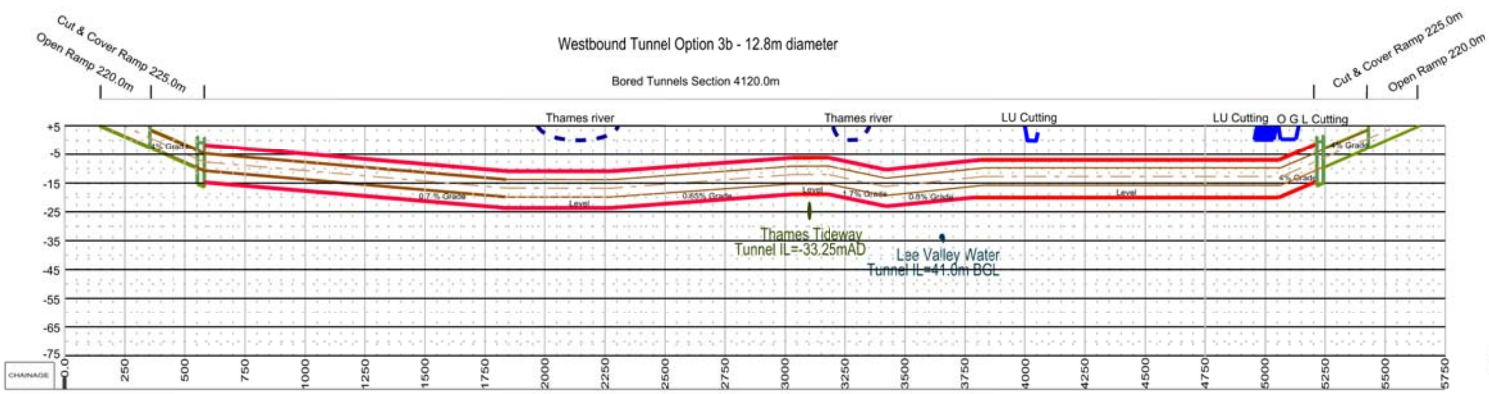

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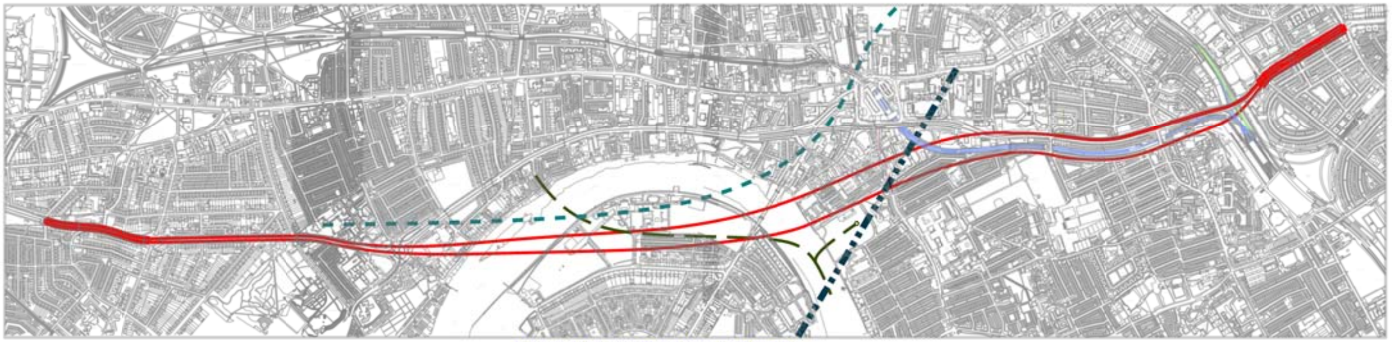

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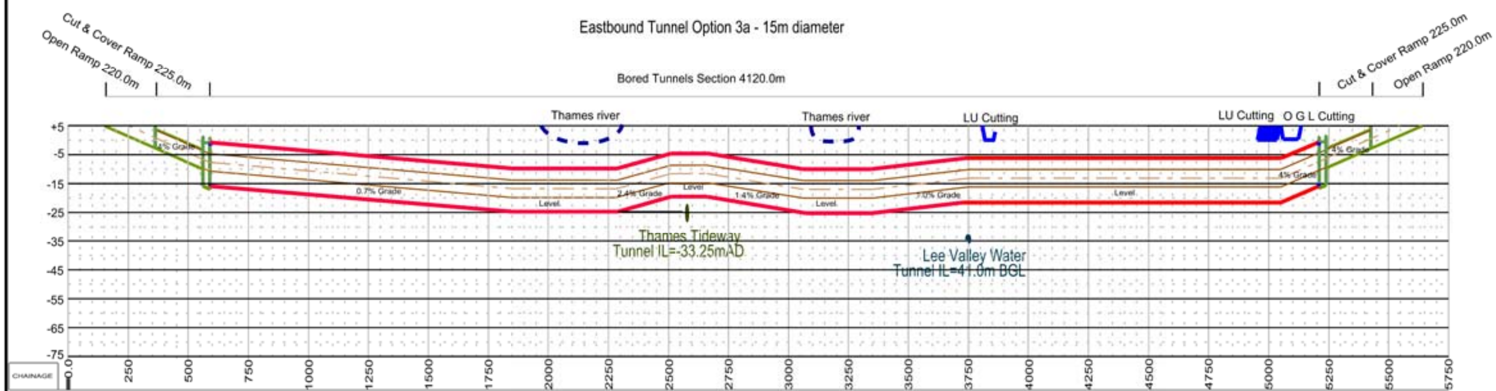

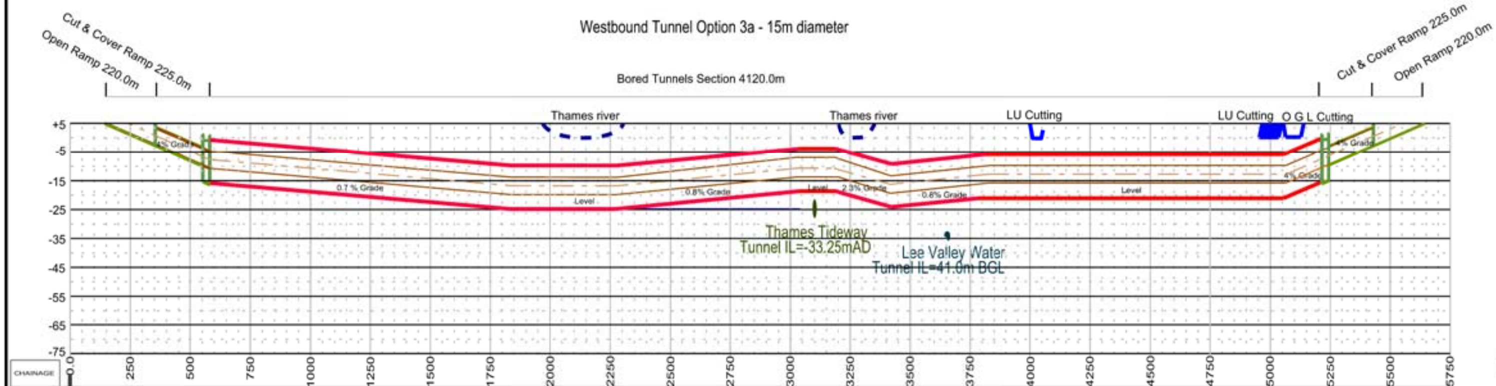

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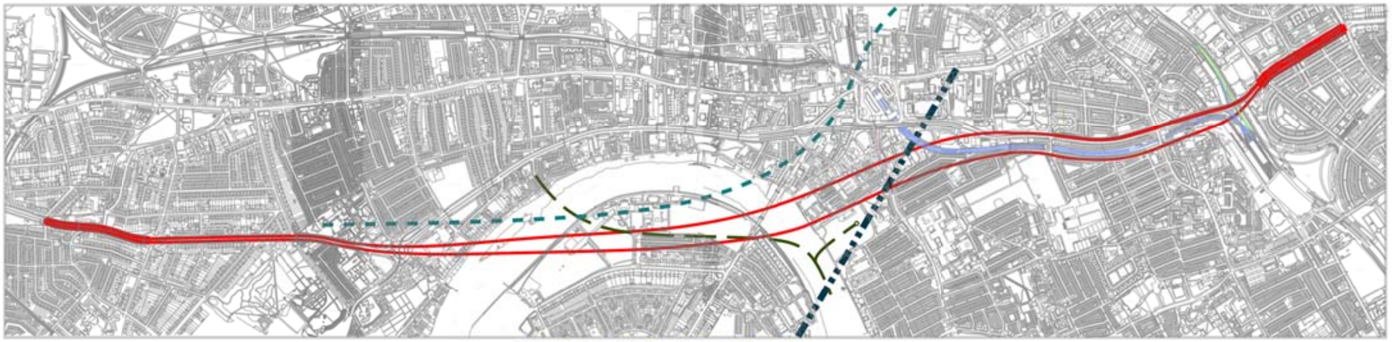

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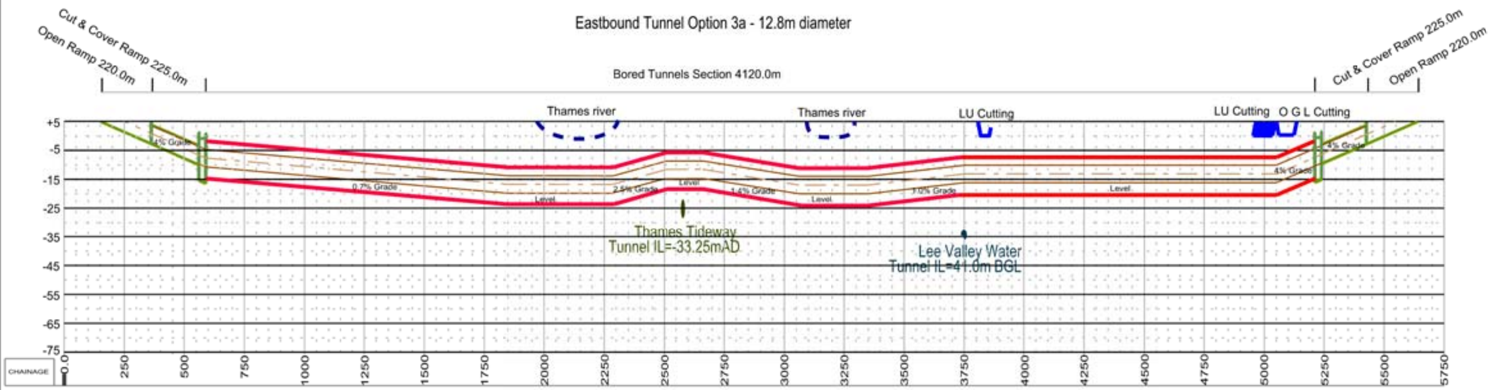
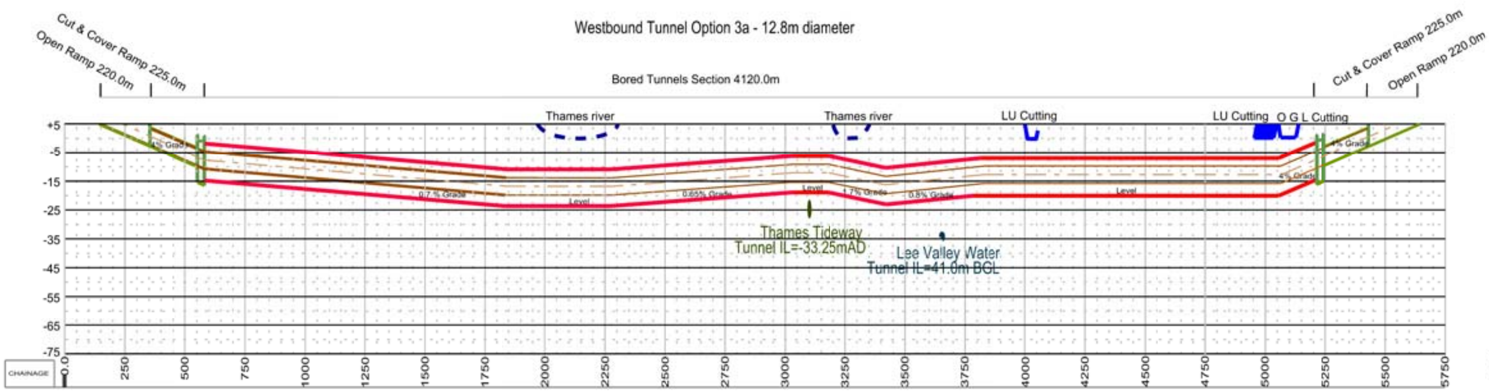
Eastbound Tunnel Option 3a - 12.8m diameter



Westbound Tunnel Option 3a - 12.8m diameter



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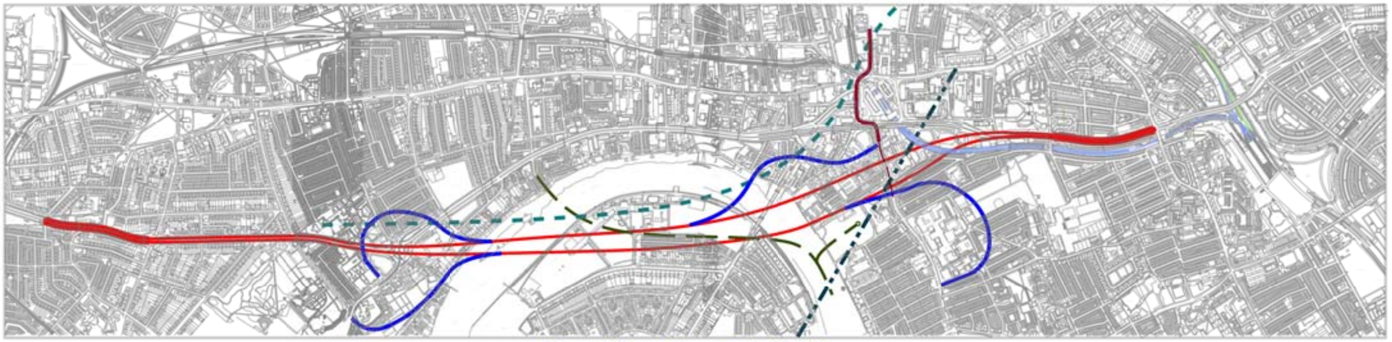

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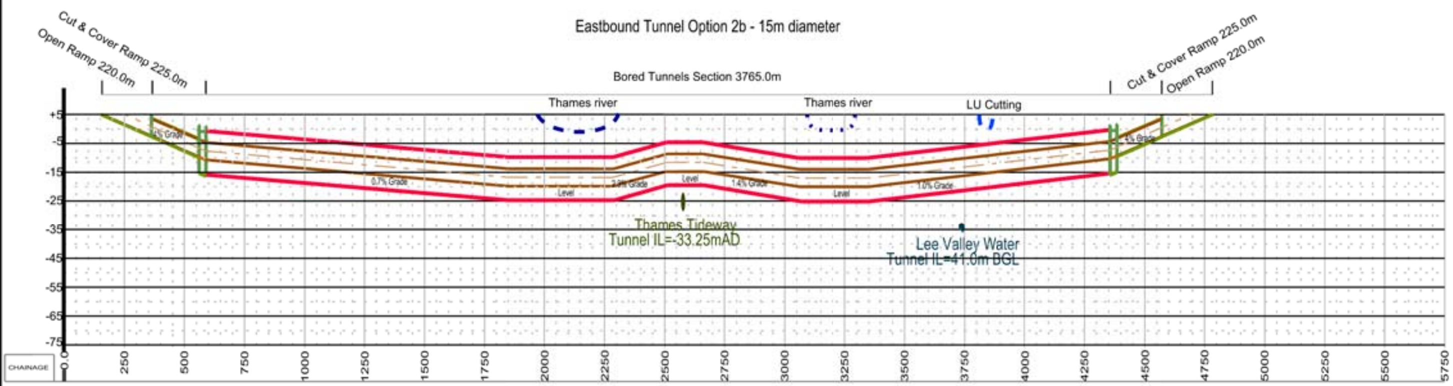

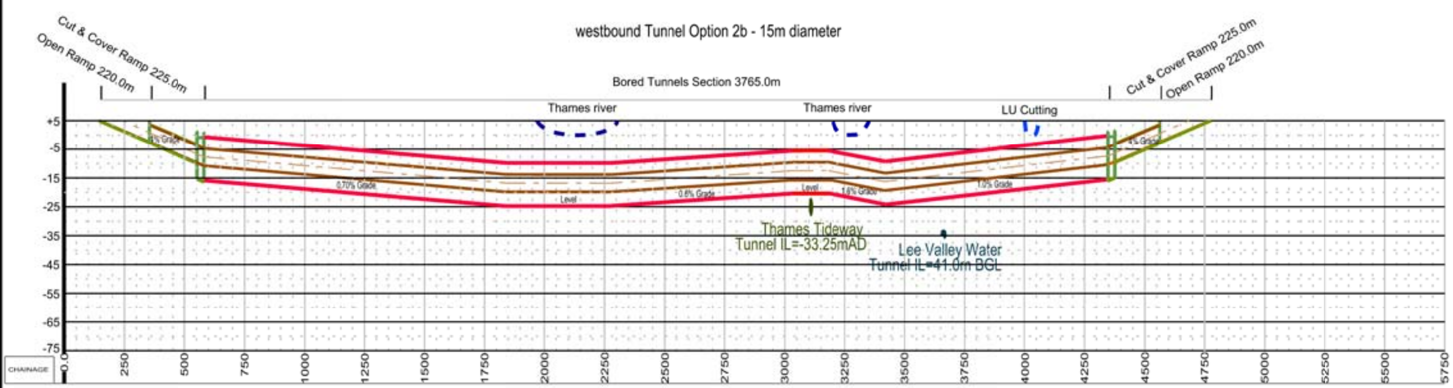

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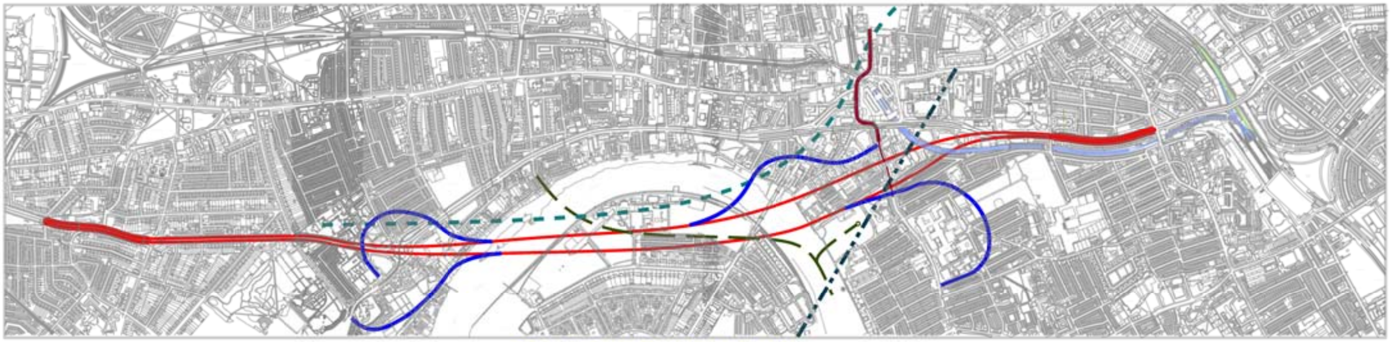

