Thames Tideway Tunnel
Thames Water Utilities Limited

Development Consent Order

Application Reference Number: WWO10001

Documents for Certification
September 2014

We, Lindsay Speed and Sarah Fairbrother hereby certify that this is a true copy of the environmental statement referred to in Article 61 (1) (f) of the Thames Water Utilities Limited (Thames Tideway Tunnel) Order 2014.

Lindsay Speed   Sarah Fairbrother

September 2014

Thames Tideway Tunnel
Creating a cleaner, healthier River Thames

Thames Tideway Tunnel
Thames Water Utilities Limited

Application for Development Consent

Application Reference Number: WWO10001

Environmental Statement

Doc Ref: **6.2.03**

Volume 3: Project-wide effects assessment appendices

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Appendix F: Land quality

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Appendix F: Land quality

F.1 Introduction

F.1.1 Construction and operational project-wide effects assessments for this topic do not require the provision of any supporting information, so this appendix is intentionally empty.

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Appendix G: Noise and vibration

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Appendix G: Noise and vibration

G.1 Introduction

G.1.1 Project-wide construction and operational effects assessments for this topic do not require the provision of any supporting information, so this appendix is intentionally empty.

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Appendix H: Socio-economics

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Appendix H: Socio-economics

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Appendix H: Socio-economics

H.1 Baseline community profile

H.1.1 The community profile is based on local authority level data from the Office of National Statistics (ONS). The data have been obtained from four sources: Census 2001[1] (the last census for which data are available), Department of Communities and Local Government Deprivation Indices 2010[2], London Public Health Observatory 2012[3], and the Network of Public Health Observatories 2011[4] (see Volume 2 Methodology). Data is grouped according to those 'protected characteristics'[i] or groups which are relevant for consideration in relation to this socio-economic impact assessment.

H.1.2 On the basis of likely impacts on receptors identified in this socio-economic assessment, the community profile examines the project-wide area surrounding the construction site (ie, at a Greater London level) and the overall England level statistics. Data at a borough level is also considered for the 13 boroughs in which there are proposed construction sites.

H.1.3 The main risk groups concentrated[ii] at a Greater London level are:

a. people belonging to Black and Minority Ethnic (BME) groups.

b. people belonging to the Muslim and Hindu faiths.

c. households which do not own cars.

Resident population

H.1.4 The resident population within Greater London was approximately 7,172,091 at the time of the last census for which a complete dataset is available[iii].

H.1.5 The total population within each of the 13 boroughs is outlined in Vol 3 Table H.1 below.

Vol 3 Table H.1 Socio-economics - population by borough

Borough	Total residential population
London Borough (LB) of Ealing	300,948
LB of Hammersmith and Fulham	165,242
LB of Richmond	172,335
LB of Wandsworth	260,380

[i] The Equalities Act 2010 defines 'protected characteristics' as: age, disability, gender reassignment, marriage and civil partnership, pregnancy and maternity, race, religion or belief, sex, and sexual orientation. Of these characteristics, age, disability, race and religion are relevant for consideration in relation to this socio-economic impact assessment.

[ii] In this instance, 'concentrated' refers to the occurrence of a particular protected characteristic group, the proportion of which is notably higher than the borough wide proportions.

[iii] Census 2001. This type of data for the 2011 Census has not yet been released at the time of the assessment .

Borough	Total residential population
RB of Kensington and Chelsea	158,919
LB of Lambeth	266,169
City of Westminster	181,286
City of London	7,185
LB of Southwark	244,866
LB of Tower Hamlets	196,106
LB of Lewisham	248,922
RB of Greenwich	214,403
LB of Newham	243,891

Gender and age

H.1.6 Of the total population within Greater London, 51.6% residents are female, broadly in line with the England average proportion (51.3%).

H.1.7 The proportion of under 16 year olds within Greater London (20.2%) is in line with the proportion of under 16 year olds within England, also 20.2%. Of the 13 relevant boroughs, City of London has the lowest proportion of under 16 year olds (9.4%) at less than half the Greater London average (20.2%). By contrast, the LB of Newham has the highest proportion of under 16 year olds (26.2%), somewhat higher than the Greater London level (20.2%). LB of Lewisham (21.1%) and RB of Greenwich (21.8%) are also slightly higher than the Greater London level.

H.1.8 The proportion of over 65 year olds within Greater London (12.4%) is moderately lower than the England level (15.9%). Of the 13 boroughs, the LB of Newham has the lowest proportion of over 65 year olds (8.9%) somewhat lower than the Greater London level (12.4%) and considerably lower than the proportion of over 65 year olds within England (15.9%). Over 65 year olds within LB of Lambeth and LB of Tower Hamlets (9.3% in both boroughs) also account for a somewhat lower proportion than Greater London, and considerably lower than the England average.

Vol 3 Table H.2 Socio-economics - age breakdown by catchment area

Age group	Catchment area	
	Greater London	England
Under 16 years old	20.2%	20.2%
Over 65 years old	12.4%	15.9%

Ethnicity

H.1.9 Within Greater London, White residents comprise 71.2% of the population with BME groups comprising the remaining 28.8%. The proportion of

White residents within Greater London is moderately lower than the England average (90.9%). Of the 13 boroughs, LB of Newham has the lowest proportion of White residents (39.4%) considerably lower than the Greater London average (71.2%) and lower still than the England average (90.1%). The LB of Ealing also has a notably lower proportion of White residents (58.9%) than the Greater London and England averages.

H.1.10 Within Greater London, Asian residents make up the largest minority group amounting to 12.1% of the total population. Within England, Asian residents are also the most predominant minority group (4.6%), however they account for a considerably lower proportion of the population than the Greater London average. The second most populous minority group within Greater London is Black residents, accounting for 10.9% of the population, considerably higher than the proportion of Black residents within England (2.3%).

H.1.11 Both the Asian and Black communities account for over one in ten Londoners. However, within the 13 boroughs Asian residents account for a lower proportion locally than the average figure for Greater London, with the exception of three boroughs: LB of Ealing (24.5%), LB of Tower Hamlets (36.6%) and LB of Newham (32.5%). In most of the 13 boroughs, the proportion of Black residents is also lower than the London average with the exception of four boroughs: LB of Lambeth (25.8%), LB of Southwark (25.9%), LB of Newham (21.6%) and LB of Greenwich (11.1%).

Vol 3 Table H.3 Socio-economics - ethnicity by catchment area

Ethnicity	Catchment area	
	Greater London	England
White	71.2%	90.9%
BME	28.8%	9.1%
Asian	12.1%	4.6%
Black	10.9%	2.3%
Other	2.7%	0.9%
Mixed	3.2%	1.3%

Note: The figure for BME data presented in Table H.3 is the sum of data for Asian, Black, Other and Mixed ethnicities.

Religion and belief

H.1.12 Within Greater London and England, Christians are the predominant religious group at 58.2% and 71.7% respectively. The proportion of Christians within Greater London is somewhat lower than the England average.

H.1.13 Muslims are the second most predominant religious group within Greater London and England; however the Muslim population within Greater London (8.5%) is considerably larger than the proportion of Muslims within England (3.1%).

H.1.14 Hindus are the next most predominant religious group within Greater London and England. Proportionately Hindu residents within Greater London (4.1%) are almost four times higher than the England average (1.1%).

H.1.15 Within Greater London, the proportion of residents who do not follow or state a religion (24.3%) is broadly in line with the England average (22.3%).

Health indicators

H.1.16 Within Greater London, 15.5% of residents have a long term or limiting illness, somewhat below the England average (17.9%). Of the 13 boroughs, the LB of Richmond upon Thames has the lowest proportion of residents suffering from a long term illness (12.4%). The majority of 13 boroughs experience a lower instance of long term or limiting illness in comparison with England wide levels, the exceptions being LB of Tower Hamlets (17.2%), RB of Greenwich (17.4%) and LB of Newham (17.3%) which have levels broadly in line with the England average.

H.1.17 Those residents who claim disability living allowance within Greater London (4.5%) are somewhat lower than the England average of 5.3%. Of the 13 boroughs, the City of London and LB of Richmond Upon Thames have the lowest proportions of disability allowance claimants (at 2.4% and 2.6% respectively), considerably lower than the Greater London and England averages. By contrast, the LB of Southwark (5.4%), LB of Tower Hamlets (5.4%), LB of Newham (5.6%) and RB of Greenwich (5.9%) have slightly higher claimant levels than England as a whole, higher still than the Greater London average.

Vol 3 Table H.4 Socio-economics - health indicators by catchment area

Health indicator	Catchment area	
	Greater London	England
Long term limiting sick	15.5%	17.9%
Disability living allowance	4.5%	5.3%

H.1.18 The majority of the 13 boroughs largely fall within the lowest or middle quintiles of adult obesity, the exceptions being LB of Southwark and LB of Newham which largely fall within the highest or second highest quintile (ie, the highest being the worst) relative to Greater London. All of the 13 boroughs experienced high rates of child obesity; all boroughs largely fall within the highest or second highest quintiles relative to Greater London.

H.1.19 The average life expectancy for males in Greater London is 78.6 years, broadly in line with the England average of 78.3 years. Female life expectancy in Greater London is 83.1 years, approximately one year higher than the England average (82.3 years).

Lifestyle and deprivation indicators

H.1.20 The proportion of households in Greater London that do not own cars (37.5%) is moderately higher than the England average (26.8%) where just over a quarter of households do not own cars. Of the 13 boroughs, the LB of Richmond Upon Thames has a somewhat lower proportion of households without cars (23.7%) than the England average, considerably lower than within Greater London. The City of Westminster, LB of Tower Hamlets and City of London all have considerably higher proportions of no car households than Greater London and England (56.4%, 56.8% and 62.0% respectively) and this is likely to be largely due to the central location of these boroughs, generally high levels of public transport accessibility and a shortage of car parking spaces.

H.1.21 The incidence of income and overall deprivation within Greater London (30.8% and 24.5% respectively) is moderately higher than the England averages (both 20.0%). Both income deprivation and overall deprivation within the LB of Tower Hamlets (76.6% and 69.6% respectively) and LB of Newham (90.7% and 80.7%) are considerably higher than the Greater London and England wide averages. By contrast, there is no recorded incidence of income or overall deprivation within the City of London, and no recorded overall deprivation within the LB of Richmond Upon Thames.

Vol 3 Table H.5 Socio-economics – lifestyle and deprivation levels by catchment area

Deprivation	Catchment area	
	Greater London	England
No car households	37.5%	26.8%
Income	30.8%	20.0%
Overall	24.5%	20.0%

H.2 Baseline economic profile

H.2.1 This economic profile examines data on employment, businesses and the resident workforce at a Greater London level and at a local authority level for the boroughs in which there are proposed construction sites (hereafter referred to as the 13 boroughs[iv]).

H.2.2 The data have been obtained from the Experian National Business Database 2012[5] which draws primarily on regularly updated records from Companies House.

H.2.3 Information on the skills and occupational profile of residents of Greater London and the 13 boroughs in which there are proposed construction sites, is set out in the *Skills and Employment Strategy (which accompanies the application)*.

Employment and businesses

H.2.4 In total across the 13 boroughs there are approximately 2.4 million jobs[v]. Vol 3 Table H.6[vi] below illustrates the breakdown of employment by sector, based on the UK Standard Industrial Classification (SIC) 2007. Data is shown for sectors which account for more than 5% of the total employment within each of the 13 boroughs. It can be seen that:

a. Wholesale and Retail Trade employment accounts for a slightly lower proportion (14%) than the average figure for Greater London (16%), with the exception of three boroughs: LB of Tower Hamlets (20%), RB of Kensington and Chelsea (20%) and RB of Greenwich (17%).

b. Professional, Scientific and Technical Activities employment accounts for 13% of employment within the 13 boroughs, slightly more than within Greater London as a whole (11%). However there are large variances between boroughs, from 5% of jobs within the LB of Newham, to 24% of jobs within the City of London.

c. Accommodation and Food Service Activities employment accounts for 8% to 9% of employment across both geographical scales. However, of the 13 boroughs the City of Westminster and RB of Kensington and Chelsea have a considerably higher proportion of jobs within this sector (14% and 15% respectively), whilst the LB of Newham has somewhat lower employment levels (4%) comparatively.

d. Administrative and Support Services employment accounts for 8% of employment across the 13 boroughs and Greater London as a whole.

[iv] The relevant boroughs are the London Borough (LB) of Ealing; LB of Hammersmith and Fulham, LB of Richmond-upon-Thames, LB of Wandsworth, Royal Borough (RB) of Kensington and Chelsea, LB Lambeth, City of Westminster, City of London, LB of Southwark, LB of Tower Hamlets, LB of Lewisham, RB of Greenwich, and LB of Newham.

[v] Employees data reflect a head count of workers on-site rather than Full Time Equivalent (FTE) jobs . While employee figures are mostly based on actual reported data, a proportion is based on modelled data.

[vi] Data in tables rounded to nearest whole percentage and do not always sum due to rounding.

e. Human Health and Social Work Activities employment accounts for 7% to 8% of employment, though four boroughs notably have a somewhat greater proportion: LB of Lambeth (13%), LB of Wandsworth (13%), LB of Southwark (12%) and LB of Lewisham (11%).

f. Information and Communication employment accounts for approximately 7% of employment across the 13 boroughs and within Greater London as a whole, though LB of Hammersmith and Fulham is notable as having a greater proportion (14%) within this sector.

g. Financial and Insurance Activities employment accounts for 7% of employment within the 13 boroughs, nearly double the proportion within Greater London as a whole (4%). However, employment within the sector ranges from 1% within the LB of Wandsworth, LB of Ealing, LB of Hammersmith and Fulham, LB of Lambeth, LB of Newham and the LB of Greenwich to 29% of jobs within the City of London.

h. Education Activities employment accounts for 6% to 7% of employment across the 13 boroughs and Greater London, with the exception of four boroughs: the LB of Lewisham (13%), RB of Greenwich (12%), LB of Newham (11%) and LB of Wandsworth (10%).

Vol 3 Table H.6 Socio-economics – employment by top eight sectors (2012)

	Assessment area	
Sector (Standard Industrial Code 2007)	**13 boroughs**	**Greater London**
Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles	14%	16%
Professional, Scientific and Technical Activities	13%	11%
Accommodation and Food Service Activities	9%	8%
Administrative and Support Services	8%	8%
Human Health and Social Work Activities	7%	8%
Information and Communication	7%	7%
Financial and Insurance Activities	7%	4%
Education	6%	7%
Other (including unclassified)	31%	31%

H.2.5 Across the 13 boroughs there are approximately 249,000 businesses (defined here as business locations[vii]). The split of businesses by sector generally reflects the breakdown of employment by sector set out above, with a relatively high number of businesses engaged in Wholesale and Retail Trade (12%), Professional, Scientific and Technical Activities (11%) and Administrative and Support Service Activities (10%).

H.2.6 Vol 3 Table H.7 illustrates the size of businesses in terms of the number of employees on site. Businesses within the smallest size band (1 to 9 employees) account for the greatest proportion across the 13 boroughs (85%) and within Greater London as a whole (88%).

H.2.7 There are a number of 13 boroughs which have a greater proportion of smaller businesses (1 to 9 employees) than Greater London as a whole, such as the LB of Lewisham (92%), LB of Newham (92%), RB of Greenwich (91%), LB of Richmond (91%), LB of Ealing (90%), LB of Wandsworth (90%) and LB of Lambeth (89%). Conversely within the City of London there are many more businesses employing more than 50 employees (7%) than the average across all 13 boroughs and Greater London as a whole (both 2%).

Vol 3 Table H.7 Socio-economics - businesses by size band (number of employees)

Assessment area	Size band (employees at site)					
	1-9	10-24	25-49	50-99	100-249	250+
13 boroughs	85%	10%	2%	1%	1%	0%
Greater London	88%	8%	2%	1%	1%	0%

H.2.8 Vol 3 Table H.8 illustrates the breakdown of business locations and jobs within the Construction, Manufacturing and Transport and Storage sectors across the 13 boroughs and Greater London. There are approximately 12,600 Construction sector businesses and 89,000 Construction sector jobs. With respect to the distribution of these businesses and jobs across 13 boroughs, a particularly high share of the Construction businesses are located in the City of Westminster (15%) and LB of Ealing (14%). The City of Westminster and LB of Ealing also account for the highest share of Construction jobs (24% and 11% respectively).

H.2.9 Across the 13 boroughs there are approximately 7,100 Manufacturing businesses and approximately 69,600 Manufacturing jobs. Of the 13 boroughs, the City of Westminster and LB of Ealing have a highest share of Manufacturing sector businesses (15% and 12% respectively).

H.2.10 Across the 13 boroughs there are approximately 5,800 Transport and Storage sector businesses and 69,700 Transport and Storage sector jobs. Both the LB of Ealing and City of Westminster account for a high share of

[vii] This count relates to business 'locations' or 'units'; an enterprise may have a number of business locations / units. It includes private sector, public sector and voluntary sector / charitable entities.

Transport and Storage sector businesses (14% and 12% respectively). The LB of Newham accounts for the greatest share of Transport and Storage sector jobs (16%) but only 8% of all Transport and Storage sector business locations.

Vol 3 Table H.8 Socio-economics – employment and business locations for the construction, manufacturing and transport and storage sectors

	Construction sector		Manufacturing sector		Transport and storage sector	
Borough	**Jobs**	**Business locations**	**Jobs**	**Business locations**	**Jobs**	**Business locations**
City of London	8%	2%	5%	3%	4%	3%
Ealing	11%	14%	14%	12%	14%	14%
Greenwich	6%	8%	4%	6%	7%	6%
Hammersmith and Fulham	5%	6%	12%	7%	7%	7%
Kensington and Chelsea	4%	4%	7%	5%	3%	4%
Lambeth	7%	7%	7%	7%	5%	8%
Lewisham	5%	8%	4%	7%	4%	7%
Newham	7%	7%	5%	6%	16%	8%
Richmond	5%	8%	4%	7%	5%	6%
Southwark	5%	6%	5%	8%	7%	8%
Tower Hamlets	7%	5%	8%	7%	10%	8%
Wandsworth	6%	9%	5%	9%	6%	8%
Westminster	24%	15%	20%	15%	12%	12%
13 boroughs	89,052 (100%)	12,610 (100%)	69,609 (100%)	7,161 (100%)	69,722 (100%)	5,871 (100%)
Greater London	228,405	39,213	168,410	20,553	174,390	15,777

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[1] ONS. *Neighbourhood Statistics* (2001). Available at: http://neighbourhood.statistics.gov.uk/dissemination/

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Appendix I: Townscape and visual

I.1 Introduction

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Appendix J: Transport

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Appendix J: Transport

J.1 Sensitivity testing in relation to the Transport Strategy

Introduction

Overview

J.1.1 This appendix provides details of the sensitivity testing of the construction lorry flows set out in the *Transport Strategy*, which accompanies the application, particularly in relation to the Annual Average Daily Traffic (AADT) and Annual Average Weekday Traffic (AAWT) flows and the associated air quality and noise assessments which have been undertaken as part of the EIA.

J.1.2 Section 3 of the *Transport Assessment* explains in detail how sensitivity testing has been undertaken in relation to highway network capacity and operation.

J.1.3 This appendix sets out the following:

a. the basis of the core assessment of transport effects

b. the context within which sensitivity testing has been considered and reasons why it is appropriate

c. how sensitivity testing on construction lorry numbers relates to AADT and AAWT values

d. the implications of a sensitivity test for the air quality and noise assessments reported in the site assessment volumes (Vols 4 to 27) of the *Environmental Statement*.

Basis of core assessment

J.1.4 The assessment of transport effects related to the project takes account of the anticipated numbers of construction lorries, and those of other construction vehicles, at each project worksite at different points in the construction programme. The transport assessment is concerned primarily with the effects on highway network operation during peak hours.

J.1.5 The analysis underlying the assessment of transport effects has also been used to derive baseline, base case and development case AADT and AAWT flows for use in the air quality and noise assessments within the EIA.

J.1.6 The core scenario for the assessment of transport effects is that contained in the *Transport Strategy* (referred to as the '*Transport Strategy*' scenario). This sets out the project commitment that Thames Water will use all reasonable endeavours to ensure that at least 90% of the following materials will be transported (to and from the 11 worksites listed below) by river except in certain circumstances (as listed in Appendix B of the *Transport Strategy*):

a. Main tunnel excavated material from the main tunnel drive sites (Carnwath Road Riverside, Kirtling Street, and Chambers Wharf).

b. Shaft excavated material at ten sites in the foreshore, or with direct river access. These are Putney Embankment Foreshore, Carnwath Road Riverside, Cremorne Wharf Depot, Chelsea Embankment Foreshore, Heathwall Pumping Station, Albert Embankment Foreshore, Victoria Embankment Foreshore, Blackfriars Bridge Foreshore, Chambers Wharf and King Edward Memorial Park Foreshore.

c. Import of temporary and permanent cofferdam fill material and export of temporary cofferdam fill material at all foreshore sites.

d. Excavated material from short connection tunnels, interception chambers and associated structures at eight sites. These are Putney Embankment Foreshore, Cremorne Wharf Depot, Chelsea Embankment Foreshore, Albert Embankment Foreshore, Victoria Embankment Foreshore, Blackfriars Bridge Foreshore, Chambers Wharf and King Edward Memorial Park Foreshore.

e. Import of sand and aggregates for secondary lining works for the main tunnel sites at Carnwath Road Riverside, Kirtling Street and Chambers Wharf.

J.1.7 The above materials types can be transported by river but there will be practicality reasons why it is not always possible to use river transport. For the assessment of transport impacts, as reported in the *Transport Assessment* and *Environmental Statement*, it is assumed that a minimum of 90% of these materials would be transported by river. This is to allow some flexibility for the use of road transport for periods, for example, when river transport may be unavailable, or for material that is unsuitable for river transport (such as excessively wet spoil or any contaminated materials), or if a major site equipment failure occur. The construction contractors will be incentivised to transport as much of the above material by river as practical, in order to achieve an amount closer to 100%. All other materials will be transported by road from these 11 worksites.

J.1.8 The 90% figure has been used to allow a realistic worst case, one in which a value materially below the 90% figure is not considered sufficiently likely to require specific assessment.

J.1.9 At the other 13 sites, all materials would be transported by road.

J.1.10 The traffic-related assessments presented in the *Environmental Statement* (principally transport, air quality and noise) are based on the lorry numbers set out in the *Transport Strategy*. The transport assessment (and those traffic-related elements of the air quality and noise assessments) has adopted the peak month(s) of construction at each worksite (ie the month(s) in which the average daily number of lorries would reach a maximum). When considering project-wide effects the assessment has adopted the overall peak month of activity (ie the month in which the total average daily number of lorries generated by all worksites would reach a maximum).

J.1.11 This approach is considered to be robust because:

a. it examines the months in which the average daily numbers of lorries would be at their greatest

b. it therefore reports effects associated with these peak months, even though many other months in the construction programme at a worksite, or project-wide, would experience lower levels of lorry flows and thus potentially lesser effects

c. although there may be occasions when the number of lorry movements at a site exceed the average daily figure in the peak month, in the context of the overall construction programme the number of such instances of exceedance would be small and would be 'offset' by other times when the number of daily lorry movements would be less than the average (including non-peak months)

d. if lorry movements are required outside 'core' working hours (08:00hrs to 18:00hrs on weekdays and 08:00hrs to 13:00hrs on Saturdays) this would be agreed with the relevant local authorities (see *CoCP, Part A* Section 4.2).

Sensitivity testing

Context

Transport Strategy

J.1.12 Sensitivity testing has been used as a means of examining the effects of the project in the event that disruption to river transport means additional road transport for construction materials is necessary for an extended period of time. Paras. J.1.13 to J.1.16 discuss the range of issues that form the context within which such sensitivity testing should be viewed.

J.1.13 As the core assessment already examines the peak month(s) of activity at each worksite, as explained in paras. J.1.10 and J.1.11, it already addresses a situation which would represent the upper bound of the number of movements that could be expected on any day within the overall programme at each worksite, assuming the *Transport Strategy* scenario.

J.1.14 As para. J.1.11 explains, if this peak month average daily figure were to be exceeded, this is likely to be on an infrequent basis and the number of instances would be very small in the context of the overall construction programme.

J.1.15 Given the commitments set out in the *Transport Strategy*, it is very unlikely that river transport would not be used for the whole construction programme. A situation in which all construction materials were transported by road for all worksites for the whole construction period (a full 'All By Road' scenario) is therefore not considered to be realistic and thus not a likely scenario that requires assessment in terms of air quality and noise effects.

Derogations for departure from using river transport

J.1.16 There is, however, the possibility that river transport might not be available for short periods of time at one or more worksites. These 'trigger events' are listed in Appendix B of the *Transport Strategy* and include:

a. planned closures or restrictions on the river (eg maintenance or testing of the Thames Barrier, sporting events or river works by other parties)

b. unplanned closures and restrictions on the river (eg weather effecting river transport, incidents from river transport, Thames Barrier closures for flood defence)

c. project-related occurrences ie events which might occur at one of the project sites and affect the ability of the contractor to use the river, for example, breakdown or failure of equipment, damage to loading infrastructure, material production and storage area issues

d. material unsuitable for river transport (for example, excavated materials from the clay and Thanet Sand tunnel drives that fail the International Maritime Solid Bulk Cargoes Code transportable moisture limit test and are unsuitable to be transported by barge).

J.1.17 The procedures and processes to ensure robust and consistent management of project-related river operations, and to respond to the trigger events outlined above are being discussed with the GLA, TfL and PLA, so that transfer to road transport can be assessed and implemented without unnecessary delay.

J.1.18 The agreed procedures will form the basis of contract requirements and will be referenced within the traffic management plans, river transport management plans and construction environmental management plans. The criteria and procedures for the derogations will also be incorporated within the contractor's work information, and agreements with key stakeholders.

J.1.19 If any of these issues arise, it is likely that they would be a short-term occurrence rather than give rise to abandoning the river in favour of road transport. Furthermore, these issues are unlikely to affect river transport at all relevant worksites at the same time or in the same way.

Sensitivity testing in the assessment of transport effects

J.1.20 In relation to the assessment of transport effects, sensitivity testing around the core assessment has been discussed with Transport for London (TfL). In transport terms, a primary issue has been to ensure that the assessment addresses the operation of the strategic and local highway networks in terms of highway capacity and delay.

J.1.21 Discussions with TfL in relation to sensitivity testing of strategic highway capacity and delay issues considered a range of possible scenarios and variations to the core assessment (*Transport Strategy*) figures. There is inherent uncertainty in understanding exactly what the implications of individual 'trigger events' might be, including the way in which the construction management team might respond to mitigate them. It was therefore agreed that to simplify the approach and provide a worst case variation from the *Transport Strategy* for such strategic traffic-related issues, the sensitivity test would be the forecast lorry movements for an 'All By Road' (ABR) situation (ie assuming that no river transport was used and that all materials were transported by road for the whole construction period).

J.1.22 Whilst the actual nature and extent of any disruption to the use of river transport cannot be predicted with certainty, it is considered appropriate to select a representative period so as to enable a realistic, informative and proportionate sensitivity test to be undertaken. A representative period of one month has therefore been used for the purposes of this sensitivity test. Whilst the possibility of a disruption of greater than one month cannot be entirely excluded, in view of the approach and commitments set out in the *Transport Strategy*, and the fact that any disruption is in practice likely to be materially shorter than a month, significantly longer periods of disruption are not considered sufficiently likely to require specific assessment.

J.1.23 Sensitivity testing of traffic flows for the air quality and noise assessments has therefore been based on a scenario equivalent to the levels of traffic implied by the 'All By Road' figures occurring for approximately one month. This is referred to as the 'ABR (1 month)' sensitivity test and it represents a short to medium term loss of river transport at all worksites with the construction lorry movements represented by the *Transport Strategy* occurring over the remaining 11 months of the year.

J.1.24 It is noted that consideration of these sensitivity tests does not imply a deviation from the commitments to river transport made in the *Transport Strategy* although the tests are consistent with the strategy in that the strategy provides for the possibility that there may be temporary interruptions to the use of river transport.

Relationship to air quality and noise assessments

J.1.25 When considering transport-related effects, the air quality and noise assessments draw on traffic flow information relating to AADT flows and AAWT flows respectively. The transport assessment is typically based on forecast peak hour traffic flows which cover a shorter period than AADT or AAWT flows although such flows are derived from the transport assessment for use in the air quality and noise assessments.

J.1.26 AADT flows represent the total annual traffic flow on a particular road, averaged across 365 days. AAWT flows represent the total annual traffic flow on weekdays only, averaged across 260 days. For the air quality and noise assessments, comparisons have been made between the construction base and development cases – the latter includes Thames Tideway Tunnel project traffic also averaged across 365 or 260 days as appropriate.

J.1.27 For the air quality assessment, locations where the project would add more than 200 lorries a day are identified. This approach is consistent with the Highways Agency Design Manual for Roads and Bridges criteria for assessment and the project-wide air quality assessment methodology described in Vol 2 Section 4.8 of the *Environmental Statement*.

J.1.28 For noise assessment, road links where there would be an increase in total traffic flow of 25%, or a 5% increase in HGV composition during the peak month are identified. These increases indicate changes above negligible impact of 1dB, although significant effects would not be associated with changes of less than 3dB. This approach is consistent with the noise and vibration assessment methodology described in Vol 2 Section 9.5 of the *Environmental Statement*.

J.1.29 The analysis set out below uses these thresholds for the purposes of assessing whether the scenario adopted for the purposes of sensitivity testing shows a variation in the AADT / AAWT flows that would give rise to a material change in the findings of the air quality and noise assessments, based on the *Transport Strategy*, as reported in the site and project wide assessments in the *Environmental Statement*.

Approach to analysis

J.1.30 The analysis has considered the 11 worksites at which river transport is proposed in the *Transport Strategy*, as only these would be susceptible to an interruption in river use.

J.1.31 Using the *Transport Strategy* and ABR (1 month) figures, it is possible to identify:

a. the 12 month period in which the total number of construction lorries at each worksite would be highest, for the *Transport Strategy*

b. the 12 month period in which the total number of construction lorries at each worksite would be highest, for the ABR (1 month) scenario

c. the equivalent AADT and AAWT (note: peak daily flow during ABR (1 month) scenario also considered) flows for project lorry traffic <u>only</u> for each of these two periods, and the difference between them.

J.1.32 Using this information, it is possible to identify the degree to which the underlying (base case) AADT and AAWT figures would change, if the additional project lorry traffic were applied in each case.

J.1.33 For this analysis, the degree of change has been based on a range of AADT / AAWT flow levels to illustrate how sensitive a location might be to change.

J.1.34 It is clear that the lower the base case AADT and AAWT flows, the greater the percentage change that is likely to result from a given level of construction lorry movements. Where project construction lorries need to use local roads to access worksites, base case flows are likely to be lower on those roads than on the strategic road network and therefore these local roads may be more susceptible to smaller changes in AADT/AAWT flows resulting from additional construction lorry movements.

ABR (1 month) sensitivity test for air quality and noise assessments

Overview

J.1.35 For each worksite, this analysis examines the 12 month period in which the *Transport Strategy* figures produce the highest number of lorry movements. It then substitutes the month with the highest number of lorry movements from the 'All By Road' scenario. Thus it examines the highest 11 months of the *Transport Strategy* plus the highest month of the 'All By Road' scenario.

J.1.36 These figures have then been compared with the highest 12 month period for the *Transport Strategy* in order to demonstrate whether changes in the resulting AADT figures would give rise to a material change in the assessments reported in the *Environmental Statement* and if so, at what level of base case traffic flow.

J.1.37 In the case of the analysis of the AAWT figures for the consideration of noise impacts, the 'All By Road' daily flows have been considered for the one month in which the increased flows would occur (to determine noise level changes during the worst-case month) .

AADT analysis

Local highway network

J.1.38 Vol 3 Table J.1 and Vol 3 Table J.2 show that for Thames Tideway Tunnel lorry traffic only, the AADT figures for the *Transport Strategy* range between 10 movements (at Cremorne Wharf Depot) and 135 movements (at Kirtling Street) per day. For the ABR (1 month) sensitivity test, the equivalent AADT figures range from 11 movements (at Cremorne Wharf Depot) to 172 movements (at Kirtling Street) per day.

J.1.39 The increases at an individual worksite as a result of the ABR (1 month) sensitivity test (11 months of *Transport Strategy* plus one month of 'All By Road') therefore range between 1 and 37 vehicle movements a day on average.

J.1.40 Vol 3 Table J.2 shows the percentage of additional movements that these figures represent, when added to a range of 'base case' AADT figures.

J.1.41 Considering a minimum base case AADT of 2,000 vehicles an hour and the thresholds of addition of 200 AADT lorry movements (see para. J.1.27), Vol 3 Table J.2 shows that:

a. none of the worksites individually is expected to generate more than 200 AADT lorry movements a day in either the *Transport Strategy* or the ABR (1 month) sensitivity test scenarios

b. roads with lower traffic volumes a day would experience a higher % increase in AADT for both *Transport Strategy* and ABR (1 month) scenarios

c. Kirtling Street would experience the highest % increase in AADTs for the ABR (1 month) scenario compared to the base case followed by Chambers Wharf although these increases are less than 200 movements AADT. Given that both sites have sensitive receptors located at minor roads with low traffic volumes and NO_2 concentrations close to the UK annual mean objective, additional dispersion modelling was carried out to verify the effects of the ABR (1 month) scenario (see paras. J.1.45-J.1.46).

Strategic highway network

J.1.42 The strategic highway network modelling takes account of the potential origins and destinations of construction lorries travelling to or from project worksites. This shows that key construction routes used by lorry traffic generated by the project would include the A2 corridor to the east of London and the A205 (South Circular Road) corridor. The consideration of how the sensitivity test applies to these corridors is discussed below and it is important to note that this includes lorries associated with sites where river transport would not be used, as well as those where river transport forms part of the *Transport Strategy*.

A2 corridor

J.1.43 For the *Transport Strategy* scenario, it is estimated that there would be a maximum annual average daily flow of approximately 180 construction lorries travelling in each direction on the A2, or a total of 360 construction lorry movements a day on that route. For the ABR (1 month) scenario, this figure would increase to a maximum annual average daily flow of approximately 200 construction lorries travelling in each direction on the A2, or a total of 400 construction lorries a day on that route. The effect of the ABR (1 month) scenario would therefore be to increase annual average daily construction lorry flows on the A2 corridor by approximately 20 lorries in each direction, or 40 lorry movements in total. This is the upper estimate of flows that could occur.

A205 corridor

J.1.44 For the *Transport Strategy* scenario, it is estimated that there would be a maximum annual average daily flow of approximately 50 construction lorries travelling in each direction on the A205, or a total of 100 construction lorry movements a day on that route. For the ABR (1 month) scenario, this figure would increase to a maximum annual average daily flow of approximately 104 construction lorries travelling in each direction on the A205, or a total of 208 construction lorry movements a day on that route. The effect of the ABR (1 month) scenario would therefore be to increase annual average daily construction lorry flows on the A205 corridor by approximately 54 lorries in each direction, or 108 lorry movements in total. This is the upper estimate of flows that could occur.

Air quality assessment

J.1.45 Additional dispersion modelling undertaken at Kirtling Street and Chambers Wharf for the local highway network ABR (1 month) scenario indicates that this scenario would not result in any change to the significance of effects described in the site volumes of the *Environmental Statement* respective site Volumes Section 4.

J.1.46 According to the threshold used for the project-wide assessment (*Environmental Statement,* Vol 2 Section 4) taken from the DMRB assessment methodology (see para. J.1.27), an increase of 200 heavy duty vehicles (HDVs) a day requires an assessment. Given that both the A2 and the A205 exceed the DMRB threshold, NO_2 concentrations have been predicted at sensitive receptors located along these corridors. No other road corridors are likely to experience an increase of 200 heavy duty vehicles a day with the ABR (1 month) scenario.

J.1.47 In relation to the strategic road network A2 corridor, an increase of 40 AADT of heavy duty vehicles on the A2 for the ABR (1 month) scenario compared to the *Transport Strategy* (or an additional 400 AADT HDVs compared to the base case) is likely to be, at most, 0.2 $\mu g/m^3$ higher than the NO_2 impacts predicted for the project-wide assessment contained in the *Environmental Statement* (Vol 3 Section 4) or an increase of 1.5 $\mu g/m^3$ compared to the base case. For the strategic road network A205 corridor, an increase of 108 AADT of heavy duty vehicles on the A205 for the ABR (1 month) scenario compared to the *Transport Strategy* (or an additional 208 AADT HDVs compared to the base case) relates to a maximum NO_2 impact of 1.1 $\mu g/m^3$ compared to the *Transport Strategy* or 1.2 $\mu g/m^3$ compared to the base case.

J.1.48 Using the significance criteria for the ABR (1 month) scenario as described in the *Environmental Statement* (Vol 2 Section 4), the impacts on the A2 would be unchanged from those reported in the *Environmental Statement* (Vol 3 Section 4). For the A205 they are considered to be of a small magnitude and a minor adverse significance for the ABR (1 month) scenario and negligible magnitude and significance for the *Transport Strategy*. All other road corridors do not exceed the DMRB threshold thus a negligible air quality impact is expected.

J.1.49 Overall, the 'ABR (1 month)' scenario does not result in any material change to the effects identified in the site specific and project-wide air quality assessments as reported in the *Environmental Statement.*

Vol 3 Table J.1 Number of construction lorry movements, AADT

Site	Lorry movements				AADT flows		
	Peak 12 months Transport Strategy	***11 months Transport Strategy***	***Peak month 'All By Road'***	**Total 'ABR (1 month)' annual movements**	**Transport Strategy**	**'ABR (1 month)' sensitivity test**	**Difference**
Putney Embankment Foreshore	4,484	*4,111*	*2,352*	6,463	13	18	5
Carnwath Road Riverside	22,656	*20,768*	*7,728*	28,496	63	79	16
Cremorne Wharf Depot	3,332	*3,055*	*768*	3,823	10	11	1
Chelsea Embankment Foreshore	6,342	*5,814*	*6,480*	12,294	18	34	16
Kirtling Street	49,224	*45,122*	*17,520*	62,642	135	172	37
Heathwall Pumping Station	4,292	*3,935*	*2,352*	6,287	12	18	6
Albert Embankment Foreshore	6,380	*5,849*	*3,936*	9,785	18	27	9
Victoria Embankment Foreshore	3,846	*3,526*	*3,984*	7,510	11	21	10
Blackfriars Bridge Foreshore	13,224	*12,122*	*6,096*	18,218	37	50	13
Chambers Wharf	21,332	*19,555*	*15,120*	34,675	59	95	36
King Edward Memorial Park	10,072	*9,233*	*5,136*	14,369	28	40	12

Vol 3 Table J.2 Percentage change to AADT base case thresholds

Site	Construction lorry movements, AADT		% increase if base AADT = 2,000 veh		% increase if base AADT = 5,000 veh		% increase if base AADT = 10,000 veh		% increase if base AADT = 20,000 veh	
	Transport Strategy	'ABR (1 month)' test	Transport Strategy	'ABR (1 month)' test	Transport Strategy	'ABR (1 month)' test	Transport Strategy	'ABR (1 month)' test	Transport Strategy	'ABR (1 month)' test
Putney Embankment Foreshore	13	18	0.7%	0.9%	0.3%	0.4%	0.1%	0.2%	0.1%	0.1%
Carnwath Road Riverside	63	79	3.2%	4.0%	1.3%	1.6%	0.6%	0.8%	0.3%	0.4%
Cremorne Wharf Depot	10	11	0.5%	0.6%	0.2%	0.2%	0.1%	0.1%	0.1%	0.1%
Chelsea Embankment Foreshore	18	34	0.9%	1.7%	0.4%	0.7%	0.2%	0.3%	0.1%	0.2%
Kirtling Street	135	172	6.8%	8.6%	2.7%	3.4%	1.4%	1.7%	0.7%	0.9%
Heathwall Pumping Station	12	18	0.6%	0.9%	0.2%	0.4%	0.1%	0.2%	0.1%	0.1%
Albert Embankment Foreshore	18	27	0.9%	1.4%	0.4%	0.5%	0.2%	0.3%	0.1%	0.1%
Victoria Embankment Foreshore	11	21	0.6%	1.1%	0.2%	0.4%	0.1%	0.2%	0.1%	0.1%
Blackfriars Bridge	37	50	1.9%	2.5%	0.7%	1.0%	0.4%	0.5%	0.2%	0.3%

Site	Construction lorry movements, AADT		% increase if base AADT = 2,000 veh		% increase if base AADT = 5,000 veh		% increase if base AADT = 10,000 veh		% increase if base AADT = 20,000 veh	
	Transport Strategy	‘ABR (1 month)’ test	Transport Strategy	‘ABR (1 month)’ test	Transport Strategy	‘ABR (1 month)’ test	Transport Strategy	‘ABR (1 month)’ test	Transport Strategy	‘ABR (1 month)’ test
Foreshore										
Chambers Wharf	59	95	3.0%	4.8%	1.2%	1.9%	0.6%	1.0%	0.3%	0.5%
King Edward Memorial Park	28	40	1.4%	2.0%	0.6%	0.8%	0.3%	0.4%	0.1%	0.2%

AAWT analysis

J.1.50 Vol 3 Table J.3 and Vol 3 Table J.4 show that for Thames Tideway Tunnel lorry traffic only, the AAWT figures for the *Transport Strategy* scenario range between 13 movements (at Cremorne Wharf Depot) and 190 movements (at Kirtling Street) per day. For the ABR (1 month) sensitivity test, the equivalent daily figures, averaged across a 12 month period including the single month of 'all by road' operation, range from 15 movements (at Cremorne Wharf Depot) to 241 movements (at Kirtling Street) per day.

J.1.51 Vol 3 Table J.3 also shows the average weekday number of lorry movements in the busiest month of the *Transport Strategy* and 'ABR (1 month) scenarios. These figures are termed 'peak daily flows' in the table and have been derived by examining the total number of lorry movements expected in the busiest month in each case, and averaging them across 22 weekdays in that month.

Noise and vibration assessment

J.1.52 Changes in peak daily HGV composition relative to the base case for the peak month of each scenario have been determined to consider the realistic worst-case change on any link around the sites along which construction traffic would pass. The percentage changes in HGV composition relative to base case are shown in brackets in Vol 3 Table J.5. Putney Bridge Foreshore and King Edward Memorial Park show increases of greater than 5% in HGV composition relative to the base case (associated approximately with a >1dB change in traffic noise). Only Chambers Wharf shows increases in HGV composition greater than 20% (associated approximately with a >3dB change in traffic noise).

J.1.53 Vol 3 Table J.5 shows the percentage of additional movements that these peak daily figures represent, when added to a range of 'base case' AAWT figures.

J.1.54 Considering a minimum base case AAWT of 2,000 vehicles an hour and a threshold of a 25% change in AAWT for even a 1dB increase in traffic noise, Vol 3 Table J.5 shows that only Kirtling Street and Chambers Wharf show changes over 25% for the ABR (1 month) scenario.

J.1.55 Overall, the 'ABR (1 month)' scenario does not result in any material change to the effects identified in the site specific and project-wide noise and vibration assessments as reported in the *Environmental Statement*.

Vol 3 Table J.3 Number of construction lorry movements, AAWT

Site	Lorry movements				AAWT flows			Peak daily flows		
	Peak 12 months Transport Strategy	***11 months Transport Strategy***	***Peak month 'All By Road'***	**Total 'ABR (1 month)' annual movements**	**Transport Strategy**	**'ABR (1 month)' sensitivity test**	**Difference**	**Transport Strategy (%HGV increase relative to base composition in brackets)**	**'ABR (1 month)' sensitivity test (%HGV increase relative to base composition in brackets)**	**Difference**
Putney Embankment Foreshore	4,484	*4,111*	*2,352*	6,463	18	25	7	46 (5.5%)	107 (11.9%)	61
Carnwath Road Riverside	22,656	*20,768*	*7,728*	28,496	88	110	22	99 (0.7%)	352 (2.4%)	253
Cremorne Wharf Depot	3,332	*3,055*	*768*	3,823	13	15	2	0.427 (0.2%)	35 (0.5%)	8
Chelsea Embankment Foreshore	6,342	*5,814*	*6,480*	12,294	25	48	23	92 (0.2%)	295 (0.7%)	203
Kirtling Street	49,224	*45,122*	*17,520*	62,642	190	241	51	210 (0.6%)	797 (2.4%)	587
Heathwall Pumping Station	4,292	*3,935*	*2,352*	6,287	17	25	8	38 (0.1%)	107 (0.3%)	69
Albert Embankment Foreshore	6,380	*5,849*	*3,936*	9,785	25	38	13	42 (0.1%)	179 (0.5%)	137

Site	Lorry movements				AAWT flows			Peak daily flows		
	Peak 12 months Transport Strategy	***11 months Transport Strategy***	***Peak month 'All By Road'***	**Total 'ABR (1 month)' annual movements**	**Transport Strategy**	**'ABR (1 month)' sensitivity test**	**Difference**	**Transport Strategy (%HGV increase relative to base composition in brackets)**	**'ABR (1 month)' sensitivity test (%HGV increase relative to base composition in brackets)**	**Difference**
Victoria Embankment Foreshore	3,846	*3,526*	*3,984*	7,510	15	29	14	31 (0.0%)	182 (0.3%)	151
Blackfriars Bridge Foreshore	13,224	*12,122*	*6,096*	18,218	51	71	20	101 (0.2%)	278 (0.4%)	177
Chambers Wharf	21,332	*19,555*	*15,120*	34,675	83	134	51	120 (8.3%)	688 (34.0%)	568
King Edward Memorial Park	10,072	*9,233*	*5,136*	14,369	39	56	17	90 (4.6%)	234 (11.1%)	144

AAWT flows represent the total number of lorry movements in a 12 month period, averaged over 260 weekdays in that period
Peak daily flows represent the total number of lorry movements in the busiest month for each scenario, averaged over 22 weekdays in that period.

Vol 3 Table J.4 Percentage change to AAWT base case thresholds

Site	Daily construction lorry movements (AAWT)		% increase if base daily flow = 2,000 veh		% increase if base daily flow = 5,000 veh		% increase if base daily flow = 10,000 veh		% increase if base daily flow = 20,000 veh	
	Transport Strategy (AAWT)	'ABR (1 month)' test (AAWT)	Transport Strategy (AAWT)	'ABR (1 month)' test (AAWT)	Transport Strategy (AAWT)	'ABR (1 month)' test (AAWT)	Transport Strategy (AAWT)	'ABR (1 month)' test (AAWT)	Transport Strategy (AAWT)	'ABR (1 month)' test (AAWT)
Putney Embankment Foreshore	18	25	0.9%	1.3%	0.4%	0.5%	0.2%	0.3%	0.1%	0.1%
Carnwath Road Riverside	88	110	4.2%	5.5%	1.7%	2.2%	0.9%	1.1%	0.4%	0.6%
Cremorne Wharf Depot	13	15	0.6%	0.8%	0.3%	0.3%	0.1%	0.2%	0.1%	0.1%
Chelsea Embankment Foreshore	225	48	1.2%	2.4%	0.5%	1.0%	0.2%	0.5%	0.1%	0.2%
Kirtling Street	190	241	8.7%	12.1%	3.7%	4.8%	1.9%	2.4%	0.9%	1.2%
Heathwall Pumping Station	17	25	0.8%	1.3%	0.3%	0.5%	0.2%	0.3%	0.1%	0.1%
Albert Embankment Foreshore	25	38	1.3%	1.9%	0.5%	0.8%	0.3%	0.4%	0.1%	0.2%
Victoria Embankment Foreshore	15	29	0.7%	1.5%	0.3%	0.6%	0.1%	0.3%	0.1%	0.1%
Blackfriars	51	71	2.5%	3.6%	1.0%	1.4%	0.5%	0.7%	0.3%	0.4%

Site	Daily construction lorry movements (AAWT)		% increase if base daily flow = 2,000 veh		% increase if base daily flow = 5,000 veh		% increase if base daily flow = 10,000 veh		% increase if base daily flow = 20,000 veh	
	Transport Strategy (AAWT)	'ABR (1 month)' test (AAWT)	Transport Strategy (AAWT)	'ABR (1 month)' test (AAWT)	Transport Strategy (AAWT)	'ABR (1 month)' test (AAWT)	Transport Strategy (AAWT)	'ABR (1 month)' test (AAWT)	Transport Strategy (AAWT)	'ABR (1 month)' test (AAWT)
Bridge Foreshore										
Chambers Wharf	83	134	4.0%	6.7%	1.6%	2.7%	0.8%	1.3%	0.4%	0.7%
King Edward Memorial Park	39	56	1.9%	2.8%	0.8%	1.1%	0.4%	0.6%	0.2%	0.3%

AAWT flows represent the total number of lorry movements in a 12 month period, averaged over 260 weekdays in that period

Vol 3 Table J.5 Percentage change to peak month daily base case thresholds

Site	Daily construction lorry movements Average weekday in peak month)		% increase if base daily flow = 2,000 veh		% increase if base daily flow = 5,000 veh		% increase if base daily flow = 10,000 veh		% increase if base daily flow = 20,000 veh	
	Transport Strategy	Peak month	Transport Strategy	Peak month	Transport Strategy	Peak month	Transport Strategy	Peak month	Transport Strategy	Peak month
Putney Embankment Foreshore	46	107	2.3%	5.4%	0.9%	2.1%	0.5%	1.1%	0.2%	0.5%
Carnwath Road Riverside	99	352	5.0%	17.6%	2.0%	7.0%	1.0%	3.5%	0.5%	1.8%
Cremorne Wharf Depot	27	35	1.4%	1.8%	0.5%	0.7%	0.3%	0.4%	0.1%	0.2%

Site	Daily construction lorry movements Average weekday in peak month)		% increase if base daily flow = 2,000 veh		% increase if base daily flow = 5,000 veh		% increase if base daily flow = 10,000 veh		% increase if base daily flow = 20,000 veh	
	Transport Strategy	Peak month	Transport Strategy	Peak month	Transport Strategy	Peak month	Transport Strategy	Peak month	Transport Strategy	Peak month
Chelsea Embankment Foreshore	92	395	4.6%	14.8%	1.8%	5.9%	0.9%	3.0%	0.5%	1.5%
Kirtling Street	210	797	10.5%	39.9%	4.2%	15.9%	2.1%	8.0%	1.1%	4.0%
Heathwall Pumping Station	38	107	1.9%	5.4%	0.8%	2.1%	0.4%	1.1%	0.2%	0.5%
Albert Embankment Foreshore	42	179	2.1%	9.0%	0.8%	3.6%	0.4%	1.8%	0.2%	0.9%
Victoria Embankment Foreshore	31	182	1.6%	9.1%	0.6%	3.6%	0.4%	1.8%	0.2%	0.9%
Blackfriars Bridge Foreshore	101	278	5.1%	13.9%	2.0%	5.6%	1.0%	2.8%	0.5%	1.4%
Chambers Wharf	120	688	6.0%	34.4%	2.4%	13.8%	1.2%	6.9%	0.6%	3.4%
King Edward Memorial Park	90	234	4.5%	11.7%	1.8%	4.7%	0.9%	2.3%	0.5%	1.2%

Peak daily flows represent the total number of lorry movements in the busiest month for each scenario, averaged over 22 weekdays in that period.

Summary and conclusions

J.1.56 Vol 3 Table J.6 summarises where the selected thresholds would be exceeded at individual sites for the *Transport Strategy* and the 'ABR (1 month)' sensitivity test.

Vol 3 Table J.6 Summary of significant changes to AADT and AAWT

Site	AADT		AAWT	
	Transport Strategy	'ABR (1 month)' sensitivity test	Transport Strategy (AAWT)	'ABR (1 month)' sensitivity test
Putney Embankment Foreshore	None	None	None	None
Carnwath Road Riverside	None	None	None	None
Cremorne Wharf Depot	None	None	None	None
Chelsea Embankment Foreshore	None	None	None	None
Kirtling Street	None	None	None	None
Heathwall Pumping Station	None	None	None	None
Albert Embankment Foreshore	None	None	None	None
Victoria Embankment Foreshore	None	None	None	None
Blackfriars Bridge Foreshore	None	None	None	None
Chambers Wharf	None	None	None	>20% increase in HGV composition, associated with approx >3dB increase in traffic noise.
King Edward Memorial Park	None	None	None	None

J.1.57 To place the summary results in Vol 3 Table J.6 in the context of the strategic road network in the vicinity of the main tunnel drive sites (ie those which would generate most lorry traffic in the absence of river transport):

a. at Carnwath Road Riverside, typical AADT figures on Wandsworth Bridge Road are in the order of 40,000 vehicles per day, which implies that increases due to the project should be well below 5% of this figure irrespective of the ‘ABR (1 month)’ sensitivity test

b. at Kirtling Street, typical AADT figures on Nine Elms Lane are in the order of 33,000 vehicles per day, which implies that increases due to the project should be well below 5% of this figure irrespective of the ‘ABR (1 month)’ sensitivity test

c. at Chambers Wharf, typical AADT figures on Jamaica Road are in the order of 23,000 vehicles per day, which implies that increases due to the project should be well below 5% of this figure irrespective of the ‘ABR (1 month)’ sensitivity test.

d. the increase in traffic at the Chambers Wharf site during the ‘ABR (1 month)’ scenario indicates an exceedance of more than 3dB which would be potentially significant. However, for a worst-case duration of one month, this is assessed as not significant.

J.1.58 The largest changes in either flow or %HGV relative to the most lightly trafficked links around the site have been identified in order to determine worst-case effects. For the connecting major feeder roads (eg A2 or A205) the proportionate changes would be considerably less than those worst-case changes identified around the individual sites. On both the local and strategic road networks the changes arising from the ‘ABR (1 month)’ scenario are classified as not significant due to the short duration of the ABR month.

J.1.59 On this basis it is concluded that changes in the AADT/AAWT figures as a result of the ‘ABR (1 month)’ scenario would not be significant and therefore the effects on air quality and noise and vibration would not be materially different from those presented in Vol 4-27 Sections 4 and 9 of the *Environmental Statement*.

Thames Tideway Tunnel
Thames Water Utilities Limited

Application for Development Consent

Application Reference Number: WWO10001

Environmental Statement

Doc Ref: **6.2.03**

Volume 3: Project-wide effects assessment appendices

Appendix K: Water resources - groundwater

APFP Regulations 2009: Regulation **5(2)(a)**

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Creating a cleaner, healthier River Thames

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Thames Tideway Tunnel

Environmental Statement

Volume 3 Appendices: Project-wide effects assessment

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Appendix K: Water resources – groundwater

K.1 Groundwater environmental monitoring strategy

Introduction

K.1.1 The Thames Tideway Tunnel Project will install a tunnel to transfer sewage from the most polluting combined sewer overflows (CSO) through central London to Beckton Sewage works. The tunnel extends from Ealing in the west, to Newham in the east and Greenwich in the south east. It is proposed to construct twenty four shafts both to facilitate the construction of the tunnel and to connect the tunnel to the CSOs.

K.1.2 The Environment Agency (EA) has requested that a groundwater monitoring strategy be included with the Environmental Statement for the project as required within any Development Consent Order (DCO). The results of the monitoring outlined in this strategy would be periodically reported via a *Groundwater environmental monitoring report* which would be issued to the EA for approval.

Objectives

K.1.3 The objective of this document is to set out a strategy to monitor the effects of the proposal on groundwater quality and quantity in the upper and lower aquifer throughout construction and operation of the Thames Tideway Tunnel. This includes measures to monitor the following:

a. mobilisation and migration (with the prevailing groundwater flow) of constituents (ie in grout mixes) used in tunnel/ shaft construction which have a contaminative potential, both during construction and in the long term

b. increased turbidity in groundwater due to the physical action of tunnelling construction within the chalk, and subsequent migration with the prevailing groundwater flow

c. seepage from the tunnel on groundwater quality

d. mobilisation of contaminants by the creation of alternative pathways, or significantly altering existing pathways

e. changes in water quality and levels as a result of dewatering.

K.1.4 This report outlines the strategy for the installation and monitoring of existing and additional monitoring holes for baseline, construction, post-construction and long-term monitoring, and identifies generic mitigation measures in the event of significant exceedences in groundwater quality during and post construction.

K.1.5 The strategy has been developed in consultation with the EA. A number of iterations of this document have been produced during the pre-application period. These iterations have taken into account feedback from the EA. It is possible that further changes to the monitoring network would be required. Any changes would be agreed with the EA prior to implementation and would be reported in an updated version of this document.

Scope of groundwater monitoring

K.1.6 Monitoring of construction and operational effects are embedded in the environmental design of the project through the application of this groundwater environmental monitoring strategy. The monitoring includes groundwater levels and groundwater quality. The monitoring regime described in the report will be developed during the life of the project in order to ensure that the project can identify and respond to changes in groundwater levels or groundwater quality as a result of any changes in the design and/or the site conceptual model.

Baseline groundwater monitoring

K.1.7 Baseline groundwater quality monitoring will continue prior to construction.

K.1.8 The pre-construction baseline will inform the setting of trigger levels, both quality and levels for the construction monitoring phase.

Construction monitoring

K.1.9 Construction groundwater quality monitoring will be undertaken during all phases of construction of the Thames Tideway Tunnel project.

K.1.10 At the end of construction, a start of operation baseline will be established against which the operational phase monitoring will be assessed.

Operational monitoring

K.1.11 Operational groundwater quality monitoring may be undertaken throughout the operational life of the Thames Tideway Tunnel. The intensity and frequency of operational monitoring would be agreed with the EA periodically.

Structure of document

K.1.12 Part A of this document contains the Thames Tideway Tunnel project context, the proposed construction methods, the geology to be encountered and the source-pathway-receptor model.

K.1.13 Part B gives details of the monitoring network, the measurement procedures and the suites of determinands to be analysed. The organisations most likely to be responsible for the delivery of the monitoring and reporting for the pre-, during construction and operation of the Thames Tideway Tunnel project are also included here.

Part A

Project context

Project layout

K.1.14 The proposed tunnel alignment and locations of the shafts are shown in Vol 3 Figure K.1.1 (see separate volume of figures).

Shaft construction

K.1.15 The Thames Tideway Tunnel would require the construction of 24 shafts, and associated shallow infrastructure, at 23 sites (two shafts would be required at Beckton Sewage Treatment Works).

K.1.16 The depth of the shafts would depend on their location with shaft depth becoming deeper from west to east. Where a shaft, and associated shallow infrastructure, would interact with the lower aquifer, dewatering would be required to enable construction. The construction methods likely to be employed at each shaft site are described in Vol 3 Table K.1.

Vol 3 Table K.1 Shaft Method of Construction

Area	Shaft site	Sprayed concrete lining (SCL)	Piled wall[i]	Segmental Shaft	Diaphragm walls[ii]	Depressurisation[iii] of Lambeth Group
West	Acton Storm Tanks	✓	✓	×	×	×
	Hammersmith Pumping Station	✓	✓	×	×	×
	Barn Elms	✓	✓	×	×	×
	Putney Bridge Foreshore	✓	✓	×	×	×
	Dormay Street	✓	✓	×	×	×
	King George's Park	✓	✓	×	×	×
	Carnwath Road Riverside	✓	✓	×	×	✓
	Falconbrook Pumping Station	✓	✓	×	×	×
	Cremorne Wharf Depot	✓	✓	×	×	×
Central	Chelsea Embankment	×*	×	✓	×	✓

[i] Sheet or secant pile wall – a sub-surface structure installed to support excavation and which amongst other things helps to control inflows of shallow groundwater typically formed of intersecting concrete or overlapping shafts of concrete.

[ii] Diaphragm wall – a sub-surface barrier installed around construction works to support the required excavation and which amongst other things helps to control inflows of groundwater typically formed of reinforced concrete. This barrier would extend down by up 8m below the base of the shaft invert, for structural reasons and to increase the length of the flow path and hence reduce the amount of groundwater inflows

[iii] Depressurisation – a term used to describe dewatering or lowering of hydraulic pressures in a confined aquifer.

Area	Shaft site	Sprayed concrete lining (SCL)	Piled wall[i]	Segmental Shaft	Diaphragm walls[ii]	Depressurisation[iii] of Lambeth Group
	Foreshore					
	Kirtling Street	×**	×	×	✓	×
	Heathwall Pumping Station	✓	✓	✓	×	✓
	Albert Embankment Foreshore	✓	✓	×	✓	×
	Victoria Embankment Foreshore	✓	✓	✓	×	✓
	Blackfriars Bridge Foreshore	×	✓	×	✓	×
East	Chambers Wharf	×	✓	×	✓	×
	King Edward Memorial Park Foreshore	×	✓	×	✓	×
	Earl Pumping Station	×	✓	×	✓	×
	Deptford Church Street	×	✓	×	✓	×
	Greenwich Pumping Station	×	✓	×	✓	×
	Abbey Mills Pumping Station	✓	×	×	✓	×
	Beckton Sewage Treatment Works	×	✓	×	✓	×

* Sprayed concrete lining would be required for the construction of the connection tunnel at Chelsea Embankment Foreshore.
** Sprayed concrete lining would be required for the construction of the chambers at the Kirtling Street site.

Shaft dewatering

K.1.17 No dewatering of the upper aquifer would be required for construction of the drop/main tunnel shafts or the tunnel route due to planned piling, segmental shaft or diaphragm walls to seal out the River Terrace Deposits.

K.1.18 Groundwater levels would have to be lowered in the vicinity of the central and eastern area shafts by dewatering of the lower aquifer to allow construction of the main tunnel shafts and CSO drop shafts. These areas are where either construction activities extend down into the lower aquifer or where the construction activities come close enough to the lower aquifer for them to be affected by the groundwater under high pressure, potentially causing heave effects (uplift). No dewatering is anticipated to be required for the construction of the main tunnels. Connection tunnels in the central section would require dewatering or depressurisation. The dewatering proposed at the shaft sites associated with these connection tunnels (at Cremorne Wharf Depot, Chelsea Embankment Foreshore, Heathwall Pumping Station, Albert Embankment Foreshore and Victoria Embankment Foreshore) would be sufficient for the construction of the connection tunnels.

Tunnel construction

K.1.19 The elements of construction for the proposed development, relevant to the consideration of groundwater includes:

a. A main tunnel approximately 25km in length and extending from Acton Storm Tanks to Abbeys Mills Pumping Station, with the following drive strategy:
   - i 6.5m internal diameter (ID) main tunnel driven from Carnwath Road Riverside to Acton Storm Tanks
   - ii 7.2m ID main tunnel driven from Kirtling Street to Carnwath Road Riverside
   - iii 7.2m ID main tunnel driven from Kirtling Street to Chambers Wharf
   - iv 7.2m ID main tunnel driven from Chambers Wharf to Abbey Mills.

b. Two long connection tunnels, with the following dimensions:
   - v 5.0m ID 4.6km Greenwich connection tunnel driven from Greenwich Pumping Station to Chambers Wharf
   - vi 2.6m to 3m ID 1.1km Frogmore connection tunnel driven from Dormay Street north to the main tunnel at Carnwath Road Riverside and south to King George's Park.

c. Nine short connection tunnels totalling approximately 1.2km which would be constructed in the London Clay and the Lambeth Group.

Geology

Regional geology

K.1.20 The regional geology of the London Basin is summarised in Vol 3 Table K.2.

Vol 3 Table K.2 Regional Geology (solid strata) of the London Basin

Era	Group	Formation	Approx Thickness (m)
Palaeogene	Thames	Bagshot Formation	10-25
		Claygate Member London Clay	30-90
		Harwich Formation	0-10
	Lambeth	Woolwich and Reading Beds	10-20
		Upnor Formation	5-7
	Thanet Sands		0-30
Cretaceous	Chalk		180-245

(Source: BGS Memoir Geology of London 2004)

K.1.21 Not all formations are represented throughout the London Basin and superficial deposits comprising Alluvium, Terrace Gravels, Brickearth and Peat are often present, and these may be overlain or replaced by Made Ground.

K.1.22 The following sections describe the anticipated tunnel geology and the geology at each shaft site.

Tunnel alignment geology

K.1.23 The route of the main tunnel would pass from west to east through a sequence of sedimentary strata from the London Clay Formation for approximately 12,000m then through the Lambeth Group (6,400m), Thanet Sands Formation (600m) and finally into the Chalk Group (6,100m). This sequence is shown in Vol 3 Table K.3 and in Vol 3 Figure K.1.1 (see separate volume of figures).

Vol 3 Table K.3 Geology of Main Tunnel and Connection Tunnel Sections

Geology	Tunnel chainage m (start)	Tunnel Chainage m (end)	Approx. m ATD (start)	Approx. m ATD (end)
Main Tunnel – Acton Storm Tanks to Abbey Mills				
London Clay	0	9150	75	61
Lambeth Group	9150	16700	61	51
Thanet Sands	16700	18850	51	51
Chalk	18850	25150	51	49
Greenwich Connection Tunnel – Chambers Wharf to Greenwich Pumping Station				
Chalk	0	4600	49	59
Frogmore Connection Tunnel – King George's Park to Carnwath Road Riverside				
London Clay	0	1120	83	55

Shaft geology

K.1.24 Of the twenty three shafts, eight shafts would extend down into the London Clay Formation, seven into the Lambeth Group and eight into the Thanet Sands/ Seaford Chalk. The geology and hydrogeology at these sites are summarised in Vol 3 Table K.4.

Vol 3 Table K.4 Geology at base of Shaft Sites

Site Name	Approx. Shaft Depth (m)	Geology
Acton Storm Tanks	30.8	London Clay Formation
Hammersmith Pumping Station	32.6	London Clay Formation
Barn Elms	33.8	London Clay Formation
Putney Embankment Foreshore	36.2	London Clay Formation
Dormay Street	23.6	London Clay Formation
King George's Park	20.4	London Clay Formation
Carnwath Road Riverside	42.3	Lambeth Group
Falconbrook Pumping Station	40.1	London Clay Formation

Site Name	Approx. Shaft Depth (m)	Geology
Cremorne Wharf Depot	42.1	London Clay Formation
Chelsea Embankment Foreshore	45.5	Lambeth Group
Kirtling Street	47.6	Upnor Formation
Heathwall Pumping Station	46.3	Lambeth Group
Albert Embankment Foreshore	47.1	Upnor Formation
Victoria Embankment Foreshore	49.5	Lambeth Group
Blackfriars Bridge Foreshore	53.3	Thanet Sands Formation
Chambers Wharf	57.3	Chalk
King Edward Memorial Park Foreshore	60.3	Chalk
Earl Pumping Station	50.4	Chalk
Deptford Church Street	47.8	Chalk
Greenwich Pumping Station	45.9	Chalk
Abbey Mills Pumping Station	66.8	Chalk
Beckton Sewage Treatment Works - Drive Shaft	32.0	Upnor Formation
Beckton Sewage Treatment Works - Reception Shaft	30.0	Thanet Sands Formation

Hydrogeology

K.1.25 The Chalk is the main aquifer of the London Basin and is confined over much of the area by the Tertiary formations (the Lambeth Group and Thanet Sands) and superficial deposits (Alluvium and River Terrace Deposits). The Chalk is classified by the EA as a Principal Aquifer. The Upnor Formation, Thanet Sands and Chalk are referred to as the lower aquifer.

K.1.26 The most permeable superficial deposits, the River Terrace Deposits, are referred to as the upper aquifer and are classified by the EA as a Secondary A Aquifer. The Alluvium, overlying the River Terrace Deposits, may act as confining layer for the upper aquifer at certain locations. At other locations, the Alluvium may be in hydraulic continuity with the upper aquifer.

K.1.27 The upper and lower aquifers are generally hydraulically separated by the London Clay Formation. The London Clay Formation is considered to act as an aquiclude between the upper and lower aquifers. Any groundwater present in a majority of the London Clay Formation is likely to consist of localised seepages and/or minor flows. The London Clay Formation is absent or less than 1m thick at the King Edward Memorial Park, Earl Pumping Station, Deptford Church Street and Greenwich Pumping Station shaft sites and therefore in these locations, depending on local conditions, the upper and lower aquifers may be in hydraulic continuity.

K.1.28 The Harwich Formation is present across much of the assessment area and is considered to form a minor aquifer unit where it is isolated from the lower aquifer by the Lambeth Group.

K.1.29 Within the Lambeth Group, several confined groundwater bodies are expected to be encountered. Groundwater is expected to be present through the Upper Shelly Beds and Upper Mottled Beds (potentially small inflows) and under high pressure within the Laminated Beds (formerly part of the Woolwich Formation).

K.1.30 The Thanet Sands and the Upnor Beds (lower unit of the Lambeth Group) are known as the 'Basal Sands' and are in hydraulic continuity with the Chalk aquifer beneath London. The Basal Sands is classified by the EA as a Secondary Aquifer.

K.1.31 The regional direction of groundwater flow within the London Basin is towards a point of low piezometric levels within central London. However, the groundwater gradient may be affected locally by abstractions, particularly during peak demand periods associated with major licences.

K.1.32 There are limited monitoring boreholes within the upper aquifer and at most shaft sites it has not been possible to accurately determine the direction of groundwater flow at these depths; however, it is likely to be local and towards the River Thames due to surrounding topography.

K.1.33 The Chalk groundwater level is shown in Vol 3 Figure K.1.1 (Environment Agency, 2011) (see separate volume of figures). The lower aquifer is likely to be confined and the tunnel is likely to be below the water table of the lower aquifer as it passes from the Lambeth Group into the Thanet Sands.

Licensed abstractions

K.1.34 There is one EA licensed abstraction (28/39/39/0225) from the upper aquifer located within 1km of the proposed shaft sites and the tunnel route. This licensed abstraction abstracts from the River Terrace Deposits.

K.1.35 There are 40 EA licensed abstractions from the lower aquifer either located within 1km (where abstractions are identified to be of particular importance and are beyond a kilometre from the tunnel they have been considered) of the proposed shaft sites or the tunnel route. The licensed abstraction sources listed in Vol 3 Table K.5 all abstract from the lower aquifer. In addition, there is one source in the upper aquifer, located in the central area which is used for industrial, commercial and public service purposes. The abstractions from the lower aquifer are summarised in table below

Vol 3 Table K.5 EA licensed abstractions from the lower aquifer

Area	Licence purpose	No. of licences
Central	Drinking water supply	11
	GSHP (heat pump or cooling)	12
	Industrial, commercial & public service (process water or irrigation)	4
Eastern	Drinking water supply	5
	GSHP (cooling)	3
	Industrial, commercial & public service (amenity top up water or horticultural)	4

K.1.36 There are three unlicensed abstractions from the Chalk aquifer located within 1km of the shaft sites and tunnel route, based on information provided by the London Boroughs. One of these unlicensed sources is used for drinking water supply and the purpose of the remaining two is unknown.

Source protection zones

K.1.37 The EA defines Source Protection Zones (SPZ) around all public water supply abstractions sources and large licensed private abstractions in order to safeguard groundwater resources from potentially polluting activities. SPZs are split into three zones: an SPZ 1 defined as a 50 day travel time to a source; an SPZ 2 defined as a 400 day travel time to a source; and an SPZ 3 represents the total catchment zone of a source.

K.1.38 The proposed Kirtling Street and Heathwall Pumping Station shaft sites are located within SPZ 1 associated with the Thames Water Battersea public water abstraction.

K.1.39 The proposed Deptford Church Street shaft is located within SPZ 3 of the Thames Water Deptford public water abstraction. Greenwich Pumping Station shaft is located within SPZ 1 of the Deptford abstraction.

K.1.40 The tunnel crosses SPZ 1 and 2 associated with the Battersea abstraction, and passes in close proximity to the SPZ 1 associated with the Mantilla Ltd Dolphin Square private water supply.

K.1.41 The tunnel passes through SPZ 1 and 2 associated with the Thames Water Deptford abstraction between Earl and Greenwich Pumping Station shafts .

Pollutant linkages

Sources of contamination

Made ground

K.1.42 The proposed development will involve the removal of the Made Ground from within the footprint of the shaft as part of the development of the shafts. It is considered that the potential sources of contamination would be removed, subject to the findings of the Quantiative Risk Assessments to be undertaken for each site.

Upper aquifer

K.1.43 The baseline groundwater quality data have been sourced from the ground investigation and monitoring works undertaken as part of the Thames Tideway Tunnel project and compared to UK drinking water standards and relevant Environmental Quality Standards (EQS).

K.1.44 Widespread existing groundwater contamination has been identified within the River Terrace Deposits (or upper aquifer). Vol 3 Table K.6 summarises pollutants detected to date.

Vol 3 Table K.6 Elevated Concentrations of Determinands within upper aquifer

Locations (nearest shaft)	Borehole	Response Zone Strata	Detected determinands*
Acton Storm Tanks	SA4302	ALV	1,1,1 – Trichloroethane, Benzene, Diuron, Trichloroethene, Xylene, Nickel
Chelsea Embankment Foreshore	PR1088U	RTD	Carbendazim, Carbetamide, Chlortoluron, Cypermethrin, Diuron, Mercury, Xylene,
Heathwall Pumping Station	PR1085	ALV	Benzene, Benzo[a]Pyrene, Cadmium, Mercury, Aluminium, Lead
King Edward Memorial Park	SR1033A	RTD	Benzene, Cadmium, Cypermethrin, Mercury, Xylene, Aluminium, Arsenic, Chromium, Lead, Nickel, Zinc
Bell Lane Creek	SR1108	RTD	Benzene, Bromate,

Locations (nearest shaft)	Borehole	Response Zone Strata	Detected determinands*
(Dormay Street)			Chloroform, Clopyralid, Mercury, Xylene
Jews Row (Carnwath Road Riverside)	SR1102A	RTD	Benzene, Benzo[a]Pyrene, Cypermethrin, Mercury, Trietazine, Xylene, Arsenic, Nickel
Bridge Court Car Park (Falconbrook Pumping Station)	SA1099A	RTD	Benzene, Dalapon, Mercury, Trichloroethene,
Earl Pumping Station	SA6455, SA6450 and SR4118	RTD	Anthracene, Benzene, Fluroanthene, Naphthalene, Phenol, Polycyclic Aromatic Hydrocarbons (PAH) and Xylene

*Non-hazardous substances are listed where they have breach their respective standard.

Lower aquifer

K.1.45 Several 'hotspots' of groundwater contamination have been identified within the Thanet Sands and the Chalk (lower aquifer), around the central and eastern shaft sites. This contamination is spatially variable and indicative of poor groundwater quality near the shaft sites and the tunnel route. Vol 3 Table K.7 summarises pollutants detected to date.

K.1.46 Approximately ten sites (out of total of 13 central and eastern sites) are known to be or expected to be contaminated within the lower aquifer.

K.1.47 In addition, elevated baseline levels of salinity are present within the upper and lower aquifers along the eastern part of the main tunnel route and around the eastern shaft sites. The occurrence of brackish conditions is to be expected given the close proximity of the tunnel route to the tidal Thames.

Vol 3 Table K.7 Elevated Concentrations of Determinands within lower aquifer

Locations	Borehole	Response Zone Strata	Detected determinands*
Chelsea Embankment Foreshore	SR1089	TSF	Benzo[a]Pyrene, Carbendazim, Chlortoluron, Diuron, Mercury, Aluminium, Arsenic
Blackfriars Bridge Foreshore	SR1061A	TSF	Benzene, Benzo[a]Pyrene, Carbendazim, Cypermethrin, Diuron, Mercury, PAHs, Toluene, Xylene, Aluminium, Lead,

Locations	Borehole	Response Zone Strata	Detected determinands*
			Molybdenum, Titanium, Zinc
King Edward Memorial Park	SR1033H	Chalk	Benzo[a]Pyrene, Mercury, Xylene,
Earl Pumping Station	SR1048	Chalk	Benzene, Benzo[a]Pyrene, Cypermethrin, Mecoprop, Mercury, PAHs, Toluene, Xylene, Aluminium, Barium, Tin, Titanium
Greenwich Pumping Station	SR1024	Chalk	Atrazine, Benzo[a]Pyrene, Cadmium, Cypermethrin, Dichlorprop, Diuron, Mercury, Xylene, Aluminium, Barium, Tin, Titanium
Kings Stairs Garden (near Chambers Wharf)	SR1055	Chalk	Benzene, Cadmium, Mercury, PAHs, Toluene, Xylene, Arsenic, Barium, Lead, Nickel, Titanium
Abbey Mills to King Stairs Route	SR3007	Chalk	1,2 – Dichloroethane, Benzene, Benzo[a]Pyrene, Mercury, PAHs, Toluene, Xylene, Aluminium, Lead, Titanium
Earl Pumping Station	SA6451 & SA6455	TSF	Anthracene, Benzene, heavy metals, Naphthalene, Phenol, PAHs and Xylene

*Non hazardous substances listed where they have breach their respective standards.

Construction materials

K.1.48 There is the potential for construction materials to come into contact with groundwater. As outlined in the *CoCP,* approval will be sought from the Environment Agency regarding all materials prior to use. As part of the approval process a risk assessment will be undertaken to determine whether the materials pose a risk of polluting groundwater. The materials that may be used and have the potential to act as sources of pollution include:

a. Bentonite Support Fluid for Diaphragm Wall

b. Diaphragm Wall and Base Slab Concrete

c. Shaft/ Tunnel Grout and Tail Skin Sealant.

Tunnel seepage

K.1.49 Seepage of CSO discharges during operation of the tunnel has the potential to act as a source of pollution.

K.1.50 Groundwater quality monitoring will be introduced at each shaft site prior to construction and in between certain shaft sites. Depending on the shaft/tunnel construction depths, monitoring of the upper aquifer and (where relevant) the lower aquifer water quality will be required to form a comprehensive baseline suite. Section K.1.56 discusses and elaborates on the need for groundwater quality monitoring locations across the project area.

Pathways

K.1.51 There is the potential for a direct pathway to the lower aquifer at the following shaft sites:

a. Blackfriars Bridge Shaft which penetrates the Thanet Sands

b. Chambers Wharf, King Edward Memorial Park, Earl Pumping Station, Deptford Church Street, Greenwich Pumping Station, and Abbey Mills Pumping Station shafts, all within the Chalk

c. Kirtling Street and Albert Embankment Foreshore, whose base slabs are within the Upnor Formation.

K.1.52 No other potential direct pathways to the lower aquifer have been identified in Appendix K.1.

Receptors

K.1.53 The main receptors are the upper aquifer (River Terrace Deposits), lower aquifer, and the various Chalk abstractions, including commercial, industrial, drinking water abstractions and ground source heat pump schemes.

Part B

Monitoring strategy

Objectives and rationale

K.1.54 Based on the source-pathway-receptor linkages identified above, monitoring of groundwater in the lower aquifer is proposed to enable the following:

a. Collection of groundwater level data pre-, during construction and operation to provide a baseline and to assess whether the tunnel and shafts have significantly impacted groundwater flow during construction and operation.

b. Collection of groundwater quality samples pre-construction to:

   i Establish baseline groundwater quality and identify trends and determine trigger levels, where possible

c. Collection of groundwater quality samples during construction, and operation, to establish whether:

i mobilisation and migration of constituents in grout/ lubricant mixes has taken place

ii increases in turbidity in groundwater due to the physical action of tunnelling construction within the chalk can be detected

iii significant changes in water quality as a result of dewatering and tunnel seepages have occurred

K.1.55 Before reviewing the monitoring deliverables in each of the three phases, a summary of the monitoring network and methodologies to be used is given.

Proposed monitoring holes

K.1.56 44 groundwater monitoring locations have been selected along the tunnel alignment to satisfy the above objectives. The locations of the boreholes have been chosen based on the tunnel/ shaft geology, anticipated groundwater flow directions during abstraction, proximity to groundwater abstractions, and groundwater quality. They also take into account existing third part monitoring locations, for example EA and Thames Water Monitoring boreholes.

K.1.57 The borehole locations are shown in Vol 3 Figure K.1.1 (see separate volume of figures). The purpose and justification of each borehole is summarised in Vol 3 Table K.8.

K.1.58 The network of monitoring holes will be reviewed following further site investigation currently being undertaken for the Thames Tideway Tunnel project. For example, if a sufficient thickness of clay in the Lambeth Group is present below the base of the shafts at Kirtling Street, Heathwall Pumping Station, Albert Embankment Foreshore and Victoria Embankment Foreshore and the risks of the construction of the shaft polluting the lower aquifer is shown to be negligible then monitoring of the lower aquifer at these locations may not be necessary.

K.1.59 It is recommended that a groundwater level recorder/logger be installed within the Thanet Sands and/or Chalk where it is proposed to dewater and where the borehole is positioned to monitor the impacts of construction on a licensed abstraction.

Vol 3 Table K.8 Purpose and justification of monitoring boreholes

Locations	Borehole	Status	Purpose	Response Zone	Justification
Main Tunnel					
Acton Storm Tanks	SA4302	Existing	GWQL	ALV	Shaft – water quality/ levels
Hammersmith Pumping Station	PR1117	Existing	GWQL	RTD	Shaft – water quality/ levels
Barn Elms	SA1115	Existing	GWQL	RTD	Shaft – water quality/ levels
Putney Embankment Foreshore	SA6910	Proposed	GWQL	RTD	Shaft – water quality/ levels
Carnwath Road Riverside	SA6301	Proposed	GWQL	RTD	Shaft – water quality/ levels
Bridge Court Car Park (Falconbrook Pumping Station)	SA1099A	Existing	GWQL	RTD	Shaft – water quality/ levels
Cremorne Wharf Depot	SA1098	Existing	GWQL	MG/RTD	Shaft – water quality/ levels
Chelsea Embankment Foreshore	SR1091	Existing	GWQL	RTD	Shaft – water quality/ levels
	SR1089	Existing	GWQL/ logger	TSF	Shaft – water quality/ levels / Depressurisation LG
Kirtling Street	SR6907	Proposed	GWQL/ logger	CHALK	Shaft – water quality/ levels/ DWS 28/39/42/0072/ Depressurisation LG by under draining Chalk
	SA1084	Existing	GWQL	RTD	Shaft – water quality/ levels
	PR1081	Existing	GWQL	CHALK	Shaft – water quality/ levels

Locations	Borehole	Status	Purpose	Response Zone	Justification
Main Tunnel					
Heathwall Pumping Station	PR1085	Existing	GWQL	ALV	Shaft – water quality/ levels
	PR1081	Existing	GWQL	CHALK	Shaft – water quality/ levels
	SR6908	Proposed	GWQL/ logger	CHALK	Shaft – water quality/ levels/ DWS 28/39/39/0141
Albert Embankment Foreshore	SR6090	Proposed	GWQL	RTD	Shaft – water quality/ levels
	SR6091	Proposed	GWQL	CHALK	Shaft – water quality/ levels/ Depressurisation LG by under draining Chalk
	SR6906	Existing	GWQL/ logger	CHALK	Shaft – water quality/ levels/ DWS 28/39/39/0139
Victoria Embankment Foreshore	SA1066D	Existing	GWQL	RTD	Shaft – water quality/ levels
	4053	Proposed	GWQL/ logger	TSF	Shaft – water quality/ levels / Depressurisation of LG
Blackfriars Bridge Foreshore	6391	Proposed	GWQL	RTD	Shaft – water quality/ levels
	SR6390	Proposed	GWQL/ logger	CHALK	Shaft – water quality/ levels / Depressurisation LG by under draining Chalk
City Hall (between Blackfriars Bridge and Chambers Wharf)	SR6909	Proposed	GWQL/logger	CHALK	Shaft – water quality/ levels/ DWS 28/39/42/0062
Chambers Wharf	SR4102	Proposed	GWQL/ logger	CHALK	Shaft – water quality/ levels / Dewatering of Chalk (internal)
	SA4104	Proposed	GWQL	RTD	Shaft – water quality/ levels /

Locations	Borehole	Status	Purpose	Response Zone	Justification
Main Tunnel					
					Dewatering of Chalk (internal)
Kings Stairs Garden (near Chamber Wharf)	SR1055	Existing	GWQL	CHALK	Shaft – water quality/ levels/ DWS 28/39/42/0048
King Edward Memorial Park	SR1033H	Existing	GWQL	CHALK	Shaft – water quality/ levels / Dewatering of Chalk (internal)
	SR1033A	Existing	GWQL	RTD	Shaft – water quality/ levels
Abbey Mills to King Edward Memorial Park	SR3007	Existing	GWQL	CHALK	Tunnel – water quality/ levels
Abbey Mills PS	PW1	Existing Lee Tunnel	GWQL	CHALK	Shaft – water quality/ levels/ DWS 29/38/09/0149/ Dewatering of Chalk (internal)
	BH13D-1	Existing Lee Tunnel	GWQL	RTD	Shaft – water quality/ levels/ DWS 29/38/09/0149/ Dewatering of Chalk (internal)
	SP1-CH	Existing Lee Tunnel	GWQL/ logger	CHALK	Shaft – water quality/ levels/ DWS 29/38/09/0149/ Dewatering of Chalk (internal)
Greenwich Connection Tunnel					
Surrey Quays Shopping Centre (BH3) (near Earl Pumping Station)	SR4021	Proposed	GWQL/ logger	CHALK	Shaft – water quality/ levels/ DWS 28/39/42/0048
Earl Pumping Station	4093	Proposed	GWQL	RTD	Shaft – water quality/ levels
	SR4118	Proposed	GWQL	CHALK	Shaft – water quality/ levels / Dewatering of Chalk (internal)

Locations	Borehole	Status	Purpose	Response Zone	Justification
Main Tunnel					
	SA6453A	Proposed	GWQL	TSF	Shaft – water quality/ levels
Deptford Church Street	SR4117	Proposed	GWQL	CHALK	Shaft – water quality/ levels / Dewatering of Chalk (internal)
	SA4031	Proposed	GWQL	RTD	Shaft – water quality/ levels
	SR6902	Proposed	GWQL	CHALK	Shaft – water quality/ levels / Dewatering of Chalk (internal)
Greenwich Pumping Station	SR1024	Existing	GWQL	CHALK	Shaft – water quality/ level/ DWS 28/39/43/0019/ Dewatering of Chalk (internal)
	PR1023	Existing	GWQL	ALV	Shaft – water quality/ levels
	4087	Proposed	GWQL/logger	CHALK	Shaft – water quality/ levels/ DWS 28/39/43/0019/ Dewatering of Chalk (internal)
Frogmore Connection Tunnel					
Dormay Street	PR1107	Existing	GWQL	RTD	Shaft – water quality/ levels
King George's Park	SA1110	Existing	GWQL	MG	Shaft – water quality/ levels

Note: MG-Made Ground, RTD-River Terrace Deposits, ALV-Alluvium and TSF-Thanet Sand Formation, GWQL – Groundwater quality and level monitoring from boreholes

K.1.60 Borehole construction will be in accordance with: BS ISO 5667-22: 2009 "Water Quality – Sampling – Part 22: Guidance on the design and installation of groundwater monitoring points"

K.1.61 The deep boreholes are intended to measure water levels in, and enable sample collection from the lower aquifer. This comprises Thanet Sands overlying the Chalk aquifer.

K.1.62 The shallow boreholes are intended to measure water levels and groundwater quality of the upper aquifer in the vicinity of the shafts.

K.1.63 The deep borehole well screens will be installed within either the Chalk or Thanet Sands using a minimum screen length of 10m. A bentonite seal will be used through the Made Ground, Lambeth Group, Upnor Formation and Thanet Sands to ensure that no contamination pathway is created between the lower and the upper aquifers. For the same reason, standard practice aquifer protection methods will be employed during drilling.

K.1.64 All construction details will be provided once installation has been completed.

Sample collection methodology

General

K.1.65 Groundwater will be sampled in accordance with BS ISO 5667-11: 2009 "Water Quality – Sampling – Part 11: Guidance on sampling of groundwaters".

Data loggers

K.1.66 Data loggers will be installed within trigger monitoring boreholes to record measurements of water level, pH, temperature, electrical conductivity, and turbidity at 1 hour intervals.

Groundwater

K.1.67 Groundwater samples will not be collected from monitoring holes until the standing water/stagnant water has been purged/removed, to ensure that the groundwater sample collected is representative of groundwater within a given formation. Prior to purging the well on first sampling visit, a dip meter will be used to establish the groundwater level.

K.1.68 Some groundwater chemistry parameters are unstable and are liable to change during sample collection, handling, transport and storage. Representative readings of the following parameters will be taken in the field, before the samples are placed in suitable containers:

a. pH value

b. Electrical Conductivity (µS/cm)

c. Redox Potential

d. Dissolved Oxygen (%)

e. Temperature (^{o}C).

Monitoring frequency

Baseline

K.1.69 It is proposed to monitor and sample the monitoring holes on a quarterly basis in the year before construction starts and analyse for the parameters identified in Vol 3 Table K.9. Any new boreholes be sampled and a comprehensive suite of analysis completed using the long list (see Annex A).

K.1.70 Data loggers will be used to monitor water level, pH, temperature, electrical conductivity, turbidity (if the shaft/ tunnel is within the Chalk) at 1 hour intervals to provide a pre-construction baseline.

Construction

K.1.71 It is proposed to monitor water level, pH, temperature, electrical conductivity, and turbidity (if the shaft/ tunnel is within the Chalk) at 1 hour intervals.

K.1.72 Monthly borehole monitoring of groundwater quality will be undertaken using the parameters identified in Vol 3 Table K.9.

K.1.73 If dewatering is required at a shaft site weekly monitoring of discharge water (in-line tap) will be undertaken using the parameters identified in Vol 3 Table K.9.

Operation

K.1.74 It is proposed to monitor water level, pH, temperature, electrical conductivity, and turbidity (where the shaft/ tunnel is within the Chalk) at 1 hour intervals for a period of up to 12 months.

K.1.75 Quarterly monitoring of groundwater quality will be undertaken using the parameters identified in Vol 3 Table K.9 for a period of up to 12 months and reported with two months.

Long term

K.1.76 Annual monitoring of groundwater will be undertaken using the parameters identified in Vol 3 Table K.9, or a reduced suite and frequency will be agreed with the EA.

Determinands for analysis

K.1.77 The list of determinands for analyses has been developed in consultation with the EA. It is proposed that the list of determinands are used to define baseline groundwater quality for the Thames Tideway Tunnel project. Baseline monitoring will be an iterative process, the first round of monitoring at any borehole would use an extended list, the “long list” (see Annex A), to define baseline conditions. This list consists of around 300 substances and Gas Chromatography Mass Spectrometry scans to identify additional parameters.

K.1.78 Subsequently, a Thames Tideway Tunnel specific substance list (the Project list), consisting of approximately 80 substances (including field parameters, major and minor ions, metals, herbicides, pesticides, Poly-Aromatic Hydrocarbons (PAH), phenols, solvents, urons and pyrethroids) would be applied. The Project list is summarised in Vol 3 Table K.9.

K.1.79 Those additional substances detected from the long list sampling will be added to the Project list for on-going monitoring. Once the construction materials have been identified (ie grouts, tail skins sealant) the Project list will be further updated. The Project list is not definitive and will routinely be reviewed and updated.

Vol 3 Table K.9 Determinands for analysis – Project list

Determinands	Limit of Detection	Units
Calcium	<7.4	mg/l
Magnesium	<0.1	mg/l
Sodium	<2.5	mg/l
Potassium	<0.75	mg/l
Alkalinity (Carbonate)	<4	mg/l as CaCO3
Alkalinity (Bicarbonate)	<10	mg/l
Chloride	<0.05	mg/l
Sulphate	<1.7	mg/l as SO4
Extra over Item B to undertake Suite 1 (WS1) Testing		
1,1,1-Trichloroethane	<1.3	µg/l
1,1,2-Trichloroethane	<2.2	µg/l
1,2-dichloroethane	<1	µg/l
Ammonia	<0.05	mg/l as N
Atrazine	<0.003	µg/l
Bentazone	<0.008	µg/l
Benzene	<0.007	µg/l
Bromate	<0.5	µg/l
Carbon tetrachloride	<0.07	µg/l
Chlorfenvinphos	<0.009	µg/l
Chloroform	<0.6	µg/l
Cypermethrin	<0.005	µg/l
Diazinon	<0.009	µg/l
Dichloromethane	<3	µg/l
Diuron	<0.005	µg/l
Isoproturon	<0.003	µg/l

Determinands	Limit of Detection	Units
Mecoprop	<0.01	µg/l
Nitrate	<0.043	mg/l as N
Pentachlorophenol	<0.02	µg/l
Permethrin-cis+trans	<0.01	µg/l
Phenol	<0.5	µg/l
Propetamphos	<0.005	µg/l
Simazine	<0.004	µg/l
Tetrachloroethene (PCE)	<0.09	µg/l
Trichloroethene (TCE)	<0.07	µg/l
Xylene-p+m	<0.09	µg/l
Extra over Items B and WS1 to undertake Suite 2 (WS2) Testing		
Aluminium	<0.012	mg/l
Arsenic	<1	µg/l
Benzo(a)pyrene	<0.001	µg/l
Boron	<10	µg/l
Cadmium	<1.5	µg/l
Carbendazim	<0.003	µg/l
Carbetamide	<0.006	µg/l
Chlortoluron	<0.004	µg/l
Chromium	<0.7	µg/l
Clopyralid	<0.019	µg/l
Copper	<5.5	µg/l
Cyanazine	<0.007	µg/l
Dalapon	<0.05	µg/l
Dichlorprop	<0.011	µg/l
Fluoride	<0.06	mg/l
Glyphosate	<0.014	µg/l
Lead	<5	µg/l
MCPA	<0.009	µg/l
Mercury	<0.002	µg/l
Metazachlor	<0.008	µg/l
Nickel	<4	µg/l

Determinands	Limit of Detection	Units
Propazine	<0.004	µg/l
Terbutryn	<0.003	µg/l
Trietazine	<0.006	µg/l
Trifluralin	<0.01	µg/l
Zinc	<5	µg/l
Others		
Barium	<2	µg/l
Iron	<0.018	mg/l
Manganese	<0.012	mg/l
Molybdeum	<5	µg/l
Strontium	<0.29	mg/l
Tin	<5	µg/l
Titanium	<16	µg/l
Cypermethrin	<0.1	µg/l
PAH	<0.1	µg/l
Ethlybenzene	<1	µg/l
Xylene	<1	µg/l
Toluene	<0.06	µg/l
Total Petroleum Hydrocarbons (TPH)	<10	µg/l
pH	<1	pH units

Note WS1 and WS2 refer to laboratory suites currently used by Thames Tunnel

Generic trigger levels for groundwater quality and levels

K.1.80 The baseline groundwater level and water quality data would be used to derive trigger levels using statistical techniques for trigger monitoring sites. The trigger levels would be reported as a range, value ie single reading available or a step-change ie two readings any significantly different, depending on the available data, above which the contingency plan would be activated. If the water quality data is of sufficient quantity the basis for defining these values would be a full statistical analysis of the baseline monitoring data, otherwise the range for each parameter will be used. The water level trigger level would be based on undertaking a risk assessment and defining a water level at a compliance point. The trigger levels would be approved by the Environment Agency and would be site specific.

K.1.81 The trigger levels will be used as a guide to determine whether the contingency plan needs to be activated. During construction it is anticipated that the groundwater level and quality data will be screened on a weekly basis. The loggers will measure physical and chemical parameters as listed in Vol 3 Table K.10.

Vol 3 Table K.10 Data logger physical and chemical parameter monitoring

Test	Unit	Trigger Level	Basis
pH	pH units	range	Range based on baseline monitoring
EC (20°C)	mS /cm	>value	Value based on baseline monitoring
Turbidity	ntu	>value	Value based on baseline monitoring
Temperature	°C	>Step-change	Step change based on baseline monitoring
Water Level	m	>value	Value based on baseline monitoring and impact assessment

K.1.82 The baseline groundwater quality data would also be used to define site specific ranges for each determinand in the Project list. The construction and operational groundwater quality monitoring would be compared with these ranges to determine whether any exceedances have occurred. If the data is of sufficient quantity the approach to selecting these ranges would be based on similar principles to those used for the Lee Tunnel monitoring statistical analysis ie an early warning level defined as the maximum recorded result and a maximum exceedance level defined as 1.645 standard deviations above that of the early warning level (Mott MacDonald, 2010[1]). If no previous detectionsof non-hazardous substances have been observed the early warning would be 3 times the detection limit and the maximum level 5 times the detection limit. The underlying assumption is that the variation in water quality is normally distributed. Trigger level for hazardous substances are detections.

Monitoring deliverables

K.1.83 The groundwater monitoring deliverables (at the following project stages: pre-, during construction and operational phases) are shown below. The monitoring frequency would be as outlined above.

Baseline groundwater monitoring

K.1.84 Monitoring has been undertaken by the Thames Tideway Tunnel project and is reported in the *Environmental Statement* groundwater baseline monitoring report (in preparation).

Pre-construction baseline groundwater monitoring

K.1.85 Baseline groundwater quality monitoring will be the responsibility of the Thames Tideway Tunnel project and would involve:

a. continuous groundwater level, electrical conductivity, temperature, pH and turbidity using downhole loggers at identified trigger sites

b. quarterly monitoring of a range of organic and inorganic determinands

c. identification of baseline conditions, including trends and trigger levels of key determinands.

K.1.86 A one-off pre-construction groundwater baseline monitoring report would be prepared two months ahead of construction, setting out the baseline conditions and trigger level against which construction monitoring can be prepared.

Construction monitoring

K.1.87 Construction groundwater quality monitoring will be undertaken by the contractor(s), which will involve:

a. continuous groundwater level, electrical conductivity, temperature, pH and turbidity using downhole loggers at trigger sites

b. monthly monitoring of a range of organic and inorganic determinands

c. weekly monitoring of pumped water during dewatering activities of a range of organic and inorganic determinands

d. comparison of construction monitoring with baseline trends and identified trigger levels

e. consistency checks on measurements with blank samples and/or inter-laboratory comparisons.

K.1.88 Regular construction monitoring reports would be produced. A final Construction Groundwater Environmental Monitoring Report would also be produced.

Operational monitoring

K.1.89 Operational groundwater quality monitoring would be undertaken by Thames Water or the infrastructure operator should this be different and would involve:

a. continuous groundwater level, electrical conductivity, temperature, pH and turbidity using downhole loggers at trigger sites

b. quarterly monitoring of a range of organic and inorganic determinands for a period of up to one year

c. comparison of operational monitoring with baseline trends and identified trigger levels

d. consistency checks on measurements with blank samples and/or inter-laboratory comparisons.

K.1.90 Long-term groundwater quality monitoring will be undertaken by Thames Water , which would involve the annual operational monitoring of a range of organic and inorganic determinands.

K.1.91 This groundwater environmental monitoring strategy will be a live document, to be updated as necessary. The frequency and detail of monitoring would be amended to suit conditions and in consultation with EA.

Contingency action plan

K.1.92 If, during construction or operation, trigger levels are exceeded the Contingency Action Plan (CAP) would be followed. This would include the following actions:

a. Contact with the Environment Agency within a week

b. Determining the cause of any exceedences

c. Evaluation of location, likely scale, duration and effect

d. Identification of mitigation measures.

K.1.93 Potential solutions are to be identified by the contractor in advance and an emergency preparedness plan drawn up. The plan could include, for example ground treatment, and water treatment options in the event of a trigger level being exceeded, as well as identifying possible alternative routes for the safe disposal of water should the need arise.

Reporting and sign-off

K.1.94 The responsibility for reporting will be in-line with the deliverables for pre-, during construction and operation phases set out above.

Baseline groundwater reporting

K.1.95 An *Environmental Statement* baseline groundwater monitoring report containing all the groundwater levels and groundwater quality information used in the preparation of the *Environmental Statement* would be produced by the time of publication of the *Environmental Statement*.

K.1.96 Following the completion of the pre-construction baseline monitoring a second baseline monitoring report and 'contingency action plan' will be prepared and agreed with the Environment Agency. This 'pre-construction' baseline report will include all historic and current groundwater level and quality data, including the most recent Thames Tunnel and Environment Agency information. Trends in key water quality parameters will be assessed and appropriate trigger levels defined at this stage.

Construction reporting

K.1.97 During construction regular groundwater quality monitoring reports will be prepared and submitted to the Environment Agency for approval on a six month basis.

K.1.98 At the end of construction period, a 'pre-start of operation baseline monitoring report' will be prepared and submitted to the Environment Agency within two months of the start of operational phase.

Operational reporting

K.1.99 For the operational monitoring phase, annual reports will be submitted to the Environment Agency for information.

K.2 Impact of shaft construction dewatering on groundwater levels simulated by a regional numerical groundwater model

Summary

K.2.1 A distributed numerical groundwater model has been developed to quantify the effect of shaft dewatering on:

a. licensed and unlicensed groundwater users

b. water resources in the lower aquifer as a whole

c. saturation of the Thanet Sands

d. groundwater flow direction and velocity.

K.2.2 The model simulates the lower aquifer (Thanet Sands and Chalk) and incorporates three layers; the Lambeth Group, Thanet Sands and Chalk. It includes major faults and uses the same hydraulic properties as the EA London Basin Groundwater Model (LBM), (EA and ESI, 2010)[2] where possible.

K.2.3 The Thames Tideway Tunnel project model has been produced using USGS MODFLOW 2000 to simulate the change in water level as a result of dewatering in the lower aquifer and at a number of specific locations within central London. The sensitivity of the model to input parameters was examined.

K.2.4 The model was also used to quantify the volumes of water to be abstracted to achieve the shaft construction dewatering aims, and to identify the strategies that could result in reduction in the effect of the shaft construction dewatering activities.

K.2.5 The main points relating to the model, its development and use are as follows:

a. A multi layer numerical model of the London Basin was developed, including the major faults in the Greenwich area and hydraulic property information provided by the London basin model (LBM).

b. Drawdown across London was simulated, including assessments of effects on specific targets/receptors.

c. Dewatering proposals around Deptford Church Street, Earl Pumping Station, Abbey Mills Pumping Station and Greenwich Pumping Station were reviewed. The dewatering strategy was revised at these sites and embedded mitigation in the form of internal dewatering was adopted to minimise the effects of dewatering.

K.2.6 The results of the model are used in the groundwater impact assessments for each site and also in the project-wide groundwater assessment.

K.2.7 The shafts with the greatest predicted dewatering are at Kirtling Street and Blackfriars Bridge Foreshore.

K.2.8 The model results have some sensitivity to the parameters used, but the greatest sensitivity is to the hydrogeological and hydraulic conditions associated with faults.

K.2.9 The LMB has been run to simulate project dewatering and to verify the predictions of the Thames Tideway Tunnel project model (see para K.2.98).

Introduction

Background

K.2.10 Dewatering activities will take place at selected sites. The impact of dewatering can extend beyond the immediate vicinity of the shaft and dewatering at one shaft can assist with the dewatering at a nearby shaft. This interference of dewatering effects means that an assessment of dewatering at an individual shaft would overestimate the pumping effort required. A project wide approach to the impact of dewatering has therefore been adopted.

K.2.11 Initially the impact of dewatering was assessed using well interference calculations. The method allowed a programme of pumping to be simulated. However it was limited to the use of uniform transmissivity and uniform abstraction rates. The transition between confined and unconfined conditions could not be incorporated nor leakage between layers with different hydraulic properties. To circumvent the limitations of spreadsheet well interference calculations a distributed numerical groundwater model has been developed; referred to in this report as the Thames Tideway Tunnel project model.

K.2.12 The model simulates the lower aquifer (Thanet Sands and Chalk) and incorporates three layers; the Lambeth Group, Thanet Sands and Chalk. It includes major faults and uses the same hydraulic properties as the EA London Basin Groundwater Model (LBM), (EA and ESI, 2010)[3] where possible. The LBM properties were provided for use in the Thames Tideway Tunnel project model prior to the final version of the LBM issued to the EA, thus the values of hydraulic properties may in some areas differ to the LBM.

K.2.13 The Thames Tideway Tunnel project model has been produced using USGS MODFLOW 2000 to simulate the change in water level as a result of dewatering in the lower aquifer and at a number of specific locations within central London. It does not attempt to replicate the LBM model, but rather to be an improvement upon earlier analytical methods to estimate dewatering impacts. The model simulates the difference, or drawdown, between the piezometry with and without dewatering at the construction shafts; it does not simulate absolute water levels in the London basin, although these can be calculated from the results.

K.2.14 An initial run of the LBM has been undertaken in order to to simulate project dewatering and to verify the predictions of the Thames Tideway Tunnel project model.

Objectives

K.2.15 The objectives of the Thames Tideway Tunnel project model are to:

a. Take account of regional variations in aquifer hydraulic parameters and configuration across the project area.

b. Establish the impact of dewatering upon;

c. i) licensed and unlicensed groundwater users

d. ii) water resources in the lower aquifer as a whole

e. iii) saturation of the Thanet Sands

f. Quantify the volumes of water to be abstracted to achieve the shaft construction dewatering aims. Identify the strategies that could result in reduction in the effect of the shaft construction dewatering activities

Geology and Hydrogeology

Geology

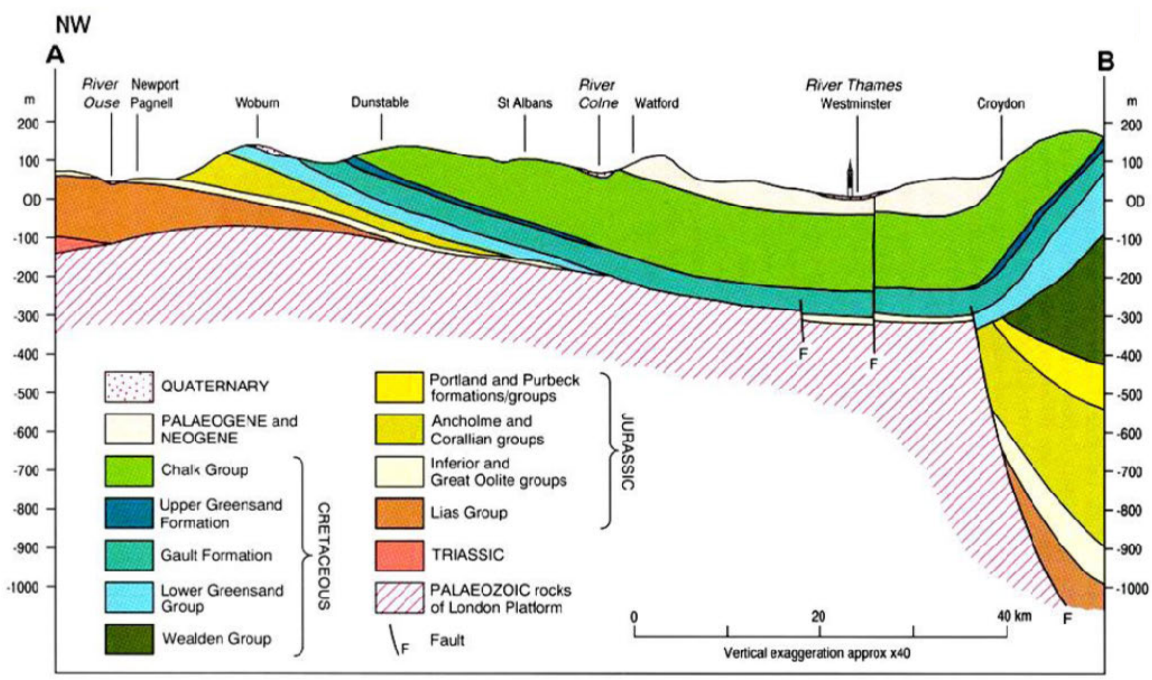
K.2.16 The London Basin is entirely underlain by sedimentary bedrock geology, dominantly Cretaceous Chalk; overlain by heterogeneous Palaeogene deposits; Quaternary river terrace deposits, glacial and peri-glacial deposits and alluvium.

K.2.17 Lithological outcrop reflects the geological history of the area, which has undergone phases of subsidence, uplift and tectonism that have resulted in folding and faulting, erosion and marine incursion.

K.2.18 A summary of the geological succession and the depths and thicknesses of geological layers within the Thames Basin, as derived from ESI/EA 20102 , is shown in Vol 3 Table K.11.

K.2.19 A geological cross section is shown in Vol 3 Plate K.1 for the London Basin (adapted from BGS 1996[4] and de Freitus 2010[5]).

Vol 3 Plate K.1 Groundwater – simplified Geological Cross Section of the London Basin (adapted from BGS 1996; and de Freitas, 2010)



K.2.20 The main geological formations of relevance to the Thames Tideway Tunnel project and the Thames Tideway Tunnel project model are the White Chalk, Thanet Sands, Lambeth Group and London Clay.

Vol 3 Table K.11 Groundwater – summary of London Basin geological succession

Period	Series	Group	Formation		Thickness (m) London[i]	Thickness (m) Central London[ii]
Quaternary	Holocene	Superficial Deposits	Made ground			
			Alluvium			
			Langley Silt (or other local silt deposits)			
	Pleistocene		River Terrace Deposits			
Palaeogene	Eocene	Thames	Bagshot Beds		10-25	
			London Clay		90-130	
			Harwich		0-10	
	Palaeocene	Lambeth***	Reading and Woolwich Beds	Upper Shelly Beds	10-20 (total)	0-20 (thickest in SW, thins to the E passing laterally into Woolwich Formation)
				Upper Mottled Beds		
				Upper Shelly Beds (Clay)		0-3
				Laminated Beds		0-5
				Mid-Lambeth Hiatus*		
				Lower Mottled Beds (Clay)		0-6
			Upnor			0-12
		No group	Thanet Sand		0-30	
Cretaceous	Upper Cretaceous	White Chalk Subgroup	Undivided mainly Seaford Chalk**		Up to 70	32-47
			Lewes Nodular Chalk		25-35[ii]	34-46
			New Pit Chalk		30-40	33-49

Period	Series	Group	Formation	Thickness (m)	
			Holywell Nodular Chalk	13-18	11-18
		Grey Chalk Subgroup	Undivided Zig Zag Chalk	65-70 (combined)	30-50
			Undivided West Melbury Marly Chalk		14-31
	Middle Cretaceous		Upper Greensand	Up to 17	
			Gault	50-70	

** Not a Formation but an important depositional feature*
*** Subdivided into the Haven Brow, Cuckmere and Belle Tout members.*
**** Localised channel deposits and sand lenses may be present in the Lambeth Group*
i source: Ellison et al., 2004[6] BGS Memoir; ii source: Royse, 2008[7] London Chalk Model
iii EA and ESI (2010) recent data from R.N. Mortimore[8] indicates Lewes Chalk is thicker than documented data sources in the east London - Thames Gateway area and Croydon area.

Cretaceous

K.2.21 The ***White Chalk Group*** subdivides into five formations – the Holywell Nodular Chalk and the New Pit Chalk Formations (formerly referred to as the Middle Chalk) and the Lewes Chalk Nodular Formation and undivided strata equivalent to the Seaford Chalk, Margate and Newhaven Chalk formations (formerly referred to as the Upper Chalk). These formations are summarised below:

K.2.22 The ***Holywell Nodular Chalk*** is broadly shelly with low induration[iv] and nodular content with marl horizons estimated to have a thickness of up to 11 to 18m in central London (Royse, 2008)[9].

K.2.23 The ***New Pit Chalk*** is softer, smooth in texture and more massively bedded than the underlying Holywell Chalk. It has a thickness of between 33 and 49m in central London (Royse, 2008)[10], and commonly contains thin marly chalk horizons and marl seams, notably the New Pit Marls and the Glynde Marls.

K.2.24 The ***Lewes Nodular Chalk*** is the oldest formation encountered by the Thames Tideway Tunnel project. It is typically 34-46m thick in central London (Royse, 2008)[11], and outcrops towards the top of the North Downs. The richly fossiliferous Lewes Nodular Chalk contains several hard grounds and marls, with marl seams up to 0.1m thick (Ellison *et al.*, 2004)[12]. Regularly spaced nodular flints layers locally exceed 0.2m in length. The Shoreham Marls mark the upper beds of the Lewes Nodular Chalk. EA and ESI (2010) indicate that the thickness of the Lewes Chalk may be underestimated in some areas.

K.2.25 The ***Seaford Chalk*** dominates the North Downs outcrop area. The Seaford Chalk is up to 70m thick (Ellison et al., 2004)[13], although in central London, Royse (2008)[14]established the Seaford Chalk as 32-47m thick due to erosion of the younger formations (EA and ESI, 2010)[15]. The undivided upper strata of the Chalk is regarded as firm to soft non-nodular Chalk with flint beds by Ellison *et al*. (2004)[16]. Thin marl seams are found in the lower 8m and absent higher up. A hard ground marks the top of the Seaford Chalk.

Palaeocene and Eocene

K.2.26 Palaeogene sediments were deposited on the eroded surface of the Chalk during a period characterised by marine transgressions and regressions.

K.2.27 The ***Thanet Sand Formation*** defines the first marine transgression following erosion of the Chalk (Andrews et al., 1995)[17]. It sits unconformably on the approximately planar eroded Chalk surface; comprising the sandy aquifer unit known as the 'Basal Sands' - a pale to medium-grey to brownish-grey, fine to fine-grained sand; and a conglomerate up to 0.5m thick comprising rounded to angular flint cobble

[iv] the process by which a soft geological sediment becomes hard

and gravel sized clasts set in a clayey, fine to coarse-grained sand matrix with glauconite pellets forming the basal bed of the Thanet Sand – referred to as the ***Bullhead Bed***.

K.2.28 The ***Thanet Sand Formation*** comprises well sorted, uniform sand, with evidence of intense bioturbation removing bedding structures. With approximately 10 percent fine-grained sand at the base, the lower part is typically clayey and silty, coarsening and greater sorting upward to the upper beds containing as much as 60 percent fine-grained sand. Lateral grain size variation is observed, coarsening northwards through the southern part of the London Basin (Andrews et al., 1995)[18]. The Thanet Sands thicken to in excess of 20m towards the south east but thin to 4m or less in the north west, becoming absent in the north east.

K.2.29 Deposition of the ***Lambeth Group*** followed a period of marine regression and erosion of the top of the Thanet Sand Formation. The ***Lambeth Group*** subdivides into three formations; the ***Upnor Formation***, the ***Woolwich Formation*** and the ***Reading Formation*** (this replaces the previous Woolwich and Reading Beds nomenclature for this group). The Lambeth Group is mostly a mottled clay with fine-grained sand, laminated clay, flint pebble beds and shelly clay layers (Ellison et al., 2004)[19] . Considerable range in textures and fabrics within a short stratigraphical sequence (generally between 15 and 40m) are observed by Page and Skipper (2000)[20]. Because these formations are highly heterogeneous, they divide into informal lithological units, laterally passing into each other becoming interdigitate in central and south-east London. This is emphasised in the schematic cross-section through the Lambeth Group across central and south-east London (Vol 3 Plate K.1) as established by Ellison et al. (2004)[21]; note the ends of the section are not spatially located (therefore not marked). Vertical and spatial variability reflects coastal and possibly estuarine deposition affected by small sea level fluctuations.

K.2.30 The transition between the top of the Thanet Sand and the base of the Lambeth Group – marked by a unit referred to as the ***Upnor Formation*** – is not clearly defined, causing difficulty in the accuracy of some stratigraphic interpretations.

K.2.31 The ***Upnor Formation*** comprises variably bioturbated fine- to medium-grained sand with glauconite, rounded flint pebbles and minor clay, with distinctive pebble beds and base and top, the former up to 1m thick, the latter up to 3m thick in south-east and central London. A fossil soil horizon with localised development of carbonate concretions, and translocation of clays from the Reading Formation above is observed in the Upnor Formation in the north and west of the London Basin.

K.2.32 ***Reading Beds*** comprising the ***Lower Mottled Beds*** and the ***Upper Mottled Beds***. The Mottled Beds of the Reading Beds comprise of silty clay and clay, generally un-bedded, fissured and blocky. These units comprise up to 50 per cent silt and sand, notably in the east of the London Basin.

K.2.33 The ***Woolwich Beds*** are characterised by mottled, silty clay and clay – with silts and sands comprising up to 50% of the beds, notably in the east of the London Basin. The Woolwich Beds are typically un-bedded, fissured and blocky. Three main units are found in the Woolwich Beds – the **Lower Shelly Beds**, the **Laminated Beds**; and the **Upper Shelly Beds**.

K.2.34 The ***Lower Shelly Beds*** comprise dark grey to black clay with abundant shells, with increasing sand content towards east London. A thin – less than 0.3m thick - seam of Lignite is commonly found at its base. Above the Lower Shelly Beds are the ***Laminated Beds***, comprising a thinly interbedded fine to medium grained sand, silt and clay with shells, with sand lenses found locally in south-east London. At the top of the Woolwich Beds are the ***Upper Shelly Beds*** comprising grey, shelly clays with scattered glauconite grains increasing to mainly sand in south-east London.

K.2.35 The ***Harwich Formation*** comprises of fine-grained glauconitic sand and rounded black flinty pebble beds, commonly deposited in a series of superimposed channels. The Harwich Formation is less pebbly and predominantly fine-grained sand with beds of volcanic ash towards the northeast of the London Basin.

K.2.36 The ***London Clay*** comprises clayey silt beds grading to silty fine-grained sand that increase in number from east to west; and increase in homogeneity upwards through the deposit. Weathering is observed to a depth between 5 and 10m below the outcrop (Chandler and Apted, 1988[22]; EA and ESI, 2010[23]) although a greater depth of weathering may occur in sandy beds. The upper sandier formation is informally referred to as the Claygate Member to distinguish its coarser-grained nature.

K.2.37 The London Clay divides into a series of units, or facies, referred to from oldest to youngest as A to E, each with distinct lithological features.

Structural Geology

K.2.38 The structural geology used in development of the LBM is described by EA and ESI (2010)[24] as follows:

K.2.39 The Thames Basin has a synformal structure; and has been considerably affected by faulting and superimposed folds. Significant lateral and vertical movement is found on some of these faults. Faults in the Chalk and Lambeth Group, in particular, are regarded as significant from a hydrogeological perspective, as they can both impede and channel groundwater flow. Pathways through less transmissive horizons can also form along faults and structurally controlled fissures.

K.2.40 Reactivation of earlier faults and structural weakness occurred during the Mesozoic and Cenozoic eras, notably resulting in faults, bedding plane fractures and join sets in the Chalk and Lambeth Formation.

K.2.41 North-east to south-west trending normal faults predominate in the London Basin, with throws across these faults and fault complexes up to 30m. Andrews et al. (1995)[25] identified orthogonal fault sets, but these are not shown by Royse (2008)[26] (apart from the Rotherhithe Fault).

K.2.42 The confined ***Seaford Chalk Formation*** is heavily fractured with sub-vertical, inclined and horizontal, well-connected joints, more open towards the higher up in formation. Contrastingly, the lower part of the *Lewes*

Nodular Chalk Formation has irregularly fractures. Steeply inclined fractures dissipating along marl seems are found in the New Pit Chalk; whereas the ***Holywell Nodular Chalk*** is characterised by wide spaced conjugate joints.

K.2.43 Folding is predominantly observed in the south of the London Basin. Anticlinal crest and synclinal trough stretching and compression of competent strata may result in fracture opening and enhancing hydraulic conductivity or fracture closure and reduced flow, respectively.

K.2.44 Sub-Palaeogene erosion surface at the end of the Cretaceous resting on different stratigraphic levels in the Chalk is a reflection of differential uplift.

K.2.45 Page and Skipper (2000) have investigated the structural control on the Lambeth Group's facies and thicknesses in the central London area. In their investigations, they identified four 'effects' acting on the structure of the Lambeth Group deposits; firstly the depositional environment affecting the sediment composition and distribution grain size and sedimentary structures; the second effect is the immediate post depositional changes such as bonding, cementation, fissuring and biogenic activity. Thirdly, weathering, reductions in effective stress due to removal of overburden and periglacial effects. The fourth effect was attributed to laboratory technique, sampling method and in situ testing.

K.2.46 A marine seismic survey has indicated the presence of a significant fault in the near vicinity of Putney Bridge; it is unclear at this stage, whether this feature could facilitate hydraulic connection with the River Thames, (Newman, 2011[27]).

K.2.47 There is also a series of N-S and SSW-NNE trending faults are identified between Battersea and Chelsea bridges – referred to as the **Chelsea Embankment (Albert Bridge) Fault Zone** - intersecting the tunnel alignment close to vertical. It is reported that there is up to 5m vertical displacement of strata over this zone, resulting in uplift of the top of the Lambeth Group deposits into the proposed tunnel invert on the east side of Albert Bridge Foreshore and Chelsea Embankment Foreshore sites.

Hydrogeology

K.2.48 On a regional scale, the London Basin aquifer is defined as the whole sequence of strata between the base of the Chalk and the base of the London Clay.

K.2.49 Pore sizes in the Chalk are very small; with high matrix pore pressure, such that the Chalk matrix exhibits a low hydraulic conductivity. Most of the transmissivity is attributed to open and enhanced interconnected fractures.

K.2.50 The Grey Chalk is regarded as an aquitard, apart from where it is substantially weathered or where fractures are dissolution-enhanced, providing leakage to the Upper Greensand in places.

K.2.51 The White Chalk is a classed as a principal aquifer by the Environment Agency, and the most important aquifer in the London Basin – both in terms of the unconfined and near outcrop area, and the heavily confined Chalk in the centre of the London Basin. The hydraulic properties of the

White Chalk are controlled by fractures and their solution enhancement and interconnectivity, weathering, secondary deformation, secondary porosity and permeability and structural history. These factors contribute to stratification of Chalk hydraulic parameters – notably higher hydraulic conductivities are found in the upper horizons due to open, interconnected fractures. As a result, transmissivities and storage tend to be greatest in the Seaford and Lewes Chalk Formations.

K.2.52 Above the Chalk, the Thanet Sand Formation forms a principal aquifer; with clean, open, sand pores providing groundwater storage at the top of the Chalk-Thanet Sand system.

K.2.53 The Thanet Sands and Chalk together are referred to as the lower aquifer.

K.2.54 The Lambeth Group is broadly an aquitard; with the Reading Formation and Woolwich Formations, being generally clay-rich, tend to form an aquitard above the Chalk and Thanet Sands aquifer. However, several confined groundwater bodies are identified and perched groundwater storage and flow may be encountered. For example, groundwater may be encountered in the Upper Shelly Beds (at the top of the Lambeth Group); and sub-artesian pressures may be found within the Laminated Beds (formerly part of the Woolwich Formation).

K.2.55 The Upnor Formation forms a thin aquifer at the base of the Lambeth Group, locally in hydraulic continuity with the Thanet Sands and the Chalk aquifer, notably in the south east of the London Basin, although less so to the north and west.

Aquifer Hydraulics

K.2.56 Permeability values for the LBM modelled layers are shown in Vol 3 Table K.12. The values are taken from a number of boreholes constructed for Thames Water Utilities Ltd for a phase 1 ground investigation (EA and ESI, 2010)[28].

Vol 3 Table K.12 Groundwater – hydraulic conductivity by lithological unit

Unit	Test Type	Hydraulic conductivity (m/s)
Lambeth Group	Falling head	1.4E-09
	Rising Head	1.6E-09 to 9.05E-06
Upnor Formation	Falling head	1.60E-06
	Rising Head	1.60E-09 - 1.60E-06
Thanet Sand Formation	Falling head	1.50E-06 - 4.40E-06
	Rising Head	4.80E-08 - 2.40E-06
Seaford Chalk	Rising head, Falling head and Double packer test	3.00E-09 - 1.20E-04
Lewes Chalk	Rising head, Falling head and Double packer test	4.40E-09 - 1.20E-04

Thames Tideway Tunnel Groundwater Model

Conceptual Groundwater Model

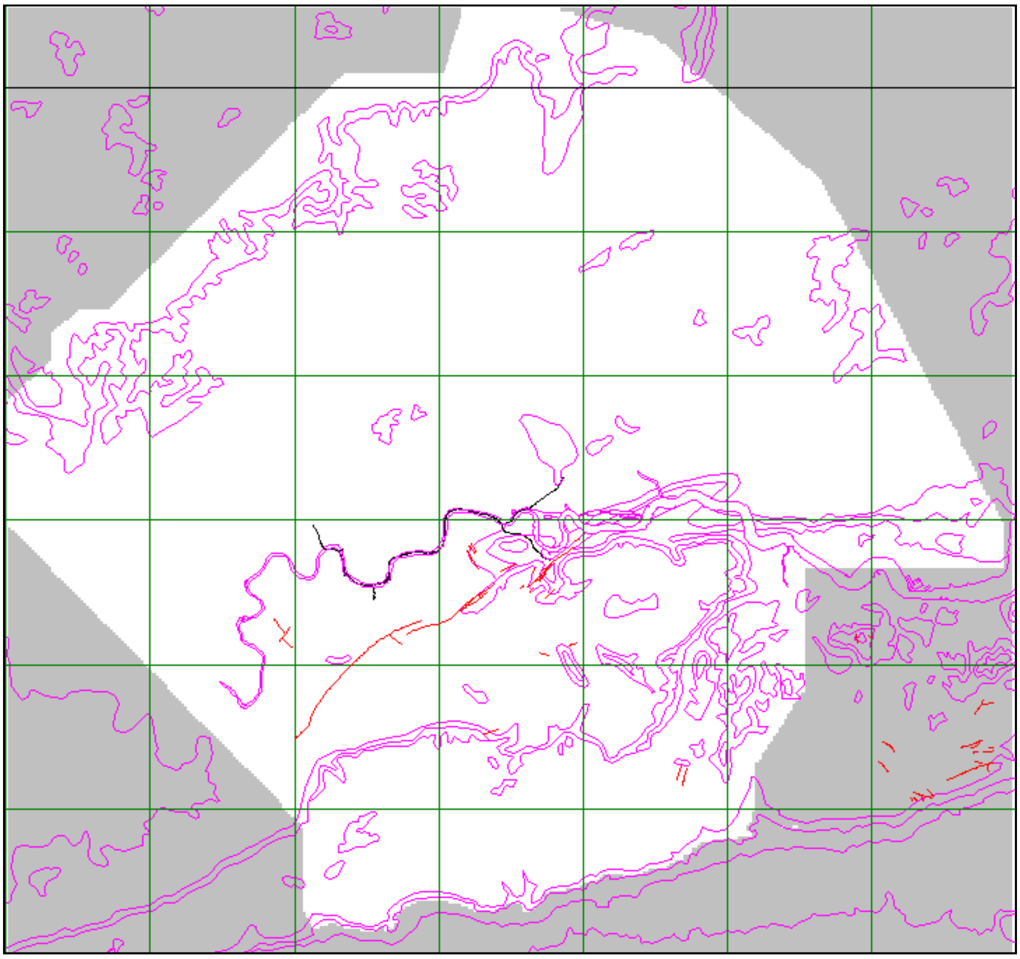
K.2.57 The conceptual model of the London Basin comprises a lower aquifer (the Chalk and Thanet Sands in hydraulic continuity) overlain by the Lambeth Group and London Clay. With transition from west to east, conditions change from confined to unconfined Chalk at outcrop. Where pumping takes place the lower aquifer can become unconfined even where there is a covering of London Clay.

Numerical Groundwater Model

K.2.58 The model area of interest is central London and the route of the Thames Tideway Tunnel project from Acton Storm Tanks to Abbey Mills Pumping Station. The shafts where external dewatering is anticipated lie along the route of the main tunnel from Cremone Wharf Depot in the west to King Blackfriars Bridge Foreshore in the east.

K.2.59 The extent of the modelled area is much greater than the area of interest. The model area runs from an origin at 500,200mE and 150,000mN and covers an area of 4,558.8km². The area is slightly smaller than the extent of the EA's LBM under development during the preparation of the modelling. The EA model extends further east into north Kent, whereas the Thames Tideway Tunnel project model has no active cells in the area east of the river Darent and south of the River Thames. The active area of the model is 2,789km² as shown in Vol 3 Plate K.2.

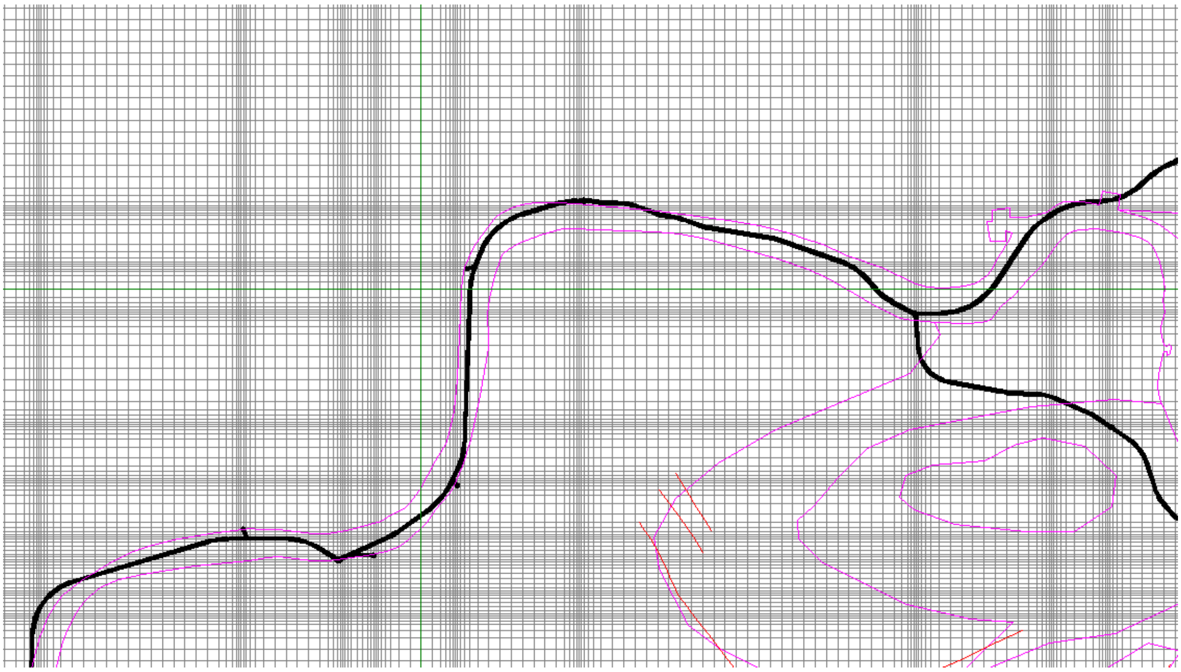
Vol 3 Plate K.2 Groundwater – extent of model domain



White = Active cells in layer 3; Grey = no flow cells; Magenta = solid geology; Green = 10km grid origin at 500,000E, 150,000N.

K.2.60 The model uses 200m grid spacing over the majority of the model area, but is refined down to a 20m grid spacing in the vicinity of many of the shaft sites. The central area of the model with the tunnel alignment and the pattern of variable grid spacing are shown in Vol 3 Plate K.3.

Vol 3 Plate K.3 Groundwater – model grid in central London



Grey = grid lines; Magenta = solid geology; Black = tunnel alignment.

Model layers

K.2.61 The model comprises three layers, these represent:

a. Layer 1 - the Lambeth Group.

b. Layer 2 - the Thanet Sand Formation.

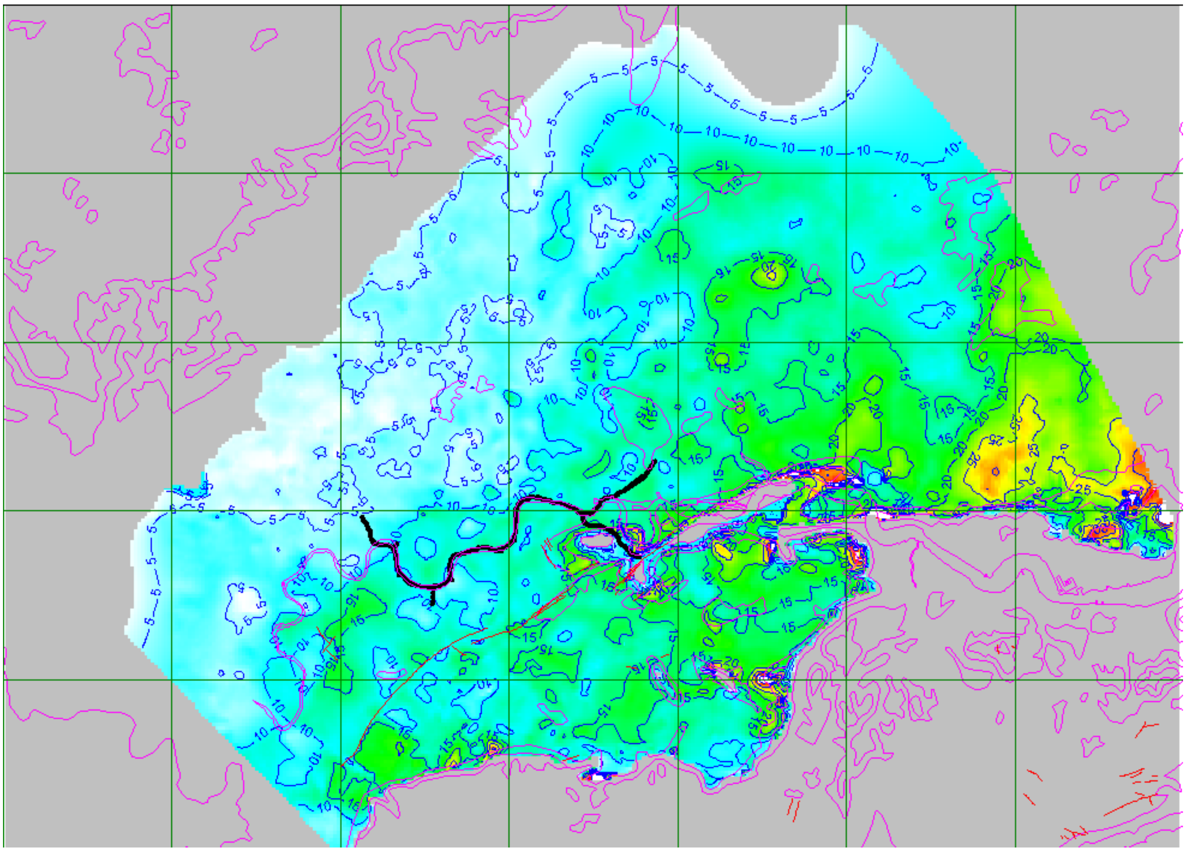
c. Layer 3 - the Chalk.

K.2.62 The extent of layers 2 and 3 are closely aligned to the layers in the LBM where these are known from information supplied on the thickness of the Thanet Sand. The extent of the active cells in layers 1 and 2 has been adjusted to conform to the extent of the solid geology in the vicinity of the Greenwich connection tunnel.

K.2.63 The Lambeth Group and Chalk are assigned a constant thickness within the model. The Lambeth Group is 15m and the Chalk is 40m thick. In reality the Chalk is more than 40m thick but for the purpose of the model it is considered that the upper 40m provides the zone with the fractures and fissures. The thickness of the Thanet Sand is the same as the thickness in the LBM and ranges from 2m to over 50m with an average of 12m.

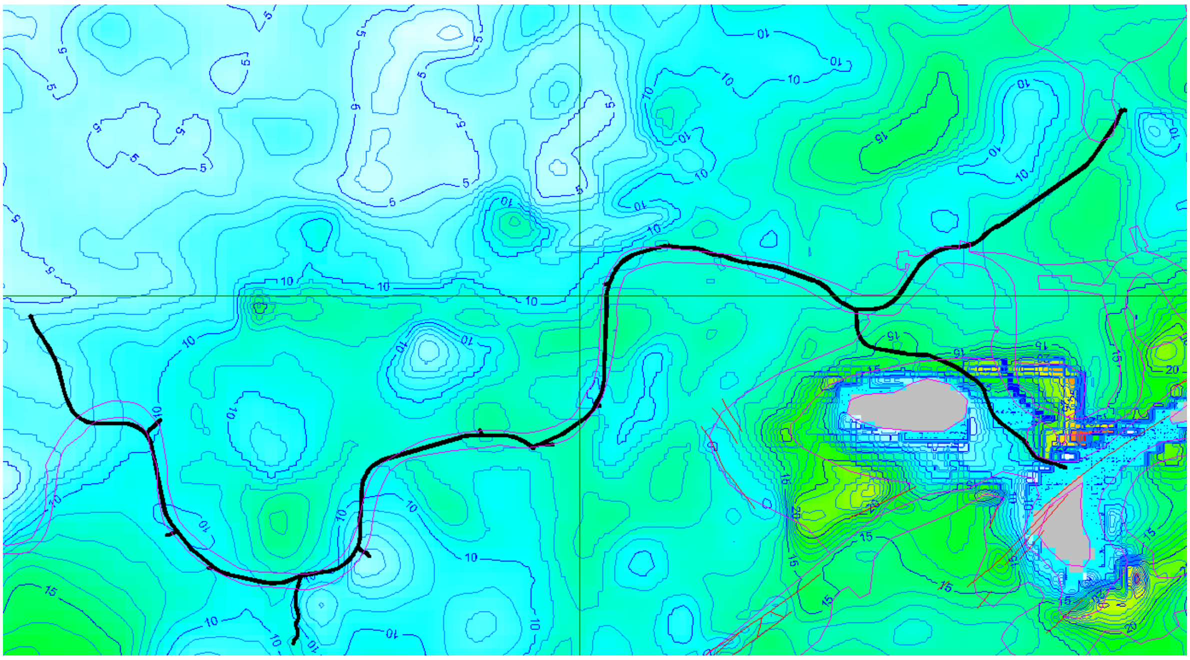
K.2.64 Plates Vol 3 Plate K.4 and Vol 3 Plate K.5 illustrate the model thickness of Thanet Sand. This detail was added to the model to allow the effect of dewatering on the saturation of the Thanet Sands to be examined.

Vol 3 Plate K.4 Groundwater – thickness of Thanet Sand Formation whole model



Thickness of layer 2; Red = greater than 30m; Green = 15-20m; Mid blue = 10-15m; Pale blue = 5-10m

Vol 3 Plate K.5 Groundwater – thickness of Thanet Sand Formation central area



Thickness contoured 1m interval with labels at 5m intervals.

K.2.65 The elevation for the model layers was derived from the elevation of the base and the thickness of the Thanet Sands as follows:

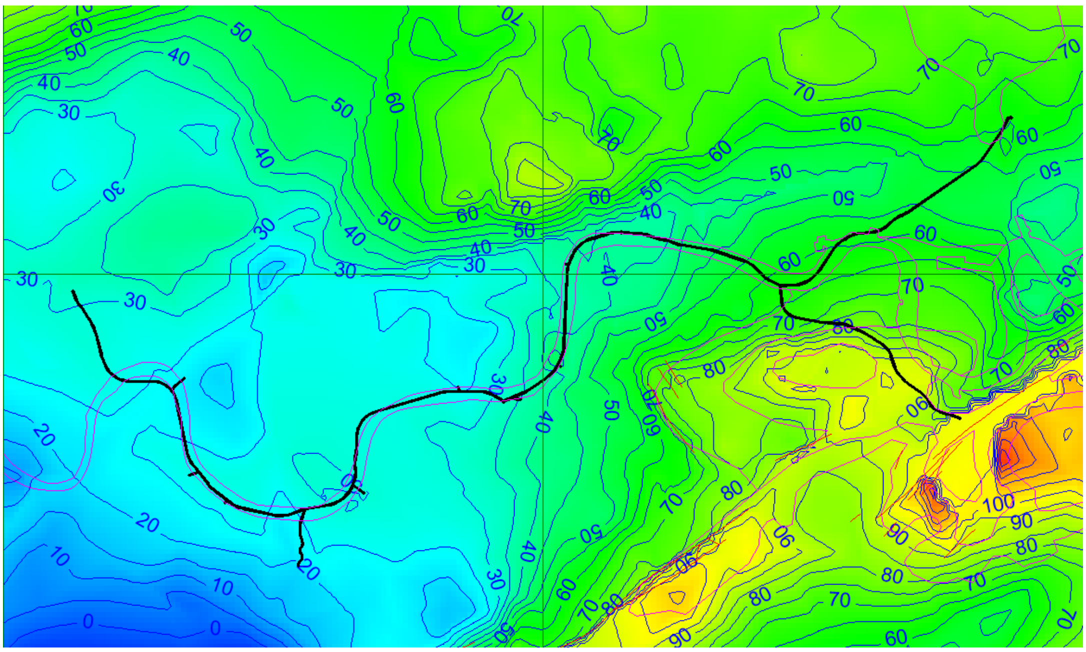
a. The base of the Thanet Sands was exported at 100m cell size as provided by the EA. The grid provided was smaller than the Thames Tideway Tunnel project model area, but fully covers the central London area.

b. The thickness of the Thanet Sand Formation was extracted from the LBM and supplied as a shape file by the EA.

K.2.66 The model examines the change of groundwater level as a result of dewatering activities. It is a relative model and does not give absolute elevations of the groundwater level. The groundwater levels in the London basin are dependent on recharge and abstraction. The model produced does not attempt to replicate these conditions, but to predict the drawdown as a consequence of dewatering.

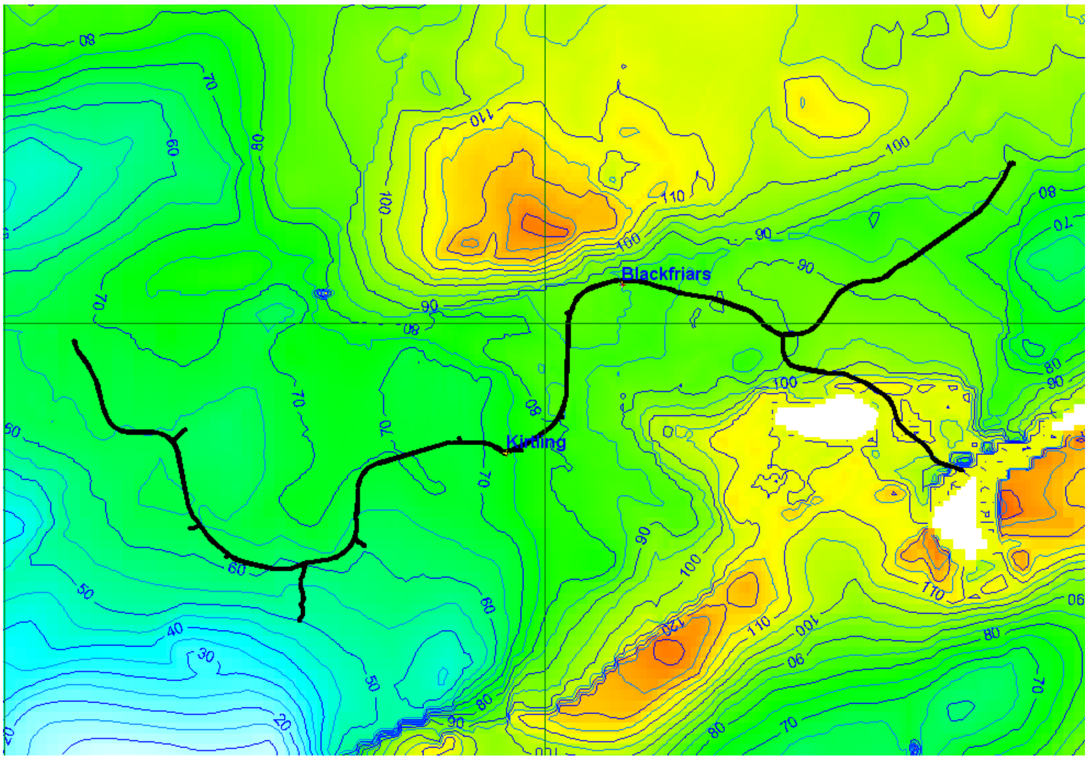
K.2.67 The initial condition of the model sets groundwater levels at an arbitrary value of 100m. To ensure that confined and unconfined conditions are reflected in the groundwater model, when the groundwater levels are adjusted the levels of the layers are also adjusted by the same amount. The modifications are different in all parts of the model area as illustrated by Vol 3 Plate K.6 and Vol 3 Plate K.7.

Vol 3 Plate K.6 Groundwater – absolute elevation for top of Thanet Sand Formation central area



Elevation, mATD, contoured 5m interval.

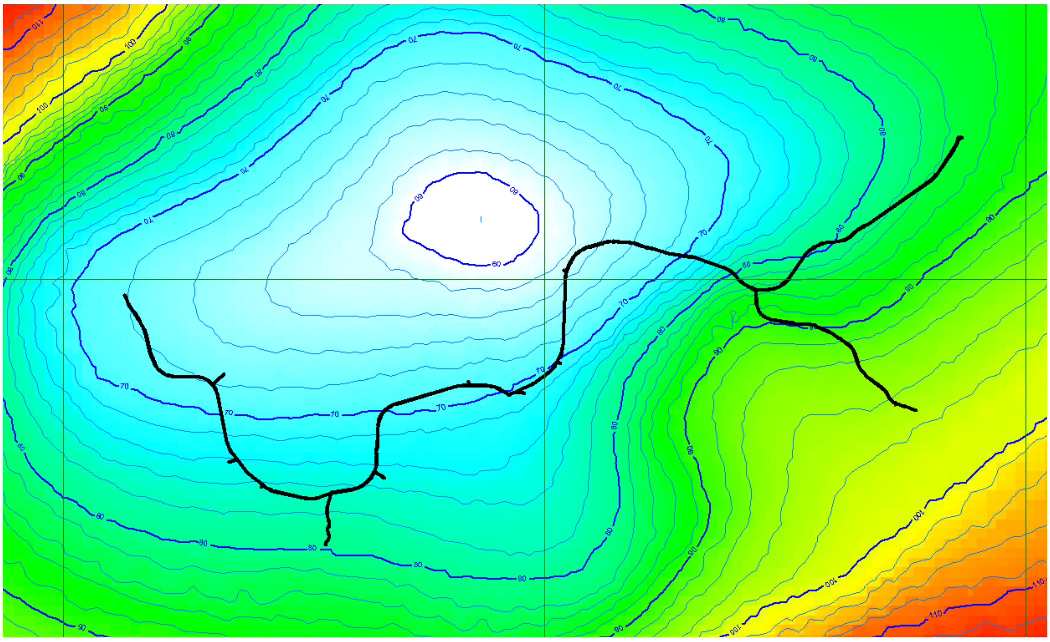
Vol 3 Plate K.7 Groundwater – relative elevation for top of Thanet Sand Formation central area



Elevation relative to lower aquifer water level with a defined elevation of 100mATD.

K.2.68 The initial water level is the piezometry published by the EA for January 2011 (EA, 2011)[29]. The contours are presented in the EA report with a 10m vertical interval. To prepare the information for use in the groundwater model the contour data is converted to a value for every cell in the model. The initial heads are stored within the groundwater model but are not used for calculations during the simulation. The initial heads combined with calculated drawdown values are used to generate groundwater level surfaces for particular stress periods of the model simulation. The initial water levels are illustrated in Vol 3 Plate K.8.

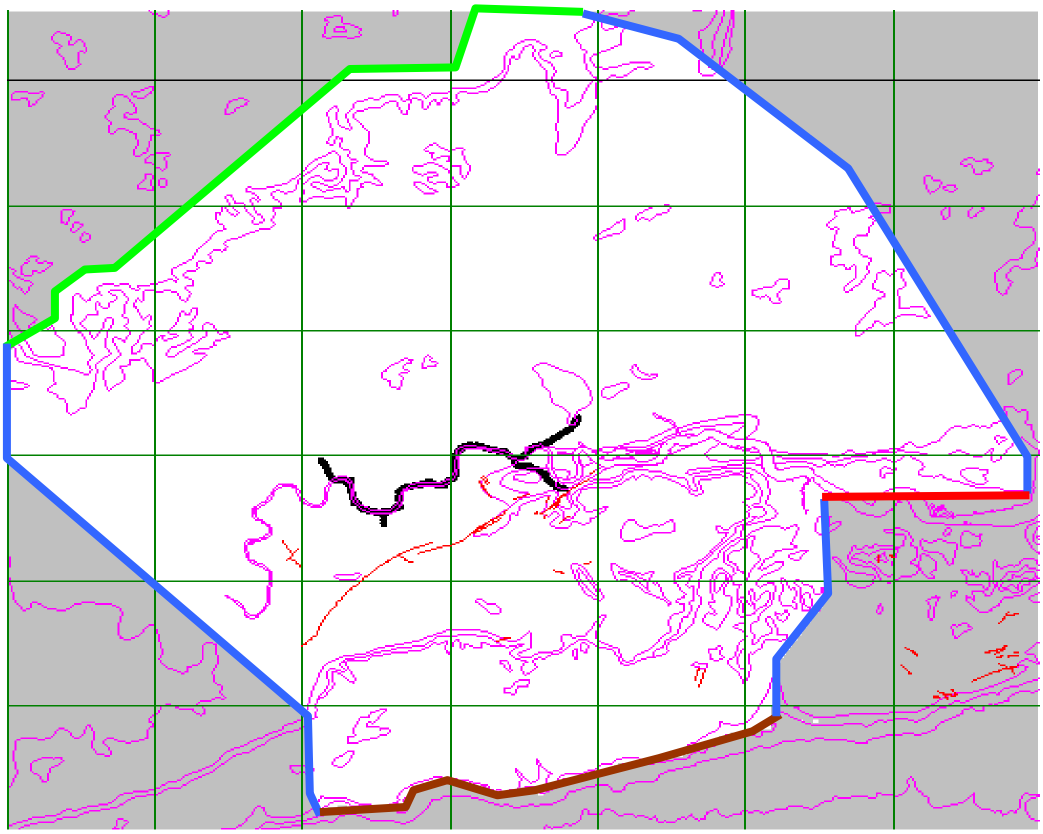
Vol 3 Plate K.8 Groundwater – initial water levels in central model area



Black line = tunnel alignment; Thick blue line = groundwater contour 10m intervals, labelled as mAOD; Thin blue line = groundwater contour 2m intervals; Flood colour from white = 60mATD to red = 110mATD

K.2.69 External boundary conditions in layer 3 (Chalk) are illustrated in Vol 3 Plate K.9. The external boundaries of the model are all represented as no flow boundaries. The flow line and groundwater divide, blue and brown lines in the plate, are no flow boundaries in the LBM. The flux boundary allows flow into the LBM and the flow convergence does not exist in the LBM. All the external boundaries in this model are considered to be far enough away from internal boundaries that the nature of the external boundary will not have a significant impact upon the behaviour of the central portion of the model.

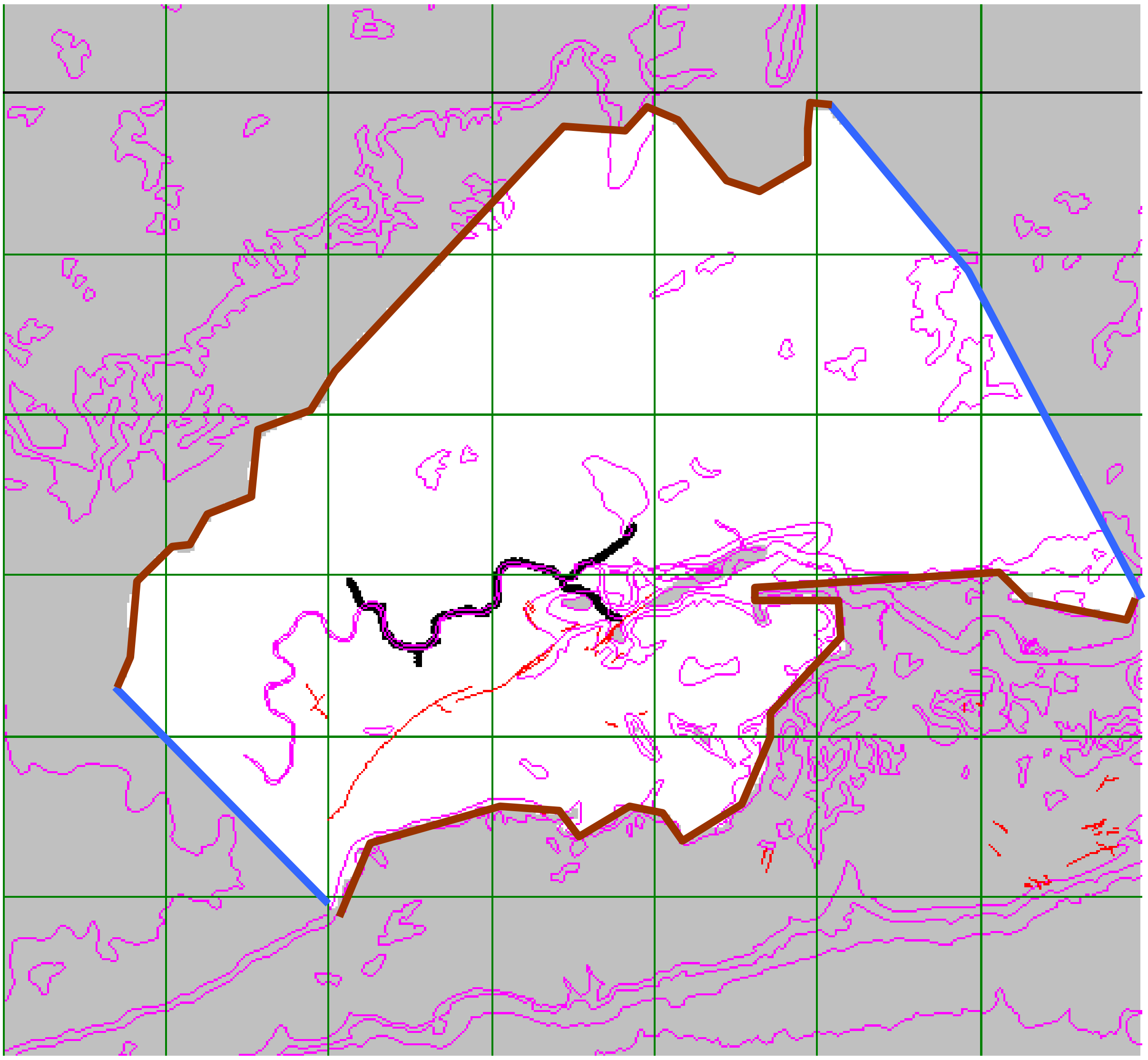
Vol 3 Plate K.9 Groundwater – external boundaries Layer 3 (Chalk)



Blue line = flow line; Green line = inward flux ; Brown line = groundwater divide/edge of aquifer; Red line = flow convergence; Black line = tunnel alignment.

K.2.70 External boundaries in layer 2 (Thanet Sands) are shown in Vol 3 Plate K.10. The layer 2 extent is the same as in the LBM. The northern boundary is the 2m thickness contour for the Thanet Sand Formation. The layer 1 boundary is approximately the same as the layer 2 boundary except for in the Greenwich area where the solid geology base map has been used to mark the extent of the Lambeth Group. Elsewhere the boundary in layer 1 is considered too far away from the area of interest in the Thames Tideway Tunnel project model to have a significant influence upon the results of the modelling.

Vol 3 Plate K.10 Groundwater – external boundaries layer 2



Blue line = flow line; Brown line = groundwater divide/edge of aquifer; Black line = tunnel alignment. Detail in Greenwich area not shown.

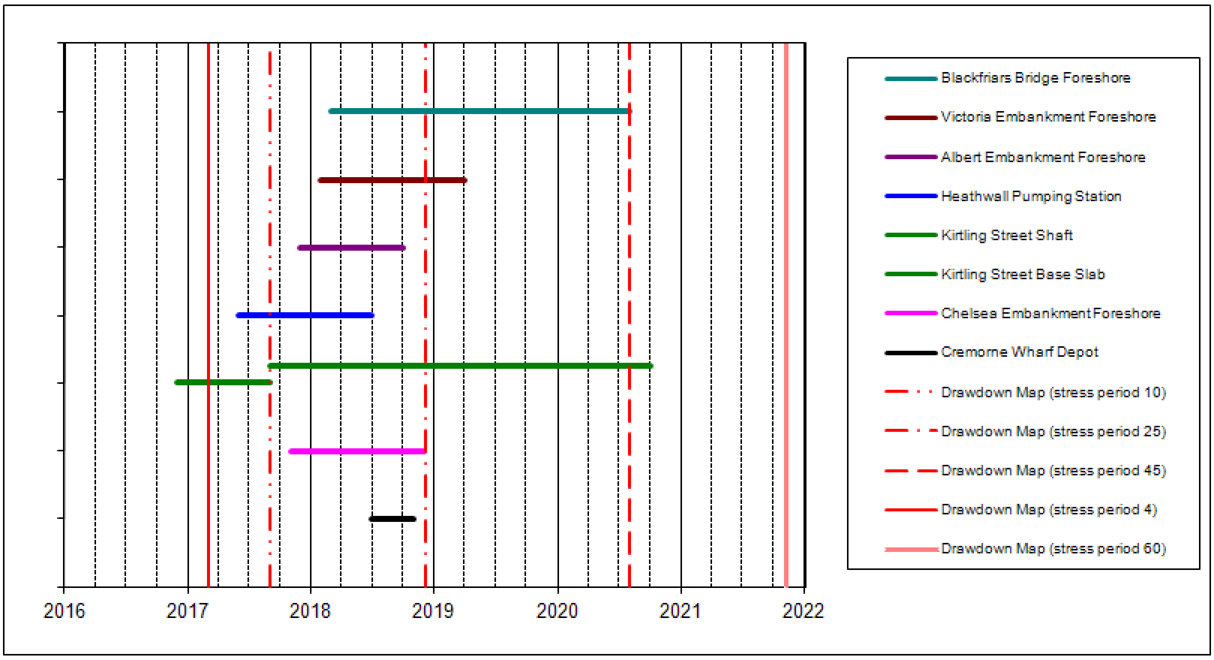
K.2.71 The area of interest for the model is the central area of London in the vicinity of the main tunnel route and in particular within 2km of each of the sites. The precise configuration of the model in areas remote to the central area is unlikely to have any significant impact upon the conditions in the central area.

K.2.72 Internal boundaries are used to simulate the dewatering of the shafts during their construction. The dewatering is simulated by the inclusion of a drain cell at the position of the shaft which removes water from the model. The drain cell has a high conductance so that the water level is drawn down within the drain cell to the required construction level. This is similar to employing a variable abstraction at the shaft site, except that the model calculates the variable abstraction to achieve the required drawdown at the shaft.

K.2.73 The construction dewatering sequence has been adopted for all the modelled scenarios. The dewatering depth is set at the construction level for the whole of the shaft construction period. In reality the dewatering level will be gradually taken to lower elevations as the shaft construction proceeds. The method used is thus precautionary and is more likely to over estimates than under estimate the dewatering rates and cumulative volumes.

K.2.74 The construction sequence used in the modelling is illustrated in Vol 3 Plate K.11. The horizontal lines mark the period of dewatering at the sites. Only those sites where external dewatering of shafts is planned are included in the Vol 3 Plate K.11.

Vol 3 Plate K.11 Groundwater – construction sequence used for dewatering periods



K.2.75 Internal boundary elevations are determined from the shaft construction depth (dewatering target elevation) and the existing groundwater level. The difference between these two levels is the drawdown required at the shaft site. The drain elevations are expressed relative to the arbitrary initial water level of 100m. The elevations are presented in Vol 3 Table K.13. The conductance assigned to the drains cells is set high enough to ensure that the calculated water level is the same as the drain elevation.

Vol 3 Table K.13 Groundwater – dewatering and drain elevations by shaft

Site	Drain in layer	Dewatering target level (mATD)	Groundwater level (mATD)	Drain level (initial water level 100m) (m)
Cremone Wharf Depot	1	56.42	73	83.42

Site	Drain in layer	Dewatering target level (mATD)	Groundwater level (mATD)	Drain level (initial water level 100m) (m)
Chelsea Embankment Foreshore	1	56.95	72	84.95
Kirtling Street (top shaft)	1	54.86	75	81.86
Kirtling Street (base shaft)	2	48.86	75	73.86
Heathwall Pumping Station	1	54.14	75	79.14
Albert Embankment Foreshore	1	54.35	73	81.35
Victoria Embankment Foreshore	1	52.08	60	92.08
Blackfriars Bridge Foreshore	2	46.28	60	86.28

K.2.76 The model is only used to assess change as a result of dewatering, therefore recharge to the model is defined as zero and there are no abstractions from the model. If simulation of the cessation of abstraction was needed at a licensed source for example, it would be undertaken by the inclusion of a point recharge equal to the abstraction rate. Additional abstractions could likewise be incorporated by the use of point abstractions.

Model hydraulic properties

K.2.77 The model has adopted the best available estimates for the distribution of properties. These have been obtained from the LBM for the permeability of the Chalk aquifer and from EA and ESI (2010) where the “most likely” values have been used. A summary of the parameters is given in Vol 3 Table K.14.

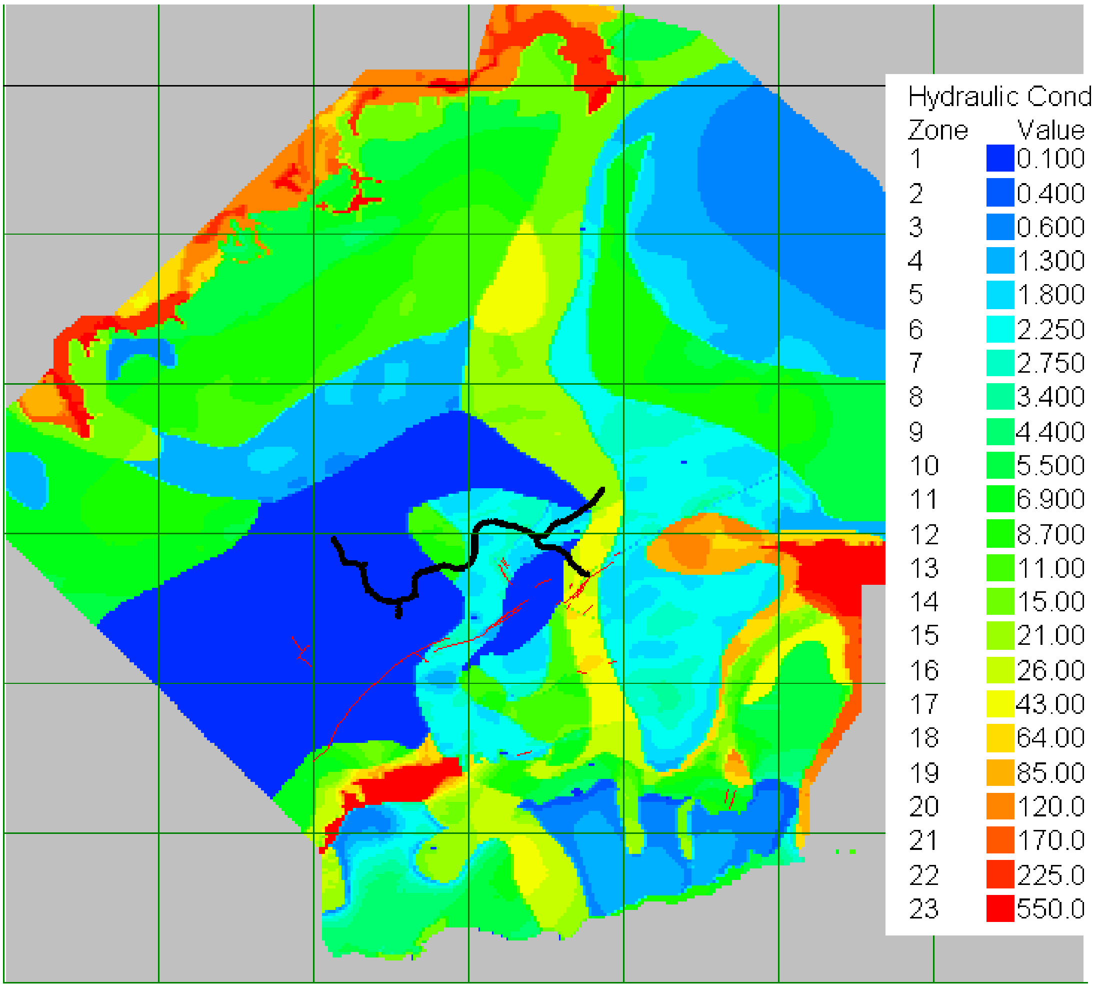
K.2.78 The hydraulic properties of layer 1 are uniform with a horizontal and vertical conductivity of $2x10^{-3}$m/d, specific yield of 10% and a storativity of $2x10^{-5}$. For layer 2 a uniform horizontal conductivity of 5m/d and vertical of 0.25m/d were used with the storage and specific yield the same as layer 1. The hydraulic properties of layer 3 use a distribution of transmissivity from the LBM (as issued prior to the final calibration of the LBM so may differ to the current LBM hydraulic properties). The transmissivity values are used as an equivalent hydraulic conductivity in Modflow with the layer thickness of 40m. The storativity is 10^{-4} and the specific yield is 2%. The hydraulic conductivity distribution is illustrated for the whole model domain in Vol 3 Plate K.12 and for the central part of the model in Vol 3 Plate K.13.

K.2.79 The confined storage coefficient is entered into the groundwater model in units of per metre as required by Modflow 2000. The storage coefficient and specific yield are both divided by layer thickness.

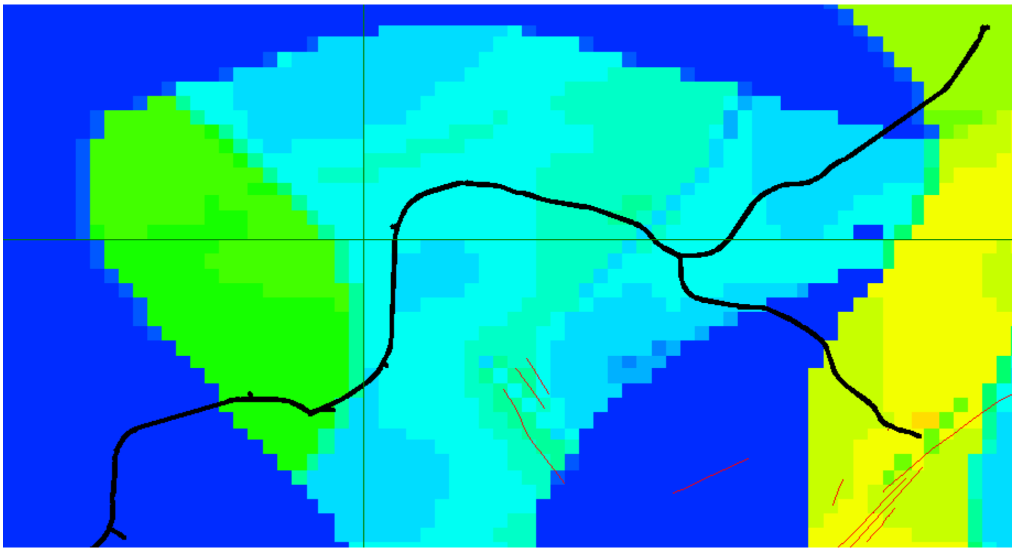
Vol 3 Table K.14 Groundwater – hydraulic parameters

Parameter	Layer 1	Layer 2	Layer 3
Thickness (m)	15	variable	40
Horizontal hydraulic conductivity (m/d)	0.0002	5	variable
Vertical hydraulic conductivity (m/d)	as horizontal	0.25	as horizontal
Confined storage coefficient	2 x 10-5	2 x 10-5	10-4
Specific yield	0.1	0.1	0.02

Vol 3 Plate K.12 Groundwater – layer 3 hydraulic conductivity – whole model



Vol 3 Plate K.13 Groundwater – layer 3 hydraulic conductivity – central area



Model results

K.2.80 The modelling process creates an output of a water level at every cell for every time period of each stress period of the model and associated flow to adjacent cells. The output is too extensive to appreciate without selecting particular aspects that are indicative of the impacts of the dewatering stresses.

K.2.81 The results are summarised in the following:

a. Annex B Groundwater hydrographs (see Vol 3 Plate K.24 to Vol 3 Plate K.32)

b. Annex C Groundwater contour maps (see Vol 3 Plate K.33 to Vol 3 Plate K.42)

c. Annex D Groundwater drawdown maps (see Vol 3 Plate K.49 to Vol 3 Plate K.57Vol 3 Plate K.56)

d. Annex E Saturated, unsaturated and dry cells in each layer at the initial and lowest levels (see Vol 3 Plate K.58 to Vol 3 Plate K.63)

e. Annex F Time series of dewatering flows (drain cell flux) (see Vol 3 Plate K.64 to Vol 3 Plate K.72)

f. maximum dewatering flow for each scenario (Vol 3 Plate H.22), and

g. maximum drawdown for each scenario (Vol 3 Plate H.23).

K.2.82 The model was run using the best estimate of the hydraulic properties and the boundary conditions (sensitivity runs were also carried out as described in the next section). The drawdown was examined at receptor sites, including all identified licensed and unlicensed groundwater abstractions from the lower aquifer. The resultant predicted drawdowns are presented in Vol 3 Table K.15.

Vol 3 Table K.15 Groundwater – impact at abstraction locations

Licence Number	Location	Maximum Assessed Available Drawdown (m)	Predicted Maximum Drawdown (m)	Nr Months Drawdown Exceeded
08/37/54/0062	Windmill Lane, Stratford - ELRED 'A'	23	0.50	0
28/39/39/0004	Wilton Road	26	5.91	0
28/39/39/0005	New Parliamentary Buildings – Bh A	19	4.70	0
28/39/39/0008	1 New Change, City of London	19	4.88	0
28/39/39/0013	North House	35.0	5.35	0
28/39/39/0046	Central Hall, Matthew Parker Street	20.0	5.18	0
28/39/39/0080	Chelsea Manor Street	37.0	5.60	0
28/39/39/0139	152 Grosvenor Road – Bh 'B'	18.0	6.39	0
28/39/39/0141	Dolphin Square – Bh A	9.0	7.59	0
28/39/39/0157	Lots Road, Chelsea	24.6	4.44	0
28/39/39/0209	Marsham Street	25.0	5.76	0
28/39/39/0212	The National Gallery	15.0	4.39	0
28/39/39/0226	Eaton Place	15.0	5.73	0
28/39/39/0229	Grange St Paul's Hotel	4.0	5.47	28
28/39/39/0232	Davis House - Bh A	11.0	6.12	0
28/39/39/0236	6 St Martins Place	18.0	4.41	0
28/39/39/0238	Eaton Square	18.0	5.75	0
28/39/42/0004	Stamford House	18.0	5.68	0
28/39/42/0033	Montford Place	20.0	4.30	0
28/39/42/0048	Canada Water, Surrey Quays Road Bh 'A'	7.0	2.02	0
28/39/42/0048	Canada Water, Surrey Quays Road Bh 'B'	16.0	2.04	0
28/39/42/0062	City Hall, –Bh 'B'	34.0	3.52	0
28/39/42/0069	Royal Festival Hall, Bh ‘B’	20.0	5.02	0
28/39/42/0070	Stewarts Lane Goods Yard	30.0	6.25	0
28/39/42/0072	Battersea Pumping Station	21.0	8.55	0

Licence Number	Location	Maximum Assessed Available Drawdown (m)	Predicted Maximum Drawdown (m)	Nr Months Drawdown Exceeded
28/39/42/0073	1 Surrey Quays Road	13.0	1.64	0
28/39/42/0074	Battersea Power Station - Borehole	44.0	7.89	0
28/39/42/0076	Brook Street - Bh 2	6.1	3.78	0
28/39/43/0019	Deptford Pumping Station Point F	5.8	0.67	0
28/39/44/0003	National Maritime Museum	10.0	0.68	0
28/39/44/0007	Greenwich Wharf	25.0	0.67	0
29/38/09/0113	Dace Road (Old Ford) Pumping Station	11.6	0.52	0
29/38/09/0149	Canning Road - Borehole A	115.0	0.56	0
29/38/09/0177	Wick Lane	20.0	0.54	0
29/38/09/0201	Temple Mills Lane - Boreholes 'B'	10.0	0.5	0
28/38/09/0009	Pudding Mill Lane	17.0	0.53	0

K.2.83 The key locations for the drawdown are distributed along the route of the tunnel. Those licensed abstractions that are most at risk are where the dewatering results in a drawdown are greater than, or close to, the maximum available drawdown. For example if the additional drawdown means that water levels fall below the pump or an adit. The locations are:

a. Licence Nr 28/39/39/0141, Dolphin Square - Borehole A
b. Licence Nr 28/39/39/0229, Grange St Paul's Hotel – Borehole
c. Licence Nr 28/39/42/0062, City Hall, The Queens Walk - Borehole B
d. Licence Nr 28/39/42/0048, Canada Water - Borehole A
e. Licence Nr 28/39/42/0076, Brook Street abstraction borehole 2
f. Licence Nr 28/39/43/0019, Deptford Pumping Station Point F

K.2.84 Graphs showing drawdown against time and the maximum available drawdown are provided in Annex B for these key locations.

K.2.85 The plates illustrate the drawdown and recovery as different sites are dewatered in accordance with the construction sequence. Key times in the construction programme are:

a. Stress period 4 time step 5 (Mar, 2017), only dewatering at Kirtling Street Shaft

b. Stress period 10 time step 5 (Sept, 2017), end of base slab dewatering at Kirtling Street Shaft

c. Stress period 25 time step 5 (Dec, 2018),

d. Stress period 45 time step 5 (Aug, 2020), end of Blackfriars Bridge Foreshore shaft dewatering

K.2.86 The model output includes dewatering rates and volumes to achieve the construction dewatering level imposed at the shaft. The resultant rates and volumes are presented in Vol 3 Plate K.14 for the key dewatering sites. The greatest dewatering is at Kirtling Street and Blackfriars Bridge Foreshore, with peak rates ranging from around 0.5Ml/d to 2.8Ml/d. The duration of pumping is dependent on the construction programme, illustrated on Vol 3 Plate K.11.

Vol 3 Plate K.14 Groundwater – shaft dewatering

K.2.87 During the development of the project, additional dewatering was proposed towards the east, at sites including Earl Pumping Station, Deptford Church Street, Greenwich Pumping Station and Abbey Mills Pumping Station. Dewatering rates were well in excess of 5 Ml/d and the predicted effects were major adverse. A change to the construction practice was consequently made to allow for internal dewatering. Internal dewatering reduces the dewatering to within the shaft so that effects on the aquifer outside the shaft are negligible.

K.2.88 Annex C shows the regional drawdown in response to dewatering. Each page shows the water levels at key times in the construction sequence. The upper image includes piezometry and colour wash to illustrate drawdown. The lower image uses colour wash and contours to show the piezometry. The greatest predicted drawdown occurs around Kirtling Street and Blackfriars, as would be expected.

K.2.89 More detailed drawdown plots are also included in Annex D (see Vol 3 Plate K.49 to Vol 3 Plate K.57) which also labels the shafts and potential receptors.

K.2.90 The effect of dewatering is to lower groundwater levels in some areas so that confined conditions become unconfined and fully saturated aquifers are partially dewatered. Dewatering of the Thanet Sands, where it has not occurred historically, can lead to oxidation of pyrite and creation of sulphate. This deterioration of groundwater quality has been identified as a potentially adverse effect. The model was therefore used to locate those areas where such effects may arise. Annex E (Vol 3 Plate K.58 to Vol 3 Plate K.63) includes maps of dry zones. These are used in Vol 3 Section 10 Water resources - groundwater when assessing the effect of dewatering on the Thanet Sands and mixing of groundwater.

K.2.91 The other potential effect of dewatering is to change the rate of movement or direction of flow such that existing contamination moves faster or in a different direction. Where contamination has been identified, the groundwater assessment for individual sites or project-wide effects, includes an estimate of change in contaminant movement based on the Thames Tideway Tunnel project model results. It should be noted however that the model does not simulate solute transport and that the predictions are based on changes in hydraulic gradient.

Model sensitivity

K.2.92 A set of nine different model scenarios were run to demonstrate the sensitivity of the model to input parameters. The scenarios include varying hydraulic properties and boundary conditions to examine the sensitivity of the model to changes in parameters and conditions. The first scenario, documented as RUN1 represents the best estimate of the hydraulic properties and the boundary conditions. The subsequent scenarios, documented as RUN2 to RUN9 modify one parameter from the first scenario. Details of the scenarios are summarised in Vol 3 Table K.16.

Vol 3 Table K.16 Groundwater – model scenarios

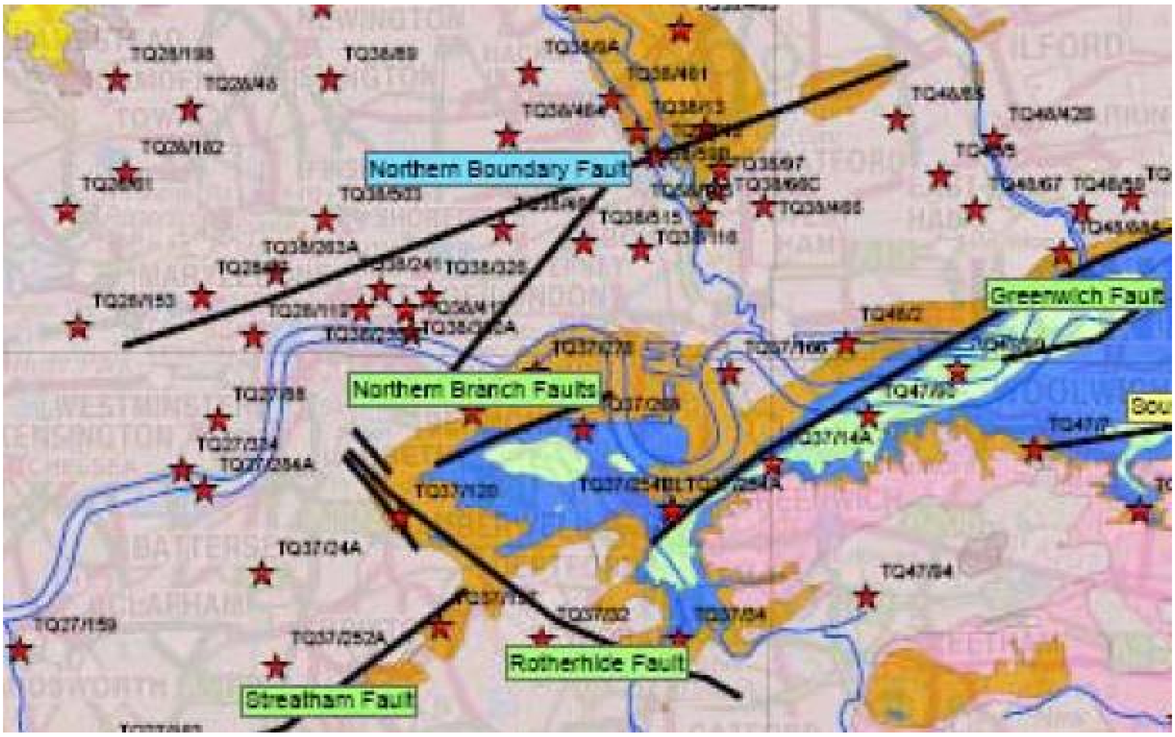
Run Nr	Hydraulic conductivity factor	Storage factor	Drain level (m)	No flow Faults	Fixed heads
1	1	1	0	no	no
2	1	1	0	yes	no
3	1	1	-10	no	no
4	1	1	-3	no	no
5	1.25	1	0	no	no
6	0.75	1	0	no	no
7	1	1.5	0	no	no
8	1	0.5	0	no	no

Run Nr	Hydraulic conductivity factor	Storage factor	Drain level (m)	No flow Faults	Fixed heads
9	1	1	0	no	yes

K.2.93 The different runs are summarised below.