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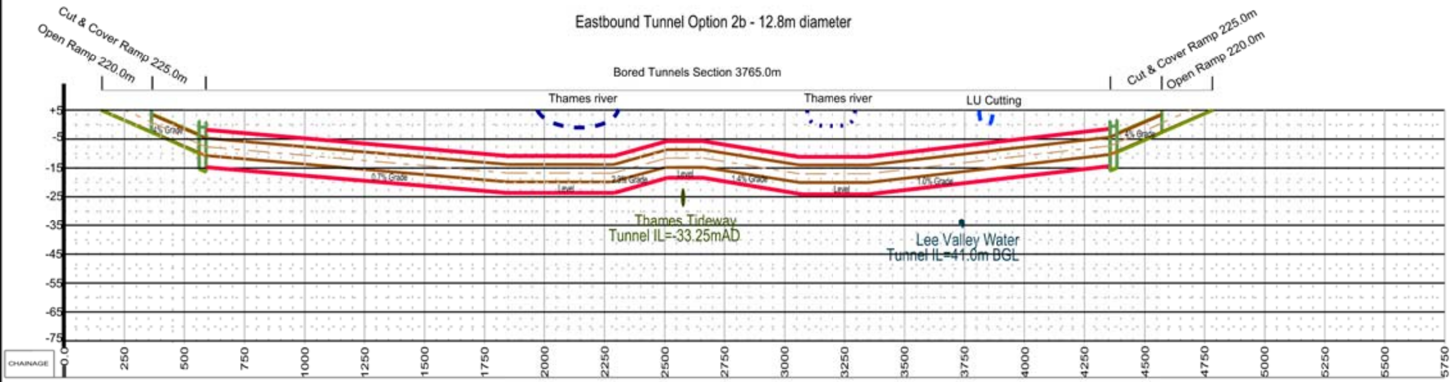

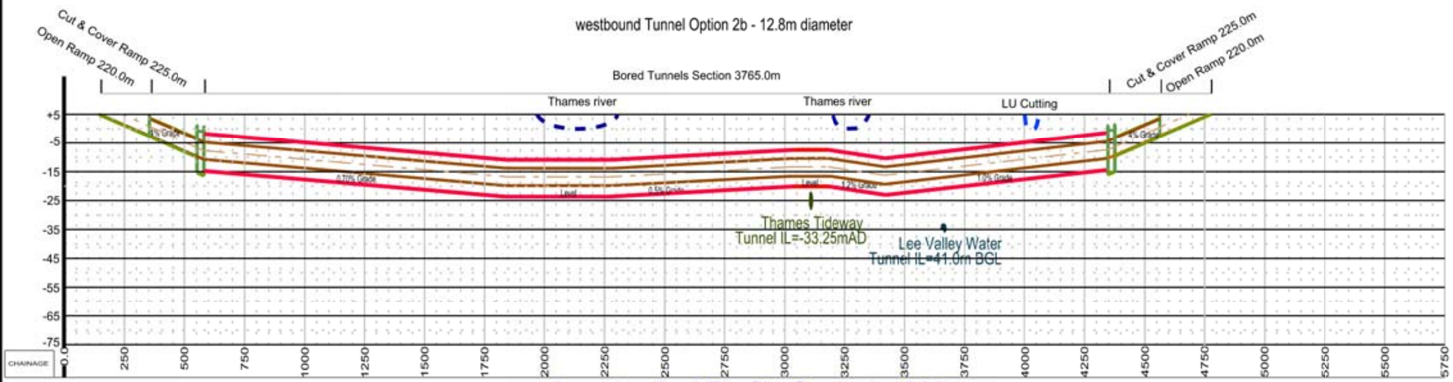

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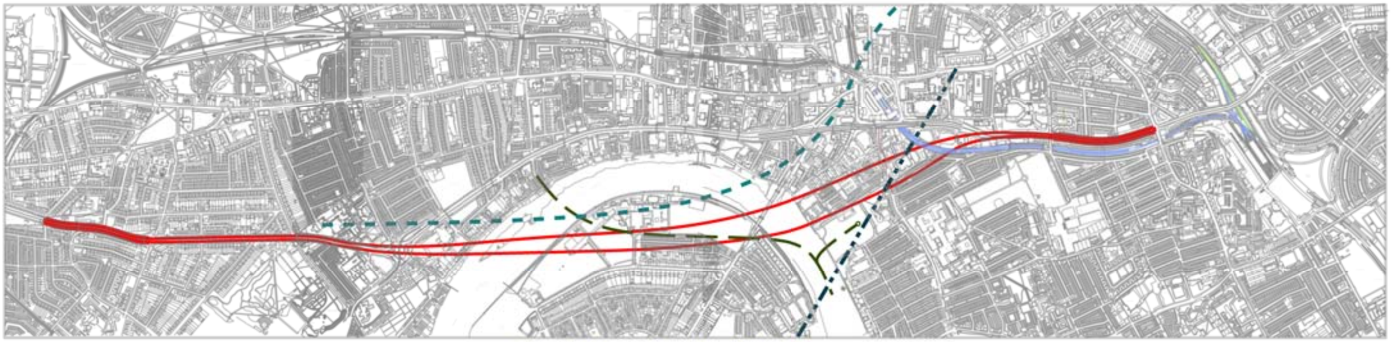
HAMMERSMITH FLYUNDER
PHASE 1 STUDY

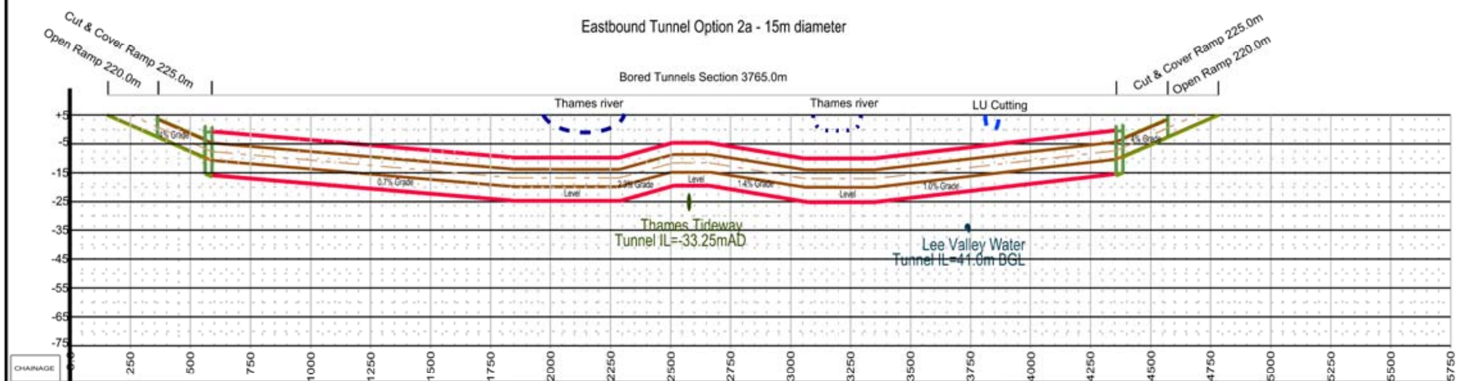
Bored Tunnel Option 2b Plan and Longitudinal section
Sheet 1 of 2

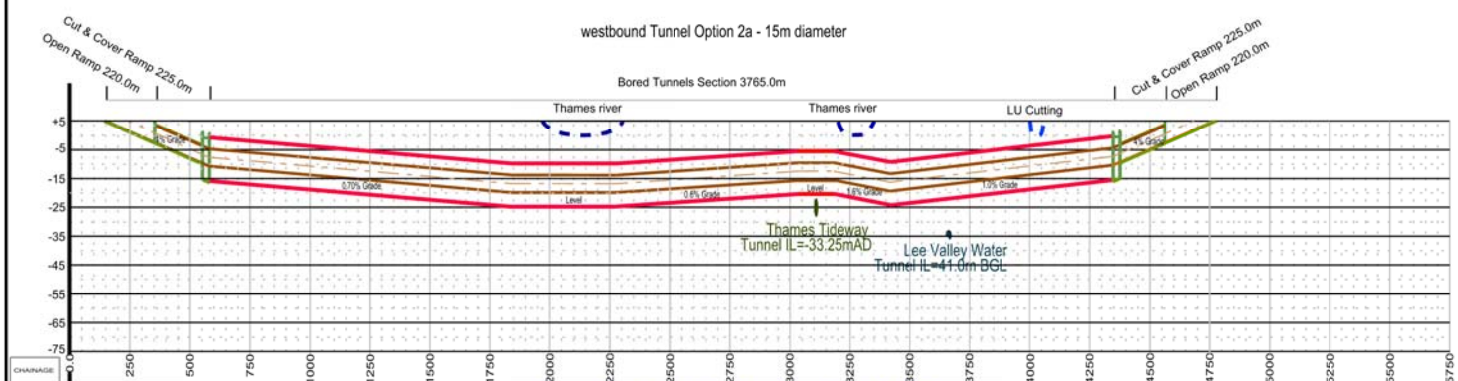
Designed: Hamidat Zerouali
Drawn: Hamidat Zerouali

A0



Plan View Scale 1:2500





Longitudinal Profile Scale 1:1500

0 100m 200m 500m

HORIZONTAL SCALE 1:2500 @ A1

0 20m 40m

VERTICAL SCALE 1:500 @ A1

N

NOTES:
1. LEVELS ARE TO ORDINANCE DATUM
2. ALL DIMENSIONS ARE IN METERS UNLESS NOTED OTHERWISE.

Key to Symbols;

- Proposed Main Bored Tunnels Route Section
- Cut & Cover and Open Cut Section
- Existing Thames Lee Valley Water Tunnel
- Proposed Thames Tideway Tunnel
- Existing Thames Lee Valley Water Tunnel
- Proposed Thames Tideway Tunnel
- Existing Thames Water Ring Main
- London Underground Lines (LUL) Cuttings
- London Overground Lines (OGL)

Rev	Date	Description of Revisions	Drawn	Chkd	Appr

Status: PRELIMINARY

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HAMMERSMITH FLYUNDER
PHASE 1 STUDY

Drawing Title

Bored Tunnel Option 2a Plan and Longitudinal section Sheet 2 of 2

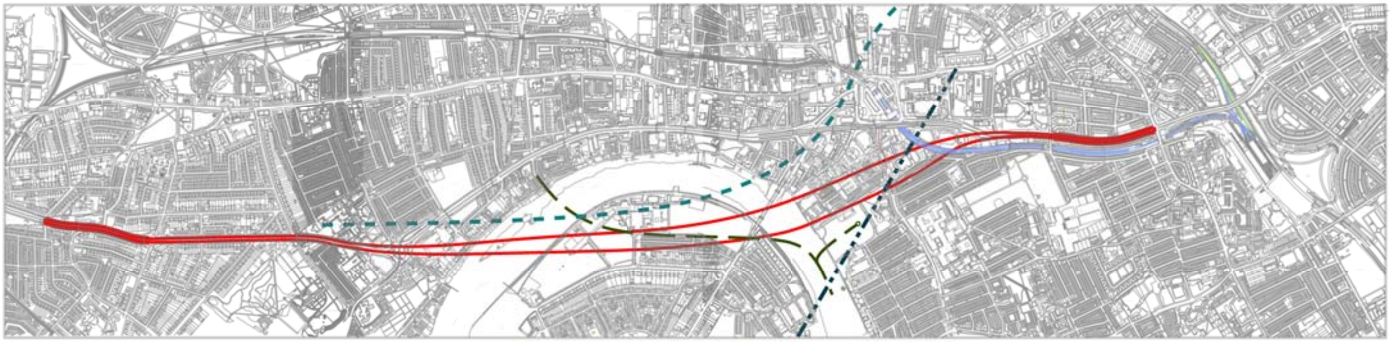
Designed	Hamidat Zerouali	Signed		Date	
Drawn	Hamidat Zerouali	Signed		Date	
Checked		Signed		Date	
Approved		Signed		Date	
Scale(s)		ELR & Mileage			
Alternative Reference		Sheet	of		
Drawing Number		Revision	A0		

Sheet Size A1 594 x 841

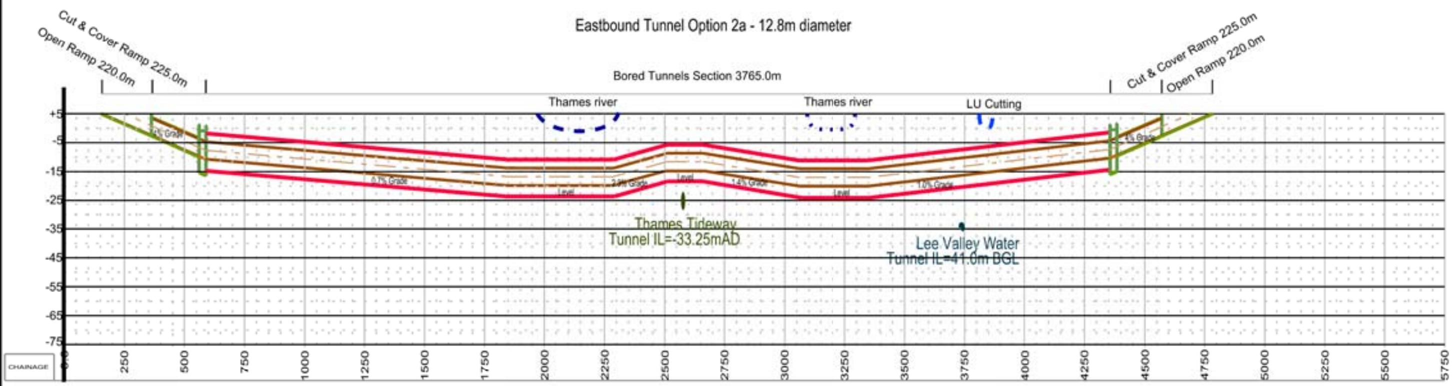
NOTES:
1. LEVELS ARE TO ORDINANCE DATUM
2. ALL DIMENSIONS ARE IN METERS UNLESS NOTED OTHERWISE.

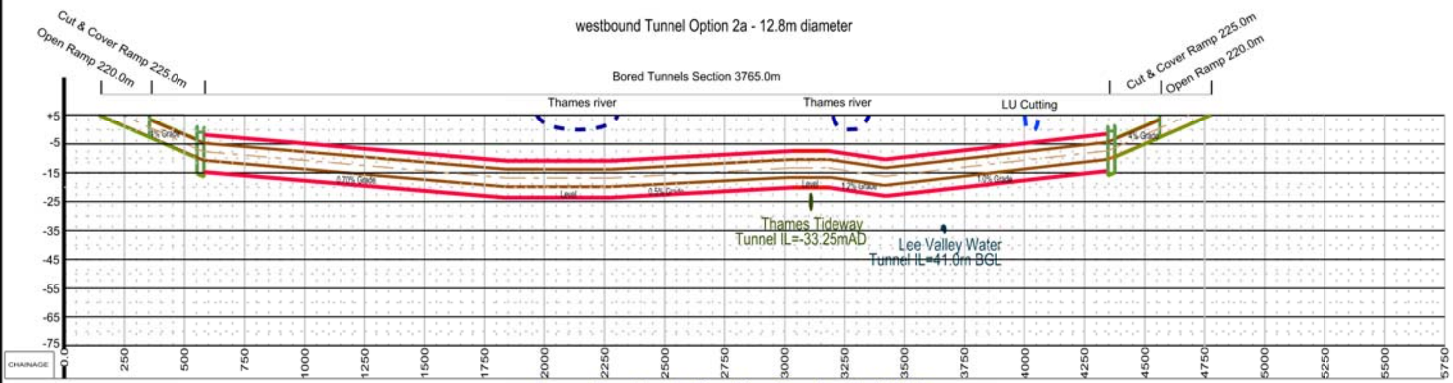
Key to Symbols;

- Proposed Main Bored Tunnels Route Section
- Cut & Cover and Open Cut Section
- Existing Thames Lee Valley Water Tunnel
- Proposed Thames Tideway Tunnel
- Existing Thames Lee Valley Water Tunnel
- Proposed Thames Tideway Tunnel
- Existing Thames Water Ring Main
- London Underground Lines (LUL) Cuttings
- London Overground Lines (OGL)



Plan View Scale 1:2500





Longitudinal Profile Scale 1:1500

0 100m 200m 500m

HORIZONTAL SCALE 1:2500 @ A1

0 20m 40m VERTICAL SCALE 1:500 @ A1

Rev	Date	Description of Revisions	Drawn	Chkd	Appr

Status: PRELIMINARY

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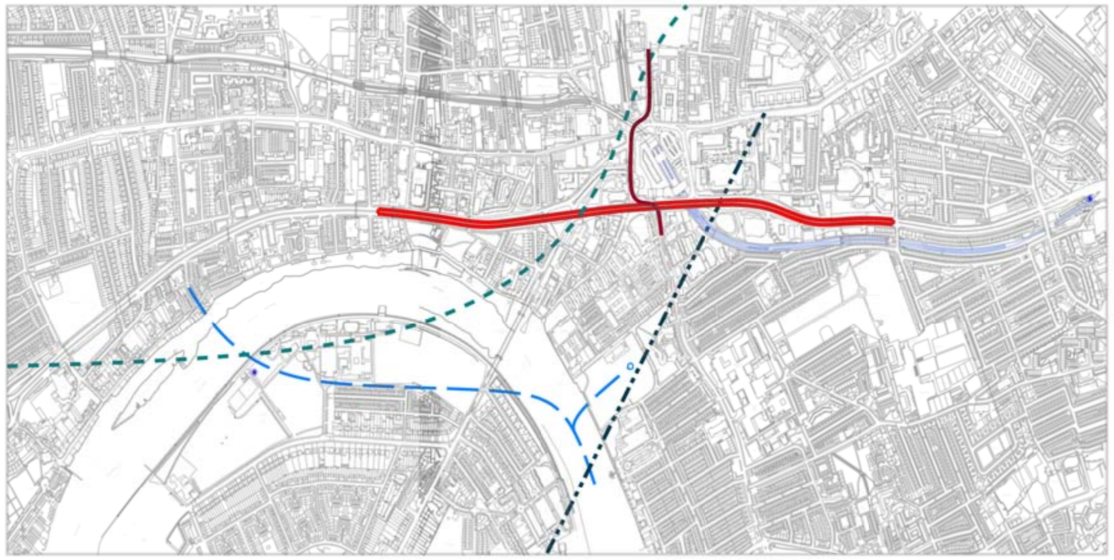
HAMMERSMITH FLYUNDER
PHASE 1 STUDY

Drawing Title: Bored Tunnel Option 2a Plan and Longitudinal section Sheet 1of 2

Designed	Hamidat Zerouati	Signed	Date
Drawn	Hamidat Zerouati	Signed	Date
Checked		Signed	Date
Approved		Signed	Date
Scale(s)		ELR & Mileage	
Alternative Reference		Sheet of	
Drawing Number		Revision	A0