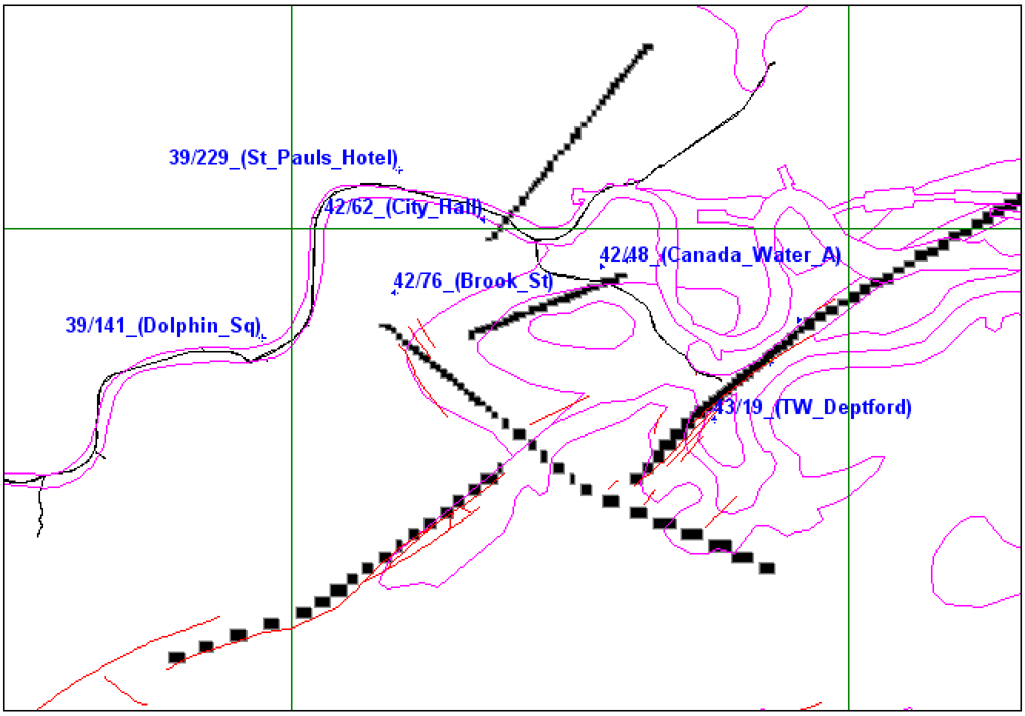
a. RUN2. The faults that cross through the area (see Vol 3 Plate K.15 and Vol 3 Plate K.16) are set to be no flow cells to act as impermeable barriers to flow. The Greenwich Fault, Northern Branch Fault, Rotherhithe Fault and Streatham Fault are all marked in green indicating "faults thought to be impermeable". The Northern Boundary Fault is marked in blue and is "without evidence to indicate a low permeability". Classification of faults is according to the EA[v]. The barrier boundary faults reduce the drawdown on the far side of the fault from a dewatered shaft. Whereas on the same side of the barrier as the shaft the drawdown can be greater than it would have been if the fault was not a barrier. The minimum water levels at the six key locations (para. K.2.83) from RUN 2 are compared to the water levels from RUN 1 (see Vol 3 Plate K.17).

Vol 3 Plate K.15 Groundwater – fault positions hydrogeological characteristics in central London



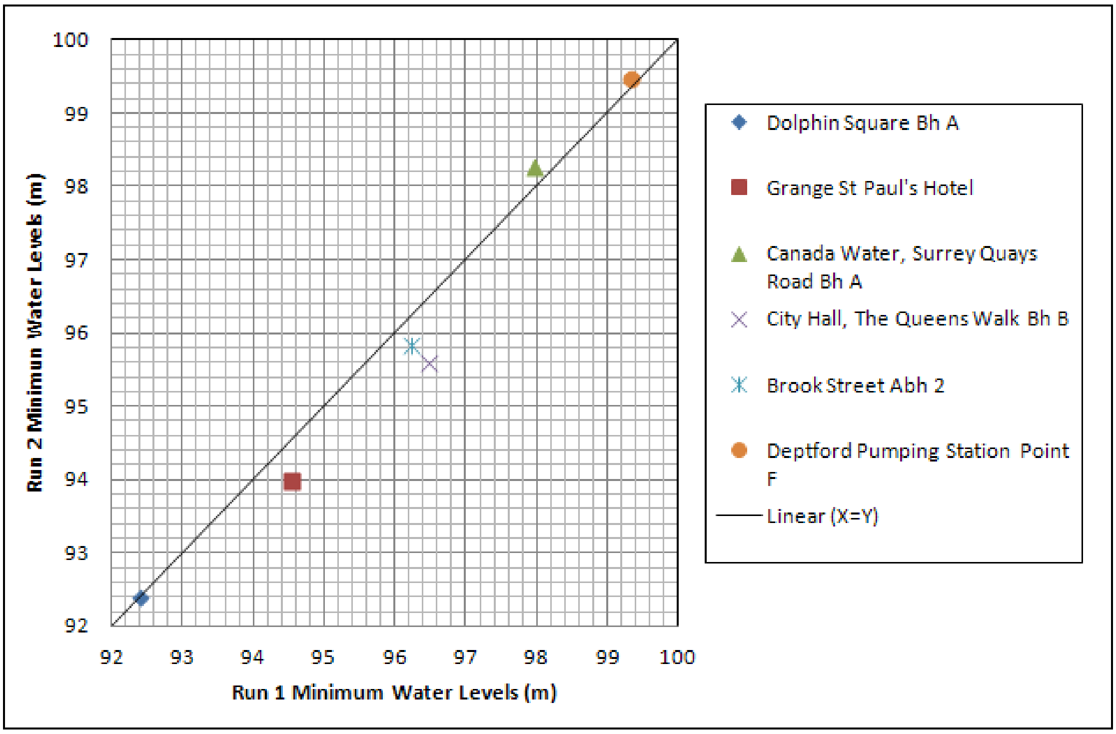
[v] Environment Agency "Management of the London Basin Chalk Aquifer", Status report 2011.

Vol 3 Plate K.16 Groundwater – fault positions in groundwater model in central London



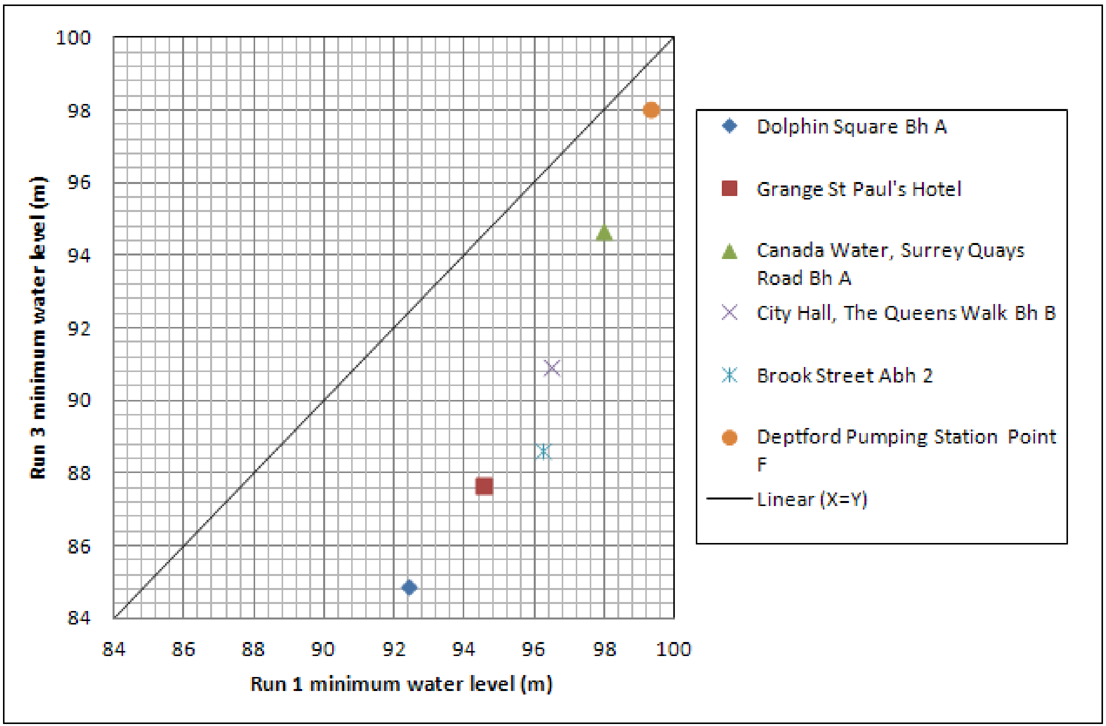
Black = no flow cell, Magenta = solid geology boundaries

Vol 3 Plate K.17 Groundwater – Impacts of Faults



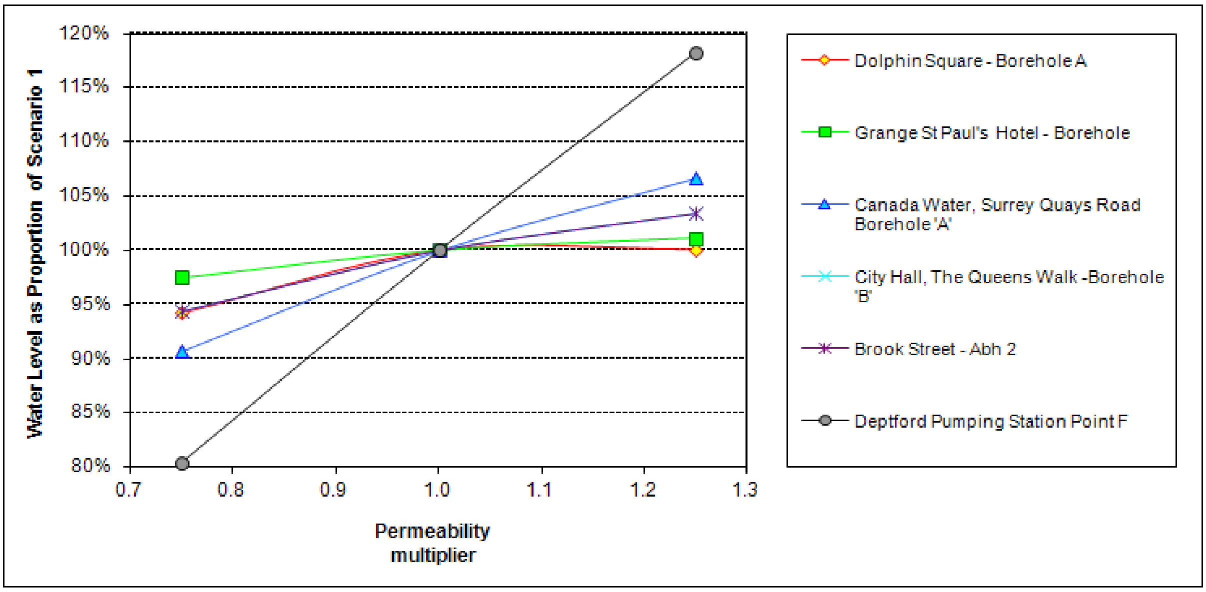
b. RUN3 and RUN4 examine the effect of a requirement for a deeper level of dewatering where the drain cells at the shaft sites are lowered by 10m and 3m. The lowering by 10m requires the positioning of drain cells in some of the shaft sites not in the Lambeth Group (layer 2), but the Chalk or Thanet Sands. The impact of lowering the drains by 10m has a greater effect on drawdown and dewatering flows than any of the other scenarios examined. The additional drawdown created in RUN 3 is compared to RUN 1 at the key locations (see Vol 3 Plate K.18).

Vol 3 Plate K.18 Groundwater – Impact of Shaft Dewatering Depth



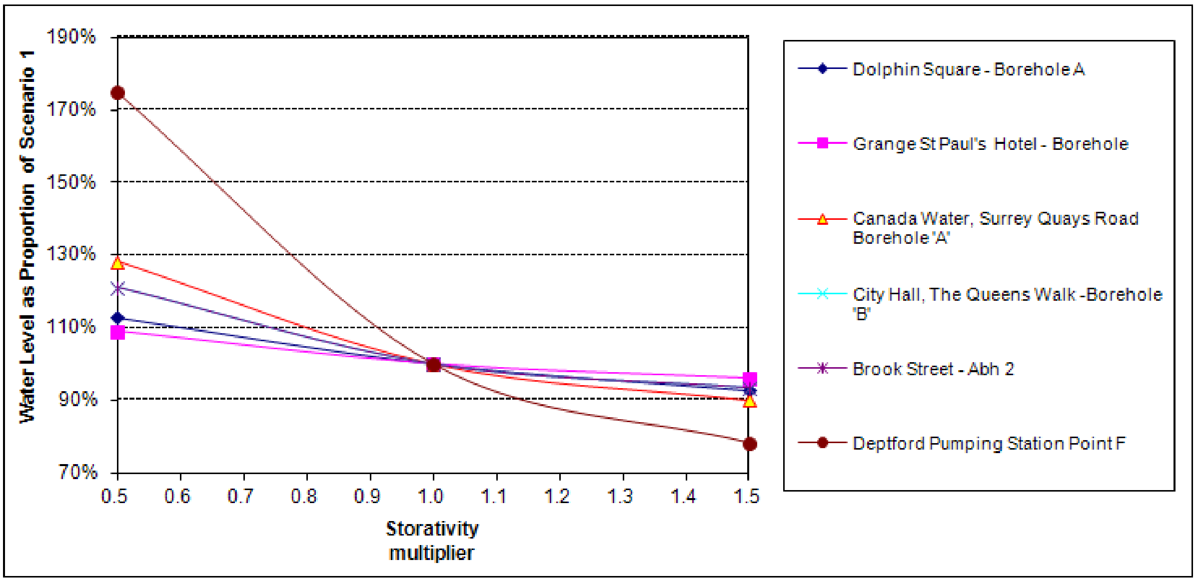
c. RUN5/6 has been used to examine the effect of changes in hydraulic conductivity. The hydraulic conductivity is modified with an increase or reduction of 25%. There are relatively small changes in the predicted drawdown with the percentage change in drawdown being less than the percentage change in conductivity. Not all areas of the model respond in the same manner. Although it has a smaller absolute drawdown the percentage change in drawdown experienced in the Greenwich area is greater than for other parts of the model. The sensitivity is illustrated in Vol 3 Plate K.19. Generally the groundwater system is not particularly sensitive to hydraulic conductivity.

Vol 3 Plate K.19 Groundwater – water level sensitivity to changes in hydraulic conductivity



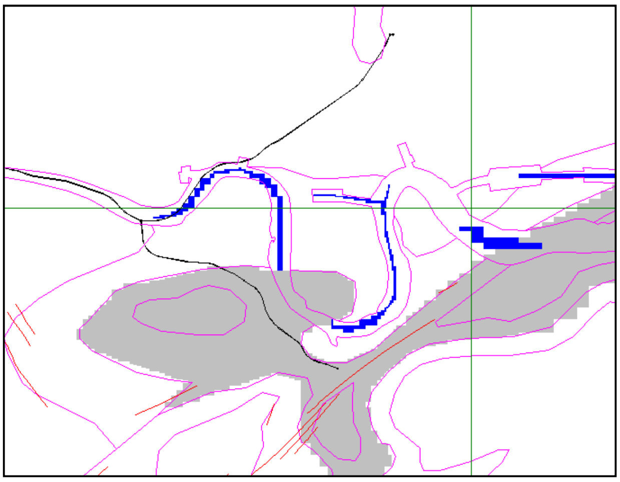
d. RUN7/8 has been used to examine the effect of changes in storativity and specific yield of the aquifer. The parameters are modified either with an increase or reduction of 50%. There are relatively small changes in the predicted drawdown. With the percentage change in drawdown being less than the percentage change in storage. The Greenwich area is most sensitive to changes in model storage. The sensitivity is illustrated in Vol 3 Plate K.20. Generally the groundwater system is not particularly sensitive to storage.

Vol 3 Plate K.20 Groundwater – water level sensitivity to changes in aquifer storativity



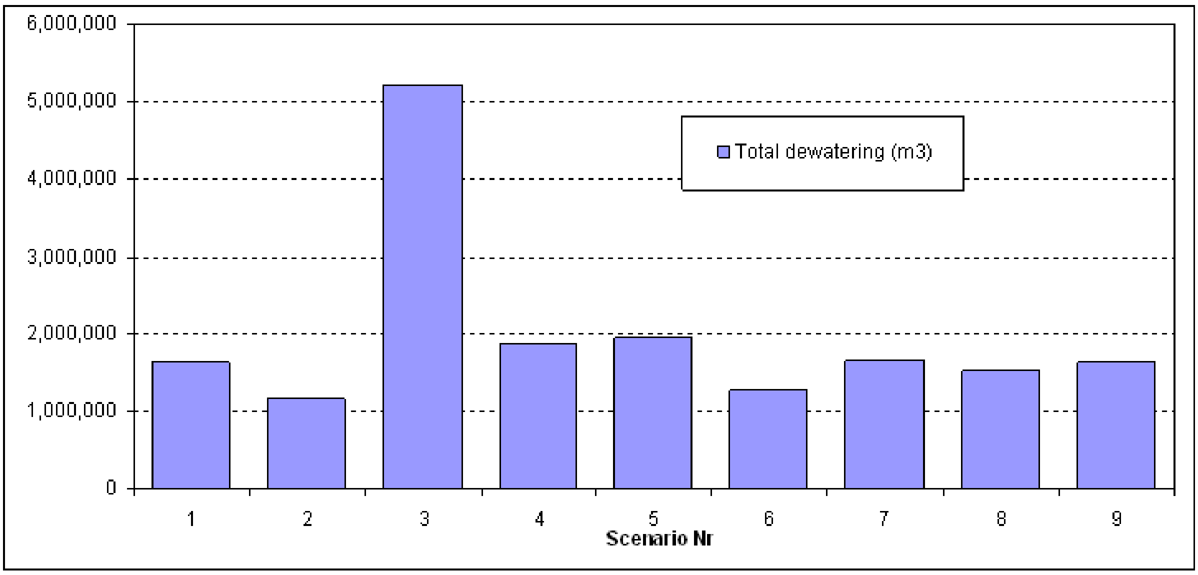
e. RUN9 has been used to examine the possible connection between the River Thames and the lower aquifer in east London where the London Clay is absent and the Lambeth Group is in places also thin or absent. The effect of this feature has been to fix the drawdown at these cells at zero as illustrated in Vol 3 Plate K.21.

Vol 3 Plate K.21 Groundwater – layer 1 fixed head cells in east London for RUN9 scenario



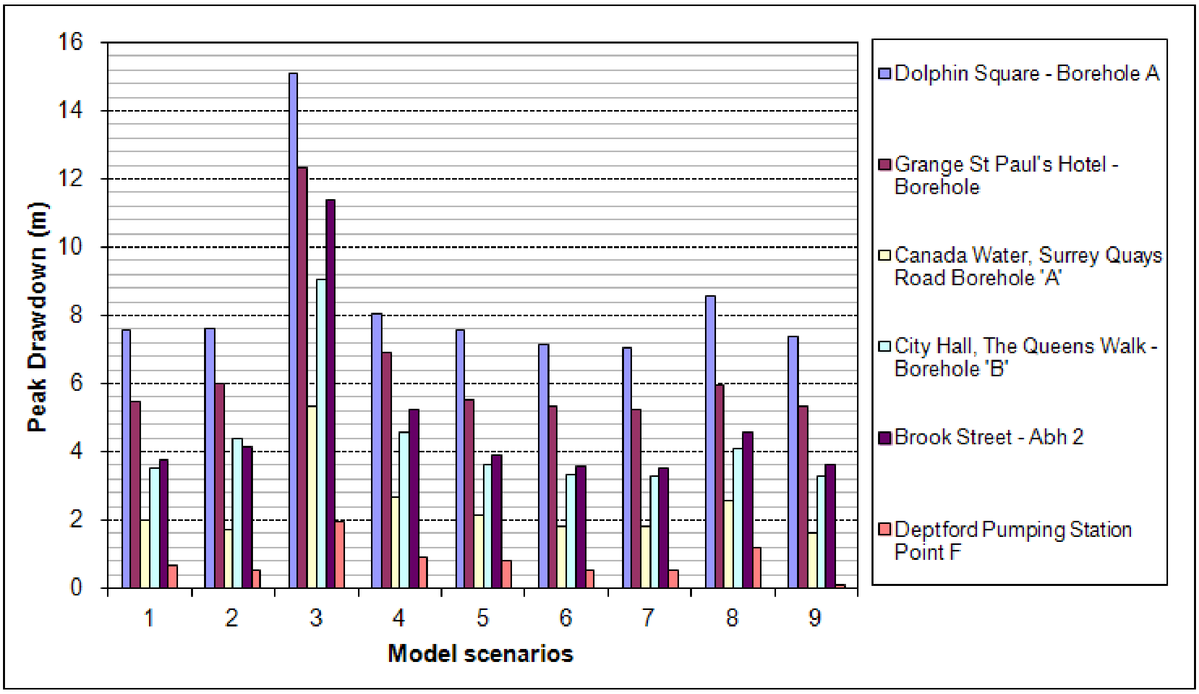
K.2.94 Vol 3 Plate K.22 shows the range of predicted abstraction volumes for each scenario. The volumes range between around 1 Mm^3 to 2 Mm^3 with a peak value of around 6.2 Mm^3 if dewatering levels are lower.

Vol 3 Plate K.22 Groundwater – model scenarios and simulated total dewatering volume



K.2.95 Vol 3 Plate K.23 illustrates the effect of the modification of different model parameters on the key selected water users (para. K.2.83).

Vol 3 Plate K.23 Groundwater – model scenarios and simulated receptor drawdown



Model Limitations

K.2.96 The Thames Tideway Tunnel project model relies on parameters used in the LBM. It covers a large area and its main purpose is to assess the project-wide impact on groundwater levels of dewatering. The model cannot be used to assess the effects of dewatering or pore pressures at the shaft scale but gives a reasonable indication of the change in groundwater levels at a regional scale.

K.2.97 Where the model indicates that effects may be major or adverse, further work is recommended. For example, if excessive drawdown at an existing abstraction borehole is predicted, further testing and local investigation is recommended. If movement of contaminants is anticipated, a quantitative risk assessment should be undertaken.

Comparison of Thames Tideway Tunnel groundwater model and London Basin model

K.2.98 The EA have been developing a regional groundwater model the London Basin Model (LBM) during the preparation of the Environmental Statement. The Thames Tideway groundwater model has been developed using some of the same data as the LBM but the final calibrated version of the LBM was not issued until after the modelling with the Thames Tideway Tunnel groundwater model had been completed.

K.2.99 The LBM simulates absolute groundwater levels in the lower aquifer using the Environment Agency's VKD[vi]. An executable version of the program has been provided by the EA to enable the LBM to be used. Coupled with the LBM is a 4R model that derives recharge, runoff and river flow from rainfall. The grid of the LBM is a uniform 200m mesh that aligns with the British National Grid. The LBM simulates both groundwater levels and stream flow and has been calibrated for the period 1965 to 2007. The model incorporates historical actual groundwater abstractions and daily rainfall patterns for the whole calibration period. Data on rainfall and actual abstraction post 2007 is not incorporated in the model files provided by the EA. A comparison of some of the key features of the LBM and the Thames Tideway Tunnel groundwater model are shown in Vol 3 Table K.17.

Vol 3 Table K.17 Comparison of features of the LBM and Thames Tideway Tunnel groundwater model

Feature	LBM	Thames Tideway Tunnel groundwater model
Basis of Model	Absolute water levels and flows	Relative water levels (drawdowns) compared to Jan 2011 conditions
Model Grid	200m uniform	200 to 20m variable
Layer Geometry	True elevations of strata	Strata relative to chalk water level in Jan 2011
Thickness of Chalk	Variable	Uniform
Thickness of Thanet Sand	Variable	Variable and based on LBM
Model code	Modflow with VKD	Modflow 2000
Hydraulic conductivity in Chalk	Variable with VKD	Variable and provided by EA for one representative instant of time from VKD model
Hydraulic conductivity in Thanet Sand	Variable	Uniform
Abstractions	Historical data	None
Recharge	Determined by recharge model	None
Discontinuities	Fault zones impermeable	Faults in one of the sensitivity model runs
Dewatering drainage	Actual abstractions	Drainage cells to

[vi] VKD. This is a version of the United States Geological Survey's modflow code that has been adapted to accommodate variations (V) in hydraulic conductivity (K) and storage with depth (D) in a model layer. The code was developed to specifically model the Chalk aquifer in England. Unlike the modflow code which is in the public domain the VKD code and documentation is not published.

Feature	LBM	Thames Tideway Tunnel groundwater model
	used	simulate abstraction
Model simulated period	1965 to 2007	None
Model predictive period	No predictive scenario data sets provided	Nov 2016 to Nov 2021
Stress periods	Three per month divided into 2 time steps (six steps per month)	One per monthly divided into 5 time steps (five steps per month)

K.2.100 The LBM has been used to compare the impact of the shaft dewatering derived from the Thames Tideway Tunnel groundwater model. The basis for the two modelling techniques is different. It is not meaningful to compare the drawdowns predicted from one model with the absolute groundwater levels predicted from the other model. To compare the models the LBM was run twice for the period 1965 to 2007. In the first run the model used the input files as provided by the EA. The model output represents the EA's accepted calibrated water levels and stream flows simulated for the historical period. In the second model run a series of drainage cells are inserted that represent the dewatering target elevations at shaft sites. These are organised to become active in the same sequence as in the Thames Tideway Tunnel groundwater model. The water levels of the two model runs are compared, the difference between the two levels being comparable with the Thames Tideway Tunnel groundwater model drawdown results.

K.2.101 The dewatering imposed on the LBM is for the end of the historical simulated period from 2003 to 2007. Thus the water levels that need to be controlled by drainage cells are those that are simulated for a period in the historical record whereas in the Thames Tideway Tunnel groundwater model they are from a basis of water levels from January 2011 as contoured by the EA.

K.2.102 The model geometry and layers in the two models can in places be slightly different, this is because the LBM uses a uniform 200m grid spacing and the Thames Tideway Tunnel groundwater model uses a variable grid with the elevation derived from 100m grid data. The consequence is that the Kirtling Street drain cell is in a very low permeability layer in the LBM and in a Thanet Sand Formation layer in the Thames Tideway Tunnel groundwater model. The LBM thus results in lower dewatering rates at Kirtling Street. Concern over the possible under prediction of drawdown in the LBM as a result of the subtle difference in layer elevations has been investigated. A further LBM run has been undertaken that ensured that the drain cells were in the Thanet Sand layer at Kirtling Street. The drawdown from the model run was higher, but except for the nearest level target (28/39/39/0141 – Mantilla Limited), the drawdown was no greater than those from the Thames Tideway Tunnel groundwater model.

K.2.103 The examination of the results from the two modelling approaches demonstrates that they are broadly in agreement. Moreover, the LBM that uses water groundwater level conditions from 2003 to 2007, predicts somewhat smaller impacts on water levels as a result of simulated dewatering than the results from the Thames Tideway Tunnel groundwater model that is used in the impact assessment.

Conclusions

K.2.104 The Thames Tideway Tunnel numerical groundwater model has been used to quantify the effect of dewatering on licensed and unlicensed abstractions and on the lower aquifer. The model has also been used to estimate the volume of water that would be generated during construction dewatering.

K.2.105 The main points relating to the model, its development and use are as follows:

a. A multi layer numerical model of the London Basin was developed, including the major faults around Greenwich and hydraulic property information provided by the LBM.

b. Drawdown across London was simulated, including assessments of effects on specific targets/receptors.

c. Dewatering proposals around Deptford Church Street, Earl Pumping Station, Abbey Mills Pumping Station and Greenwich Pumping Station were reviewed. The dewatering strategy was revised at these sites and embedded mitigation in the form of internal dewatering was adopted to minimise the effects of dewatering.

K.2.106 The results of the model are used in the groundwater impact assessments for each site and also in the project-wide groundwater assessment.

K.2.107 The shafts with the greatest predicted dewatering are at Kirtling Street (average of 440m^3/d with a peak amount of 2700m^3/d) and Blackfriars Bridge Foreshore (average of 1085m^3/d).

K.2.108 The model results have some sensitivity to the parameters used but the greatest sensitivity is to the lowering of the drain cells.

K.2.109 The Thames Tideway Tunnel groundwater model has been compared with the EA's LBM. The results from the two modelling approaches are in broad agreement with respect of the anticipated drawdown in the lower aquifer in the vicinity of the dewatered shaft sites. Locations that are remote to the dewatering sites are predicted to have a smaller impact by the LBM compared to the Thames Tideway Tunnel groundwater model. The predicted dewatering rates simulated by the two modelling techniques are very similar. The results from the use of the LBM indicates that the impact of the dewatering on water levels will be similar or less than those derived from the Thames Tideway Tunnel model.

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Annex A Long list of substances

Vol 3 Table K.18 Long list of subtsnaces

Name	Units	Method	EA suite
CALCIUM : MAGNESIUM RATIO	UNITLESS	Calculated	YES
CONDUCTIVITY @25C	uS/cm	Field	YES
HARDNESS TOTAL - as CACO3	mg/l	Calculated	YES
IONIC BALANCE (ANIONS/CATIONS)	%	Calculated	YES
NITRATE - as N	mg/l	Calculated	YES
OXYGEN DISSOLVED (INSTRUMENTAL - IN SITU) - AS O	mg/l	Calculated	YES
OXYGEN DISSOLVED (INSTRUMENTAL) - AS % SATN	%	Field	YES
PAHS, TOTAL	µg/l	Calculated	YES
PH IN SITU MEASUREMENT	PHUNITS	Field	YES
SODIUM : CHLORIDE RATIO	UNITLESS	Calculated	YES
TEMPERATURE WATER	CEL	Field	YES
ARSENIC - AS AS	µg/l	Low	YES
SELENIUM - AS SE	µg/l	Low	YES
FAECAL COLIFORMS PRESUMPTIVE	NO/100ml	Low	YES
STREPTOCOCCI FAECAL PRE-MF	NO/100ml	Low	YES
CYANIDE - AS CN	mg/l	Low	YES
ALKALINITY PH 4.5 - as CACO3	mg/l	Low	YES
AMMONIA - AS N	mg/l	Low	YES
CARBON DIOXIDE FREE - AS CO2	mg/l	Low	YES
CARBON ORGANIC DISSOLVED - AS C	mg/l	Low	YES
CHLORIDE ION - AS CL	mg/l	Low	YES
FLUORIDE - AS F	mg/l	Low	YES
NITRITE - as N	mg/l	Low	YES
NITROGEN TOTAL OXIDISED - AS N	mg/l	Low	YES
ORTHOPHOSPHATE - as P	mg/l	Low	YES
PH - AS PH UNITS	PHUNITS	Low	YES
SILICATE REACTIVE DISSOLVED - AS	mg/l	Low	YES

Name	Units	Method	EA suite
SIO2			
BROMATE	mg/l	Low	YES
BROMIDE ION - AS BR	mg/l	Low	YES
IODIDE ION - AS I	mg/l	Low	YES
(2,4,5-TRICHLOROPHENOXY)ETHANOIC ACID	µg/l	Low	YES
(2,4-DICHLOROPHENOXY)ETHANOIC ACID	µg/l	Low	YES
2,3,6-TBA {2,3,6-TRICHLOROBENZOIC ACID}{CAS RN 5	µg/l	Low	YES
2,4-DB	µg/l	Low	YES
BENAZOLIN	µg/l	Low	YES
BENTAZONE	µg/l	Low	YES
BROMOXYNIL	µg/l	Low	YES
CLOPYRALID	µg/l	Low	YES
DICAMBA {3,6-DICHLORO(O-METHOXYBENZOIC ACID)}	µg/l	Low	YES
DICHLORPROP	µg/l	Low	YES
FENOPROP	µg/l	Low	YES
FLUROXYPYR	µg/l	Low	YES
IOXYNIL	µg/l	Low	YES
MCPA { }	µg/l	Low	YES
MCPB	µg/l	Low	YES
MECOPROP { }	µg/l	Low	YES
PICHLORAM	µg/l	Low	YES
TRICLOPYR	µg/l	Low	YES
MERCURY - AS HG	µg/l	Low	YES
ALUMINIUM - AS AL	µg/l	Low	YES
ANTIMONY - AS SB	µg/l	Low	YES
BARIUM - AS BA	µg/l	Low	YES
BERYLLIUM - AS BE	µg/l	Low	YES
BORON - AS B	µg/l	Low	YES
CADMIUM - AS CD	µg/l	Low	YES

Name	Units	Method	EA suite
CALCIUM - AS CA	mg/l	Low	YES
CHROMIUM - AS CR	µg/l	Low	YES
COBALT - AS CO	µg/l	Low	YES
COPPER - AS CU	µg/l	Low	YES
IRON - AS FE	µg/l	Low	YES
LEAD - AS PB	µg/l	Low	YES
LITHIUM - AS LI	µg/l	Low	YES
MAGNESIUM - AS MG	mg/l	Low	YES
MANGANESE - AS MN	µg/l	Low	YES
MOLYBDENUM - AS MO	µg/l	Low	YES
NICKEL - AS NI	µg/l	Low	YES
POTASSIUM - AS K	mg/l	Low	YES
SILVER - AS AG	µg/l	Low	YES
SODIUM - AS NA	mg/l	Low	YES
STRONTIUM - AS SR	µg/l	Low	YES
SULPHATE - AS SO4	mg/l	Low	YES
THALLIUM - TOTAL AS TL	µg/l	Low	YES
TIN - AS SN	µg/l	Low	YES
TITANIUM	µg/l		YES
URANIUM - AS U	µg/l	Low	YES
VANADIUM - AS V	µg/l	Low	YES
ZINC - AS ZN	µg/l	Low	YES
ALUMINIUM DISSOLVED - AS AL	µg/l	Low	YES
BARIUM DISSOLVED - AS BA	µg/l	Low	YES
BORON DISSOLVED- AS B	µg/l	Low	YES
CADMIUM DISSOLVED	µg/l	Low	YES
CALCIUM DISSOLVED - AS CA	mg/l	Low	YES
CHROMIUM (DISSOLVED)	µg/l	Low	YES
COPPER (DISSOLVED)	µg/l	Low	YES
IRON DISSOLVED - AS FE	µg/l	Low	YES
LEAD (DISSOLVED)	µg/l	Low	YES
LITHIUM DISSOLVED - AS LI	µg/l	Low	YES

Name	Units	Method	EA suite
MAGNESIUM DISSOLVED - AS MG	mg/l	Low	YES
MANGANESE DISSOLVED - AS MN	µg/l	Low	YES
NICKEL (DISSOLVED)	µg/l	Low	YES
POTASSIUM DISSOLVED - AS K	mg/l	Low	YES
SODIUM DISSOLVED - AS Na	mg/l	Low	YES
STRONTIUM DISSOLVED - AS SR	µg/l	Low	YES
ZINC (DISSOLVED)	µg/l	Low	YES
ACENAPTHENE	µg/l	Low	YES
ACENAPTHYLENE	µg/l	Low	YES
ANTHRACENE	µg/l	Low	YES
BENZ[A]-ANTHRACENE	µg/l	Low	YES
BENZO-[A]-PYRENE	µg/l	Low	YES
BENZO-[B]-FLUORANTHENE	µg/l	Low	YES
BENZO-[GHI]-PERYLENE	µg/l	Low	YES
BENZO-[K]-FLUORANTHENE	µg/l	Low	YES
CHRYSENE	µg/l	Low	YES
DIBENZ-[A,H]-ANTHRACENE	µg/l	Low	YES
FLUORANTHENE	µg/l	Low	YES
FLUORENE	µg/l	Low	YES
INDENO-[1,2,3-CD]-PYRENE	µg/l	Low	YES
NAPHTHALENE	µg/l	Low	YES
PHENANTHRENE	µg/l	Low	YES
PYRENE	µg/l	Low	YES
1,2,3-TRICHLOROBENZENE	µg/l	Low	YES
1,2,4-TRICHLOROBENZENE	µg/l	Low	YES
1,3,5-TRICHLOROBENZENE	µg/l	Low	YES
2,3,5,6-TETRACHLOROAMINOBENZENE {2,...ANILINE}	µg/l	Low	YES
2,3,5,6-TETRACHLOROTHIOANISOLE	µg/l	Low	YES
ALDRIN	µg/l	Low	YES
CHLORDANE CIS/Z/ALPHA	µg/l	Low	YES
CHLORDANE TRANS	µg/l	Low	YES

Name	Units	Method	EA suite
CHLOROPROPHAM	µg/l	Low	YES
CHLOROTHALONIL	µg/l	Low	YES
CIS-HEPTACHLOR EPOXIDE	µg/l	Low	YES
DDE (OP)	µg/l	Low	YES
DDE (PP)	µg/l	Low	YES
DDT (OP)	µg/l	Low	YES
DDT (PP)	µg/l	Low	YES
DICHLOBENIL	µg/l	Low	YES
DIELDRIN	µg/l	Low	YES
ENDOSULPHAN ALPHA	µg/l	Low	YES
ENDOSULPHAN BETA	µg/l	Low	YES
ENDRIN	µg/l	Low	YES
HCH ALPHA	µg/l	Low	YES
HCH BETA	µg/l	Low	YES
HCH DELTA	µg/l	Low	YES
HCH GAMMA	µg/l	Low	YES
HEPTACHLOR	µg/l	Low	YES
HEXACHLORO 1,3 BUTADIENE	µg/l	Low	YES
HEXACHLOROBENZENE	µg/l	Low	YES
ISODRIN	µg/l	Low	YES
METHOXYCHLOR	µg/l	Low	YES
PCB CONGENER 028	µg/l	Low	YES
PCB CONGENER 052	µg/l	Low	YES
PCB CONGENER 101	µg/l	Low	YES
PCB CONGENER 105	µg/l	Low	YES
PCB CONGENER 118	µg/l	Low	YES
PCB CONGENER 138	µg/l	Low	YES
PCB CONGENER 153	µg/l	Low	YES
PCB CONGENER 156	µg/l	Low	YES
PCB CONGENER 180	µg/l	Low	YES
PENDIMETHALIN	µg/l	Low	YES
PROPACHLOR	µg/l	Low	YES

Name	Units	Method	EA suite
TDE (OP)	µg/l	Low	YES
TDE (PP)	µg/l	Low	YES
TECNAZENE	µg/l	Low	YES
TRANS-HEPTACHLOR EPOXIDE	µg/l	Low	YES
TRIFLURALIN	µg/l	Low	YES
ATRAZINE { }	µg/l	Low	YES
ATRAZINE DESETHYL {DE-ETHYL ATRAZINE}	µg/l	Low	YES
ATRAZINE DESISOPROPYL	µg/l	Low	YES
AZINPHOS-ETHYL	µg/l	Low	YES
AZINPHOS-METHYL	µg/l	Low	YES
BENDIOCARB	µg/l	Low	YES
BUPIRIMATE	µg/l	Low	YES
CARBOPHENOTHION	µg/l	Low	YES
CHLORFENVINPHOS	µg/l	Low	YES
CHLORPYRIFOS	µg/l	Low	YES
CHLORPYRIPHOS-METHYL	µg/l	Low	YES
COUMAPHOS	µg/l	Low	YES
CYANAZINE	µg/l	Low	YES
DESMETRYNE	µg/l	Low	YES
DIAZINON	µg/l	Low	YES
DICHLORVOS	µg/l	Low	YES
DIMETHOATE	µg/l	Low	YES
ETHION	µg/l	Low	YES
ETHOFUMESATE	µg/l	Low	YES
FENCHLORPHOS {RONNEL.}	µg/l	Low	YES
FENITROTHION	µg/l	Low	YES
FENPROPIMORPH	µg/l	Low	YES
FENTHION	µg/l	Low	YES
FONOFOS	µg/l	Low	YES
IODOFENPHOS	µg/l	Low	YES
IPRODIONE	µg/l	Low	YES
IRGAROL 1051	µg/l	Low	YES

Name	Units	Method	EA suite
MALATHION	µg/l	Low	YES
METALAXYL	µg/l	Low	YES
METAZACHLOR	µg/l	Low	YES
MEVINPHOS	µg/l	Low	YES
NAPROPAMIDE	µg/l	Low	YES
PARATHION {PARATHION ETHYL}	µg/l	Low	YES
PARATHION-METHYL { }	µg/l	Low	YES
PHORATE	µg/l	Low	YES
PIRIMICARB	µg/l	Low	YES
PIRIMIPHOS METHYL {METHYL PIRIMIPHOS}	µg/l	Low	YES
PIRIMIPHOS-ETHYL	µg/l	Low	YES
PROCHLORAZ	µg/l	Low	YES
PROMETHRYN	µg/l	Low	YES
PROPAZINE	µg/l	Low	YES
PROPETAMPHOS	µg/l	Low	YES
PROPYZAMIDE	µg/l	Low	YES
SIMAZINE	µg/l	Low	YES
TERBUTRYN	µg/l	Low	YES
TRIAZOPHOS	µg/l	Low	YES
TRIETAZINE	µg/l	Low	YES
2,3-DIMETHYLPHENOL {2,3-XYLENOL}	µg/l	Low	YES
2,4,5-TRICHLOROPHENOL	µg/l	Low	YES
2,4,6-TRICHLOROPHENOL	µg/l	Low	YES
2,4-DICHLOROPHENOL	µg/l	Low	YES
2,4-DIMETHYLPHENOL {2,4-XYLENOL}	µg/l	Low	YES
2,5-DICHLOROPHENOL	µg/l	Low	YES
2,5-DIMETHYLPHENOL {2,5-XYLENOL}	µg/l	Low	YES
2,6 DIMETHYLPHENOL {2,6 XYLENOL}	µg/l	Low	YES
2,6-DICHLOROPHENOL	µg/l	Low	YES
2-CHLOROPHENOL	µg/l	Low	YES
2-METHYLPHENOL {O-CRESOL}	µg/l	Low	YES
3,4 DIMETHYLPHENOL {3,4 XYLENOL}	µg/l	Low	YES

Name	Units	Method	EA suite
3,5-DIMETHYLPHENOL {3,5-XYLENOL}	µg/l	Low	YES
3-CHLOROPHENOL	µg/l	Low	YES
3-METHYLPHENOL {M-CRESOL}	µg/l	Low	YES
4-CHLORO-3-METHYLPHENOL {P-CHLORO-M-CRESOL}	µg/l	Low	YES
4-CHLOROPHENOL	µg/l	Low	YES
4-METHYLPHENOL {P-CRESOL}	µg/l	Low	YES
PENTACHLOROPHENOL	µg/l	Low	YES
PHENOL	µg/l	Low	YES
GCMS : Low Level Semi-Volatile Screen : Gwtrs	Text	Low	
BIFENTHRIN	µg/l	Low	YES
CYFLUTHRIN	µg/l	Low	YES
CYPERMETHRIN	µg/l	Low	YES
CYPERMETHRIN ID	µg/l	Text	YES
DELTAMETHRIN	µg/l	Low	YES
FLUMETHRIN	µg/l	Low	YES
LAMBDA CYHALOTHRIN	µg/l	Low	YES
PERMETHRIN, CIS	µg/l	Low	YES
PERMETHRIN, TRANS	µg/l	Low	YES
CHLORMEQUAT	µg/l	Low	YES
1,1,1-TRICHLOROETHANE	µg/l	Low	YES
1,1,2-TRICHLOROETHANE	µg/l	Low	YES
1,1-DICHLOROETHANE	µg/l	Low	YES
1,1-DICHLOROETHENE	µg/l	Low	YES
1,2 -DICHLOROETHENE (CIS)	µg/l	Low	YES
1,2 -DICHLOROETHENE (TRANS)	µg/l	Low	YES
1,2-DICHLOROETHANE {ETHYLENE DICHLORIDE}	µg/l	Low	YES
1,2-DIMETHYLBENZENE {O-XYLENE}	µg/l	Low	YES
BENZENE	µg/l	Low	YES
BROMODICHLOROMETHANE	µg/l	Low	YES
CHLORODIBROMOMETHANE	µg/l	Low	YES

Name	Units	Method	EA suite
ETHENYLBENZENE {VINYLBENZENE} {STYRENE}	µg/l	Low	YES
ETHYLBENZENE	µg/l	Low	YES
GCMS : Volatile Screen for Gwtrs	text	Low	
TETRACHLOROETHENE (PER/TETRACHLOROETHYLENE)	µg/l	Low	YES
TETRACHLOROMETHANE {CARBON TETRACHLORIDE}	µg/l	Low	YES
TOLUENE (METHYLBENZENE)	µg/l	Low	YES
TRIBROMOMETHANE {BROMOFORM}	µg/l	Low	YES
TRICHLOROETHENE (TRICHLOROETHYLENE)	µg/l	Low	YES
TRICHLOROMETHANE {CHLOROFORM}	µg/l	Low	YES
XYLENE (META & PARA){1,3+1,4-dimethylbenzene}	µg/l	Low	YES
METHANE - AS CH4	mg/l	Low	YES
1,1,1,2 -TETRACHLOROETHANE	µg/l	Low	YES
1,1,2,2-TETRACHLOROETHANE {ACETOSAN}{BONAFORM}{C	µg/l	Low	YES
ETHYL TERTIARY BUTYL ETHER (ETBE)	µg/l	Low	YES
MTBE {METHYL TERT-BUTYL ETHER}	µg/l	Low	YES
TERTIARY AMYL METHYL ETHER (TAME)	µg/l	Low	YES
SULPHIDE - AS S	mg/l	Low	YES
ALDICARB	µg/l	Low	YES
ALDICARB SULPHONE	µg/l	Low	YES
ALDICARB SULPHOXIDE	µg/l	Low	YES
ASULAM	µg/l	Low	YES
CARBARYL	µg/l	Low	YES
CARBENDAZIM	µg/l	Low	YES
CARBETAMIDE	µg/l	Low	YES
CARBOFURAN	µg/l	Low	YES
CHLORIDAZON	µg/l	Low	YES
CHLOROTOLURON	µg/l	Low	YES

Name	Units	Method	EA suite
CHLOROXURON	µg/l	Low	YES
DIFLUROBENZURON	µg/l	Low	YES
DIURON	µg/l	Low	YES
ETHIOFENCARB	µg/l	Low	YES
FENURON	µg/l	Low	YES
ISOPROTURON (DIIP1,3DITHIOLAN-2-YLIDENEMALONATE)	µg/l	Low	YES
LINURON	µg/l	Low	YES
METHABENZTHIAZURON	µg/l	Low	YES
METHIOCARB	µg/l	Low	YES
METHOMYL	µg/l	Low	YES
METOXURON	µg/l	Low	YES
METSULFURON - METHYL	µg/l	Low	YES
MONOLINURON	µg/l	Low	YES
MONURON	µg/l	Low	YES
NEBURON	µg/l	Low	YES
OXAMYL	µg/l	Low	YES
PROPOXUR	µg/l	Low	YES
FLUTRIAFOL	µg/l	Low	YES
BICARBONATE - AS HCO3	mg/l	Calculated	YES
Multi residual (GCMS) scan, determinands tested listed below	text	low	YES
1200: Trihalomethn, µg/l			NO
5955: SI-G2, UNITLESS			NO
5957: SI-G4, UNITLESS			NO
6906: TETRACHLOROE, µg/l			NO
6940: PhenolsSWAD, µg/l			NO
8383: Xylene Tot, µg/l			NO
9695: HcarbonsFilt, µg/l			NO
9823: Permthrn c+t, µg/l			NO
6946: Cyanide elib, µg/l			NO
9880: Nitrate -NO3, mg/l			NO
1,1-Dichloropropene			NO

Name	Units	Method	EA suite
1,2-Dichloropropane			NO
1,3-Dichloropropane TRANS			NO
2 4 5-T			NO
Ammonium	mg/l		NO
Bromomethane			NO
Chloroethane			NO
Clofenvinfos			NO
COD			NO
Chloromethane			NO
Dalapon			NO
DDT TOTAL			NO
Delta.-Lindane			NO
Dichlorobenzoic Acid			NO
Dichlorodifluoromethane			NO
Dichloromethane			NO
Endosulfan A			NO
Endosulfan B			NO
Gasoline Range Organics/Extractable Petroleum Hydrocarbons Organics (as a screening for light (C4-C10) and heavy (C10-C40) hydrocarbons)			NO
Glyphosate			NO
Phosphamidon			NO
Phosphate			NO
Trichlorofluoromethane			NO
Turbidity			NO
VinylChloride			NO

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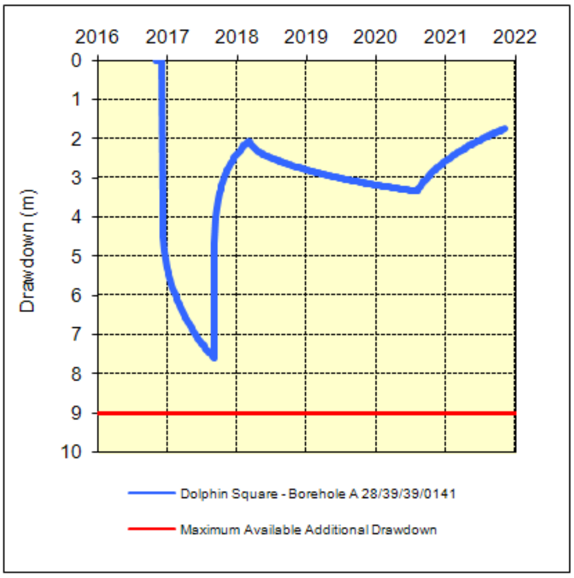
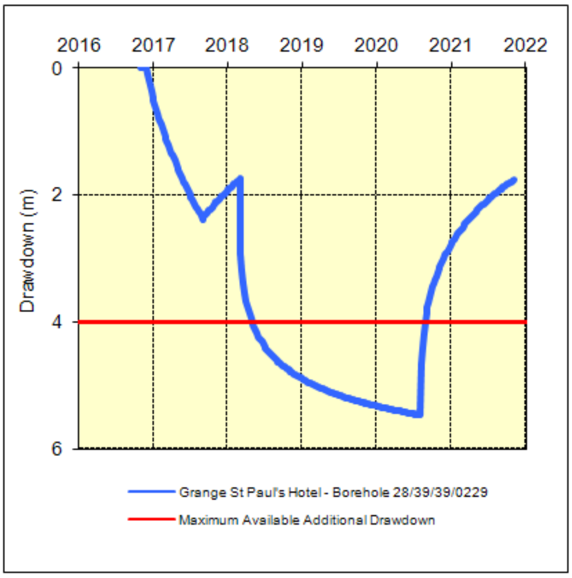
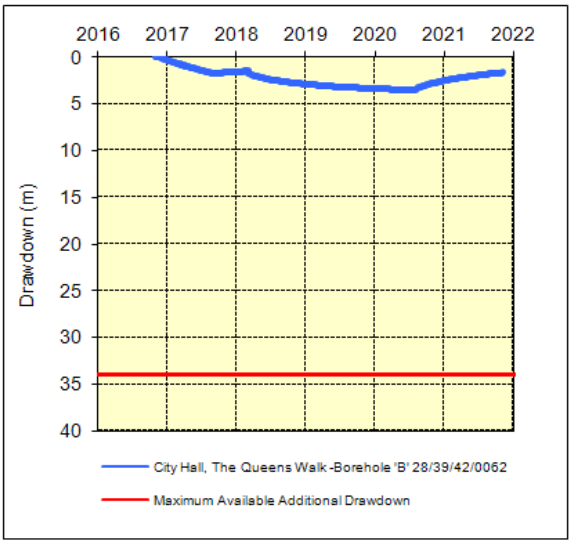
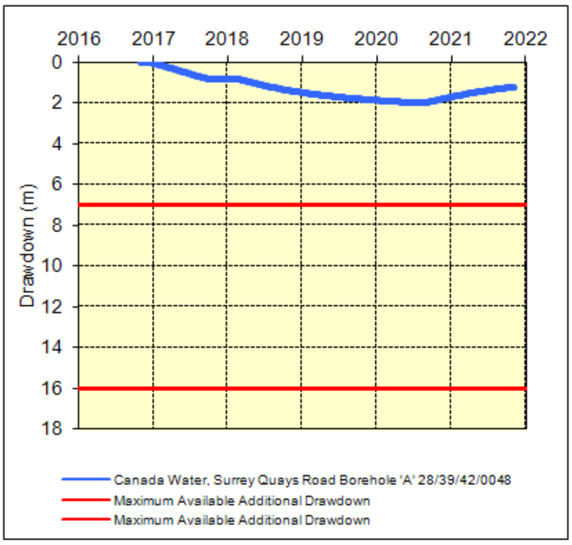
Annex B Drawdown Time Series

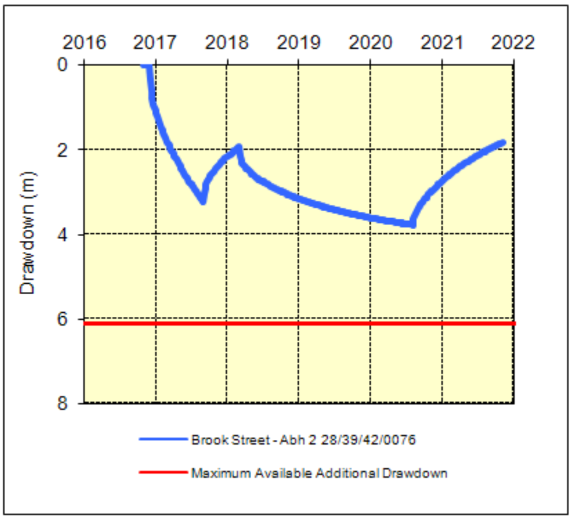
Vol 3 Plate K.24 Groundwater – Drawdown Time Series RUN 1

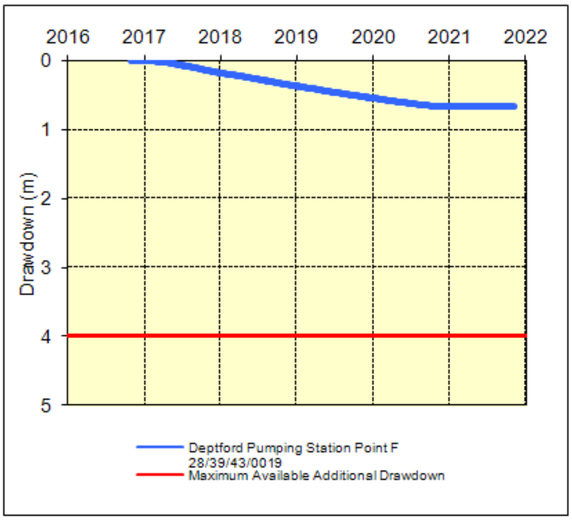






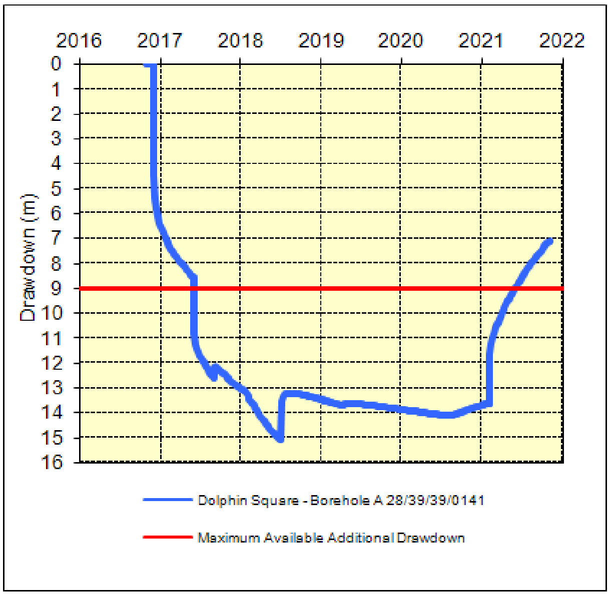


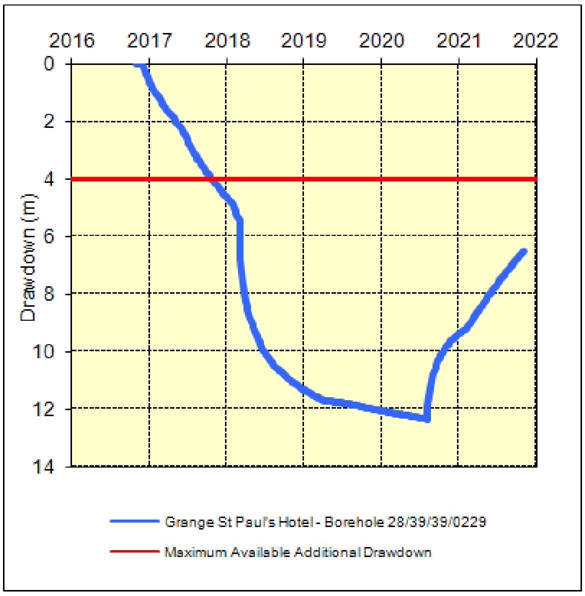


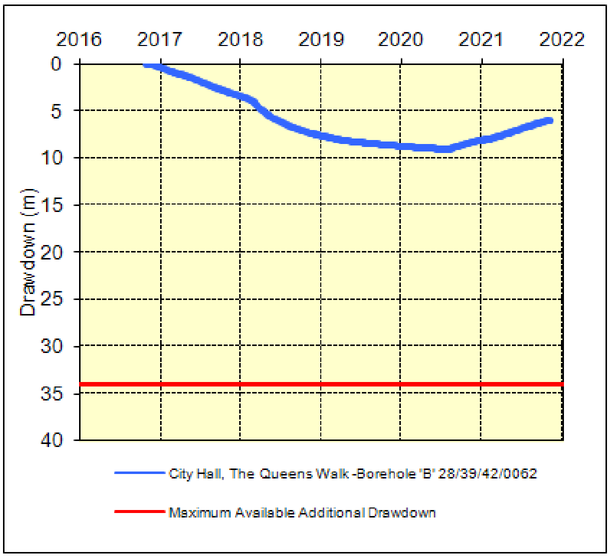


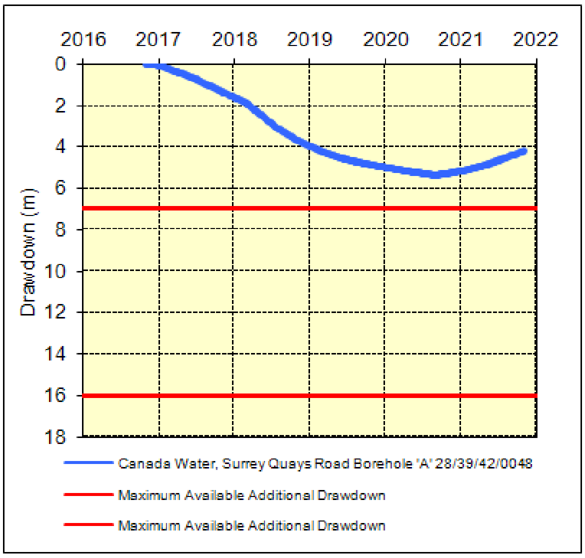
Vol 3 Plate K.25 Groundwater – Drawdown Time Series RUN 2

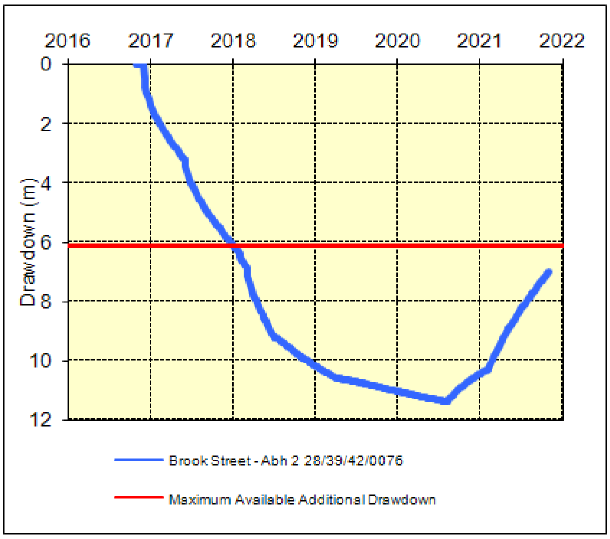
Vol 3 Plate K.26 Groundwater – Drawdown Time Series RUN 3

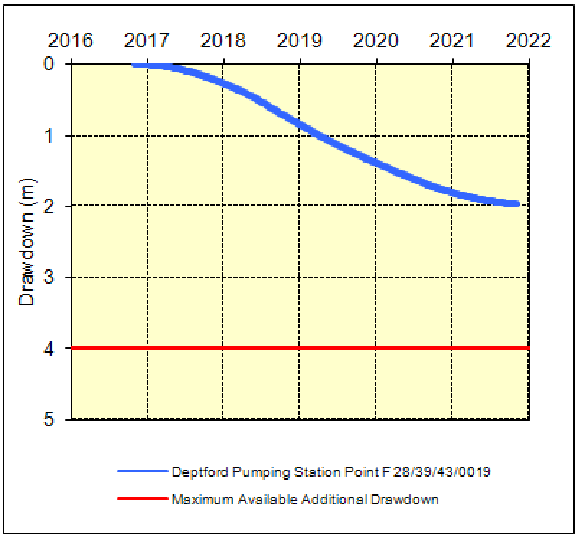




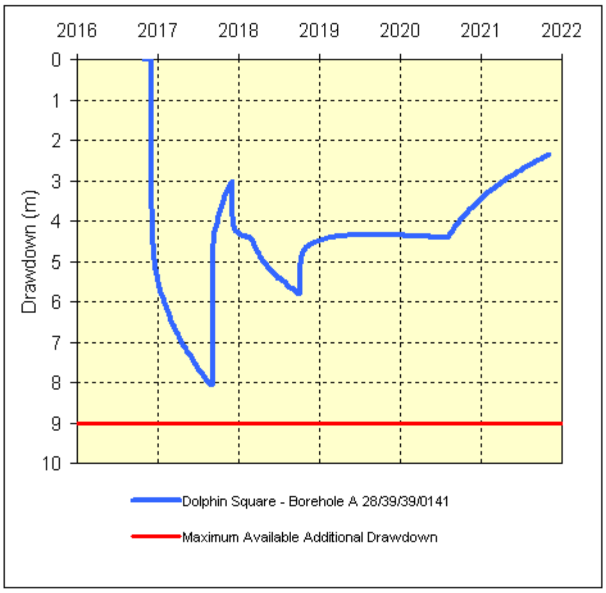


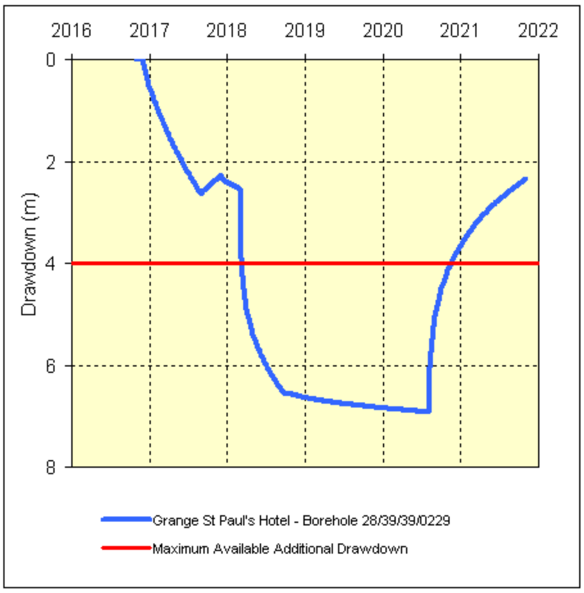


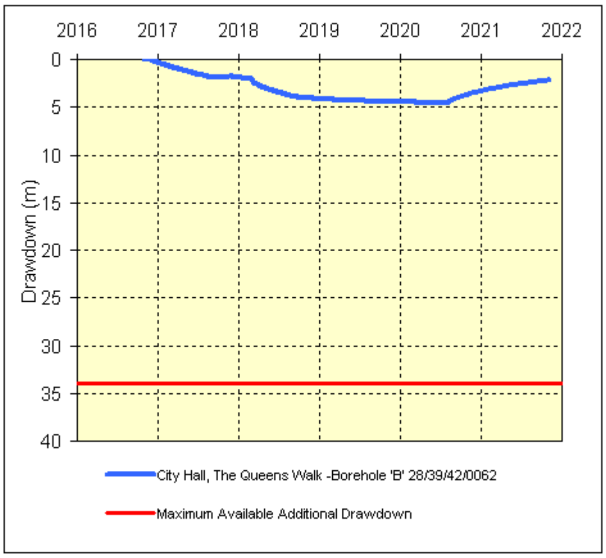


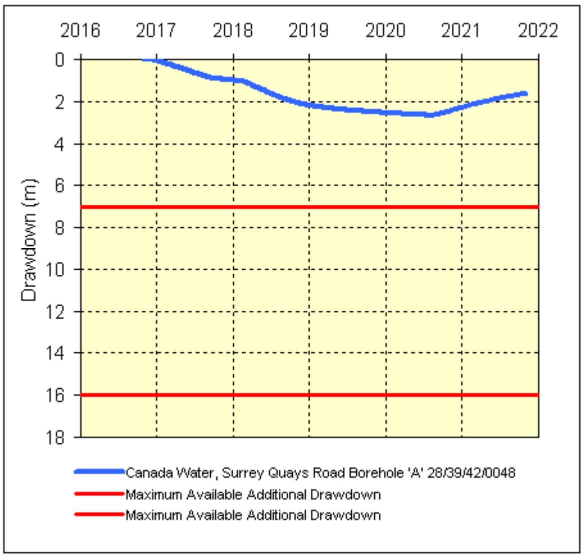


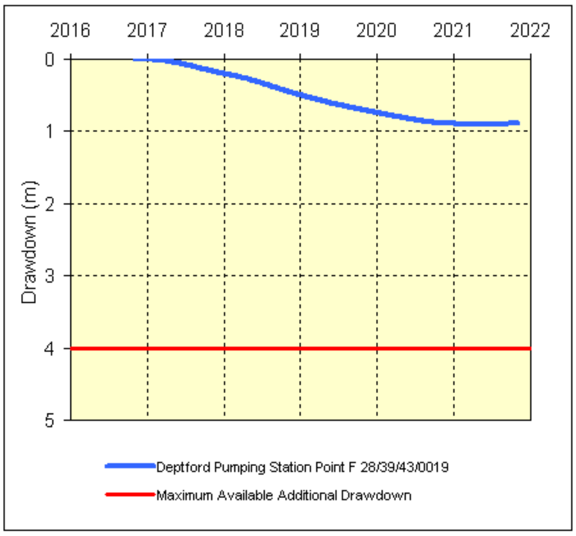
Vol 3 Plate K.27 Groundwater – Drawdown Time Series RUN 4



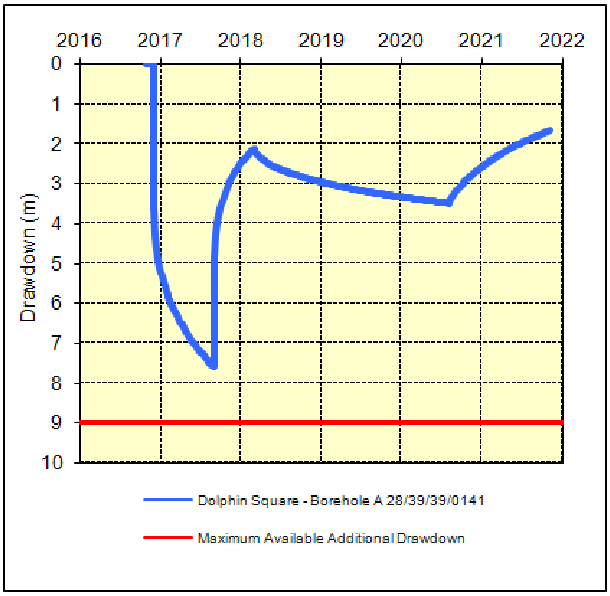


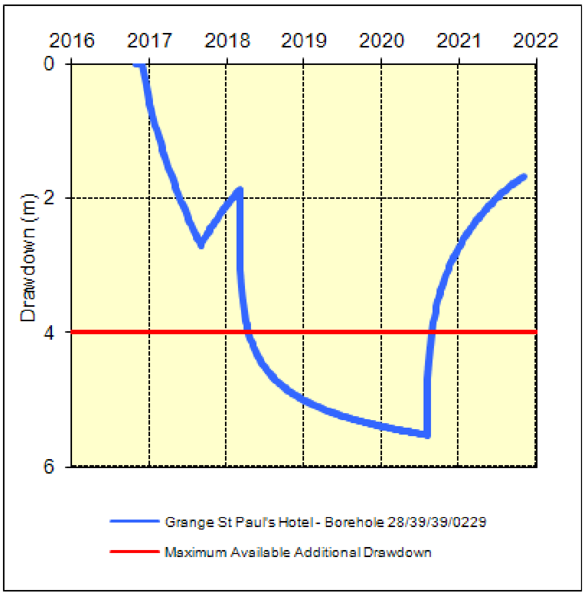


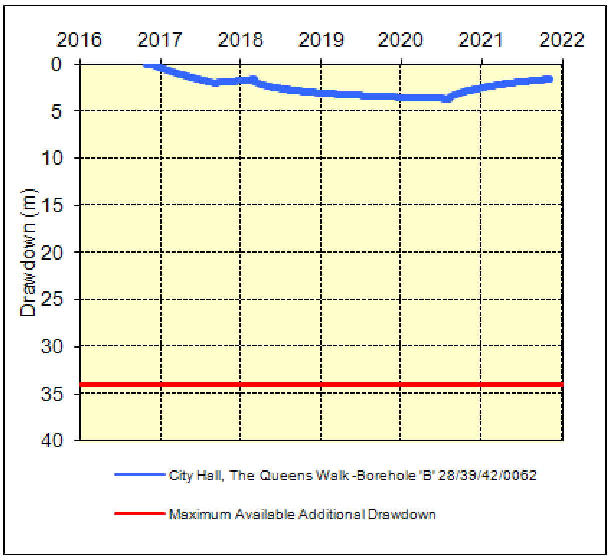


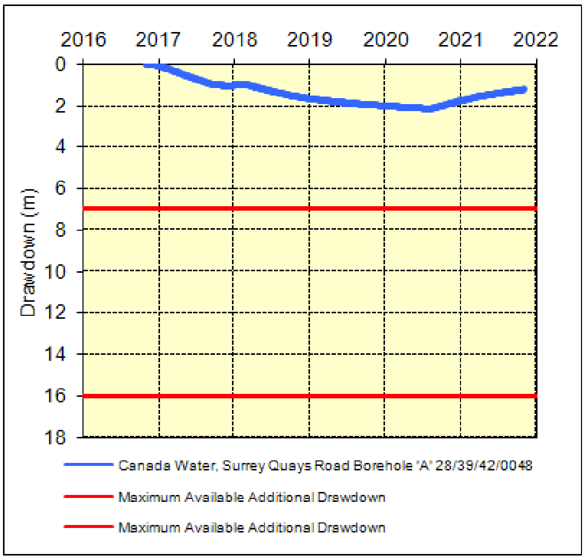


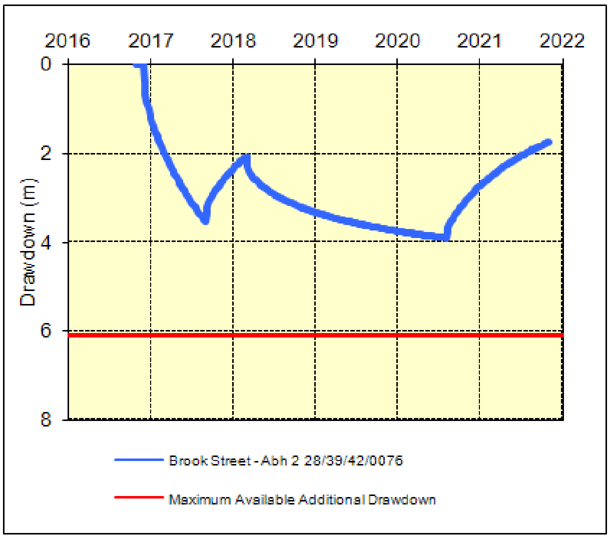
Vol 3 Plate K.28 Groundwater – Drawdown Time Series RUN 5

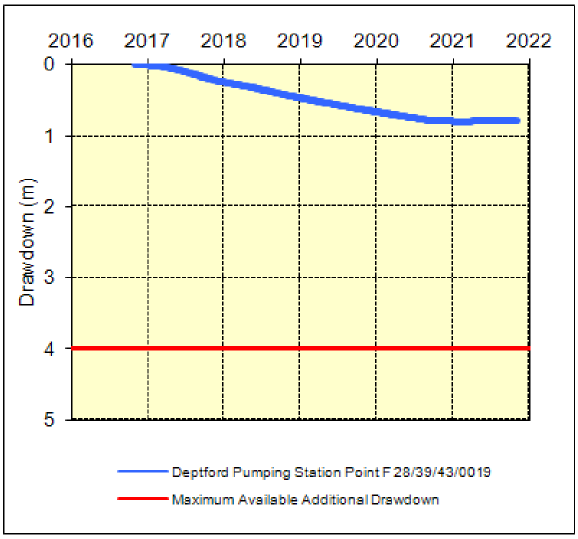




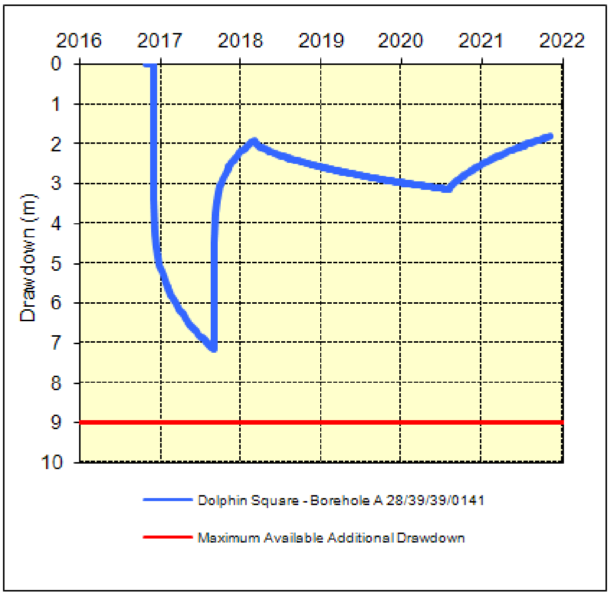


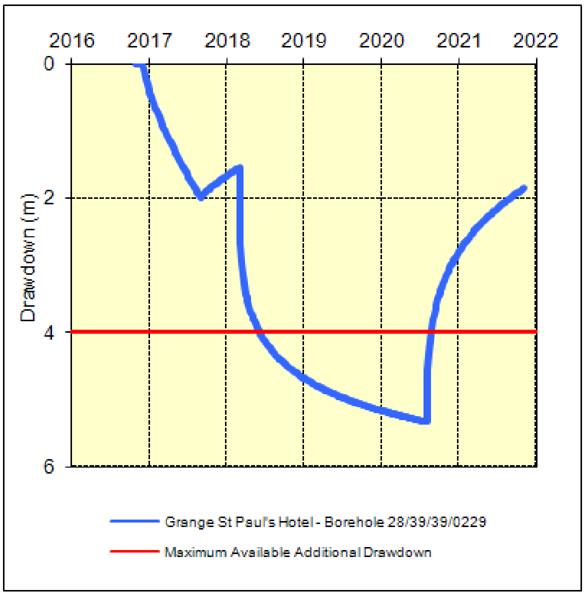


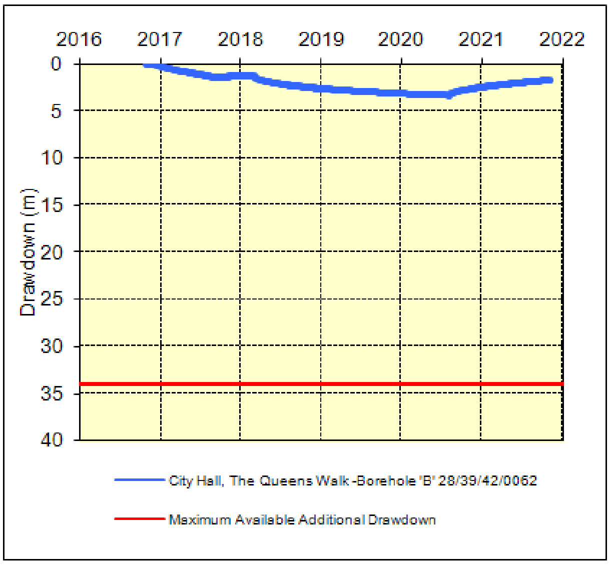


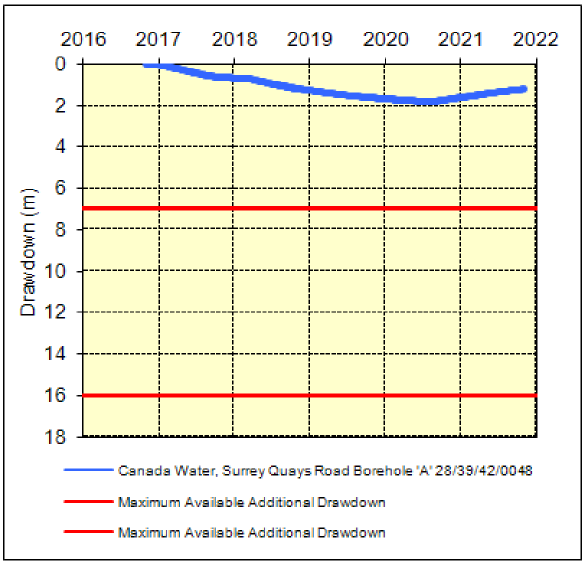


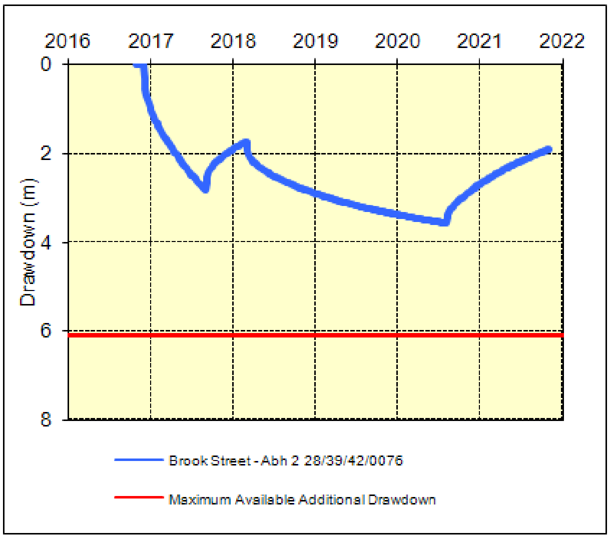
Vol 3 Plate K.29 Groundwater – Drawdown Time Series RUN 6

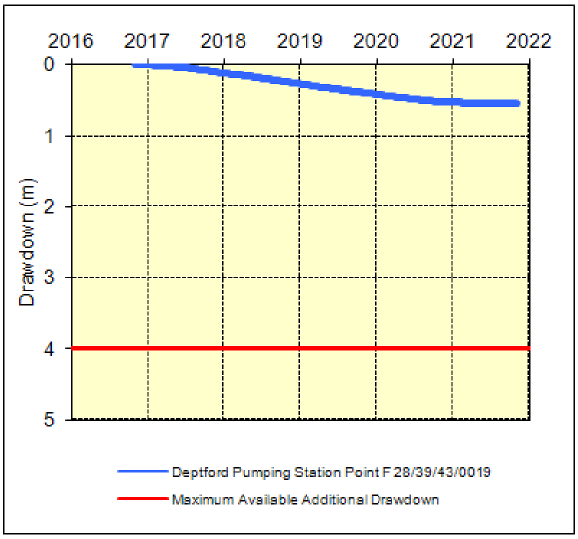






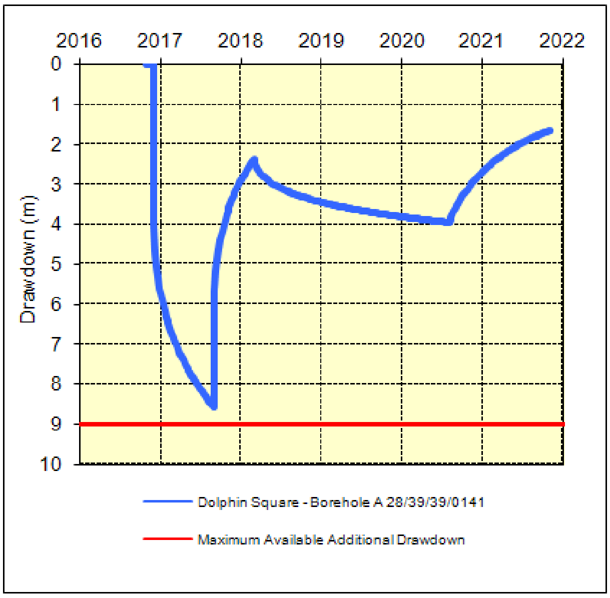


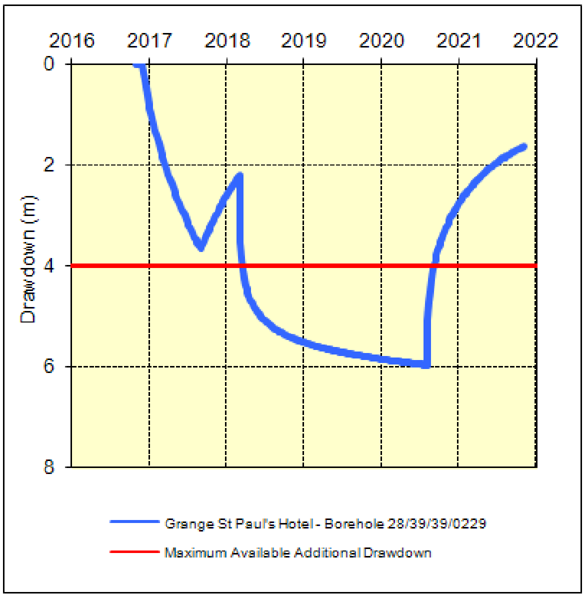


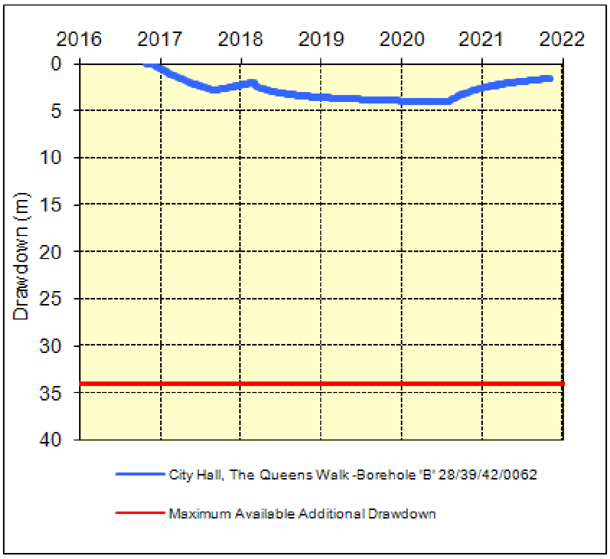


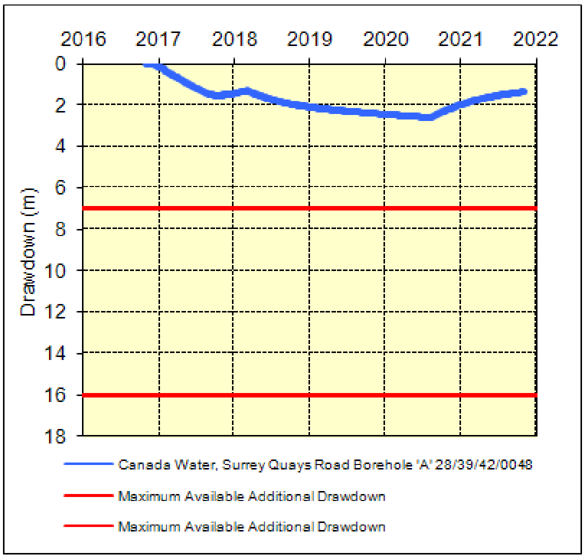
Vol 3 Plate K.30 Groundwater – Drawdown Time Series RUN 7

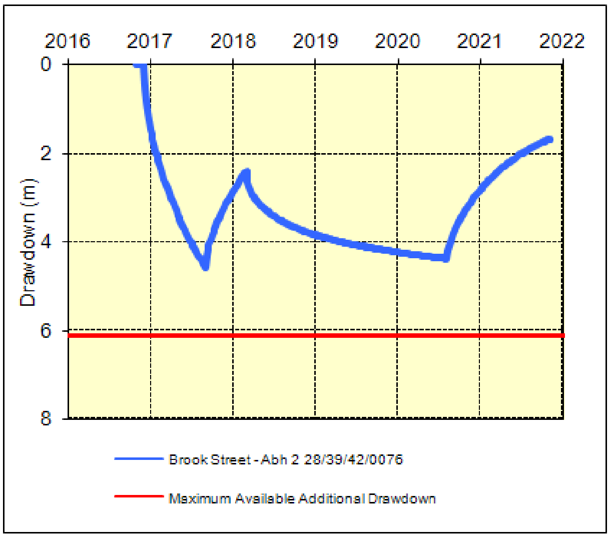
Vol 3 Plate K.31 Groundwater – Drawdown Time Series RUN 8

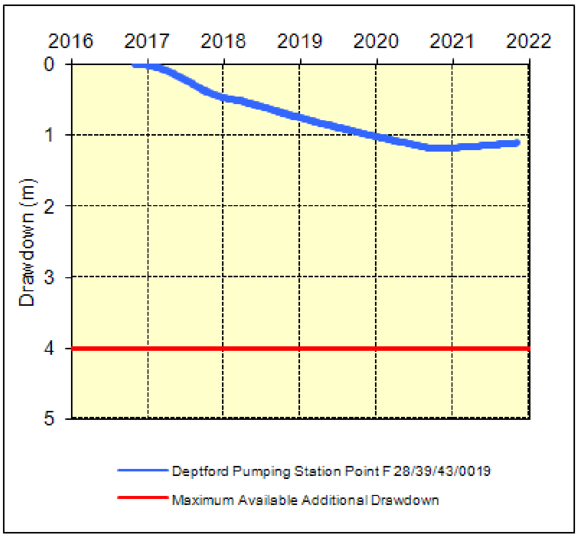




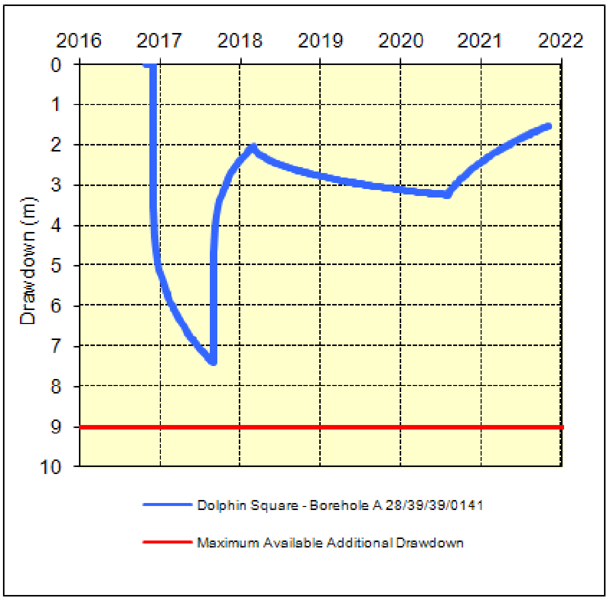


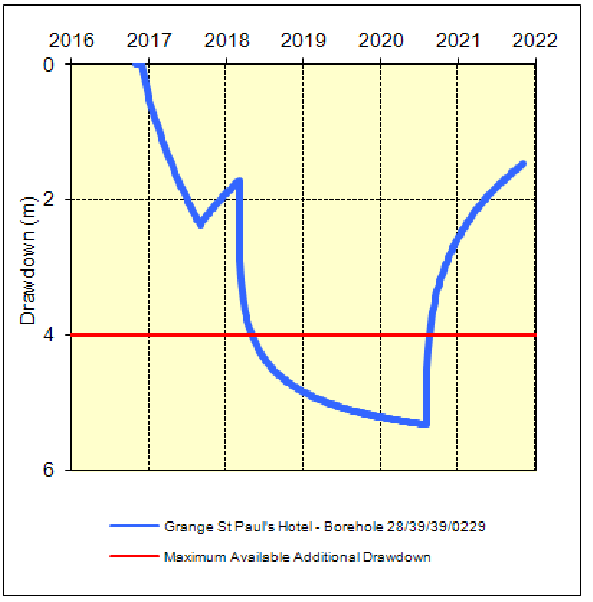


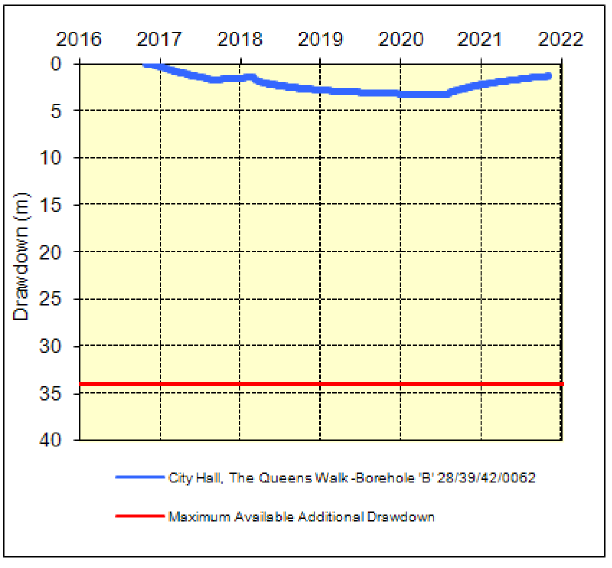


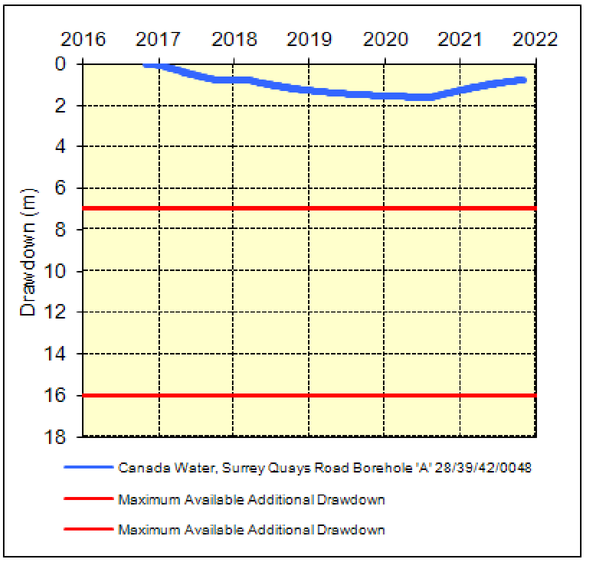


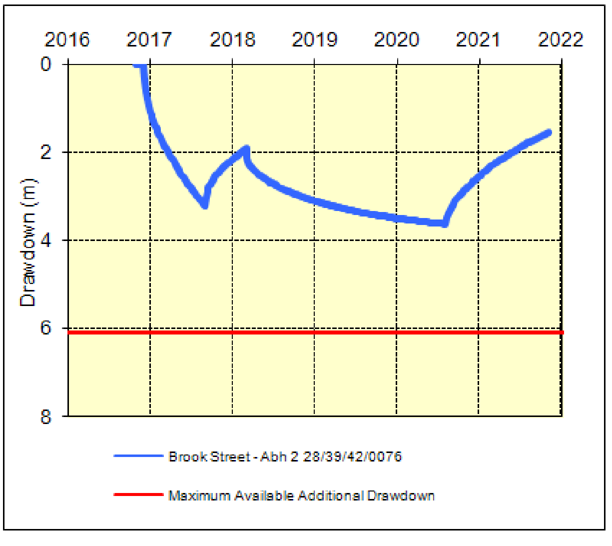
Vol 3 Plate K.32 Groundwater – Drawdown Time Series RUN 9

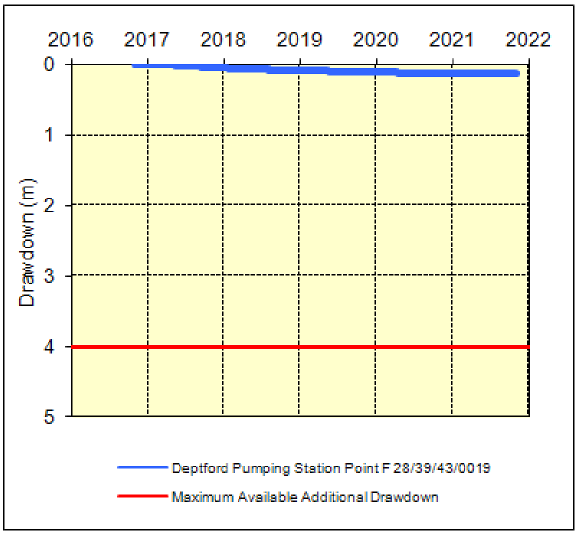












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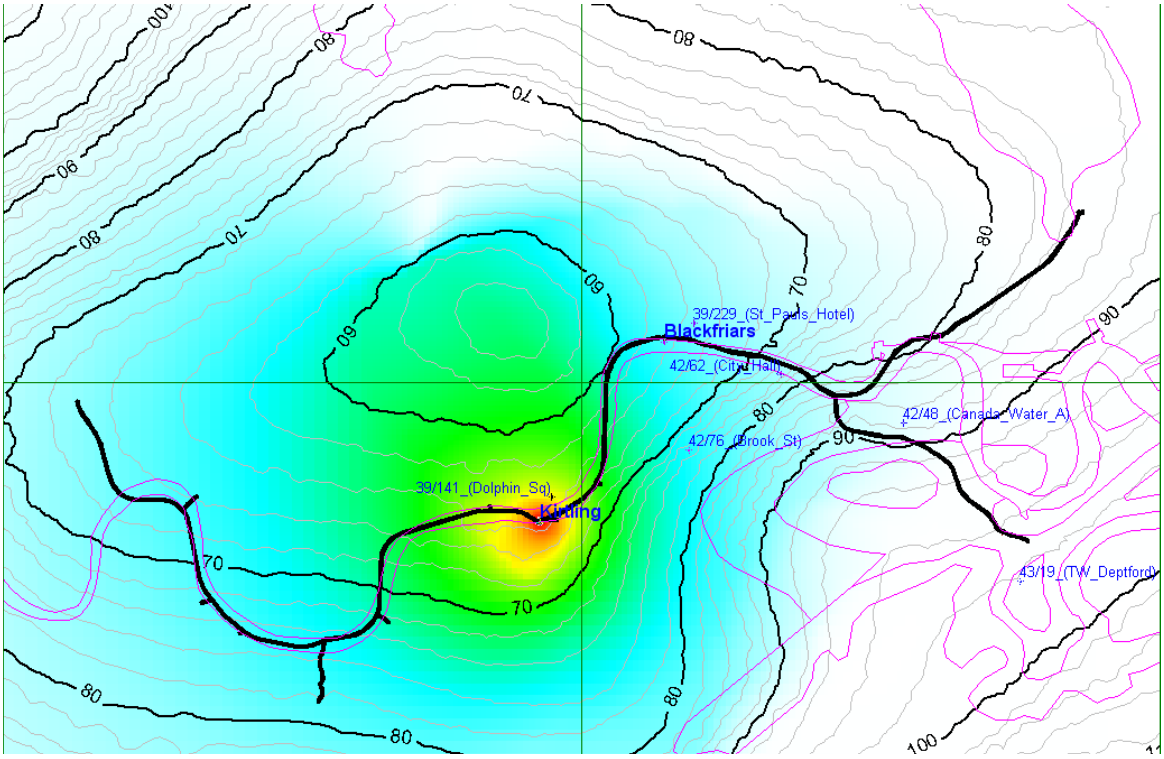
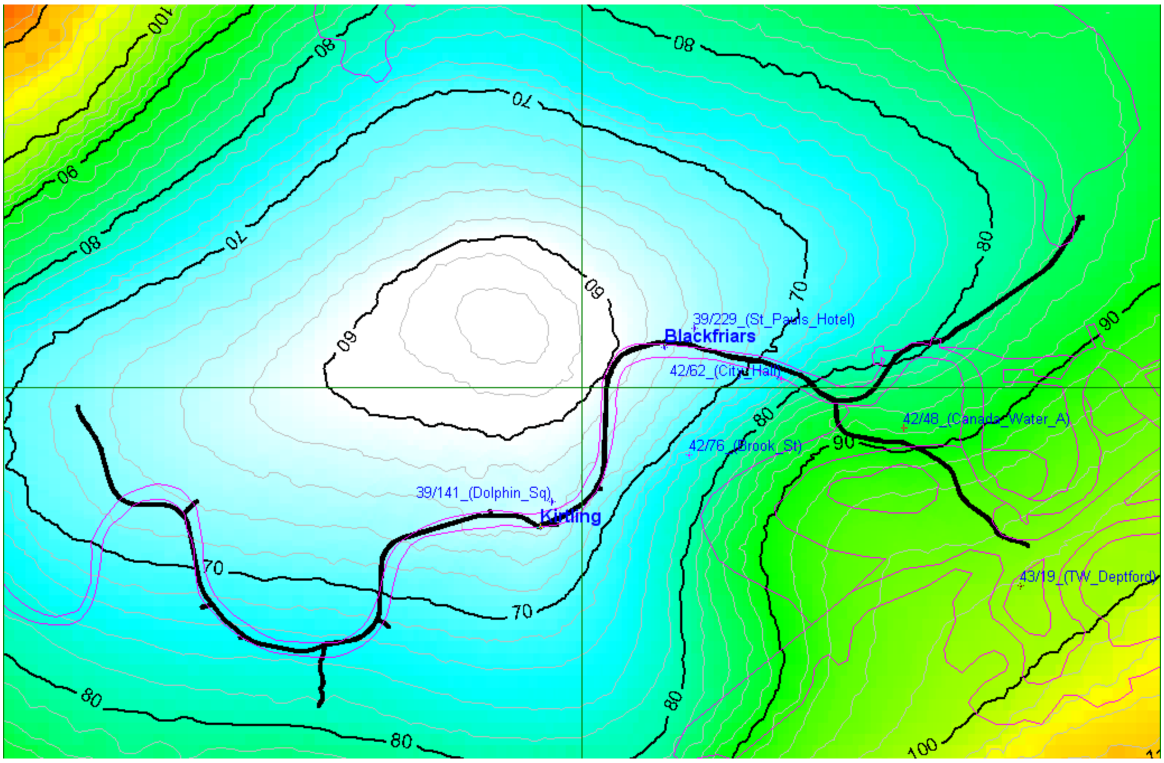
Annex C Groundwater contour maps

Groundwater Levels RUN1 – SP4, TS5

Vol 3 Plate K.33 Groundwater – contours on lower aquifer water level, mATD, flood colour denotes drawdown.

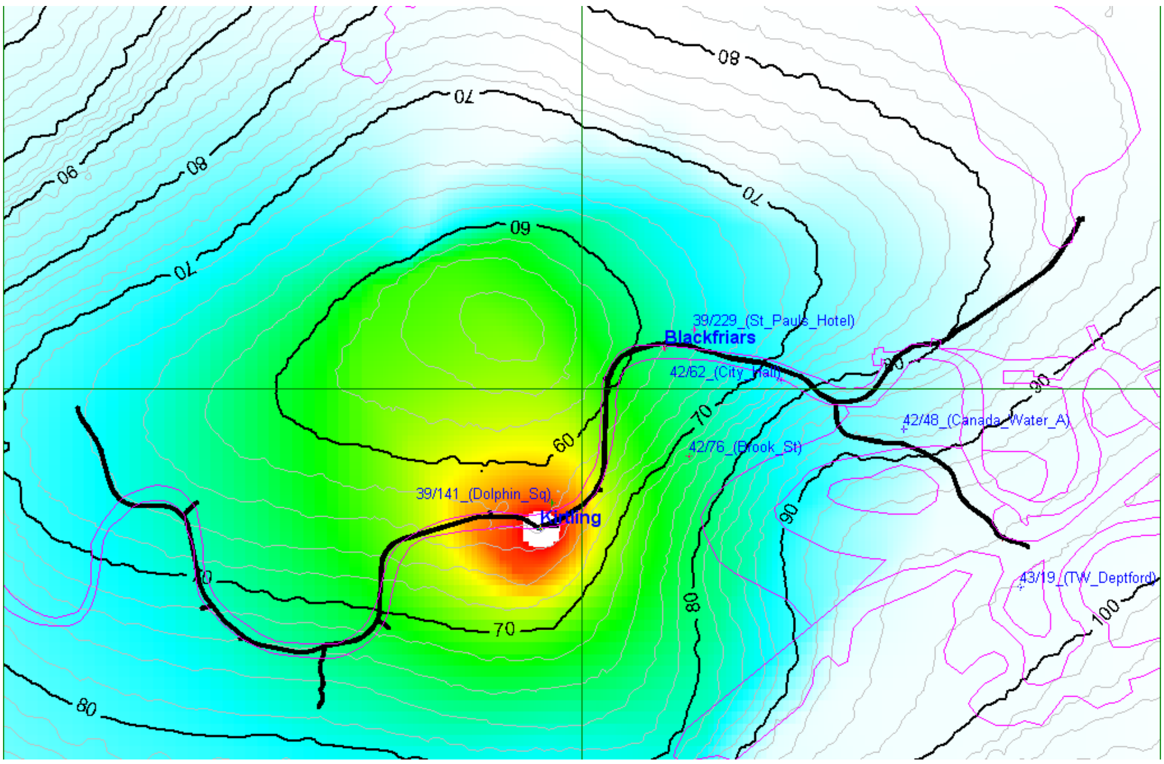


Vol 3 Plate K.34 Groundwater – contours on lower aquifer water level, mATD, flood colour denotes elevation

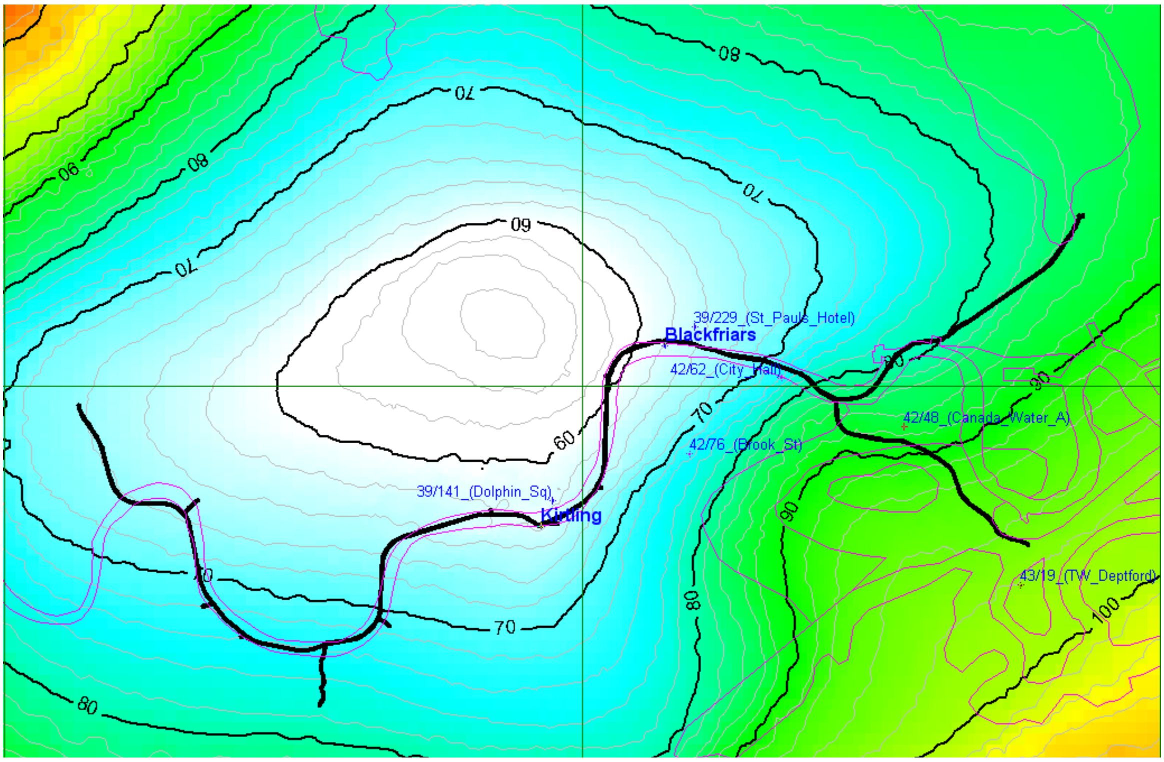


Groundwater levels RUN1 – SP10, TS5

Vol 3 Plate K.35 Groundwater – contours on lower aquifer water level, mATD, flood colour denotes drawdown.

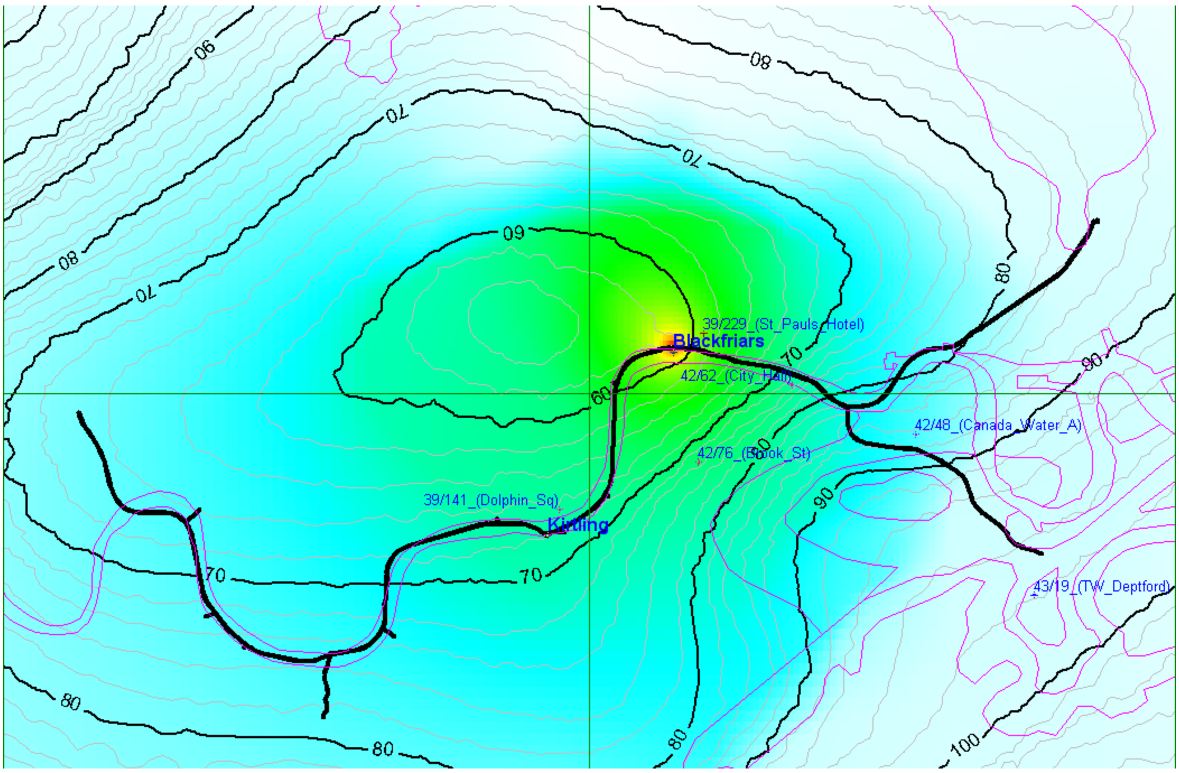


Vol 3 Plate K.36 Groundwater – contours on lower aquifer water level, mATD, flood colour denotes elevation

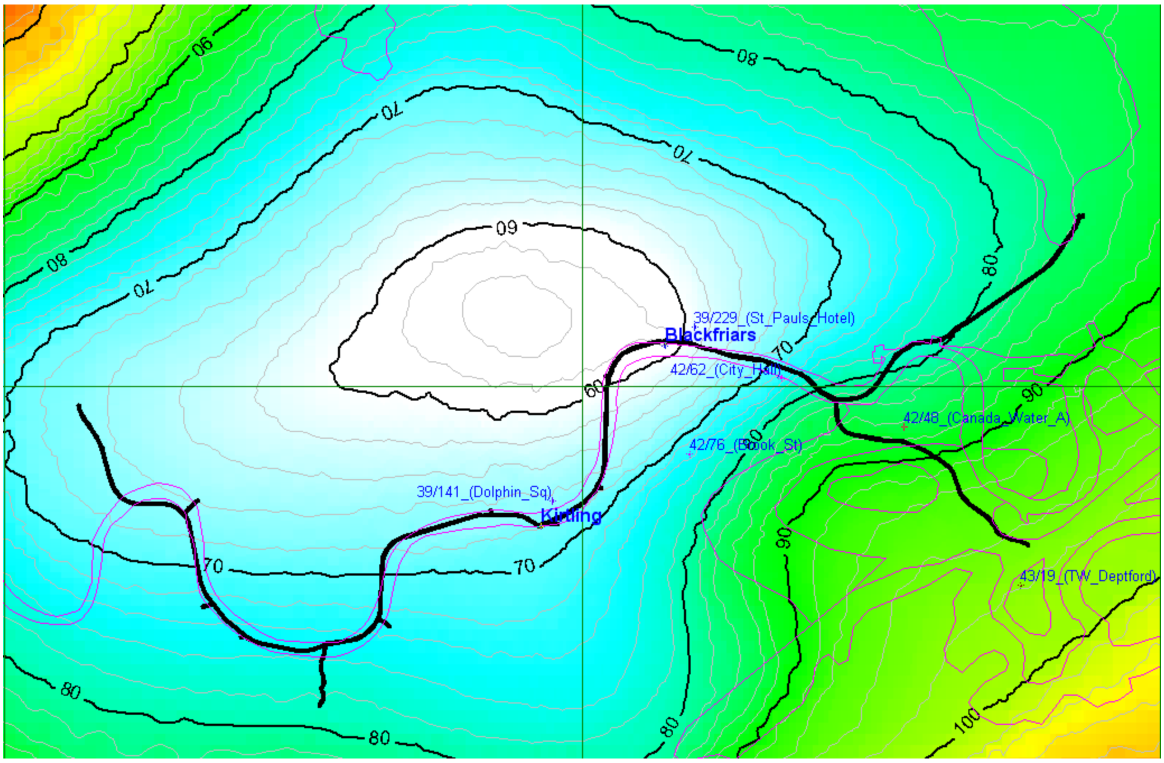


Groundwater levels RUN1 – SP25, TS5

Vol 3 Plate K.37 Groundwater – contours on lower aquifer water level, mATD, flood colour denotes drawdown

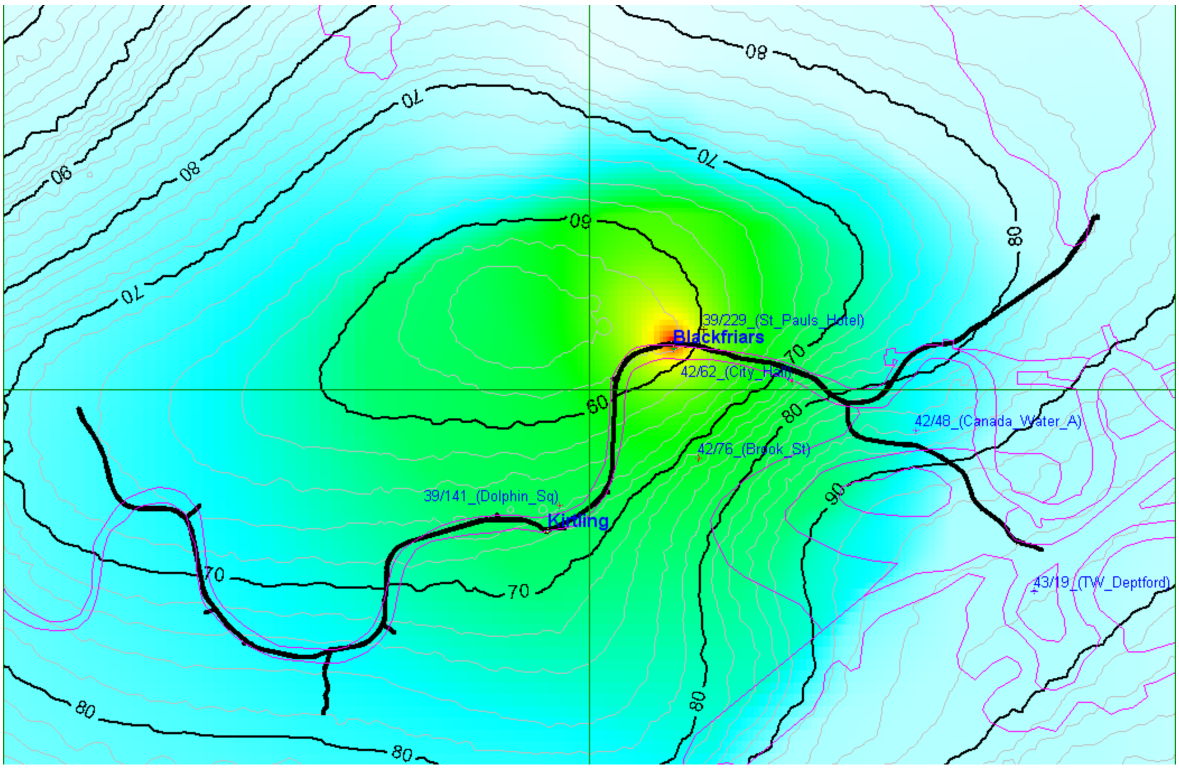


Vol 3 Plate K.38 Groundwater – contours on lower aquifer water level, mATD, flood colour denotes elevation

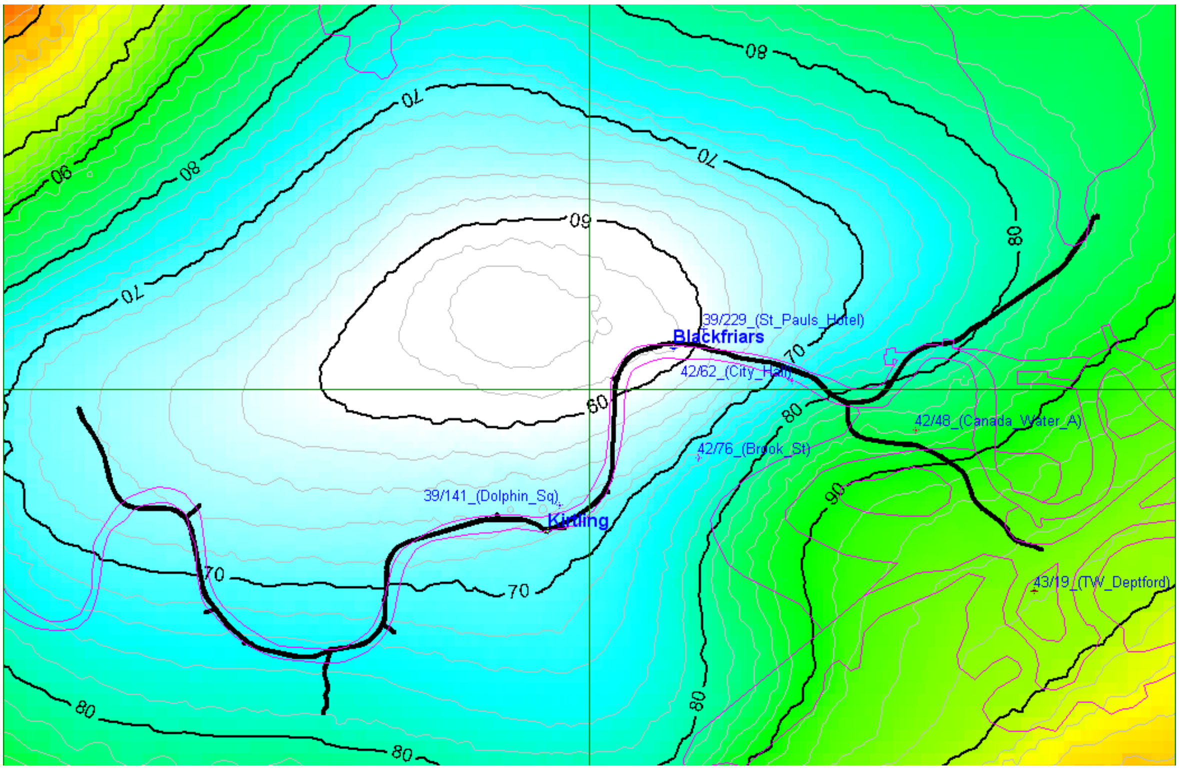


Groundwater levels RUN1 – SP45, TS5

Vol 3 Plate K.39 Groundwater – contours on lower aquifer water level, mATD, flood colour denotes drawdown

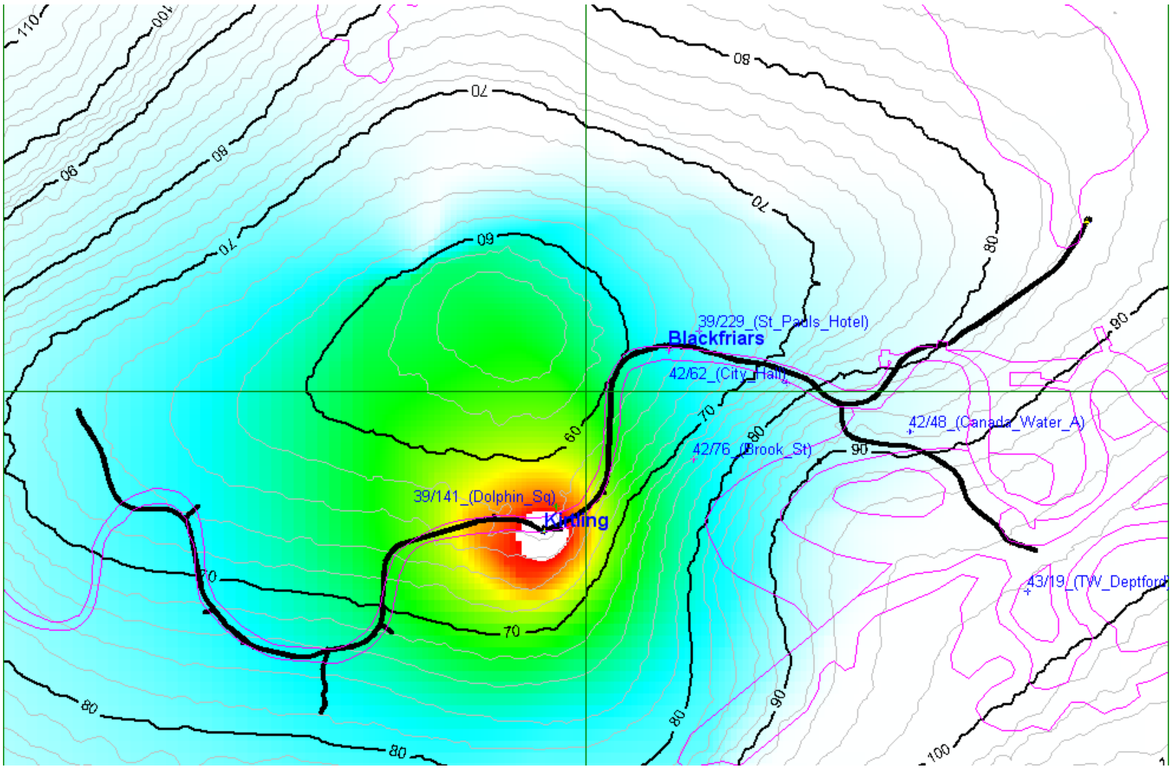


Vol 3 Plate K.40 Contours on lower aquifer water level, mATD, flood colour denotes elevation

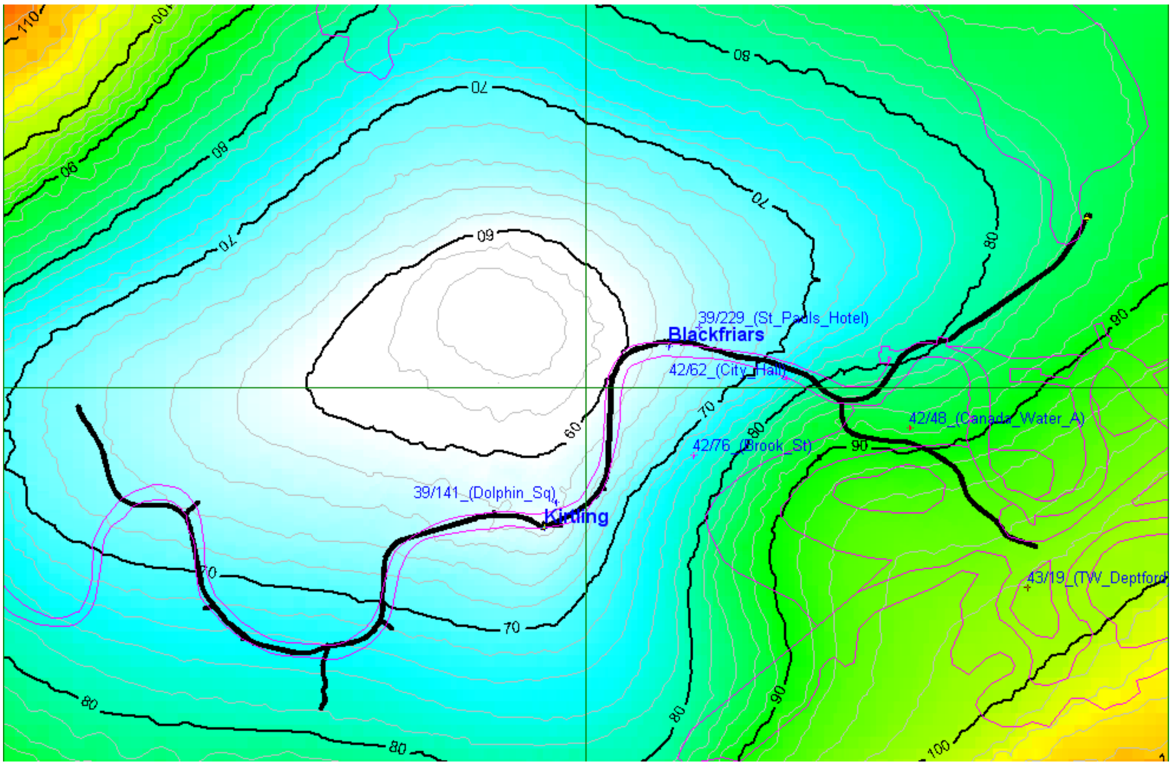


Groundwater levels RUN3 – SP4, TS5

Vol 3 Plate K.41 Contours on lower aquifer water level, mATD, flood colour denotes drawdown.

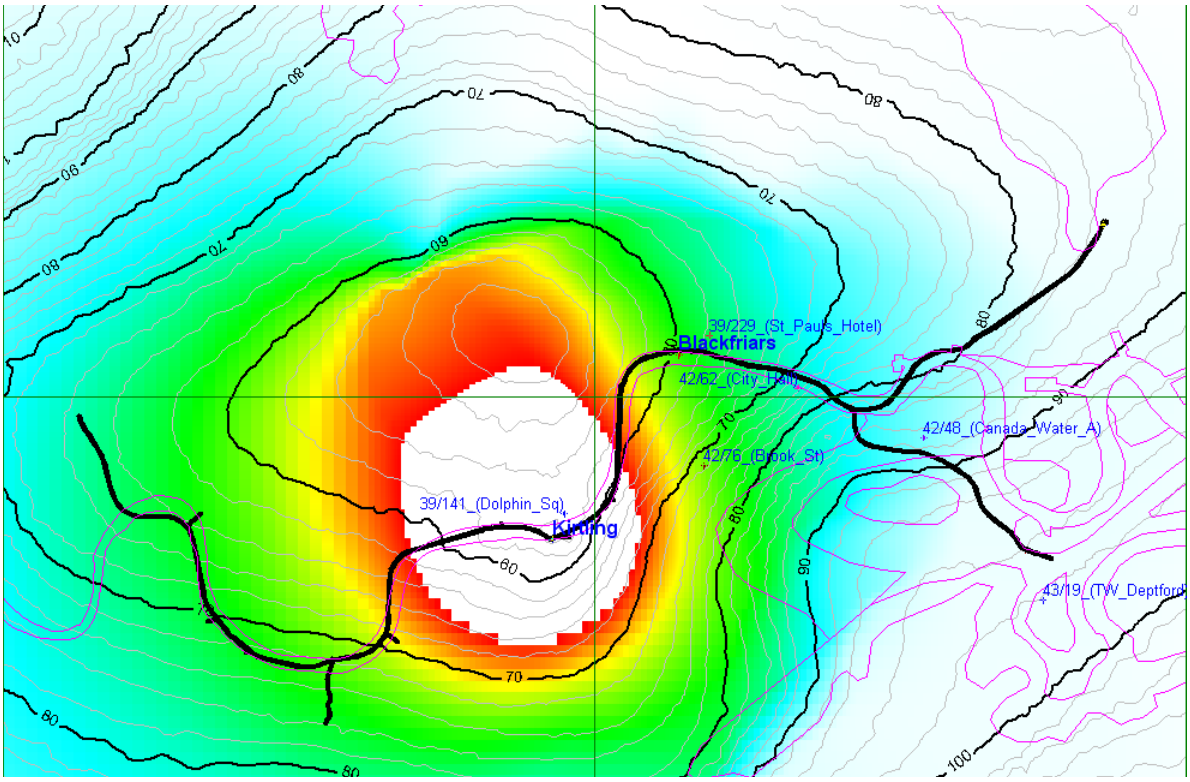


Vol 3 Plate K.42 Contours on lower aquifer water level, mATD, flood colour denotes elevation

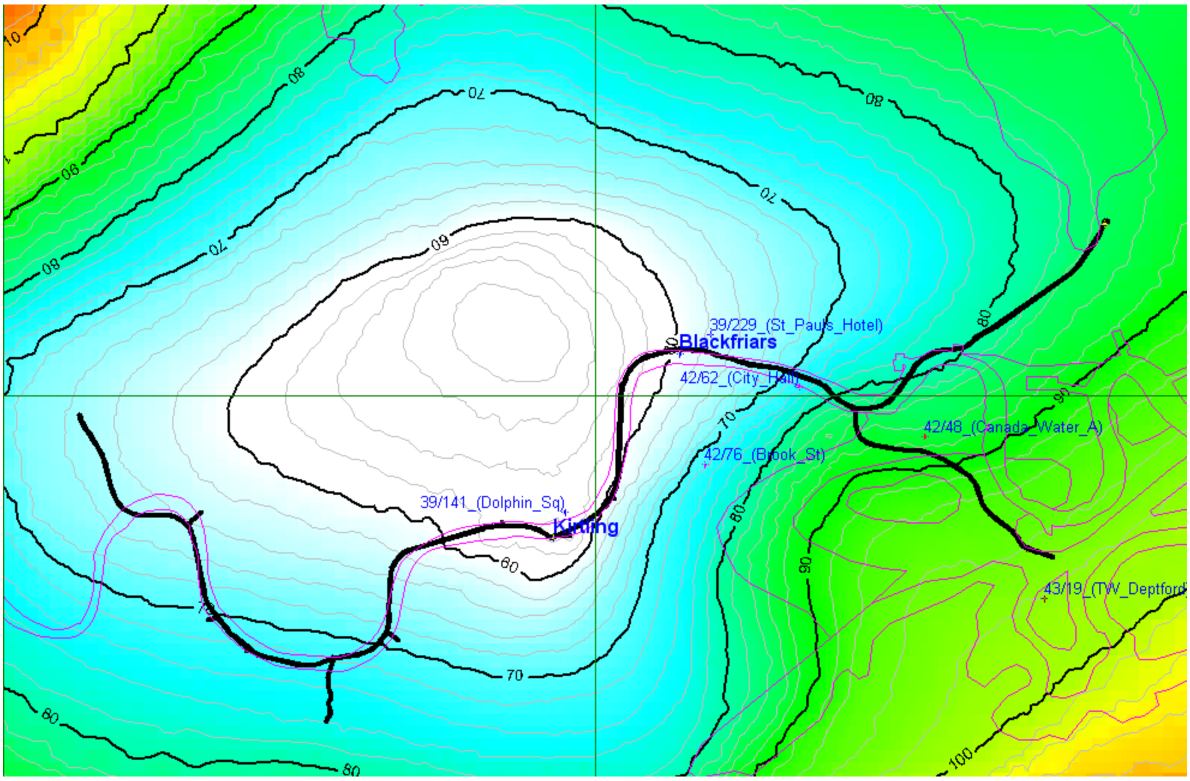


Groundwater levels RUN3 – SP10, TS5

Vol 3 Plate K.43 Contours on lower aquifer water level, mATD, flood colour denotes drawdown.

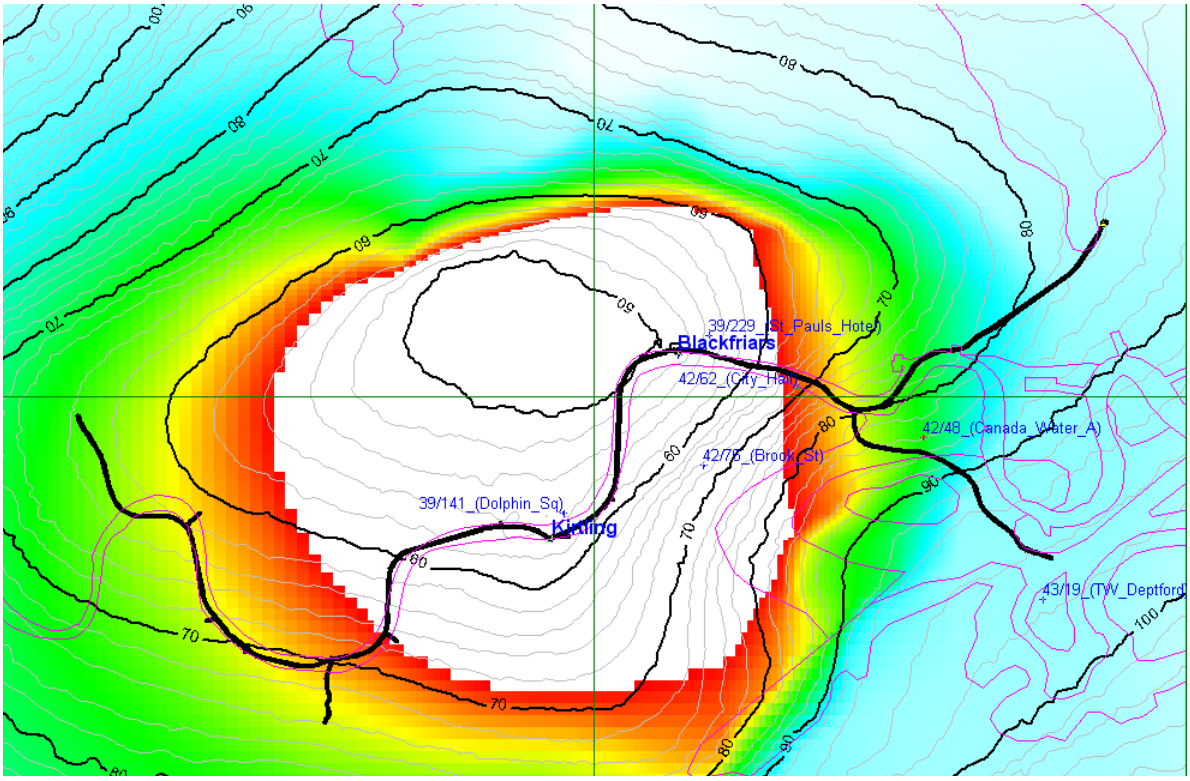


Vol 3 Plate K.44 Contours on lower aquifer water level, mATD, flood colour denotes elevation

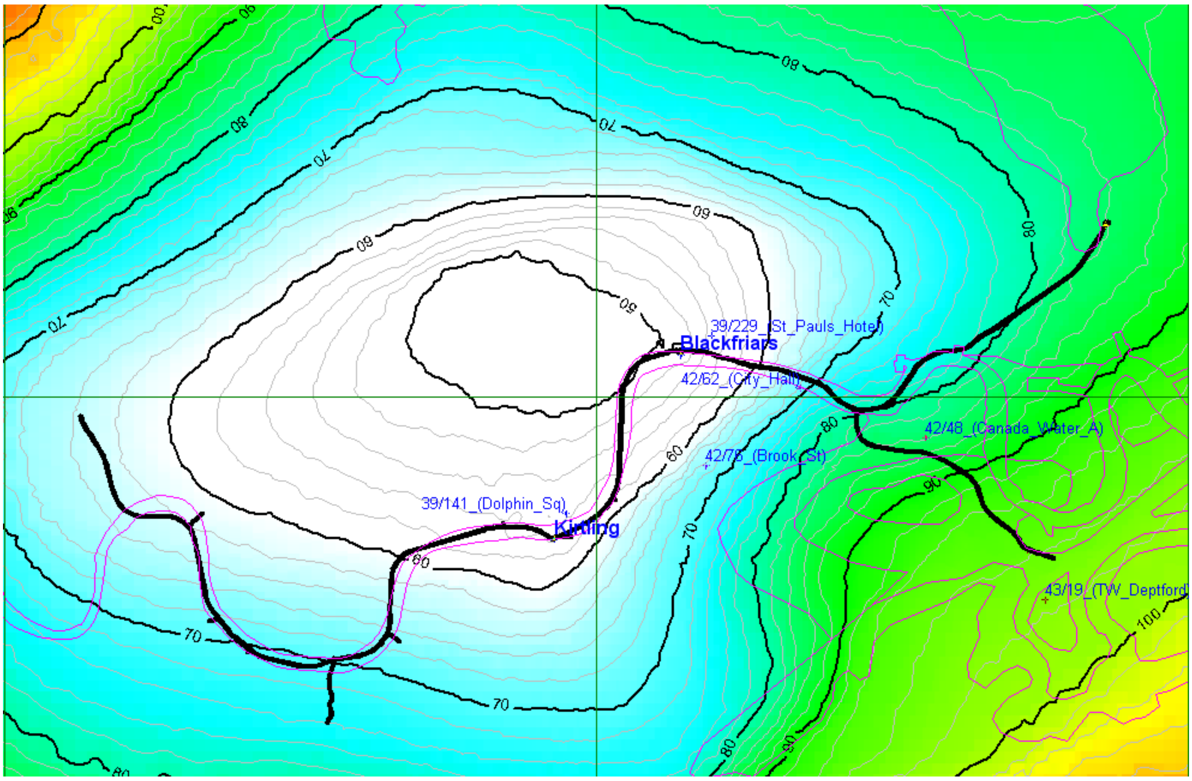


Groundwater levels RUN3 – SP25, TS5

Vol 3 Plate K.45 Contours on lower aquifer water level, mATD, flood colour denotes drawdown.

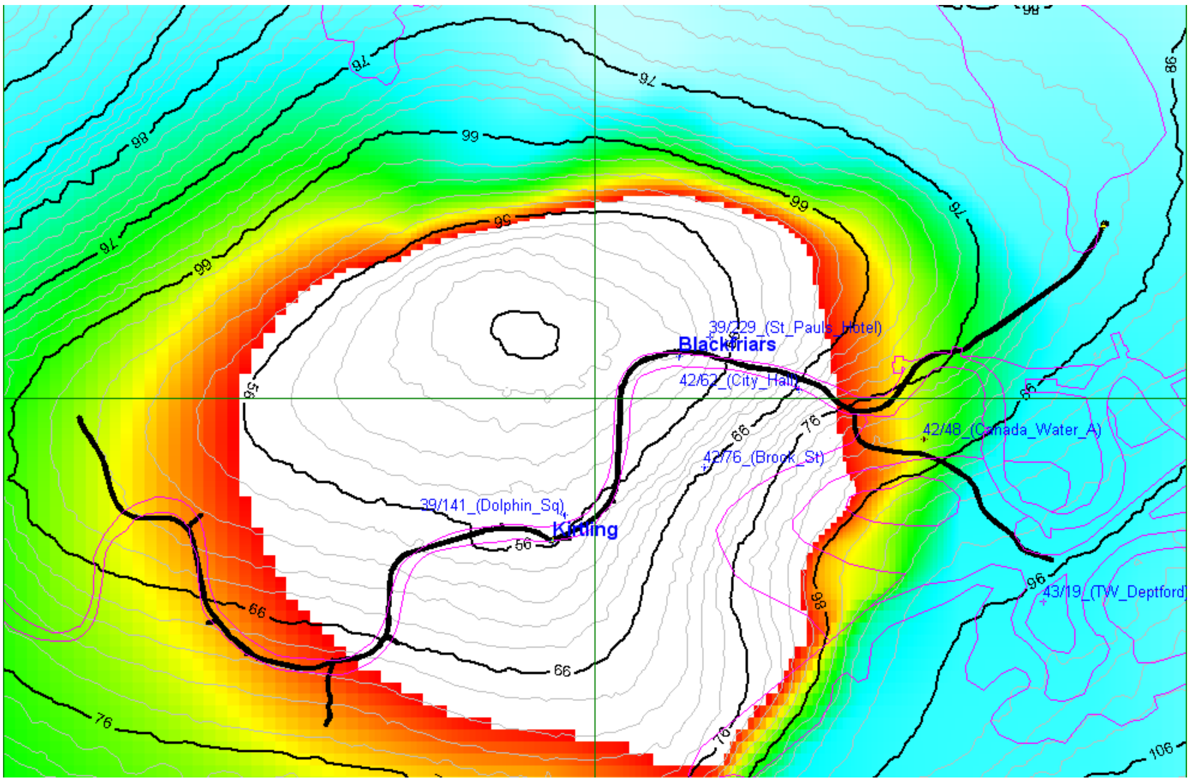


Vol 3 Plate K.46 Contours on lower aquifer water level, mATD, flood colour denotes elevation

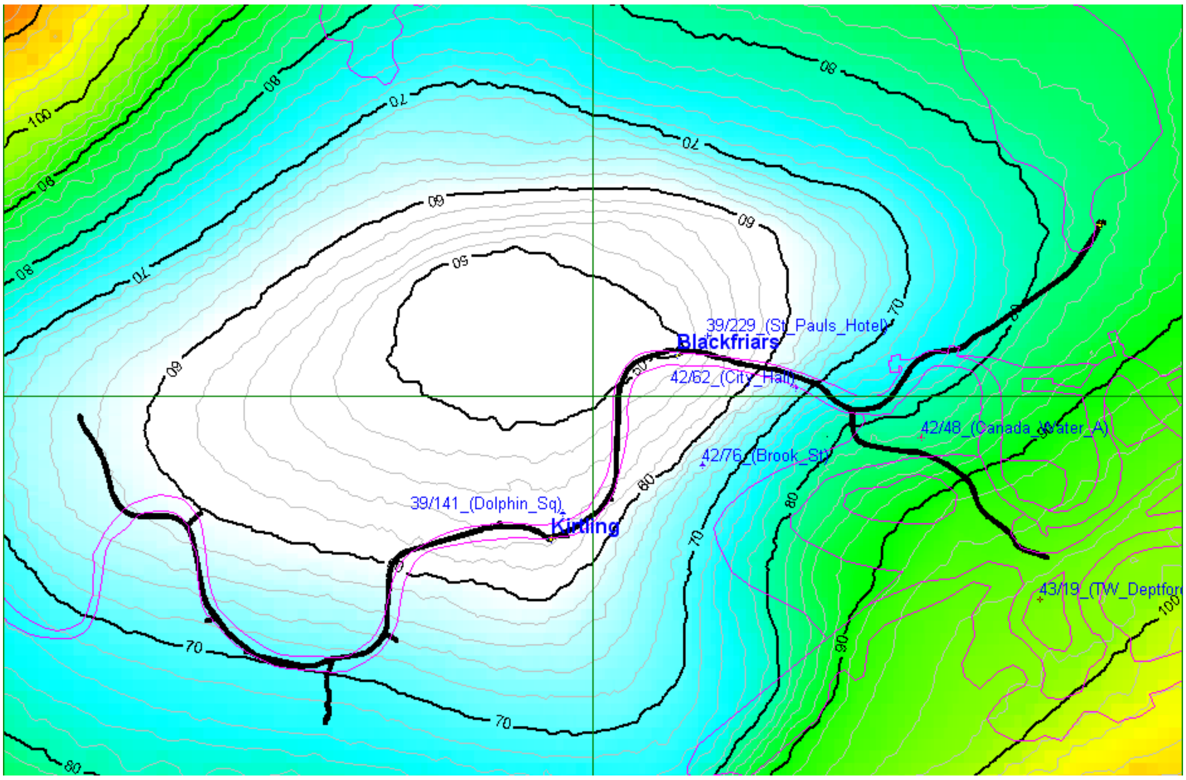


Groundwater levels RUN3 – SP45, TS5

Vol 3 Plate K.47 Contours on lower aquifer water level, mATD, flood colour denotes drawdown.



Vol 3 Plate K.48 Contours on lower aquifer water level, mATD, flood colour denotes elevation



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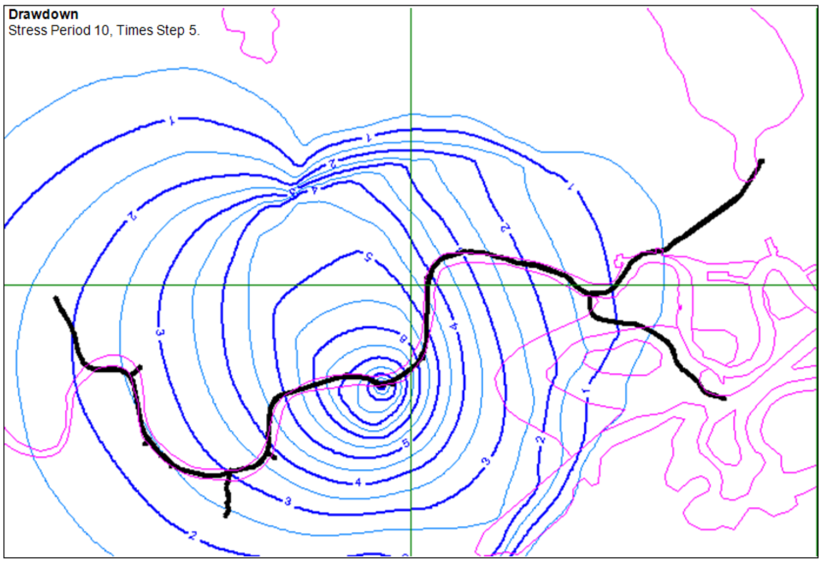
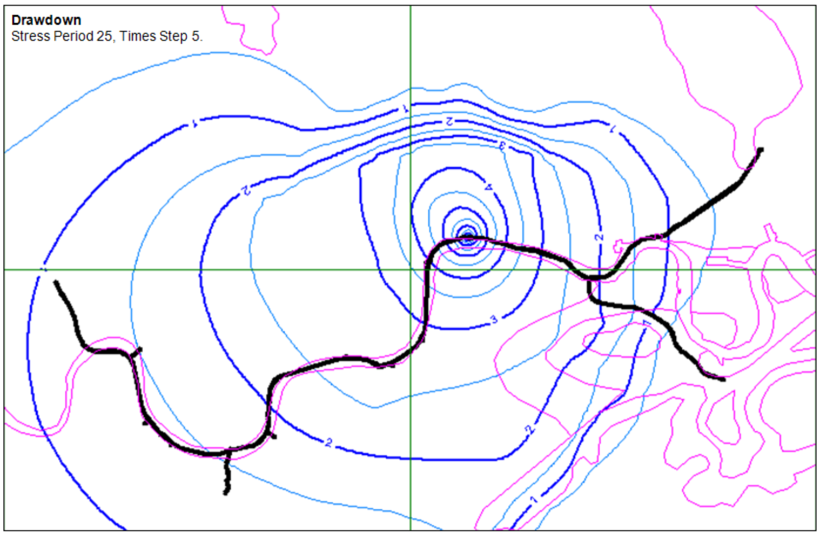
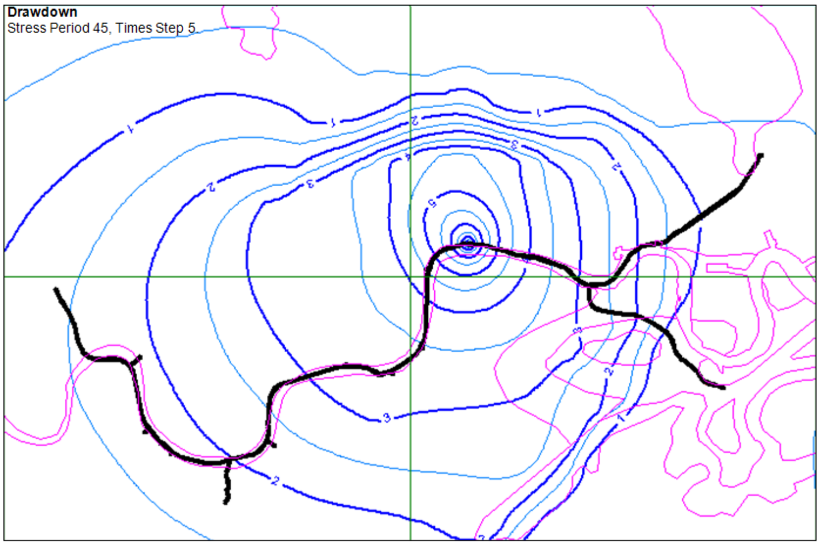
Annex D Groundwater drawdown maps

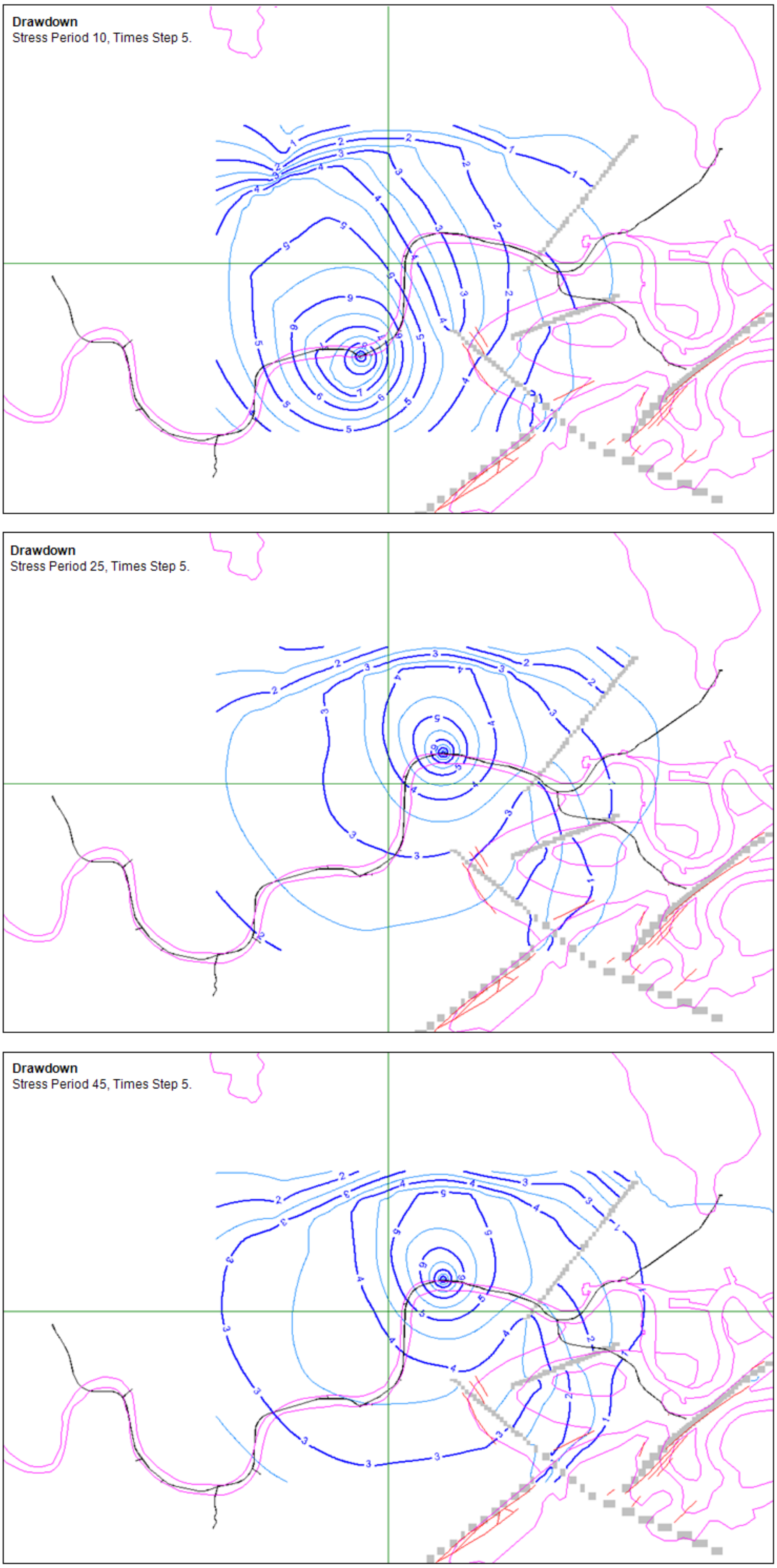
Vol 3 Plate K.49 Groundwater – Contour Maps Groundwater Drawdown RUN 1



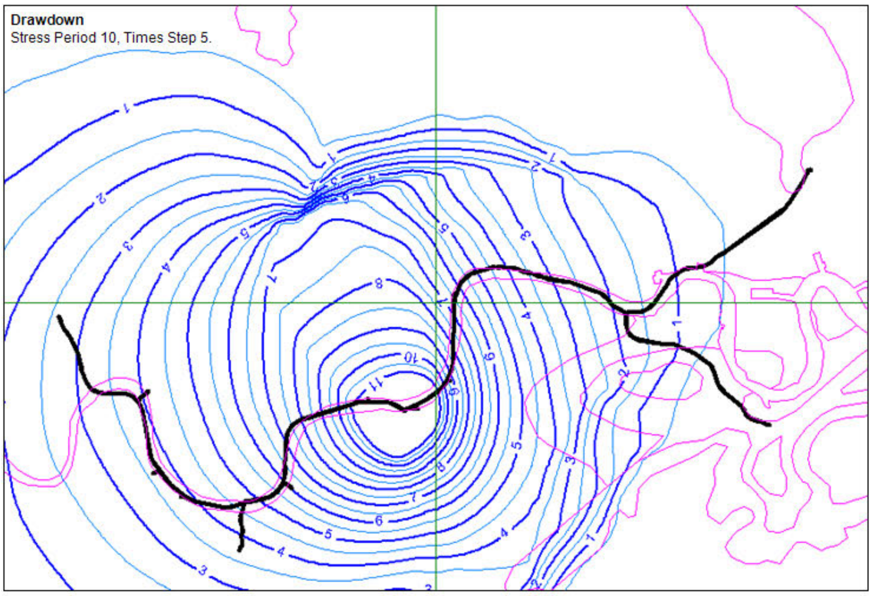


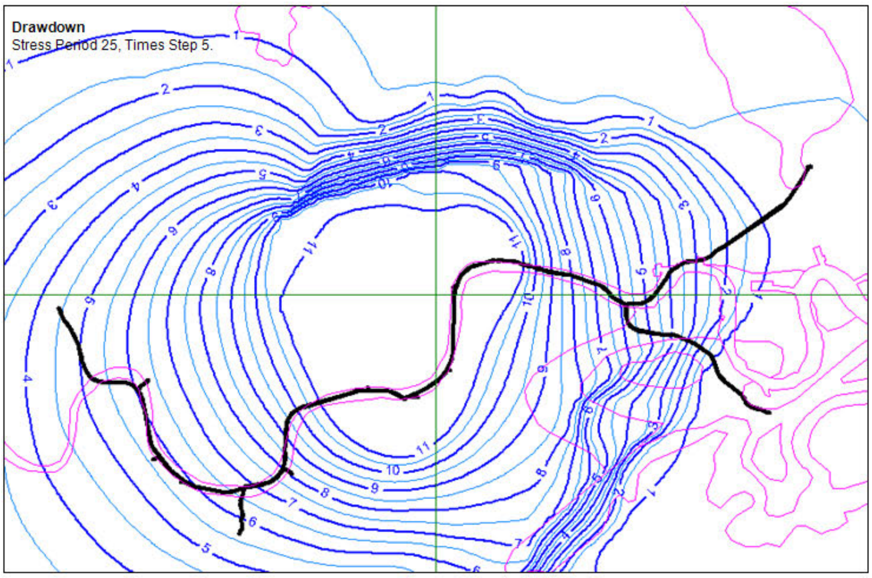


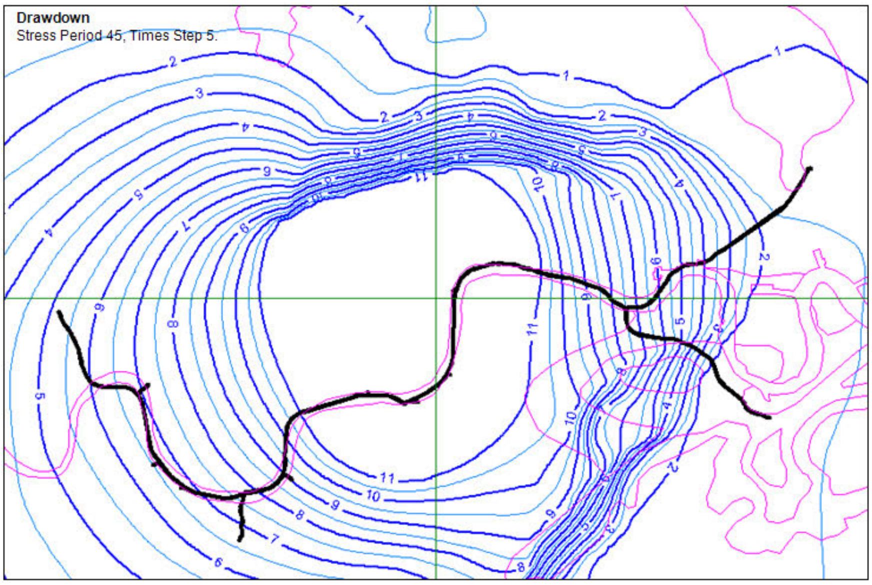
Vol 3 Plate K.50 Groundwater Drawdown RUN 2



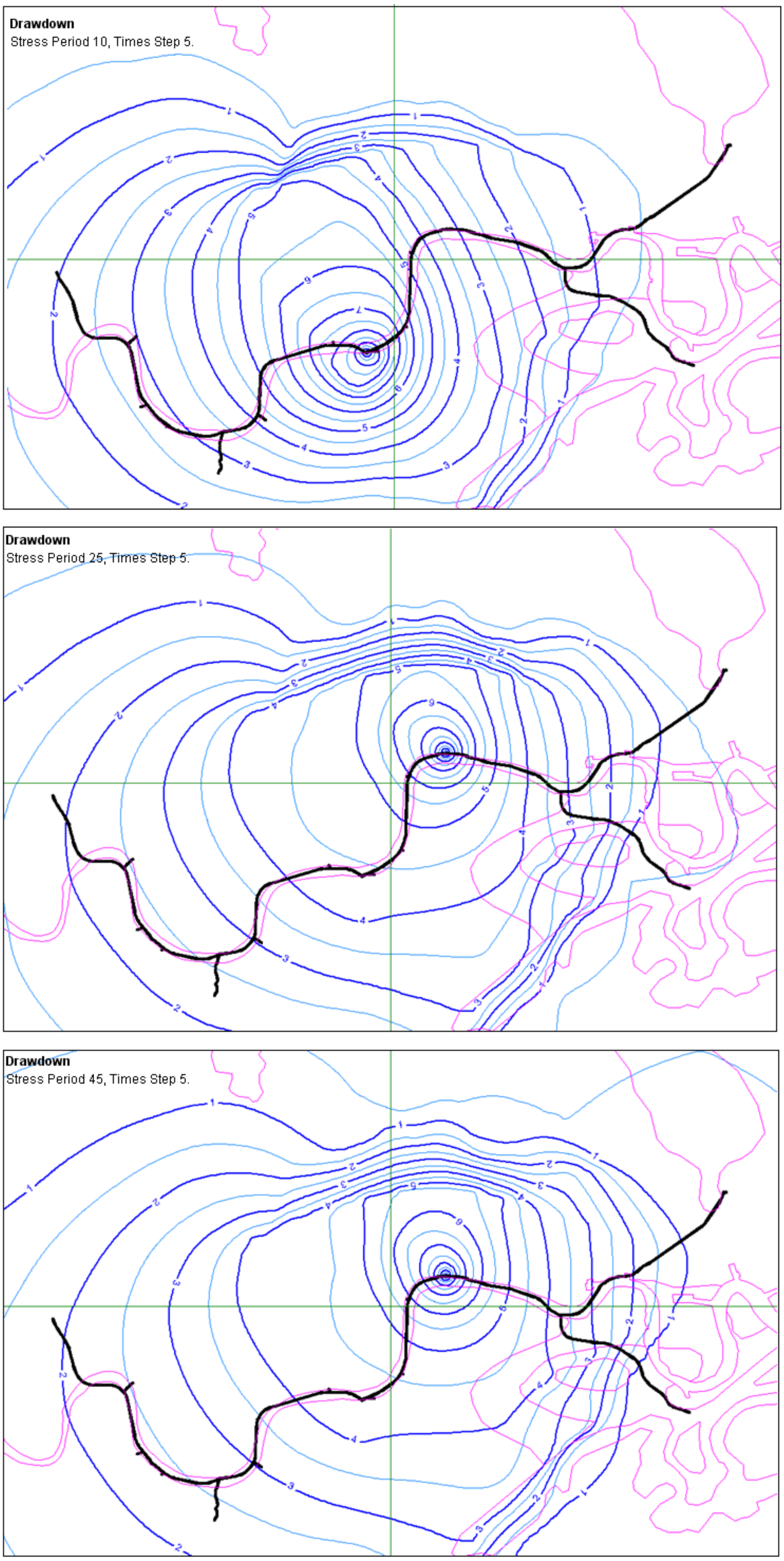
Vol 3 Plate K.51 Groundwater Drawdown RUN 3



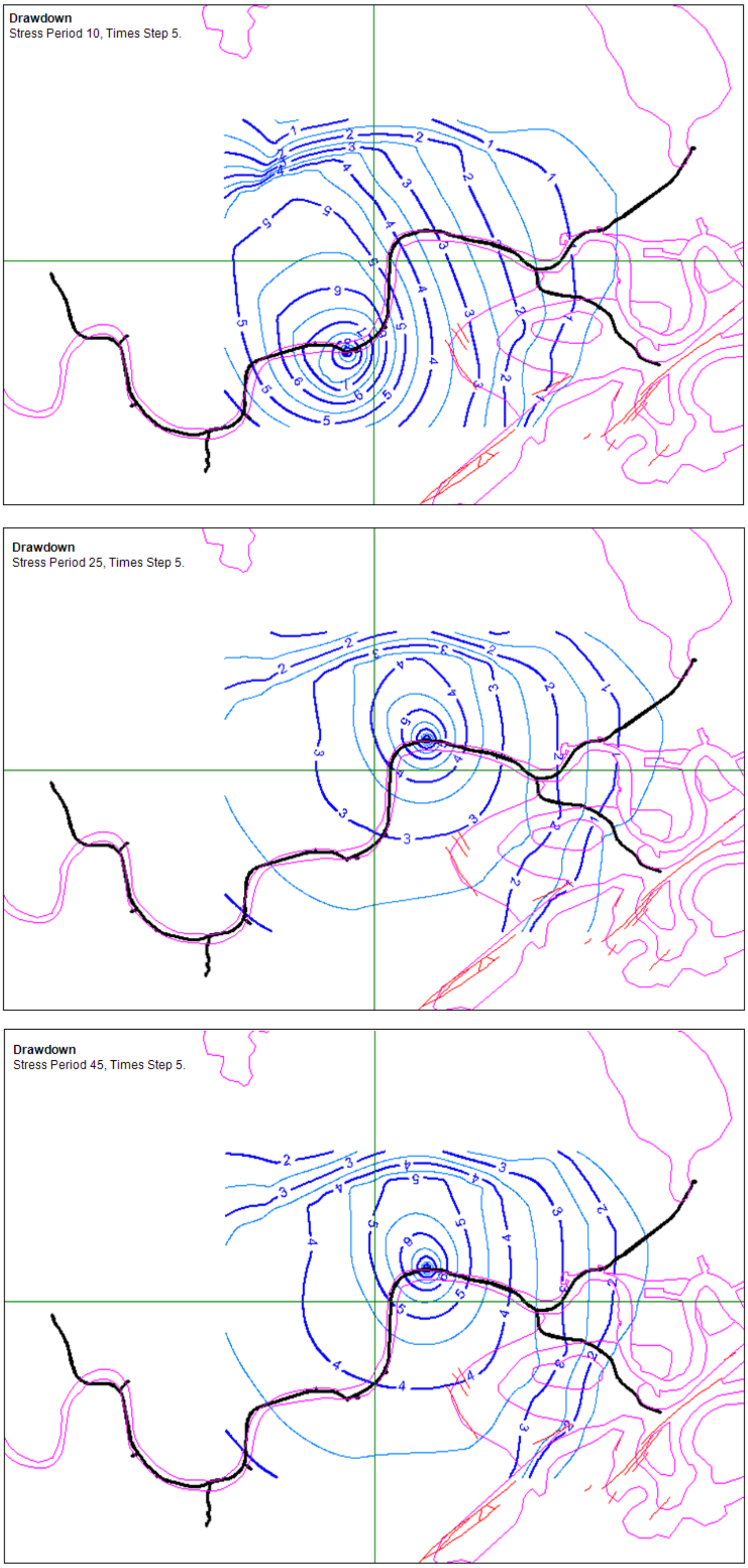




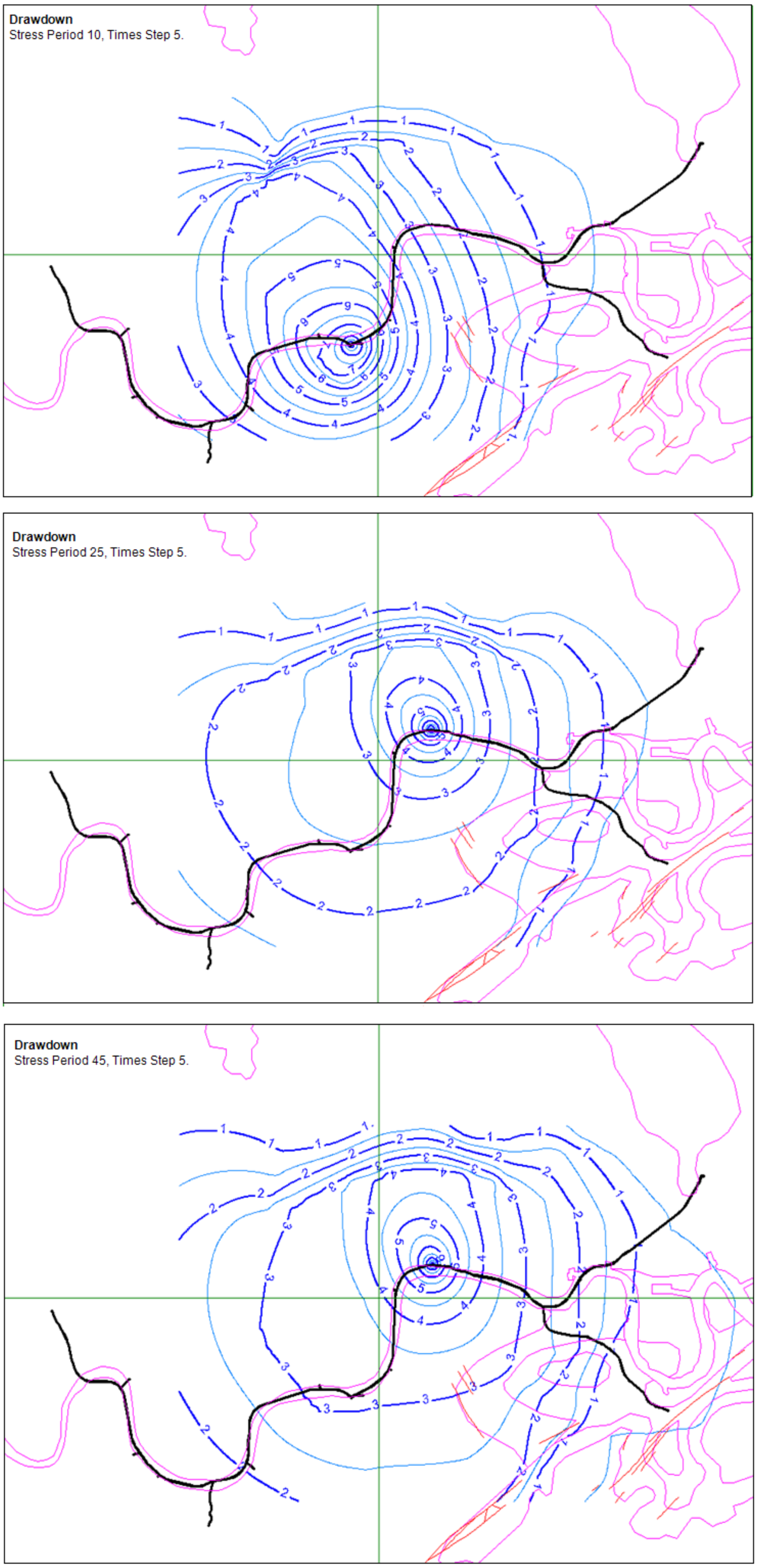
Vol 3 Plate K.52 Groundwater Drawdown RUN 4



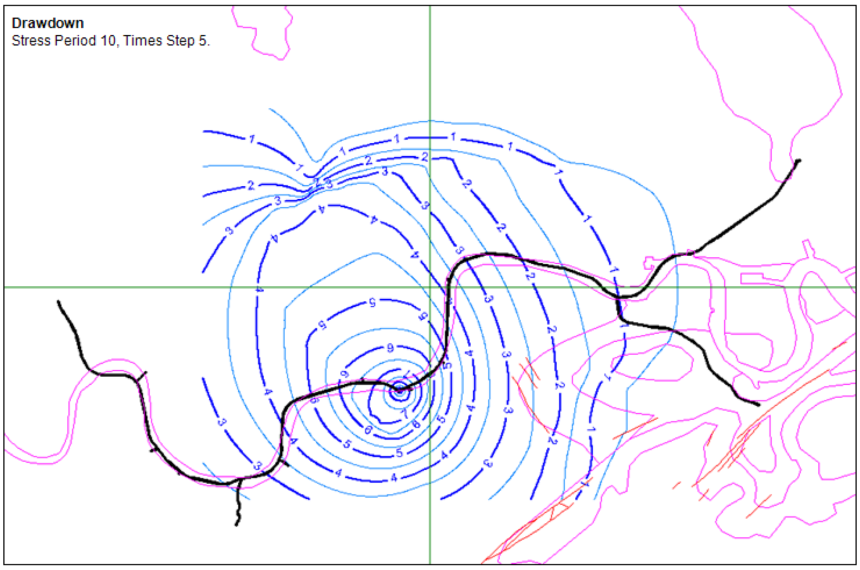
Vol 3 Plate K.53 Groundwater Drawdown RUN 5

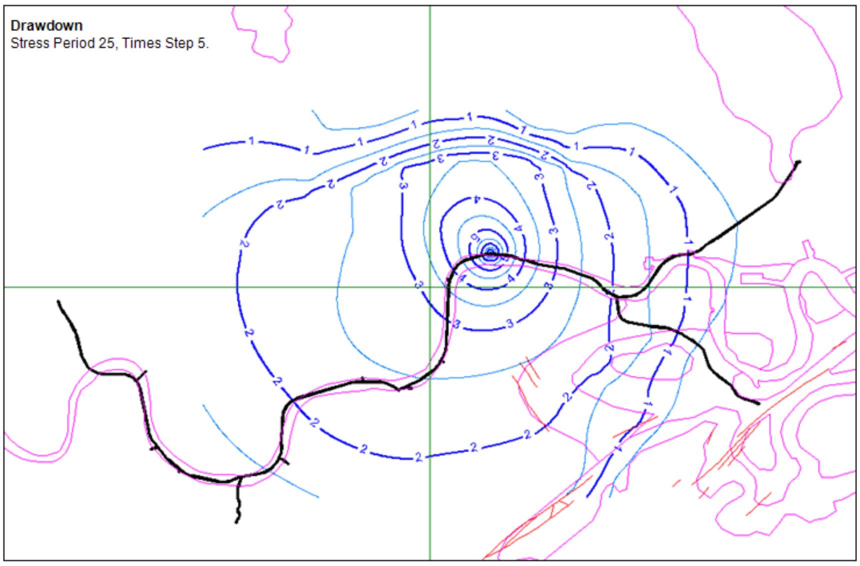


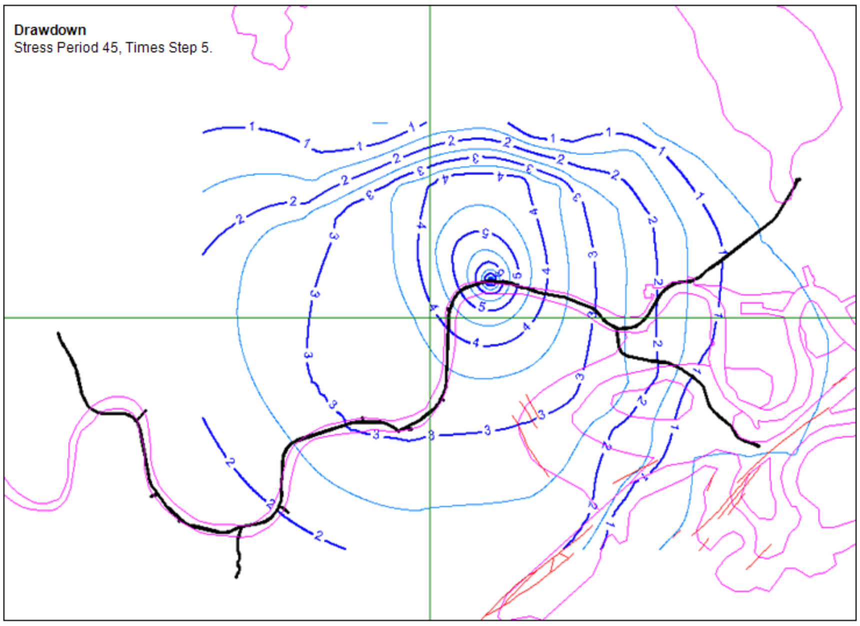
Vol 3 Plate K.54 Groundwater Drawdown RUN 6



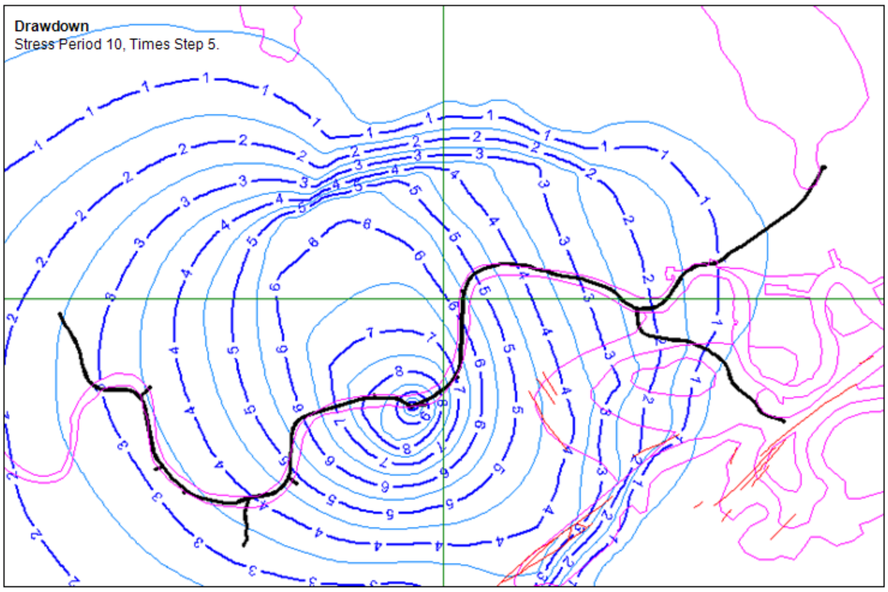
Vol 3 Plate K.55 Groundwater Drawdown RUN 7

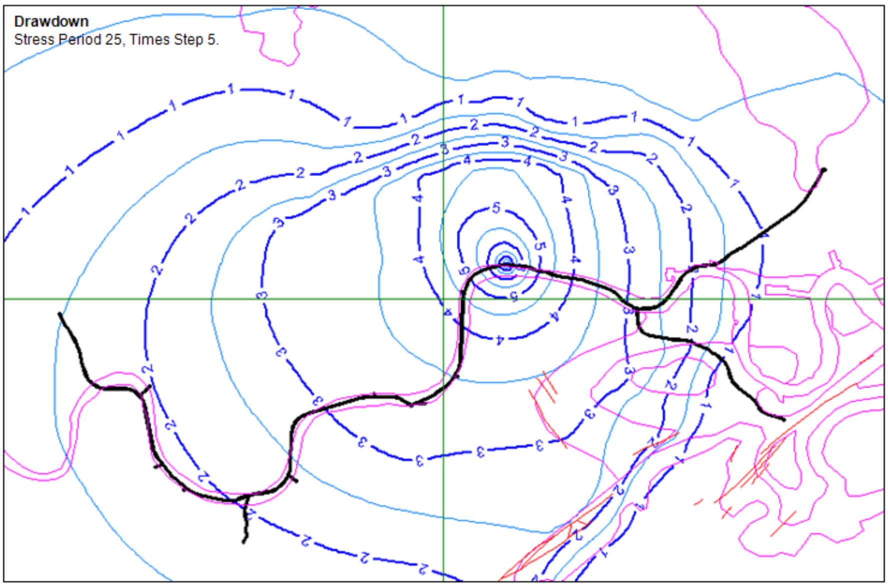


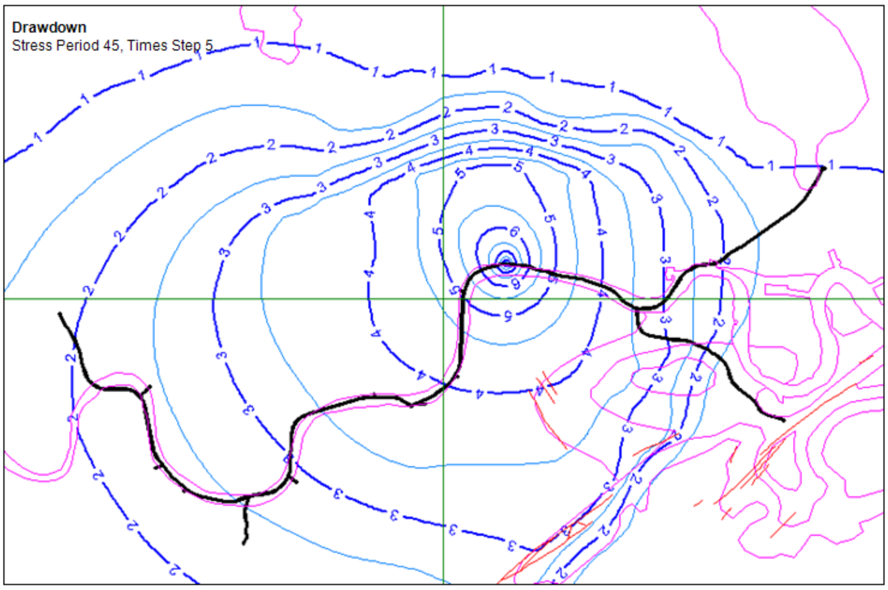




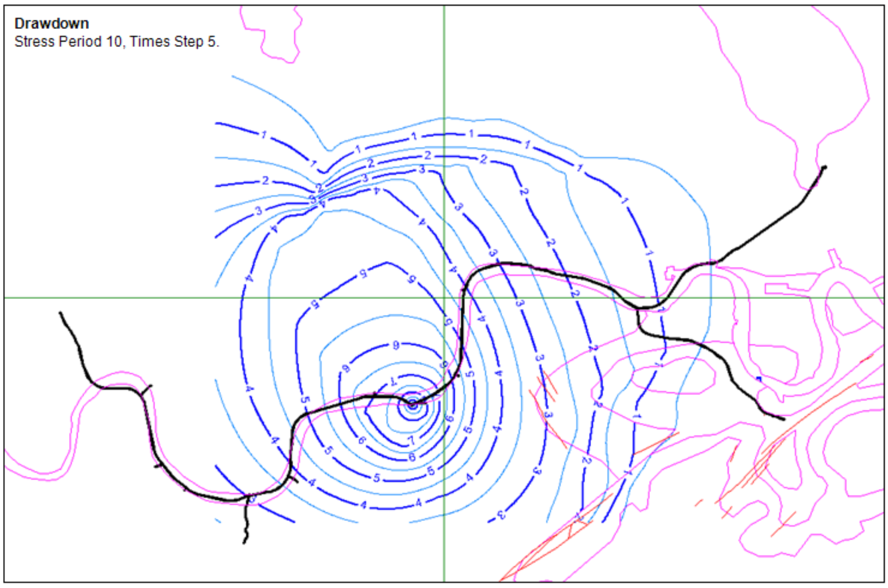
Vol 3 Plate K.56 Groundwater Drawdown RUN 8