Sheet Size A1 594 x 841



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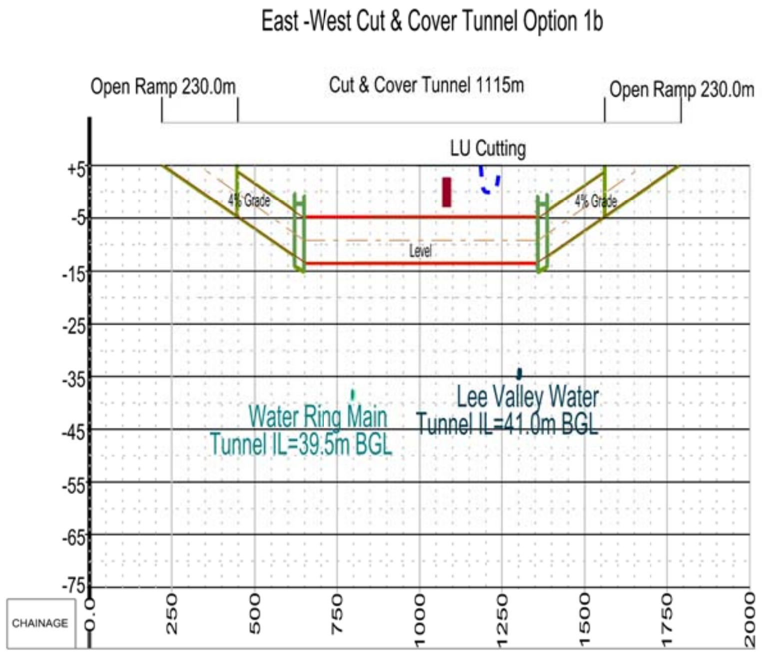

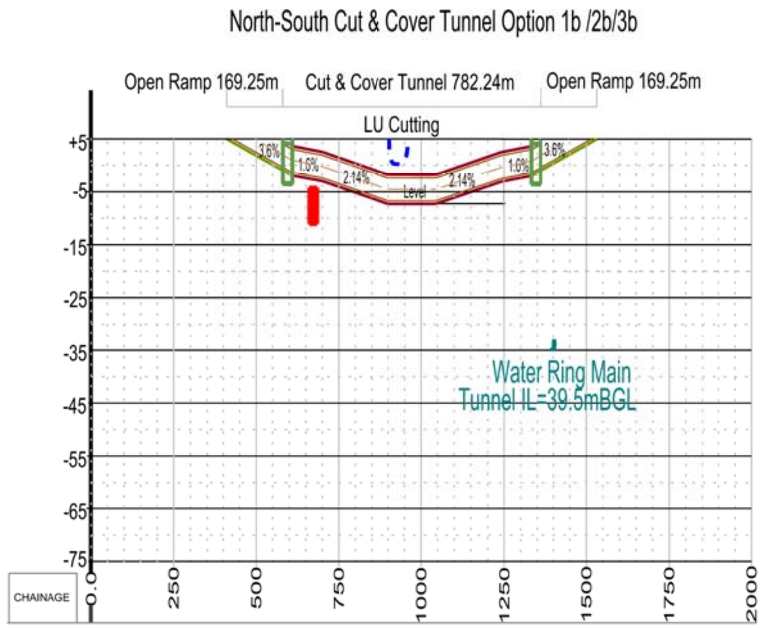

Longitudinal Profile Scale 1:1500

0 100m 200m 500m
HORIZONTAL SCALE 1:2500 @ A1

0 20m 40m
VERTICAL SCALE 1:500 @ A1

Notes;

1. Levels are to Ordinance Datum
2. ALL Dimensions are in meters unless noted Otherwise
3. All Borholes Location are Approximate
4. Borholes Titled Alphabetically are BGS Historical Borholes

Key to Symbols;

- Proposed Main C&C Tunnel Section
- Proposed Open Cut Sections
- Existing Thames Lee Valley Water Tunnel ID=3.010m
- Existing Thames Lee Valley Water Tunnel
- Proposed Thames Tideway Tunnel
- Existing Thames Water Ring Main ID=3.31m
- London Underground Lines (LUL) Cuttings
- Proposed North /South C&C Tunnels Route Section

Rev	Date	Description of Revisions	Drawn	Chkd	Appr

Status: PRELIMINARY

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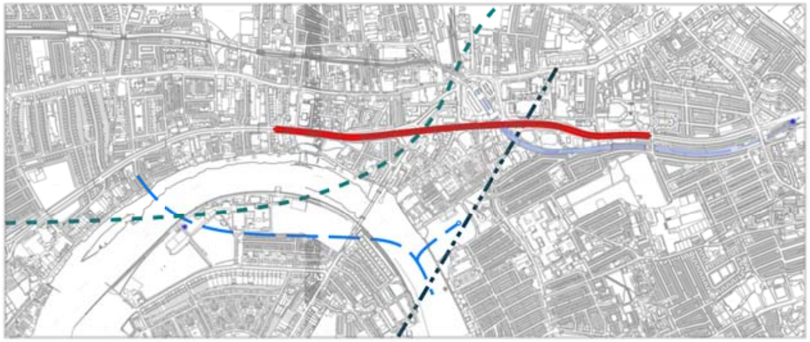
HAMMERSMITH FLYUNDER
PHASE 1 STUDY

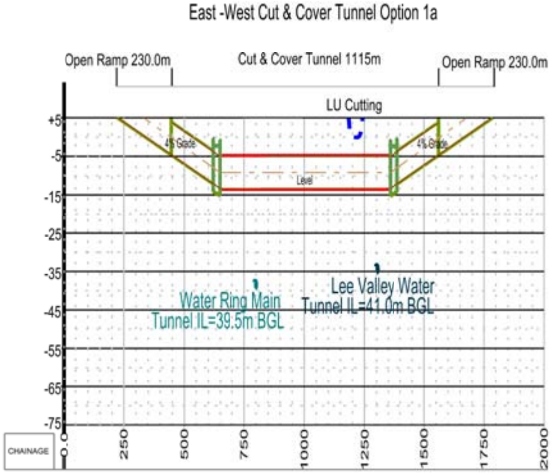
Drawing Title
Cut and Cover Tunnel Options 1b, 2b & 3b
Plan and Longitudinal sections
Sheet 2 of 2

Designed: Hamidat Zerouati		Signed	Date
Drawn: Armstrong Rick		Signed	Date
Checked: Hamidat Zerouati		Signed	Date
Approved		Signed	Date
Scale(s)		ELR & Mileage	
Alternative Reference		Sheet of	
Drawing Number		Revision A0	

Sheet Size A1 594 x 841



Plan View Scale 1:2500



Longitudinal Profile Scale 1:1500

0 100m 200m 500m

HORIZONTAL SCALE 1:2500 @ A1

0 20m 40m

VERTICAL SCALE 1:500 @ A1

Notes;

1. Levels are to Ordinance Datum
2. ALL Dimensions are in meters unless noted Otherwise
3. All Borholes Location are Approximate
4. Borholes Titled Alphabetically are BGS Historical Borholes

Key to Symbols;

- Proposed Main C&C Tunnel Section
- Proposed Open Cut Sections
- Existing Thames Lee Valley Water Tunnel ID=3.010m
- Existing Thames Lee Valley Water Tunnel
- Proposed Thames Tideway Tunnel
- Existing Thames Water Ring Main ID=3.31m
- London Underground Lines (LUL) Cuttings

Rev	Date	Description of Revisions	Drawn	Chkd	Appr

Status

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HAMMERSMITH FLYUNDER
PHASE 1 STUDY

Drawing Title

Bored Tunnel Option 1a Plan
and Longitudinal section
Sheet 1 of 2

Designed	Hamidat Zerouali	Signed		Date	
Drawn	Armstrong Rick	Signed		Date	
Checked	Hamidat Zerouali	Signed		Date	
Approved		Signed		Date	

Scale(s)

ELR & Mileage

Alternative Reference

Sheet of

Drawing Number

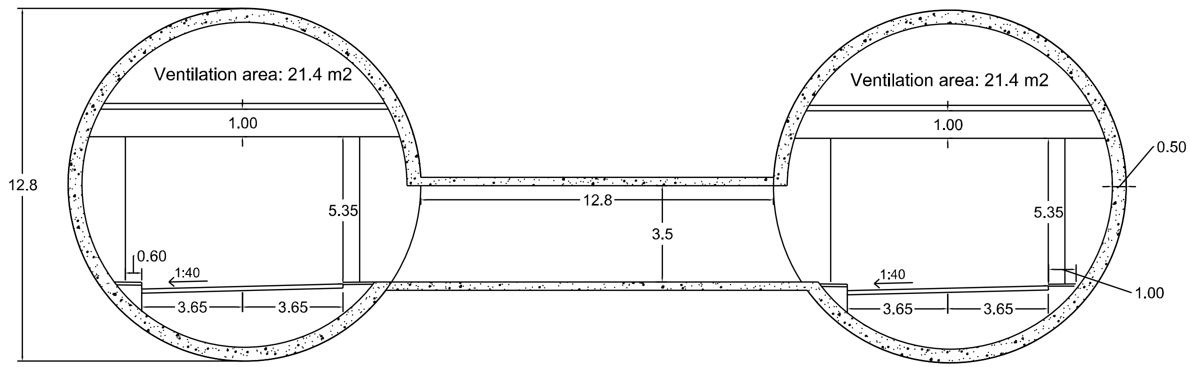
Revision A0

Sheet Size A1 594 x 841

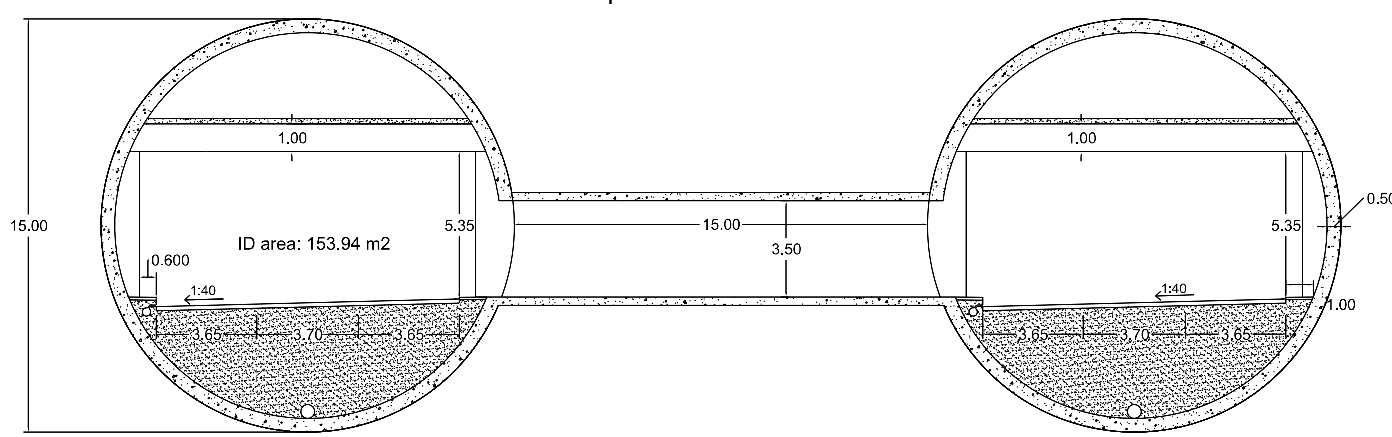
N

NOTES:
1. LEVELS ARE TO ORDINANCE DATUM
2. ALL DIMENSIONS ARE IN METERS UNLESS NOTED OTHERWISE.

2 lane (min. OD considering ventilation)



3 lane Urban All-Purpose Roads Mainline Twin Tunnels



0 5.0 m 10.0m

SCALE 1:200 @ A3

Rev	Date	Description of Revisions	Drawn	Chkd	Appr

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HAMMERSMITH FLYUNDER
PHASE 1 STUDY

Drawing Title
Bored Tunnel Option 2a,2b
Cross Section 12.8m and
15.0m OD
Sheet 1 of

Designed		Signed	Date
Drawn		Signed	Date
Checked		Signed	Date
Approved		Signed	Date
Scale(s)		ELR & Mileage	

Alternative Reference

Sheet
of

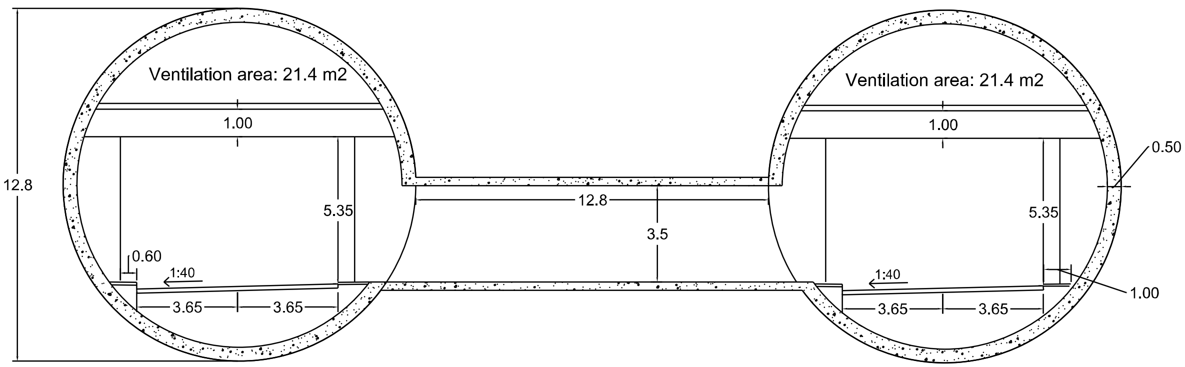
Drawing Number

Revision
A0

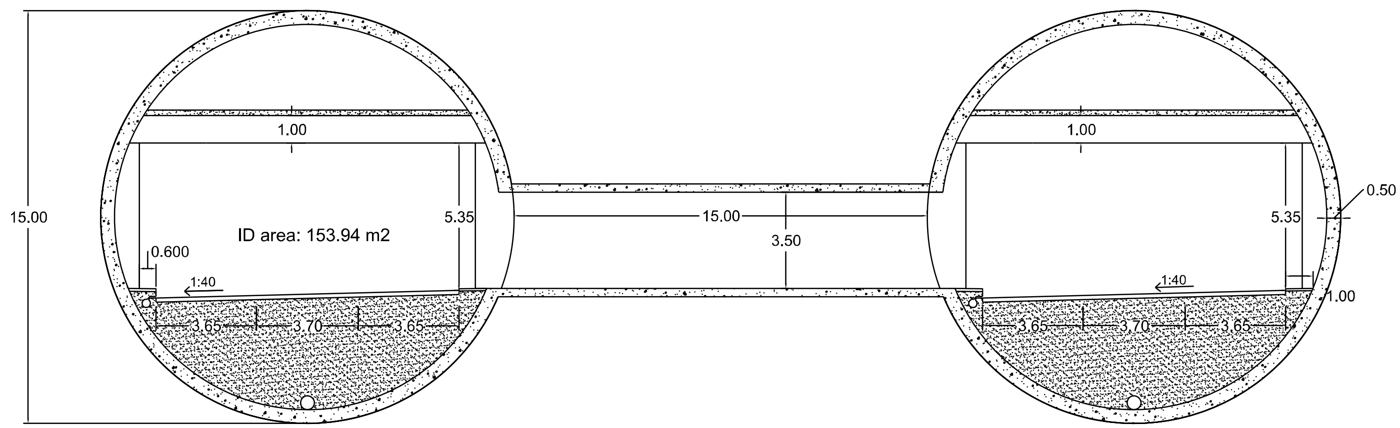
Sheet Size A1 594 x 841

NOTES:
1. LEVELS ARE TO ORDINANCE DATUM
2. ALL DIMENSIONS ARE IN METERS UNLESS NOTED OTHERWISE.

2 lane (min. OD considering ventilation)



3 lane Urban All-Purpose Roads Mainline Twin Tunnels



0 5.0 m 10.0m

SCALE 1:200 @ A3

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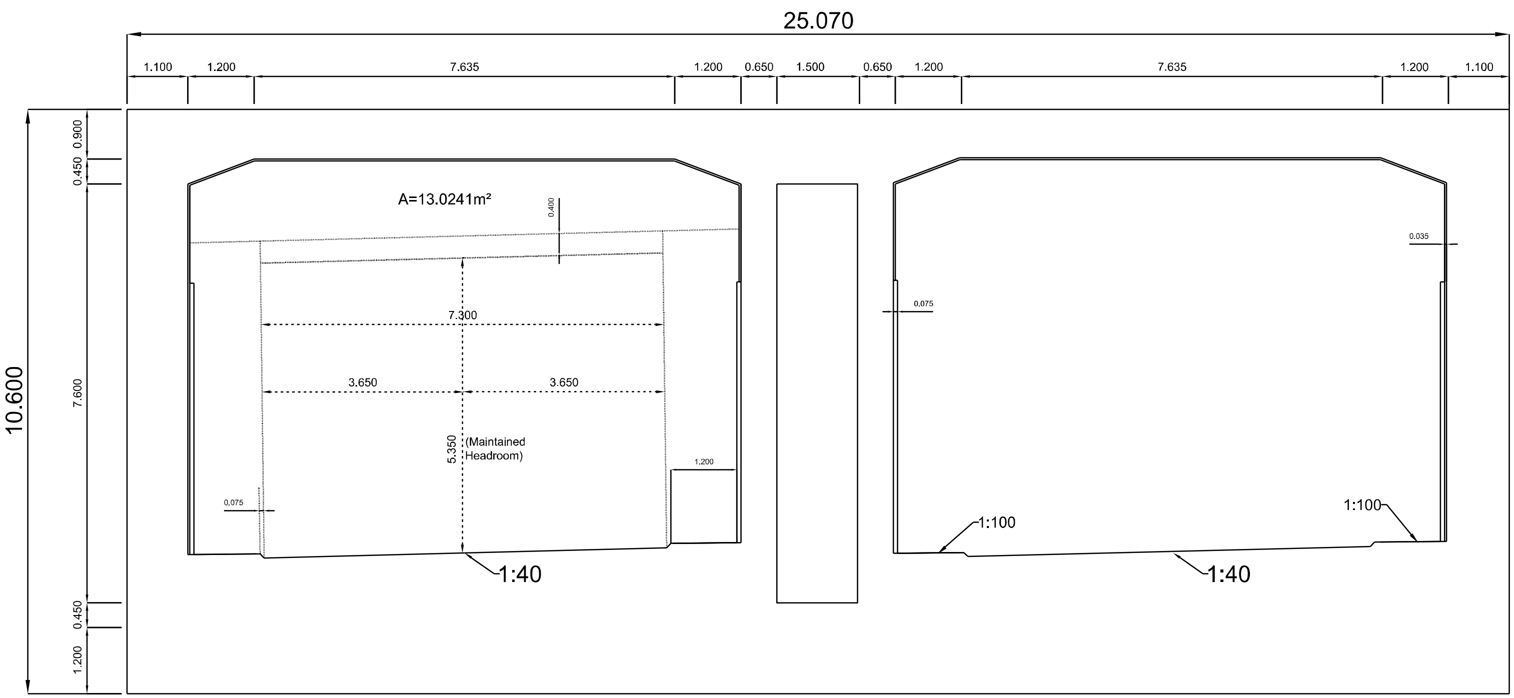
PHASE 1 STUDY

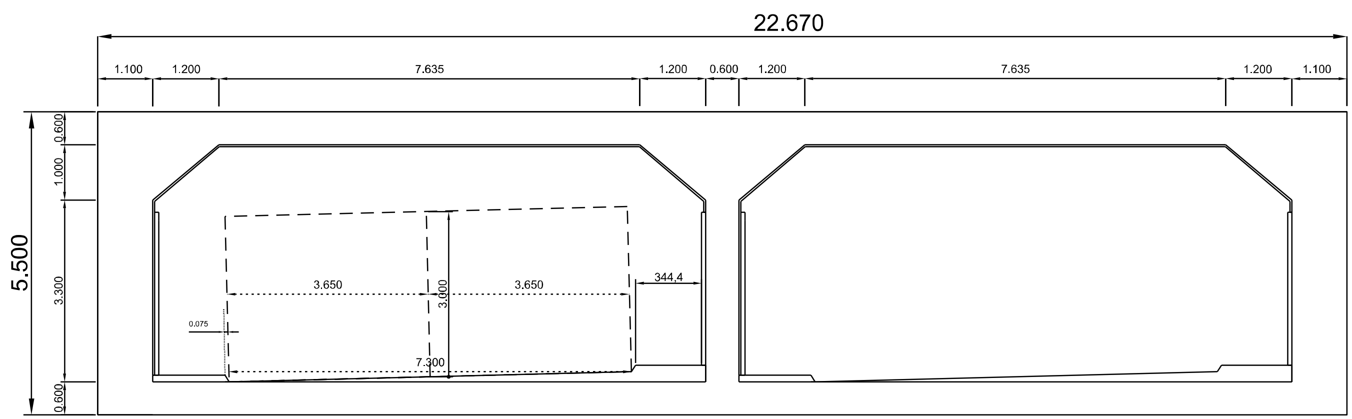
Drawing Title: Bored Tunnel Option 2a,2b Cross Section 12.8m and 15.0m OD Sheet 1 of

Designed		Signed		Date	
Drawn		Signed		Date	
Checked		Signed		Date	
Approved		Signed		Date	
Scale(s)		ELR & Mileage			
Alternative Reference				Sheet of	
Drawing Number				Revision	A0

Sheet Size A1 594 x 841

East - West Tunnel Cross Section





North South Tunnel Cross Section

0 1m 5m

SCALE 1:100 @ A3

N

NOTES:
1. LEVELS ARE TO ORDINANCE DATUM
2. ALL DIMENSIONS ARE IN METERS UNLESS NOTED OTHERWISE.