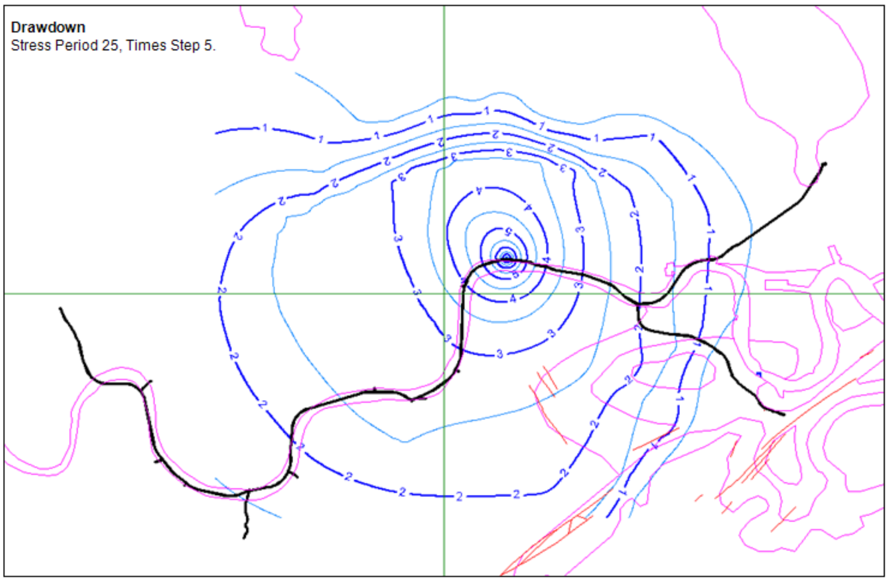


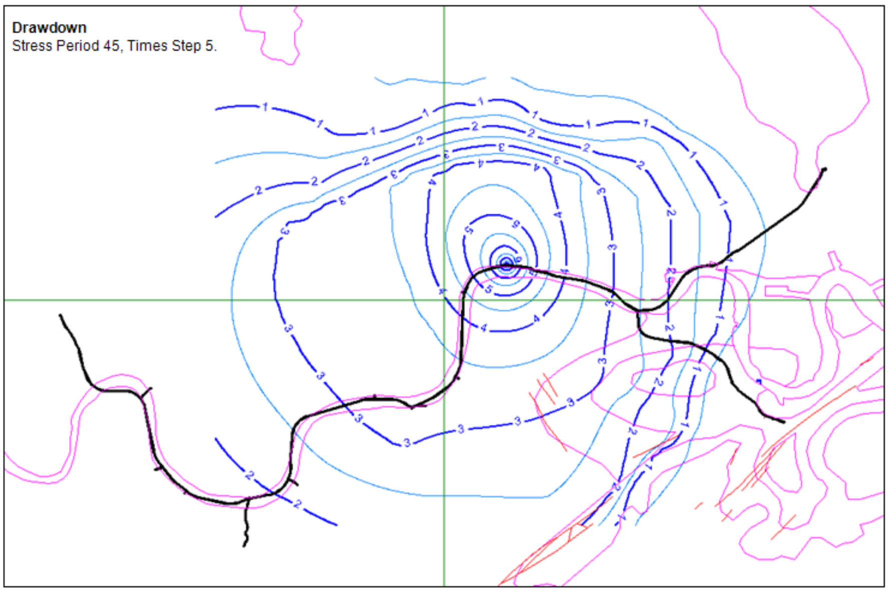




Vol 3 Plate K.57 Groundwater Drawdown RUN 9







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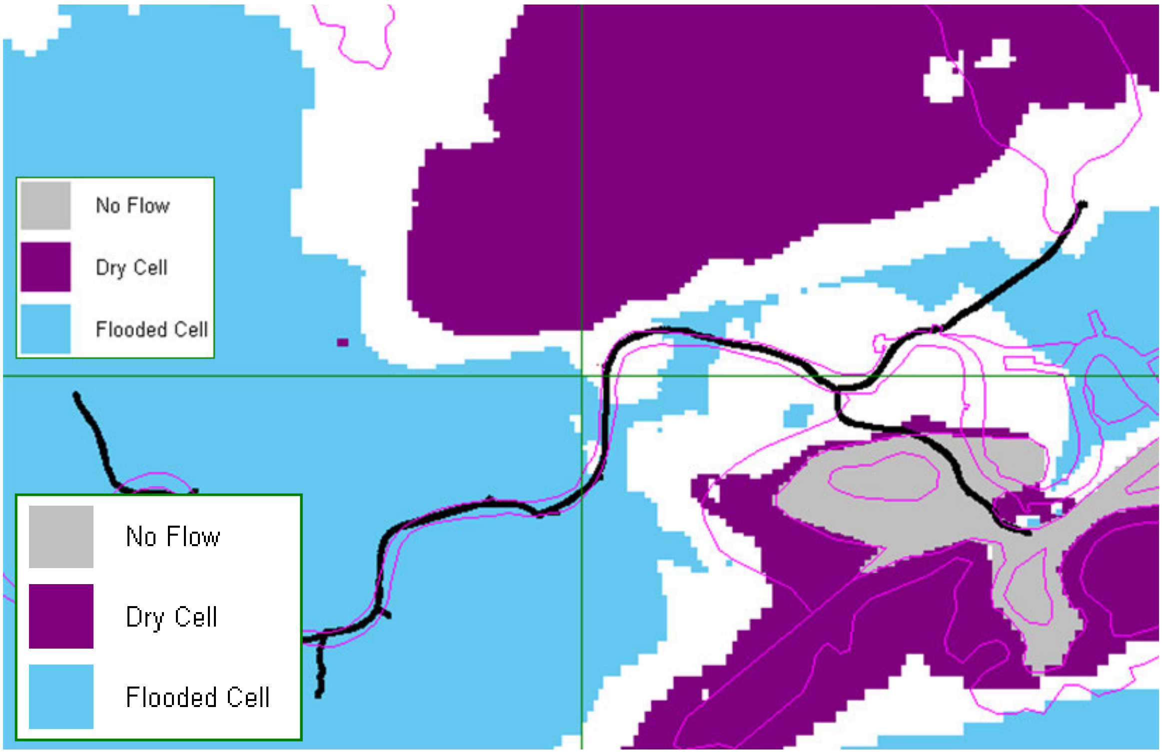
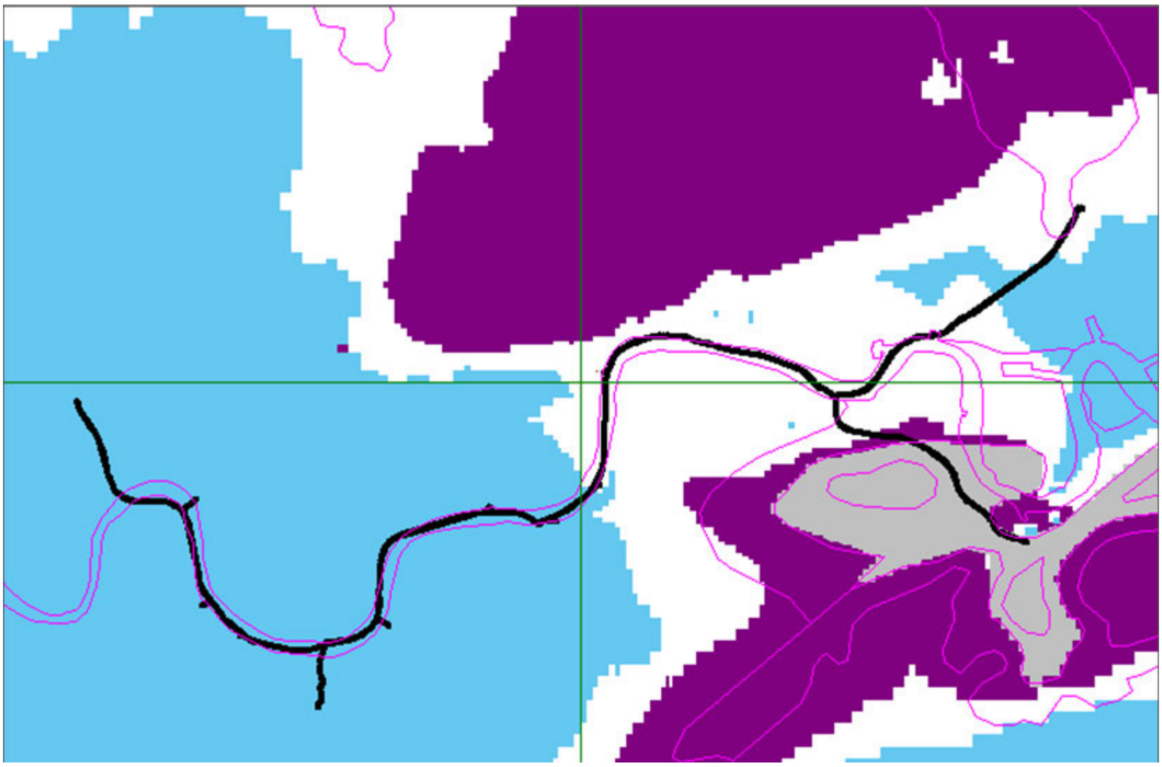
Annex E Saturated and dry zone maps

Layer 1. Extent of Saturated/Unsaturated/Dry Conditions (RUN1)

Vol 3 Plate K.58 Groundwater – Stress Period 1 Time Step 1

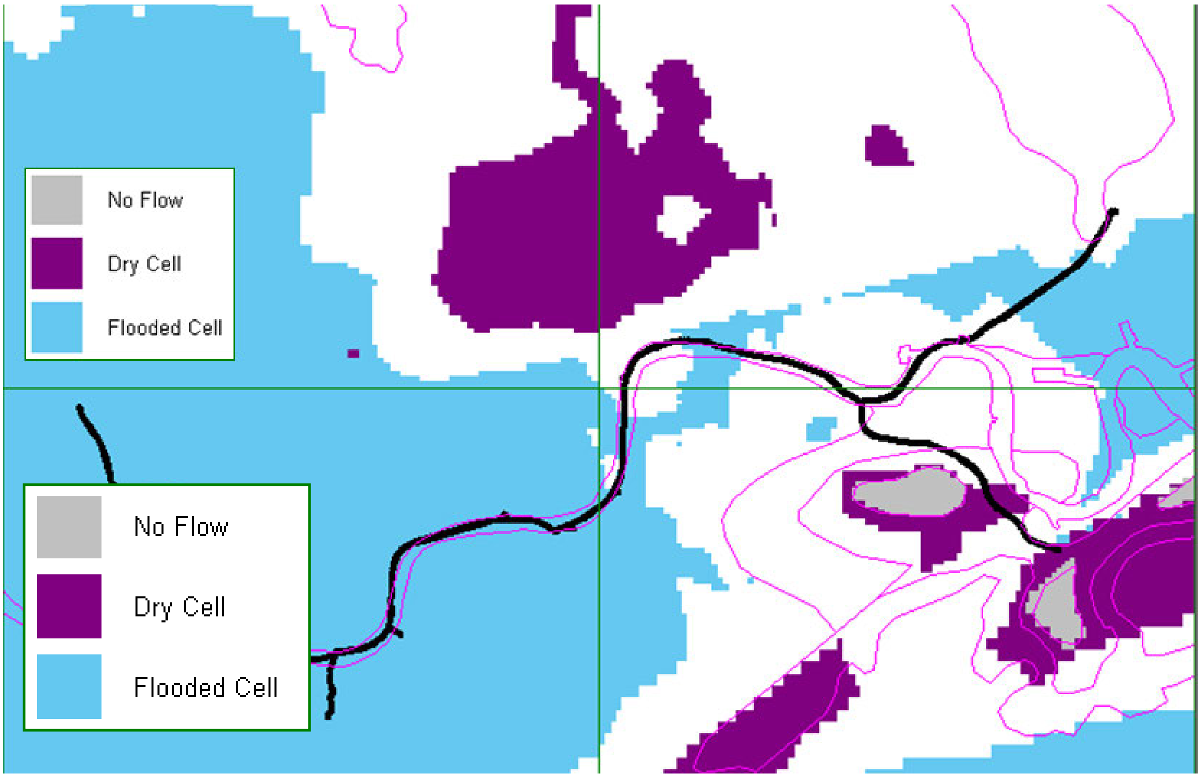


Vol 3 Plate K.59 Groundwater – Stress Period 45 Time Step 5

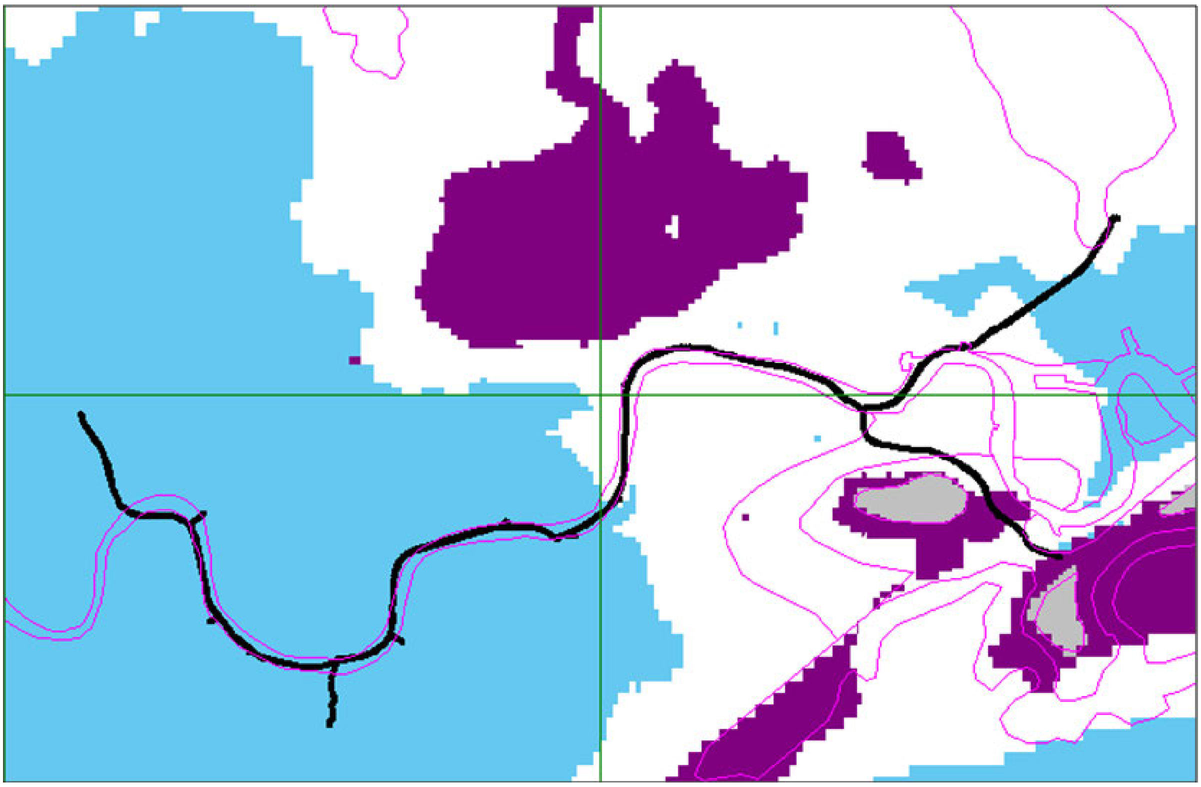


Layer 2. Extent of Saturated/Unsaturated/Dry Conditions (RUN 1)

Vol 3 Plate K.60 Groundwater –Stress Period 1 Time Step 1

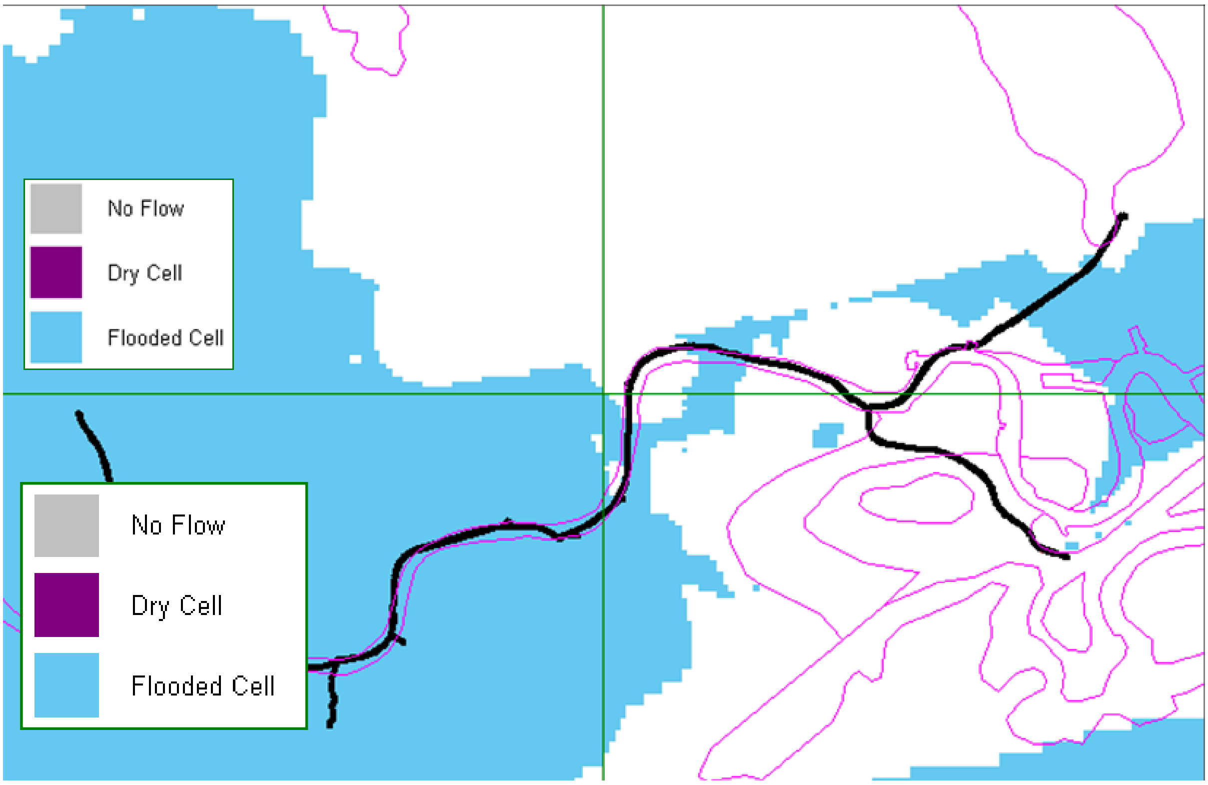


Vol 3 Plate K.61 Groundwater – Stress Period 45 Time Step 5

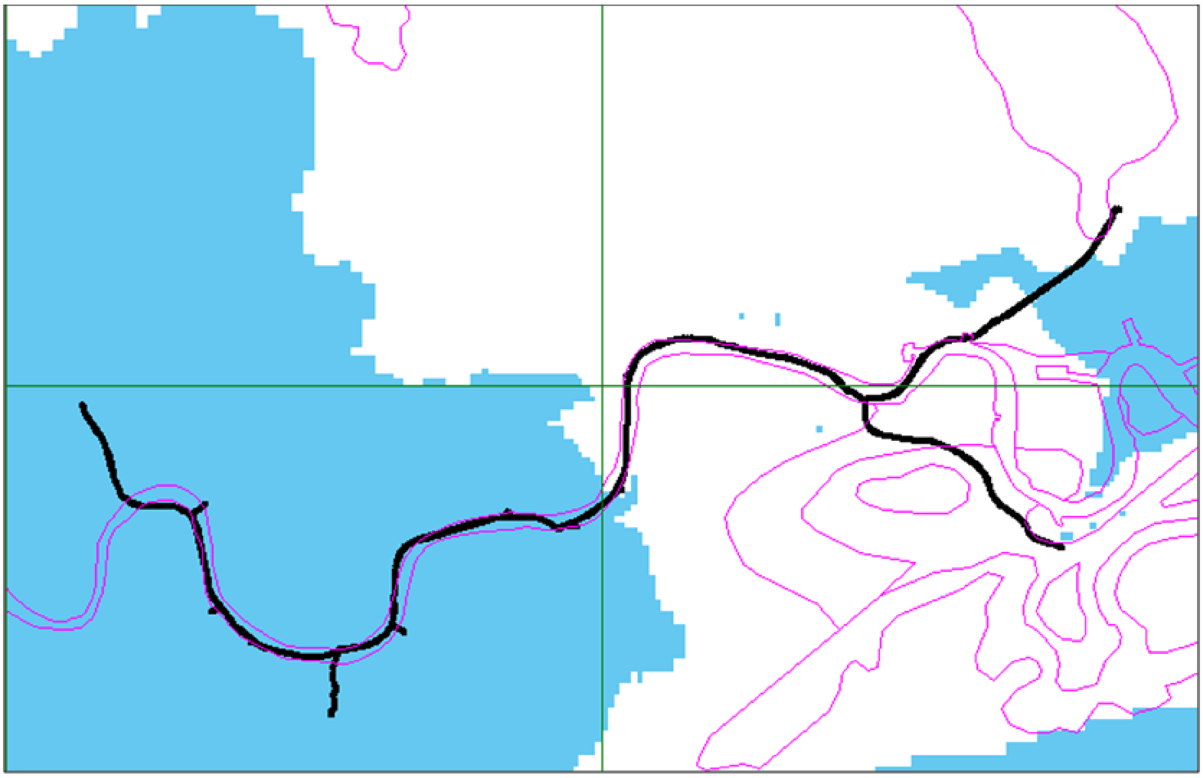


Layer 3. Extent of saturated/unsaturated/dry conditions (RUN 1)

Vol 3 Plate K.62 Groundwater – Stress Period 1 Time Step 1



Vol 3 Plate K.63 Groundwater – Stress Period 45 Time Step 5



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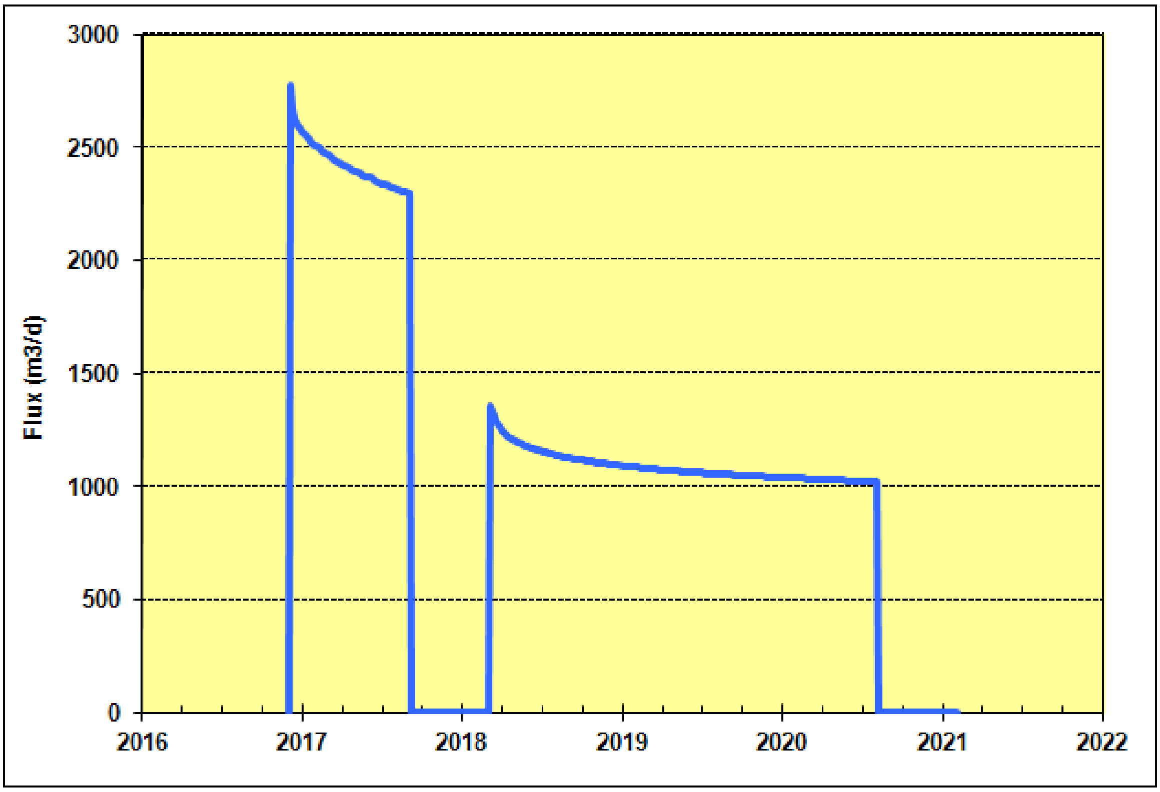
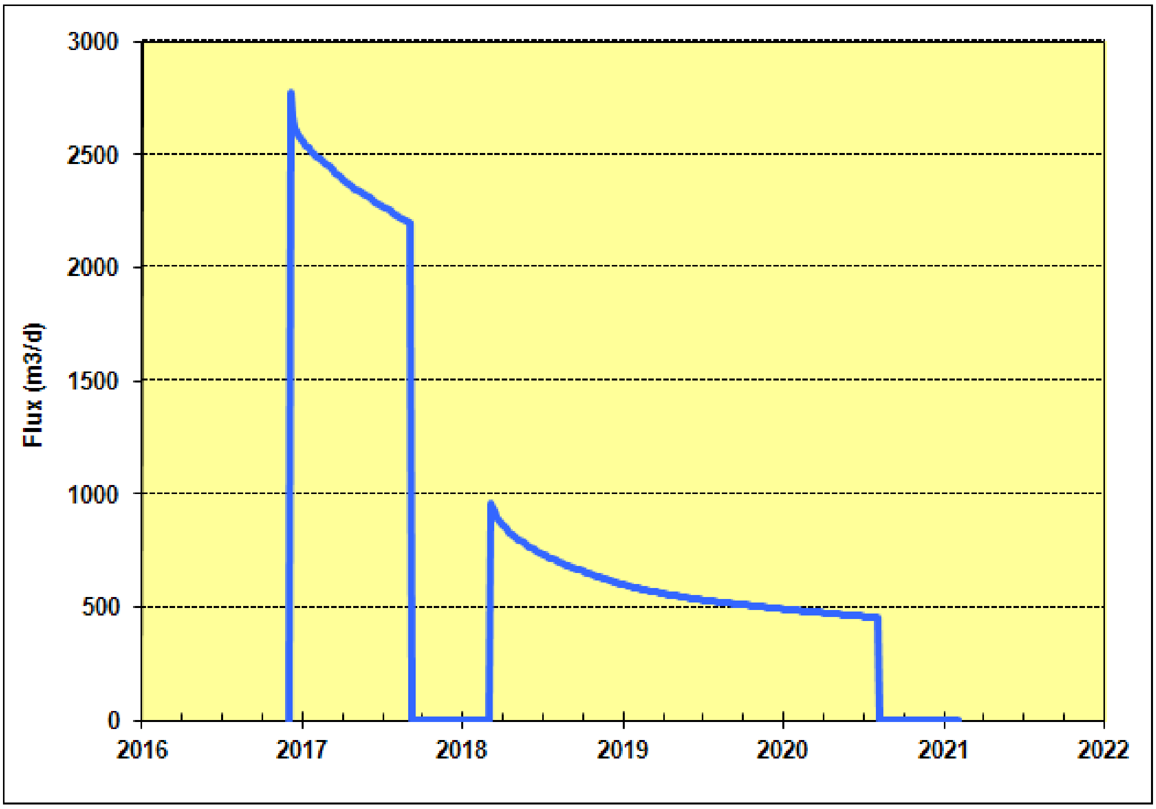
Annex F Drain cell flux

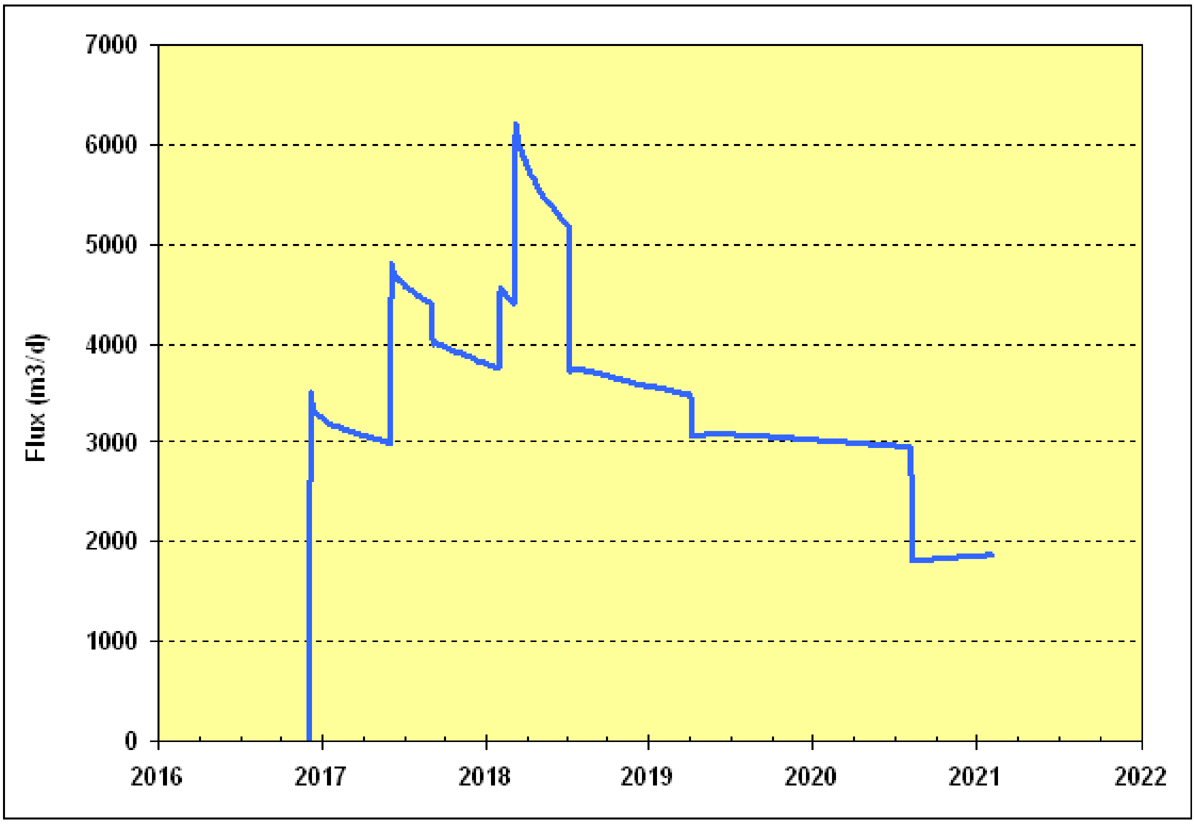
Vol 3 Plate K.64 Groundwater – Drain Cells Flux (RUN 1)



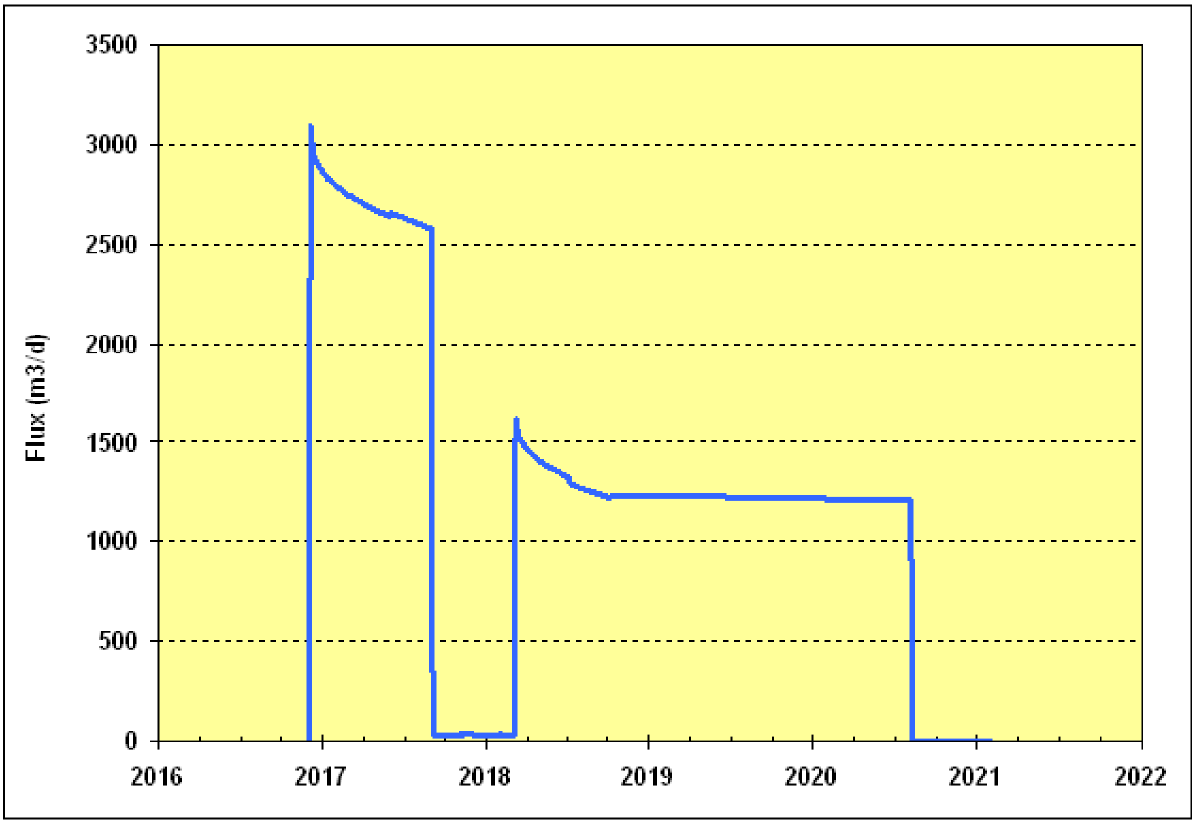
Vol 3 Plate K.65 Groundwater – Drain Cells Flux (RUN 2)



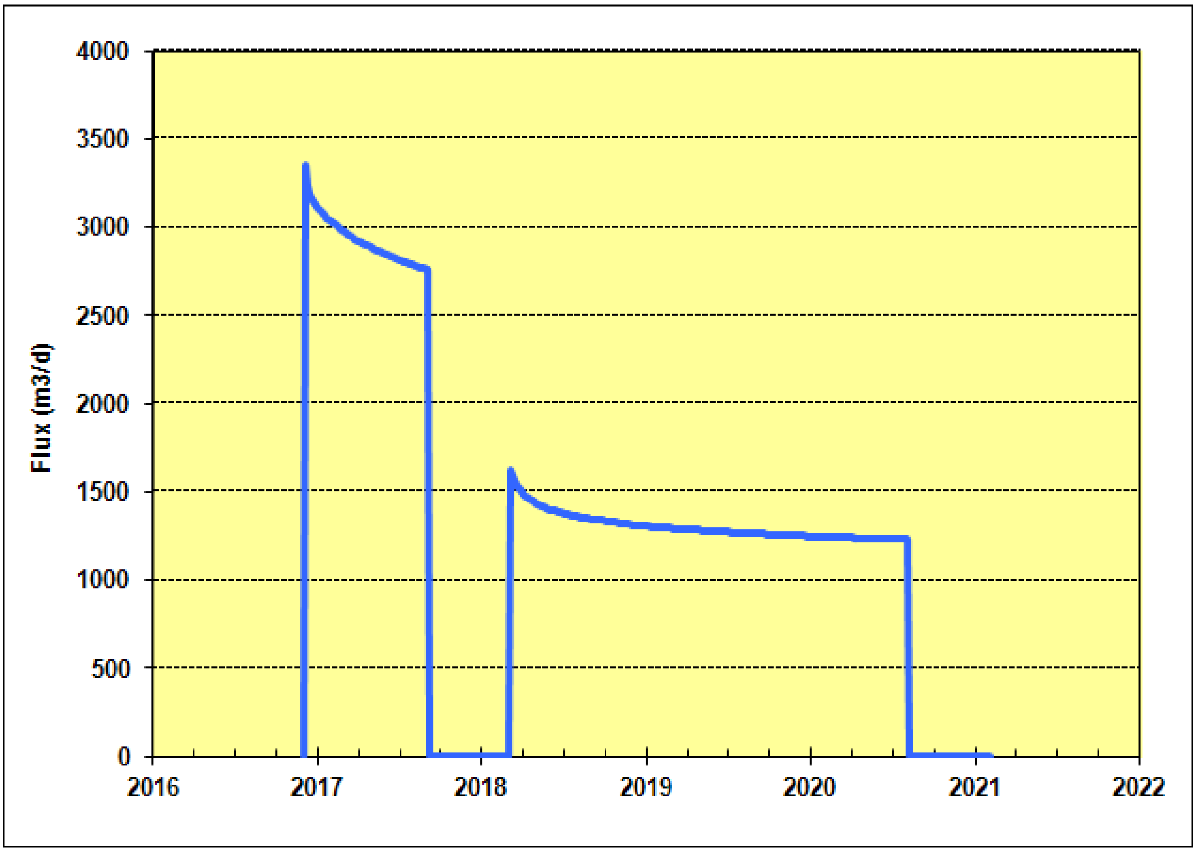
Vol 3 Plate K.66 Groundwater – Drain Cells Flux (RUN 3)



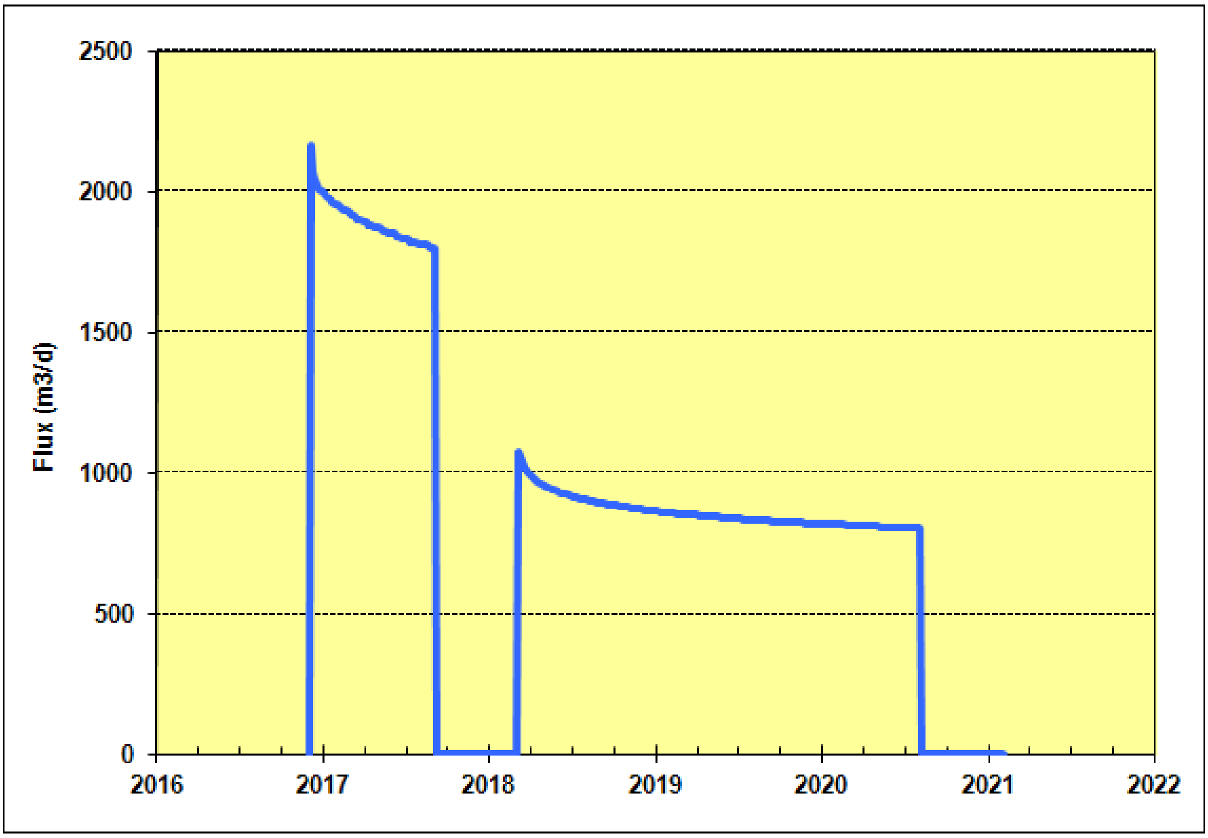
Vol 3 Plate K.67 Groundwater – Drain Cells Flux (RUN 4)



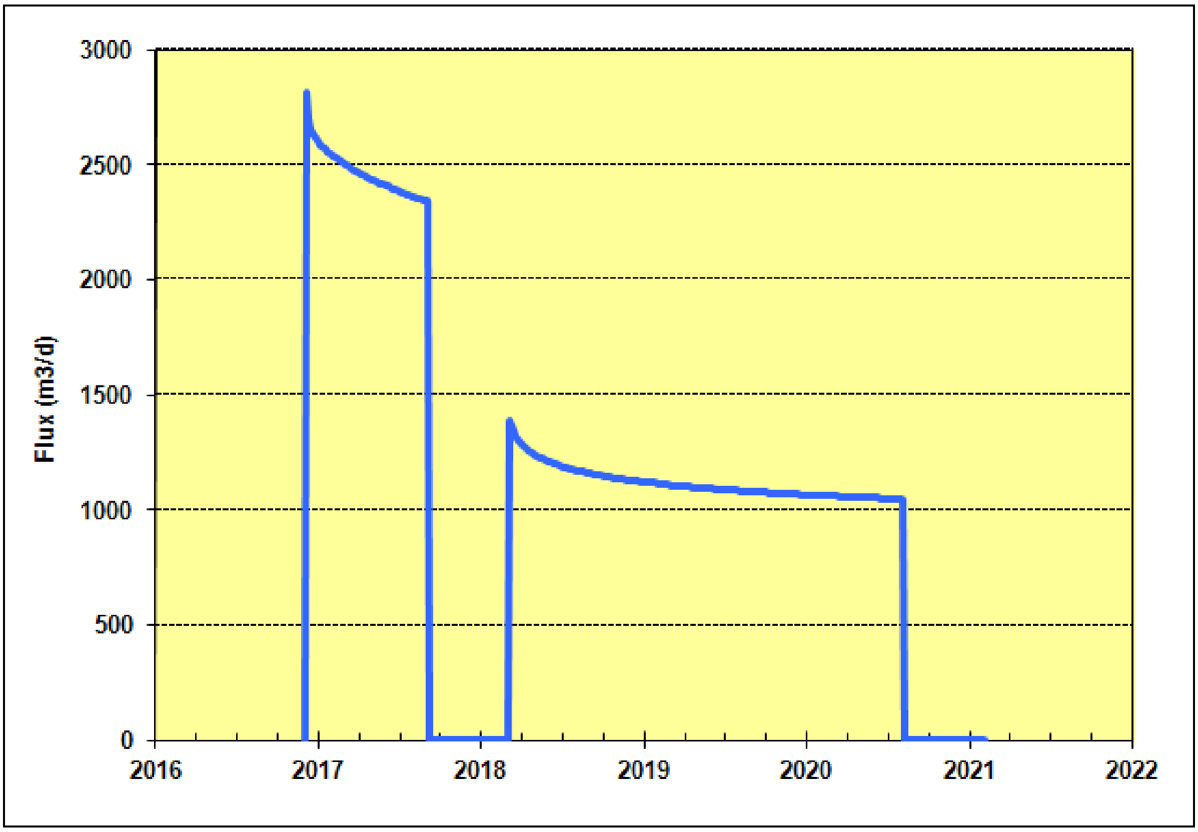
Vol 3 Plate K.68 Groundwater – Drain Cells Flux (RUN 5)



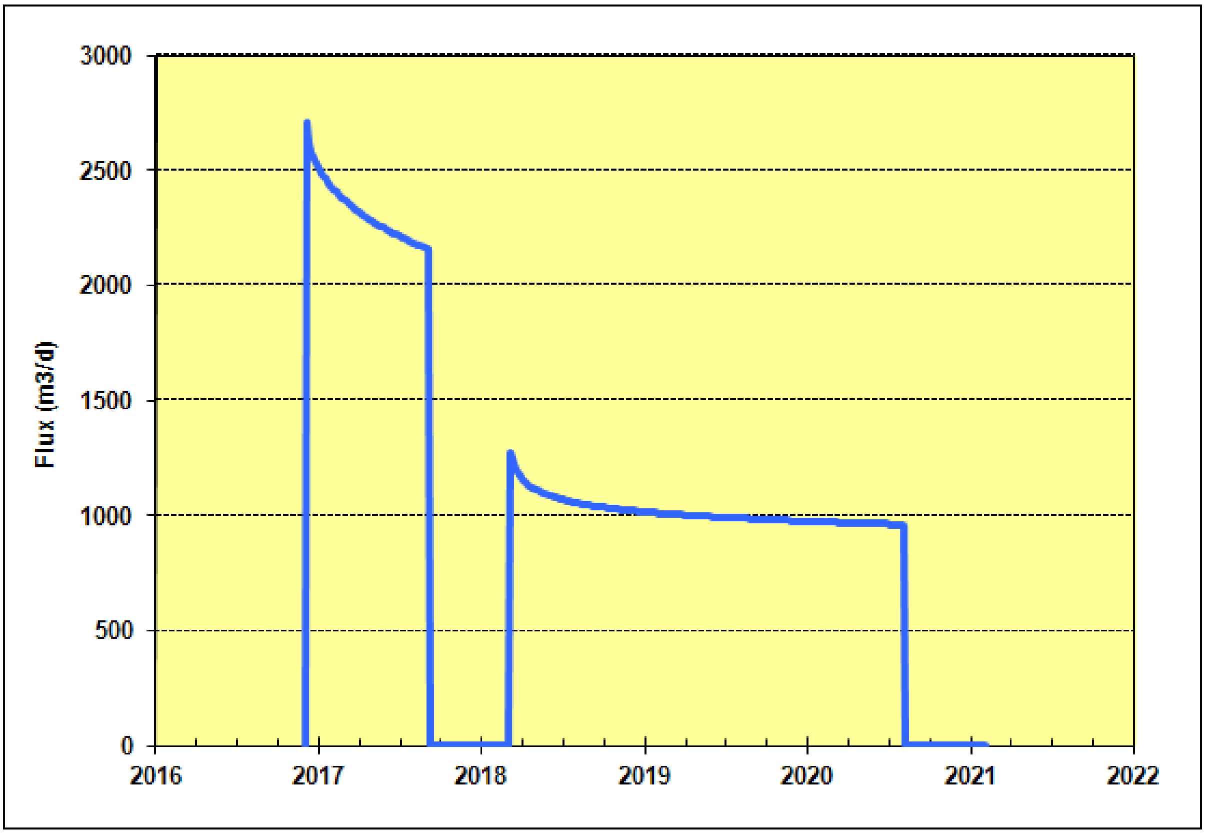
Vol 3 Plate K.69 Groundwater – Drain Cells Flux (RUN 6)



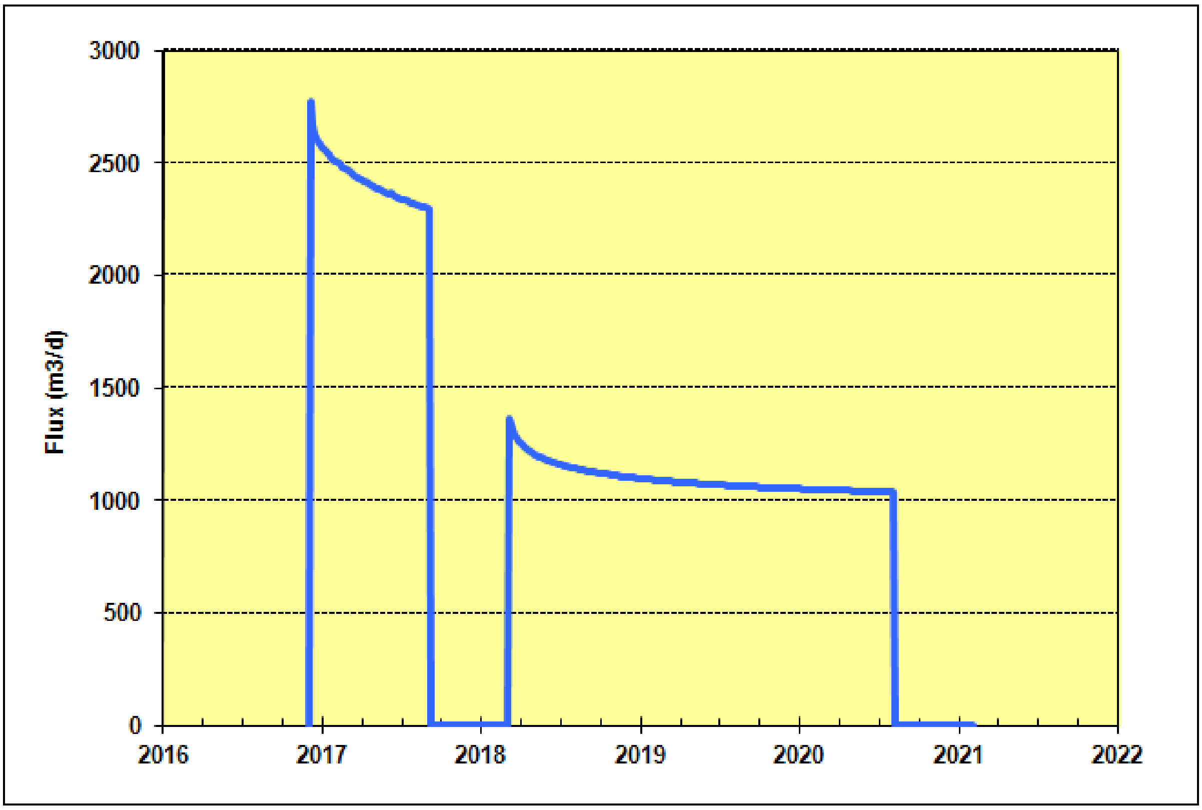
Vol 3 Plate K.70 Groundwater – Drain Cells Flux (RUN 7)



Vol 3 Plate K.71 Groundwater – Drain Cells Flux (RUN 8)



Vol 3 Plate K.72 Groundwater – Drain Cells Flux (RUN 9)



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[13] Ellison *et al.* See citation above.

[14] Royse, K.R. See citation above.

[15] Environment Agency and ESI. See citation above.

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Thames Tideway Tunnel
Thames Water Utilities Limited

Application for Development Consent

Application Reference Number: WWO10001

Environmental Statement

Doc Ref: **6.2.03**

Volume 3: Project-wide effects assessment appendices

Appendix L: Water resources - surface water

APFP Regulations 2009: Regulation **5(2)(a)**

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January 2013

Thames Tideway Tunnel
Creating a cleaner, healthier River Thames

Thames Tideway Tunnel

Environmental Statement

Volume 3 Project-wide effects assessment appendices

Appendix L: Water resources – surface water

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Thames Tideway Tunnel
Thames Water Utilities Limited

Application for Development Consent

Application Reference Number: WWO10001

Environmental Statement

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Volume 3: Project-wide effects assessment appendices

Appendix L.1: CSO control and performance of the Thames Tideway Tunnel

APFP Regulations 2009: Regulation **5(2)(a)**

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January 2013

Thames Tideway Tunnel
Creating a cleaner, healthier River Thames

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Appendix L: Water resources – surface water

L.1 CSO control and performance of the Thames Tideway Tunnel

L.1.1 The following report has its own table of contents.

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L.1 CSO control and performance of the Thames Tideway Tunnel

Introduction

L.1.1 This report summarises the objectives and proposed levels of performance for the Thames Tideway Tunnel project.

L.1.2 The Thames Tideway Tunnel project is part of the London Tideway Improvements (LTI). The London Tideway Improvements comprise three major engineering schemes to reduce combined sewer overflows and improve water quality in the River Thames. These comprise:

a. Sewage treatment works (STW) improvements - upgrades are proposed at five major STW affecting the Tidal Thames; Mogden, Beckton, Crossness, Riverside and Long Reach STW.

b. The Lee Tunnel – a storage and transfer tunnel from Abbey Mills Pumping Station to Beckton STW and the interception of the Abbey Mills combined sewer overflow (CSO). The Lee Tunnel is currently under construction.

c. The Thames Tideway Tunnel.

L.1.3 The Lee Tunnel and the Thames Tideway Tunnel are known collectively as the London Tideway Tunnels.

L.1.4 The reported modelled performances in this report are based on the catchment modelling and simulation runs. Three modelling scenarios are presented:

a. The Existing System is the scenario based on 2006 population figures and the existing sewerage system and STW capacity. This is the existing baseline.

b. The Lee Tunnel is the scenario with projected 2020s population, the sewage works upgrades at the five STWs and completion of the Lee Tunnel. This is the base case performance for the Thames Tideway Tunnel.

c. The Thames Tideway Tunnel is the scenario with projected 2020s population, the STW upgrade at the five STWs, the Lee Tunnel and completion of the Thames Tideway Tunnel.

L.1.5 This report includes specific details on the following:

a. CSO categorisation and the baseline and base case conditions for the Thames Tideway Tunnel scenario

b. Proposed control performance objectives for CSOs requiring control and proposed CSO performance at all other Tidal Thames CSOs.

c. Proposed operating strategy and control of discharges from the Abbey Mills pumping station CSO which form the basis of the Operating Techniques[i].

d. Evaluation of the London Tideway Improvements in meeting dissolved oxygen (DO) targets in the Tidal Thames.

Objectives of the Thames Tideway Tunnel project

L.1.6 The overall objectives of the project are to help meet the requirements of the Urban Wastewater Treatment Directive (UWWTD)[1] and the bespoke water quality standards developed in the *Thames Tideway Strategic Study (TTSS)* (Thames Water, 2005)[2]. The Thames Tideway Tunnel project would help to achieve compliance with the Water Framework Directive (WFD).

L.1.7 The UWWTD does not specify numerical values for the level of control: either for CSO volume, number of discharges or duration of discharges. The setting of values is devolved to and is the responsibility of the appropriate authority in the member states of the European Union. The project's CSO control targets have therefore been developed based on discussions with the Environment Agency (EA) with the primary objective of controlling unsatisfactory CSOs to no more than 4 events per year in a Typical Year under current conditions.

L.1.8 The EA have been consulted and involved throughout the development of the system design and operating strategy. They have expressed continuous support for the Thames Tideway Tunnel as well as confirming that when the London Tideway Improvements is completed, the dissolved oxygen standards developed by the TTSS are met and that the Thames Tideway Tunnel targets comply with the UWWTD.

L.1.9 The WFD requires Member States to set targets for ecological condition in all water bodies. The UK has set a target for a 'good' ecological potential for the Tidal Thames by 2027. The Thames Tideway Tunnel as part of the London Tideway Improvements will help towards compliance with the WFD, however as part of the TTSS, bespoke dissolved oxygen standards for water quality in the Tidal Thames has also been set.

L.1.10 Although the proposed date for completion of the Thames Tideway Tunnel is 2023, the project is intended to control CSOs for a much longer period and so would need to be resilient to change. Change would occur in population and climate which would affect flows in the system. To assess the resilience of the project to change, projections of population and climate for 2080have been evaluated in the *Resilience to Change* report and this is considered in Volume 3 Section 14.

L.1.11 During the TTSS, the EA categorised the 57 CSOs that were identified as discharging to the Tidal Thames to determine which CSOs were

[i] The Environment Agency have agreed to regulate the residual CSO discharges to the Tidal Thames with Permits to Discharge that include Operating Techniques as the principal condition for compliance, The Operating Techniques for the London Tideway Tunnels describe how the tunnel system will be operated in conjunction with the main STW to achieve compliance with the Permit.

unsatisfactory (Category 1 and 2) and not unsatisfactory (Category 3 and 4*)*. The CSO categories are classed as follows:

a. Category 1: CSOs that operate frequently and have an adverse environmental impact.

b. Category 2: CSOs that do not operate frequently but which have an adverse environmental impact.

c. Category 3: CSOs which have no significant environmental impact.

d. Category 4: CSOs that operate frequently but have been assessed as not having an adverse environmental impact.

L.1.12 The EA identified 36 of the 57 CSOs as unsatisfactory CSOs which should be controlled. Of the 36 CSOs, 34 CSOs discharge to the Tidal Thames while the other two CSO discharges to the River Lee. The Abbey Mills CSO to the River Lee would be controlled by the Lee Tunnel (which is currently under construction) and the Wick Lane CSO controlled by a separate project.

L.1.13 Monitoring of CSO discharges over the past few years and the current analysis of the sewerage system generally reinforce this categorisation of CSOs. No change to the characterisation of CSOs is currently proposed. However, the EA may, at their discretion, change the characterisation of some of the lower volume and frequency CSOs. Such changes are not expected to change the Thames Tideway Tunnel.

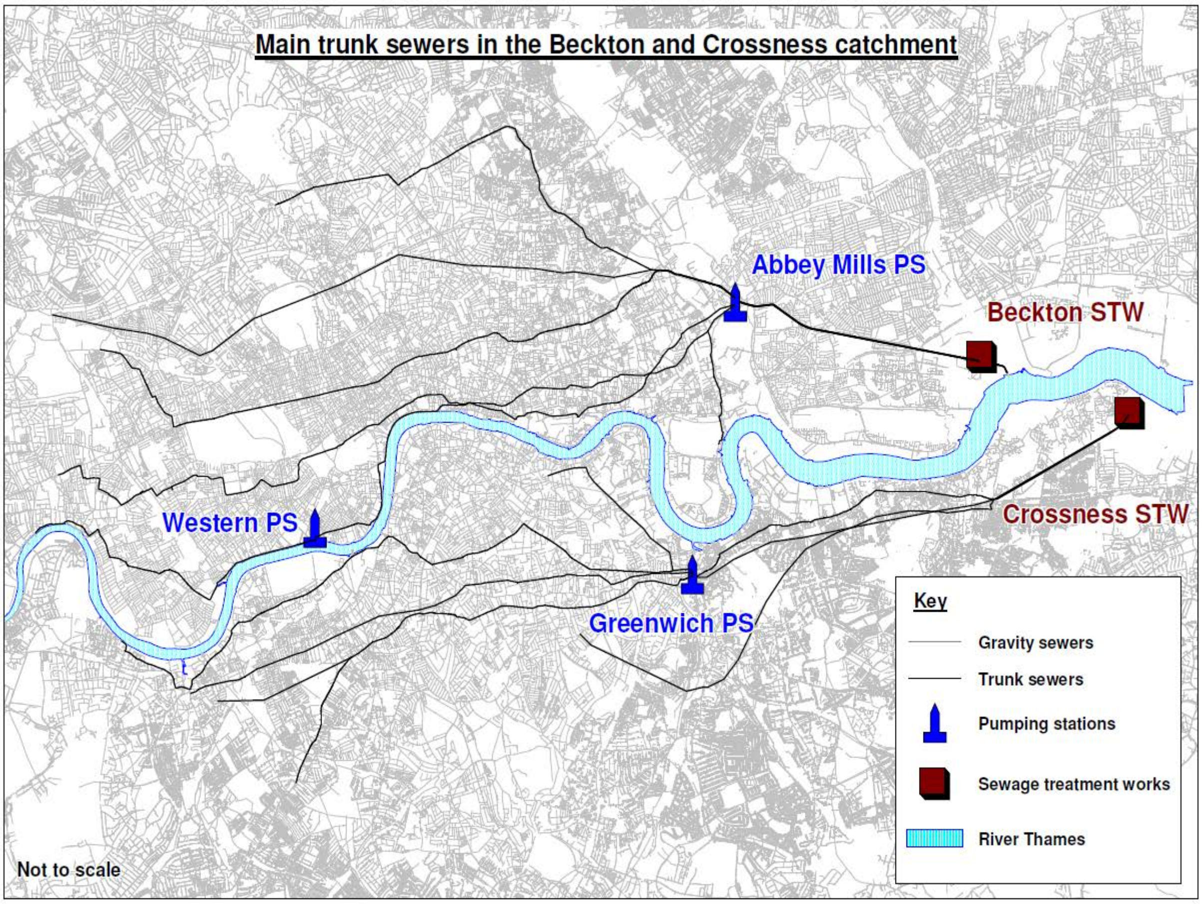
Description of existing conditions

L.1.14 During dry weather flow (DWF), foul flow in the Beckton and Crossness STW catchment are collected by local, trunk and interceptor sewers which generally run west to east. These are represented in Vol 3 Plate L.1

L.1.15 In the Beckton catchment (north of the Tidal Thames), the main interceptor trunk sewers are High Level No. 1, Mid Level No. 1 and No. 2 and Low Level No. 1 and No.2. The High Level No. 1 and Mid Level No.1 and No.2 sewers deliver flow by gravity to the Beckton STW via the Northern Outfall sewers (NOS). The Northern Low Level No.1 and No.2 are pumped to the NOS at Abbey Mills Pumping Station. The NOS delivers flow by gravity to Beckton STW.

L.1.16 In the Crossness catchment (south of the Tidal Thames), the main interceptor trunk sewers are the High Level No. 1 and No.2, and Low Level No. 1 and No. 2. The High Level sewers deliver flow by gravity to the inlet pumping station at Crossness STW. The southern Low Level sewers are pumped to the Southern Outfall sewers (SOS) No.1 and No.2 at Greenwich Pumping Station (Vol 3 Plate L.1). The Southern Outfall sewers deliver flow by gravity to the inlet pumping station at Crossness STW.

Vol 3 Plate L.1 Beckton and Crossness Trunk Interceptor Sewers



L.1.17 During rainfall and subsequent runoff, additional flow (a mixture of untreated sewage and captured rainfall runoff) occurs in the sewer system. The additional flow can cause the diversion structures (weirs, etc) to overtop and spill into the storm relief (SR) sewers which discharge at various outfalls along the Tidal Thames as well as the River Lee, River Wandle and Deptford Creek as CSOs. The system is designed to differentially spill untreated sewage combined with rainfall runoff to the Tidal Thames rather than flood streets and properties.

L.1.18 The Typical Year was selected during the TTSS to represent the most “typical” 12 month period of rainfall observed between 1970 and 2011 and is used to evaluate the annual CSO performance of the existing sewerage system and later the Thames Tideway Tunnel. It covers the period from October 1979 to September 1980 and is a leap year (8,784 hours). The period from October Year X to September Year X+1 is termed a water year and is a better representation of hydrologic conditions than that given by a calendar year. The Typical Year is the 1980 water year.

L.1.19 The total volume, number and duration of discharges at each CSO during the Typical Year for the existing and 2020s conditions are represented in Vol 3 Table L.1 and Vol 3 Plate L.2 and Vol 3 Plate L.3 This shows the progressive improvements that would be achieved through the sewage works upgrades (STW improvements) and the Lee Tunnel project in 2020s against the existing system CSO performance.

L.1.20 For each river reach, the total discharge volume and maximum number and maximum duration of discharges from all modelled CSOs in that reach is reported.

L.1.21 With the STW improvements to Beckton and Crossness, the annual total CSO volume reduces to about 24 million m^3, representing a 40% capture of the existing system of about 39 million m^3. Reduction in annual CSO discharges and events are predicted at Abbey Mills and Greenwich Pumping Station CSO because more flows are passed towards the STWs before diversion to the river due to the expanded treatment capacity at Beckton and Crossness STW respectively. Some increase in CSO volume and discharge events are predicted at the remaining unsatisfactory CSOs due to increased population in the 2020s.

L.1.22 With the STW improvements and Lee Tunnel project, the annual total CSO volume reduces to about 18 million m^3, representing a 56% capture of the existing system of about 39 million m^3. Over 50 separate discharge events are predicted at Hammersmith pumping station CSO. Three other pumping stations record over 40 separate discharge events and a total of 17 CSOs producing 20 or more discharge events in the Typical Year.

L.1.23 There will no longer be any discharges at the existing Abbey Mills CSOs, because the Lee Tunnel will capture the Abbey Mills CSO discharges. The captured flow will be transferred to the Beckton STW for treatment or will be discharged from the new Tideway CSO (at Beckton STW)when the Lee Tunnel fills to the Tideway CSO overflow level of 4.2mAOD.

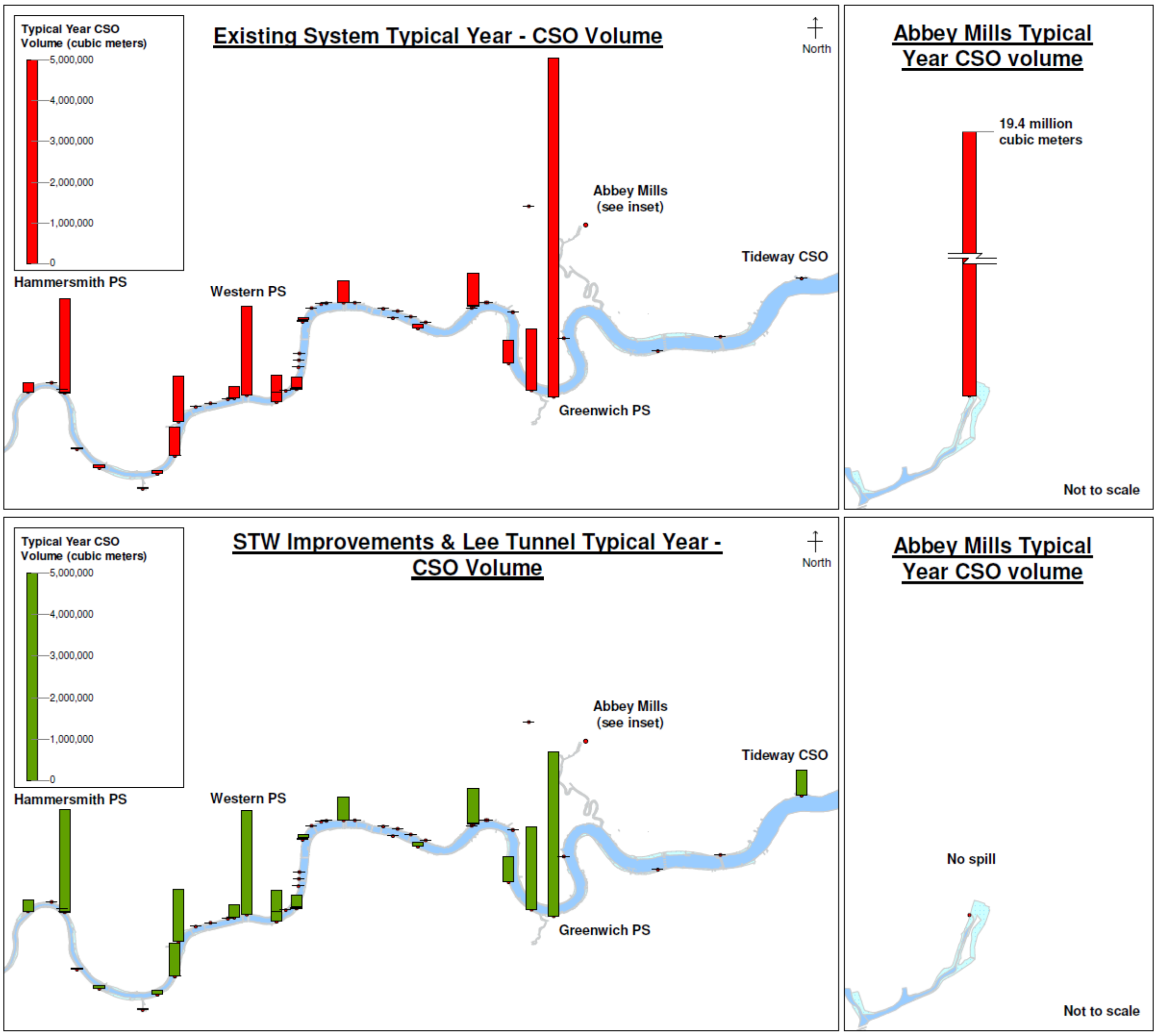
L.1.24 In the Typical Year, the majority of CSO discharges from Abbey Mills will be captured by the Lee Tunnel and transferred to Beckton STW. The exceptions are three events where the Lee Tunnel will fill to the new Tideway CSO overflow level, and discharge to the river at Beckton STW, producing an annual discharge volume of about 609,000m^3 over a total annual spill duration of 18 hours.

L.1.25 The STW improvements and Lee Tunnel in 2020s is the base case for evaluating the performance of the Thames Tideway Tunnel.

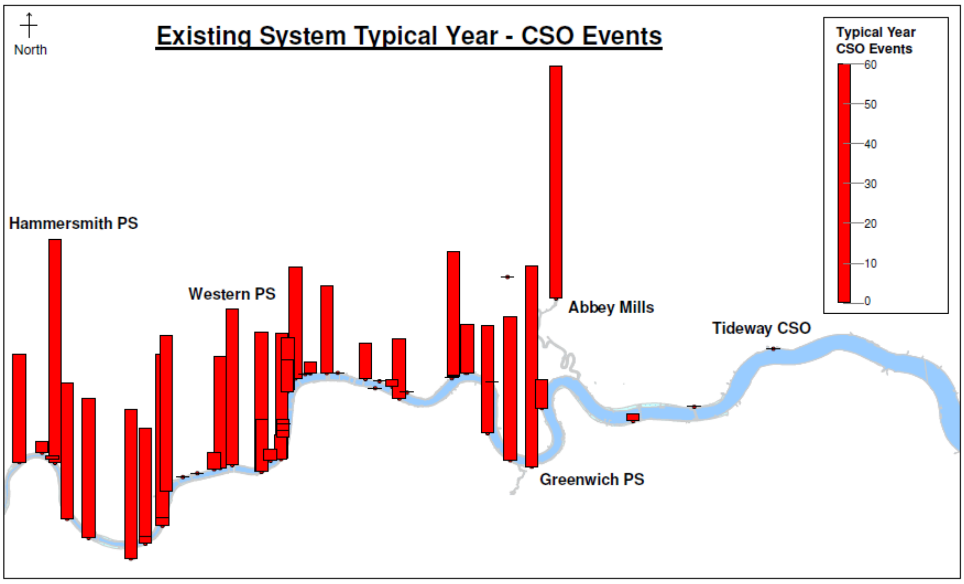
Vol 3 Table L.1 Typical year CSO performance for the existing system, existing system with STW Improvements and 2020s population and Lee tunnel with STW Improvements and 2020s population

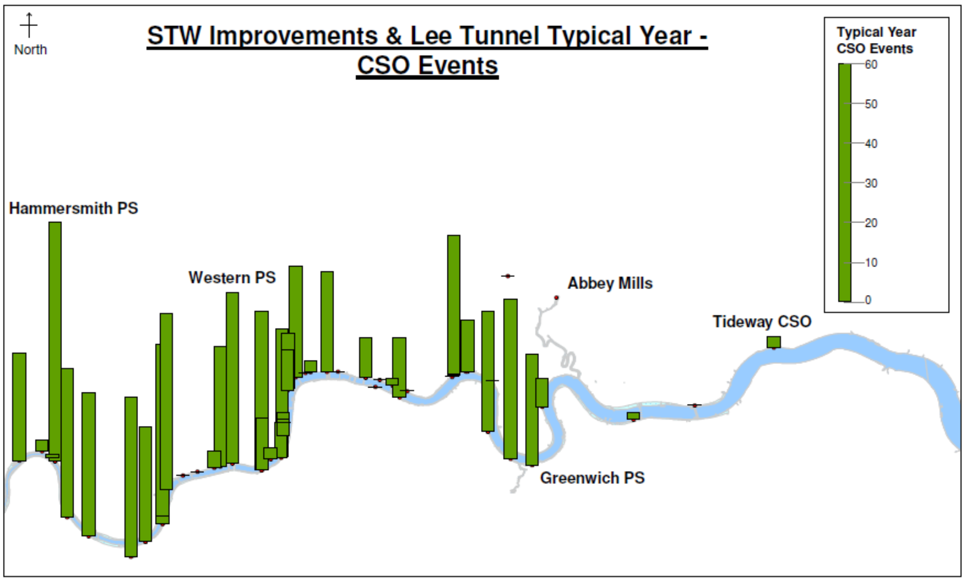
LTT ID	EA Cat	CSO Name	Existing System & Existing STW 2006			Existing System and STW Improvements 2020s			STW Improvements and Lee Tunnel 2020s		
			Total Volume (m^3) [a/b.]	No. of Spills [a.]	Spill Duration (hrs) [a.]	Total Volume (m^3) [a/b.]	No. of Spills [a.]	Spill Duration (hrs) [a.]	Total Volume (m^3) [a/b.]	No. of Spills [a.]	Spill Duration (hrs) [a.]
CS01X	Cat 1	Acton Storm Relief	312,000	29	152	324,000	30	163	178,000	17	84
CS02X	Cat 2	Stamford Brook Storm Relief	500	2	2	500	2	2	300	2	2
CS05X	Cat 1	West Putney Storm Relief	35,000	30	118	37,000	30	121	37,000	31	123
CS37X	Cat 3	LL1 Brook Green	0	0	0	0	0	0	0	0	0
CS03X	Cat 2	North West Storm Relief	2,800	1	1	4,000	1	1	3,900	1	1
CS04X	Cat 1	Hammersmith Pumping Station	2,210,000	51	650	2,360,000	53	693	2,350,000	54	698
CS06X	Cat 1	Putney Bridge	68,000	33	107	71,000	33	110	71,000	33	110
		Upstream Putney Bridge Total / Maximum [b/c.]	**2,630,000**	**51**	**650**	**2,800,000**	**53**	**693**	**2,640,000**	**54**	**698**
CS07A	Cat 1	Frogmore Storm Relief - Bell Lane	18,000	32	136	19,000	32	141	19,000	32	141
CS07B	Cat 1	Frogmore Storm Relief - Buckhold Road	86,000	21	72	89,000	21	72	89,000	21	72
CS08A	Cat 1	Jews Row - Wandle Valley Storm Relief	300	1	2	3,000	2	7	3,000	2	7
CS08B	Cat 3	Jews Row - Falcon Brook Storm Relief	7,400	2	7	7,500	2	7	7,500	2	7
CS09X	Cat 1	Falcon Brook Pumping Station	709,000	42	267	780,000	42	291	780,000	42	291
CS10X	Cat 1	Lots Rd Pumping Station	1,140,000	38	346	1,260,000	42	409	1,260,000	42	407
CS11X	Cat 2	Church Street	0	0	0	0	0	0	0	0	0
CS12X	Cat 2	Queen Street	0	0	0	0	0	0	0	0	0
CS13A	Cat 2	Smith Street Main Line	1,400	4	8	1,500	4	8	1,500	4	8
CS13B	Cat 2	Smith Street Relief	0	0	0	0	0	0	0	0	0
CS14X	Cat 1	Ranelagh	283,000	26	142	306,000	29	157	306,000	29	157
CS15X	Cat 1	Western Pumping Station	2,050,000	37	200	2,320,000	41	228	2,320,000	41	228
CS17X	Cat 1	South West Storm Relief	228,000	13	39	239,000	13	40	239,000	13	40
CS16X	Cat 1	Heathwall Pumping Station	655,000	34	200	748,000	39	248	748,000	39	248
CS18X	Cat 2	Kings Scholars Pond Storm Relief	1,400	3	5	1,800	3	5	1,800	3	5
CS19X	Cat 1	Clapham Storm Relief	13,000	6	14	14,000	6	15	14,000	6	15
CS20X	Cat 1	Brixton Storm Relief	265,000	29	133	279,000	31	141	279,000	31	141
CS21X	Cat 2	Grosvenor Ditch	2,600	3	7	3,000	4	9	3,000	4	9
CS39X	Cat 3	Horseferry	3,400	3	7	3,800	3	7	3,800	3	7
CS40X	Cat 3	Wood Street	0	0	0	0	0	0	0	0	0
CS22X	Cat 1	Regent Street	22,000	5	13	26,000	10	21	26,000	10	21
CS23X	Cat 1	Northumberland Street	72,000	13	34	88,000	14	43	88,000	14	43
CS24X	Cat 2	Savoy Street	8,500	20	51	8,600	20	51	8,600	20	51
CS25X	Cat 2	Norfolk Street	0	0	0	0	0	0	0	0	0
CS26X	Cat 2	Essex Street	2,100	3	6	2,300	3	6	2,300	3	6
CS27X	Cat 1	Fleet Main	521,000	21	75	571,000	23	83	571,000	23	83
CS42X	Cat 3	Pauls Pier	0	0	0	0	0	0	0	0	0
CS55X	Cat 4	London Bridge	8,300	7	14	9,100	9	16	9,100	9	16
		Downstream Putney Bridge to London Bridge Total / Maximum [b/c.]	**6,100,000**	**42**	**346**	**6,780,000**	**42**	**409**	**6,780,000**	**42**	**407**
CS28X	Cat 1	Shad Thames Pumping Station	92,000	15	70	101,000	15	70	100,000	15	69
CS43X	Cat 3	Battle Bridge	0	0	0	0	0	0	0	0	0
CS44X	Cat 3	Beer Lane	0	0	0	0	0	0	0	0	0
CS45X	Cat 3	Iron Gate	200	1	2	200	1	2	200	1	2
CS46X	Cat 3	Nightingale Lane	0	0	0	0	0	0	0	0	0
CS49X	Cat 3	Cole Stairs	0	0	0	0	0	0	0	0	0
CS50X	Cat 3	Bell Wharf	0	0	0	0	0	0	0	0	0
CS29X	Cat 1	North East Storm Relief	782,000	31	286	847,000	32	307	848,000	32	307
CS51X	Cat 3	Ratcliffe	0	0	0	0	0	0	0	0	0
CS31X	Cat 1	Earl Pumping Station	539,000	26	184	593,000	29	205	594,000	30	207
CS30X	Cat 1	Holloway Storm Relief	7,900	9	21	8,500	10	25	8,500	10	25
CS52X	Cat 3	Blackwall Sewer	0	0	0	0	0	0	0	0	0
CS36X	Cat 2	Wick Lane	0	0	0	0	0	0	0	0	0
CS32X	Cat 1	Deptford Storm Relief	1,470,000	36	252	1,970,000	39	341	1,980,000	39	342
CS33X	Cat 1	Greenwich Pumping Station	8,320,000	51	672	3,930,000	28	239	3,940,000	28	240
		Downstream London Bridge to Greenwich Total / Maximum [b/c.]	**11,200,000**	**51**	**672**	**7,450,000**	**39**	**341**	**7,470,000**	**39**	**342**
CS56X	Cat 4	Isle of dogs Pumping Station (Foul only)	13,000	6	9	13,000	7	11	13,000	7	11
CS35X	Cat 1	Abbey Mills Pumping Station from STATION F	15,300,000	56	873	5,040,000	42	266	0	0	0
CS35X	Cat 1	Abbey Mills Pumping Station from STATION A	4,100,000	45	403	1,760,000	36	163	0	0	0
CS57X	Cat 4	Canning Town Pumping Station	0	0	0	0	0	0	0	0	0
CS34X	Cat 1	Charlton Storm Relief	600	2	3	900	2	3	900	2	3
CS53X	Cat 3	Henley Road	0	0	0	0	0	0	0	0	0
		Downstream Greenwich to Henley Road Total / Maximum [b/c.]	**19,400,000**	**56**	**873**	**6,810,000**	**42**	**266**	**14,000**	**7**	**11**
		Crossness STW Storm Tanks	308,000	5	27	50,000	3	8	50,000	3	8
		Tideway CSO				0	0	0	609,000	3	18
		Total / Maximum [b/c.] to the River (CSO + Tunnel Overflow)	**39,600,000**	**56**	**873**	**23,900,000**	**53**	**693**	**17,600,000**	**54**	**698**
Sewarage Treatment Works [d.]		Beckton Catchment	444,600,000		8784	509,500,000	0	8784	508,500,000		8784
		Tunnel Pump Out	n/a		n/a	n/a	0	0	6,200,000		784
		Beckton STW (Catchment + Tunnel Pump Out)	444,600,000		8784	509,500,000	0	0	514,700,000		8784
		Crossness STW	200,600,000		8784	231,600,000	0	8784	230,900,000		8784

Vol 3 Plate L.2 Typical year CSO volume performance along the tidal Thames



Vol 3 Plate L.3 Typical year CSO event performance along the tidal Thames





Thames Tideway Tunnel overview and modelling methodology

Overview

L.1.26 The following sections outline which CSOs need to be controlled, where work is required, how CSOs would be intercepted and/or controlled and the basic dimensions of the system.

L.1.27 The proposed works would connect and control 34 unsatisfactory Category 1 and Category 2 CSOs to the Thames Tideway Tunnel which would extend approximately 25km from Acton Storm Tanks (in west London) to a connection to the Lee Tunnel at Abbey Mills (in east London).

L.1.28 From Acton Storm Tanks to Carnwath Road Riverside (approximately 6.8km), the main tunnel would be 6.5m internal diameter and from Carnwath Road Riverside to Abbey Mills (approximately 18.2km), the main tunnel would be 7.2m internal diameter.

L.1.29 Combined sewage captured by the Thames Tideway Tunnel and Lee Tunnel (the London Tideway Tunnels) would be transferred to the Tideway Pumping Station which would pump flows to the Beckton STW for treatment. The Tideway CSO (established as part of the Lee Tunnel project) would discharge pumped flows from the tunnel system to the Tidal Thames at Beckton STW when the tunnel system reaches a pre-set level that is near full storage capacity.

L.1.30 Additional connection tunnels would store and convey combined sewage from CSOs not immediately adjacent to the main tunnel and would include:

a. A 5m internal diameter 4.5km long connection tunnel from Greenwich Pumping Station to the main tunnel at Chambers Wharf. The Greenwich connection tunnel would also capture flow from Deptford CSO and Earl Pumping Station CSO.

b. A 2.6m internal diameter 1.1km long connection tunnel from Frogmore-Buckhold Road CSO to the main tunnel at Carnwath Road Riverside. The Frogmore connection tunnel would also capture flow from Frogmore – Bell Lane Creek CSO.

L.1.31 All 34 unsatisfactory CSOs would be controlled either by direct interception through construction of interception chambers and ancillary works at existing CSOs or through modifications to sewer system operations, particularly at pumping stations.

L.1.32 At three locations along the northern Low Level No.1 (nLL1) sewer, relief weirs are proposed d which would allow for greater capture of flow at the proposed adjacent CSO interception. This additional capture of flow would provide additional relieve to the nLL1, and avoid the need for construction of interception chambers and tunnel connection shafts at other unsatisfactory CSOs along the nLL1.

General assumptions

L.1.33 There are assumptions and dimensions that affect CSO control and overall system performance. These are set parameters which form the basis for the Thames Tideway Tunnel performance evaluation and are summarised as follows:

a. STW capacity improvement (expansion) at Beckton STW to 27m^3/s and at Crossness STW to 12.9m^3/s

b. completion of the 7.2m internal diameter Lee Tunnel from Abbey Mills Pumping Station to Beckton STW and to the Tideway CSO

c. creation of a new CSO at Beckton: the Tideway CSO

d. expansion of pumping capacity of the Tideway Pumping Station to 12.2m^3/s

e. Thames Tideway Tunnel, Lee Tunnel and ancillary tunnels and shafts storage volume of about 1.57 million m^3 at the tunnel completely full level of 0mAOD

f. discharges from the Abbey Mills CSO at an estimated frequency of, on average, once every ten years based on the long term annual series rainfall events selected from 1970 to 2011

g. evaluations of system annual performance based on the Typical Year of October 1979 to September 1980

h. evaluation of system performance based on projected 2020s population

L.1.34 More specific modelling assumptions are also discussed in Catchment modelling methodology and assumptions and Water quality modelling methodology and assumptions.

Proposed method of CSO control and overall plan

L.1.35 Vol 3 Table L.2 provides an overview of how each of the 34 unsatisfactory CSO is proposed to be controlled.

Vol 3 Table L.2 Method of flow control for each CSO

CSO ref	Combined sewer overflow	Method of overflow control
CS01X	Acton Storm Relief	Interception
CS02X	Stamford Brook Storm Relief	Control measures at other CSOs would indirectly control this CSO
CS03X	North West Storm Relief	Hammersmith Pumping Station interception and pumping station operation changes would indirectly control this CSO

CSO ref	Combined sewer overflow	Method of overflow control
CS04X	Hammersmith Pumping Station	Upstream interception and pumping station operation changes
CS05X	West Putney Storm Relief	Interception
CS06X	Putney Bridge	Interception
CS07A CS07B	Frogmore Storm Relief – Bell Lane Creek Frogmore Storm Relief – Buckhold Road	Interception
CS08A CS08B	Jews Row Wandle Valley Storm Relief Jews Row Falconbrook Storm Relief	Modifications already in place so CSO is satisfactorily controlled
CS09X	Falconbrook Pumping Station	Upstream interception and pumping station operation changes
CS10X	Lots Road Pumping Station	Downstream interception
CS11X	Church Street	Controlled indirectly by nLL1 sewer connection relief works at Ranelagh
CS12X	Queen Street	Controlled indirectly by nLL1 sewer connection relief works at Ranelagh
CS13A CS13B	Smith Street – Main Line Smith Street – Storm Relief	Controlled indirectly by nLL1 sewer connection relief works at Ranelagh
CS14X	Ranelagh	Interception and additional nLL1 sewer connection relief
CS15X	Western Pumping Station	Controlled indirectly by nLL1 sewer connection relief works at Ranelagh and Western Pumping Station operational control changes to stop pumping at higher flows and instigate the relief at the nLL1 connection weir to Ranelagh.
CS16X	Heathwall Pumping Station	Downstream interception
CS17X	South West Storm Relief	Interception
CS18X	Kings Scholars Pond	Controlled indirectly by sewer connection relief works at other

CSO ref	Combined sewer overflow	Method of overflow control
		CSOs* and Western Pumping Station operational control changes to limit pass-forward flow from Western Pumping Station to $3m^3/s$.
CS19X	Clapham Storm Relief	Interception
CS20X	Brixton Storm Relief	Interception
CS21X	Grosvenor Ditch	Controlled indirectly by sewer connection relief works at other CSOs*
CS22X	Regent Street	Interception and additional sewer connection relief
CS23X	Northumberland Street	Controlled indirectly by sewer connection relief works at other CSOs* and change to outfall weir level.
CS24X	Savoy Street	Controlled indirectly by sewer connection relief works at other CSOs* and adjustment to relief weir levels to divert more flow to nLL2.
CS25X	Norfolk Street	Controlled indirectly by sewer connection relief works at other CSOs*. However outfall believed blocked hence no CSO possible.
CS26X	Essex Street	Controlled indirectly by sewer connection relief works at other CSOs*.
CS27X	Fleet Main	Interception and additional nLL1 sewer connection relief
CS28X	Shad Thames Pumping Station	Pumping station modifications and operational changes.
CS29X	North East Storm Relief	Interception
CS30X	Holloway Storm Relief	Local modifications
CS31X	Earl Pumping Station	Upstream interception
CS32X	Deptford Storm Relief	Interception

CSO ref	Combined sewer overflow	Method of overflow control
CS33X	Greenwich Pumping Station	Upstream interception and pumping station operation changes to stop pumping at higher flows and instigate relief to the tunnel.
CS34X	Charlton Storm Relief	Controlled by operation changes at Greenwich Pumping Station and improvements at Crossness STW

** The additional sewer connection relief would be connections into the northern Low Level Sewer No.1 at Ranelagh, Regent Street and Fleet Main CSOs*

L.1.36 Vol 3 Plate L.4, Vol 3 Plate L.5 and Vol 3 Plate L.6 show a general schematic layout of the tunnel alignment and identification of CSO locations. Vol 3 Plate L.7 shows the general arrangement plan of CSO connections to the London Tideway Tunnels.

L.1.37 These figures show the arrangement of CSOs and help to define the system model, particularly naming conventions and sizes of main features such as shaft and tunnel diameters.

Vol 3 Plate L.4 System control schematic – CSO key

Index of Intercepted CSOs

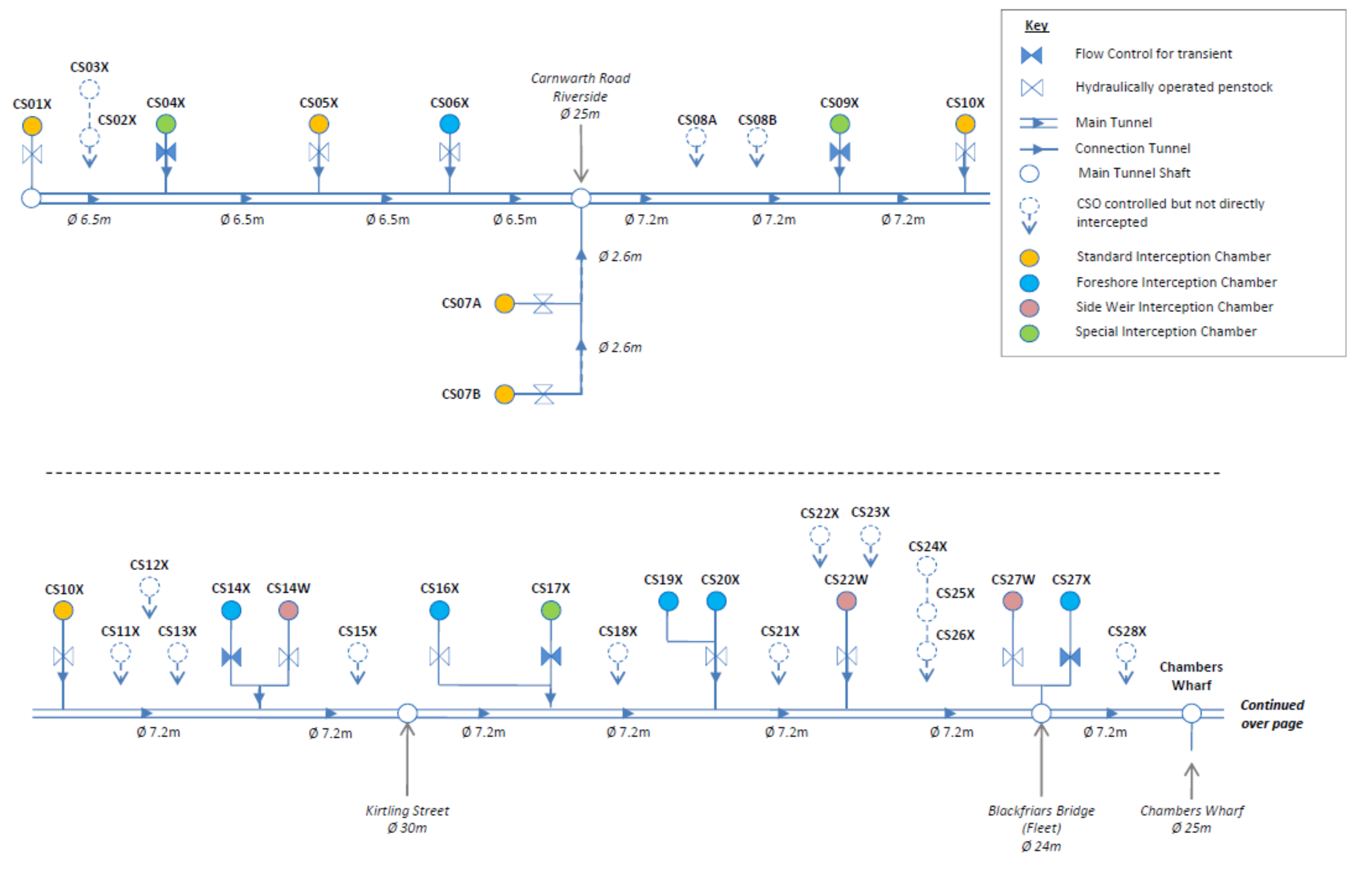
	CSO ID	CSO Name
Orange	CS01X	Acton Storm Relief
Green	CS04X	Hammersmith Pumping Station
Orange	CS05X	West Putney Storm Relief
Blue	CS06X	Putney Bridge
Orange	CS07A	Frogmore Storm Relief - Bell Lane
Orange	CS07B	Frogmore Storm Relief - Buckhold Road
Green	CS09X	Falconbrook Pumping Station
Orange	CS10X	Lots Road Pumping Station
Blue	CS14X	Ranelagh - CSO interception control
Pink	CS14W	Ranelagh - Low Level 1 interception control
Blue	CS16X	Heathwall Pumping Station
Green	CS17X	South West Storm Relief
Blue	CS19X	Clapham
Blue	CS20X	Brixton
Pink	CS22W	Low Level 1 interception control (near Northumberland / Regent St)
Blue	CS27X	Fleet Main - CSO interception control
Pink	CS27W	Fleet Main - Low Level 1 interception control
Blue	CS29X	North East Storm Relief
Orange	CS31X	Earl Pumping Station
Orange	CS32X	Deptford Storm Relief
Green	CS33X	Greenwich Pumping Station
Green	CS35X	Abbey Mills Pumping Station from Stations A & F

Index of CSOs that are controlled but not intercepted

CSO ID	CSO Name
CS02X	Stamford Brook
CS03X	North West Storm Relief
CS08A	Jews Row - Wandle Valley Storm Relief
CS08B	Jews Row - Falconbrook Storm Relief
CS11X	Church Street
CS12X	Queen Street
CS13X	Smith Street
CS15X	Western Pumping Station
CS18X	King's Scholar's Pond
CS21X	Grosvenor Ditch
CS22X	Regent Street
CS23X	Northumberland
CS24X	Savoy Street
CS25X	Norfolk Street
CS26X	Essex Street
CS28X	Shad Thames Pumping Station
CS30X	Holloway Storm Relief
CS34X	Charlton

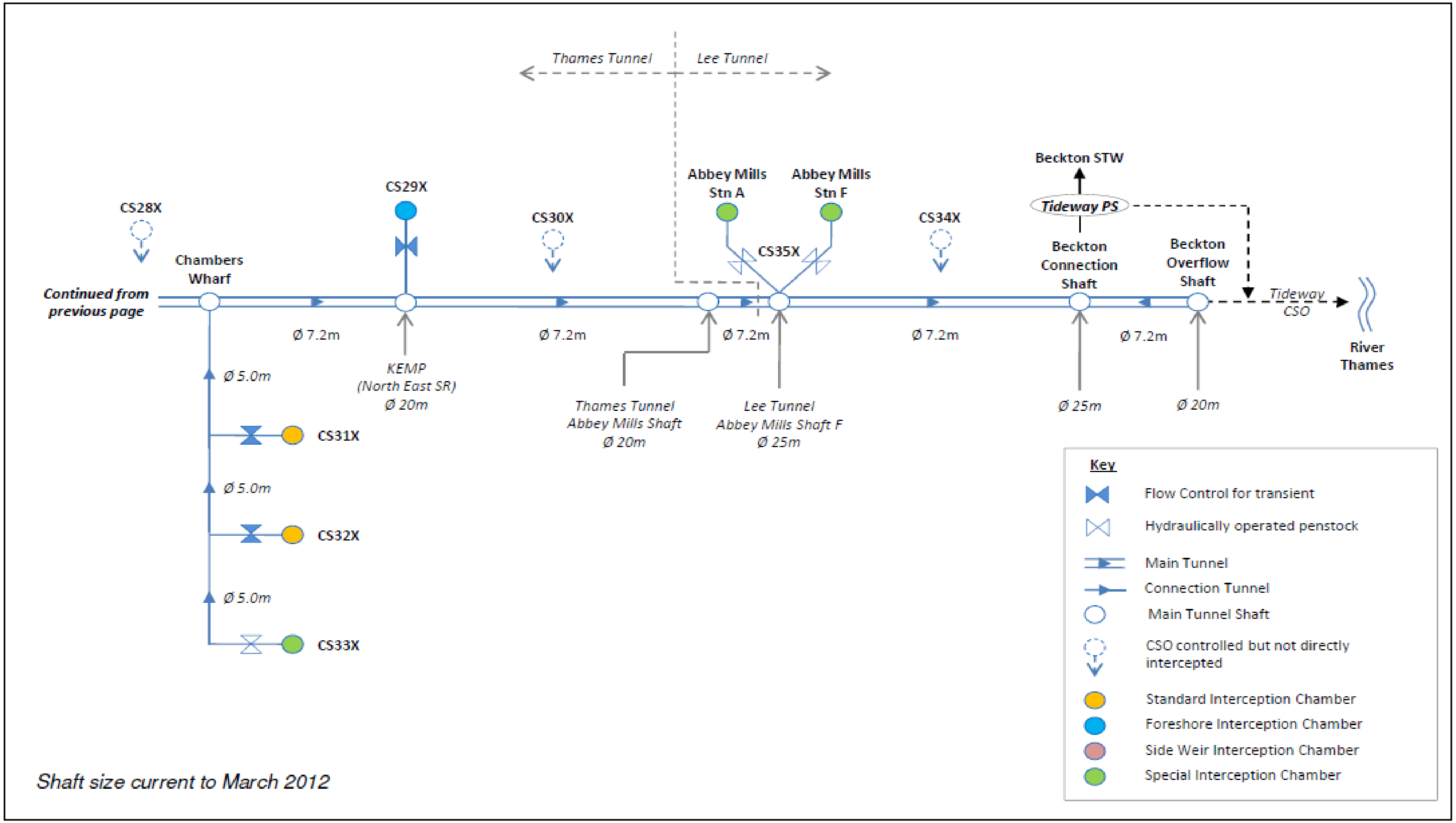
	Interception Chamber Type
Orange	Standard Interception Chamber
Blue	Foreshore Interception Chamber
Pink	Side Weir Interception Chamber
Green	Special Interception Chamber

Vol 3 Plate L.5 System control schematic – western reaches

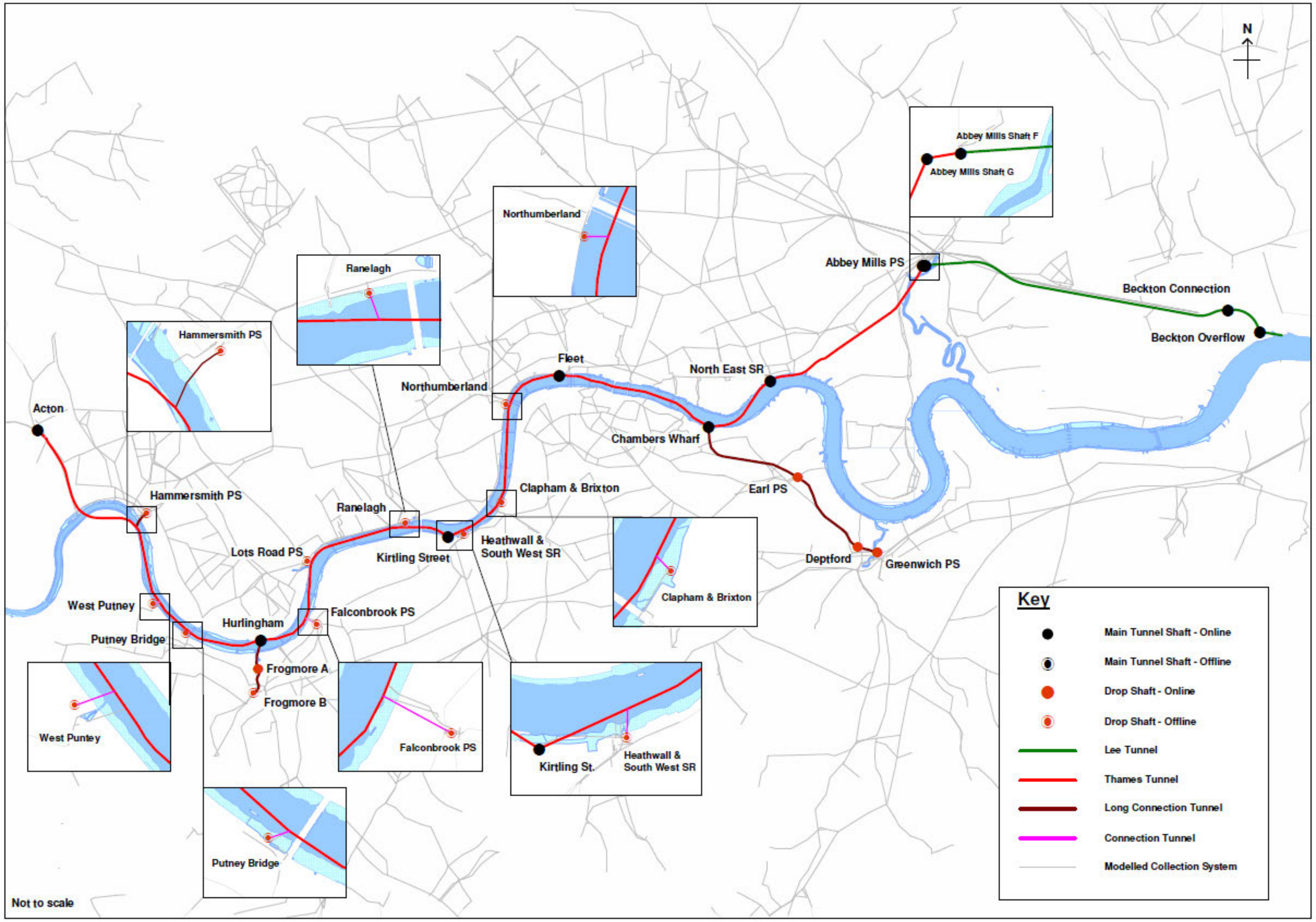


Shaft size current to March 2012

Vol 3 Plate L.6 System control schematic – eastern reaches



Vol 3 Plate L.7 London Tideway Tunnels – General Plan



Catchment modelling methodology and assumptions

L.1.38 Sewer catchment models are used to determine how flows are transported through the collection system (sewers) and delivered to the STWs. Flows are derived from established wastewater generated from domestic and non-domestic (commercial and trade) flows, rainfall-runoff processes and infiltration[ii].

L.1.39 The sewer catchment model for the Beckton STW and Crossness STW catchments provided the platform for compliance and design flow analysis of the proposed Thames Tideway Tunnel and the operational strategy of the overall sewerage system.

L.1.40 The Thames Water sewer model is an InfoWorks macro (planning) model representation of the Beckton and Crossness catchment main trunk sewer system. It does not contain all the local sewers, but includes storage compensation for the missing local sewers. The catchment model has been used for the Thames Tideway Tunnel project since 2008 and in the TTSS.

L.1.41 No additional calibration of the model has been carried out for the project: however internal audits have been carried out on impermeable area, connected area and population contribution, and any misrepresentations revised. Additional findings from sewer line and level surveys undertaken by the project have also been used to update the Beckton and Crossness sewer catchment model.

L.1.42 The sewer catchment model simulates the dry weather and storm response of the catchment to rainfall. Using the model, estimations of CSO discharge frequency, duration and volume can be made. In addition flows to the STWs, the design flows for hydraulic structures and alternative operational strategies can be evaluated.

L.1.43 Key major inputs to the sewer catchment model are the rainfall events and pumping stations capacity. Over 300 rainfall events including design storms have been simulated. These rainfall events have been selected from the 1970 to 2011 rainfall record.

L.1.44 The sewer catchment model has assumed installed pumping capacity at all pumping stations i.e. all pumps installed are operating. This maximises delivery of flow to the Tidal Thames and the Lee Tunnel and Thames Tideway Tunnel for design purposes.

L.1.45 The catchment storm response and CSO performances have been assessed for a standard set of rainfall events established for this project. The rainfall data sets discussed in this report are outlined in Vol 3 Table L.4.

L.1.46 The Thames Tideway Tunnel CSO performance is gauged against the Typical Year which represents the most "typical" 12 month period of rainfall observed between 1970 and 2011.

[ii] Infiltration occurs through imperfections in the sewer system (e.g. cracks). This can be a) dry weather base-flow which is the night time flow into the sewer system from sources such as ground water table or adjacent leaking clean water system which can vary seasonally or b) rainfall related infiltration from surrounding permeable area.

L.1.47 As explained in the description of existing conditions section of the appendix (para L.1.18), the Typical Year was established during the TTSS and covers the water year period of 1st October 1979 to 30th September 1980, and is a leap year.

Vol 3 Table L.3 Thames Tideway Tunnel Project Rainfall Event Data Set

Criteria / Use	Rainfall Event Data Set	Commentary
Design of hydraulic structures: interception chamber, vortex and drop shafts. Transient analysis of tunnel alignment and control strategy.	15-year Flood Estimation Handbook (FEH) design storm, 120-minute storm across the whole 550km^2 Beckton and Crossness catchment with no area reduction.	This is equivalent to a 1 in 35 year, 120-minute storm with an area reduction of 0.76 for the 550km^2 drainage area. No area reduction was applied to ensure the peak flows arriving at individual interception locations is also representative of a 15 year local storm. The 120-minute storm is the critical duration storm established for the CSOs across the catchment.
Compliance to the UWWTD - Representative Year Compliance to the Water Framework Directive – Representative Year	Typical Year – October 1979 to September 1980	The Typical Year represents the most "typical" 12 month period of rainfall observed between 1970 and 2011 and covers the water year period of 1st October 1979 to 30th September 1980 (the 1980 water year).
Compliance to bespoke dissolved oxygen standards set for the Tidal Thames during the TTSS	Compliance Test Procedure (CTP) Summer Events 242 Summer (April to October) rainfall events	Selected summer storm events from 1970 to 2010 which are large enough to have an impact on dissolved oxygen levels in the Tidal Thames.

Criteria / Use	Rainfall Event Data Set	Commentary
Demonstrating compliance to the UWWTD – Long Term Series	Long Term Annual Series Rainfall comprising: 242 large events 79 CTP events Total of 321 events: the merged series	242 events selected from 1970 to 2011representing large summer and winter storm events that would likely fill the tunnel. These are selected using weighted average rainfall depth data at hourly intervals for the 48 rain gauges covering the Beckton and Crossness catchment. This has been reconciled with CTP events which were not included in the 242 event series, to produce a merged series comprising 321 events.

L.1.48 As part of the Thames Tideway Tunnel project, the Beckton and Crossness catchment model components have been continuously updated with tunnel alignment and interception design revisions as part of the optimisation process for CSO control. More than 100 tunnel variations have been simulated between 2008 and 2012.

L.1.49 For the purposes of modelling to demonstrate levels of CSO control and performance for the existing system, the STW Improvements and Lee Tunnel and the Thames Tideway Tunnel, it was necessary to assume that the operating state of the system pumping stations and diversion structure settings within the local sewer system remained unchanged.

L.1.50 All rainfall simulation events outlined in Vol 3 Table L.3 have been carried out without the presence of tides with the exception of the CTP[iii] summer event series. The presence of tide gates at the CSO outfalls will reduce or prevent CSO discharge along the foreshore when the tide level is higher than water level in the sewer. To maximise the CSO flow at the outfalls, tides have not been simulated, allowing for a free discharge at each CSO outfall.

L.1.51 The sewer catchment model is considered appropriate for the purpose of demonstrating the impact on CSO control achieved by the completion of the Thames Tideway Tunnel and the sewage flows conveyed to the STWs. It is also appropriate for evaluating alternative arrangements and control options, demonstrating compliance with the relevant legislation and allowing comparisons of CSO control performance to the base case i.e. the STW improvements and Lee Tunnel.

Water quality modelling methodology and assumptions

L.1.52 The QUESTS water quality model has been used to determine how the dissolved oxygen in the Tidal Thames would change under different CSO and STW discharges that are reflective of the project impacts upon the system.

L.1.53 The QUESTS water quality model was developed by the EA and WRc in the early 2000s as part of the TTSS. The model was verified and calibrated against monitored events that showed significant depression in the dissolved oxygen profile along the Tidal Thames between Teddington and downstream of Beckton/Crossness STWs. Events included those with rainfall over the catchment which produced high flows at the STWs and CSO discharges.

L.1.54 The CTP was developed to select rainfall events from the period of record that would stress the river, particularly during elevated STW discharges and CSO discharges. The CTP procedure defines critical summer rainfall events and currently 242 events from the 1970 to 2010 summer period have been selected for simulation.

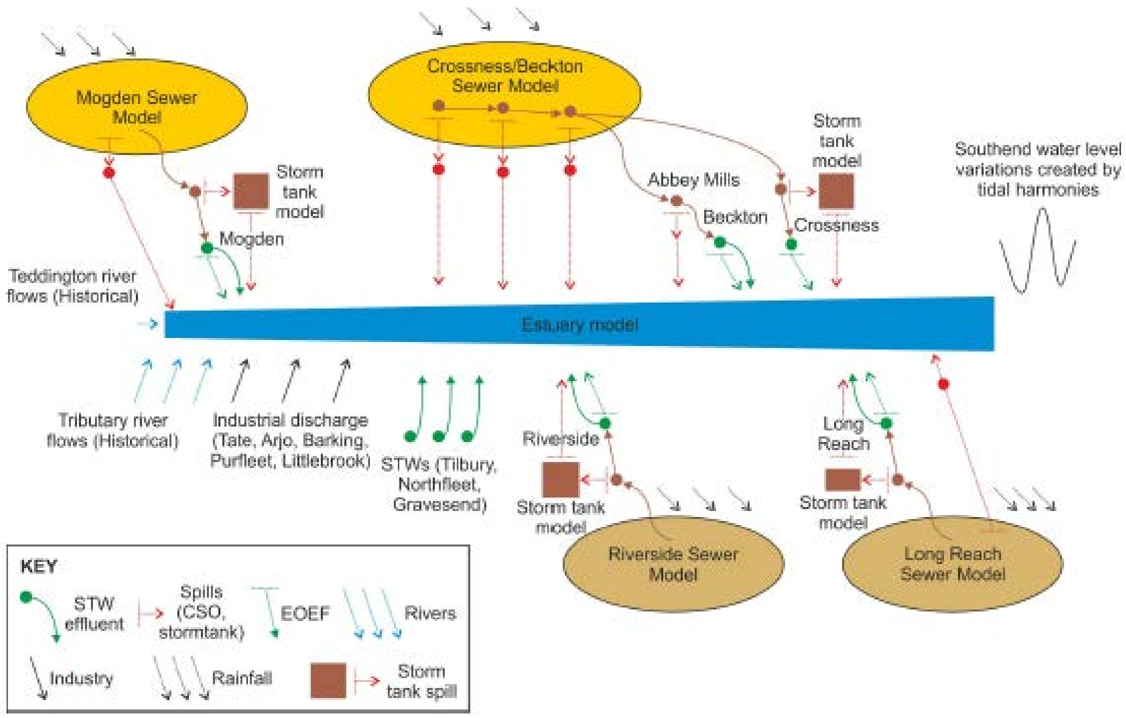
L.1.55 Water quality modelling of the Tidal Thames has been undertaken for the CTP events to evaluate alternative tunnel alignment performances and scenarios for compliance against the dissolved oxygen standards

[iii] The methodology outlined for the CTP includes simulation with historical tides to represent the ebb and flood tides in the estuary water quality model.

set by the TTSS (see Performance: Compliance to Dissolve Oxygen Standards section of this appendix).

L.1.56 The water quality model has various inputs. The sewer catchment model provides treated effluent flow data from the 5 main STWs (Beckton, Crossness, Mogden, Riverside and Long Reach) and discharges from CSOs into the QUESTS model. Historical gauged data has been used to represent the flows from river tributaries into the Tidal Thames. The schematic for the overall water quality modelling framework is illustrated in Vol 3 Plate L.11.

Vol 3 Plate L.8 Schematic of Overall Water Quality Modelling Framework



L.1.57 Parameters such as river temperature, tides and fresh water inflow have been kept consistent between scenarios representing the existing and 2020s conditions.

L.1.58 Standard default InfoWorks water quality parameters have been used in all the model simulations. The simulated results for CSO discharges (flows), CSO water quality and STW effluent flows have been used in the QUESTS water quality modelling.

L.1.59 The use of the QUESTS model is considered appropriate to inform decisions on option selection on a comparative basis and confirmation that the environmental benefits (dissolved oxygen standards) would be met.

Thames Tideway Tunnel performance objectives and operating strategy

Introduction

L.1.60 This section provides details of the system performance objective and the corresponding operating strategy proposed for the Thames Tideway Tunnel with the completion of the STW Improvements and the Lee Tunnel.

Performance objectives

L.1.61 The Thames Tideway Tunnel CSO performance has evolved from the TTSS through detailed evaluation of the alternative tunnel alignments, which have been developed since 2008. However, through the evaluation of alternative tunnel alignments, the general performance objectives have remained consistent and are discussed in this section.

L.1.62 The performance objectives of the Thames Tideway Tunnel are to achieve the following control performance targets:

a. Based on the interpretation of Defra, meet the requirements of the UWWTD and to assist in meeting WFD goals.

b. Comply with the four bespoke dissolved oxygen standards (see Vol 3 Table L.9) set to protect the ecology of the Tidal Thames habitat against adverse effects from low dissolved oxygen levels due to STW discharges and intermittent CSO discharges.

c. The operation of the tunnel system would aid in compliance with the WFD requirements. WFD requirements are percentile requirements that are more applicable to continuous discharges: hence the London Tideway Improvements project of which the Thames Tideway Tunnel is an important component.

d. Following development of the project: a general annual target of no more than 4 events at controlled CSOs during the Typical Year (October 1979 to September 1980).

e. Following development of the project: a residual annual CSO spill volume of between 2.1 to 2.6 million m^3 in the Typical Year.

f. Following development of the project: an overall greater than 90% volume capture from baseline conditions.

g. Control of spills from Abbey Mills Pumping Station to on average once every ten years.

Operating strategy

L.1.63 In setting the project operating strategy, the following operating criteria were considered:

a. The tunnel system operating strategy has been developed to meet the CSO Performance Target, set out in the performance objectives section above, while maintaining controlled water levels in the tunnel to 0mAOD[iv] or lower.

b. Fundamental to the operating strategy is maximising flows to the Beckton and Crossness STWs and maintaining storage capacity in the tunnel system to meet the 1 in 10 year control of CSO discharge at the Abbey Mills Pumping Station CSO.

c. The tunnel system would comprise the Thames Tideway Tunnel and the Lee Tunnel. This combination of tunnels would be known as the London Tideway Tunnels when completed.

d. The Crossness and Beckton STWs, the existing sewer system and the London Tideway Tunnels would form a single system. Each component of the system is mutually dependent.

e. Inflow control during large storm events is necessary to limit the potential for adverse hydraulic and pneumatic conditions within the tunnel system.

f. Simple rules and control systems with limited rainfall forecasting and operator decisions would form the basis of the operating strategy.

L.1.64 To control Abbey Mills Pumping Station CSO discharges to an average of 1 in 10 year (para. L.1.62g), it is necessary to reserve storage in the London Tideway Tunnels to capture flow from Abbey Mills Pumping Station. This would be done by redirecting CSOs along the Tidal Thames to the river before the tunnel system is completely full and by starting bypass pumping at the Tideway Pumping Station to the Tideway CSO.

L.1.65 Bypass pumping would occur when the tunnel system is at least 79% full (see Vol 3 Table L.5 for volume percentages). This control of CSO discharge at Abbey Mills Pumping Station results in some storage being left unused during the Typical Year simulation for the larger storm events.

L.1.66 To minimise the risk of adverse transient and pneumatic conditions in the tunnel system due to high flows and differential filling of the tunnel from the disperse locations of flows entering the tunnel, selective inflow control during large storm events is required.

L.1.67 The inflow control strategy would be either to shut the hydraulic penstocks at specific sites when pre-set peak flow targets (see Vol 3 Table L.4) are reached or in anticipation of larger storms move the penstocks to pre-set positions. The peak flows are generally equivalent

[iv] 0mAOD (above ordinance datum) is equivalent to 100mATD (above tunnel datum). Flood defences along the river vary and ranges from 5 to 7 mAOD.

to a 1 in 5 year design storm peak flow, and therefore do not affect a Typical Year performance.

L.1.68 Balancing the operational criteria outlined above, the following system operating strategy is proposed. All results presented in this report are based on this proposed operating strategy:

a. The operating strategy for the London Tideway Tunnels is a two mode operation comprising wet weather operation and extreme wet weather operation. The switch from wet weather to extreme wet weather would occur when the weighted forecast of rainfall across the whole catchment is 22mm or more in the next 24 hours. The forecast is proposed to be obtained from the Met Office twice per day and acted upon by the system operators.

b. Each operating mode is set with predetermined target water levels (in order of operation) to:

   i divert CSO discharges along the Tidal Thames from the tunnel to the river,

   ii start bypass pumping to the Tideway CSO

   iii divert flows from the Abbey Mills Pumping Station CSO to the Channelsea River (and then to the River Lee) when the tunnel system is nearing full capacity at 99% storage utilised (approximately -3mAOD)

c. The target water level is nominally set in the sewer catchment model as the measured water level at the Chambers Wharf site. However, for operational control, this would be at multiple shaft locations to provide assurance of obtaining accurate water levels in the prototype system.

L.1.69 Transient inflow control has been set at eight CSO sites, and would limit flows to the tunnel to set flow targets as outlined in Vol 3 Table L.4. The inflow control is proposed to operate only during the extreme wet weather mode of operation. This would allow local extreme storms to be captured by the tunnel system.

L.1.70 Vol 3 Table L.4 shows the eight sites with proposed flow control and Vol 3 Table L.5 summarises the pre-set target water levels and the corresponding tunnel usage for the two operating modes of wet weather and extreme wet weather.

L.1.71 Vol 3 Plate L.12 shows the tunnel storage curve and storage utilisation under the wet weather and extreme wet weather operating modes. At 0mAOD, the total tunnel storage[v] of the London Tideway Tunnels is approximately 1.57million m^3.

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[v] This includes a 20% reduction in shaft volume to account for internal structures within the shaft.

Vol 3 Table L.4 Proposed Transient Flow Control Sites

CSO Site	Site Name	Flow control limit (m^3/s)
Hammersmith Pumping Station	Hammersmith Pumping Station	40
Ranelagh	Chelsea Embankment Foreshore	15
South West Storm Relief	Heathwall Pumping Station	25
Fleet Main	Blackfriars Bridge Foreshore	30
North East Storm Relief	King Edward Memorial Park Foreshore	25
Deptford Storm Relief	Deptford Church Street	25
Earl Pumping Station	Earl Pumping Station	20
Falconbrook Pumping Station	Falconbrook Pumping Station	12

L.1.72 In the Typical Year rainfall series, the extreme event setting would occur once. For the recorded rainfall for 1970 to 2010 modelled in the long term series comprising 321 rainfall events (see Vol 3 Table L.3), there are 60 events that met the rainfall depth threshold for extreme events.

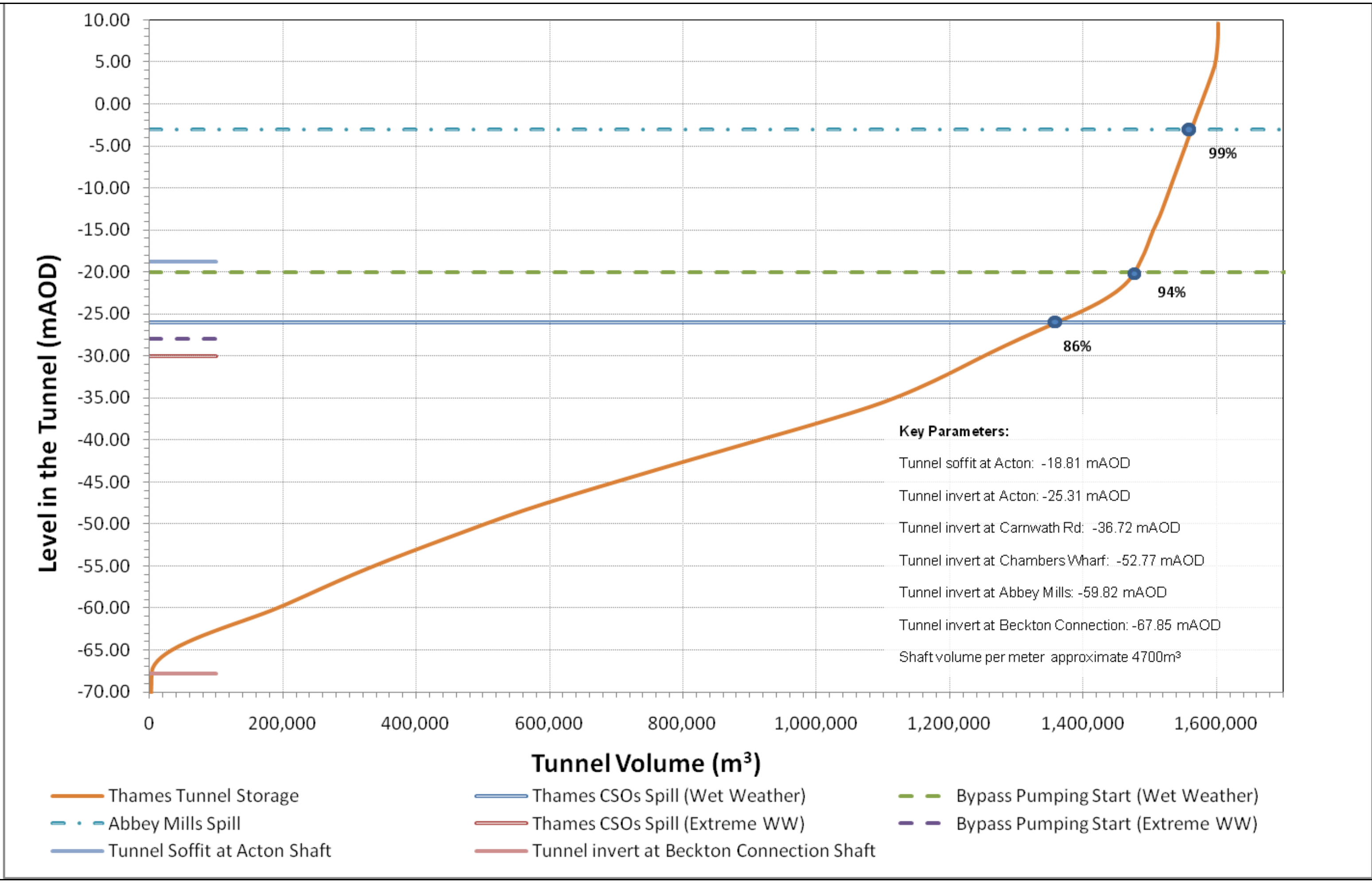
L.1.73 The operating strategy set out above has been used to demonstrate the Thames Tideway Tunnel system performance against the annual and long term rainfall series. This is described in more detail in the Thames Tideway Tunnel overview and modelling methodology section.

Vol 3 Table L.5 Proposed Control Target Water Levels for Wet Weather and Extreme Wet Weather Conditions

		Wet Weather[1]			Extreme Wet Weather[1]		
		Thames CSO[2.]	Bypass Pumping	Abbey Mills	Thames CSO[3.]	Bypass Pumping	Abbey Mills
Level at Chambers Wharf (mAOD)	Shut Tunnel Penstocks, Start Bypass Pumping	-26	-20	-3	-30	-28	-3
	Reopen Tunnel Penstocks, Stop Bypass Pumping	-41	-24	-10	-41	-32	-10
Tunnel Volume Used/ Remaining (m3)	Shut Tunnel Penstocks, Start Bypass Pumping	1,360,000	1,477,000	1,562,000	1,250,000	1,303,000	1,562,000
	Reopen Tunnel Penstocks, Stop Bypass Pumping	887,000	1,414,000	1,530,000	887,000	1,201,000	1,530,000
Percentage of Tunnel Volume Used (%)	Shut Tunnel Penstocks, Start Bypass Pumping	86%	94%	99%	79%	83%	99%
	Reopen Tunnel Penstocks, Stop Bypass Pumping	56%	90%	97%	56%	76%	97%

1.The switch from wet weather to extreme wet weather would occur when the weighted forecast of rainfall across the whole catchment is 22mm or more in the next 24 hours.
2. Except Acton CSO, West Putney CSO and Putney Bridge CSO, divert to the River at -10mAOD
3. Except Acton CSO, divert to the River at -10mAOD for additional protection against on-site flooding during high tides. Includes transient flow control at eight CSO sites to limit flows to pre-set targets .

Vol 3 Plate L.9 Modelled Storage Curve and Tunnel Utilisation under Wet Weather and Extreme Wet Weather Conditions



Thames Tideway Tunnel CSO control performance

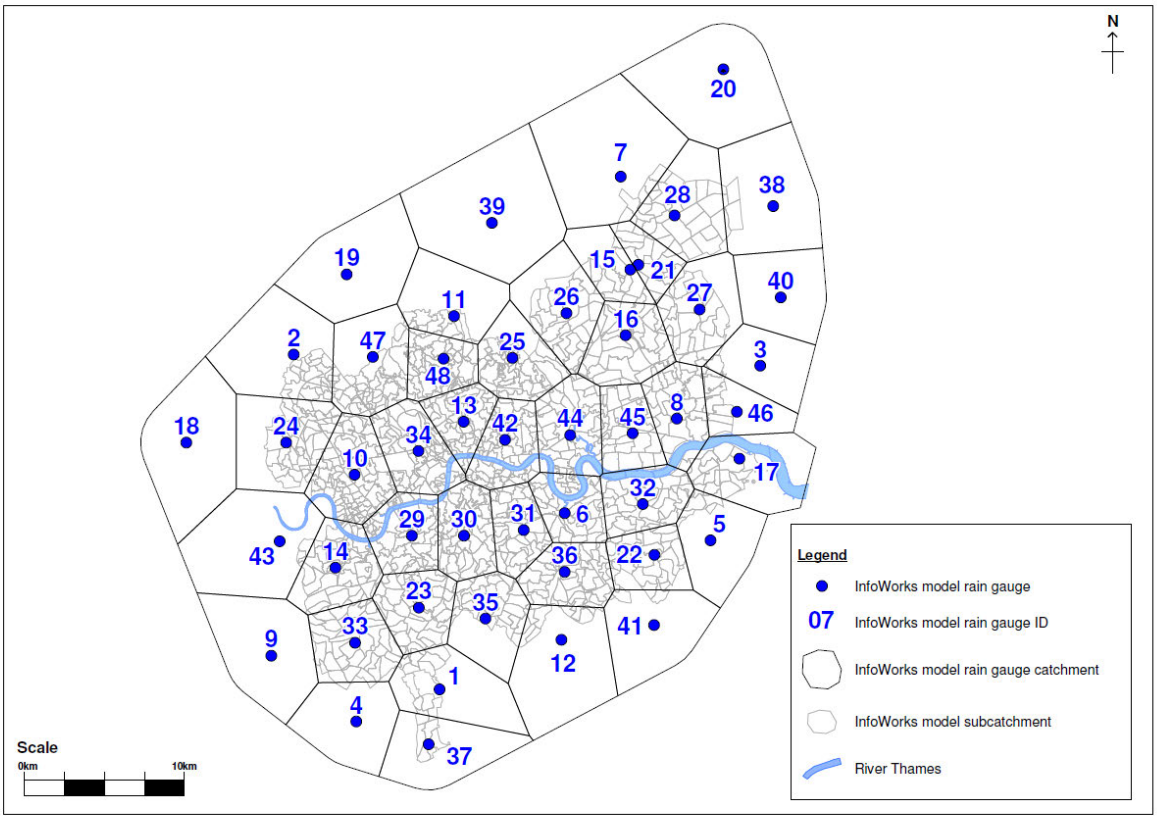
Introduction

L.1.74 This section summarises the system performance levels based on modelling simulations for the Thames Tideway Tunnel with the completion of the STW Improvements and the Lee Tunnel.

Performance: Typical Year

L.1.75 As explained in the description of existing conditions section of this appendix, the Typical Year is a single water year from October 1979 to September 1980 selected from the 1970 to 2011 rainfall records and best represents the average rainfall over the Beckton and Crossness catchment. The rainfall record includes 48 rainfall sites to represent the variable spatial distribution of rainfall across the catchment as shown in Vol 3 Plate L.13.

Vol 3 Plate L.10 Spatial Rainfall Distribution across Beckton and Crossness



L.1.76 Vol 3 Plate L.14, Vol 3 Plate L.15 and Vol 3 Table L.6 provide the simulated annual volume, frequency and duration of discharges at each modelled CSO location along the Tidal Thames in the Typical Year for the following three scenarios:

a. 2006 existing conditions and existing STW capacities.

b. 2020s conditions with upgraded STW improvements, increased population to 2020s and the Lee Tunnel.

c. 2020s conditions with the upgraded STW improvements, increased population to 2020s, the Lee Tunnel and the Thames Tideway Tunnel.

L.1.77 For each river reach, the total discharge volume and maximum number and duration of CSO discharges from all modelled CSOs in that reach is reported.

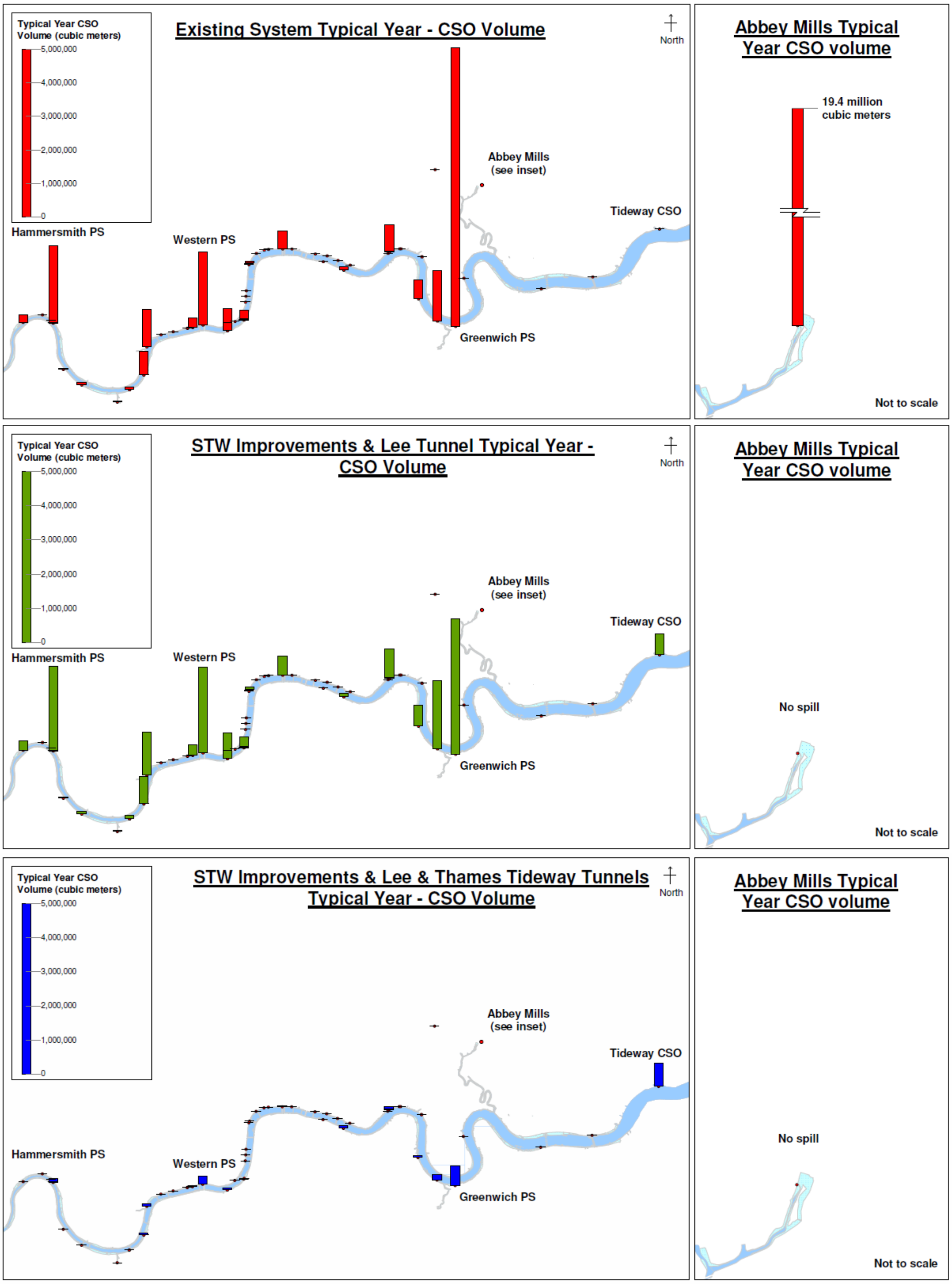
L.1.78 As explained in the Catchment modelling methodology and assumptions section, all simulations for the Typical Year have been simulated without tidal influence to maximise the flows and discharges at each CSO to the river. In this Typical Year rainfall series, the extreme event mode of operation is modelled once.

L.1.79 A minimum CSO discharge volume of $50m^3$ has been agreed in consultation with the EA. All simulated CSO discharges of less than $50m^3$ are therefore discarded and not reported as an ‘event’.

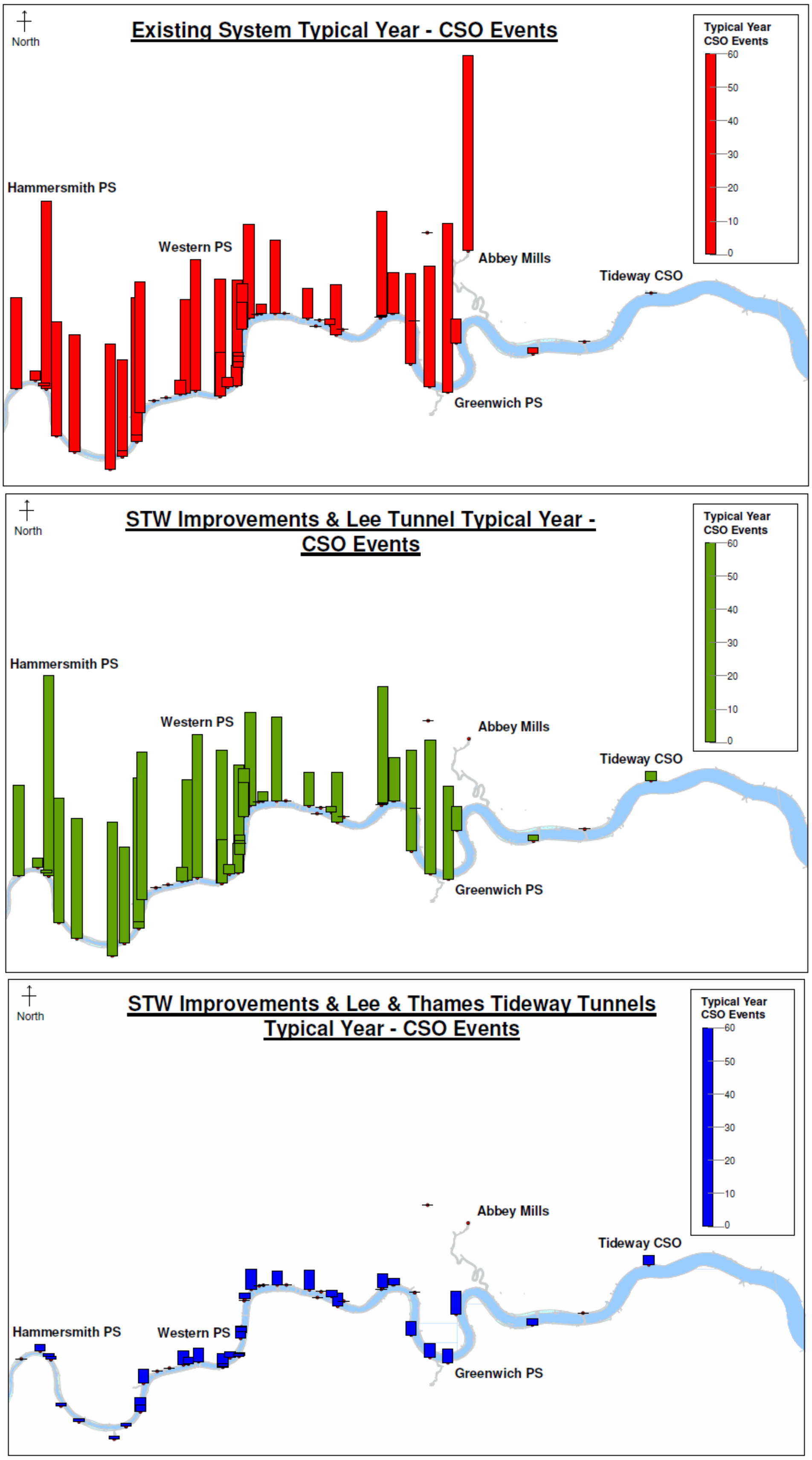
L.1.80 A spill event as defined in the tables and figures in this report is defined by 24 hours of no CSO discharge from the end of the one spill to the start of the next spill event (generally considered as the inter-event time).

L.1.81 Vol 3 Table L.7 provides the CSO event volume and duration for each modelled CSO during the four residual CSO events in the Typical Year with the Thames Tideway Tunnel completed.

Vol 3 Plate L.11 Typical Year CSO Volume Performance along the Tidal Thames



Vol 3 Plate L.12 Typical Year CSO Event Performance along the Tidal Thames



Vol 3 Table L.6 Comparison of Typical Year Annual CSO Performance

LTT ID	EA Cat	CSO Name	Existing System & Existing STW 2006			STW Improvements and Lee Tunnel 2020s			STW Improvements, Lee Tunnel and Thames Tideway Tunnel 2020s		
			Total Volume (m^3) [a/b.]	No. of Spills [a.]	Spill Duration (hrs) [a.]	Total Volume (m^3) [a/b.]	No. of Spills [a.]	Spill Duration (hrs) [a.]	Total Volume (m^3) [a/b.]	No. of Spills [a.]	Spill Duration (hrs) [a.]
CS01X	Cat 1	Acton Storm Relief	312,000	29	152	178,000	17	84	0	0	0
CS02X	Cat 2	Stamford Brook Storm Relief	500	2	2	300	2	2	400	2	2
CS05X	Cat 1	West Putney Storm Relief	35,000	30	118	37,000	31	123	1,500	1	4
CS37X	Cat 3	LL1 Brook Green	0	0	0	0	0	0	0	0	0
CS03X	Cat 2	North West Storm Relief	2,800	1	1	3,900	1	1	600	1	1
CS04X	Cat 1	Hammersmith Pumping Station	2,210,000	51	650	2,350,000	54	698	104,000	1-3	16
CS06X	Cat 1	Putney Bridge	68,000	33	107	71,000	33	110	1,600	1	3
		Upstream Putney Bridge Total / Maximum [b/c.]	**2,630,000**	**51**	**650**	**2,640,000**	**54**	**698**	**108,000**	**3**	**16**
CS07A	Cat 1	Frogmore Storm Relief - Bell Lane	18,000	32	136	19,000	32	141	500	1	4
CS07B	Cat 1	Frogmore Storm Relief - Buckhold Road	86,000	21	72	89,000	21	72	1,500	1	3
CS08A	Cat 1	Jews Row - Wandle Valley Storm Relief	300	1	2	3,000	2	7	0	0	0
CS08B	Cat 3	Jews Row - Falcon Brook Storm Relief	7,400	2	7	7,500	2	7	7,600	2	7
CS09X	Cat 1	Falcon Brook Pumping Station	709,000	42	267	780,000	42	291	45,000	4	22
CS10X	Cat 1	Lots Rd Pumping Station	1,140,000	38	346	1,260,000	42	407	92,000	4	31
CS11X	Cat 2	Church Street	0	0	0	0	0	0	0	0	0
CS12X	Cat 2	Queen Street	0	0	0	0	0	0	0	0	0
CS13A	Cat 2	Smith Street Main Line	1,400	4	8	1,500	4	8	1,500	4	8
CS13B	Cat 2	Smith Street Relief	0	0	0	0	0	0	0	0	0
CS14X	Cat 1	Ranelagh	283,000	26	142	306,000	29	157	19,000	2	10
CS15X	Cat 1	Western Pumping Station	2,050,000	37	200	2,320,000	41	228	246,000	4	24
CS17X	Cat 1	South West Storm Relief	228,000	13	39	239,000	13	40	3,900	1	3
CS16X	Cat 1	Heathwall Pumping Station	655,000	34	200	748,000	39	248	63,000	4	26
CS18X	Cat 2	Kings Scholars Pond Storm Relief	1,400	3	5	1,800	3	5	500	2	3
CS19X	Cat 1	Clapham Storm Relief	13,000	6	14	14,000	6	15	7,900	1	5
CS20X	Cat 1	Brixton Storm Relief	265,000	29	133	279,000	31	141	5,700	1	4
CS21X	Cat 2	Grosvenor Ditch	2,600	3	7	3,000	4	9	600	2	4
CS39X	Cat 3	Horseferry	3,400	3	7	3,800	3	7	300	1	2
CS40X	Cat 3	Wood Street	0	0	0	0	0	0	0	0	0
CS22X	Cat 1	Regent Street	22,000	5	13	26,000	10	21	0	0	0
CS23X	Cat 1	Northumberland Street	72,000	13	34	88,000	14	43	300	1	2
CS24X	Cat 2	Savoy Street	8,500	20	51	8,600	20	51	800	4	7
CS25X	Cat 2	Norfolk Street	0	0	0	0	0	0	0	0	0
CS26X	Cat 2	Essex Street	2,100	3	6	2,300	3	6	0	0	0
CS27X	Cat 1	Fleet Main	521,000	21	75	571,000	23	83	37,000	4	14
CS42X	Cat 3	Pauls Pier	0	0	0	0	0	0	0	0	0
CS55X	Cat 4	London Bridge	8,300	7	14	9,100	9	16	4,400	6	11
		Downstream Putney Bridge to London Bridge Total / Maximum [b/c.]	**6,100,000**	**42**	**346**	**6,780,000**	**42**	**407**	**538,000**	**6**	**31**
CS28X	Cat 1	Shad Thames Pumping Station [d.]	92,000	15	70	100,000	15	69	72,000	4	14
CS43X	Cat 3	Battle Bridge	0	0	0	0	0	0	0	0	0
CS44X	Cat 3	Beer Lane	0	0	0	0	0	0	0	0	0
CS45X	Cat 3	Iron Gate	200	1	2	200	1	2	300	1	2
CS46X	Cat 3	Nightingale Lane	0	0	0	0	0	0	0	0	0
CS49X	Cat 3	Cole Stairs	0	0	0	0	0	0	0	0	0
CS50X	Cat 3	Bell Wharf	0	0	0	0	0	0	0	0	0
CS29X	Cat 1	North East Storm Relief	782,000	31	286	848,000	32	307	85,000	4	32
CS51X	Cat 3	Ratcliffe	0	0	0	0	0	0	0	0	0
CS31X	Cat 1	Earl Pumping Station	539,000	26	184	594,000	30	207	51,000	4	26
CS30X	Cat 1	Holloway Storm Relief [d.]	7,900	9	21	8,500	10	25	7,000	2	9
CS52X	Cat 3	Blackwall Sewer	0	0	0	0	0	0	0	0	0
CS36X	Cat 2	Wick Lane	0	0	0	0	0	0	0	0	0
CS32X	Cat 1	Deptford Storm Relief	1,470,000	36	252	1,980,000	39	342	163,000	4	29
CS33X	Cat 1	Greenwich Pumping Station	8,320,000	51	672	3,940,000	28	240	573,000	4	36
		Downstream London Bridge to Greenwich Total / Maximum [b/c.]	**11,200,000**	**51**	**672**	**7,470,000**	**39**	**342**	**951,000**	**4**	**36**
CS56X	Cat 4	Isle of dogs Pumping Station (Foul only)	13,000	6	9	13,000	7	11	13,000	7	11
CS35X	Cat 1	Abbey Mills Pumping Station from STATION F	15,300,000	56	873	0	0	0	0	0	0
CS35X	Cat 1	Abbey Mills Pumping Station from STATION A	4,100,000	45	403	0	0	0	0	0	0
CS57X	Cat 4	Canning Town Pumping Station	0	0	0	0	0	0	0	0	0
CS34X	Cat 1	Charlton Storm Relief	600	2	3	900	2	3	900	2	3
CS53X	Cat 3	Henley Road	0	0	0	0	0	0	0	0	0
		Downstream Greenwich to Henley Road Total / Maximum [b/c.]	**19,400,000**	**56**	**873**	**14,000**	**7**	**11**	**14,000**	**7**	**11**
		Crossness STW Storm Tanks	308,000	5	27	50,000	3	8	51,000	3	9
		Tideway CSO				609,000	3	18	684,000	3	21
		Total / Maximum [b/c.] to the River (CSO + Tunnel Overflow)	**39,600,000**	**56**	**873**	**17,600,000**	**54**	**698**	**2,350,000**	**7**	**36**
Sewarage Treatment Works [e.]		Beckton Catchment	444,600,000		8784	508,500,000		8784	508,500,000		8784
		Tunnel Pump Out	n/a		n/a	6,200,000		784	22,300,000		1987
		Beckton STW (Catchment + Tunnel Pump Out)	444,600,000		8784	514,700,000		8784	530,800,000		8784
		Crossness STW	200,600,000		8784	230,900,000		8784	230,500,000		8784

Notes

a. *CSO spills less than 50m3 have been removed from the number of spill count. Volume and duration have also been adjusted.*

b. *Individual volumes have been rounded depending on magnitude. Totals may differ because of rounding.*

c. *For Volume, the sum of all CSO spills in the reach is reported. For Number of Spills and Duration of Spills, the maximum number in the reach is reported.*

d. *With lower operating level at Shad Pumping Station, and with diversion to the Low Level 1 at Holloway Storm Relief*

e. *Typical Year Model simulation is only for 270 days. The table includes infilling the remaining days with average daily DWF for Beckton and Crossness STW.*

Vol 3 Table L.7 Remaining CSO Discharges: Typical Year Simulation for the Thames Tideway Tunnel

LTT ID	EA Cat	CSO Name	STW Improvements, Lee Tunnel and Thames Tideway Tunnel 2020s [a]							
			Event 01: 06-Oct-1979		Event 02: 24-Oct-1979		Event 06: 18-Dec-1979		Event 22: 26-July-1980	
			Total Volume (m^3)	Discharge Duration (hrs)	Total Volume (m^3)	Discharge Duration (hrs)	Total Volume (m^3)	Discharge Duration (hrs)	Total Volume (m^3)	Discharge Duration (hrs)
CS01X	Cat 1	Acton Storm Relief	0	0	0	0	0	0	0	0
CS02X	Cat 2	Stamford Brook Storm Relief	100	1	0	0	0	0	300	1
CS05X	Cat 1	West Putney Storm Relief	0	0	0	0	1,500	4	0	0
CS37X	Cat 3	LL1 Brook Green	0	0	0	0	0	0	0	1
CS03X	Cat 2	North West Storm Relief	600	1	0	0	0	0	0	0
CS04X	Cat 1	Hammersmith Pumping Stn	0	0	0	0	104,000	16	0	0
CS06X	Cat 1	Putney Bridge	0	0	0	0	1,600	3	0	0
		Upstream Putney Bridge Totals [b]	**700**	**1**	**0**	**0**	**107,000**	**16**	**300**	**1**
CS07A	Cat 1	Frogmore SR - Bell Lane	0	0	0	0	500	4	0	0
CS07B	Cat 1	Frogmore SR - Buckhold Road	0	0	0	0	1,500	3	0	0
CS08A	Cat 1	Jews Row - Wandle Valley SR	0	0	0	0	0	0	0	0
CS08B	Cat 3	Jews Row - Falcon Brook SR	5,700	4	0	0	0	0	1,900	3
CS09X	Cat 1	Falcon Brook Pumping Stn	2,200	5	4,700	4	38,000	12	800	1
CS10X	Cat 1	Lots Rd Pumping Stn	5,600	5	13,000	6	69,000	16	4,400	4
CS11X	Cat 2	Church Street	0	0	0	0	0	0	0	0
CS12X	Cat 2	Queen Street	0	0	0	0	0	0	0	0
CS13A	Cat 2	Smith Street Main Line	800	2	100	2	0	0	500	3
CS13B	Cat 2	Smith Street Relief	0	0	0	0	0	0	0	0
CS14X	Cat 1	Ranelagh	0	1	0	0	17,000	6	1,500	4
CS15X	Cat 1	Western Pumping Stn	25,000	4	43,000	5	163,000	13	15,000	2
CS17X	Cat 1	South West Storm Relief	0	0	0	0	3,900	3	0	0
CS16X	Cat 1	Heathwall Pumping Stn	3,300	4	11,000	5	47,000	14	1,500	3
CS18X	Cat 2	Kings Scholars Pond Storm Relief	500	2	0	0	0	0	100	1
CS19X	Cat 1	Clapham Storm Relief	0	0	0	0	7,900	5	0	0
CS20X	Cat 1	Brixton Storm Relief	0	0	0	0	5,700	4	0	0
CS21X	Cat 2	Grosvenor Ditch	500	3	0	0	0	0	100	1
CS39X	Cat 3	Horseferry	300	2	0	0	0	0	0	1
CS40X	Cat 3	Wood Street	0	0	0	0	0	0	0	0
CS22X	Cat 1	Regent Street	0	0	0	0	0	0	0	0
CS23X	Cat 1	Northumberland Street	300	2	0	1	0	0	0	2
CS24X	Cat 2	Savoy Street	400	2	100	1	0	0	300	2
CS25X	Cat 2	Norfolk Street	0	0	0	0	0	0	0	0
CS26X	Cat 2	Essex Street	0	0	0	0	0	0	0	0
CS27X	Cat 1	Fleet Main	400	2	1,000	3	35,000	6	300	3
CS42X	Cat 3	Pauls Pier	0	0	0	0	0	0	0	0
CS55X	Cat 4	London Bridge	1,000	2	100	1	0	0	2,700	3
		Downstream Putney Bridge to London Bridge Totals [b]	**46,000**	**5**	**73,000**	**6**	**389,000**	**16**	**29,000**	**4**
CS28X	Cat 1	Shad Thames Pumping Stn	23,000	3	15,000	3	3,000	5	31,000	3
CS43X	Cat 3	Battle Bridge	0	0	0	0	0	0	0	0
CS44X	Cat 3	Beer Lane	0	0	0	0	0	0	0	0
CS45X	Cat 3	Iron Gate	0	2	0	0	0	0	300	2
CS46X	Cat 3	Nightingale Lane	0	0	0	0	0	0	0	0
CS49X	Cat 3	Cole Stairs	0	0	0	0	0	0	0	0
CS50X	Cat 3	Bell Wharf	0	0	0	0	0	0	0	0
CS29X	Cat 1	North East Storm Relief	12,000	7	8,100	7	48,000	10	18,000	8
CS51X	Cat 3	Ratcliffe	0	0	0	0	0	0	0	0
CS31X	Cat 1	Earl Pumping Stn	2,200	3	6,300	6	41,000	13	1,300	4
CS30X	Cat 1	Holloway Storm Relief	6,900	8	0	0	0	0	200	1
CS52X	Cat 3	Blackwall Sewer	0	0	0	0	0	0	0	0
CS36X	Cat 2	Wick Lane	0	0	0	0	0	0	0	0
CS32X	Cat 1	Deptford Storm Relief	36,000	5	27,000	5	68,000	14	32,000	5
CS33X	Cat 1	Greenwich Pumping Stn	92,000	9	98,000	8	317,000	14	66,000	5
		Downstream London Bridge to Greenwich Totals [b]	**172,000**	**9**	**154,000**	**8**	**477,000**	**14**	**149,000**	**8**
CS56X	Cat 4	Isle of dogs Pumping Stn (Foul only)	5,400	3	200	1	0	0	6,200	2
CS35X	Cat 1	Abbey Mills Pumping Station from STATION F	0	0	0	0	0	0	0	0
CS35X	Cat 1	Abbey Mills Pumping Station from STATION A	0	0	0	0	0	0	0	0
CS57X	Cat 4	Canning Town Pumping Stn	0	0	0	0	0	0	0	0
CS34X	Cat 1	Charlton Storm Relief	200	1	0	0	0	0	700	2
CS53X	Cat 3	Henley Road	0	0	0	0	0	0	0	0
		Downstream Greenwich to Henley Road Totals [b]	**5,600**	**3**	**200**	**1**	**0**	**0**	**6,900**	**2**
		Crossness STW Storm Tanks	31,000	3	0	0	8,800	3	11,000	3
		Tideway CSO	40,000	2	111,000	3	534,000	16	0	0
		Total / maximum [b] to the River (CSO and Tunnel Overflow)	**295,000**	**9**	**338,000**	**8**	**1,520,000**	**16**	**196,000**	**8**

Notes

a. All CSO discharges less than 50m3 have been removed. Individual volumes have been rounded depending on magnitude. Totals may differ because of rounding.

b. For Volume, the sum of all CSO discharges in the reach is reported. For duration of discharges, the maximum hours of discharge in the reach is reported.

L.1.82 The STW improvements and the operation of the Lee Tunnel would result in a 56% capture of the 39 million m^3 annual CSO discharges estimated to occur in the existing 2006 scenario. The volume reduction is mainly a result of the captured CSO discharges from the Abbey Mills Pumping Station by the Lee Tunnel and Beckton STW expansion and the reduction of CSO discharges at Greenwich Pumping Station due to Crossness STW expansion.

L.1.83 With the Lee Tunnel, there will no longer be any discharges at the existing Abbey Mills CSOs. All CSO discharges from Abbey Mills will be captured by the Lee Tunnel, except for 3 events in the Typical Year where the Lee tunnel would be filled to the new Tideway CSO overflow level, and discharge to the river at Beckton STW, totalling an annual discharge volume of about 609,000m^3 and total spill duration of 18 hours.

L.1.84 No material change in CSO discharges at the 34 unsatisfactory CSOs along the Tidal Thames would be obtained by STWs improvements and the Lee Tunnel.

L.1.85 With the completion of the Thames Tideway Tunnel, the residual spill volume in the Typical Year is approximately 2.4 million m^3. 12 of the 34 unsatisfactory CSOs is predicted to have a residual discharge of four events during the Typical Year while the other 22 CSOs have less than four residual discharge events. With the Thames Tideway Tunnel, the Tideway CSO would discharge three times, and its annual volume and spill duration from these three events would increase marginally to 684,000m^3 and 21 hours. This increase is due to the capture of additional discharges from CSOs intercepted along the Tidal Thames by the Thames Tideway Tunnel. The annual CSO volume and frequency would meet the performance objectives of between 2.1 and 2.6 million m^3 and no more than four spill events in a Typical Year from unsatisfactory CSOs.

L.1.86 There are no CSO discharges in the Typical Year at Abbey Mills CSO. The control of Abbey Mills discharge frequency to an average of one in 10 year is shown by the long term annual series performance.

L.1.87 The Thames Tideway Tunnel in conjunction with the STW improvements and Lee Tunnel would capture about 94% of the 39 million m^3 of CSO discharge predicated in the existing system model during the Typical Year for 2006 conditions. This level of control meets the 90% capture objective set out for the project in the Thames Tideway Tunnel performance objectives and operating system section of this appendix.

Performance: Long Term Annual Series

L.1.88 The long term annual performance has been simulated to demonstrate how the completion of the Thames Tideway Tunnel in conjunction with the STW Improvements and Lee Tunnel performs with varying annual rainfall volumes and spatial distribution. This includes recorded rainfall data from a significant number of years which experienced low, medium and high levels of rainfall. This demonstrates the overall robustness of the project in terms of overall CSO capture and illustrates how the performance of the system can change with varying rainfall.

L.1.89 The 321 significant rainfall events to represent the long term annual series were developed by merging 79 CTP events and 242 annual rainfall events (mainly in winter months) selected from the 1970 to 2011 rainfall record. The CTP events are summer period rainfall (May to October) which are selected because the resulting rainfall run-off into the existing sewer network is likely to cause dissolved oxygen stress in the Tidal Thames from existing CSO discharges. The 242 annual rainfall events are significant rainfall events which are selected from the entire 12 months of the year and are likely to fill the Thames Tideway and Lee tunnels to high levels and cause residual CSO discharges. Overlapping events are removed by selecting the longer event dataset which results in only 79 CTP events being used.

L.1.90 60 of the events in the 321 rainfall event merged series meet the rainfall depth threshold for extreme wet weather control of 22mm depth or more weighted across the catchment in 24 hours.

L.1.91 In the merged series, the annual rainfall events (the 242) have been simulated without tidal influence to maximise flow and spills at the CSO. The CTP events are simulated with tidal influence, in line with the agreed methodology set for CTP event analysis.

L.1.92 The long term annual series is grouped into water years (October Year X to September Year X+1) for the 1970 to 2010 period. It represents full water years from 1971 to 2010 (total of 40 years). 1970 is not a full water year, because catchment rainfall record from October to December 1969 is not simulated.

L.1.93 The long term summary of CSO control performance for the Thames Tideway Tunnel and the estimated annual weighted average rainfall for the full water year is given in Vol 3 Plate L.16 and Vol 3 Plate L.17. These plates show the residual CSO discharge volume and number of events for each water year from 1970 to 2010 with the completion of the Thames Tideway Tunnel. The decadal average is also included in the figures which show that CSO performance will vary between water years depending on rainfall volume and spatial distribution.

L.1.94 In interpreting annual residual CSO discharges it should be recognised that the highest annual rainfall does not necessary correspond with the largest annual CSO discharge volume or frequency. This is due to intensity, duration and location of rainfall which will vary across the catchment throughout the year and therefore impact how rainfall run-off enters the catchment sewer system.

L.1.95 For example, the lowest annual total CSO discharge volume in a year is in the 1998 water year, at about 8,000m^3 and a maximum discharge frequency of 1 (see Vol 3 Table 1.8). This has an annual rainfall depth of 462mm, which is the 35th wettest year in the 40 year series i.e. not the year with the lowest rainfall. The highest annual total CSO discharge volume is in the 1975 water year with more than 9 million m^3 and a maximum discharge frequency of 7 events. This is only the 7th wettest water year in the series. The maximum discharge frequency of 8 events is recorded in 2002, which is the 20th wettest year. The driest year in the series in 1976, and has an annual discharge volume ranked 31st highest total annual CSO discharge volume.

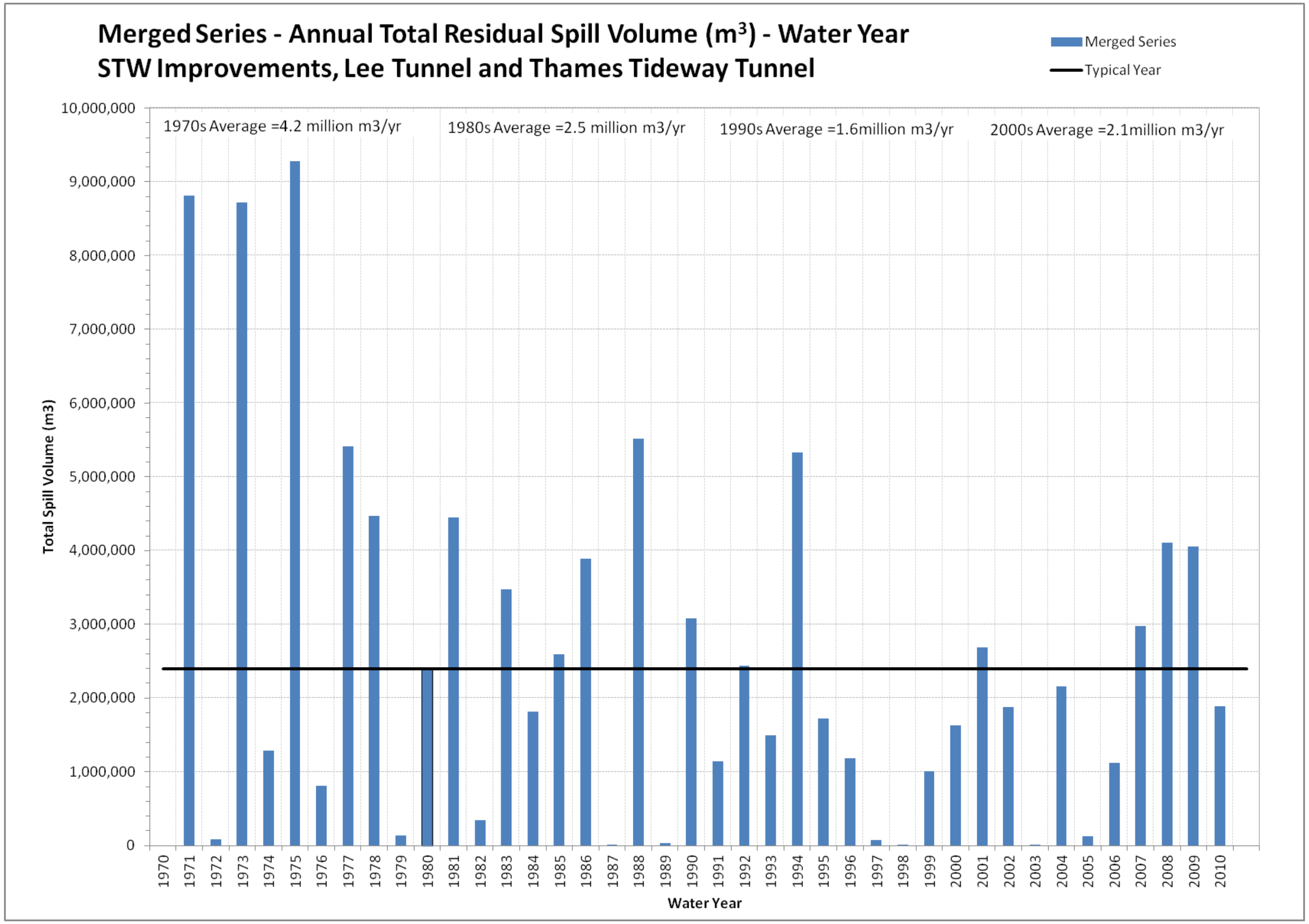
L.1.96 There are 4 events from the 40 year long term annual series rainfall where discharges at Abbey Mills CSO are predicted because the Thames Tideway Tunnel would fill to its maximum capacity at 0mAOD. The modelling showed these events occurring in water years 1972, 1975, 1980 and 2000, giving a long term average CSO discharge frequency of 1 in 10 year which meets the Abbey Mills control objective set out for the project.

Vol 3 Table L.8 Long term annual series performance for the Thames Tideway Tunnel

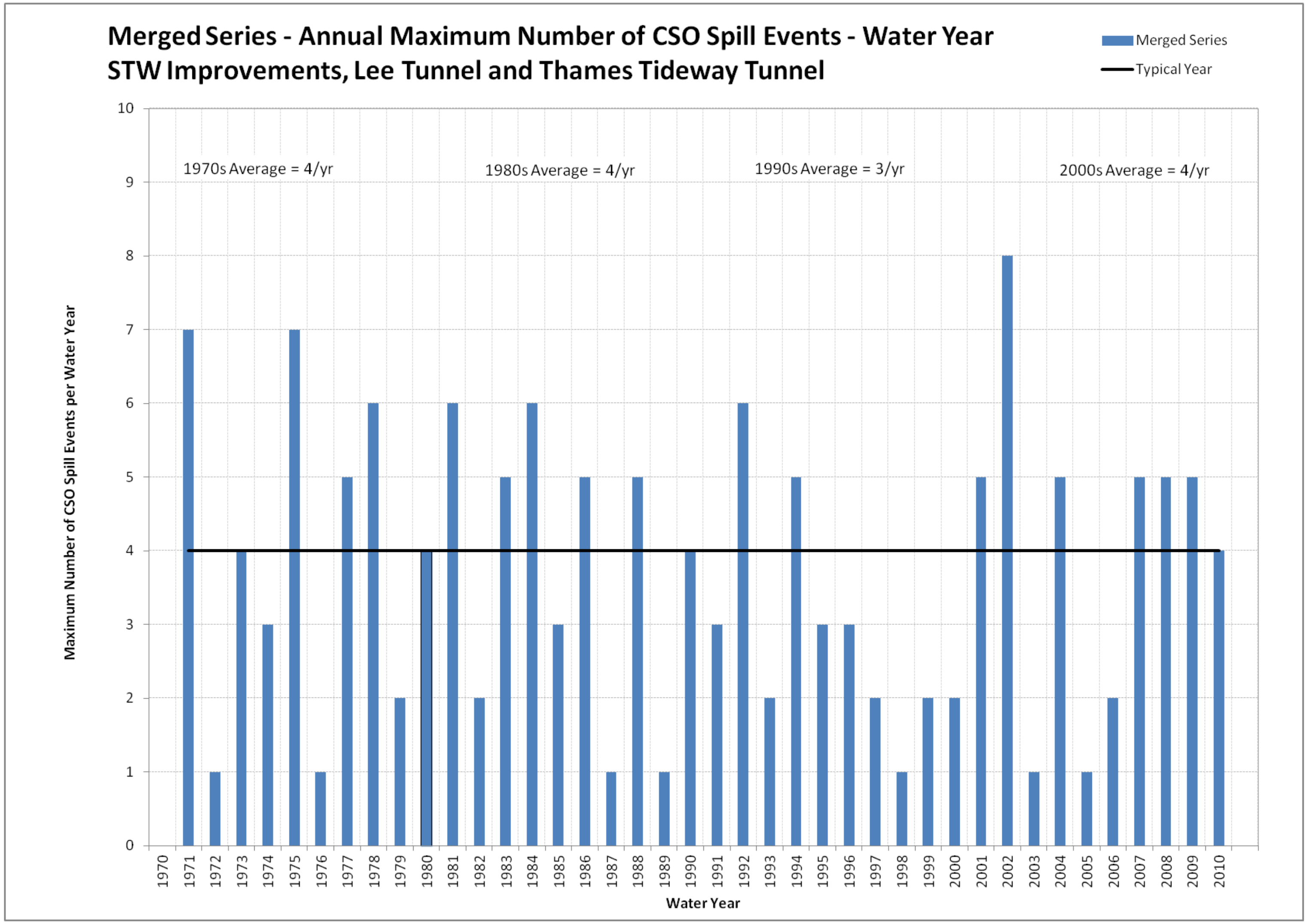
Full Water Year	Annual Rainfall (mm)	Annual Maximum Number of Discharges	Annual Discharge Volume (m^3)	Rank Annual Rainfall	Rank Maximum Number of Discharges	Rank Annual Discharge Volume
1971	669	7	8,810,000	8	2	2
1972	452	1	90,000	36	34	35
1973	534	4	8,720,000	28	18	3
1974	553	3	1,280,000	25	22	26
1975	702	7	9,280,000	7	2	1
1976	317	1	810,000	40	34	31
1977	705	5	5,410,000	6	8	5
1978	624	6	4,470,000	14	4	7
1979	638	2	140,000	13	27	33
1980 Typical Year	**588**	**4**	**2,400,000**	**21**	**18**	**18**
1981	613	6	4,450,000	16	4	8
1982	589	2	340,000	23	27	32
1983	647	5	3,470,000	11	8	12
1984	511	6	1,810,000	32	4	22
1985	610	3	2,590,000	17	22	16
1986	595	5	3,890,000	18	8	11
1987	618	1	11,000	15	34	39

Full Water Year	Annual Rainfall (mm)	Annual Maximum Number of Discharges	Annual Discharge Volume (m^3)	Rank Annual Rainfall	Rank Maximum Number of Discharges	Rank Annual Discharge Volume
1988	657	5	5,520,000	10	8	4
1989	407	1	40,000	37	34	37
1990	472	4	3,080,000	34	18	13
1991	518	3	1,140,000	30	22	28
1992	484	6	2,440,000	33	4	17
1993	595	2	1,490,000	19	27	25
1994	639	5	5,330,000	12	8	6
1995	576	3	1,730,000	24	22	23
1996	367	3	1,180,000	38	22	27
1997	361	2	80,000	39	27	36
1998	462	1	8,000	35	34	40
1999	525	2	1,010,000	29	27	30
2000	590	2	1,630,000	22	27	24
2001	821	5	2,690,000	3	8	15
2002	592	8	1,870,000	20	1	21
2003	517	1	13,000	31	34	38
2004	707	5	2,160,000	5	8	19
2005	551	1	130,000	26	34	34
2006	544	2	1,120,000	27	27	29
2007	862	5	2,980,000	1	8	14
2008	823	5	4,110,000	2	8	9
2009	668	5	4,060,000	9	8	10
2010	722	4	1,890,000	4	18	20
Long Term - 1971 to 2010 Water Years						
25 Percentile	518	2	960,000			
50 Percentile	591	4	1,880,000			
75 Percentile	649	5	3,930,000			
Average	586	4	2,590,000			
Minimum	317	1	8,000			
Maximum	862	8	9,280,000			

Vol 3 Plate L.13 Long Term Annual Series – Annual Total Spill Volume (m^3)



Vol 3 Plate L.14 Long Term Annual Series – Annual Maximum Number of CSO Spills



Performance: Compliance to Dissolve Oxygen Standards

L.1.97 Under the UWWTD, the UK has an obligation to limit pollution and the effects of discharges from STWs and collection systems including discharges from CSOs. Four dissolved oxygen standards were developed by the TTSS for the Tidal Thames to provide a mechanism of comparison of alternatives and to allow design of a solution to meet this obligation.

L.1.98 Vol 3 Table L.9 shows the four dissolved oxygen standards developed to protect the ecology of the Tidal Thames from intermittent discharges from CSOs and the continuous discharges at the five STWs. The standards include a specific dissolved oxygen value, tidal duration and how often the standard can be exceeded (or the allowable frequency of the depressed dissolved oxygen value).

L.1.99 Detailed water quality modelling has been undertaken for the project to determine how dissolved oxygen in the Tidal Thames would be affected by the development of the STW improvements to the Mogden, Beckton, Crossness, Long Reach and Riverside STWs, the Lee Tunnel and the Thames Tideway Tunnel.

L.1.100 The Compliance Test Procedure (CTP) methodology was developed to assess and compare the performance of each scenario for water quality dissolved oxygen compliance. For each scenario, 242 summer rainfall events selected from the catchment rainfall record between 1970 and 2010 to stress the Tidal Thames were simulated.

Vol 3 Table L.9 Dissolved Oxygen standards developed by the TTSS for the Tidal Thames

Standard	Dissolved Oxygen Concentration Threshold (mg/l)	Duration (tides[1])	Allowable Return Period (years)	Allowable number of exceedances in 41 years[2]
1	4	29	1	41
2	3	3	3	13
3	2	1	5	8
4	1.5	1	10	4

[1] A tide is a single ebb or flood.
[2] Failure of the standard occurs when the predicted number of exceedances at a single reach exceeds the allowable number of exceedances.

L.1.101 The assessment of dissolved oxygen compliance for the existing system, the STW improvements and Lee Tunnel, and the STW improvements, Lee Tunnel and Thames Tideway Tunnel is presented in Vol 3 Table L.10. The maximum number of exceedances from 242 CTP events at any 1km reach of the 2km QUESTS model of the Tidal Thames is shown in the Vol 3 Table L.10.

Vol 3 Table L.10 Simulated number of exceedances and scenario compliance against DO Standards for the Tidal Thames

DO Standard	**1**	**2**	**3**	**4**
DO value and tidal duration threshold	**4 mg/l for 29 tides[1]**	**3 mg/l for 3 tides**	**2 mg/l for 1 tide**	**1.5 mg/l for 1 tide**
Allowable exceedances in 41 years (frequency)	**41 (1:1yr)**	**13 (1:3yr)**	**8 (1:5yr)**	**4 (1:10yr)**
Scenario	***Simulated maximum number of exceedances of DO thresholds***			
Existing System	211	193	99	60
	Fails[2]	Fails	Fails	Fails
STWs Improvement and Lee Tunnel	75	40	12	7
	Fails	Fails	Fails	Fails
Thames Tideway Tunnel (includes STW Improvements and Lee Tunnel)	21	4	1	1
	Compliant	Compliant	Compliant	Compliant

[1] A tide is a single ebb or flood.
[2] Failure of the standard occurs when the predicted number of exceedances at a single reach exceeds the allowable number of exceedances.

L.1.102 The existing system and the scenario with the STWs improvements and Lee Tunnel fail all four dissolved oxygen standards.

L.1.103 With the completion of the Thames Tideway Tunnel, all four dissolved oxygen standards are met and so the London Tideway Improvements project (STW improvements and London Tideway Tunnels) is compliant with the dissolved oxygen standards set by the TTSS for the Tidal Thames.

L.1.104 Specific dissolved oxygen conditions along the Tidal Thames during individual events are best evaluated by reviewing the half tide plots[vi] of the dissolved oxygen concentration for each CTP event simulation. The half tide plots reflects changing tides and the progression of dissolved oxygen depression (sag) and recovery of the river after the CSO discharges have occurred. An example of such a series of half tide plots is given in Vol 3 Plate L.18.

[vi] The 'half tide' condition is defined as where the volume of water upstream of the location is at its mean value.

L.1.105 Vol 3 Plate L.18 illustrates how a simulated dissolved oxygen concentration changes across the Tidal Thames for a selected CTP event between the three scenarios during the half tide. The event on the 3rd of August 2004 illustrates the improvement in dissolved oxygen exceedances with the STWs improvements and Lee Tunnel and continued improvement with the Thames Tideway Tunnel. This event was also associated with a fish kill incident in the Tidal Thames during August 2004. River conditions during this event were sensitive to discharges because of a dry summer, with low river flows and higher than average temperatures.

L.1.106 For the existing system, the August 2004 event exceeds all four dissolved oxygen thresholds. With the combination of STWs improvements and the Lee Tunnel, three of the standards are exceeded (the 4mg/l, 3mg/l and 2mg/l dissolved oxygen standards). Once the Thames Tideway Tunnel is completed, the QUESTS model predicts that only the 4mg/l dissolved oxygen threshold is exceeded.

L.1.107 The August 2004 event is not the largest rainfall event in the 242 CTP event series. It is the 123rd largest rainfall volume at a weighted 17mm depth over the entire catchment. However, this event had intense rainfall over the north-west area of the catchment which also caused activated sludge washout from the Mogden STW to occur. This added additional load in addition to the CSO loads to the upper Tidal Thames.

L.1.108 For the existing system, this event resulted in approximately 1.6million m^3 of discharge to the Tidal Thames. With the completion of the Thames Tideway Tunnel it has been estimated that only 12,000m^3 of CSO discharge would occur. The total CSO discharge volume and effluent discharge from Beckton (including tunnel pump out) and Crossness STWs for the August 2004 event are given in Vol 3 Table L.11

Vol 3 Table L.11 Summary of CSO spills from the August 2004 event

Scenario	Total CSO Discharge to the River (m^3)	CSO Discharge Volume Ranking out of 242 events	Total STW flow from Beckton and Crossness (m^3)[1]	STW Effluent Ranking out 242 events
Existing 2006[1.]	1.6 million	90th	8.72 million	215th
STW Improvements and Lee Tunnel [2.]	1.2 million	53th	10.4 million	218th
STW Improvements, Lee Tunnel and Thames Tideway Tunnel [2.]	12,000	86th	11.7 million	170th

1: Total volume for CSO and STW for Existing scenario is lower than the Lee and Thames Tideway Tunnel due to 2006 population.

2: Difference in the Lee Tunnel and Thames Tideway Tunnel total volume for CSO and STW due to rounding.

L.1.109 The majority of the rainfall run-off, including the high volumes in the northwest of the catchment, would be captured by the tunnel system and was transferred for treatment at the Beckton STW via the Thames Tideway Tunnel. Only a small volume of residual CSO (12,000m^3) would enter the Tidal Thames mainly from unsatisfactory CSOs not directly intercepted by the Thames Tideway tunnel or from the not unsatisfactory CSOs.

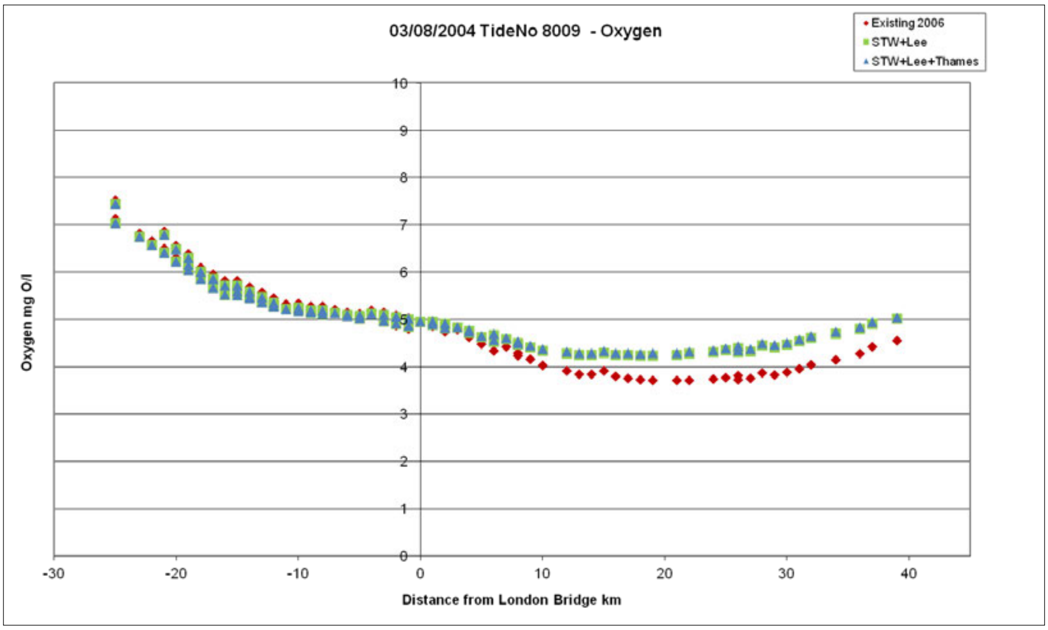
L.1.110 This illustrates a key advantage of the Thames Tideway Tunnel whereby the full tunnel storage volume is made available to local areas when localised heavy rainfall occurs and causes significant run-off and flow within the local system.