Key to Symbols;

- Proposed Main Bored Tunnels Route Section
- Cut & Cover and Open Cut Sections
- Existing Thames Lee Valley Water Tunnel
- Proposed Thames Tideway Tunnel
- Existing Thames Lee Valley Water Tunnel
- Proposed Thames Tideway Tunnel
- Existing Thames Water Ring Main
- London Underground Lines (LUL) Cuttings
- London Overground Lines (OGL)
- Proposed North /South Tunnels Route Section
- Proposed Slips in/out Tunnels Section

Rev	Date	Description of Revisions	Drawn	Chkd	Appr

Status
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HAMMERSMITH FLYUNDER
PHASE 1 STUDY

Drawing Title

Bored Tunnel Option 3b Plan
and Longitudinal section
Sheet 1 of

Designed		Signed		Date	
Drawn		Signed		Date	
Checked		Signed		Date	
Approved		Signed		Date	
Scale(s)		ELR & Mileage			
Alternative Reference				Sheet of	
Drawing Number				Revision A0	

Sheet Size A1 594 x 841

Appendix B – Geotechnical Profile

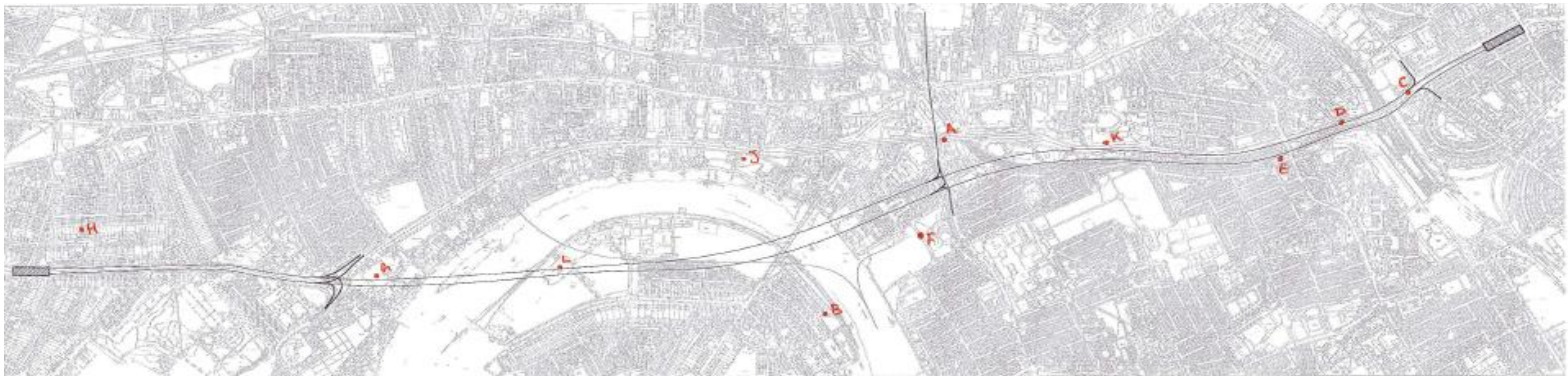
Hammersmith Flyunder Borehole Log

http://www.bgs.ac.uk/GeoIndex/wms.htm

Enquiries:-

http://www.bgs.ac.uk/geoindex/gdi/enquiries/geneng.cfm

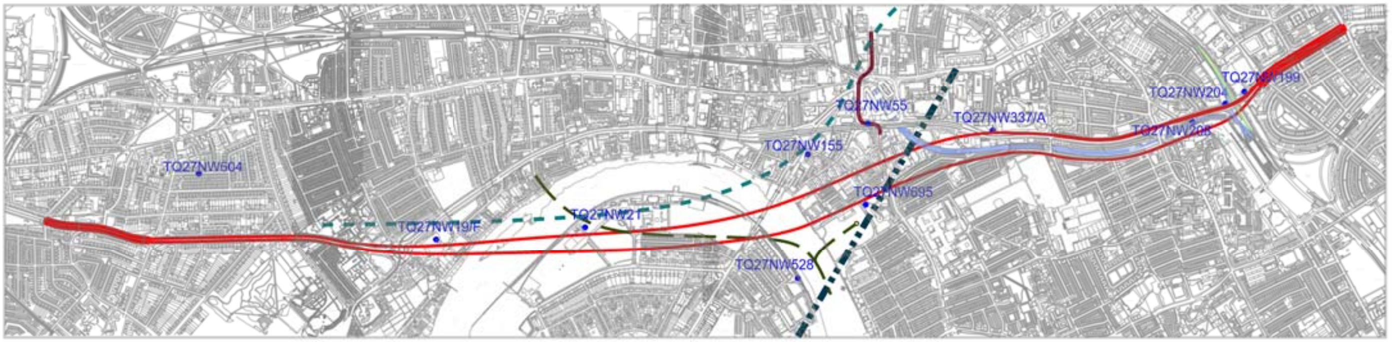
BH Ref	Map Ref	Depth (m)	Year	No. of Docs	Name	Approx. Depth to London Clay (below ground level)
TQ27NW155	A	23.16	1959	1	CROMWELL ROAD EXIT BH111 HAMMERSMITH	6 -10 m
TQ27NW528	B	30.30	1987	4	RIVERSIDE BARNES 6	5.5 m
TQ27NW199	C	30.48	1968	3	WEST CROSS ROUTE (G.L.C) BH25	6.8 m
TQ27NW204	D	30.48	1968	3	WEST CROSS ROUTE (G.L.C) BH31	9.1 m
TQ27NW208	E	36.58	1968	3	WEST CROSS ROUTE (G.L.C) BH36	8.5 m
TQ27NW55	F	42.67	1948	4	METRO WATER BOARD W6 HAMMERSMITH	18 m
TQ27NW19/F	G	396.24 ft	1912	6	GRIFFIN BREWERY CHISWICK	9.2 - 12.2 m
TQ27NW604	H	100.27 ft	Numerous	5	ROYAL AVENUE CHISWICK	5.6 m
TQ27NW695	J	10.52	1970	2	HAMMERSMITH FLYOVER 2	9.6 m
TQ27NW337/A	K	10.00	1961	1	GREAT CHURCH LANE BH1	8.2 m
TQ27NW21	L	9.83	Unknown	1	ENGINE HOUSE CHISWICK	4.5 m



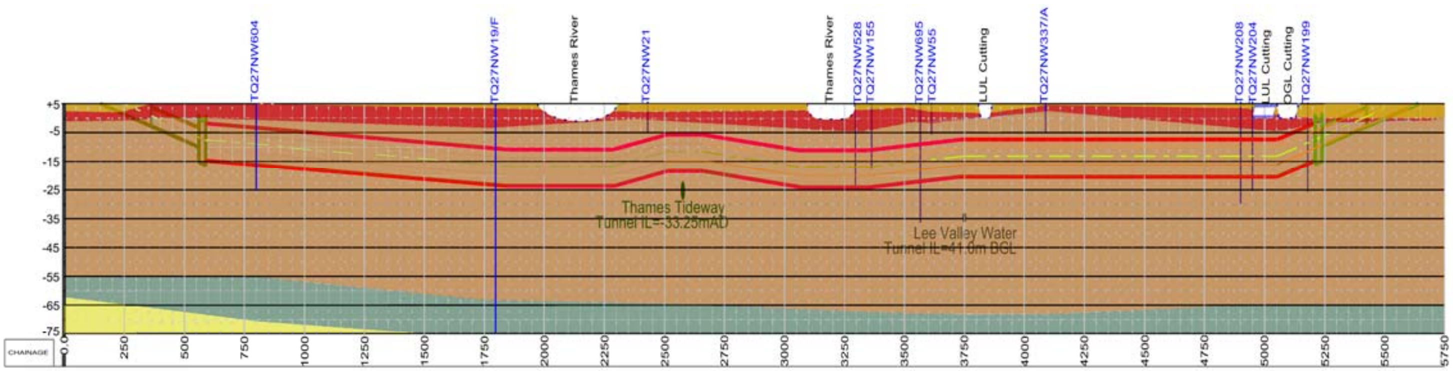
N

Notes;
1. Levels are to Ordinance Datum
2. ALL Dimensions are in meters unless noted Otherwise
3. All Borholes Location are Approximate
4. Borholes Titled with TQ are BGS Historical Borholes

Key to Symbols;
- Made Ground
- Drift Deposits
- London Clay
- Lambeth Group
- Thanet Sand
- Mean Water Level +7.0mAOD
- Proposed Main Bored Tunnels Route Section
- Proposed North /South Tunnels Route Section
- Cut & Cover and Open Cut Section
- Existing Thames Lee Valley Water Tunnel
- Proposed Thames Tideway Tunnel
- Available (GIS) Borholes
- Existing Thames Lee Valley Water Tunnel
- Proposed Thames Tideway Tunnel
- Existing Thames Water Ring Main
- London Underground Lines (LUL) Cuttings
- London Overground Lines (OGL)



Plan View Scale 1:2500



Longitudinal Profile Scale 1:1500

0 100m 200m 500m

HORIZONTAL SCALE 1:2500 @ A1

0 20m 40m

VERTICAL SCALE 1:1500 @ A1

Rev	Date	Description of Revisions	Drawn	Chkd	Appr

Status
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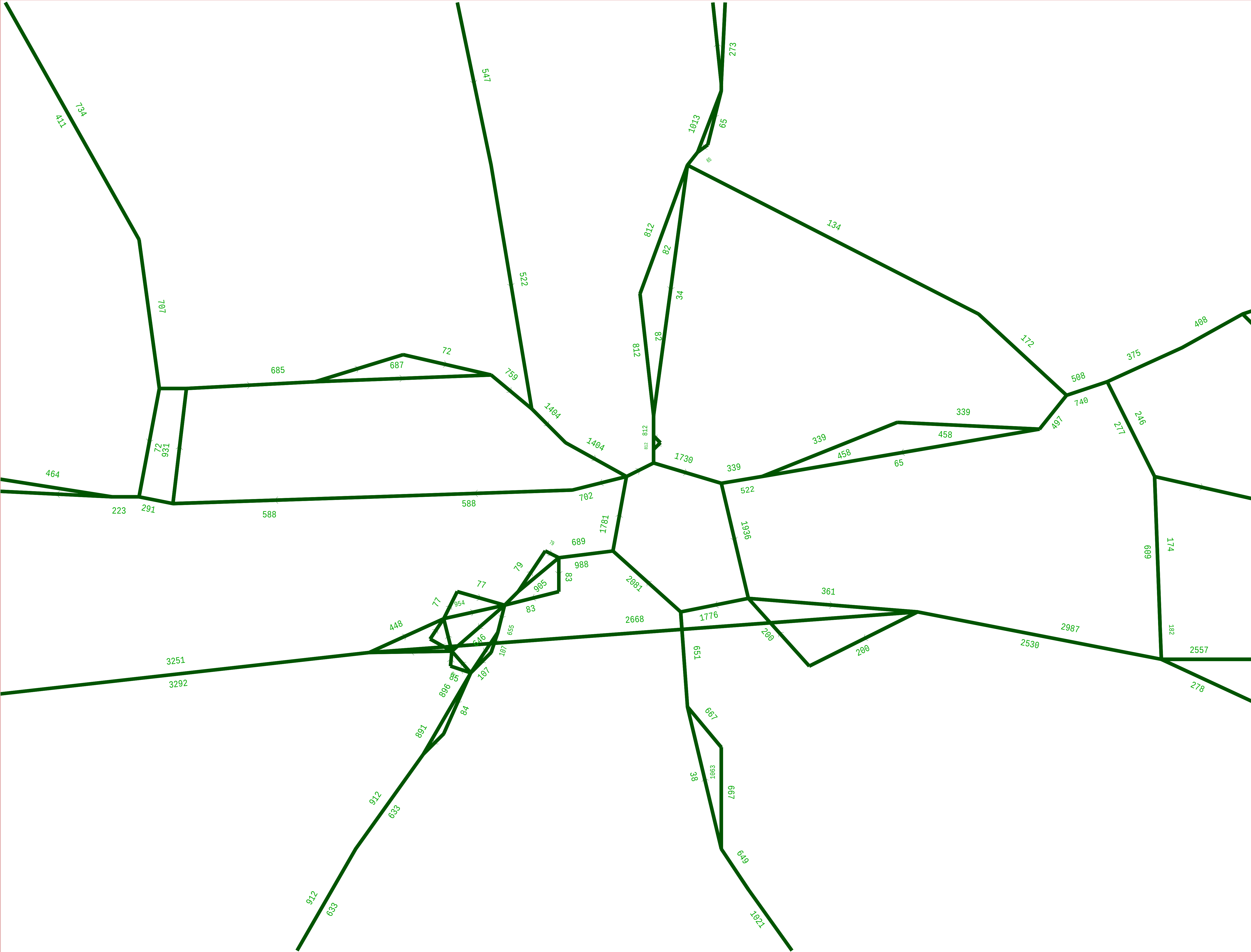
HAMMERSMITH FLYUNDER
PHASE 1 STUDY

Drawing Title
Geotechnical Long Section

Designed	Hamidat Zerouati	Signed	Date
Drawn	Hamidat Zerouati	Signed	Date
Checked		Signed	Date
Approved		Signed	Date
Scale(s)		ELR & Mileage	
Alternative Reference		Sheet of	
Drawing Number		Revision	A0

Sheet Size A1 594 x 841

Appendix C – Saturn Traffic Flow Model Data



SATURN

Atkins Ltd /
DVV / ITS

W1_B09_02B_A
.UFS

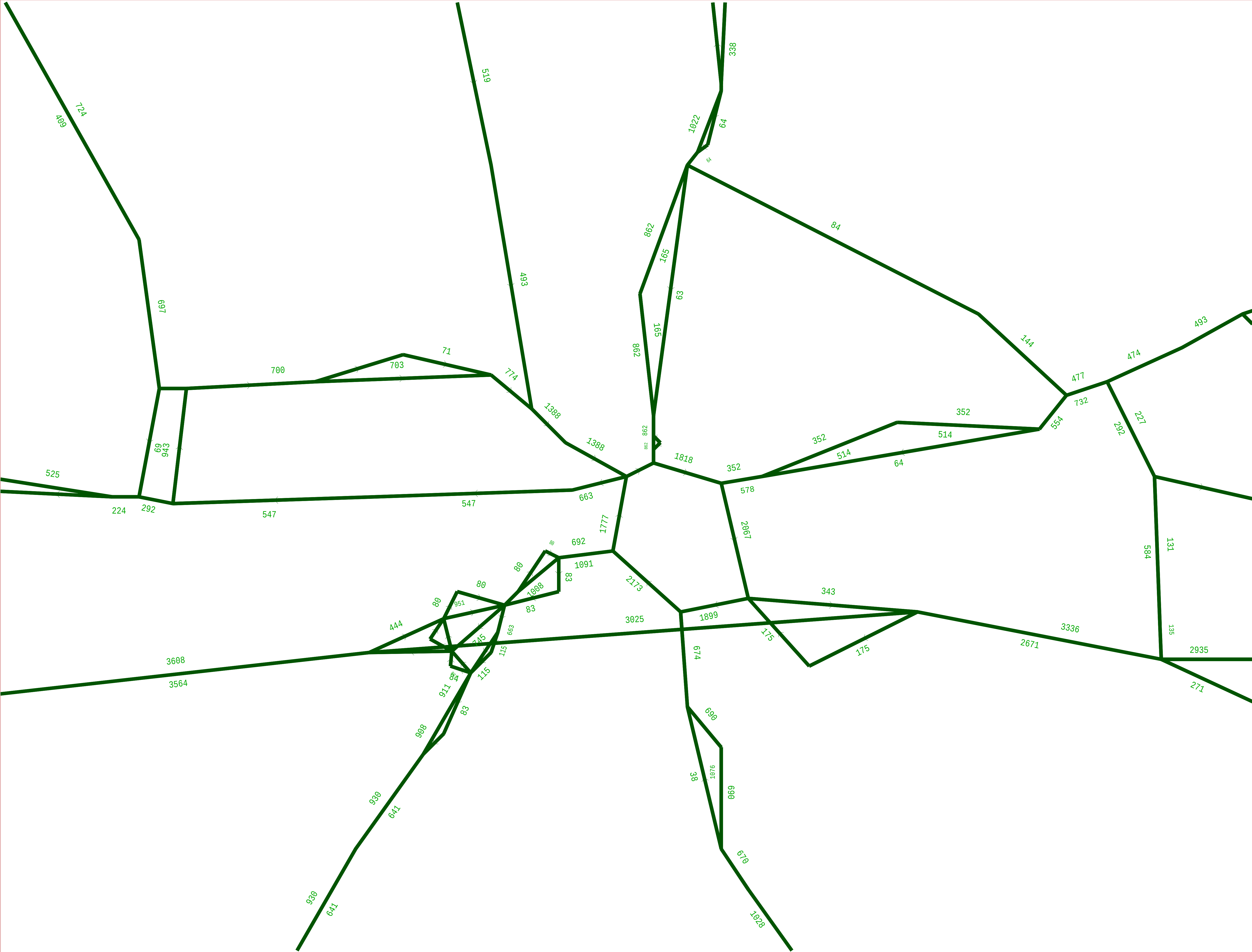
Scale 4905

Link Annot:

Actual flow

16-10-13
TRANSPORT FO

WeLoHAM Model HYDER V30 AECOM V49 TFL V16 AM PASSQ 16-10-13



SATURN

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2031\AM\W1_R31_02D_A.UFS

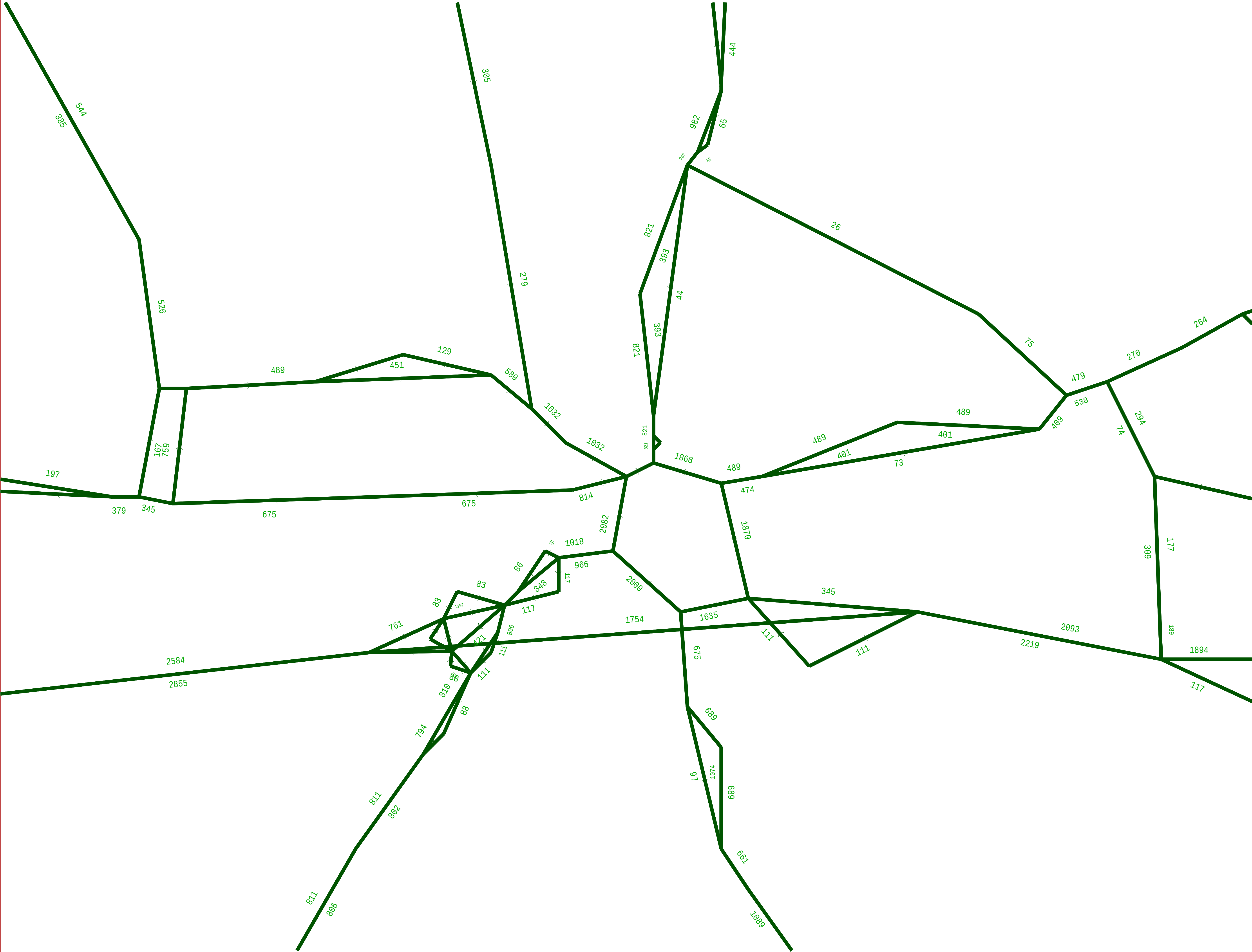
Scale 4905

Link Annot:

Actual flow

16-10-13
TRANSPORT FO

AM Reference Case 2031 16-10-13



SATURN

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DVV / ITS

2009\IP\W1_B
09_02B_I.UFS

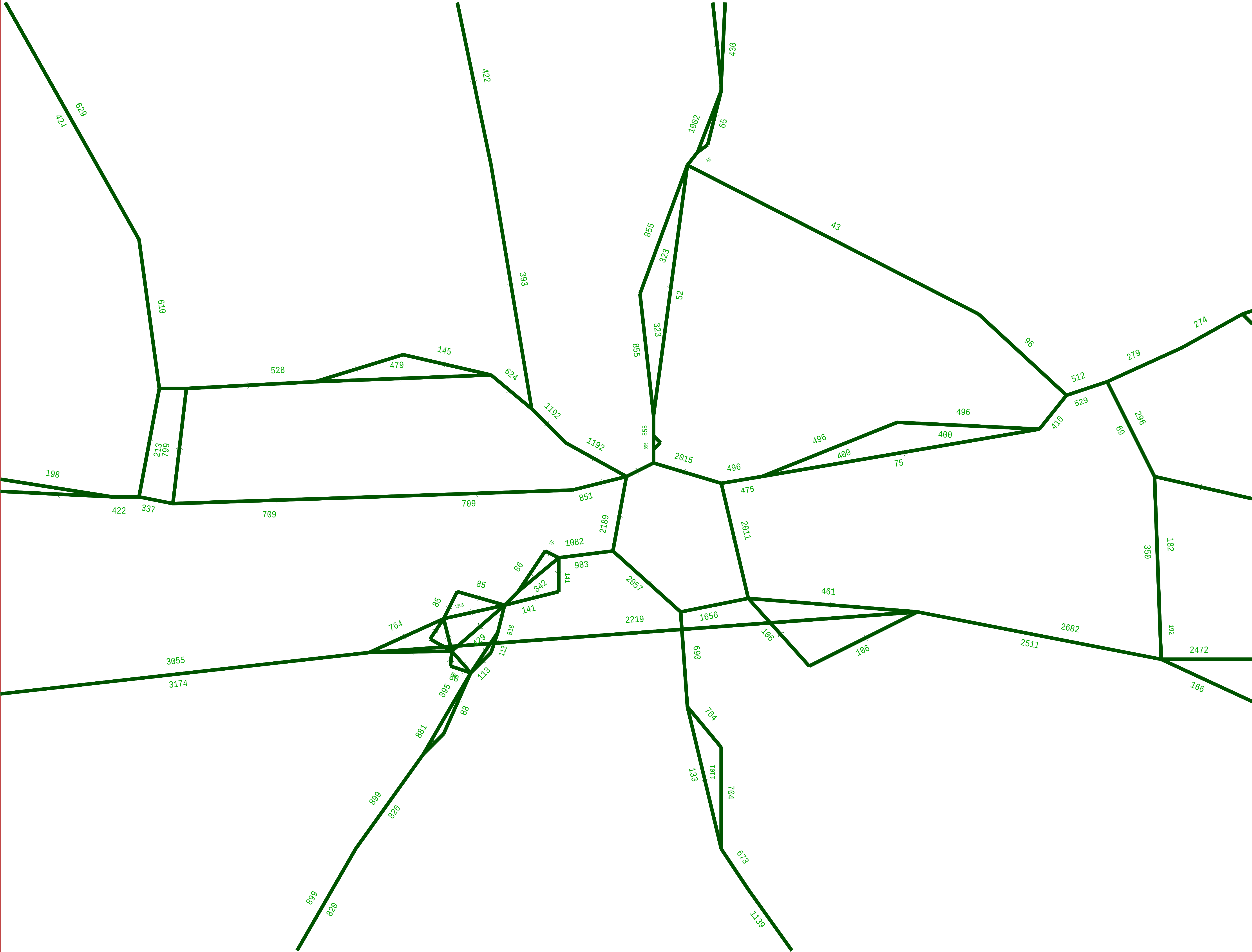
Scale 4905

Link Annot:

Actual flow

16-10-13
TRANSPORT FO

WeLoHAM Model HYDER V30 AECOM V49 TFL V16 IP FULL 16-10-13



SATURN

Atkins Ltd /
DVV / ITS

2031\IP\W1_R
31_02D_I.UFS

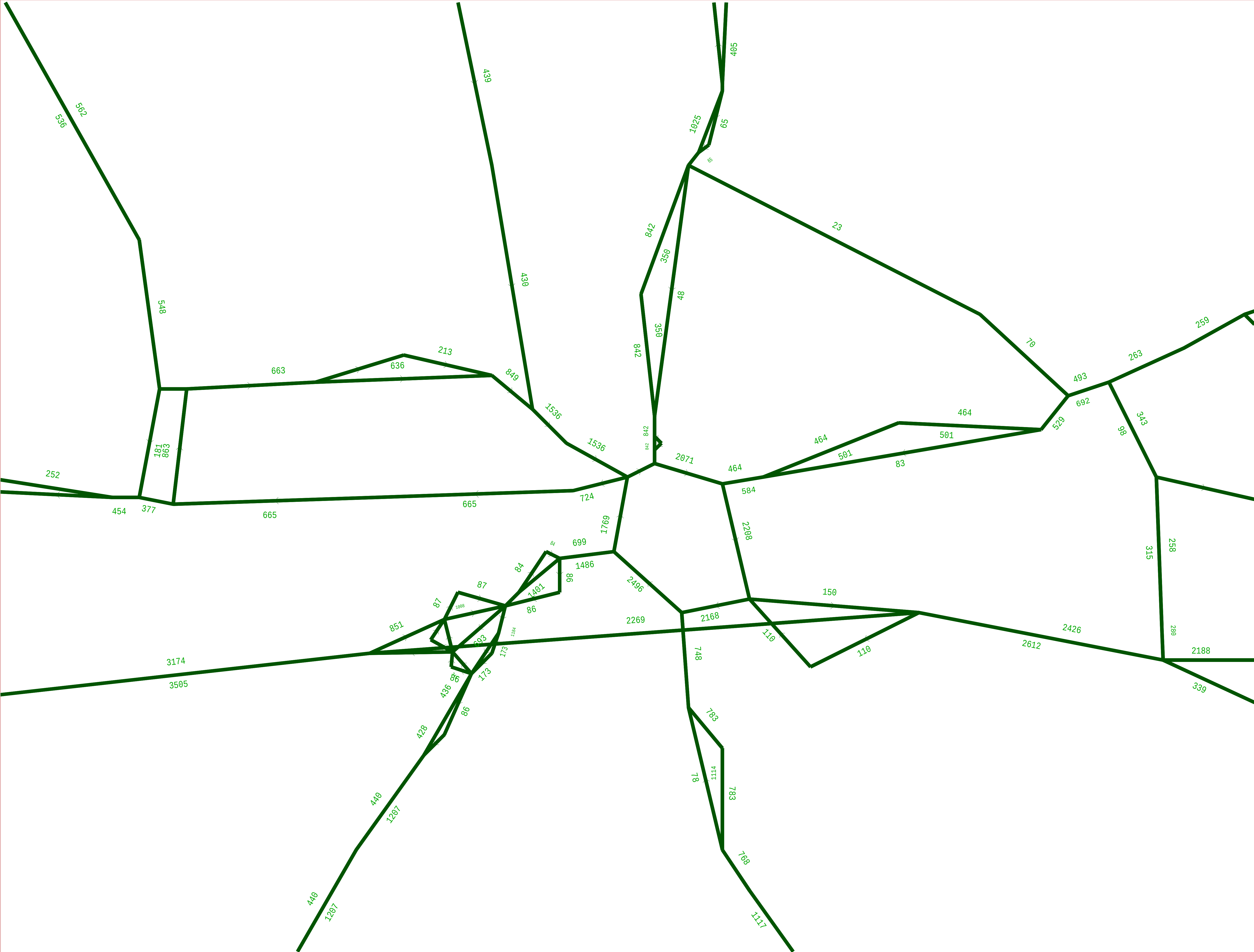
Scale 4905

Link Annot:

Actual flow

16-10-13
TRANSPORT FO

IP Reference Case 2031 16-10-13



SATURN

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DVV / ITS

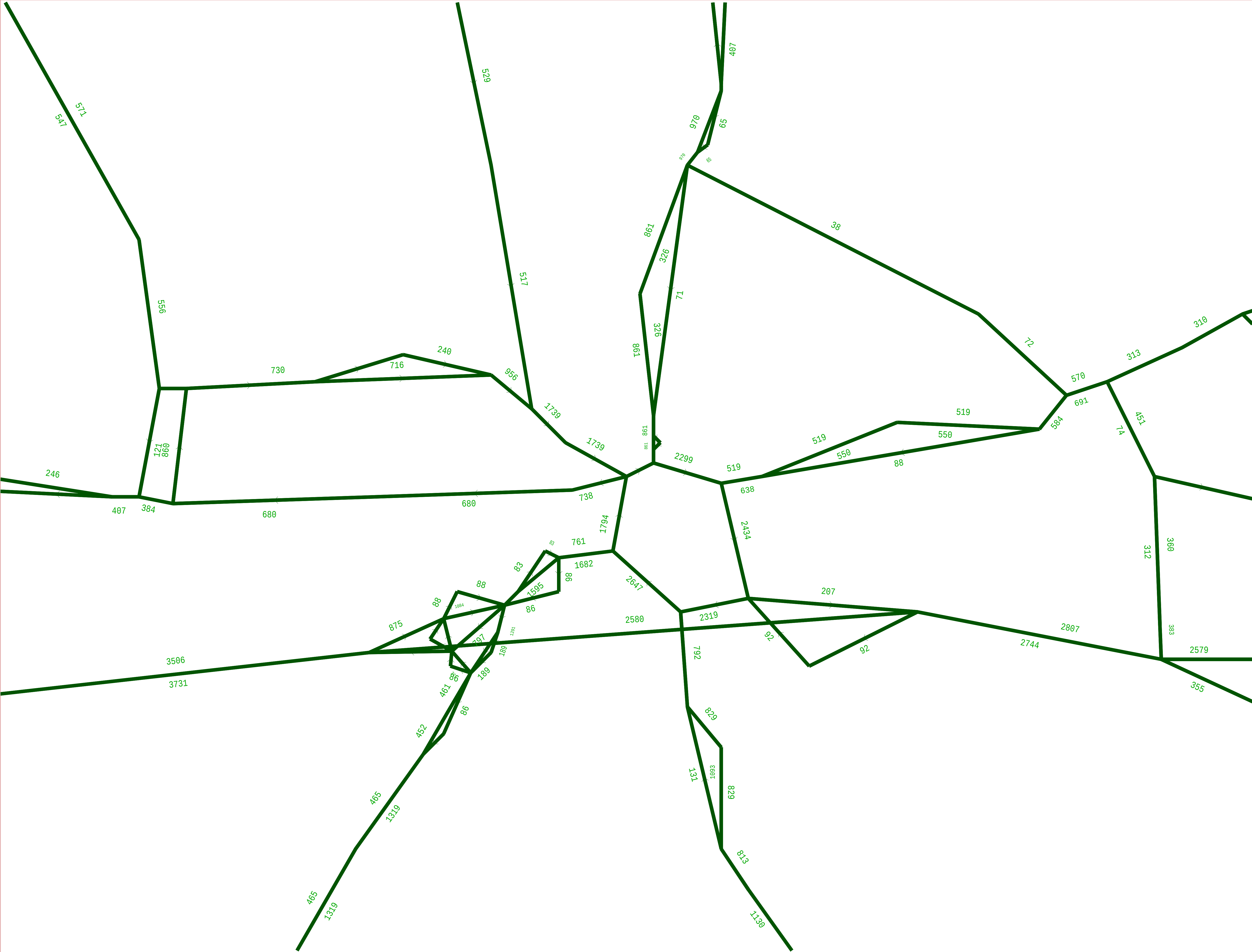
9\PM_V3\W1_B
09_03B_P.UFS

Scale 4905

Link Annot:

Actual flow

16-10-13
TRANSPORT FO



SATURN

Atkins Ltd /
DVV / ITS

2031\PM\W1_R
31_02D_P.UFS

Scale 4905

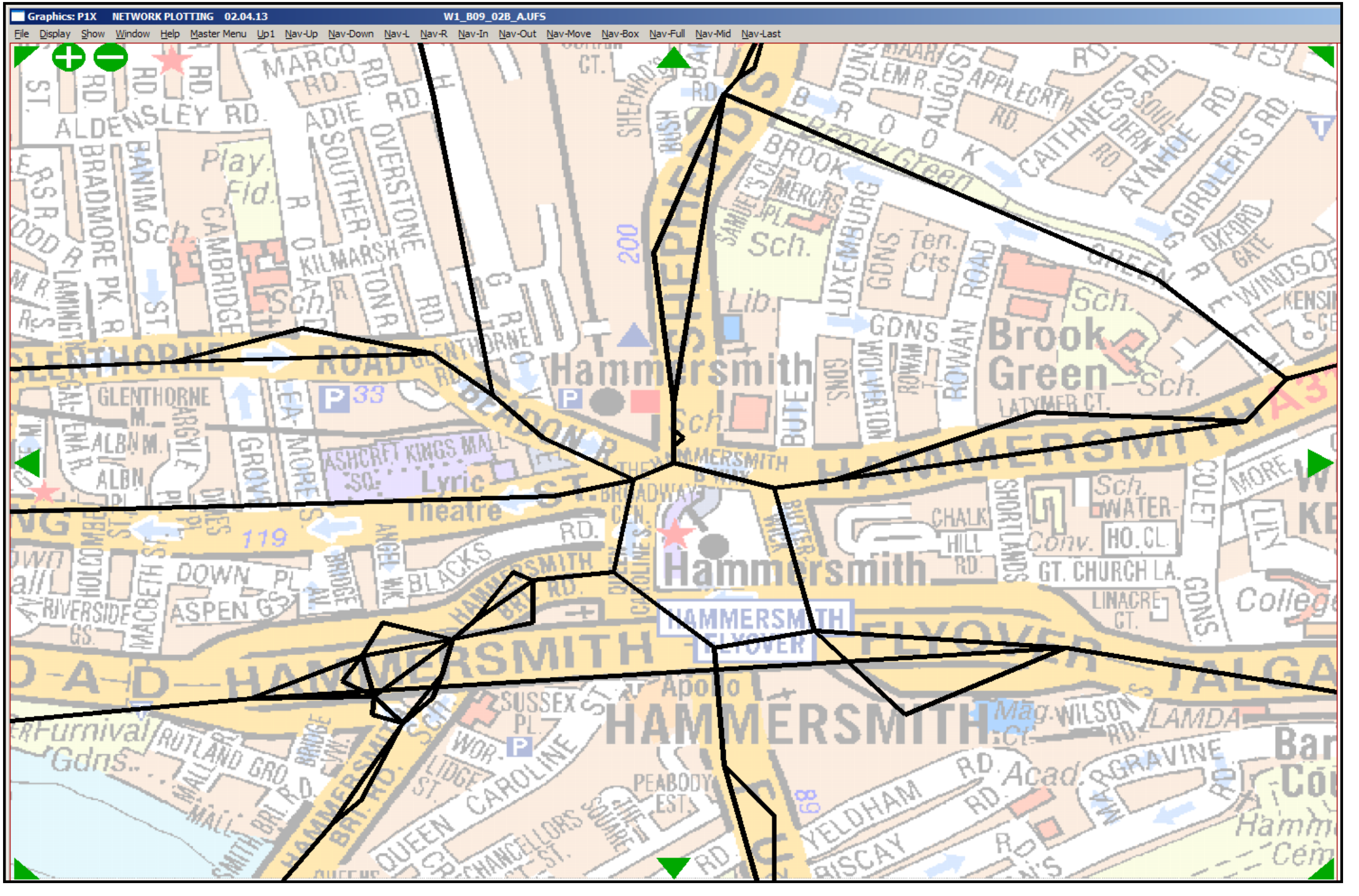
Link Annot:

Actual flow

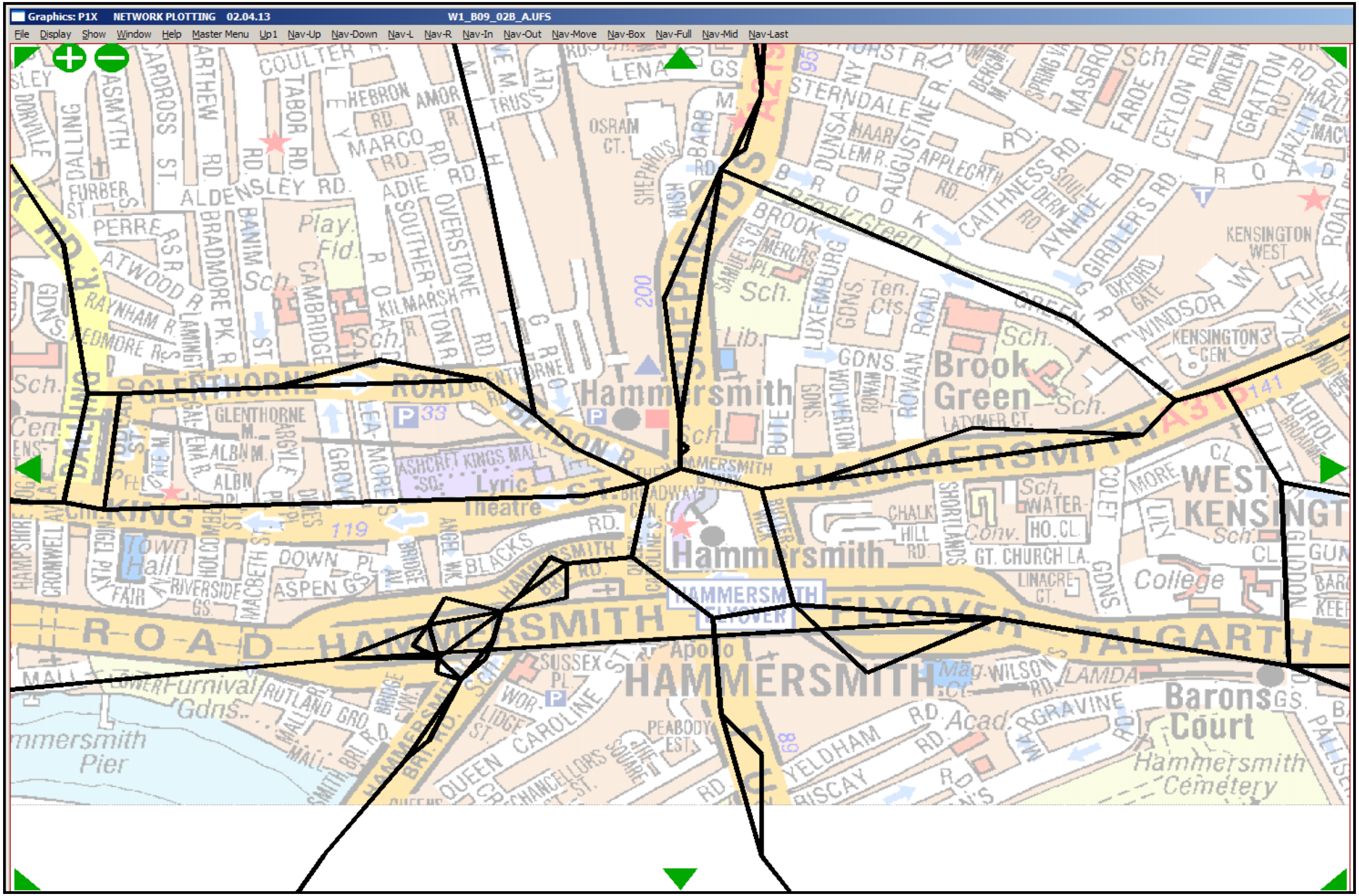
16-10-13
TRANSPORT FO

PM Reference Case 2031 16-10-13

WeLHAM network for the Hammersmith area



WeLHAM network for the Hammersmith area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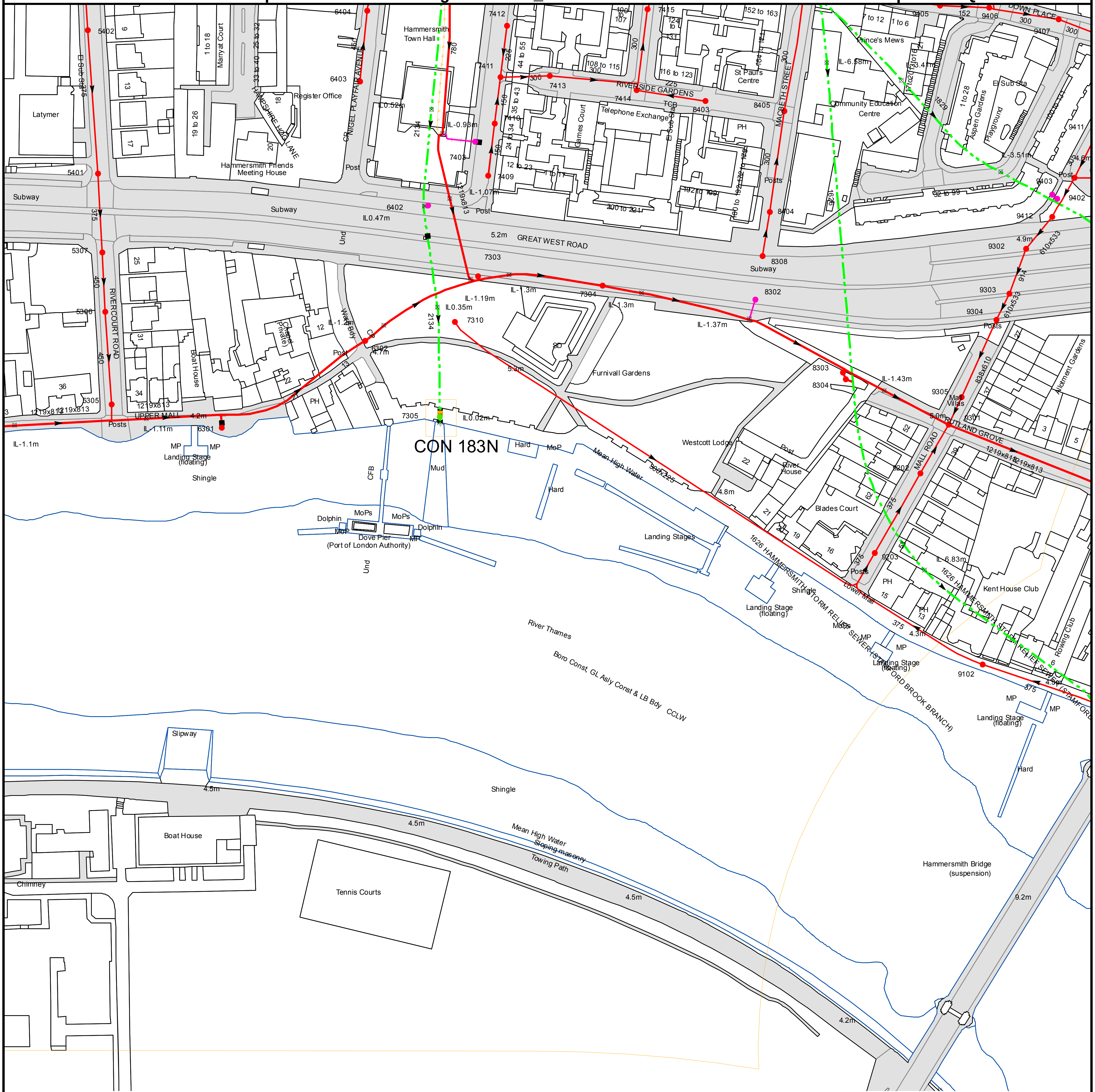
Hammersmith
Brook Green
WEST KENSINGTON
HAMMERSMITH FLYOVER
TALGARTH
HAMMERSMITH
Barons Court
Hammersmith Cemetery
GLENTHORNE ROAD
Lyric Theatre
Town Hall
Apollo
College
Hammersmith Pier
Furnival Gdns.

Appendix D – Utilities Information

UTILITY SUMMARY
HAMMERSMITH FLYUNDER

No.	Utility	CH2M Ref	Asset Owner	Area	Location	Orientation to Alignment	Depth	Size	Reference
1	Gas	-	National Grid	Hammersmith	Numerous - follow Hammersmith Street layouts	Normal & Parallel	TBC	TBC	National Grid Drawing
2	Electricity	E - 001	-	Hammersmith	Fulham Palace Road - Willesden Junction (Wedge Block Lining Tunnel)	Normal	35m ??	2.44 m	CH2MHill - Halcrow
3	Combined Sewers	CS - 001	Thames Water	Hammersmith	Queen Caroline Street	Normal	TBC	300 mm	Thames Water Sewerage Drawings
4	Combined Sewers	CS - 002	Thames Water	Hammersmith	Talgarth Road	Normal & Parallel	TBC	300 mm	Thames Water Sewerage Drawings
5	Combined Sewers	CS - 003	Thames Water	Hammersmith	Fulham Palace Road	Normal	TBC	300 mm	Thames Water Sewerage Drawings
6	Combined Sewers	CS - 004	Thames Water	Hammersmith	Butterwick Road	Normal	TBC	300 mm	Thames Water Sewerage Drawings
7	Combined Sewers	CS - 005	Thames Water	Hammersmith	Hammersmith Bridge Road	Normal	TBC	300 mm	Thames Water Sewerage Drawings
8	Combined Sewers	CS - 006	Thames Water	Hammersmith	Shortland Road	Normal	TBC	300 mm	Thames Water Sewerage Drawings
9	Pressure Main	PM - 001	Thames Water	Hammersmith	Novtel Hotel	Normal	TBC	TBC	Thames Water Sewerage Drawings
10	Pressure Main	PM - 002	Thames Water	Hammersmith	Hammersmith Flyover	Normal	TBC	TBC	Thames Water Sewerage Drawings
11	Pressure Main	PM - 003	Thames Water	Hammersmith	Wilson Road	Normal	TBC	TBC	Thames Water Sewerage Drawings
12	Pressure Main	PM - 004	Thames Water	Hammersmith	Hammersmith Bridge Road	Normal	TBC	TBC	Thames Water Sewerage Drawings
13	Water Main	WM - 001	Thames Water	Hammersmith	Butterwick Road	Normal	TBC	8 Inch	Thames Water Sewerage Drawings
14	Water Main	WM - 002	Thames Water	Hammersmith	Hammersmith Flyover	Normal	TBC	250 mm	Thames Water Sewerage Drawings
15	Water Main	WM - 003	Thames Water	Hammersmith	Queen Caroline Street	Normal	TBC	9 Inch	Thames Water Sewerage Drawings
16	Water Main	WM - 004	Thames Water	Hammersmith	Talgarth Road	Parallel	TBC	6 Inch	Thames Water Sewerage Drawings
17	Water Main	WM - 005	Thames Water	Hammersmith	Hammersmith Flyover	Parallel	TBC	250 mm	Thames Water Sewerage Drawings
18	Water Main	WM - 006	Thames Water	Hammersmith	Hammersmith Bridge Road	Parallel	TBC	125 mm	Thames Water Sewerage Drawings
19	Water Main	WM - 007	Thames Water	Hammersmith	Hammersmith Bridge Road	Parallel	TBC	90 mm	Thames Water Sewerage Drawings
20	Abandonded Asset	AA - 001	Thames Water	Hammersmith	Hammersmith Station	Normal	TBC	TBC	Thames Water Sewerage Drawings
21	Electricity	E - 002	EDF Engery	Earls Court	Ashfield House	TBC	TBC	TBC	Arup Geotechnical Desk Study
22	Electricity	E - 003	EDF Engery	Earls Court	Empress State Building	TBC	TBC	TBC	Arup Geotechnical Desk Study
23	Electricity	E - 004	EDF Engery	Earls Court	Empress State Building	TBC	TBC	TBC	Arup Geotechnical Desk Study
24	Electricity	E - 005	EDF Engery	Earls Court	Empress State Building	TBC	TBC	TBC	Arup Geotechnical Desk Study
25	Electricity	E - 006	EDF Engery	Earls Court	West London Line	TBC	TBC	TBC	Arup Geotechnical Desk Study
26	Electricity	E - 007	EDF Engery	Earls Court	ECEB	TBC	TBC	TBC	Arup Geotechnical Desk Study
27	Gas	G - 001	National Grid	Earls Court	Earls Court Exhibition Centre (MP Supply)	TBC	TBC	36 Inch	Arup Geotechnical Desk Study
28	Gas	G - 002	National Grid	Earls Court	Beaumont Avenue	TBC	TBC	150 mm	Arup Geotechnical Desk Study
29	Gas	G - 003	National Grid	Earls Court	Empress State Building - North	TBC	TBC	180 mm	Arup Geotechnical Desk Study
30	Gas	G - 004	National Grid	Earls Court	Empress Palace	TBC	TBC	TBC	Arup Geotechnical Desk Study
31	Gas	G - 005	National Grid	Earls Court	Lillie Bridge	TBC	TBC	TBC	Arup Geotechnical Desk Study
32	Gas	G - 006	National Grid	Earls Court	Lillie Bridge - MP	TBC	TBC	TBC	Arup Geotechnical Desk Study
33	Water Main	WM - 008	Thames Water	Earls Court	ECEB - Metered	TBC	TBC	6 Inch	Arup Geotechnical Desk Study
34	Water Main	WM - 009	Thames Water	Earls Court	ECEB - Fire	TBC	TBC	10 Inch	Arup Geotechnical Desk Study
35	Water Main	WM - 010	Thames Water	Earls Court	ECEB	TBC	TBC	250 mm	Arup Geotechnical Desk Study
36	Water Main	WM - 011	Thames Water	Earls Court	ECEB	TBC	TBC	180 mm	Arup Geotechnical Desk Study
37	Water Main	WM - 012	Thames Water	Earls Court	Beaumont Avenue - Fire	TBC	TBC	125 mm	Arup Geotechnical Desk Study
38	Water Main	WM - 013	Thames Water	Earls Court	Beaumont Avenue - Fire	TBC	TBC	125 mm	Arup Geotechnical Desk Study
39	Water Main	WM - 014	Thames Water	Earls Court	Beaumont Avenue - Fire	TBC	TBC	125 mm	Arup Geotechnical Desk Study
40	Water Main	WM - 015	Thames Water	Earls Court	Beaumont Avenue	TBC	TBC	90 mm	Arup Geotechnical Desk Study
41	Sewer	SW - 001	Thames Water	Earls Court	Warwick Road	TBC	TBC	TBC	Arup Geotechnical Desk Study
42	Telecom	TC - 001	BT	Earls Court	4 routes in area	TBC	TBC	TBC	Arup Geotechnical Desk Study
43	Telecom	TC - 002	Thus	Earls Court	West London Line	TBC	TBC	TBC	Arup Geotechnical Desk Study
44	Telecom	TC - 003	Verizon	Earls Court	ECEB	TBC	TBC	TBC	Arup Geotechnical Desk Study
45	Telecom	TC - 004	OFCOM	Earls Court	6 base stations in area	TBC	TBC	TBC	Arup Geotechnical Desk Study
46	Water Tunnel	WT - 001	Thames Water	Hammersmith	Thames Water Ring Main	TBC	TBC	TBC	ARUP _WEST LONDON LINK DESIGN
47	Water Tunnel	WT - 002	Thames Water	Hammersmith	Thames Water Lee Valley Water Tunnel	TBC	TBC	TBC	ARUP _WEST LONDON LINK DESIGN
48	Water Tunnel	WT - 003	Thames Water	Hammersmith	Old Barnes to Hammermsith Water Tunnels	TBC	TBC	TBC	ARUP _WEST LONDON LINK DESIGN
49	Water Tunnel	WT - 004	Thames Water	Hammersmith	Old Barnes to Hammermsith Water Tunnels	TBC	TBC	TBC	ARUP _WEST LONDON LINK DESIGN
50	Gas	G - 007	National Grid	Hammersmith	National Grid Cable Tunnels	TBC	TBC	TBC	ARUP _WEST LONDON LINK DESIGN

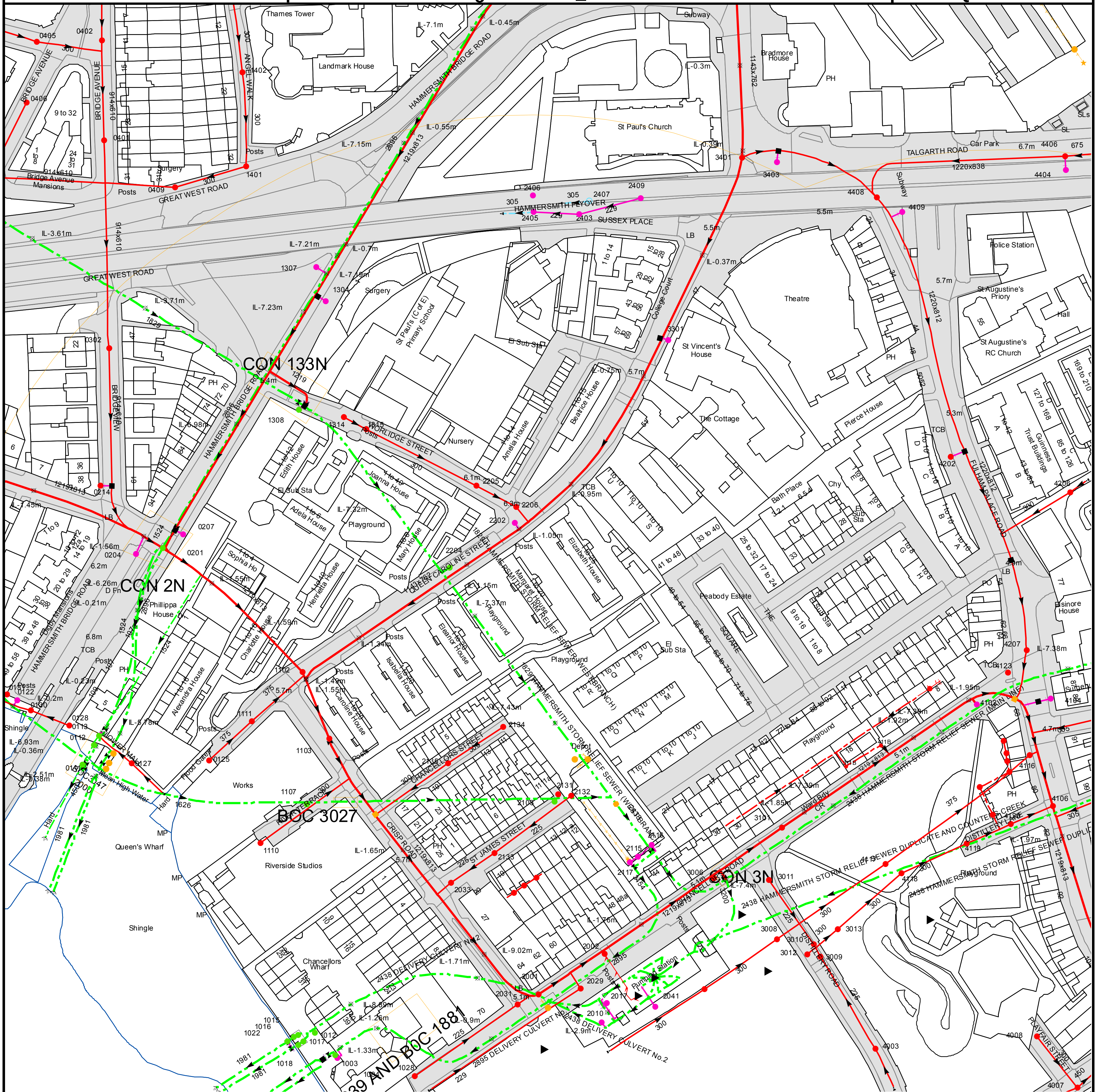
Asset Location Search Sewer Map - ALS/ALS Non Chargeable/2012_2369743 | TQ2278SE



The width of the displayed area is 500m and the centre of the map is located at OS coordinates 522750,178250

The position of the apparatus shown on this plan is given without obligation and warranty, and the accuracy cannot be guaranteed. Service pipes are not shown but their presence should be anticipated. No liability of any kind whatsoever is accepted by Thames Water for any error or omission. The actual position of mains and services must be verified and established on site before any works are undertaken.