L.1.111 The full CTP event analysis shows that the CSO control and STW improvements created by the completed LTI project, including the Thames Tideway Tunnel results in compliance with all four dissolved oxygen standards developed by the TTSS for the Tidal Thames.

Vol 3 Plate L.15 Comparison of half-tide plots along the Tidal Thames and discussion of plots for CTP event on the 3rd August, 2004

Starting Dissolved Oxygen condition (Tide 8009 – Ebb Tide) on the 03/08/2004:

At the start of the CTP event on the 3rd of August 2004, the STWs improvements, the Lee Tunnel and the Thames Tideway Tunnel help to create better (higher) background river dissolved oxygen conditions following the simulation of the 6 weeks preceding[vii] compared to the existing 2006 scenario. The improvement in background dissolved oxygen level starting about 10km downstream of London Bridge is due to the STWs[viii] upgrade and improved effluent quality and to some extent the capture of CSO by the tunnels.



[vii] The 6 weeks preceding is simulated using the WRc SIMPOL3 model. The total rainfall depth in the preceding 6 week period is 70mm (ranked 95th out of 242 events for preceding rainfall) with no CTP events occurring during this period.

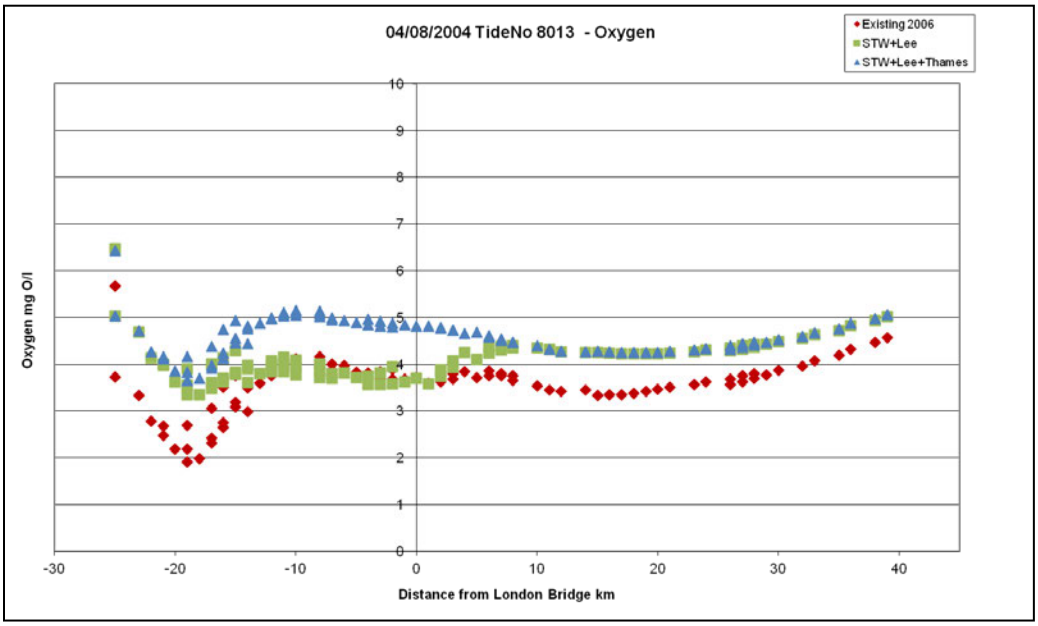
[viii] Beckton STW discharges at about 20km downstream of London Bridge.

Following series of four ebb- tide plots:

Tide 8013, Tide 8015, Tide 8017, Tide 8021 from 04/08/2004 to 06/08/2004

The following series of dissolved oxygen half tide plots occurs after the CTP event, where 17mm (average weighted) depth of rainfall fell on 03/08/2004 with significantly higher rainfall occurring in the north-west of the catchment. The plot series shows the movement of the dissolved oxygen sag progressively downstream with each subsequent ebb tide and how each CSO control scenario affects the dissolved oxygen in the river.

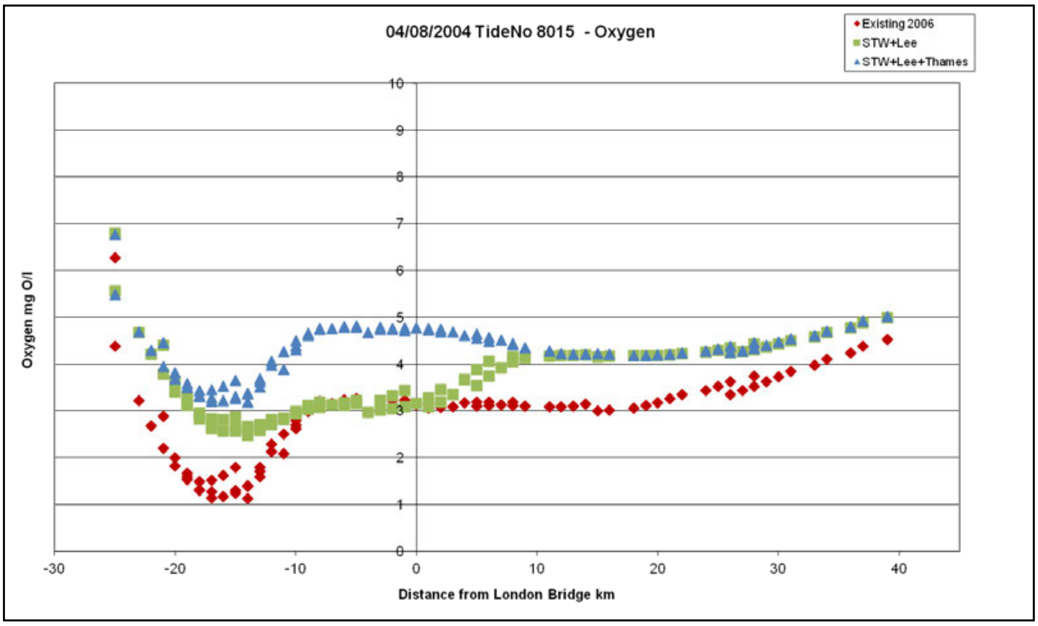
Ebb Tide 8013:



At tide 8013, the dissolved oxygen profile for both the Lee Tunnel and Thames Tideway Tunnel begins to fall below the 4mg/l dissolved oxygen, and will stay below this for more than 29 continuous tides, resulting in an exceedance of the 4mg/l threshold for this event.

At tide 8013, the dissolved oxygen profile for the existing 2006 scenario begins to fall below 2mg/l dissolved oxygen, and will continue to stay below this for more than 1 tide, resulting in an exceedence of the 2mg/l threshold during this event.

Ebb Tide 8015:



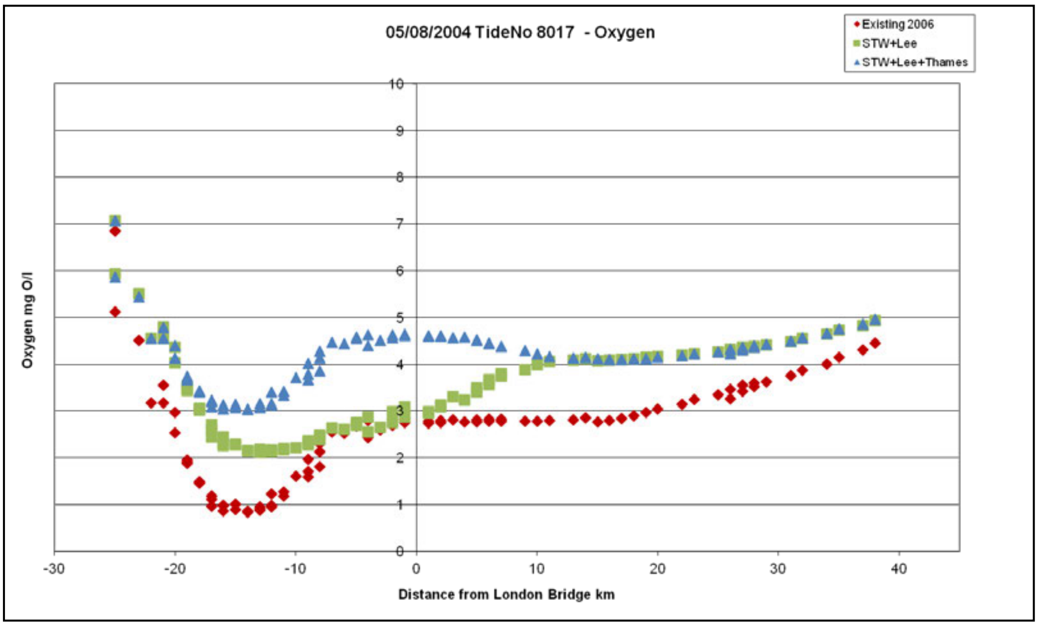
At tide 8015, the dissolved oxygen sag below 2 mg/l during the existing 2006 scenario is linked to the lower quality effluent discharges from the Mogden STW, and the larger spills from Mogden storm tanks.

Better dissolved oxygen performance is expected with the planned STW improvements at Mogden STW and this is demonstrated in the dissolved oxygen profile of the STW Improvements and Lee tunnel and the Thames Tideway Tunnel.

With the Thames Tideway Tunnel, better dissolved oxgen is predicted in the upper reaches between -15km to +10km from London Bridge, demonstrating the benefits of CSO cpature by the Thames Tideway Tunnel within the upper reaches.

At tide 8015, the dissolved oxygen profile for the Lee Tunnel project begins to fall below the 3mg/l dissolved oxygen, and will stay below this for more than 3 tides, resulting in an exceedance of the 3mg/l threshold during this event.

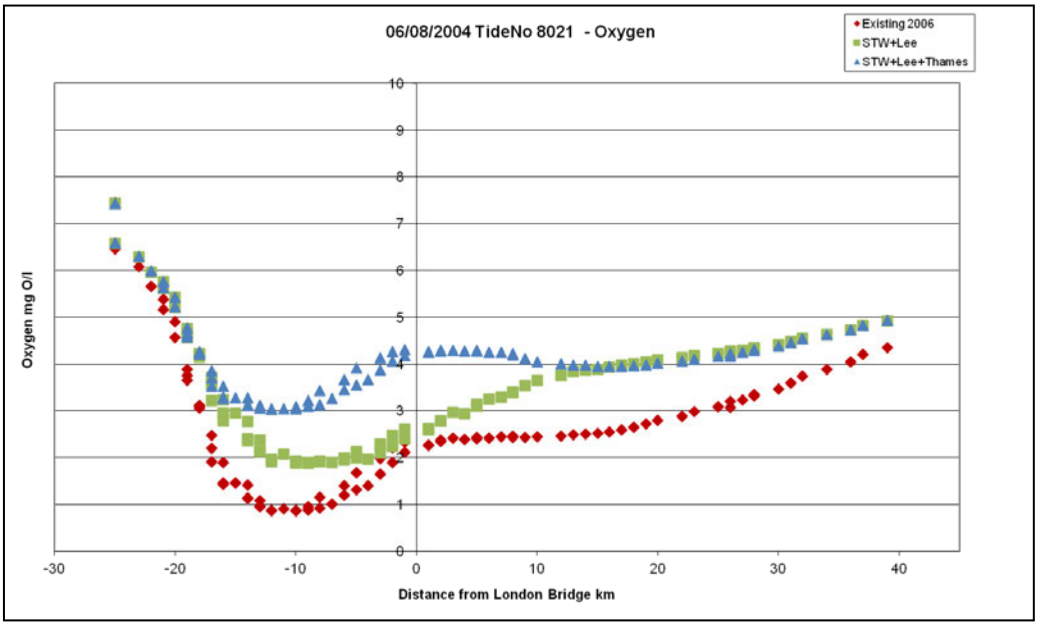
Ebb Tide 8017:



At tide 8017, the dissolved oxygen profile for the existing 2006 scenario begins to fall below 1.5mg/l dissolved oxygen, and will continue to stay below this for more than 1 tide, resulting in an exceedence of the 1.5mg/l threshold during this event.

A reported fish kill event occurred during this event, and the Quests model confirms this, with dissolved oxygen sags dropping below 1 mg/l on the 05/08/2004 in the upper reaches. Reports also attribute the dissolved oxygen sag to activated sludge washout from the Mogden STW. However the Quests model does not directly model the effects of sludge washout and therefore the dissolved oxygen sag in the upper reach could be under represented.

Ebb Tide 8021:



At tide 8021, the dissolved oxygen profile for the Lee Tunnel project begins to fall below the 2mg/l dissolved oxygen, and will stay below below this for more than1 tide, resulting in an exceedance of the 2mg/l threshold during this event.

Performance: Water Framework Directive

L.1.112 The WFD sets targets for ecological condition in the rivers of England and Wales with at target for a 'good' potential status for the Tidal Thames water bodies by 2027. The status of each water body in the UK is reported in the first River Basin Management Plans (RBMP), published by the EA in December 2009.

L.1.113 The relevant WFD standards for the Tidal Thames are the dissolved oxygen standards for transitional and coastal waters. These are expressed as an annual 5- percentile i.e. the annual dissolved oxygen concentration should be better for 95 percent of the time, or the annual dissolved oxygen concentration should not fall below the dissolved oxygen levels determined from Vol 3 Table L.12in combination with Vol 3 Plate L.19 for more than 5 percent of the time.

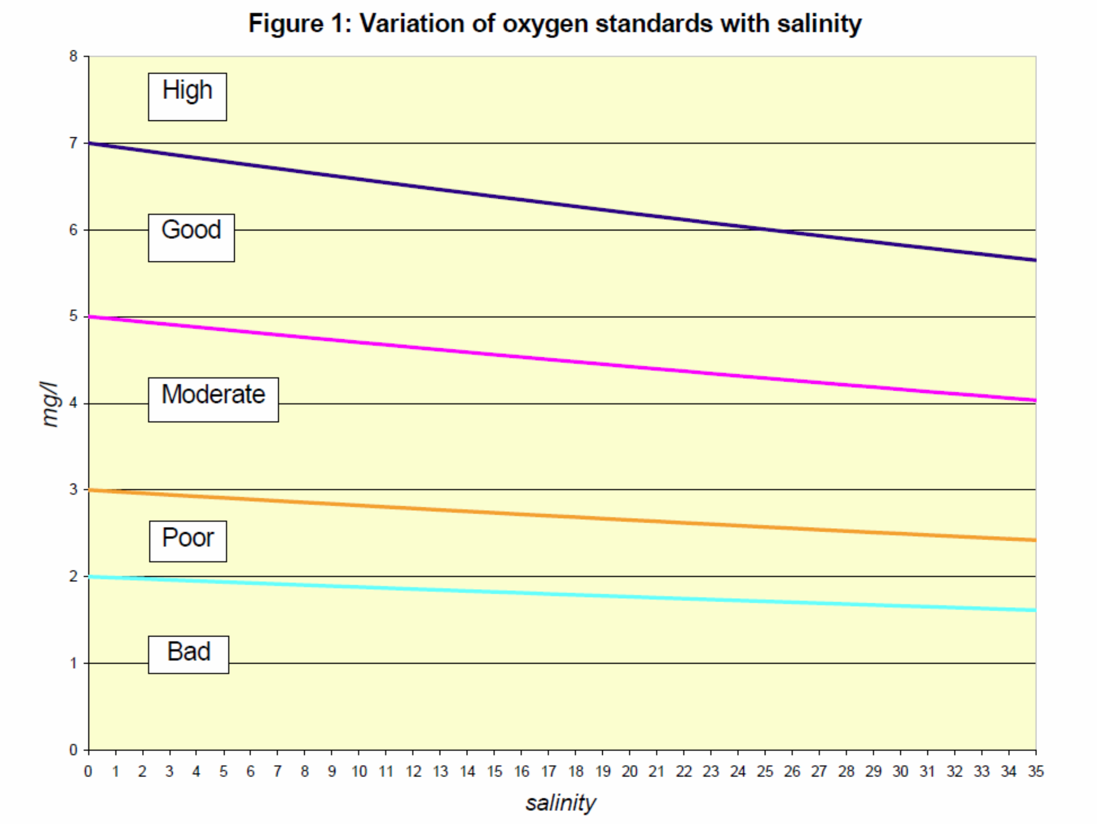
L.1.114 The dissolved oxygen threshold varies with salinity, and is set out in Table 21 and Figure 1 from the UK Technical Advisory Group "*UK Environmental Standards and Conditions (Phase 1) Final Report*" on the Water Framework Directive (April 2008). Table 21 and Figure 1 from this report are reproduced below for information (see Vol 3 Table L.12 and Vol 3 Plate L.19). The use of salmonid fish is primarily an indicator of the level of dissolved oxygen to protect salmonid and other sensitive fish species and is not meant as a goal for establishment of salmon fishery or confirmation of actual salmon present in the water body.

Vol 3 Table L.12 Reproduced "Table 21- Dissolved oxygen standards for transitional and coastal waters"

Table 21: Dissolved oxygen standards for transitional and coastal waters

	Freshwater	Marine	Description
	5-percentile (mg/l)		
High	7	5.7	Protects all life-stages of salmonid fish
Good	5 - 7	4.0 – 5.7	Resident salmonid fish
Moderate	3 - 5	2.4 – 4.0	Protects most life-stages of Non-salmonid adults
Poor	2 - 3	1.6 – 2.4	Resident non-salmonid fish, poor survival of salmonid fish
Bad	2	1.6	No salmonid fish. Marginal survival of resident species

Vol 3 Plate L.16 Reproduced "Figure 1- Variation of oxygen standards with salinity"

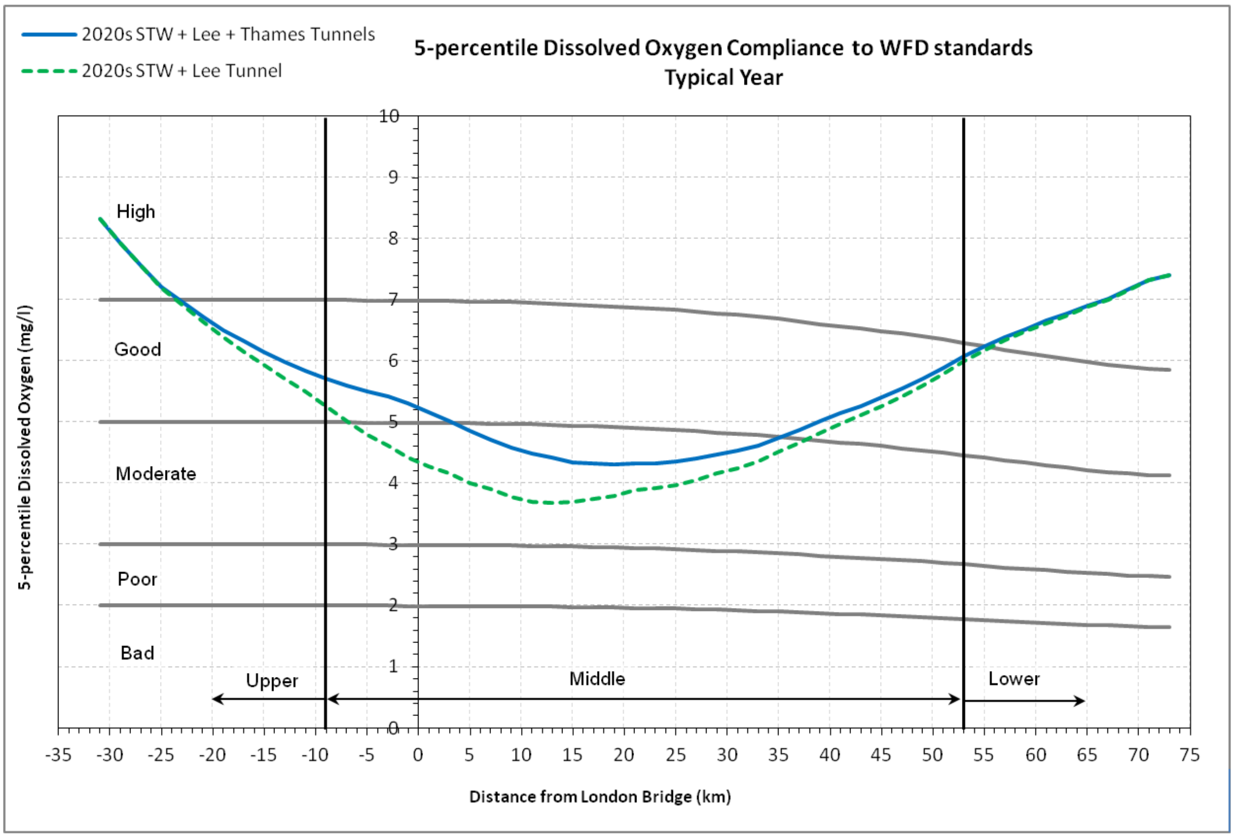


L.1.115 The WFD assessment was undertaken by WRc using the catchment model results for the Typical Year (October 1979 to September 1980) and the Quests river model to demonstrate the annual 5-percentile dissolved oxygen concentration across the Tidal Thames.

L.1.116 The STWs Improvements and Lee Tunnel base case and the Thames Tideway Tunnel (including STW Improvements and Lee Tunnel) performance in 2020s for WFD have been considered. Vol 3 Plate L.20 shows the 5-percentile dissolved oxygen compliance to the WFD standard for the Typical Year in 2020s, and Vol 3 Table L.13 summarises the corresponding approximate distances and length along the Tidal Thames within each WFD status category.

L.1.117 Results show that with the completion of the Thames Tideway Tunnel, the Thames Middle remains within Moderate DO status. The Thames Tideway Tunnel however, does help improve the length of the Tidal Thames achieving good potential from moderate status by approximately 13km.

Vol 3 Plate L.17 Comparison of 5-percentile dissolved oxygen compliance to the WFD standard for the Typical Year



Vol 3 Table L.13 Summary of approximate distances of WFD status along the Tidal Thames for the Typical Year

Typical Year	WFD Status Category		
	High	Good	Moderate
	Distance from London Bridge (km)		
STWs Improvements and Lee Tunnel	-35 to -24 and +55 to +75	-24 to -8 and +38 to +55	-8 to +38
Total length (km)	31	33	46
STWs Improvements, Lee Tunnel and Thames Tideway Tunnel	-35 to -24 and 55 to 75	-24 to +2 and 35 to 55	+2 to +35
Total length (km)	31	46	33
Improvement (km)	-	+13	-13

References

[1] The Council Directive 91/271/EEC concerning urban waste-water treatment

[2] Thames Water. *Thames Tideway Strategic Study* (February 2005)

Thames Tideway Tunnel
Thames Water Utilities Limited

Application for Development Consent

Application Reference Number: WWO10001

Environmental Statement

Doc Ref: **6.2.03**

Volume 3: Project-wide effects assessment appendices

Appendix L.2: Water Framework Directive Assessment

APFP Regulations 2009: Regulation **5(2)(a)**

Hard copy available in

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January 2013

Thames Tideway Tunnel
Creating a cleaner, healthier River Thames

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L.2 Water Framework Directive assessment

L.2.1 The following report has its own table of contents.

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Thames Tideway Tunnel

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L.2 Water Framework Directive Assessment

Introduction

L.2.1 This document presents the findings of a Water Framework Directive[1] (WFD) assessment or the Thames Tideway Tunnel project. The WFD aims to protect and enhance the quality of the water environment by requiring member states to classify the current 'status' (or potential[i]) of waterbodies and set a series of objectives for maintaining or improving waterbodies so that they maintain or reach 'good status' or 'good potential'.

L.2.2 The Environment Agency (EA) is the competent authority for implementing the WFD in England and Wales and has reported waterbody status and objectives via a series of River Basin Management Plans (RBMPs) (EA, 2009)[2]. As part of its role, the EA must consider whether proposals for new development have the potential to affect the objectives of the WFD in protecting the water environment as set out in the RBMPs. These four key specific objectives of the WFD, are:

a. WFD objective 1: Prevent deterioration of the status of all bodies of surface water and groundwater.

b. WFD objective 2: Protect, enhance and restore all bodies of surface water and groundwater, with the aim of achieving good status by 2015 (or 2027 where measures will take longer to implement[ii]).

c. WFD objective 3: Protect and enhance all artificial and heavily modified bodies of water, with the aim of achieving good ecological potential (GEP) and good chemical status of all water bodies by 2015 (or 2027 where measures will take longer to implement).

d. WFD objective 4: Reduce pollution from priority substances and cease or phase out emissions, discharges and losses of priority hazardous substances.

L.2.3 New development that has the potential to impact on waterbodies and their WFD objectives should therefore ensure that the proposed development is assessed for compliance against these WFD objectives for the potentially affected waterbodies.

L.2.4 Delivery and operation of the proposed Thames Tideway Tunnel project has the potential to impact both positively and negatively on WFD objectives for several waterbodies. The project has been identified in the

[i] The WFD recognises that some waterbodies have been physically altered, for example for navigation or flood defence, and allows for these water bodies to be designated as Heavily Modified Water Bodies (HMWB) or Artificial Water Bodies (AWB) and need to achieve good potential rather than status. Ecological potential means that the waterbody is managed to achieve the biology that can be achieved given its modified condition.

[ii] If the measures proposed by the RBMP to achieve good status (or potential) could not achieve the target by 2015 due to disproportionate cost or technical infeasibility, a target of achieving good status (or potential) by 2027 has been set.

Thames RBMP[3] as a key measure to help move the tidal Thames surface waterbodies towards good potential[iii] as a result of water quality and ecological benefits that the project would facilitate. However, through its delivery and operation it also has the potential to adversely affect other elements that support good potential in the affected surface waterbodies, as well as the status of groundwater bodies.

L.2.5 A WFD assessment has therefore been identified as a requirement for the project.

Assessment reporting

L.2.6 Although the Environmental Impact Assessment (EIA) process for the project has assessed the impacts from the Thames Tideway Tunnel project and identified the effects that are likely on many of the supporting elements used in WFD classification, separate documentation of the assessment of the project against WFD objectives was considered to be appropriate because:

a. some supporting elements which determine surface water WFD status (or potential) span several EIA disciplines (eg, hydromorphology) and hence are not assessed in a way that is entirely consistent with WFD requirements

b. the *Environmental Statement* for the project is a substantial document with the relevant topic areas relevant to the WFD reported in different sections and volumes and as such, for clarity and ease of reference, a separate single documentation of WFD compliance assessment has been produced.

L.2.7 There is currently no guidance available on the undertaking of a WFD assessment for new development; hence a bespoke assessment process has been developed for the Thames Tideway Tunnel project through discussion with the EA using guidance developed by EA (EA, 2010)[4]. Broadly, the assessment has followed a two stage process:

a. a preliminary assessment that determined the waterbodies that could potentially be affected, and screened which project elements have the potential to impact on those waterbodies, and which supporting elements of WFD status or potential are likely to be affected

b. a detailed compliance assessment of those project elements that cannot be screened out as not having an impact on WFD objectives for potentially affected waterbodies.

WFD classification process

L.2.8 Prior to detailing the assessment process and results, this section of the report details what constitutes a waterbody's status/potential under the WFD.

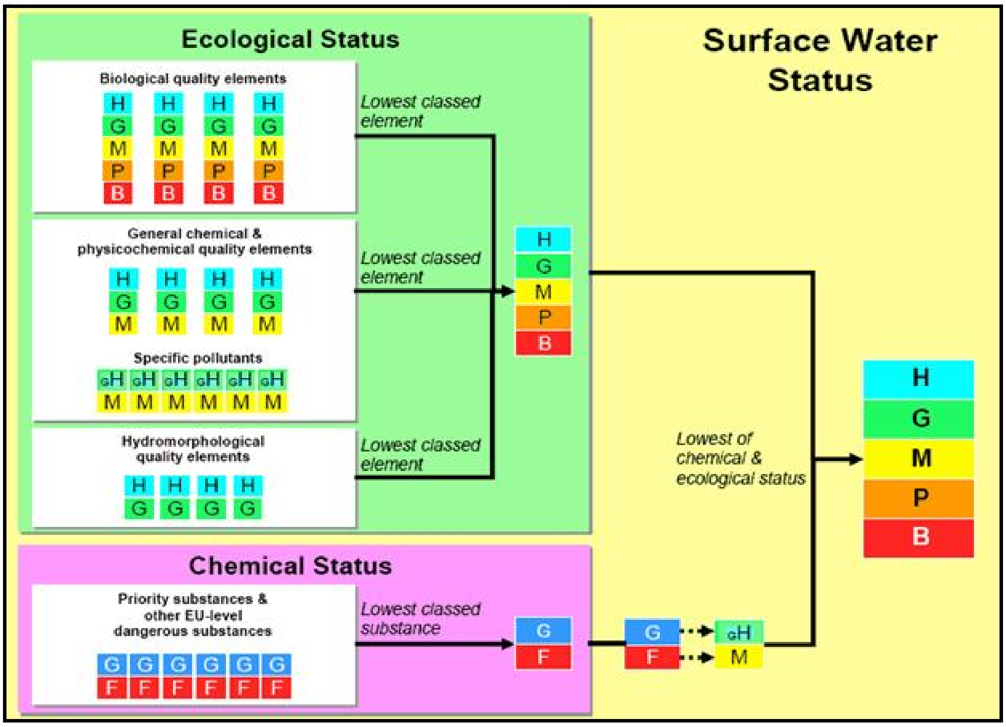
[iii] All surface waterbodies affected by the project are HMWBs and as such, are assessed for potential as opposed to status

Surface waterbodies

L.2.9 Application of the WFD by the EA involves allocating an overall status/potential classification to all surface waterbodies, on a scale of high, good, moderate, poor and bad, where high represents largely undisturbed conditions.

L.2.10 The overall status/potential for surface waterbodies is made up of two main elements; an ecological status/potential and (where applicable) a chemical status. An overview of the status elements is shown in Vol 3 Plate L.1 and explained in more detail below.

Vol 3 Plate L.1 Elements making up overall status/potential of a surface water body[5]



Ecological status colour key

Chemical status colour key

Ecological status/potential

L.2.11 Ecological status/potential is broken down into a range of supporting elements covering water quality parameters (physico-chemical and specific pollutants); biological indicators (eg, presence and diversity of fish); and the amount of water and physical condition (or physical form) of the waterbody (termed hydromorphology).

L.2.12 The physico-chemical assessment uses elements such as temperature and nutrient levels, which support the biological communities. The hydromorphological assessment uses water flow, sediment composition and movement, continuity (in rivers) and the structure of physical habitat.

L.2.13 The waterbody ecological status is classified on the scale of high, good, moderate, poor and bad, where high represents largely undisturbed conditions. The classification is based on the lowest (worst) scoring quality element; known as the 'one-out-all-out' approach. For example, if a waterbody achieved good status for physico-chemical assessments, but only achieved moderate status for the biological assessment; it would be classed overall as having moderate ecological status. It is also important to note that water quality supporting elements can only influence status down to moderate; as such, only biological elements can determine poor or bad status[6].

L.2.14 In addition, Heavily Modified Waterbodies (HMWBs) have an additional classification step that considers whether all the mitigation measures that are required in order to reach good potential are in place (see Annex A and Annex D). If they are not, the 'potential' of that waterbody is limited to moderate.

Chemical status

L.2.15 Chemical status is recorded as 'good' or 'fail' based on concentrations of a range of key pollutants that are priority substances and/or priority hazardous substances listed in the Environment Quality Standards Directive (2008/105/EC), known as 'Annex X' substances.

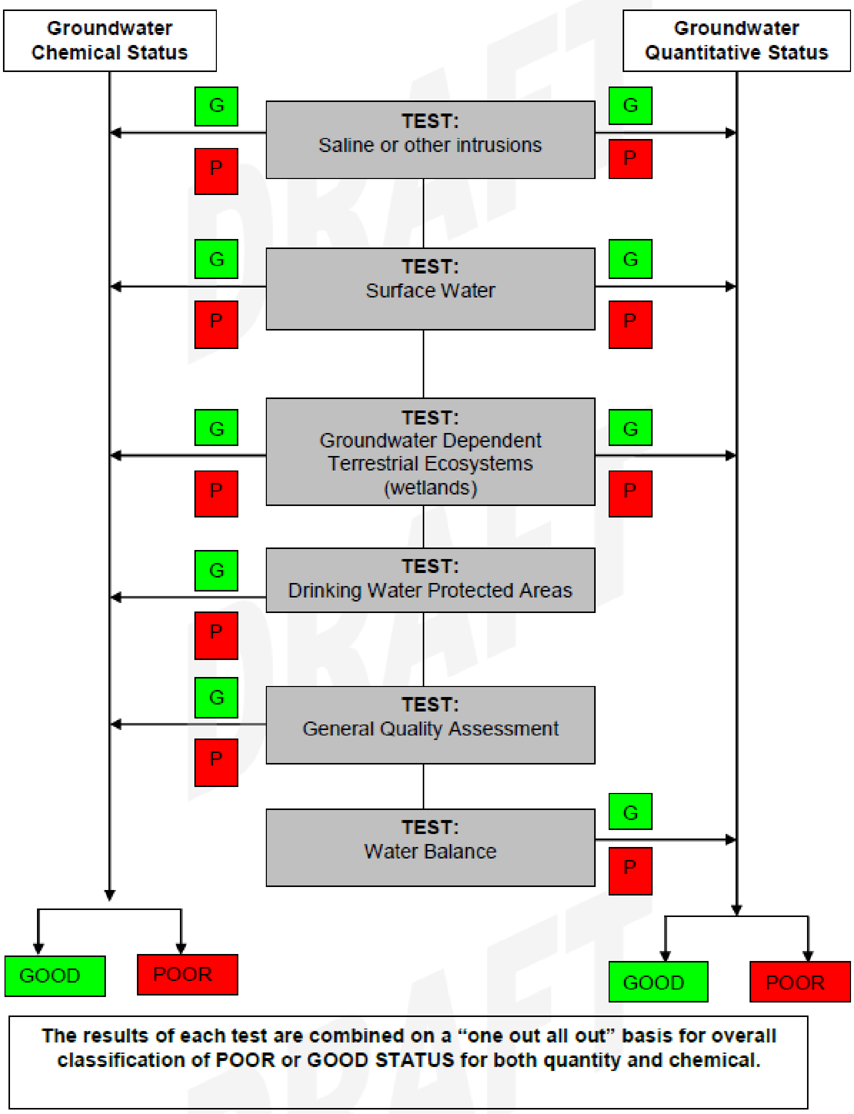
L.2.16 Chemical status is determined by the worst scoring chemical (known as the 'one-out-all-out' approach)[7]. Assessment of pollutants is only required in waterbodies where there are known discharges of these 'Annex X' substances.

Groundwater bodies

L.2.17 Application of the WFD by the EA involves allocating an overall status classification to all groundwater bodies, on a scale of good and bad, where good represents largely undisturbed conditions.

L.2.18 The overall status for groundwater bodies is made up of two main elements; a quantitative status and a chemical status. An overview of the elements that make up the status of groundwater bodies is shown in Vol 3 Plate L.2 and explained in more detail below.

Vol 3 Plate L.2 Elements making up overall status of a groundwater body[8]



Quantitative status

L.2.19 Quantitative status is recorded as good or poor based on the overall measure of the water balance of the groundwater body and on three other tests that must be satisfied for the groundwater body to be at good status (Vol 3 Plate L.2). This includes impacts to Groundwater Dependent Terrestrial Ecosystems (GWDTEs), surface water and saline or other intrusions.

L.2.20 Quantitative status is determined by the worst case classification from the four quantitative tests and is reported as the overall quantitative status.

Chemical status

L.2.21 Chemical status is recorded as good or poor based on threshold values for pollutants (or prescribed groundwater quality standards for nitrates and pesticides) that must be satisfied for the groundwater body to be at good status. This includes values for general quality and saline or other intrusions and for impacts to Drinking Water Protected Areas, GWDTEs and surface water bodies.

L.2.22 Chemical status is determined by the worst classification from the five chemical tests and is reported as the overall chemical status.

Preliminary assessment

Methodology overview

L.2.23 As explained in para. L.2.17, the WFD assessment has followed two stages; a preliminary assessment and a detailed assessment. The preliminary assessment undertook a high level review of the scheme and how it could either affect current Potential (for surface water) or Status (for groundwater) of any waterbody, or prevent future Good Potential or Good Status from being attained.

L.2.24 A series of project elements (or activities) for construction and operation of the scheme (eg requirement for foreshore sites) that could affect each of the WFD supporting elements for the waterbodies was derived. These project elements were used to undertake an impact screening process for the preliminary assessment and are detailed in Vol 3 Table L.1.

Vol 3 Table L.1 Project elements assessed

Construction (temporary)	Operation (permanent)
• Jetties • Campsheds • Dredging • Dewatering • Piling • Diaphragm walls • Grouting • Tunnelling	• Permanent Structures • Scour Protection measures • Combined sewer overflow (CSO) interception • Sustainable drainage systems (SuDS)

Surface waterbody assessment methodology

L.2.25 The first step of the preliminary assessment was the identification of the waterbodies that could be affected by the proposed development.

Waterbody identification

L.2.26 The main surface waterbodies affected by the project for all supporting WFD elements are the Thames Upper and Thames Middle waterbodies which, along with the Thames Lower waterbody make up the tidal Thames, as shown in Vol 3 Table L.2 below.

L.2.27 The Lower Thames was not considered in this assessment as there are no physical modifications required in this waterbody during construction or operation of the project. In addition, water quality modelling and the *Habitats Regulation Assessment: No Significant Effects Report* for the project has identified no significant effect from the operation of the project in this waterbody.

L.2.28 From a water quality perspective, the fluvial sections of the tributaries of the tidal Thames are not impacted directly (Beverley Brook, River Crane and Ravensbourne) although there is the potential for indirect effects through impacts on mobile ecological populations (eg, fish). The tidal sections of these tributaries are included within the Thames Upper and Thames Middle waterbodies and the water quality effects on these waterbodies therefore have not been considered separately. The exception is the River Wandle which has the potential to be directly affected from the combined sewer overflow (CSO) interception at King Georges Park and water quality elements are therefore considered for this waterbody.

L.2.29 The River Lee Navigation (tidal section) is not fully tidal, as it is dependent on the overtopping of the Prescott Lock during high tide events. As the proposed works at the Abbey Mills Pumping Station site lie downstream of this, there is no potential for the River Lee (tidal section) to be affected by the proposed development and it has therefore not been considered within this assessment.

L.2.30 The Regents Canal was also considered within the screening assessment. However, the lock gates in the Limehouse Basin at the confluence of the Regents Canal and the tidal Thames are only opened intermittently for the passage of individual boats for four hours either side of high tide, which therefore prevent water movement for the majority of the time. The water quality effects of the proposed development have therefore not been assessed for the Regents Canal.

L.2.31 From a biological and hydromorphological perspective, the aforementioned tributaries have been assessed separately to the tidal Thames waterbodies because there could be the potential for the Thames Tideway Tunnel project to deliver some of the mitigation measures listed in the Thames RBMP[iv] for these waterbodies as part of wider mitigation measures being considered for the project. The biological components have also been considered because the organisms within the waterbodies are mobile, particularly in the case of fish, and the water quality effects of the proposed development would affect populations that use the both the tidal and fluvial waterbodies during their lifecycle.

L.2.32 The current and target overall status of each of these waterbodies is given below in Vol 3 Table L.2. The worst scoring quality element (ie, the component determining the current status as per para. L.2.13) is also shown. It should be noted that all of the surface waterbodies affected (directly or indirectly) are either HMWBs or Artificial Waterbodies (AWB) and hence are considered for their ‘Ecological Potential’ as opposed to ‘Status’.

[iv] This is subject to EA confirmation of which of the RBMP planned actions are scheduled for delivery in the next RBMP round. Appendix B details the mitigation measures listed in the RBMP for each waterbody.

Vol 3 Table L.2 Surface waterbodies status classified by WFD

Water body name/ID	Hydro-morphological status	Current ecological Potential	Current chemical Status	Worst scoring quality element	2015 predicted ecological Status	2015 predicted chemical Status
Thames Upper GB530603911403	Heavily modified	Moderate	Good	Not all mitigation measures in place[v] (Moderate)	Moderate	Good
Thames Middle GB530603911402	Heavily modified	Moderate	Fail	Not all mitigation measures in place (Moderate)	Moderate	Fail
Beverley Brook (Motspur Park to Thames) and Pyl Brook at West Barnes GB106039022850	Heavily modified	Poor	Fail	Fish and macrophytes (Poor)	Moderate	Fail
Wandle (Croydon to Wandsworth) and the R. Gravney GB106039023460	Heavily modified	Poor	Good	Fish and phytobenthos (Poor)	Poor	Good

[v] if not all the mitigation measures that are required for a HMWB to reach Good Potential are in place, then the Potential of that waterbody is limited to Moderate. Mitigation examples include operational and structural changes to locks, sluices, weirs, beach control and management of sediment.

Surface water assessment approach

L.2.33 For each surface waterbody the current and target Potential was identified for each of the WFD supporting elements that make up the Potential classification of the waterbody.

L.2.34 Each WFD supporting element was assessed against each of the identified project elements. Each project element was considered in terms of whether it could:

a. result in deterioration of the classification for that supporting element; or

b. prevent delivery of any of the mitigation measures identified as being required to move failing waterbodies to their target Potential.

L.2.35 The supporting elements considered are for transitional waterbodies as listed in EA guidance[9] (EA, 2010). These elements and the current classification for each of these elements are detailed in Vol 3 Table L.3 for each waterbody.

Vol 3 Table L.3 WFD supporting elements and current classification for each surface waterbody

WFD supporting Element	WFD Quality Element	Thames Upper GB530603911403	Thames Middle GB530603911402	Beverley Brook (Motspur Park to Thames) and Pyl Brook at West Barnes GB106039022850	Wandle (Croydon to Wandsworth) and the R. Gravney GB106039023460
Hydromorphological elements	Hydrological Regime	No classification for HMWBs[vi]			
	River Continuity	No classification for HMWBs			
	Morphological conditions	No classification for HMWBs			
	Tidal Regime	No classification for HMWBs			
Biological Elements	Macroalgae	Moderate	High	Not listed in the RBMP	Not listed in the RBMP
	Phytobenthos	Not listed in the RBMP	Not listed in the RBMP	Moderate	Not listed in the RBMP
	Benthic Invertebrate fauna	Moderate	Moderate	Moderate	Good
	Fish Fauna	Moderate	Moderate	Poor	Poor
Critical Sensitive Habitats	Priority Habitats and species:	Intertidal mudflat Subtidal gravels Smelt	Intertidal mudflat Subtidal gravels Smelt	Not listed in the RBMP	Not listed in the RBMP

[vi] There is no classification for hydromorphological supporting elements for HMWBs, however the effect of the scheme on these elements has been assessed as the elements form a key component part of the biological supporting element assessment,

WFD supporting Element	WFD Quality Element	Thames Upper GB530603911403	Thames Middle GB530603911402	Beverley Brook (Motspur Park to Thames) and Pyl Brook at West Barnes GB106039022850	Wandle (Croydon to Wandsworth) and the R. Gravney GB106039023460
		Eel	Eel		
Physico-chemical elements	Nutrient concentrations (Dissolved Inorganic nitrogen)	Not listed in the RBMP	Moderate	Not classified in RBMP	Not classified in RBMP
	Oxygen balance	Good	Moderate	Good	High
Chemical elements	Priority or other substances	Good	Fail	Fail	Good

L.2.36 The following WFD supporting elements were not considered in the preliminary assessment and hence are not included in Vol 3 Table L.3:

a. Protected Sites – there are no protected sites within any of the waterbodies included within the assessment and the separate HRA identified no significant impacts on sites within the Lower Thames waterbody

b. Phytoplankton – phytoplankton have been scoped out of the EIA, and therefore also scoped out of the assessment of ecological status in this WFD assessment, as the proposed development is considered unlikely to have significant effects on this receptor. Phytoplankton abundance and the occurrence of 'blooms' is largely a function of nutrient loading and water column clarity and although there would be some removal of nutrients and suspended solids through the secondary treatment process at Beckton Sewage Treatment Works (STW), it is not considered likely to significantly affect phytoplankton abundance or composition.

c. Other aquatic flora, including angiosperms, sea grass, seaweed, and habitats including salt marsh, which make up component parts of the biological supporting elements, have also been scoped out of the WFD assessment on the basis that they do not occur within the waterbodies likely to be affected by the scheme.

d. Physico-chemical elements – The following parameters do not have an impact pathway associated with any of the project elements and hence were not included in the assessment: salinity, pH, acid neutralising capacity, or temperature.

L.2.37 In determining potential for deterioration, reference was made to the EA's published document on classification of surface waterbodies and for the impact on mitigation measures (see Annex A) reference has been made to the Thames RBMP[10].

L.2.38 With respect to the specific assessment of the fish fauna supporting element, the potential hydraulic impact of the temporary and permanent structures on fish migration was assessed for the EIA using an Individual Based Modelling (IBM) approach. 'Virtual' fish have been introduced into the existing hydraulic model of the tidal Thames, which incorporates the temporary and permanent Thames Tideway Tunnel structures. The model was used to measure the time taken for a shoal of fish to migrate through the tidal Thames, with and without the temporary and permanent Thames Tideway Tunnel project structures.

L.2.39 It should be noted that the preliminary assessment was based on readily available information and assessments already undertaken for the *Environmental Statement* and hence no further modelling or assessment was undertaken. However, the preliminary assessment did benefit from a site walkover (for foreshore sites) by a geomorphologist.

Future Good Potential - mitigation base case

L.2.40 As described in para. L.2.14 HMWBs have an additional classification step that considers whether all the mitigation measures that are required in order to reach good potential are in place. If they are not, the ‘potential of that waterbody is limited to moderate.

L.2.41 In order to assess whether the proposed development would prevent the waterbodies assessed reaching good potential, it is necessary to consider whether it would prevent any of the mitigation measures listed in the RBMP being implemented by 2027. The RBMP lists numerous mitigation measures for each of the waterbodies that have been assessed; these are listed in Annex A. However, many of these proposed measures are fairly generic in nature and it is therefore necessary to refine them and to quantify which of them is likely to be implemented by 2027. This can then form the base case against which the effects on RBMP mitigation measures can be assessed.

L.2.42 At the time of completing the detailed assessment, the EA was preparing the next round of RBMP, due for publication in 2015, with the Stage 3 outputs due in December 2012. The Stage 3 work is due to identify broad areas in the tidal Thames and its tributaries where mitigation measures could be delivered. However, as this was not available for the purposes of this assessment, a judgement has been taken as to whether the mitigation measures are likely to be implemented by 2027. This has been based on discussions and information obtained for the *Environmental Statement*, or where no information was available, a precautionary approach was taken and it was assumed that the mitigation measure would be implemented. The relevant policies in the Thames Estuary 2100 (TE2100) project (EA, 2012)[11] have also been referenced.

L.2.43 The assessment of the mitigation measures likely to be implemented by 2027, and therefore the base case against which the effects of the proposed development on the mitigation measures have been assessed is given in Annex C.

Groundwater body assessment methodology

Waterbody identification

L.2.44 The Thames RBMP shows a groundwater body designation for the Greenwich Tertiaries (Lambeth Group, Thanet Sands, and Blackheath Formation and the overlying alluvium and River Terrace Deposits where the London Clay is absent) and the Chalk across the Thames Tideway Tunnel project area.

L.2.45 The current and target status of this groundwater body is given below in Vol 3 Table L.4, the worst scoring chemical and quantitative elements (ie, the component determining the current status) are also shown. The overall objective is to achieve good status by 2027.

Vol 3 Table L.4 Groundwater body status classified by WFD

Water body name/ID	Current chemical status	Current quantitative status	2015 predicted chemical status	2015 predicted quantitative status	Justification of failures
Greenwich Tertiaries and Chalk GB40602G602500	Poor (Poor for impacts to surface waters and for saline or other intrusions)	Poor (Poor for impacts to Drinking Water Protected Areas and for saline or other intrusions)	Poor	Poor	Impact on surface waters and saline intrusion - disproportionately expensive Drinking Water Protected Area – technically infeasible

L.2.46 This groundwater body is penetrated at depth by the shafts and tunnels at the Kirtling Street, Albert Embankment Foreshore and Blackfriars Bridge Foreshore sites within the central area of the proposed Thames Tideway Tunnel project area. In addition, it is also penetrated at the Chambers Wharf, King Edward Memorial Park Foreshore, Earl Pumping Station, Deptford Church Street, Greenwich Pumping Station, Abbey Mills Pumping Station and Beckton Sewage Treatment Works sites within the eastern area. The groundwater body outcrops at the surface within the eastern area and includes the overlying alluvium and River Terrace Deposits around Earl Pumping Station, Deptford Church Street and Greenwich Pumping Station sites, where the London Clay is absent.

Groundwater assessment approach

L.2.47 The preliminary assessment for groundwater has been undertaken in consultation with the EA team working on WFD groundwater quantitative assessment. The 2012 EA publication ‘Groundwater Protection – Principles and Practice (GP3) (EA, 2012)[12], was recommended as a key piece of overall guidance for groundwater.

L.2.48 Once the groundwater bodies and their current (and target) objectives were identified, each of the supporting elements were assessed against each of the identified project elements or activities to determine if the proposed development could have the potential to deteriorate the current status of the groundwater body and thereby potentially cause deterioration in the status, or prevent good status being achieved in the future.

L.2.49 In accordance with the EA guidance (EA, 2010)[13] where impacts are considered temporary (ie, less than 6 years or recover without the need for any restoration measures before the next RBMP) these were considered not to constitute deterioration of status and further assessment was considered not to be required.

L.2.50 The WFD supporting elements or criteria for assessing potential of the development to cause deterioration in element classification were selected with reference to the UKTAG published documents on chemical classification of groundwater bodies[14], on quantitative classification of groundwater bodies[15] and on determining 'significant damage' to GWDTE's[16]. This follows a similar approach to the assessment of effects on surface waterbodies and also incorporates specific criteria recommended for inclusion through consultation with the EA team working on WFD groundwater quantitative assessment. These criteria include:

a. screening against the Drinking Water Standard[17] for chemical status

b. screening against any potential impact to wetlands, surface waterbodies, licensed abstractions and resource availability status of the groundwater management unit in the London Catchment Abstraction Management Strategy (CAMS)[18] for quantitative status.

L.2.51 As with the surface waterbody assessment, the screening assessment for groundwater bodies was based on readily available information and assessments already undertaken for the *Environmental Statement* and hence no further modelling or assessment was undertaken.

Preliminary assessment results

L.2.52 Annexes B and C contain the detailed results of the preliminary assessment of the scheme elements against each of the waterbodies' supporting WFD elements and mitigation measures.

L.2.53 For the assessment of whether the proposed development would result in deterioration of the classification for a particular supporting element (the 'no deterioration' assessment), a tabulated assessment has been provided for each of the potentially affected waterbodies (surface and groundwater) and includes WFD supporting elements for transitional and groundwater waterbodies (see Annex B).

L.2.54 The tables detail how the hydromorphological, biological and physico-chemical elements have been considered for surface waterbodies current classification and how the supporting elements of current qualitative and quantitative status for groundwater bodies have been considered.

L.2.55 Annex C contains the details of the assessment of each of the project elements against each HMWB's mitigation measures that are not currently in place, and hence details where project elements have the potential to impact on future attainment of good potential.

L.2.56 A summary of results is provided in this section of the report for the assessment of:

a. the project elements on the 'no deterioration' objective of the WFD (see para. L.2.2 for details on the objective)

b. the project elements on the attainment of the target Potential/Status of the waterbodies (see para. L.2.2 for details on the objectives)

c. the cumulative impacts on WFD compliance

d. impacts on sensitive species.

L.2.57 All project elements that could not be screened out in the preliminary assessment have been taken forward to the detailed assessment reported in this report.

Screening summary - No deterioration

L.2.58 The following WFD supporting elements have been screened out following the preliminary assessment and it can be concluded that no project elements would significantly affect on the current classification of these supporting element for the waterbodies.

a. Hydrological regime – hydraulic modelling carried out for the project (see Vol 3 Appendix M.1) has shown that although small localised impacts on flow dynamics would result from both the temporary and permanent structures, this would not affect the quantity of flow in any of the waterbodies assessed.

b. Migration of fish - the technical report accompanying the Fish Risk Modelling study undertaken for the EIA concluded that there was no statistical difference between the time taken for the shoals of fish to migrate through the tidal Thames with or without the temporary and permanent structures. Although changes in water velocity caused by constriction in the channel may hinder movements of fish against the tide, including their ability to withstand, or hold station in the flow, the adverse effects were offset by the minor beneficial effects arising from increased opportunities for shelter.

c. Migration of aquatic mammals - the hydraulic impact of the temporary and permanent structures on the migration of marine mammals within the tidal Thames (comprising various cetacean and piniped species) was considered to be negligible. The effects of noise on migratory patterns were also considered. Given the vibro piling techniques proposed for construction of the cofferdam structures, effects were not considered significant.

d. Quantitative elements of groundwater bodies would not be affected by dewatering, as dewatering internal to diaphragm walls and ground freezing is proposed, which would limit the amount of dewatering required. These elements would also not be affected by permanent structures obstructing groundwater flow, as these impacts would be localised and insignificant; and by seepage into shafts and tunnels, as the lining would limit the theoretical seepage volumes.

e. Chemical elements of groundwater bodies would not be affected by dewatering, as the dewatering internal to diaphragm walls and ground freezing proposals would limit the movement of poor quality groundwater. These elements would also not be affected by grouting and creating contaminant pathways, as the application would prevent the loss of hazardous substances and would control loss of non-hazardous substances to groundwater; and by seepage from shafts and tunnels, as the lining would limit the theoretical seepage volumes. All projects components have therefore been screened out for impact on groundwater.

L.2.59 The assessment demonstrated that the following WFD supporting elements could be adversely affected by the proposed development and hence the project elements impacting on these supporting elements have been considered further in a detailed assessment:

a. morphological conditions (river depth and width variation, and structure and substrate of the river bed and the riparian zone/intertidal zone)

b. benthic invertebrate fauna (composition and abundance)

c. fish fauna (species composition and abundance, presence of type-specific disturbance sensitive species and age structure of fish communities)

d. priority habitats and species ie, Common smelt (Osmerus eperlanus) and European eel (Anguilla anguilla), and intertidal mudflats and subtidal gravels.

L.2.60 The following WFD supporting elements could be beneficially affected by the proposed development and hence the project elements impacting on these supporting elements should be considered further in a detailed assessment:

a. river continuity (sediment transport)

b. macrophytes and phytobenthos (taxonomic composition)

c. physico-chemical elements (nutrient concentrations and oxygen balance) which would in turn have beneficial effects on ecological communities

d. chemical elements of groundwater bodies by the reduction in pollution, by priority and other substances, being discharged into the water body.

Screening summary – future Good Potential

L.2.61 To ensure no impact on future GEP in the affected waterbodies, the screening assessment included details of each of the identified measures that are not currently in place that could be affected in their future delivery by the proposed development. 'Identified measures' refers to the programme of measures developed as part of the Thames RBMP which are needed to move failing waterbodies towards their future target status or Potential. The mitigation measures identified as not being in place in the RBMP for each waterbody are given in Annex A.

L.2.62 During the process undertaken for the WFD assessment of the project, the EA was not able to confirm which of the proposed RBMP mitigation measures are scheduled for delivery in the next round of RBMP. This is because, at the time of undertaking the assessment work, the EA was assessing each of the possible mitigation measures for their 'technical feasibility' and consideration of cost of delivery and whether it would be 'disproportionate' as required by the directive. Therefore, for the purposes of this assessment, a view has been taken as to which of the possible mitigation measures are likely to be implemented by 2027 and an assessment carried out of whether the proposed development has the potential to affect their delivery. This is reported in Annex C and a summary of the project elements which could affect the delivery of mitigation measures and therefore prevent future Good Potential are detailed in Vol 3 Table L.5 below.

Vol 3 Table L.5 Project elements potentially adversely affecting mitigation measures

Surface Waterbody	Mitigation measure affected	Project Elements	Reason for not screening out of assessment
Thames Upper & Thames Middle	Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone	Permanent structures, scour protection	The requirement for permanent structures and permanent scour protection on the foreshore could affect 'good potential' in relation to marginal aquatic habitat and riparian zone

Delivery of offsite mitigation measures

L.2.63 As noted in para. L.2.31, there could be the potential for the Thames Tideway Tunnel to deliver some of the mitigation measures listed in the Thames RBMP. This is because a number of potential offsite compensation schemes have been identified to offset significant effects assessed in the EIA on intertidal and subtidal habitats.

L.2.64 All of the offsite compensation schemes under consideration are located on tributary watercourses (River Crane/Duke of Northumberland River, River Wandle and River Ravensbourne). The potential benefits of these compensation schemes have been considered within the WFD assessment, as shown in Annex B.

L.2.65 Details of the potential schemes are provided below:

a. River Crane/ Duke of Northumberland River: Multi-species fish pass would be fitted to the Kidds Mill Sluice at the mouth of the Duke of Northumberland River and the Mogden STW weir on the River Crane would be removed. This would improve the access for fish into freshwater reaches of the River Crane, with the aim of improving spawning success and migration for freshwater and diadromous species.

b. River Wandle: Fish pass on the Bell Lane Sluice at the upstream end of the Bell Lane Creek (a side spill of the River Wandle). This would improve migration of fish species into the freshwater reaches of the Wandle with benefits to the composition and abundance, presence of type-specific species and the age demographic of the fish population.

c. River Ravensbourne: Notching of the Weir at Lewisham College on the River Ravensbourne. This would improve migration of fish species into the freshwater reaches of the Ravensbourne with benefits to the composition and abundance, presence of type-specific species and the age demographic of the fish population.

Potential cumulative impacts

L.2.66 No other projects have been identified that have the potential for cumulative impacts on the waterbodies assessed within this WFD assessment.

Sensitive habitats and species check

L.2.67 Two sensitive habitats (intertidal mudflat, and intertidal and subtidal gravels) and two sensitive species (Common smelt *Osmerus eperlanus* and European eel *Anguilla anguilla*) have been identified by the screening assessment. The potential effects on these are identified in Annex B, and include adverse effects from land take (reducing available spawning grounds, and feeding, resting and nursery habitat) and piling noise, but beneficial effects improved water quality, which would result in reduced hypoxia.

Detailed assessment

Project elements - detailed assessment scope

L.2.68 The following project elements could potentially affect (adversely or beneficially) one or more of the WFD supporting elements for the identified waterbodies and these have been assessed in detail in this section of the report. The waterbodies that could be affected are shown in parenthesis.

L.2.69 These project elements have the potential to either cause a change in classification (adverse or beneficial), or prevent future good potential from being attained.

a. Campsheds – adverse. Construction of campsheds would result in temporary land take from spawning, feeding resting and nursery habitat (Thames Upper and Thames Middle).

b. Dredging – adverse. Dredging would result in disturbance to burrowing and feeding habitat (Thames Upper and Thames Middle).

c. Piling – adverse. Piling noise may impact fish species (Thames Upper and Thames Middle).

d. Permanent structures – adverse. Channel narrowing by piling and permanent structures are likely to have minor effects on flow dynamics (turbulence and velocity) and sediment transport, scour and deposition of substrate habitats up and downstream. Permanent loss of burrowing and feeding habitat from intertidal and subtidal areas. Permanent loss of habitat for all ages of fish (Thames Upper and Thames Middle)

e. CSO interception – beneficial.

i The Thames Tideway Tunnel project would result in an improvement in dissolved oxygen (DO) levels in the tidal Thames and an annual decrease in sediment loads to the tidal Thames of 2,181,900kg (12.3% decrease from the base case with the Lee Tunnel and proposed STW upgrades in place). The decrease in sediment loads would reduce fine sediment influx to local substrate habitats and the improved water quality would result in increase in pollution sensitive species. Improved water quality and reduction in sewage derived litter would improve habitat quality (Thames Upper and Thames Middle).

ii The Thames Tideway Tunnel project would also result in an improvement in DO levels in the River Wandle as a result of decreased spill volume, frequency and duration from the Frogmore Strom Relief – Buckhold Road CSO. The resultant decrease in sediment loads to the River Wandle would reduce fine sediment influx to local substrate habitats and the improved water quality will result in increase in pollution sensitive species. Improved water quality and reduction in sewage derived litter will improve habitat quality (Wandle).

f. SuDS – beneficial. SuDS would help to control surface water pollution and the discharge of priority and other substances via surface water run-off (Thames Upper and Thames Middle)

g. Mitigation – beneficial.

i Water quality improvements resulting from CSO interception and planting on permanent structures would enhance macrophyte habitat and assist towards mitigation measure 'preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone' (Thames Upper and Thames Middle). Installation of SuDS at the King George's Park site would assist towards mitigation measure 'appropriate techniques to align and attenuate flow to limit detrimental effects of these features (drainage)' (Wandle).

ii Notching of the weir as part of the proposed Lewisham College Tidal Weir Notch Compensation Scheme (para. L.2.65) would allow more migratory fish movement into the upstream reaches, which would result in improved species richness and abundance moving upstream from the Thames Middle waterbody. This would assist towards the RBMP mitigation measures 'preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone' and 'preserve and, where possible, restore historic aquatic habitats' (Ravensbourne).

iii Inclusion of a multi species fish pass and removal of the weir at Mogden STW as part of the Kidds Mill Sluice Fish Pass Implementation and Mogden STW Weir Removal Compensation Schemes would allow more migratory fish movement into the upstream reaches, which would result in improved species richness and abundance moving upstream from the Thames Upper waterbody. This would assist towards the RBMP mitigation measure 'Preserve and, where possible, restore historic aquatic habitats' (Crane).

Detailed assessment methodologies

L.2.70 Each of the project elements screened in from the preliminary assessment have been assessed in detail against each of the WFD supporting elements for each waterbody.

L.2.71 The assessment is presented under each of the project elements, with subsections for each WFD supporting element that could be affected and a summary of whether it could cause deterioration of current potential or prevent future good potential from being attained.

Hydromorphological elements

L.2.72 The assessment of potential effects on the hydromorphological elements of the waterbodies WFD classification was carried out in accordance with the EA's guidance (EA, 2010)[19] (also see Annex E).

L.2.73 The proposed landscape depression area (for flood conveyance purposes) in King George's Park has not been assessed. While the flood compensation area lies within the flood plain (Flood Zone 3) of the River Wandle, it is approximately 250m from the watercourse, which is culverted at its nearest point. The proposed flood storage area therefore does not have the potential to affect the River Wandle.

L.2.74 Bed protection – scour protection at new CSO outfalls (ie, Putney Bridge CSO, Heathwall Pumping Station and South West Storm Relief CSOs) does not impact on more than1% of the waterbody and this has therefore not been subject to detailed assessment. Similarly the proposed embankment / flood banks, revetments, walls, structures such as small boat slipways, piers, jetties and platforms have not been assessed here, as those proposed would be replacement structures.

L.2.75 The removal of natural barriers (removal of waterfalls and other in-stream natural barriers, usually to permit upstream fish migration) has not been assessed. Some of the proposed mitigation schemes identified in para. L.2.65 include the removal of barriers to upstream fish passage; however, these will not be included within the application for development consent (the 'application'). When these schemes have been agreed and finalised they will be subject to a separate consent application and therefore a separate WFD assessment.

L.2.76 The hydromorphological effects of the scheme have been assessed in terms of channel depth and width variation, the structure and substrates of the bed, the conditions of the channel banks, the structure of the riparian zone / intertidal zone, and downstream connectivity.

Physico-chemical and chemical elements

L.2.77 The assessment of potential effects on the physico-chemical and chemical elements of the waterbodies' WFD classification has been undertaken using modelling that has informed water quality assessment in the EIA (see Vol 2 Section 14).

L.2.78 Thames Water characterises the operation of the sewer network in London through the use of a series of models. Catchment models for the five sewage treatment works (STWs) (Mogden, Beckton, Crossness, Long

Reach and Riverside) have been developed by Thames Water. Each of the catchment models is able to represent flow and water quality conditions in each of the main network catchments and predict frequency, volume and duration of spills from CSOs in response to rainfall events. The catchment models represent dry weather flow[vii] (DWF) and storm flow and water quality conditions in each catchment's main sewer network and predict the frequency, volume and duration of CSO spills in response to rainfall events.

L.2.79 Future conditions in the tidal Thames have been simulated using the InfoWorks CS wastewater modelling package and the QUESTS river water quality model (WQM). WRc developed the QUESTS WQM on behalf of the EA and the Port of London Authority (PLA). The model predicts effects on the DO levels of the tidal Thames from CSO discharges and STW discharges as well as changes in natural processes. The QUESTS model was used during the *Thames Tideway Strategic Study (TTSS)* (Thames Water, 2005)[20]. The remit of which was to identify and develop potential solutions to the CSO discharges, with the ultimate aim of improving the water quality of the tidal Thames and its ecology.

L.2.80 The models described above have been used to define five modelled scenarios as follows:

a. Scenario 1 which is the current operation of the CSOs in response to different rainfall events, both in terms of the quantity and quality of the discharged flow. This has been modelled as a scenario which uses 2006 population figures, current rainfall data and existing sewage works capacities

b. Scenario 2 is the base case which incorporates the impact that predicted changes in population would have on wastewater flows in London's sewer network by 2021, as well as the effect of other major schemes which are also likely to affect water quality in the tidal Thames. The latter includes the effect of the sewage works upgrades at Mogden, Beckton, Crossness, Long Reach and Riverside STWs and the Lee Tunnel once brought into operation.

c. Scenario 3 is the proposed development case once the Thames Tideway Tunnel project is in place and includes the base case described under Scenario 2. This scenario is only applicable to the operational effects assessment.

d. Scenario 4 is the 2080 base case without the Thames Tideway Tunnel project. This simulation includes predicted population estimates, sea level change and estimated river and environmental conditions. This scenario also assumes that the Lee Tunnel and proposed sewage works upgrades are in place.

e. Scenario 5 shows the effects of climate change. This uses predicted 2080 conditions including population estimates, sea level change and estimated river and environmental conditions. This scenario assumes that the Lee Tunnel, STW improvements and Thames Tideway Tunnel

[vii] Dry weather flow is foul water flow contribution during periods of dry weather

project are all in place. As above, this scenario is only applicable to the operational effects assessment.

L.2.81 The full year CSO performance along the tidal Thames for the five scenarios described above has been assessed against rainfall data for the 1979-1980 Typical Year. The Typical Year is a single water year from October 1979 to September 1980 selected from the 1970 to 2011 rainfall records and best represents the average rainfall over the Beckton and Crossness catchment.

L.2.82 The water quality assessment of the tidal Thames for the five scenarios described above have also been assessed against 242 summer rainfall events selected with climatic conditions to have an impact on DO levels in the tidal Thames. Conditions and rainfall are based on a CTP (compliance testing procedure) established during the TTSS. The CTP rainfall events were selected from rainfall data from 1970 to 2010.

Biological supporting elements

L.2.83 The preliminary assessment demonstrated that the following biological supporting elements could be adversely affected by the proposed development and hence required detailed assessment:

a. benthic invertebrate fauna

b. fish fauna

c. priority habitats and species ie, Common smelt (*Osmerus eperlanus*) and European eel (*Anguilla anguilla*), and

d. intertidal mudflats and subtidal gravels.

L.2.84 No established methodology exists for assessing the effects of a scheme against WFD objectives 1 (ie, no deterioration of status or potential) and 3 (achievement of good ecological potential).

L.2.85 Based on the EA WFD assessment guidance the assessment has considered the impacts of the project on each of the biological elements using the parameters which form the basis for the classification of status. For example, status classification for fish is based on 10 parameters which include species composition and abundance, age structure and the presence of disturbance sensitive species. Observed data for each of these parameters is compared with reference data taken from undisturbed waterbodies in order to give an Ecological Quality Ratio (EQR). EQR values close to one indicate conditions close to their natural state and those close to zero indicate high levels of pollution or disturbance.

L.2.86 Whilst it is not possible to use these tools directly to assess the effects of a development scheme, the parameters which underpin them provide the basis for assessment criteria. In this assessment professional judgement has been used to predict whether the development will alter any of these parameters and thereby change the status/potential of the individual biological element.

L.2.87 These parameters used for each of the biological elements are listed in Vol 3 Table L.6. There are no published parameters for measuring the priority habitats and species since they are not used as the basis for watercourse classification. Bespoke parameters have been devised for these elements.

Vol 3 Table L.6 Parameters used as assessment criteria for biological supporting elements scoped into the assessment

Biological supporting element	Parameters used as assessment criteria
Benthic invertebrate fauna	• Species composition • Abundance
Fish fauna	• Species composition and abundance • Presence of type-specific disturbance sensitive species • Age structure of fish communities
Priority species (Common smelt *Osmerus eperlanus*) and European eel *Anguilla anguilla*)	• Abundance • Habitat availability
Priority habitats - Intertidal mud flats and subtidal gravels	• Habitat extent • Habitat integrity

Project Element Assessment

Temporary In river structures

Hydromorphological Elements

L.2.88 There is the potential for adverse effects from the in-river structures (ie, cofferdams, campsheds, piled jetties and scour protection). The construction of these structures has the potential to cause localised effects, which could alter flow dynamics (local turbulence and increased cross-sectional flow velocities due to channel narrowing), and the continuity of sediment transport and scouring and deposition, upstream and downstream of the foreshore sites.

L.2.89 The potential hydromorphological effects of the project were identified in the screening assessment as:

a. reduced sediment loadings

b. direct habitat losses, due to installation of permanent structures and scour protection to prevent structures being undermined

c. indirect habitat losses, due to locally altered flow dynamics and associated scour away from structures.

L.2.90 Given the heavily modified nature of the waterbody, no significant effects (either positive or negative) have been identified on the channel banks or riparian zones. Due to the distances the proposed structures would encroach into the foreshore areas of the channel there would be no impacts on downstream connectivity.

L.2.91 Reduced sediment loadings would have a positive effect on the hydromorphological environment. Excessive fine sediment decreases light penetration through the water column, thereby decreasing primary production, and can alter bed substrate composition with four primary effects on intertidal physical habitats and ecology:

a. reducing habitat space

b. physically abrading eggs in the channel bed

c. clogging interstitial pore spaces at the surface of the bed and within the bed matrix, thereby inhibiting oxygen delivery to the bed and the removal of metabolic waste products

L.2.92 A reduction in sediment loads as a result of the scheme would therefore have a positive effect on bed substrate composition and hydromorphology in the intertidal area.

L.2.93 The assessment of scour that has been undertaken for the project (see Vol 3 Appendix L.3) demonstrated that scour could occur as a result of installation of structures for the scheme. Two main types of scour could occur:

a. contraction scour, brought about by flow acceleration due to channel constriction

b. local scour, associated with increased flow velocities due to turbulence and vortices induced around structures in the flow path.

L.2.94 Any potential scour development during construction would be monitored and if relevant trigger levels are reached, appropriate protection measures would be provided. Further details are provided in Vol 3 Appendix L.4. In addition to the proposed monitoring and mitigation, the ‘conveyer belt’ replenishment of substrates delivered primarily from upstream by fluvial processes would limit the formation of scour holes around structures. A change in substrate composition could occur adjacent to structures due to the preferential removal of smaller sands and gravels by locally increased flow velocities, to leave a bed dominated by larger substrates. This effect would be highly localised relative to the scale of the tidal Thames and would be negligible compared to the scale of the existing gravel habitats of the tidal Thames. The ecological gains that would result from reduced fine sediment deposition to gravel habitats would offset or exceed any small-scale habitat losses.

Biological Elements (benthic invertebrates, fish, priority habitat sand species)

Benthic invertebrates

L.2.95 There would be direct mortality of invertebrates within sediments affected by temporary land take for cofferdams and campsheds (3.5ha across the intertidal and subtidal zones within Thames Upper and Thames Middle), and due to consolidation and disturbance of sediment during the site establishment phase. The area beneath the temporary cofferdams would also be lost as burrowing and feeding habitat for invertebrates during the construction period.

L.2.96 There would be no change in species composition due to temporary land take. Although localised abundances of invertebrates would be depleted the area affected represents less than0.5% of the total area of the tidal Thames. Invertebrate communities are expected to recover following reinstatement of the temporary works.

L.2.97 No deterioration against current potential is therefore anticipated for benthic invertebrates.

L.2.98 Cofferdams and campsheds in the intertidal zone have the potential to prevent the RBMP mitigation measure to 'preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone' from being implemented in the Thames Tideway Tunnel foreshore site locations. However, the cofferdams and campsheds would be removed at most locations at the end of the six year construction period and those habitats outside the footprint of the permanent structure and scour protection restored. Although campsheds would be retained at Cremorne Wharf and Carnwath Road Riverside both of these sites are classified as working wharfs and are therefore unlikely to be considered for habitat enhancement.

Fish

L.2.99 There is potential for the temporary loss of spawning habitat at upstream sites such as the Carnwath Road Riverside site and possibly the Putney Embankment Foreshore site, which lie within the zone where smelt and dace are known to spawn[21]. However, encroachment of the structures into the subtidal zone, which is considered to offer the most suitable spawning habitat, is likely to be minimal. There would be approximately 2,160m^2 of temporary landtake from the subtidal at Carnwath Road Riverside if the jetty option (with associated campshed) is selected (option B) and none if the campsehd only option (option A) is selected. At Putney Embankment Foreshore there would be approximately 450m^2 of temporary landtake and 370m^2 of substrate modified due to scour protection measures. The effects of land take on spawning habitat are considered to be negligible if option A at Carnwath Road is selected. Effects on spawning habitat for smelt are discussed in L.2.109.

L.2.100 In most cases the foreshore construction sites lie primarily within the shallow intertidal zone of the river, which offers feeding and migratory habitat for juvenile fish. However, the intertidal habitats affected by land take, are well represented throughout the Upper and Middle Tideway. Temporary land take represents 0.15% of the area of intertidal and subtidal habitats in the Thames Middle and Upper. This magnitude of loss is not considered to affect the overall integrity of the habitat (ie, its ecological structure and function) or its functionality in supporting the range of species that characterise the River Thames and Tidal Tributaries Site of Importance for Nature Conservation (Grade III of Metropolitan importance)[viii].

[viii] The SINC (Grade M) is designated for a range of bird and fish species, including Common tern (*Sterna hirundo*), Reed Warbler (*Acrocephalus scirpaceus*), Grey Heron (*Ardea conerea*), Teal (*Anas crecca*), Bass (*Dicentrarchus labrax*), Eel (*Anguilla anguilla*) and Flounder (*Platichthys flesus*).

L.2.101 The individual and combined effects on fish of predicted changes in flow velocity associated with the temporary structures have been assessed using an individual based modelling (IBM) technique. Details of the model are provided in Vol 3 Section 5.5 and Vol 3 Appendix C.2. The study found that there were small, statistically significant differences in the rate of upriver migration between the base case and the temporary works scenarios. For example, for flounder there was a 3.3% difference in the mean (average) time taken for the population to undertake an upstream migration between the base case and temporary case. However, in real terms this represents a delay of a single tidal cycle, over a 5 day period, and is considered to arise as a result of the large size of the population sampled (2500 individuals) and therefore the inherent variation between individuals. Effects are thus considered to be negligible for flounder, eel and bass the three species used as surrogates for all Tideway fish species.

L.2.102 No effects on species composition or abundance are anticipated since the structures would not disproportionately affect the habitat of any one species and no mortality of fish is anticipated. However, there is the potential for juvenile fish to be affected since the temporary structures would result in the loss of intertidal feeding habitat important for the 0+ age class (young of the year) for a number freshwater estuarine resident and diadromous species such as dace, bass, flounder, and smelt. However, the proportion of this habitat type affected by temporary landtake is low (less than 0.5%).

L.2.103 There is also a risk that juvenile fish would be lost through being forced deeper water where current velocities and predation rates are higher. An IBM approach based on the 2D hydraulic model of the tidal Thames was used to simulate migration of juveniles through the estuary with and without the Thames Tideway Tunnel structures. The model was run for three species (bass, eel and flounder) considered to represent analogues for all fish species within the tidal Thames. The study found that the temporary structures had no significant effect on the time taken for fish to migrate through the estuary, and although predation rates increased as fish passed the structures mortality rates did not vary significantly from those recorded without the structures.

L.2.104 Overall, the temporary cofferdams and campsheds are not considered to affect the species composition and abundance, or the age structure of fish.

Other aquatic flora: Macroalgae

L.2.105 Macroalgal communities would be lost from the stretches of river wall immediately abutting and adjacent to the temporary and permanent cofferdams. In general the algal communities recorded at the Thames Tideway Tunnel project sites are characterised by widespread green algae species which are known to readily colonise new surfaces.

L.2.106 The presence of two marine red algal species (*R purpureum* and *P stricta*) at the Chambers Wharf site is notable since this is the most upstream record of these species. However, these species are widespread in the marine zone of the river and receive no legal protection.

L.2.107 No change in species composition of macro algal communities is anticipated as a result since the species recorded at each site were common and widespread throughout the tidal Thames.

Priority habitats and species

Smelt (*Osmerus eperlanus*)

L.2.108 Smelt are known to spawn on gravel habitats just below the low tide level in the upper tidal Thames in a zone extending from Wandsworth to Battersea[22] (Colclough et al 2002). Clean (ie, with a little or no silt) subtidal gravels are considered to be the most valuable spawning habitat since eggs are not at risk of being exposed to the air. Cofferdams and campsheds extending into the subtidal particularly at the Carnwath Road Riverside site and possibly at the Putney Embankment Foreshore site may result in the loss of spawning habitat.

L.2.109 The area of subtidal habitat affected by the works would be 2160m^2 if the campshed and jetty option (Option B) is selected at Carnwath Road. This represents 0.7% of the total area of spawning habitat. There would also be significant effects associated with lighting during the spring spawning season if option B were selected. Effects are not considered to be significant for option A in which the campshed is situated next to the river wall. Although there is a risk that smelt spawning success may be affected in the vicinity of the campsheds it is considered to be a sufficiently small area that no deterioration in current status is anticipated.

Eel (*Anguilla Anguilla*)

L.2.110 As a catadromous species juvenile or glass eels enter the Thames estuary and migrate upstream into freshwater tributaries. They use the shallow marginal habitats within the Tidal Thames to make their migrations. Structures which encroach into this habitat therefore have the potential to affect their migratory success. The approach to assessing the impact of the temporary and permanent structures on juvenile fish migrations is described in para. L.2.104. The modelling study found that there was no statistical difference in the rate at which juvenile eels migrated through the estuary for the three modelled scenarios (base case, with temporary structures, with permanent structures). The study is described in further detail in Vol 3 Section 5.6 and Vol 3 Appendix C.3.

Intertidal and subtidal gravels

L.2.111 In total the temporary structures would result in landtake of 2.2ha from intertidal habitat and 1.3ha from subtidal habitat, which represents 0.15% of the River Thames and tidal tributaries SINC (Grade M)[ix] and 0.46% of the intertidal and 0.08% of the subtidal habitats within this SINC. Foreshore construction sites would be in place for a maximum period of five and a half years, after which time it is estimated recovery of the foreshore would take between one and five years. This limited recovery duration would ensure that the target of GEP would not be compromised,

[ix] The SMI is designated for a range of bird and fish species, including Common Tern (*Sterna hirundo*), Reed Warbler (*Acrocephalus scirpaceus*) Grey Heron (*Ardea cinerea*), Teal (*Anas crecca*) Bass (*Dicentrarchus labrax*), Eel (Anguilla anguilla) and Flounder (*Platichthys flesus*).

as construction at the eleven sites with in-river structures (Putney Embankment Foreshore, Chelsea Embankment Foreshore, Albert Embankment Foreshore, Heathwall Pumping Station, Blackfriars Bridge Foreshore, Victoria Embankment Foreshore, King Edward Memorial Park, Chambers Wharf, Carnwath Road Riverside, Cremorne Wharf and Kirtling Street) would be complete by the end of 2021, which should ensure that recovery is complete by 2026 at the latest. This would therefore not prevent the achievement of good ecological status (GES) by 2027. The approach to reinstatement of the temporary works area is described in detail in Vol 3 Appendix C.4.

Permanent scour protection

L.2.112 At each of the foreshore sites there would be scour protection installed at the foot of the permanent CSO interception structure and a discharge apron at each site. This would consist of buried rip-rap which would be overlaid with an appropriate substrate material.

L.2.113 The scour protection is designed to minimise impacts on aquatic ecology receptors. Nevertheless, there would be effects on WFD biological elements including benthic invertebrates, fish and intertidal and subtidal habitats. Effects are assessed below.

Hydromorphological Elements

L.2.114 As the scour protection would be buried and covered with appropriate substrate material to the existing bed level, there would be no effects on the hydromorphology. No deterioration in the current WFD potential category is therefore anticipated.

Benthic invertebrates

L.2.115 The material overlying the rip rap would provide burrowing habitat for invertebrates, although the degree to which this material is scoured would depend on localised hydraulic conditions. Benthic invertebrates may thus be excluded from the areas where scour exposes the rip rap blocks. Pelagic invertebrates such as *G. zaddachi* may be attracted to these areas in order to shelter from the current.

L.2.116 No deterioration in the current WFD potential category is anticipated.

Fish (including priority species: smelt and European eel)

L.2.117 Scour protection measures would result in the modification of 3500m^2 of intertidal habitat and 3000m^2 of subtidal habitat within the Thames Upper and Middle. Whilst the buried rip rap offers some benefits for fish by improving the heterogeneity of otherwise uniform habitats, it is unlikely to have value as spawning habitat since smelt are known to select gravel habitats. However, since the area affected is small it is not considered likely to affect the availability of spawning habitat for smelt in the Thames Upper.

L.2.118 The rip rap areas may offer some benefits to juvenile fish by providing refuges from the current and from predators, particularly given its location within the shallow intertidal areas. In this respect it is analogous to artificial reef structures created in the marine environment to provide shelter for fish and increase the heterogeneity of otherwise uniform habitats.

L.2.119 Similarly, the rip rap may offer shelter for pelagic invertebrates such as *Gammarus* which represent a food source for some fish species. It is unlikely to have potential as feeding habitat for benthic feeding fish except where accretion allows colonisation by invertebrates.

L.2.120 No deterioration in the current WFD potential category is anticipated.

Intertidal habitat

L.2.121 The installation of buried rip rap as scour protection would lead to some permanent change in habitat structure in those affected areas. The rip rap would be overlain by material with a sufficiently large grain size to resist scour under normal flow conditions. Changes would therefore be most pronounced in those areas such as Victoria Embankment Foreshore where the intertidal zone is currently characterised by finer material such as sand, silt and fine gravels.

L.2.122 Although there may be some scour of material overlying the rip rap is expected to support habitat which can be colonised by benthic invertebrates.

Subtidal habitat

L.2.123 The granular material used to overlay the rip rap would be at greater risk of being removed by tidal currents in the subtidal zone. The existing subtidal habitats are heavily scoured by the current although the surface layers of substrate support an invertebrate community. In the areas affected by scour protection within the subtidal habitat with potential to support invertebrates and other aquatic fauna may accumulate in pockets between the rip rap blocks. The modification of the habitat is therefore likely to be more severe in the subtidal than in the intertidal.

L.2.124 Given the scale of the habitat subject to modification the scour protection is not considered to cause a deterioration in the current WFD potential category.

Dredging

L.2.125 Dredging is required within the area where barges would be moored at the Kirtling Street site (approximately 2500m^2, and in the area immediately surrounding the campshed at Carnwath Road Riverside (approximately 2160m^2). Dredging would also be undertaken at Blackfriars Bridge Foreshore to facilitate access for vessels to the new Millennium Pier location.

L.2.126 It would have the potential for impacts on benthic invertebrate fauna, fish and priority habitats and species. Effects on WFD objectives are discussed below.

Hydromorphological elements

L.2.127 The tidal Thames is already a very silty environment, with routine maintenance dredging carried out at several locations. The additional dredging from the proposed development would not have an effect as they would be offset by overall decrease from CSO capture and there would be a negligible effect on sediment release to the Tidal Thames.

Benthic invertebrates

L.2.128 There would be direct mortality and disturbance of subtidal habitats as a result of dredging. The area affected by dredging is limited and the habitat type, and therefore the invertebrate community is well represented throughout the tidal Thames.

L.2.129 Sediment would also be liberated during the dredging operation. However these would be negligible compared to the 40,000 tonnes of sediment (HR Wallingford, 2006)[23] that are carried on a spring tide. In this context, the volumes produced by would not be detectable against natural fluctuations in sediments. No important populations of sensitive filter feeding invertebrates are present in the upper and middle Tideway waterbodies and hence no effects from suspended solids are anticipated

Fish (including priority species common smelt and European eel)

L.2.130 Dredging has the potential to cause direct disturbance to spawning and feeding habitat, whilst sediments re-suspended during the dredging operation may cause blanketing of gravel substrates.

L.2.131 No direct mortality of fish is anticipated as a result of dredging. Given its location in the zone of the river known to be used by smelt and dace as spawning habitat, dredging of the intertidal and subtidal gravels at the Carnwath Road Riverside site, could lead to the loss of fish eggs. However, the *Code of Construction Practice (CoCP)* Section 8 (Vol 1 Appendix A) includes the following measures to control impacts during the spawning season:

a. The contractor will follow PLA guidance for dredging in the Thames Tideway and its tributaries. The critical period of June to August for dredging will be avoided, unless agreed otherwise with the relevant stakeholders. This will be achieved through programming capital dredging outside this period, and implementing a monitoring programme to identify future maintenance dredging.

b. The restricted period for dredging (ie, June to August) may need to be extended to include the spring period (ie, March to May) at sites lying close to known spawning areas or areas with fresh water reverie species.

L.2.132 Although dredging would result in disturbance to subtidal habitats and loss of the invertebrate food resource in those areas directly affected there will no overall change to the habitat structure and the areas are expected to recover following the completion of construction. The habitat type is considered to be well represented through the Thames Upper, Middle and Lower and therefore alternative feeding habitat is readily available.

L.2.133 There is a risk that resuspended sediment from dredging may blanket gravel habitats, clogging the interstitial spaces and reducing DO concentrations. The well oxygenated gravels habitats that occur in the upper Tideway provide important spawning habitat for smelt and dace.

L.2.134 Given the background levels of sediment carried by the tide (para. L.2.131) the volumes produced by dredging would not be detectable against natural fluctuations in sediments and would not have an impact on surface water resources[x]. Furthermore, the current velocities which occur in the subtidal zone which supports the habitats most important for fish spawning are sufficiently high that accretion of sediments are unlikely to occur.

L.2.135 No deterioration in the current WFD potential category is anticipated

Priority habitats

Intertidal mudflat

L.2.136 There would be no loss of intertidal mudflat as a result of dredging.

Intertidal and subtidal gravels

L.2.137 Dredging would result in the disturbance and re-profiling of subtidal gravels within the areas described in para. L.2.126. The surface layers of substrate (primarily sands and gravels) will be removed resulting in some resuspension of fine material. There will be no change to the overall composition of the habitat. Full recovery of the habitat is anticipated following the completion of construction.

L.2.138 There is a risk that fine material released during dredging will accrete on intertidal gravels; current velocities are considered too great for significant accretion within the subtidal. Fine material will tend to accrete in existing quiescent areas rather than creating new areas of accretion. The volume of fine material released during dredging is considered to be insignificant compared with the background volumes carried by the tide.

L.2.139 No deterioration in the current WFD potential category is anticipated.

Noise and vibration

L.2.140 The installation of the cofferdams at the foreshore construction sites has the potential to generate waterborne noise and vibration. Piles would be driven using vibro piling techniques, thus limiting the principal source of waterborne noise and vibration impacts. Although background levels of noise and vibration within the tidal Thames are likely to be moderately high due to existing boat movements and ground-propagated noise from transport systems, the proximity of the works to the river and their scale and duration means that underwater noise and vibration levels are likely to be elevated locally during construction.

L.2.141 Of the biological elements scoped into the assessment only fish (including the priority species common smelt and European eel) are considered sensitive. An assessment of effects against WFD objectives is provided below.