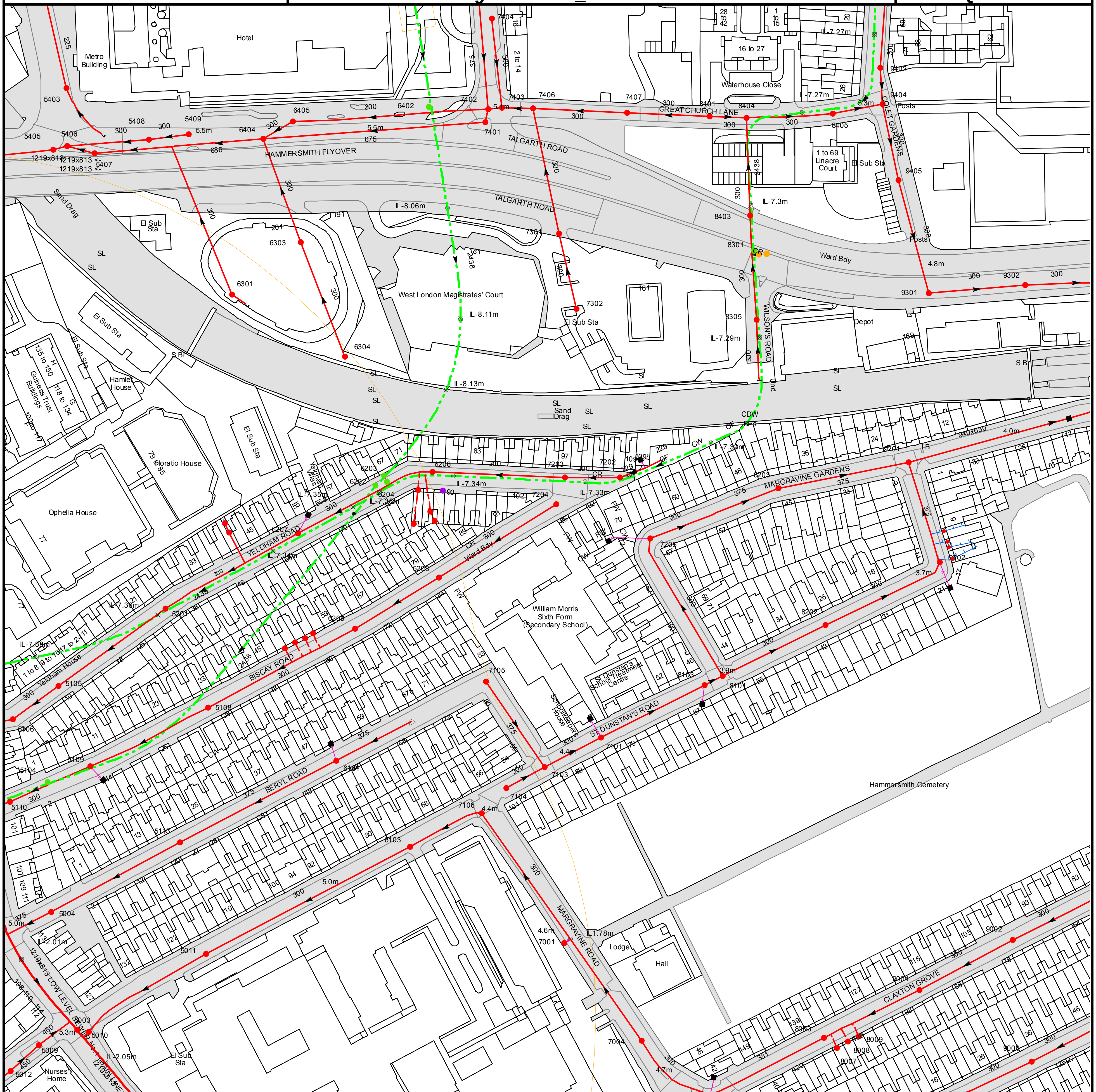
Asset Location Search Sewer Map - ALS/ALS Non Chargeable/2012_2369743	TQ2378SW



The width of the displayed area is 500m and the centre of the map is located at OS coordinates 523250,178250

The position of the apparatus shown on this plan is given without obligation and warranty, and the accuracy cannot be guaranteed. Service pipes are not shown but their presence should be anticipated. No liability of any kind whatsoever is accepted by Thames Water for any error or omission. The actual position of mains and services must be verified and established on site before any works are undertaken.

Asset Location Search Sewer Map - ALS/ALS Non Chargeable/2012_2369743	TQ2378SE

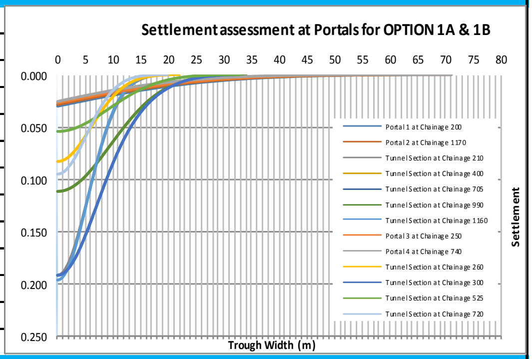
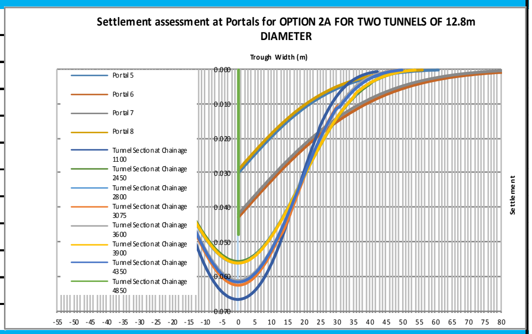
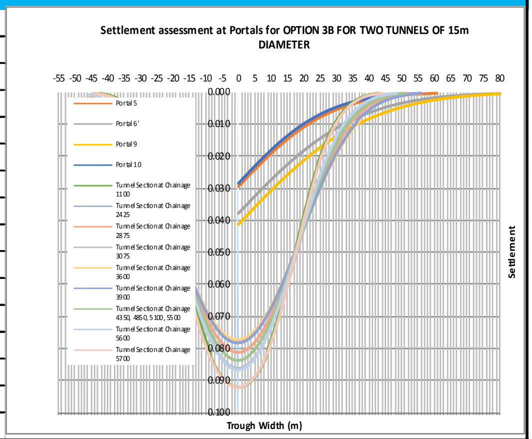


The width of the displayed area is 500m and the centre of the map is located at OS coordinates 523750,178250

The position of the apparatus shown on this plan is given without obligation and warranty, and the accuracy cannot be guaranteed. Service pipes are not shown but their presence should be anticipated. No liability of any kind whatsoever is accepted by Thames Water for any error or omission. The actual position of mains and services must be verified and established on site before any works are undertaken.

Appendix E – Ground Movement Assessment

Ground Movements Assessment

Chainage	Location	Boundaries of Ground Movement (m)	Maximum surface settlement at tunnel centreline or edge of portal excavation (m)	Distance from tunnel centreline or portal excavation for 10mm settlement contour (m)	Distance from tunnel centreline or portal excavation for 1mm settlement contour (m)	Settlement Graph
OPTION 1A & 1B						
200	Tunnel Portal at Great West Road	68.75	0.030	21.00	46.00	
210	Close to 180-192 Macbeth Street	33.3	0.191	13.50	17.50	
400	Close to 47 Bridgeview	57	0.112	21.00	28.00	
705	At Junction to Queen Caroline Street	57.9	0.110	21.00	28.50	
990	Close to West London Magistrates' Court	57	0.112	21.00	28.00	
1160	At Junction to Wilson's Road	32.4	0.196	13.25	17.00	
1170	Tunnel Portal at Talgarth Road	66.67	0.029	20.00	44.00	
250	Tunnel Portal at Fulham Palace Road	63.75	0.028	19.00	42.00	
260	Close to 34 Fulham Palace Road	36.3	0.082	12.50	28.50	
300	At Junction to Queen Caroline Street	36.3	0.192	21.00	28.50	
525	At Junction to Hammersmith Underground Railway	55.2	0.054	17.00	25.00	
720	Close to 226 Shepherd's Bush Road (Police Station)	31.5	0.095	11.25	15.50	
740	Tunnel Portal at Shepherd's Bush Road	57.08	0.025	15.00	36.00	
OPTION 2A						
850	Open Ramp Tunnel Portal at No.51 Cedars Road	69.79	0.030	22.00	46.00	
1050	Cut & Cover Tunnel Portal at No.5 Cedars Road	98.96	0.043	38.00	71.00	
1100	At Junction between Ellesmere Road and Sutton Court Road	66.75	0.046	28.50	38.50	
2450	Close to No.1 Chiswick Mall	93	0.033	34.00	48.00	
2800	Near Tennis Court Close to 49-69 Lonsdale Road	92.25	0.033	33.50	47.50	
3075	At Interface with Thames Tideway Tunnel (near St Paul's school)	77.25	0.040	31.00	43.00	
3600	At interface with Hammersmith Bridge	80.25	0.038	31.00	44.00	
3900	Close to No.1 Crisp Road	92.25	0.033	34.00	48.00	
4350	Close to No. 55a Yeldham Road	79.5	0.039	32.00	44.00	
4850	At Junction between Glidon Road and Talgarth Road	64.5	0.048	28.50	38.00	
4900	Cut & Cover Tunnel Portal close to 65-72 Talgarth Mansions	96.88	0.042	38.00	69.00	
5100	Open Ramp Tunnel Portal Close to No.61 Talgarth Road	67.71	0.029	21.00	45.00	
OPTION 3A						
850	Open Ramp Tunnel Portal at No.51 Cedars Road	68.78	0.030	21.00	46.00	
1050	Cut & Cover Tunnel Portal at No.1 Cedars Road	87.5	0.038	32.00	61.00	
1100	At Junction between Ellesmere Road and Sutton Court Road	64.76	0.065	39.50	38.50	
2425	Close to No.1 Chiswick Mall	90.95	0.047	36.00	49.00	
2875	Near Tennis Court Close to 49-69 Lonsdale Road	84.76	0.050	34.00	46.50	
3075	At Interface with Thames Tideway Tunnel (near St Paul's school)	76.19	0.056	33.50	45.00	
3600	At interface with Hammersmith Bridge	92.38	0.046	36.00	49.00	
3900	Close to No.1 Crisp Road	90.48	0.047	36.00	49.00	
4350	Close to No. 55a Yeldham Road	80.48	0.053	33.50	45.00	
4850	At Junction between Glidon Road and Talgarth Road	80.48	0.053	33.50	45.00	
5100	Close to No.55-57 Talgarth Road	80.48	0.053	33.50	45.00	
5500	Close to West Cromwell Road near Ashfield House	80.48	0.053	33.50	45.00	
5600	At the Junction of West Cromwell Road and the West London Overground Extension	75.71	0.057	32.50	43.00	
5700	Close to West Cromwell Road near No. 66 Philbeach Gardens	64.76	0.070	30.00	39.00	
5750	Cut & Cover Tunnel Portal at Junction of West Cromwell Road and Warwick Road	95.24	0.041	37.00	68.00	
5950	Open Ramp Tunnel Portal at No. 24-26 West Cromwell Road	65.48	0.028	20.00	43.00	

Assets Location	Option	Chainage based on Option	Assets Description	Max. Settlement Prediction at Tunnel Axis (mm)	Extent of Tunnel 10mm Settlement Contour (m)	Asset Distance from Tunnel Centreline (m)	Settlement at Asset Location (mm)	(Burland et al. 1977) Damage Category	(Burland et al. 1977) Severity	Comments
Fuller's Brewery, Chiswick	3B	2230	Multi-Story Buildings	49	21	21	**10**	**2**	**Slight**	
St. Pauls School, Barnes	3B	3220	Multi-Story Buildings	77	31	15	**50**	**2**	**Slight**	
Hammersmith Bridge	3B	3600	Grade II* listed	46	35	10	**30**	**1**	**Very Slight**	
No. 51 Queen Caroline Street	3B	3900	Grade II listed	47	40	140	**0**	**1**	**Very Slight**	
St. Pauls Church, Hammersmith	3B	3900	Grade II* listed	47	40	400	**0**	**0**	**Negligible**	
St. Pauls Church, Hammersmith	1B	700	Grade II* listed	100	25	15	**40**	**4**	**Severe**	*D-Wall or bored piled retaining wall to be constructed*
Apollo Theatre	3B	3900	Grade II* listed	47	35	160	**100**	**1**	**Very Slight**	
Apollo Theatre	1B	600	Grade II* listed	40	25	10	**25**	**3**	**Moderate**	*D-Wall or bored piled retaining wall to be constructed*
Structure at N0.201 Talgarth Road - The Ark	3B	4350	Structure with potentially deep foundations (≥ 6 storeys)	82	35	15	**60**	**1**	**Very Slight**	*Likely to be piled*
Structure at N0.201 Talgarth Road - The Ark	1B	400	Structure with potentially deep foundations (≥ 6 storeys)	80	25	20	**15**	**2**	**Slight**	*Building likely to be piled. D-Wall or bored piled retaining wall to be constructed*
Building a No.17 Margravine Gardens	3B	4850	Grade II listed	53	30	65	**0**	**0**	**Negligible**	
Baron's Court LUL Station	3B	4850	Grade II listed	53	30	45	**5**	**1**	**Very Slight**	
Royal Ballet School & St Paul's Studios at No. 135-155 Talgarth Road	3B	4850	Grade II listed	53	30	20	**35**	**2**	**Slight**	
Falkland House at No.1-30 West Cromwell Road	3B	5500	Structure with potentially deep foundations (≥ 6 storeys)	53	30	25	**22**	**2**	**Slight**	
St Cuthberth's Church at No. 50 Philbeach Gardens	3B	5700	Grade II* listed	70	30	95	**0**	**0**	**Negligible**	

Appendix F – Impact Assessment of Key Structures

Impact Assessment of key Assets

Assets Location	Chainage based on 3B	Assets Description	Max. Settlement Prediction (mm)	Category	Sensitivity Low / Medium / High	Potential Mitigation Measures								
						Condition Survey	Liaison with owners	Impact Assessment	Additional Relining /Strengthening	Monitoring	Micro Piling	Jet Grouting	Compensation Grouting	Other(s)
McCormack House - Close to Great West Road Chiswick	2425	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	47	5	**High**	◉	◉	◉	◉	◉	◉	◉	◉	○
Buildings close to No.1 Chiswick Mall	2425	Grade II listed	47	5	**High**	◉	◉	◉	◉	◉	◉	◉	◉	○
Hammersmith Bridge	3600	Grade II* listed	46	5	**High**	◉	◉	◉	◉	◉	◉	◉	◉	○
1 to 40 Worlidge Street - Joanna House	3900	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	47	4	**Medium**	◉	◉	◉	◉	◉	◉	○	○	○
2 to 40 Hammersmith Bridge Road - Henrietta House	3900	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	47	4	**Medium**	◉	◉	◉	◉	◉	◉	○	○	○
No. 51 Queen Caroline Street	3900	Grade II listed	47	4	**Medium**	◉	◉	◉	◉	◉	◉	○	○	○
St Vincent's House	3900	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	47	4	**Medium**	◉	◉	◉	◉	◉	◉	○	○	○
Apollo Theatre	3900	Buliding/ Structure with potentially deep foundations (≥ 6 storeys) + Grade II* listed	47	5	**High**	◉	◉	◉	◉	◉	◉	◉	◉	○
Nurses' Home and Brandenburgh House at Fulham Palace Road	3900	Grade II listed	47	3	**Medium**	◉	◉	◉	◉	◉	◉	○	○	○
Elsinore House at No.77 Fulham Palace Road	4350	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	53	5	**High**	◉	◉	◉	◉	◉	◉	◉	◉	○
Ophelia House at No.77 Fulham Palace Road	4350	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	53	5	**High**	◉	◉	◉	◉	◉	◉	◉	◉	○
Horatio House at No.79-85 Fulham Palace Road	4350	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	53	5	**High**	◉	◉	◉	◉	◉	◉	◉	◉	○
Hammersmith LU Station at Junction between Queen Caroline Street & Talgarth Road	4350	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	53	4	**Medium**	◉	◉	◉	◉	◉	◉	○	○	○
Hotel at Junction betweenButterwick & Talgarth Road	4350	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	53	4	**Medium**	◉	◉	◉	◉	◉	◉	○	○	○
Structure at N0.201 Talgarth Road - The Ark	4350	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	53	5	**High**	◉	◉	◉	◉	◉	◉	◉	◉	○
Building a No.17 Margravine Gardens	4850	Grade II listed	53	4	**Medium**	◉	◉	◉	◉	◉	◉	○	○	○
Linacre Court at No. 1-69 Talgarth Road	4850	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	53	5	**High**	◉	◉	◉	◉	◉	◉	◉	◉	○

Assets Location	Chainage based on 3B	Assets Description	Max. Settlement Prediction (mm)	Category	Sensitivity Low / Medium / High	Potential Mitigation Measures: Condition Survey	Liaison with owners	Impact Assessment	Additional Relining /Strengthening	Monitoring	Micro Piling	Jet Grouting	Compensation Grouting	Other(s)
Baron's Court LUL Station	4850	Grade II listed	53	5	**High**	●	●	●	●	●	●	●	●	○
Royal Ballet School & St Paul's Studios at No. 135-155 Talgarth Road	4850	Grade II listed	53	5	**High**	●	●	●	●	●	●	●	●	○
Hammersmith and West London College between Glidon Road and Collet Gardens	4850	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	53	5	**High**	●	●	●	●	●	●	●	●	○
Barton Court at No. 1-71 Baron's Court Road	5500	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	53	5	**High**	●	●	●	●	●	●	●	●	○
West Kensington LUL Station close to No.171 West Cromwell Road	5500	-	53	4	**Medium**	●	●	●	●	●	●	○	○	○
West Kensington Court at No.142-150 West Cromwell Road	5500	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	53	5	**High**	●	●	●	●	●	●	●	●	○
Falkland House at No.1-30 West Cromwell Road	5500	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	53	5	**High**	●	●	●	●	●	●	●	●	○
St Cuthberth's Church at No. 50 Philbeach Gardens	5700	Grade II* listed	70	4	**Medium**	●	●	●	●	●	●	○	○	○
Fenelon Place At Junction of West Cromwell Road and the West London Overground Extension	5750	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	41	5	**High**	●	●	●	●	●	●	●	●	○
Warwick Mansions at No. 11-30 West Cromwell Road	5750	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	41	4	**Medium**	●	●	●	●	●	●	○	○	○
Building at No.1-60 Pembroke Road - Malborough Court	5950	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	28	4	**Medium**	●	●	●	●	●	●	○	○	○
Building at No.1-198 Pembroke Road	5950	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	28	4	**Medium**	●	●	●	●	●	●	○	○	○
Buildings at No.200-226 Cromwell Road	5950	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	28	3	**Medium**	●	●	●	●	●	●	○	○	○
Buildings at No.171-249 Cromwell Road	5950	Buliding/ Structure with potentially deep foundations (≥ 6 storeys)	28	3	**Medium**	●	●	●	●	●	●	○	○	○

Appendix G – Risk Register

DESIGN HAZARD LOG

PROJECT TITLE:	Hammersmith Fly Under - Feasability Study
DISCIPLINE	General Review
DOCUMENT No:	XXXXXXXXXXX

HAZARD ELIMINATION/REDUCTION

No.	Option	Chainage Start (m)	Chainage End (m)	Hazard	Risk	Project Stage When Risk Exists	Risk Level			Design Mitigation Measures and Options Available in Design and Specification Process	Risk Level After Mitigation			Design Mitigation Action Owner (Name)	Target Date	Date Action Taken	Mitigation Checked By: (Name & Date)	Position	Residual Risk Owner
2	General	-	-	Access routes owned by third parties	Claim of damages to land from third parties, access to site prevented by owner.	Construction	2	3	6	Ensure that ownership of the land is known, that agreements are in place prior to works. Photographs of existing conditions to be taken prior to works starting.	1	2	2						
3	Option 1	-	-	Access routes used by site vehicles and HGVs will be heavily trafficked	Risk of collision with road users during portal construction	Construction	2	4	8	Ensure othe users of the roads are aware of the works. Ensure appropiate traffic management plan is in place. Fencing and protective barriers to be provided around the site. Managed pedestrian routes to be used also.	1	4	4						
4	General	-	-	Contaminated Land	Contamination risk to workers and other receptors from historical uses	Construction	2	3	6	Adequate EIA survey prior to works, highlighting risks	2	1	2						
5	General	-	-	Public on the site during works due to public right of way in some areas	Injury to public caused by movement of site traffic or works.	Construction	2	4	8	Adequate protection to the public - hoardings, signage, banksmen, barriers etc	2	2	4						
6	General	-	-	Services	Risk of death or serious injury and interruption to service supply.	Construction	3	5	15	Undertake in depth service study. Liaise with assets owners as to their location, nature, orientation etc. Determine depth of assets.	2	3	6						
7	General	-	-	UXO	Unexploded Ordance. Risk of injury or death	Construction	1	5	5	UXO survey to determine location of any unexploded devices	1	3	3						
8	General	-	-	Public opposition	Public opposition to the project particularly in relation to traffic, noise, vibrations and settlement	Construction	2	4	8	Early consultations with the public	2	3	6						
9	Options 2 & 3	-	-	Spoil	Spoil disposal and associated costs	Construction	2	4	8	Ensure a suitable disposal strategy and site is worked out from the commencement of the project. Disposal by river barge an option.	2	3	6						
10	General	-	-	Weather	Risk of injury from the elements.	Construction	2	3	6	Design for extreme weatehr conditions. Provide adequate weather protection for staff etc.	2	2	4						
11	General	-	-	Settlement	Settlement of assets, buildings etc along the alignement of the tunnel	Construction	3	3	9	Undertake Phase 1 and 2 settlement assessments, outlining settlement ranges, mitigation measures and intervention measures	3	2	6						
12	General	-	-	Unforeseen ground condiditons	Injury/death/delay due to unforeseen ground conditions	Construction	1	4	4	Appropiate Site Investigation carried out. Appropiate construction plant and design to be used that can be implemented in a varitey of ground condiditons.	1	3	3						
13	Option 1	0	2030	Max. Tunnel Gradients of 5%	May prove unacceptable under fire life safety and ventilation	Construction	2	3	6	Appropiate design and research undertaken to ensure the best possible gradient design is reached.	1	3	3						
14	Option 2	0	5160	Max. Tunnel Gradients of 5%	May prove unacceptable under fire life safety and ventilation	Construction	2	3	6	Appropiate design and research undertaken to ensure the best possible gradient design is reached.	1	3	3						
15	General	-	-	Charring Cross Hospital	Impact of construction works on the hospital and underground car park, causing traffic delays etc	Construction	2	3	6	Appropiate consultation and traffic management plan in place for the hospital	2	2	4						
16	General	-	-	Services	Diversion of services	Construction	2	3	6	Design to mitigate amount of services to be diverted	2	2	4						
17	General	-	-	Shafts	Location of shafts may impact on local environment	Construction	2	3	6	Design to mitigate impact on locality and consult with public on the works required.	2	2	4						
18	General	-	-	Interfaces	Risk of interface with existing tunnels including unknown tunnels, MOD tunnels and fuel lines.	Construction	2	4	8	Design to mitigate any potential clashes with existing structures/tunnels such as sewers/TT/LUL etc.	2	2	4						
19	General	-	-	Pile Interface	Potential interface with piled foundations of local buildings. Leading to damage to exsiting structures, delays in construction and un-	Construction	2	3	6	Ensure adequate research and surveying of potential interfaces are undertaken. Liaise with asset owners in the area prior to commencement of works. Have mitigation measures in place for any potential interfaces	2	2	4						
20	General	-	-	Listed Buildings	Potential settlement and damage to listed buildings/structures due to tunnelling works (e.g. The Ark, Hammersmith Bridge)	Construction	2	4	8	Undertake Phase 1 and 2 settlement assessments, outlining settlement ranges, mitigation measures and intervention measures	2	3	6						
21	General	-	-	Existing Tunnels	Interface with existing Thames Water Tunnels (Ring Main, Filtered Water Tunnels , Lee Valley Tunnel) and National Grid Cable Tunnels	Construction	2	4	8	Undertake Phase 1 and 2 settlement assessments, outlining settlement ranges, mitigation measures and intervention measures. Ensure alignment allows adequate cover to the existing tunnels.	2	3	6						
22	General	-	-	Geological Structures	Faults, geological structures, buried river channels, pingos etc.	Construction	2	2	4	Undertake geological review of area.Undertake adequate design to mitigation any potential risks	2	1	2						

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DISCIPLINE	General Review	DOCUMENT No:	XXXXXXXXXXX

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1	General	-	-	Aquisition of Land	Location of portals will impact traffic, with minimum potential to aquisition further land	Cost	2	5	10	Additional cost allowed and early contact with land owners suggested. Sufficient time to allow purchase process and traffic management plan. Site layout/Portal layout/Junction layouts to be considered at feasibality stage of design.	2	3	6						
33	General	-	-	Cost Uncertainty	Cost estimates of tunnelling work difficult to estimate at this stage in the design feasability stage	Cost	2	4	8	Undertake detailed economic review to assertain the cost-benefit assessment of the works to be undertaken. This will also assist in the decision as to which tunnelling option will offer the greater benefit	2	2	4						
36	General	-	-	Tunnel Income	Will charging a toll impact the use of the tunnel? What will the cost of that toll be?	Cost	2	4	8	Undertake traffic model review of all tunnelling options, including origin-destination surveys within the assessment.Include economic review with regard to impact of toll. Potential to make an income to contribute to the cost of the tunnelling works.	2	3	6						
37	General	-	-	Compulsary Purchase of Land	Opposition to compulsary purchasing of land	Cost	3	3	9	Early consultation with local, national politicians. Consultation with local community as to the benefits of the works and assurances in place to minimise disruption.	3	2	6						
38	General	-	-	Political Oppositon	Likely to encounter political oppostion to some of the works proposed (shafty locations, traffic restrictions, land value, impact on service etc).	Cost	3	3	9	Early consultation with local, national politicians. Consultation with local community as to the benefits of the works and assurances in place to minimise disruption.	2	3	6						

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Likelihood x Consequence (See also CIRIA SP125).

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41	Options 1b, 2b & 3b	-	-	Max. Gradient at Junctions	Steep gradients of up to 9% may be required at tunnel junctions for light vehicle access only.	Operation	2	3	6	Ensure adeqate safety measures and signage are in palce to inform users of different gradient and speed restrictions that mat be required.	2	2	4						
42	General	-	-	Air pollution	Likely to be higher concentrate of air pollution at tunnel portals and poposed ventialtion shaft locations	Operation	2	4	8	Ensure adequate safety measures are used to mitigate against this. The use of portal fans and correct tunnel design should limit the exposure of the public	2	3	6						
43	General	-	-	Noise Pollution	Noise pollution at tunnel portals and at proposed shaft ventilation sites.	Operation	2	4	8	Minimise noise pollution through use of environmental screens, bunding and cut-and-cover sections. Minimise ventialtion fan use to off-peak times to reduce distrubance.	2	3	6						
48	General	-	-	Unused space	Unused space within tunnel footprint	Operation	2	3	6	Sell space to communications companies for additional revenue	2	2	4						

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34	General	-	-	Traffic Modelling	Uncertainty as to the traffic patterns of the area. It is not clear as to the amount of traffic that will use the tunnel on a daily basis.	Traffic	2	4	8	Undertake traffic model review of all tunnelling options, including origin-destination surveys within the assessment.	2	2	4						
35	Options 2 & 3	-	-	Traffic Modelling	Uncertainty as to the benefits of constructing a tunnel in replace of the existing flyover.	Traffic	2	4	8	Undertake traffic model review of all tunnelling options, including origin-destination surveys within the assessment. Undertake cost-benefit assessment as to impact on local community. Opportunity for	2	2	4						

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23	Option 2	-	-	Tunnel Junctions	Large SCL breakouts required. Constructability of openings in limited space. Potential of large ground movements. Limited space on the	Construction	3	4	12	Undertake constructability study, ensure scope of works and method of works are achievable and agreeable to all parties. Early asset owner consulatation advised. Undertake Settlement and Volume Loss (%)	3	3	9						
24	Option 2	-	-	Tunnel Junctions	Large excavation in SCL. H &S risk in break out and danger of ground collapse	Construction	2	5	10	Ensure adequate mitigation measures are in place and a safe method of works action plan has been reviewed and implemented on site. Robotic SCL sprayer to be used.	1	5	5						
25	Option 2	-	-	TBM	Use of Earth Pressure Balancing TBM in London Clay. Risk of blockage at the excavation face if tunnel intersects a pocket of water/sand lense. Risk of interfacing with claystones.	Construction	2	3	6	Ensure appropiate maintenance measures are in place. Undertake detailed geological assessment of the proposed tunnelling alignment and highlight areas of potential risk. Allow for additional time in the programme of works to accomodate any unavoidable mitigation measures to clean/repair TBM	2	2	4						
26	Option 2	-	-	TBM	Turning TBM at the portals. Large area required. Preparation of site for turning (casting of slab, cover places). Potential delays in programme and complaints from locality	Construction	2	4	8	Early consultations with the public explaining the works. Detailed plan and method statements outlining the prodcedure. Review case studies of previous TBM turnings that have been undertaken. Ensure adequate site has been aquired prior to works commencing.	2	3	6						
27	General	-	-	Site Area at Portals	Limited space at tunnel portals.	Construction	2	4	8	Early consultation with local council. Ensure appropiate site planning has been undertaken.	2	3	6						
28	Option 1	-	-	Hammersmith Flyover	Partial closure and eventual full closure of Hammersmith Flyover during construction of C-and-C tunnelling option. Traffic delays and temporary works design required	Construction	2	4	8	Early consultation with public. Ensure competent temporary works contractor and designer are employed. Temporary works must be safe but must also allow construction of C-and-C tunnel.	2	3	6						
29	General	-	-	Tunnel Flotation	Flotation of tunnel due to weight of tunnel being less than ground it displaced	Construction	2	4	8	Ensure adequate geotechnical study is undertaken. Adequate design to be undertaken to mitigate against tunnel uplift after construction (heavy section, additional concrete ballast etc)	2	2	4						
30	General	-	-	Water Table	High water table and pressures due to tidal range of River Thames	Construction	2	4	8	Ensure fluctuating levels of the water tables are understood. Hydrogeological study of the region to be undertaken. Appropiate mitigation measures to be undertaken in areas of high risk	2	3	6						
31	Option 2	-	-	Cover to Tunnels	Low cover at tunnel portals (less than one tunnel diameter).	Construction	2	3	6	Ensure appropiate design and construction measures are undertaken to mitigate against large ground movements and any potential loadings that may act upon the tunnel linings at these locations	2	2	4						
32	Option 2	-	-	Cover to Tunnels	Cover under the Thames	Construction	2	4	8	Ensure appropiate cover (minimum one tunnel diameter) along the vertical alignment as the tunnels pass under the River Thames. In areas where this may not be possible (due to existing tunnels etc) ensure appropiate design and mitigation measures are in place to undertake the construction of the tunnels safely and avoid large surface settlements.	2	3	6						
39	General	-	-	LUL/LO Cuttings	Settlement, damage and delays to LUL/LO tracks and trains	Construction	2	4	8	Appropiate design mitigation to be undertaken to reduce impact of settlement on surface cuttings	2	3	6						
40	General	-	-	Working with Chemicals	Danger when working with chemical materials	Construction	2	4	8	Request competant Contractor.	2	4	8						
44	General	-	-	Vibration	Increased levels of vibration during construction and operations.	Construction	2	4	8	Ensure adequate mitigation measures are in place during construction (e.g. Damage assessments etc). Ensure adequate design of structure to absorb and minimise vibration effects.	2	2	4						
45	General	-	-	Waste Management	Large construction project that will produce a lot of general waste	Construction	2	3	6	Provide appropiate means for disposing of waste on site. Ensure waste is managed and removed from site on a regular basis.	2	2	4						
46	Options 2 & 3	-	-	Impact on natural environment	The location of the proposed drive box/shaft will require a large site footprint and will most likely impact on the local environment during construction.	Construction	2	4	8	Ensure mitigation measures to minimise impact of surrounding environment is considered (mist sprays, bunding, hoarding, traffic management, engineering hours etc). Full EIA to be carried out and a hand-over strategy to return the site(s) to pre-works conditions post construction	2	2	4						
47	General	-	-	Carbon Footprint	Large construction project that is likely to produce a substanital carbon footprint	Construction	2	4	8	Mitigate carbon output by re-using spoil material in a positive manner (e.g. Crossrail, Tideway). Promote the use of sustainable materials such as green conrete. Reduce the number of road site road traffic through effective management.	2	2	4						

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Appendix H – Tunnel Maintenance Costs

Hammersmith FlyUnder

Inspection & Maintenance

Estimated Total An	**£61,080.00**

No.	Issue	Maintenance	Frequency	Labour	Plant	Inspection Cost	Annual Cost	Eng	Cost/Hour	Hours	Labour	Cost/Hour	Hours
1	Water Ingress	Regular inspections of entire tunnel. Ensure leaks are maintained and repaired	Monthly	2No. Engineers 2No. Labourers	Grout	£540.00	**£6,480.00**	2	30	6	2	15	6
2	Fixings (Lights and Signage)	Inspections of tunnel fixings. Damaged to be replaced	Monthly	TBC	Replacement fixings as required	£540.00	**£6,480.00**	2	30	6	2	15	6
3	Highway Maintenance	Regular inspections of highway within tunnel. Repairs as required	Monthly	TBC	TBC	£270.00	**£3,240.00**	2	30	3	2	15	3
4	Fan Testing	Regular inspection and testing of all emission and smoke extraction fans	Monthly	TBC	TBC	£540.00	**£6,480.00**	2	30	6	2	15	6
5	Fire Inspections	Regular inspections to ensure all fire preventative measures are in place and working correctly (alarm, fire doors, sprinklers etc)	Monthly	TBC	TBC	£600.00	**£7,200.00**	2	30	8	2	15	4
6	Tunnel Washing	Tunnel regularly cleaned to provide proper tunnel luminance	Bi-Monthly Suspended during winter months	TBC	TBC	£720.00	**£4,320.00**	0	0	0	4	15	12
7	Drain Flushing	Tunnel drains to be kept free of debris etc.	Annually	TBC	TBC	£1,080.00	**£1,080.00**				6	15	12
8	Ice/Snow Removal	Removal of ice/snow from tunnel. De-icing agent to be used. Ensure damage to highway is minimum and maintained	As Required	TBC	TBC	£240.00	**£6,000.00**				2	15	8
9	Spalled Concrete/Tile Removal	Removal of hazardous damaged sections of concrete, tile, linging that may fall on the highway	As Required	TBC	TBC	£540.00	**£2,700.00**	2	30	6	2	15	6
10	Air Conditioning Unit	Inspect and maintain	Annually	TBC	TBC	£540.00	**£540.00**	2	30	6	2	15	6
11	CO Monitoring Equipment	Inspect and maintain	Semi-Annually	TBC	TBC	£540.00	**£1,080.00**	2	30	6	2	15	6
12	CCTV	Clean, re-align, inspect	Semi-Annually	TBC	TBC	£180.00	**£360.00**				2	15	6
13	Emergency Lighting	Inspect and maintain	Monthly	TBC	TBC	£270.00	**£3,240.00**	2	30	3	2	15	3
14	Traffic Signals	Inspect and maintain	Monthly	TBC	TBC	£180.00	**£2,160.00**	2	30	2	2	15	2
15	Emergency Walkways	Inspect and maintain	Monthly	TBC	TBC	£270.00	**£3,240.00**	2	30	3	2	15	3
16	Intervention Shafts	Inspect and maintain	Monthly	TBC	TBC	£540.00	**£6,480.00**	2	30	6	2	15	6