Fish

L.2.142 Underwater noise and vibration has the potential to cause both physical injury and behavioural responses in the form of avoidance. Whilst the

[x] An assessment of the potential sediment losses anticipated from construction activities within the foreshore is provided in the *Habitats Regulation Assessment*: *No Significant Effects Report*.

former may be considered more severe the latter may result in interference to migratory patterns and is therefore an important consideration. Studies[24] have been undertaken into the noise responses of various species and have resulted in the development of the dBht (species) metric. This indicates the loudness of the noise that will be perceived by individuals of the given species. Atlantic salmon is used as a representative species since it has a noise response threshold which is considered to be average for estuarine fish. In general, sounds above 50 dBht (species) is used as a very precautionary indicator of disturbance in that this is the threshold above which a reaction to the sound by a majority of individuals will be discernable. A strong avoidance reaction by virtually all individuals is unlikely to occur until approximately 90 dBht (species) is reached[25].

L.2.143 The temporary and permanent structures at the Thames Tideway Tunnel foreshore sites would be installed using vibro-piling techniques. In addition underwater noise and vibration would be controlled through a series of measures prescribed in the *CoCP* Part A Section 6, including the following:

a. avoid piling at night to ensure free windows of opportunity to allow fish to migrate past the site within each 24-hour period

b. undertake noise measurements at prescribed points and intervals to ensure compliance with the *CoCP* Part A Section 6

c. limit allowable noise and vibration levels to leave part of the river cross-section passable at all times

d. where vibro-piling is undertaken, slowly increasing the power of the driving to enable fish to swim away to leave the area before the full power of the pile driver is felt through the river

e. where predictions indicate that best practice limits would not be achievable, the underwater noise-generating activities will be confined to outside peak fish migration periods, unless otherwise agreed with the EA.

L.2.144 Nedwell et al (2005)[26] reported measurements of hydraulic piling (which includes vibro-piling) operations as part of a flood alleviation scheme in the Malling Brooke cell of the River Ouse. From the data presented in the report it was found that hydraulic piling operations in this case caused very marginal increases in underwater noise above background noise levels in the river. Hydraulic piling or other low impact piling (e.g. vibro-piling) are therefore likely to cause an avoidance reaction only within a very localised zone around the activity.

L.2.145 Shipping movements that may be associated with the Thames Tideway Tunnel project construction (ie, a tug pulling a loaded barge and a tug pulling an empty barge) give rise to sound pressure levels which, even at source fall below the levels identified as causing anything above a mild reaction in Atlantic salmon,

L.2.146 Noise arising during the construction is therefore not considered to give rise to any change in species composition and abundance, the presence of type-specific disturbance sensitive species, or the age structure of fish communities in the tidal Thames. No deterioration in the current WFD potential category is therefore anticipated.

CSO Interception

L.2.147 Modelling has been used to quantify the water quality improvements that would result from the operation of the Thames Tideway Tunnel project. The catchment model results have been used to characterise the CSO conditions in Year 1 of operation (2023) (assessed using 2021 modelled assumptions). The results are summarised below and demonstrate how the project would reduce the volume, frequency and duration of CSO discharges during rainfall in comparison to the operational base case (ie, with the Lee Tunnel and proposed sewage works upgrades in place). See Vol 3 Appendix L.1 for details of the modelling that has been carried out.

L.2.148 The catchment modelling results show that in the Typical Year (see para. L.2.82) the Thames Tideway Tunnel project would:

a. reduce the total volume of combined sewage entering the river by 87%, (15,250,000m^3 less), from 17,600,000m3 to 2,350,000m^3, when compared to the operational base case

b. reduce the maximum number of days with CSO spills from 54 days to 7 days, when compared to the operational base case

c. reduce the maximum length of time that spills would occur from all of the CSOs combined to the tidal Thames from 698 hours to 36 hours, when compared to the operational base case.

Oxygen balance

L.2.149 While the Thames Tideway Tunnel does not result in good status being achieved for the WFD DO standard, it represents an important step towards it by moving an additional 13km of the tidal Thames (Thames Middle) to good potential from moderate potential (see Vol 3 Appendix L.1). For the section of the tidal Thames which would remain at moderate potential, there would be a 1 mg/l improvement in DO levels as a result of the Thames Tideway Tunnel. The project would assist the Thames Middle waterbody in reaching good potential in combination with other measures proposed for the waterbody. Without the Thames Tideway Tunnel project reaching the WFD target of good potential for DO by 2027 would not be likely.

Priority and 'other' substances

L.2.150 Modelling has calculated the combined discharge of sediments from all the CSOs along the tidal Thames to be 2,780,000t in the Typical Year with the Lee Tunnel and proposed sewage works upgrades in place (ie, the operational base case). With the Thames Tideway Tunnel project in place this figure decreases to 292,000t in the Typical Year. There would be an increase in the discharge of sediment from Beckton STW, which would increase from 10,300,000t to 10,600,000t in the Typical Year, although Crossness STW would decrease by 10,000t from 4,620,000t to 4,610,000 in the Typical Year. This would give an overall reduction in the discharge of sediments to the tidal Thames of 2,200,000t or 12.4%.

L.2.151 This reduction of sediment inputs to the tidal Thames due to CSO interception would also result in a reduction in the inputs of priority[xi] and other[xii] substances to the tidal Thames. While there has been no direct modelling of priority substances (only DO, ammonia, nitrogen and sediments were directly modelled) it can be assumed that there would also be a reduction in priority and other substances, which tend to be associated with sediment particles.

L.2.152 In addition, the proposed development could positively influence some of the substances that are known to cause an issue within the tidal Thames, those which are associated with urban runoff eg, polycyclic aromatic hydrocarbons (PAHs) and copper. The Thames Tideway Tunnel would capture most of the discharges of surface water run-off that would otherwise discharge untreated to the tidal Thames, and transfer them to Beckton Sewage Treatment Works for treatment. There would therefore be a reduction in the levels of these substances in the tidal Thames.

L.2.153 This reduction of sediment inputs would also reduce physical degradation of habitats by fine sediment, and substantially reduce the potential for sediment-associated contaminant deposition. This would improve habitat quality by reducing the residence time of sediment-bound contaminants. Similar beneficial effects could occur in the River Wandle, from the interception of the Frogmore SR – Buckhold Road CSO at King George's Park.

Biological Elements (benthic invertebrates, fish, priority habitat sand species)

L.2.154 All of the biological elements including macroalgae, benthic invertebrate fauna, fish fauna, priority habitats and species are considered sensitive to the improvements in DO described in para. L.2.152. An assessment of effects against WFD objectives is provided below.

Macroalgae

L.2.155 The diversity and abundance of algal communities in the Thames Tideway is primarily influenced by salinity, shading and the availability of suitable substrates for colonisation. However, poor water quality, particularly during the 1950's and 1960's as one of the causes for the loss of algal species from the tidal Thames.

L.2.156 It is possible that improvements in water quality in the upper and middle Thames may benefit algal communities through increased abundance and distribution of pollution sensitive species. The improvements are not anticipated to cause a change in the current WFD potential within the Other aquatic flora supporting element since this comprises a range of taxonomic groups which are not present within the waterbodies under consideration.

[xi] Priority substances are those listed in Annex II of the Directive on Environmental Quality Standards (Directive 2008/105/EC) (EQSD), also known as the Priority Substances Directive, which set environmental quality standards (EQS) for the substances in surface waters (river, lake, transitional and coastal) and confirmed their designation as priority or priority hazardous substances, the latter being a subset of particular concern

[xii] Other substances are those identified as being discharged in significant quantities into the water body

Benthic invertebrate fauna

L.2.157 Invertebrate diversity and abundance may increase considerably under the base case due to the Lee Tunnel and sewage treatment works upgrades. However, even with these improvements in place there are still predicted to be a number of occasions during the Typical Year when TTSS DO standards would be breached. Colonisation by DO sensitive taxa such as Corophiidae, Crangonidae and Gammaridae which would otherwise occur within the brackish zone would continue to be suppressed.

L.2.158 Full compliance with the standards is expected to enable colonisation by these DO tolerant taxa. In the localised areas around CSO discharges gradual reductions organic material associated with sewage would also allow for a transition from invertebrate communities dominated by small numbers of species to a more diverse and balanced community.

L.2.159 No deterioration against current potential is therefore anticipated. As acknowledged in the RBMP the project would contribute to the achievement of good ecological potential by 2027.

Fish fauna (including priority species common smelt and European eel)

L.2.160 The Tideway Fish Risk Model (TFRM) was developed to evaluate proposed DO standards for the tidal Thames (Turnpenny et al., 2004)[27] as part of the TTSS. It assimilates data on the seasonal distribution of fish, seasonality and spatial distribution of hypoxic risk and on the lethal sensitivity of different fish species and life stages to hypoxia. Further details of the TFRM are presented in Vol 3 Section 5.4 and Vol 3 Appendix C.3.

L.2.161 Outputs from the TFRM demonstrate that during operation any mortalities associated with hypoxia are predicted to be sustainable (i.e. would not result in the loss of more than 10% of the population) across all the indicator species and life stages. Since the model is based on DO requirements of the most sensitive species the ecology of the Tideway as a whole should be protected from damage associated with hypoxia.

L.2.162 Vol 3 Table L.7 shows the predicted levels of mortality for each of the seven indicator species used within the model against the DO standards. The DO standards are described in Vol 3 Section 5.4. Mortalities for all species fall below the 10% criterion by a large margin (generally less than1% mortality), indicating a safety margin for future deterioration eg, with climate change or commercial fishing activity.

L.2.163 No deterioration against current potential is therefore anticipated. As acknowledged in the RBMP the project would contribute to the achievement of good ecological potential by 2027.

Vol 3 Table L.7 Outputs from the TFRM

Species	Lifestage	**Standard 4**	**Standard 3**	**Standard 2**	**Standard 1**
		Population Level Effect			
Salmon	Smolt	0.00%	0.00%	0.08%	0.15%
	Adult	0.71%	1.05%	5.52%	2.70%
Bass	Young Fry	0.00%	0.00%	0.00%	0.22%
	Juvenile	0.07%	0.11%	0.61%	2.70%
Sand smelt	Egg/fry	0.00%	0.00%	0.00%	0.00%
	Juvenile	0.07%	0.11%	0.61%	2.79%
	Adult	0.07%	0.11%	0.61%	4.34%
Dace	Egg/fry	0.00%	0.00%	0.00%	0.17%
	Juvenile	0.57%	0.17%	0.26%	0.47%
	Adult	0.19%	0.17%	0.26%	0.47%
Smelt	Egg/fry	0.00%	0.00%	0.00%	0.00%
	Juvenile	0.07%	0.11%	0.65%	2.79%
	Adult	0.00%	0.05%	0.83%	4.34%
Flounder	Egg/fry	0.00%	0.00%	0.00%	0.00%
	Juvenile	0.07%	0.16%	0.61%	2.70%
	Adult	0.00%	0.10%	0.82%	4.03%
Common goby	Egg/fry	0.00%	0.00%	0.00%	0.00%
	Juvenile	0.07%	0.11%	0.61%	2.70%
	Adult	0.00%	0.00%	0.00%	0.00%
	Average	0.10%	0.12%	0.60%	1.61%

Note: Table shows population level annual mortality rates associated with hypoxia for the indicator species from the TFRM model with the Thames Tideway Tunnel.

Priority habitats: Intertidal and subtidal habitats

L.2.164 Reduction in CSO discharges may be expected to lead to a recovery of habitats within the SINC (Grade M), particularly those in the immediate vicinity of discharges. For example, DO concentrations are likely to improve within gravel habitats used by species such as smelt and dace for spawning. Sediment nutrient levels are anticipated to reduce over time allowing habitats to return to more natural conditions.

L.2.165 Furthermore, the reduction in the occurrence of sewage litter would have benefits to habitats. Significant quantities of plastic waste are currently deposited on the foreshore degrade into small fragments which are taken up by organisms and enter the food chain.

L.2.166 No deterioration against current potential is therefore anticipated. As acknowledged in the RBMP the project will contribute to the achievement of good ecological potential by 2027.

Permanent structures

Biological Elements (macroalgae, benthic invertebrates, fish, priority habitat sand species)

L.2.167 The permanent CSO interception structures would result in landtake from intertidal and subtidal habitats within the Thames Upper and Thames Middle waterbodies only. As for the temporary structures there is also the potential for localised alterations to flow dynamics in the vicinity of the structures.

L.2.168 The following biological elements are scoped into the assessment: macroalgae, benthic invertebrate fauna, fish fauna, priority habitats (intertidal mudflat and intertidal and subtidal gravels) and priority species (common smelt and European eel).

Macroalgae

L.2.169 The algae recorded at each of the Thames Tideway Tunnel foreshore sites are widespread within the tidal Thames and can be expected to recolonise the new river wall (ie, the outer wall of the permanent structure) relatively quickly following the completion of construction (within five years).

L.2.170 No deterioration in the current WFD potential category is anticipated.

Benthic invertebrates

L.2.171 The area beneath the structures would be permanently lost as burrowing and feeding habitat for invertebrates. No rare or scarce species were recorded in the vicinity of the permanent structures and there would be no change in species composition due to permanent landtake. Although localised abundances of invertebrates will be depleted the area affected represents less than 0.5% of the total area of the Tidal Thames, and therefore overall abundance will not be affected.

Fish fauna (including priority species smelt and European eel)

L.2.172 There would be no encroachment of permanent structures into the subtidal zone at Putney Embankment Foreshore, which lies in a reach of the river where smelt and dace are known to spawn[28]. The effects of landtake on spawning habitat are therefore considered to be negligible.

L.2.173 The permanent structures lie primarily within the shallow intertidal zone of the river, which offers feeding, nursery and migratory habitat for juvenile fish. There is therefore a risk that the structures would affect the age structure of fish communities if juvenile fish were disproportionately affected. However, the intertidal habitats affected by landtake, are well represented throughout the Upper and Middle Tideway. Permanent landtake represents 0.0015% of the area of intertidal and subtidal habitats in the Middle and Upper Tideway.

L.2.174 No deterioration in the current WFD potential category is anticipated.

L.2.175 Landtake associated with the permanent structure is not considered to impact on the achievement of GEP by 2027 within the Thames Upper and Middle waterbodies.

Intertidal habitat

L.2.176 There would be landtake of 7400m^2 of intertidal habitats associated with the permanent structures. This represents less than 0.1% of the Upper and Middle Tideway waterbodies. The habitats affected include gravel foreshore, intertidal mudflat. Although this is considered to be a significant adverse effect in the EIA assessment it is not considered to be sufficient to cause a deterioration in status.

Subtidal habitats

L.2.177 There would be landtake of 5900m^2 of subtidal habitats associated with the permanent structures. This represents less than 0.1% of the Upper and Middle Tideway waterbodies. The habitat affected comprises primarily subtidal gravels. Although this is considered to be a significant adverse effect in the EIA assessment it is not considered to be sufficient to cause a deterioration in status.

L.2.178 The permanent structures are not considered to prevent the achievement of good ecological potential by 2027 by affecting delivery of RBMP mitigation measures (Annex A).

Mitigation measures

L.2.179 Annex A lists the RBMP identified mitigation measures and Annex C identifies which of these the proposed development has the potential to affect. No adverse effects on mitigation measures have been identified, which means that the scheme would not prevent the waterbodies assessed in achieving GEP due to the mitigation measures classification element. In fact, the scheme is proposing several compensation and mitigation schemes which would assist with meeting GEP. These are described below.

L.2.180 Intertidal terraces would be incorporated into the design of the permanent structure at Albert Embankment Foreshore and on the Bell Lane Creek at Dormay Street. At Albert Embankment Foreshore there would be five intertidal terraces of which the lower two would be unvegetated and left to accrete with sediment, whilst the upper three would be planted with species appropriate to the brackish zone of the river. Further details are provided in Vol 3 Section 5.8.

L.2.181 The intertidal terrace at Dormay Street would be 36m long by 2.9m wide and would be based on best practice guidance such as the EA's Estuary Edges Design Guidance (EA, undated)[29]. It would be designed to maximise inundation between the Mean High Water Spring and the Mean High Water Neap tidal levels in order to ensure that intertidal vegetation would establish.

L.2.182 A series of offsite habitat compensation schemes designed primarily to improve access for fish to tidal tributaries would also be undertaken. They are described in further detail in para. L.2.65. These schemes would benefit a range of freshwater and estuarine species but would have particular benefits for diadromous species such as eel and contribute to objectives identified under the European Eel Regulations.

Fish pass on the Bell Lane sluice on the lower River Wandle

L.2.183 The Bell Lane sluice is located at the upstream confluence of the River Wandle and Bell Lane Creek approximately 430m upstream of the confluence with the River Thames. It is a fixed crest weir with two adjacent penstocks. It is almost impassable to fish migrating up the River Wandle. A fish pass in this location would include diadromous species such as eel, trout and occasional salmon, as well as freshwater species.

L.2.184 Options for a fish pass include creating a notch within the existing weir, or installing a separate fish pass in a hydraulically isolated channel under the adjacent Causeway.

L.2.185 The proposed scheme would directly facilitate access for fish to a 1km reach of the River Wandle and would be considered by the EA as a trigger for a series of weir removals that would enable access to a further 13km.

Lowering/notching of the Lewisham College weir on the Ravensbourne

L.2.186 The twin weirs are located at the lower end of the Ravensbourne River where it discharges into the tidal Deptford Creek. The weirs are overtopped at high tide, but are impassable to fish at lower states of the tide.

L.2.187 Enhancement could include creation of a notch within the crest of the principal weir. Artificial media could be attached to the concrete surface beneath the notch to assist the movement of species such a eel. An alternative would be to break out of the adjacent penstock to form an open channel and install a self regulating tidal flap valve. This would enable fish to migrate through the structure from around half tide to the point when the main weir crest drowns.

L.2.188 This scheme would complement a river restoration project proposed by the EA immediately upstream at the Broadway Fields site.

L.2.189 The proposed scheme would facilitate access for fish to a 16km reach of the River Ravensbourne.

Impacts on other water bodies

L.2.190 There are no other waterbodies with the potential to be affected by the proposed development that have not been assessed.

Other European legislation

L.2.191 WFD article 4.8 requires any new scheme to be consistent with other European environmental legislation. The tidal Thames also includes a number of statutory and non-statutory sites for nature conservation. These are summarised in Vol 3 Section 5.4 and Vol 3 Figures 5.4.2 to 5.4.4. In addition, the tidal River Thames is part of the proposed South East Marine Conservation Zone (MCZ) that was submitted to Government in early 2012. If adopted, it will be designated as a national statutory site under the Marine and Coastal Access Act 2009.

L.2.192 The Thames Estuary and Marshes Special Protection Area (SPA) is designated under the EU Birds Directive[30] as the estuary and adjacent grazing marsh areas support an important assemblage of wintering water birds including grebes, geese, ducks and waders. The site is also important in spring and autumn migration periods. To the south of the river, much of the area is brackish grazing marsh. At Cliffe, there are flooded clay and chalk pits and outside the sea wall, there is a small extent of saltmarsh and broad intertidal mud-flats.

L.2.193 The Inner Thames Marshes Site of Special Scientific Interest (SSSI) is a 152ha area of littoral sediment habitat located approximately 6km downstream of the proposed development. The SSSI is in unfavourable declining condition and is no longer providing suitable conditions for wading birds, as silt deposition has ceased and as a result the land is drying out. The habitat is now rough grassland which may support raptors and invertebrates in particular, but does not support the interest features of the SSSI.

L.2.194 There would be no landtake from the Thames Estuary and Marshes SPA or the Inner Thames Marshes SSSI and therefore no direct effects on these designated sites.

L.2.195 Indirect effects could result to the improvements in water quality resulting from the proposed development, which have been assessed by the (HRA of the potential effects of the project on the Thames Estuary and Marshes SPA. The HRA concluded that there would be no Likely Significant Effects of the Thames Tideway Tunnel project on any European sites, either alone or in-combination with other projects and plans.

L.2.196 There are no fisheries designated under the Freshwater Fish Directive[31] downstream of Teddington in the Thames or in its tidal tributaries.

L.2.197 There are Shellfish Waters designated under the Shellfish Waters Directive[32] in the Thames Estuary at Foulness, Outer Thames, Southend, Sheppey, Swalecliffe, Margate, Swale Central and Swale East. As the proposed development would result in an improvement in the water quality of the Thames Estuary, it can be concluded that there would be no adverse effect on these designated Shellfish Waters.

Article 4.7 test

L.2.198 As the detailed assessment did not highlight any effects that could prevent the achievement of GEP, a WFD Article 4.7 test has not been applied.

Conclusion

L.2.199 There are overriding regulatory, social and economic reasons for the project. A discussion of reasonable alternatives is included in the *Final Report on Site Selection Process* and *Needs report*. None of the alternative options to the tunnel options are considered to constitute a suitable or cost effective alternative approach to the Thames Tideway Tunnel, for the reasons set out below in Vol 3 Table L.8.

Vol 3 Table L.8 Alternative approaches to the Thames Tideway Tunnel

Option	Response to need	Estimated costs (£ millions)	Comments
Full-length storage tunnel (Rotherhithe route)	Complies with UWWTD and environmental objectives	4,310 (accuracy range +/-10% to +/-25%)	Spills at CSOs limited to 2 events in a typical year. Is capable of being delivered by target date of 2020
Full-length storage tunnel (River Thames route)	Complies with UWWTD and environmental objectives	4,336 (accuracy range +/-10% to +/-25%)	Spills at CSOs limited to 2 events in a typical year. Is capable of being delivered by target date of 2020
Separation using new storm water sewers or new foul sewers (with storm water in existing combined network)	New sewerage designed for 1 in 30 storms. Will alleviate sewer flooding. Would eventually comply with UWWT and environmental objectives	14,000 (variance +50% to -30%)	Cost significantly greater than tunnel option. Significant disruption to residents, businesses and transportation. Prolonged timescale for completion; e.g. 30 years at £400m spend per annum, so not capable of complying with UWWTD and environmental objectives by 2020
Sustainable drainage systems (SUDS)	In certain catchments a 37% reduction in impermeable area potentially contributing to CSO discharges could be achieved	13,000 (variance +50% to -30%)	High cost and time to implement. Reduction in impermeable area still results in more than ten CSO spills in a typical year. Not able to achieve compliance with requirements of UWWTD

L.2.200 The Thames Tideway Tunnel project is an important element in ensuring the tidal Thames meets the objectives of the WFD. The Thames RBMP, developed for the River Thames as part of the requirements of the WFD, states that the London Tideway Tunnels (including both the Thames Tideway Tunnel and the Lee Tunnel) and the proposed sewage works upgrades projects “represent the primary measures to address point source pollution from the sewer system and are fundamental to the achievement of good status in this catchment (Estuaries and Coastal Waters Catchment)”.

L.2.201 The modelling undertaken for the development case demonstrates a major reduction in CSO spill frequency with a reduction from over 50 spills per year in the operational base case to seven spills per year (in the Typical Year). This would result in an 87% reduction in the volume of combined sewage entering the tidal Thames in the Typical Year. This reduction would move an additional 13km of the tidal Thames to good potential from moderate potential (see Vol 3 Appendix L.1). This would result in a 1mg/l improvement in DO levels for the section of the tidal Thames which would remain at moderate potential. Without the Thames Tideway Tunnel project, the *TTSS* DO standards would be failed and reaching WFD good potential by 2027 would not be likely.

L.2.202 The Thames Tideway Tunnel project is considered within the RBMP to be an important component of the solution to ensure that existing fish populations within the tidal Thames are sustainable in the future. There would be benefits to benthic invertebrate communities in terms of species composition and abundance. The proposed habitat compensation measures will contribute significantly to mitigation measures identified in the RBMP and to objectives under the European Eel Regulations.

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Annex A RBMP identified mitigation measures

RBMP waterbody	Mitigation measures in place	Mitigation measures not in place
Thames Upper	None	Operational and structural changes to locks, sluices, weirs, beach control, etc Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone Managed realignment of flood defence Remove obsolete structure
Thames Middle:	Modify vessel design Manage disturbance Site selection (dredged material disposal) (e.g. avoid sensitive sites) Sediment management Alter timing of dredging / disposal Reduce sediment resuspension Reduce impact of dredging Prepare a dredging / disposal strategy Avoid the need to dredge (e.g. minimise under-keel clearance; use fluid mud navigation; flow manipulation or training works)	Indirect / offsite mitigation (offsetting measures) Operational and structural changes to locks, sluices, weirs, beach control, etc Not In Place Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone Managed realignment of flood defence Remove obsolete structure
Thames Lower	Manage disturbance Site selection (dredged material disposal) (e.g. avoid sensitive sites) Alter timing of dredging / disposal	Sediment management Operational and structural changes to locks, sluices, weirs, beach control, etc Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian

RBMP waterbody	Mitigation measures in place	Mitigation measures not in place
	Reduce impact of dredging Prepare a dredging / disposal strategy Avoid the need to dredge (e.g. minimise under-keel clearance; use fluid mud navigation; flow manipulation or training works)	zone Structures or other mechanisms in place and managed to enable fish to access waters upstream and downstream of the impounding works. Managed realignment of flood defence Bank rehabilitation / reprofiling Increase in-channel morphological diversity Removal of hard bank reinforcement / revetment, or replacement with soft engineering solution Remove obsolete structure
Regent’s Canal	Manage disturbance Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone Avoid the need to dredge (e.g. minimise under-keel clearance; use fluid mud navigation; flow manipulation or training works) Prepare a dredging / disposal strategy Reduce impact of dredging Reduce sediment resuspension Alter timing of dredging / disposal Bank rehabilitation / reprofiling Site selection (dredged material disposal) (e.g. avoid sensitive sites) Awareness raising / information boards (boat wash / sources of fine sediment) Phased de-watering and other techniques	Modify vessel design

RBMP waterbody	Mitigation measures in place	Mitigation measures not in place
	Selective vegetation control regime Appropriate vegetation control technique Appropriate timing (vegetation control) Appropriate techniques (invasive species) Vessel Management Sediment management	
Beverley Brook:	Appropriate channel maintenance strategies and techniques - woody debris Appropriate channel maintenance strategies and techniques - minimise disturbance to channel bed and margins Appropriate techniques (invasive species) Appropriate timing (vegetation control) Appropriate vegetation control technique Selective vegetation control regime	Educate landowners on sensitive management practices (urbanisation) Appropriate techniques to align and attenuate flow to limit detrimental effects of these features (drainage) Retain marginal aquatic and riparian habitats (channel alteration) Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone Increase in-channel morphological diversity Removal of hard bank reinforcement / revetment, or replacement with soft engineering solution
River Wandle:	Appropriate vegetation control technique Selective vegetation control regime Appropriate timing (vegetation control) Appropriate techniques (invasive species) Appropriate channel maintenance strategies and techniques - minimise disturbance to channel bed and margins Appropriate channel maintenance strategies and	Retain marginal aquatic and riparian habitats (channel alteration) Educate landowners on sensitive management practices (urbanisation) Appropriate techniques to align and attenuate flow to limit detrimental effects of these features (drainage) Remove obsolete structure Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian

RBMP waterbody	Mitigation measures in place	Mitigation measures not in place
	techniques - woody debris	zone Structures or other mechanisms in place and managed to enable fish to access waters upstream and downstream of the impounding works Alteration of channel bed (within culvert) Increase in-channel morphological diversity Removal of hard bank reinforcement / revetment, or replacement with soft engineering solution Operational and structural changes to locks, sluices, weirs, beach control, etc
River Ravensbourne:	None	Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone Preserve and, where possible, restore historic aquatic habitats Removal of hard bank reinforcement / revetment, or replacement with soft engineering solution
River Crane:	Appropriate techniques (invasive species) Appropriate timing (vegetation control) Appropriate vegetation control technique Selective vegetation control regime	Educate landowners on sensitive management practices (urbanisation) Retain marginal aquatic and riparian habitats (channel alteration) Operational and structural changes to locks, sluices, weirs, beach control, etc Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone Structures or other mechanisms in place and

RBMP waterbody	Mitigation measures in place	Mitigation measures not in place
		managed to enable fish to access waters upstream and downstream of the impounding works Alteration of channel bed (within culvert) Re-opening existing culverts Increase in-channel morphological diversity Preserve and, where possible, restore historic aquatic habitats Removal of hard bank reinforcement / revetment, or replacement with soft engineering solution Remove obsolete structure

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Annex B No deterioration screening assessment results

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Waterbody Name	Thames Upper
Waterbody ID	GB530603911403
Current status	Moderate potential
Status objective	Good by 2027
Waterbody designation	HMWB
Reasons for failure	Not all mitigation measures in place

WFD QUALITY ELEMENTS	Construction: Jetties	Construction: Campsheds	Construction: Dredging	Construction: Dewatering	Construction: Piling	Construction: Diaphragm walls	Construction: Grouting	Construction: Tunnelling	Operation: Permanent structures	Operation: Scour protection	Operation: CSO interception	Operation: SuDS	Further assessment needed
Hydromorphological elements													
Hydrological regime:													
▪ Quantity and dynamics of water flow ▪ Connection to groundwater bodies	X - structures will not affect the quantity of flow, although small localised impacts on dynamics will result. These have been assessed for the morphological effects that could result (see rows 11 to 15 below)	X	X	X	X - structures will not affect the quantity of flow, although small localised impacts on dynamics will result. These have been assessed for the morphological effects that could result (see rows 11 to 15 below)	X	X	X	X - structures will not affect the quantity of flow, although small localised impacts on dynamics will result. These have been assessed for the morphological effects that could result (see rows 11 to 15 below)	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	X	X	X
River continuity:													
▪ Migration of aquatic organisms	X	X	X	X	X	X	X	X	X	X	X	X	
▪ Sediment transport	X - Sediment releases from construction would be offset by overall decrease from CSO capture and there would be a negligible effects on sediment release to the Tidal Thames	X - Sediment releases from construction would be offset by overall decrease from CSO capture and there would be a negligible effects on sediment release to the Tidal Thames	X - Sediment releases from construction would be offset by overall decrease from CSO capture and there would be a negligible effects on sediment release to the Tidal Thames	X	X - Sediment releases from construction would be offset by overall decrease from CSO capture and there would be a negligible effects on sediment release to the Tidal Thames	X	X	X	X - Sediment releases from scouring around permanent structures would be offset by overall decrease from CSO capture and there would be a negligible effects on sediment release to the Tidal Thames	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - TT would result in a 2,200,000kg annual decrease in sediment loads to the Tidal Thames (12.4% decrease)	X	✔
Morphological conditions:													
▪ River depth and width variation	X	X	X	X	✔ - Permanent structures and scour protection are likely to have minor effects on flow dynamics (turbulence) and sediment transport and scour.	X	X	X	✔ - Channel narrowing by piling and permanent structures are likely to have minor effects on flow dynamics (turbulence and velocity) and sediment transport and scour.	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	X	X	✔
▪ Coastal/estuarine depth variation	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Structure and substrate of the river bed	X	X	X	X	✔ - Piling could have minor effects on flow dynamics and therefore transport of sediment at the site, and scouring and deposition of substrate habitats upstream and downstream of the sites.	X	X	X	✔ - Permanent structures would result in direct loss of substrate habitats, and are likely to affect flow dynamics and therefore transport of sediment, scouring and deposition of substrate habitats up & downstream	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - TT would result in a decrease in loads of sewage derived sediment to local substrate habitats	X	✔
▪ Quantity, structure and substrate of the coastal/estuary bed	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Structure of the riparian zone/intertidal zone	X	X	X	X	✔ - Piling could have minor effects on flow dynamics and therefore transport of sediment at the site, and scouring and deposition of substrate habitats upstream and downstream of the sites.	X	X	X	✔ - Permanent structures would result in direct loss of substrate habitats, and are likely to affect flow dynamics, transport of sediment, scouring and deposition of substrate habitats up & downstream	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - The decrease in sediment loads would reduce fine sediment influx to local substrate habitats	X	✔
Tidal regime:													
▪ Tidal flow	X	X	X	X	X	X	X	X	X - impacts of permanent structures on tidal prism and flows would be negligible at the proposed scale of development	X	X	X	X
▪ Wave exposure	X	X	X	X	X	X	X	X	X - impacts of permanent structures on wave exposure would be negligible at the proposed scale of development	X	X	X	X
Biological elements													
Phytoplankton: ▪ Taxonomic composition ▪ Average abundance ▪ Planktonic bloom frequency and intensity ▪ Biomass													
Macrophytes and phytobenthos:													
▪ Taxonomic composition	X	X	X	X	X	X	X	X	✔	X	✔ - Improved water quality may result in minor increase in species diversity due to increase in distribution and abundance of pollution sensitive species	X	✔
▪ Average macrophytes and phytobenthic abundance	X	X	X	X	X	X	X	X	✔	X	X	X	X
Other aquatic flora (e.g. macroalgae, angiosperms, sea grass, sea weed salt marsh): ▪ Composition													
Benthic invertebrate fauna:													
▪ Composition	X - A jetty may be constructed at Carnwath Road but the impact is assessed to be negligible.	✔ - Construction will result in temporary land take from burrowing and feeding habitat	✔ - Dredging will result in disturbance to burrowing and feeding habitat	X - Dewatering effluent would be appropriately treated to prevent pollution	X	X	X	X	X	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - Improved water quality will result in minor increase in species diversity due to increase in distribution and abundance of pollution sensitive species	X	✔
▪ Abundance	X	✔ - Construction will result in temporary land take from burrowing and feeding habitat	✔ - Dredging will result in disturbance to burrowing and feeding habitat	X - Dewatering effluent would be appropriately treated to prevent pollution	X	X	X	X	✔ - Permananet loss of burrowing and feeding habitat from intertidal and subtidal areas	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - Improved water quality will result in increase in species abundance due to increase species able to thrive in improved conditions	X	✔
Fish fauna:													
▪ Species composition and abundance	X	✔ - Construction will result in temporary land take from spawning, feeding resting and nursery habitat	✔ - Dredging will result in removal and accretion of spawning, feeding resting and nursery habitat	X Dewatering effluent would be appropriately treated to prevent pollution	✔ - Piling noise may impact fish species	X	X	X	✔ - Permananet loss of habitat	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - Improved water quality may result in increase in species abundance and composition	X	✔
▪ Presence of type-specific disturbance sensitive species	X	✔ - Construction will result in temporary land take from spawning, feeding resting and nursery habitat	✔ - Dredging will result in removal and accretion of spawning, feeding resting and nursery habitat	X - Dewatering effluent would be appropriately treated to prevent pollution	✔ - Piling noise may impact fish species	X	X	X	✔ - Permananet loss of habitat for all species	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - Improved water quality will result in increase in pollution sensitive species	X	✔
▪ Age structure of fish communities	X	X	X	X	✔ - Piling noise may impact fish species	X	X	X	✔ - Permananet loss of habitat for all ages of fish	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - Reduction in hypoxia events will benefit all age classes, but particularly juveniles (0 and 1+ age classes)	X	✔
Critical sensitive habitats/species													
Protected sites:													
▪ SACs	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ SPAs	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ RAMSAR	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ SSSI	X	X	X	X	X	X	X	X	X	X	X	X	X
Priority habitats and species:													
Common smelt (*Osmerus eperlanus*)	X	✔ - Construction will result in temporary land take from spawning, feeding resting and nursery habitat	✔ - Dredging will result in removal and accretion of spawning habitat	X - Dewatering effluent would be appropriately treated to prevent pollution	✔ - Piling noise may impact fish species	X	X	X	✔ - Permananet loss of habitat for all ages of fish	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - Improved water quality will result in reduced hypoxia especially in cold water species such as smelt	X	✔
European eel (*Anguilla anguilla*)	X	✔ - Construction will result in temporary land take from eel habitat	✔ - Dredging will result in removal and accretion of habitat	X - Dewatering effluent would be appropriately treated to prevent pollution	✔ - Piling noise may impact fish species	X	X	X	✔ - Permananet loss of habitat	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - Improved water quality will result in reduced hypoxia especially in cold water species such as smelt	X	✔
Intertidal mudflat	X	✔ - Construction will result in temporary land take	✔ - Dredging will result in removal and accretion of habitat	X - Dewatering effluent would be appropriately treated to prevent pollution	X	X	X	X	✔ - Permananet loss of habitat	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - Improved water quality and reduction in sewage derived litter will improve habitat quality	X	✔
Intertidal and subtidal gravels	X	✔ - Construction will result in temporary land take	✔ - Dredging will result in removal and accretion of habitat	X - Dewatering effluent would be appropriately treated to prevent pollution	X	X	X	X	✔ - Permananet loss of habitat	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - Improved water quality and reduction in sewage derived litter will improve habitat quality	X	✔
Physico-chemical elements													
▪ Salinity	X	X	X	X - Dewatering effluent would be appropriately treated to prevent water quality effects	X	X	X	X	X	X	X	X	X
▪ Nutrient concentrations	X	X	X	X - Dewatering effluent would be appropriately treated to prevent water quality effects	X	X	X	X	X	X	x - While the estuary is hypernutrified, it does not show the ecological response that would constitute eutrophication, so the slight reduction in N loads would not have an effect	X	✔
▪ pH	X	X	X	X - Dewatering effluent would be appropriately treated to prevent water quality effects	X	X	X	X	X	X	X	X	X
▪ Oxygen balance	X	X	X	X - Dewatering effluent would be appropriately treated to prevent water quality effects	X	X	X	X	X	X	✔ - Modelling demonstrates the Thames Upper would reach Good potential in 2020s	X	✔
▪ Acid neutralising capacity	X	X	X	X - Dewatering effluent would be appropriately treated to prevent water quality effects	X	X	X	X	X	X	X	X	X
▪ Temperature	X	X	X	X - Dewatering effluent would be appropriately treated to prevent water quality effects	X	X	X	X	X	X	X	X	X
▪ Transparency	X - The tidal Thames is already a very silty environment and the additional sediments from construction will not have an effect	X - The tidal Thames is already a very silty environment and the additional sediments from construction will not have an effect	X - The tidal Thames is already a very silty environment and the additional sediments from construction will not have an effect	X - The tidal Thames is already a very silty environment and the additional sediments from construction will not have an effect	X - The tidal Thames is already a very silty environment and the additional sediments from construction will not have an effect	X	X	X	X	X	X	X	X
▪ Pollution by all priority substances identified as being discharged into the water body	X	X	X	X - Dewatering effluent would be appropriately treated to prevent water quality effects, particularly at contaminated sites	X	X	X	X	X	X	✔ - Modelling shows a 12.3% decrease in sediment discharges; it is assumed that the majority of priority substances would be adhered to these (no direct modelling available)	✔ - SuDS would help to control surface water pollution and the discharge of priority substances via surface water run-off	✔
▪ Pollution by other substances identified as being discharged in significant quantities into the water body	X	X	X	X - Dewatering effluent would be appropriately treated to prevent water quality effects, particularly at contaminated sites	X	X	X	X	X	X	✔ - Modelling showing decreases in BOD, sediments and nutrient levels taken as a surrogate for 'other' substances	✔ - SuDS would help to control surface water pollution and the discharge of other substances via surface water run-off	✔

Key

✔ (red)	Potential to cause deterioration in element classification - detailed assessment required
X	No potential to affect WFD classification
✔ (green)	Potential to cause an enhancement in element classification - detailed assessment required

Waterbody Name	Thames Middle
Waterbody ID	GB530603911402
Current status	Moderate potential
Status objective	Good by 2027
Waterbody designation	HMWB
Reasons for failure	Not all mitigation measures in place

	Construction								Operation				Further assessment
WFD QUALITY ELEMENTS	Jetties	Campsheds	Dredging	Dewatering	Piling	Diaphragm walls	Grouting	Tunnelling	Permanent structures	Scour protection	CSO interception	SuDS	
Hydromorphological elements													
Hydrological regime:													
▪ Quantity and dynamics of water flow	X - structures will not affect the quantity of flow, although small localised impacts on dynamics will result. These have been assessed for the morphological effects that could result (see rows 11 to 15 below)	X	X	X	X - structures will not affect the quantity of flow, although small localised impacts on dynamics will result. These have been assessed for the morphological effects that could result (see rows 11 to 15 below)	X	X	X	X - structures will not affect the quantity of flow, although small localised impacts on dynamics will result. These have been assessed for the morphological effects that could result (see rows 11 to 15 below)	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	X	X	X
▪ Connection to groundwater bodies	X	X	X	X	X	X	X	X	X	X	X	X	X
River continuity:													
▪ Migration of aquatic organisms	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Sediment transport	X - Sediment releases from construction would be offset by overall decrease from CSO capture and there would be a negligible effects on sediment release to the Tidal Thames	X - Sediment releases from construction would be offset by overall decrease from CSO capture and there would be a negligible effects on sediment release to the Tidal Thames	X - Sediment releases from construction would be offset by overall decrease from CSO capture and there would be a negligible effects on sediment release to the Tidal Thames	X	X - Sediment releases from construction would be offset by overall decrease from CSO capture and there would be a negligible effects on sediment release to the Tidal Thames	X	X	X	X - Sediment releases from scouring around permanent structures would be offset by overall decrease from CSO capture and there would be a negligible effects on sediment release to the Tidal Thames	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - TT would result in a 2,200,000kg annual decrease in sediment loads to the Tidal Thames (12.4% decrease)	X	✔
Morphological conditions:													
▪ River depth and width variation	X	X	X	X	✔ - Permanent structures and scour protection are likely to have minor effects on flow dynamics (turbulence) and sediment transport and scour.	X	X	X	✔ - Channel narrowing by piling and permanent structures are likely to have minor effects on flow dynamics (turbulence and velocity) and sediment transport and scour.	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	X	X	✔
▪ Coastal/estuarine depth variation	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Structure and substrate of the river bed	X	X	X - The amount of sediment and substrates removed by dredging would be negligible compared to natural loads	X	✔ - Piling could have minor effects on flow dynamics and therefore transport of sediment at the site, and scouring and depostion of substrate habitats upstream and downstream of the sites.	X	X	X	✔ - Permanent structures would result in direct loss of substrate habitats, and are likely to affect flow dynamics and therefore transport of sediment, scouring and deposition of substrate habitats up & downstream	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - The decrease in sediment loads would reduce fine sediment influx to local substrate habitats	X	✔
▪ Quantity, structure and substrate of the coastal/estuary bed	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Structure of the riparian zone/intertidal zone	X	X	X	X	✔ - Piling could have minor effects on flow dynamics and therefore transport of sediment at the site, and scouring and depostion of substrate habitats upstream and downstream of the sites.	X	X	X	✔ - Permanent structures would result in direct loss of substrate habitats, and are likely to affect flow dynamics, transport of sediment, scouring and deposition of substrate habitats up & downstream	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - TT would result in a decrease in loads of sewage derived sediment to local substrate habitats	X	✔
Tidal regime:													
▪ Tidal flow	X	X	X	X	X	X	X	X	X - impacts of permanent structures on tidal prism and flows would be negligible at the proposed scale of development	X	X	X	X
▪ Wave exposure	X	X	X	X	X	X	X	X	X - impacts of permanent structures on wave exposure would be negligible at the proposed scale of development	X	X	X	X
Biological elements													
Phytoplankton: ▪ Taxonomic composition ▪ Average abundance ▪ Planktonic bloom frequency and intensity ▪ Biomass													
Macrophytes and phytobenthos:													
▪ Taxonomic composition	X	X	X	X	X	X	X	X	X	X	✔ - Improved water quality will result in minor increase in species diversity due to increase in distribution and abundance of pollution sensitive species	X	✔
▪ Average macrophytes and phytobenthic abundance	X	X	X	X	X	X	X	X	✔	X	X	X	X
Other aquatic flora (e.g. macroalgae, angiosperms, sea grass, sea weed salt marsh): ▪ Composition													
Benthic invertebrate fauna:													
▪ Composition	X - A jetty is to be constructed at Kirtling Street but the impact is assessed to be negligible.	✔ - Construction will result in temporary land take from burrowing and feeding habitat	✔ - Dredging will result in disturbance to burrowing and feeding habitat	X - Dewatering effluent would be appropriately treated to prevent pollution	X	X	X	X	X	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - Improved water quality will result in minor increase in species diversity due to increase in distribution and abundance of pollution sensitive species	X	✔
▪ Abundance	X	✔ - Construction will result in temporary land take from burrowing and feeding habitat	✔ - Dredging will result in disturbance to burrowing and feeding habitat	X - Dewatering effluent would be appropriately treated to prevent pollution	X	X	X	X	✔ - Permananet loss of burrowing and feeding habitat from intertidal and subtidal areas	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - Improved water quality will result in increase in species abundance due to increase species able to thrive in improved conditions	X	✔
Fish fauna:													
▪ Species composition and abundance	X	✔ - Construction will result in temporary land take from feeding resting and nursery habitat	✔ - Dredging will result in removal and accretion to feeding resting and nursery habitat	X Dewatering effluent would be appropriately treated to prevent pollution	✔ - Piling noise may impact fish species	X	X	X	✔ - Permananet loss of habitat	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - Improved water quality may result in increase in species abundance and composition	X	✔
▪ Presence of type-specific disturbance sensitive species	X	✔ - Construction will result in temporary land take from feeding resting and nursery habitat	✔ - Dredging will result in removal and accretion to feeding resting and nursery habitat	X - Dewatering effluent would be appropriately treated to prevent pollution	✔ - Piling noise may impact fish species	X	X	X	✔ - Permananet loss of habitat for all species	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - Improved water quality will result in increase in pollution sensitive species	X	✔
▪ Age structure of fish communities	X	X	X	X	✔ - Piling noise may impact fish species	X	X	X	✔ - Permananet loss of habitat for all ages of fish	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - Reduction in hypoxia events will benefit all age classes, but particularly juveniles (0 and 1+ age classes)	X	✔
Critical sensitive habitats/species													
Protected sites:													
▪ SACs	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ SPAs	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ RAMSAR	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ SSSI	X	X	X	X	X	X	X	X	X	X	X	X	X
Priority habitats and species:													
Common smelt (*Osmerus eperlanus*)	X	✔ - Construction will result in temporary land take from feeding resting and nursery habitat	✔ - Dredging will result in removal and accretion of habitat	X - Dewatering effluent would be appropriately treated to prevent pollution	✔ - Piling noise may impact fish species	X	X	X	✔ - Permananet loss of habitat for all ages of fish	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - Improved water quality will result in reduced hypoxia especially in cold water species such as smelt	X	✔
European eel (*Anguilla anguilla*)	X	✔ - Construction will result in temporary land take from eel habitat	✔ - Dredging will result in removal and accretion of habitat	X - Dewatering effluent would be appropriately treated to prevent pollution	✔ - Piling noise may impact fish species	X	X	X	✔ - Permananet loss of habitat	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - Improved water quality will result in reduced hypoxia especially in cold water species such as smelt	X	✔
Intertidal mudflat	X	✔ - Construction will result in temporary land take	✔ - Dredging will result in removal and accretion of habitat	X - Dewatering effluent would be appropriately treated to prevent pollution	X	X	X	X	✔ - Permananet loss of habitat	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - Improved water quality and reduction in sewage derived litter will improve habitat quality	X	✔
Intertidal and subtidal gravels	X	✔ - Construction will result in temporary land take	✔ - Dredging will result in removal and accretion of habitat	X - Dewatering effluent would be appropriately treated to prevent pollution	X	X	X	X	✔ - Permananet loss of habitat	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔ - Improved water quality and reduction in sewage derived litter will improve habitat quality	X	✔
Physico-chemical elements													
▪ Salinity	X	X	X	X - Dewatering effluent would be appropriately treated to prevent water quality effects	X	X	X	X	X	X	X	X	X
▪ Nutrient concentrations	X	X	X	X - Dewatering effluent would be appropriately treated to prevent water quality effects	X	X	X	X	X	X	x - While the estuary is hypernutrified, it does not show the ecological response that would constitute eutrophication, so the slight reduction in N loads would not have an effect	X	✔
▪ pH	X	X	X	X - Dewatering effluent would be appropriately treated to prevent water quality effects	X	X	X	X	X	X	X	X	X
▪ Oxygen balance	X	X	X	X - Dewatering effluent would be appropriately treated to prevent water quality effects	X	X	X	X	X	X	✔ - Modelling demonstrates a 1 mg/l improvement within Moderate status in the Thames Middle	X	✔
▪ Acid neutralising capacity	X	X	X	X - Dewatering effluent would be appropriately treated to prevent water quality effects	X	X	X	X	X	X	X	X	X
▪ Temperature	X	X	X	X - Dewatering effluent would be appropriately treated to prevent water quality effects	X	X	X	X	X	X	X	X	X
▪ Transparency	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Pollution by all priority substances identified as being discharged into the water body	X	X	X	X - Dewatering effluent would be appropriately treated to prevent water quality effects, particularly at contaminated sites	X	X	X	X	X	X	✔ - Modelling shows a 12.3% decrease in sediment discharges; it is assumed that the majority of priority substances would be adhered to these (no direct modelling available)	✔ - SuDS would help to control surface water pollution and the discharge of priority substances via surface water run-off	✔
▪ Pollution by other substances identified as being discharged in significant quantities into the water body	X	X	X	X - Dewatering effluent would be appropriately treated to prevent water quality effects, particularly at contaminated sites	X	X	X	X	X	X	✔ - Modelling showing decreases in BOD, sediments and nutrient levels taken as a surrogate for 'other' substances	✔ - SuDS would help to control surface water pollution and the discharge of other substances via surface water run-off	✔

Key

✔	Potential to cause deterioration in element classification - detailed assessment required
X	No potential to affect WFD classification
✔	Potential to cause an enhancement in element classification - detailed assessment required

Waterbody Name	Wandle (Croydon to Wandsworth) and the R. Gravney
Waterbody ID	GB106039023460
Current status	Poor potential
Status objective	Good by 2027
Waterbody designation	HMWB
Reasons for failure	Fish and phytobenthos

	Construction								Operation				Further assessment needed
WFD QUALITY ELEMENTS	Jetties	Campsheds	Dredging	Dewatering	Piling	Diaphragm walls	Grouting	Tunnelling	Permanent structures	Scour protection	CSO interception	SuDS	
Hydromorphological elements													
Hydrological regime:													
• Quantity and dynamics of water flow	x	x	x	x	x	x	x	x	x	x	x	x	x
• Connection to groundwater bodies	x	x	x	x	x	x	x	x	x	x	x	x	x
River continuity:													
• Migration of aquatic organisms	x	x	x	x	x	x	x	x	x	x	x	x	x
• Sediment transport	x	x	x	x	x	x	x	x	x	x	✔ - Sediment loads to the Wandle would be reduced as a result of the interception of the Frogmore - Buckhold Road CSO	x	✔
Morphological conditions:													
• River depth and width variation	x	x	x	x	x	x	x	x	x	x	x	x	x
• Coastal/estuarine depth variation	x	x	x	x	x	x	x	x	x	x	x	x	x
• Structure and substrate of the river bed	x	x	x	x	x	x	x	x	x	x	x	x	x
• Quantity, structure and substrate of the coastal/estuary bed	x	x	x	x	x	x	x	x	x	x	✔ - Fine sediment delivery to the Wandle would be reduced by interception of the Frogmore - Buckhold Road CSO, offering potential improvements to bed habitats	x	✔
• Structure of the riparian zone/intertidal zone	x	x	x	x	x	x	x	x	x	x	✔ - Fine sediment delivery to the Wandle would be reduced by interception of the Frogmore - Buckhold Road CSO, offering potential improvements to inter-tidal habitats and morphological diversity	x	✔
Tidal regime:													
• Tidal flow	x	x	x	x	x	x	x	x	x	x	x	x	x
• Wave exposure	x	x	x	x	x	x	x	x	x	x	x	x	x
Biological elements													
Phytoplankton:													
• Taxonomic composition													
• Average abundance													
• Planktonic bloom frequency and intensity													
• Biomass													
Macrophytes and phytobenthos:													
• Taxonomic composition	x	x	x	x	x	x	x	x	x	x	x	x	x
• Average macrophytes and phytobenthic abundance	x	x	x	x	x	x	x	x	x	x	x	x	x
Other aquatic flora (e.g. macroalgae, angiosperms, sea grass, sea weed salt marsh):													
• Composition													
Benthic invertebrate fauna:													
• Composition	x	x	x	x	x	x	x	x	x	x	✔ - Improved water quality will result in minor increase in species diversity due to increase in distribution and abundance of pollution sensitive species	x	✔
• Abundance	x	x	x	x	x	x	x	x	x	x	✔ - Improved water quality will result in increase in species abundance due to increase species able to thrive in improved conditions	x	✔
Fish fauna:													
• Species composition and abundance	x	x	x	x	x	x	x	x	x	x	✔ - Improved water quality would result in increase in species abundance and composition	x	✔
• Presence of type-specific disturbance sensitive species	x	x	x	x	x	x	x	x	x	x	✔ - Improved water quality would result in increase in pollution sensitive species	x	✔
• Age structure of fish communities	x	x	x	x	x	x	x	x	x	x	✔ - Reduction in hypoxia events would benefit all age classes, but particularly juveniles (0 and 1+ age classes)	x	✔
Critical sensitive habitats/species													
Protected sites:													
• SACs	x	x	x	x	x	x	x	x	x	x	x	x	x
• SPAs	x	x	x	x	x	x	x	x	x	x	x	x	x
• RAMSAR	x	x	x	x	x	x	x	x	x	x	x	x	x
• SSSI	x	x	x	x	x	x	x	x	x	x	x	x	x
Priority habitats and species:													
Physico-chemical elements													
• Salinity	x	x	x	x	x	x	x	x	x	x	x	x	x
• Nutrient concentrations	x	x	x	x	x	x	x	x	x	x	x	x	x
• pH	x	x	x	x	x	x	x	x	x	x	x	x	x
• Oxygen balance	x	x	x	x	x	x	x	x	x	x	✔	x	x
• Acid neutralising capacity	x	x	x	x	x	x	x	x	x	x	x	x	x
• Temperature	x	x	x	x	x	x	x	x	x	x	x	x	x
• Transparency	x	x	x	x	x	x	x	x	x	x	x	x	x
• Pollution by all priority substances identified as being discharged into the water body	x	x	x	x	x	x	x	x	x	x	✔ - Modelling shows a 12.3% decrease in sediment discharges; it is assumed that the majority of priority substances would be adhered to these (no direct modelling available)	✔ - SuDS would help to control surface water pollution and the discharge of priority substances via surface water run-off	✔
• Pollution by other substances identified as being discharged in significant quantities into the water body	x	x	x	x	x	x	x	x	x	x	✔ - Modelling showing decreases in BOD, sediments and nutrient levels taken as a surrogate for 'other' substances	✔ - SuDS would help to control surface water pollution and the discharge of other substances via surface water run-off	✔

Key

✔ (red)	Potential to cause deterioration in element classification - detailed assessment required
x	No potential to affect WFD classification
✔ (green)	Potential to cause an enhancement in element classification - detailed assessment required

Waterbody Name	Ravensbourne
Waterbody ID	GB106037028110
Current status	Moderate potential
Status objective	Good by 2027
Waterbody designation	HMWB
Reasons for failure	Ammonia, DO, phosphate, and not all mitigation measures in place

	Construction								Operation				Lewisham College Tidal Weir Notch Compensation Scheme	Further assessment needed
WFD QUALITY ELEMENTS	Jetties	Campsheds	Dredging	Dewatering	Piling	Diaphragm walls	Grouting	Tunnelling	Permanent structures	Scour protection	CSO interception	SuDS		
Hydromorphological elements														
Hydrological regime:														
▪ Quantity and dynamics of water flow	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Connection to groundwater bodies	x	x	x	x	x	x	x	x	x	x	x	x	x	x
River continuity:														
▪ Migration of aquatic organisms	x	x	x	x	x	x	x	x	x	x	x	x	✓ - Notching of the Weir would allow more migratory fish movement into the upstream reaches	✓
▪ Sediment transport	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Morphological conditions:														
▪ River depth and width variation	x	X - Campsheds to enable flood defence strengthening would not permanently affect channel dimensions	x	x	x	x	x	x	x	x	x	x	x	x
▪ Coastal/estuarine depth variation	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Structure and substrate of the river bed	x	x	X - The amount of sediment and substrates removed by dredging would be negligible compared to natural loads	x	x	x	x	x	x	x	x	x	x	x
▪ Quantity, structure and substrate of the coastal/estuary bed	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Structure of the riparian zone/intertidal zone	x	x	X - The amount of sediment removed by dredging would be negligible compared to natural loads	x	x	x	x	x	x	x	x	x	x	x
Tidal regime:														
▪ Tidal flow	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Wave exposure	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Biological elements														
Phytoplankton:														
▪ Taxonomic composition														
▪ Average abundance														
▪ Planktonic bloom frequency and intensity														
▪ Biomass														
Macrophytes and phytobenthos:														
▪ Taxonomic composition	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Average macrophytes and phytobenthic abundance	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Other aquatic flora (e.g. macroalgae, angiosperms, sea grass, sea weed salt marsh):														
▪ Composition														
Benthic invertebrate fauna:														
▪ Composition	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Abundance	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Fish fauna:														
▪ Species composition and abundance	x	x	x	x	x	x	x	x	x	x	✓ - Improved water quality and reduction in hypoxia would result in increased populations in main river with some benefits to tributary populations although existing structures inhibiting entry to tributary would remain controlling factor	x	✓ - Notching of the Weir would result in improved species richness and abundance moving upstream from the Thames Middle waterbody	✓
▪ Presence of type-specific disturbance sensitive species	x	x	x	x	x	x	x	x	x	x	✓ - Improved water quality and reduction in hypoxia would result in increased populations in main river with some benefits to tributary populations although existing structures inhibiting entry to tributary would remain controlling factor	x	✓ - Notching of the Weir would allow more type-specific species that may have been restricted by the taller notch to move upstream	✓
▪ Age structure of fish communities	x	x	x	x	x	x	x	x	x	x	✓ - Improved water quality and reduction in hypoxia would result in increased populations in main river with some benefits to tributary populations although existing structures inhibiting entry to tributary would remain controlling factor	x	✓ - Notching of the Weir would allow more migratory fish of all ages to move into the upstream reaches	✓
Critical sensitive habitats/species														
Protected sites:														
▪ SACs	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ SPAs	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ RAMSAR	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ SSSI	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Priority habitats and species:														
Physico-chemical elements														
▪ Salinity	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Nutrient concentrations	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ pH	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Oxygen balance	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Acid neutralising capacity	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Temperature	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Transparency	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Pollution by all priority substances identified as being discharged into the water body	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Pollution by other substances identified as being discharged in significant quantities into the water body	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Key

✓ (red)	Potential to cause deterioration in element classification - detailed assessment required
x	No potential to affect WFD classification
✓ (green)	Potential to cause an enhancement in element classification - detailed assessment required

Waterbody Name	Crane (including part of the Yeading Brook)
Waterbody ID	GB106039023030
Current status	Poor potential
Status objective	Good by 2027
Waterbody designation	HMWB
Reasons for failure	Phosphate, Fish, Phytobenthos

	Construction								Operation					
WFD QUALITY ELEMENTS	**Jetties**	**Campsheds**	**Dredging**	**Dewatering**	**Piling**	**Diaphragm walls**	**Grouting**	**Tunnelling**	**Permanent structures**	**Scour protection**	**CSO interception**	**SuDS**	**Kidds Mill Sluice Fish Pass Implementation and Mogden STW Weir Removal Compensation Schemes**	**Further assessment needed**
Hydromorphological elements														
Hydrological regime:														
▪ Quantity and dynamics of water flow	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Connection to groundwater bodies	x	x	x	x	x	x	x	x	x	x	x	x	x	x
River continuity:														
▪ Migration of aquatic organisms	x	x	x	x	x	x	x	x	x	x	x	x	✓ - Inclusion of a multi species fish pass and removal of the weir at Mogden STW would allow more migratory fish movement into the upstream reaches	x
▪ Sediment transport	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Morphological conditions:														
▪ River depth and width variation	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Coastal/estuarine depth variation	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Structure and substrate of the river bed	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Quantity, structure and substrate of the coastal/estuary bed	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Structure of the riparian zone/intertidal zone	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Tidal regime:														
▪ Tidal flow	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Wave exposure	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Biological elements														
Phytoplankton:														
▪ Taxonomic composition														
▪ Average abundance														
▪ Planktonic bloom frequency and intensity														
▪ Biomass														
Macrophytes and phytobenthos:														
▪ Taxonomic composition	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Average macrophytes and phytobenthic abundance	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Other aquatic flora (e.g. macroalgae, angiosperms, sea grass, sea weed salt marsh):														
▪ Composition														
Benthic invertebrate fauna:														
▪ Composition	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Abundance	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Fish fauna:														x
▪ Species composition and abundance	x	x	x	x	x	x	x	x	x	x	✓ - Improved water quality and reduction in hypoxia would result in increased populations in main river with some benefits to tributary populations although existing structures inhibiting entry to tributary would remain controlling factor	x	✓ - Inclusion of a multi species fish pass and removal of the weir at Mogden STW would result in improved species richness and abundance moving upstream from the Thames Upper waterbody	✓
▪ Presence of type-specific disturbance sensitive species	x	x	x	x	x	x	x	x	x	x	✓ - Improved water quality and reduction in hypoxia would result in increased populations in main river with some benefits to tributary populations although existing structures inhibiting entry to tributary would remain controlling factor	x	✓ - Inclusion of a multi species fish pass and removal of the weir at Mogden STW would allow more migratory fish movement into the upstream reaches	✓
▪ Age structure of fish communities	x	x	x	x	x	x	x	x	x	x	✓ - Improved water quality and reduction in hypoxia would result in increased populations in main river with some benefits to tributary populations although existing structures inhibiting entry to tributary would remain controlling factor	x	✓ - Inclusion of a multi species fish pass and removal of the weir at Mogden STW would allow more migratory fish of all ages to move into the upstream reaches	✓
Critical sensitive habitats/species														
Protected sites:														
▪ SACs	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ SPAs	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ RAMSAR	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ SSSI	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Priority habitats and species:														
Physico-chemical elements														
▪ Salinity	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Nutrient concentrations	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ pH	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Oxygen balance	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Acid neutralising capacity	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Temperature	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Transparency	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Pollution by all priority substances identified as being discharged into the water body	x	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Pollution by other substances identified as being discharged in significant quantities into the water body	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Key

✓	Potential to cause deterioration in element classification - detailed assessment required
x	No potential to affect WFD classification
✓	Potential to cause an enhancement in element classification - detailed assessment required

Waterbody Name	Beverley Brook (Motspur Park to Thames) and Pyl Brook at West Barnes
Waterbody ID	GB106039022850
Current status	Poor potential
Status objective	Good by 2027
Waterbody designation	HMWB
Reasons for failure	Fish and macrophytes

	Construction								Operation				Further assessment needed
WFD QUALITY ELEMENTS	Jetties	Campsheds	Dredging	Dewatering	Piling	Diaphragm walls	Grouting	Tunnelling	Permanent structures	Scour protection	CSO interception	SuDS	
Hydromorphological elements													
Hydrological regime:													
▪ Quantity and dynamics of water flow	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Connection to groundwater bodies	x	x	x	x	x	x	x	x	x	x	x	x	x
River continuity:													
▪ Migration of aquatic organisms	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Sediment transport	x	x	x	x	x	x	x	x	x	x	x	x	x
Morphological conditions:													
▪ River depth and width variation	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Coastal/estuarine depth variation	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Structure and substrate of the river bed	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Quantity, structure and substrate of the coastal/estuary bed	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Structure of the riparian zone/intertidal zone	x	x	x	x	x	x	x	x	x	x	x	x	x
Tidal regime:													
▪ Tidal flow	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Wave exposure	x	x	x	x	x	x	x	x	x	x	x	x	x
Biological elements													
Phytoplankton:													
▪ Taxonomic composition													
▪ Average abundance													
▪ Planktonic bloom frequency and intensity													
▪ Biomass													
Macrophytes and phytobenthos:													
▪ Taxonomic composition	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Average macrophytes and phytobenthic abundance	x	x	x	x	x	x	x	x	x	x	x	x	x
Other aquatic flora (e.g. macroalgae, angiosperms, sea grass, sea weed salt marsh):													
▪ Composition													
Benthic invertebrate fauna:													
▪ Composition	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Abundance	x	x	x	x	x	x	x	x	x	x	x	x	x
Fish fauna:													
▪ Species composition and abundance	x	x	x	x	x	x	x	x	x	x	✓ - Improved water quality and reduction in hypoxia would result in increased populations in main river with some benefits to tributary populations although existing structures inhibiting entry to tributary would remain controlling factor	x	✓
▪ Presence of type-specific disturbance sensitive species	x	x	x	x	x	x	x	x	x	x	✓ - Improved water quality and reduction in hypoxia would result in increased populations in main river with some benefits to tributary populations although existing structures inhibiting entry to tributary would remain controlling factor	x	✓
▪ Age structure of fish communities	x	x	x	x	x	x	x	x	x	x	✓ - Improved water quality and reduction in hypoxia would result in increased populations in main river with some benefits to tributary populations although existing structures inhibiting entry to tributary would remain controlling factor	x	✓
Critical sensitive habitats/species													
Protected sites:													
▪ SACs	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ SPAs	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ RAMSAR	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ SSSI	x	x	x	x	x	x	x	x	x	x	x	x	x
Priority habitats and species:													
Physico-chemical elements													
▪ Salinity	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Nutrient concentrations	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ pH	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Oxygen balance	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Acid neutralising capacity	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Temperature	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Transparency	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Pollution by all priority substances identified as being discharged into the water body	x	x	x	x	x	x	x	x	x	x	x	x	x
▪ Pollution by other substances identified as being discharged in significant quantities into the water body	x	x	x	x	x	x	x	x	x	x	x	x	x

Key

✓ (red)	Potential to cause deterioration in element classification - detailed assessment required
x	No potential to affect WFD classification
✓ (green)	Potential to cause an enhancement in element classification - detailed assessment required

GWB Name	**Greenwich Chalk and Tertiaries**
GWB ID	GB40602G602500
Current status	Poor
Quantitative	Poor
Chemical	Poor
Predicted status	Poor
Quantitative	Poor
Chemical	Poor
Reasons for failure	Abstraction & saline intrusion, nutrients (nitrate), hazardous substances & other pollutants
Justification	Disproportionately expensive, technically infeasible
Status objective	Good quantitative & chemical status by 2027
GWB designation	Drinking water protected area
Geological units	Lambeth Group, Thanet Sands & Chalk Formation and overlying superficial deposits aquifer (alluvium & River Terrace Deposits) where in hydaulic continuity with the lower formations
Thames Tunnel sites	Central shaft sites - Chelsea Embankment, Kirtling Street, Heathwall Pumping Station, Albert Embankment, Victoria Embankment Foreshore, Blackfriars Bridge - and Eastern shaft sites - Chambers Wharf, King Edward Memorial Park, Earl Pumping Station, Deptford Church Street, Greenwich Pumping Station, Abbey Mills Pumping Station & Beckton Sewage Treatment Works

					Construction			Operation					
	WFD Classification Elements	Classification Test	Current WFD status	Criteria for assessing potential of development/ activities to cause deterioration in element classification	Dewatering	Grouting	Shafts creating pathways for pollution	Permanent structures obstructing groundwater flows	Seepage into shafts/ tunnels	Seepage out of shafts/ tunnels	Reduction of pollution to groundwater	RBMP mitigation measures	Further assessment needed
Quantitative status	▪ **Saline or other intrusions**	To identify groundwater bodies where the intrusion of poor quality water as a result of groundwater abstraction is leading to sustained upward trends in pollutant concentrations or significant impact on one or more groundwater abstractions	Poor	If groundwater abstraction results in the introduction of poor quality water from another water body (rather than movement of plume of poor quality water within body) resulting in a significant impact on a point of abstraction as a consequence of intrusion	X - No significant (see note 2) effects of dewatering anticipated due to internal dewatering and ground freezing; existing saline intrusion at all eastern shaft sites	X	X	X - No significant effects anticipated; existing saline intrusion at all eastern shaft sites	X	X	X	X	X
	▪ **Surface water**	To assess the impact of groundwater abstractions on the ecological status of surface water bodies	Poor	If groundwater abstraction contributes to over 50% of a failure of WFD objectives (i.e. good status or good ecological potential) within an associated surface water body *(see appropriate River Basin Management Plan (RBMP))*	X - No significant effects of dewatering anticipated due to internal dewatering and ground freezing; groundwater not cited as an existing reason for failure of WFD objectives at associated Ravensbourne and Thames Middle surface water bodies	X	X	X - No significant effects anticipated; groundwater not cited as an existing reason for failure of WFD objectives at associated surface water bodies	X - No significant effects anticipated; groundwater not cited as an existing reason for failure of WFD objectives at associated surface water bodies	X	X	X	X
	▪ **Groundwater Dependent Terrestrial Ecosystems (GWDTE's)**	To assess the impact of groundwater abstractions on the condition of GWDTE'S	Good	If groundwater abstraction results in 'unfavourable conditions' or 'significant damage' (see note 1) to an associated GWDTE *(see www.naturalengland.co.uk)*	X - No GWDTE's associated with groundwater body within project area	X	X	X	X	X	X	X	X
	▪ **Water balance**	To identify groundwater bodies where abstractions exceed the available resource	Good	If groundwater abstraction results in a reduction to the groundwater body resource availability status *(see appropriate CAMS)*	X - No significant effects anticipated; GWMU7 (Confined Chalk) classified as over-licensed	X	X	X - No significant effects anticipated; GWMU7 (Confined Chalk) classified as over-licensed	X - No significant effects anticipated; GWMU7 (Confined Chalk) classified as over-licensed	X	X	X	X
Chemical status	▪ **Saline or other intrusions**	To identify groundwater bodies where intrusion of poor quality water as a result of groundwater abstraction is leading to stustained upward trends in pollutant concentrations or significant impact on one or more groundwater abstractions	Poor	If groundwater abstraction results in the introduction of poor quality water from another water body (rather than movement of plume of poor quality water within body) leading to (1) the exceedance of Natural Background Concentrations (NBC's) for electric conductivity, chloride and sodium concentrations in groundwater (or other parameters indicative of the intrusion) AND EITHER (2) a sustained upward trend in pollutant concentrations OR (3) a significant impact on a point of abstraction as a consequence of intrusion	X - No significant effects anticipated; existing saline intrusion at all eastern shaft sites	X	X - No significant effects anticipated; existing saline intrusion in upper and lower aquifers at all eastern shaft sites where aquifers are in hydraulic continuity	X	X	X	X	X	X
	▪ **Surface water**	To assess the impact of groundwater abstractions on the chemical and ecological status of surface water bodies	Good	If groundwater abstraction results in (1) an associated surface water body not meeting its objectives, (2) an exceedance of Groundwater Threshold Values (GTV's) for surface water bodies (generic or individual to that surface water body) AND (3) groundwater contributes at least 50% of the relevant surface water standard *(see (1) appropriate River Basin Management Plan (RBMP) and (2) The River Basin Districts Typology, Standards and Groundwater threshold values (Water Framework Directive) (England and Wales) Directions 2009)*	X - No significant effects anticipated; groundwater not cited as an existing reason for failure of WFD objectives at associated surface water bodies	X - No significant effects anticipated; groundwater not cited as an existing reason for failure of WFD objectives at associated surface water bodies	X - No significant effects anticipated; groundwater not cited as an existing reason for failure of WFD objectives at associated surface water bodies	X	X	X - No significant effects anticipated; groundwater not cited as an existing reason for failure of WFD objectives at associated surface water bodies	✓ - Potential to cause an enhancement in water quality of associated surface water bodies	X	X
	▪ **Groundwater Dependent Terrestrial Ecosystems (GWDTE's)**	To assess the impact of nutrient concentrations in groundwater (primarily phosphates) on GWDTE's	Good	If groundwater chemical pressures result in (1) 'unfavourable condition' or 'significant damage' to an associated GWDTE, (2) an exceedance of GTV's for GWDTE's AND (3) groundwater is the significant reason for the GWDTE's failure *(see www.naturalengland.co.uk)*	X - No GWDTE's associated with groundwater body within project area	X	X	X	X	X	X	X	X
	▪ **Drinking Water Protected Areas (DrWPA's)**	To identify groundwater bodies failing to meet the DrWPA objectives defined in Article 7 of the WFD or at risk of failing in the future	Poor	If groundwater chemical pressures result in (1) a significant and sustained upward trend in one or more key determinands AND (2) an exceedance of GTV's for DrWPA's *(see The River Basin Districts Typology, Standards and Groundwater threshold values (Water Framework Directive) (England and Wales) Directions 2009)*	X - No significant effects anticipated; existing exceedances of GTV's for DrWPA's at central & eastern sites	X - No significant effects anticipated; no GTV for turbidity	X - No significant effects anticipated; existing exceedances of GTV's for DrWPA's at central & eastern sites	X	X	X - No significant effects anticipated; existing exceedances of GTV's for DrWPA's at central & eastern sites	✓ - Potential to cause an enhancement in water quality in groundwater body	X	X
	▪ **General quality assessment**	To identify groundwater bodies where widespread deterioration in quality has or will compromise the strategic use of groundwater	Good	If groundwater chemical pressures result in an exceedance of GTV's for general quality of groundwater body *(see The River Basin Districts Typology, Standards and Groundwater threshold values (Water Framework Directive) (England and Wales) Directions 2009)*	X - No significant effects anticipated; existing exceedances of GTV's for general quality at central & eastern sites	X - No significant effects anticipated; no GTV for turbidity	X - No significant effects anticipated; existing exceedances of GTV's for general quality at central & eastern sites	X	X	X - No significant effects anticipated; existing exceedances of GTV's for general quality at central & eastern sites	✓ - Potential to cause an enhancement in water quality in groundwater body	X	X

Note	1	'Significant damage' is a function of the degree of damage (including quantative, chemical and biological) caused by groundwater related factors and the significance or conservation value of the ecosystem.
	2	'Significant' adverse effects are defined as those requiring mitigation (i.e. moderate or major adverse effects)
Ref.	1	Environment Agency *River Basin Management Plan: Thames River Basin District* (2009)
	2	Environment Agency website (What's in your backyard), 2012
	3	British Geological Survey website (GeoIndex), 2012
	4	UK Technical Advisory Group on the Water Framework Directive *Paper 11b(i) Groundwater Chemical Classification for the purposes of the Water Framework Directive and the Groundwater Daughter Directive* (March 2012)
	5	UK Technical Advisory Group on the Water Framework Directive *Paper 11b(ii) Groundwater Quantitative Classification for the purposes of the Water Framework Directive* (March 2012)
	6	UK Technical Advisory Group on the Water Framework Directive *Draft Protocol for determining "Significant Damage" to a "Groundwater Dependent Terrestrial Ecosystem* (October 2005)

✓	Potential to cause deterioration in element classification - detailed assessment required
X	No potential to affect WFD classification
✓	Potential to cause an enhancement in element classification - detailed assessment required

Waterbody Name	Regents Canal, lower Section
Waterbody ID	GB70610510
Current status	Moderate potential
Status objective	Good by 2027
Waterbody designation	AWB
Reasons for failure	Not all mitigation measures in place

	Construction								Operation				
WFD QUALITY ELEMENTS	**Jetties**	**Campsheds**	**Dredging**	**Dewatering**	**Piling**	**Diaphragm walls**	**Grouting**	**Tunnelling**	**Permanent structures**	**Scour protection**	**CSO interception**	**SuDS**	**Further assessment needed**
Hydromorphological elements													
Hydrological regime:													
▪ Quantity and dynamics of water flow	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Connection to groundwater bodies	X	X	X	X	X	X	X	X	X	X	X	X	X
River continuity:													
▪ Migration of aquatic organisms	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Sediment transport	X	X	X	X	X	X	X	X	X	X	X	X	X
Morphological conditions:													
▪ River depth and width variation	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Coastal/estuarine depth variation	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Structure and substrate of the river bed	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Quantity, structure and substrate of the coastal/estuary bed	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Structure of the riparian zone/intertidal zone	X	X	X	X	X	X	X	X	X	X	X	X	X
Tidal regime:													
▪ Tidal flow	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Wave exposure	X	X	X	X	X	X	X	X	X	X	X	X	X
Biological elements													
Phytoplankton:													
▪ Taxonomic composition													
▪ Average abundance													
▪ Planktonic bloom frequency and intensity													
▪ Biomass													
Macrophytes and phytobenthos:													
▪ Taxonomic composition	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Average macrophytes and phytobenthic abundance	X	X	X	X	X	X	X	X	X	X	X	X	X
Other aquatic flora (e.g. macroalgae, angiosperms, sea grass, sea weed salt marsh):													
▪ Composition													
Benthic invertebrate fauna:													
▪ Composition	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Abundance	X	X	X	X	X	X	X	X	X	X	X	X	X
Fish fauna:													
▪ Species composition and abundance	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Presence of type-specific disturbance sensitive species	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Age structure of fish communities	X	X	X	X	X	X	X	X	X	X	X	X	X
Critical sensitive habitats/species													
Protected sites:													
▪ SACs	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ SPAs	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ RAMSAR	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ SSSI	X	X	X	X	X	X	X	X	X	X	X	X	X
Priority habitats and species:													
Physico-chemical elements													
▪ Salinity	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Nutrient concentrations	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ pH	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Oxygen balance	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Acid neutralising capacity	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Temperature	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Transparency	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Pollution by all priority substances identified as being discharged into the water body	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ Pollution by other substances identified as being discharged in significant quantities into the water body	X	X	X	X	X	X	X	X	X	X	X	X	X

Key

✓	Potential to cause deterioration in element classification - detailed assessment required
X	No potential to affect WFD classification
✓	Potential to cause an enhancement in element classification - detailed assessment required

Annex C Future Good Potential screening assessment results

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Waterbody Name	Thames Upper
Waterbody ID	GB530603911403
Current status	Moderate potential
Status objective	Good by 2027
Waterbody designation	HMWB
Reasons for failure	Not all mitigation measures in place

			Construction								Operation			Further assessment needed
Mitigation measure not in place	Are mitigation measures likely to be implemented by 2027?	TE2100 Policy	Jetties	Campsheds	Dredging	Dewatering	Piling	Diaphragm walls	Grouting	Tunnelling	Permanent structures	Scour protection	SuDS	
Operational and structural changes to locks, sluices, weirs, beach control, etc	Yes	N/A	X	X	X	X	X	X	X	X	X	X	X	X
Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone	Yes	N/A	X	X	X	X	X	X	X	X	✓ - Planting on permanent structures would enhance macrophyte habitat	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✓	✓
Managed realignment of flood defence	Possible at Barn Elms	A.1.9. To maintain, enhance and replace the river defence walls and active structures through west London over the first 25 years of the Plan from 2010 to 2034.	X - may present an initial obstruction to this measure but the jetties are temporary. Managed realignment is also unlikely at the foreshore sites in this waterbody due to their urban nature	X - may present an initial obstruction to this measure but the jetties are temporary. Managed realignment is also unlikely at the foreshore sites in this waterbody due to their urban nature	X	X	X	X - may present an initial obstruction to this measure but the jetties are temporary. Managed realignment is also unlikely at the foreshore sites in this waterbody due to their urban nature	X	X	X - Managed realignment is unlikely at any of the TT permanent forshore sites in this waterbody due to the intensive urban use of land immediately behind the new structures	X - Managed realignment is unlikely at any of the TT permanent forshore sites in this waterbody due to the intensive urban use of land immediately behind the new structures	X	X
Remove obsolete structure	No obsolete structures identified in the vicinity of the proposed development sites (ie, PEF, CRR, CWD and DST)	N/A	X	X	✓	X	X	X	X	X	X	X	X	X

Key

✓	Potential to prevent or obstruct mitgation measure - detailed assessment required
X	No potential to prevent or obstruct mitgation measure
✓	Potential to enhance or improve mitigation measure

Waterbody Name	Thames Middle
Waterbody ID	GB530603911402
Current status	Moderate potential
Status objective	Good by 2027
Waterbody designation	HMWB
Reasons for failure	Not all mitigation measures in place

Mitigation measures not in place	Are mitigation measures likely to be implemented by 2027?	TE2100 Policy	Construction								Operation				Abbey Mills Compensation Scheme	Further assessment needed
			Jetties	Campsheds	Dredging	Dewatering	Piling	Diaphragm walls	Grouting	Tunnelling	Permanent structures	Scour protection	CSO interception	SuDS		
Indirect / offsite mitigation (offsetting measures)	Yes	N/A	X	X	X	X	X	X	X	X	X	X	X	X		X
Operational and structural changes to locks, sluices, weirs, beach control, etc	No structures (locks, sluices, weirs, beach control, etc) identified in the vicinity of the proposed development sites (ie, CEF, KST, HPS, AEF, VEF, BBF, CHW, KEMP and GPS)	N/A	X	X	X	X	X	X	X	X	X	X	X	X		X
Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone	Yes	N/A	X	X	X	X	X	X	X	X	✔ - Planting on permanent structures would enhance macrophyte habitat	X - scour protection not currently proposed for permanent structures (subject to review should scour develop)	✔	✔		✔
Managed realignment of flood defence	Considered to be unfeasible for the defences at CEF, KST, HPS, AEF, VEF, BBF, KEMP and GPS, a situtation which would not be altered by the proposed TTT structures. Defences would be set back at CHW	A.2.6. To maintain, enhance or replace, the river defence walls and active structures through central London over the first 25 years of the Plan from 2010 to 2034.	X - may present an initial obstruction to this measure but the jetties are temporary. Managed realignment is also unlikely at the foreshore sites in this waterbody due to their urban nature	X - may present an initial obstruction to this measure but the jetties are temporary. Managed realignment is also unlikely at the foreshore sites in this waterbody due to their urban nature	X	X	X	X - may present an initial obstruction to this measure but the jetties are temporary. Managed realignment is also unlikely at the foreshore sites in this waterbody due to their urban nature	X	X	X - Managed realignment is unlikely at any of the TT permanent forshore sites in this waterbody due to the intensive urban use of land immediately behind the new structures	X - Managed realignment is unlikely at any of the TT permanent forshore sites in this waterbody due to the intensive urban use of land immediately behind the new structures	X	X		X
Remove obsolete structure	An obsolete structure would be removed at CHW, none identified at the other proposed development sites (ie, CEF, KST, HPS, AEF, VEF, BBF, KEMP and GPS)	N/A	X	X	X	X	X	X	X	X	X	X	X	X		X

Key

✔	Potential to prevent or obstruct mitgation measure - detailed assessment required
X	No potential to prevent or obstruct mitgation measure
✔	Potential to enhance or improve mitigation measure

Waterbody Name	Wandle (Croydon to Wandsworth) and the R. Gravney
Waterbody ID	GB106039023460
Current status	Poor potential
Status objective	Good by 2027
Waterbody designation	HMWB
Reasons for failure	Fish and phytobenthos

			Construction								Operation				
Mitigation measures not in place	**Are mitigation measures likely to be implemented by 2027?**	**TE2100 Policy**	**Jetties**	**Campsheds**	**Dredging**	**Dewatering**	**Piling**	**Diaphragm walls**	**Grouting**	**Tunnelling**	**Permanent structures**	**Scour protection**	**CSO interception**	**SuDS**	**Further assessment needed**
Retain marginal aquatic and riparian habitats (channel alteration)	Yes	N/A	x	x	x	x	x	x	x	x	x	x	x	x	x
Educate landowners on sensitive management practices (urbanisation)	Yes	N/A	x	x	x	x	x	x	x	x	x	x	x	x	x
Appropriate techniques to align and attenuate flow to limit detrimental effects of these features (drainage)	Yes	N/A	x	x	x	x	x	x	x	x	x	x	x	✓	✓
Remove obsolete structure	Yes - proposed removal of Bell Lane and EDF Weirs	N/A	x	x	x	x	x	x	x	x	x	x	x	x	x
Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone	Yes	N/A	x	x	x	x	x	x	x	x	x	x	✓ Improved water quality and reduction in sewage derived litter will improve habitat quality	x	✓
Structures or other mechanisms in place and managed to enable fish to access waters upstream and downstream of the impounding works	Yes - proposed removal of Bell Lane and EDF Weirs	N/A	x	x	x	x	x	x	x	x	x	x	x	x	x
Alteration of channel bed (within culvert)	Yes	N/A	x	x	x	x	x	x	x	x	x	x	x	x	x
Increase in-channel morphological diversity	Yes	N/A	x	x	x	x	x	x	x	x	x	x	x	x	x
Removal of hard bank reinforcement / revetment, or replacement with soft engineering solution	Yes	N/A	x	x	x	x	x	x	x	x	x	x	x	x	x
Operational and structural changes to locks, sluices, weirs, beach control, etc	Yes - proposed removal of Bell Lane and EDF Weirs	N/A	x	x	x	x	x	x	x	x	x	x	x	x	x

Key

✓ (red)	Potential to prevent or obstruct mitgation measure - detailed assessment required
x	No potential to prevent or obstruct mitgation measure
✓ (green)	Potential to enhance or improve mitigation measure

Waterbody Name	Regents Canal, lower Section
Waterbody ID	GB70610510
Current status	Moderate potential
Status objective	Good by 2027
Waterbody designation	AWB
Reasons for failure	Not all mitigation measures in place

			Construction								Operation				Further assessment needed
Mitigation measures not in place	**Are mitigation measures likely to be implemented by 2027?**	**TE2100 Policy**	**Jetties**	**Campsheds**	**Dredging**	**Dewatering**	**Piling**	**Diaphragm walls**	**Grouting**	**Tunnelling**	**Permanent structures**	**Scour protection**	**CSO interception**	**SuDS**	
Modify vessel design	Yes	N/A	X	X	X	X	X	X	X	X	X	X	X	X	X

Key

✓ (red)	Potential to prevent or obstruct mitgation measure - detailed assessment required
X	No potential to prevent or obstruct mitgation measure
✓ (green)	Potential to enhance or improve mitigation measure

Waterbody Name	Ravensbourne
Waterbody ID	GB106037028110
Current status	Moderate potential
Status objective	Good by 2027
Waterbody designation	HMWB
Reasons for failure	Ammonia, DO, phosphate, and not all mitigation measures in place

			Construction								Operation				Lewisham College Tidal Weir Notch Compensation Scheme	Further assessment needed
Mitigation measures not in place	**Are mitigation measures likely to be implemented by 2027?**	**TE2100 Policy**	**Jetties**	**Campsheds**	**Dredging**	**Dewatering**	**Piling**	**Diaphragm walls**	**Grouting**	**Tunnelling**	**Permanent structures**	**Scour protection**	**CSO interception**	**SuDS**		
Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone	Yes	N/A	X	X	X	X	X	X	X	X	X	X	X	X	✓ Scheme specifically designed to improve fish passage and diversity	✓
Preserve and, where possible, restore historic aquatic habitats	Yes	N/A	X	X	X	X	X	X	X	X	X	X	X	X	✓ Scheme specifically designed to improve fish passage and diversity	✓
Removal of hard bank reinforcement / revetment, or replacement with soft engineering solution	Yes	N/A	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Key

✓ (red)	Potential to prevent or obstruct mitgation measure - detailed assessment required
X	No potential to prevent or obstruct mitgation measure
✓ (green)	Potential to enhance or improve mitigation measure

Waterbody Name	Crane (including part of the Yeading Brook)
Waterbody ID	GB106039023030
Current status	Poor potential
Status objective	Good by 2027
Waterbody designation	HMWB
Reasons for failure	Phosphate, Fish, Phytobenthos

			Construction								Operation					
Mitigation measures not in place	**Are mitigation measures likely to be implemented by 2027?**	**TE2100 Policy**	**Jetties**	**Campsheds**	**Dredging**	**Dewatering**	**Piling**	**Diaphragm walls**	**Grouting**	**Tunnelling**	**Permanent structures**	**Scour protection**	**CSO interception**	**SuDS**	**Kidds Mill Sluice Fish Pass Implementation and Mogden STW Weir Removal Compensation Schemes**	**Further assessment needed**
Educate landowners on sensitive management practices (urbanisation)			X	X	X	X	X	X	X	X	X	X	X	X	X	X
Retain marginal aquatic and riparian habitats (channel alteration)			X	X	X	X	X	X	X	X	X	X	X	X	X	X
Operational and structural changes to locks, sluices, weirs, beach control, etc			X	X	X	X	X	X	X	X	X	X	X	X	X	X
Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone			X	X	X	X	X	X	X	X	X	X	✓ Improved water quality and reduction in sewage derived litter will improve habitat quality	X	X	✓
Structures or other mechanisms in place and managed to enable fish to access waters upstream and downstream of the impounding works			X	X	X	X	X	X	X	X	X	X	X	X	✓	X
Alteration of channel bed (within culvert)			X	X	X	X	X	X	X	X	X	X	X	X	X	X
Re-opening existing culverts																
Increase in-channel morphological diversity	Yes	N/A	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Preserve and, where possible, restore historic aquatic habitats	Yes	N/A	X	X	X	X	X	X	X	X	X	X	X	X	✓ - Inclusion of a multi species fish pass and removal of the weir at Mogden STW would result in improved species richness and abundance moving upstream from the Thames Upper waterbody	✓
Removal of hard bank reinforcement / revetment, or replacement with soft engineering solution	Yes	N/A	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Remove obsolete structure	Yes	N/A	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Key

✓ (red)	Potential to prevent or obstruct mitgation measure - detailed assessment required
X	No potential to prevent or obstruct mitgation measure
✓ (green)	Potential to enhance or improve mitigation measure

Waterbody Name	Beverley Brook (Motspur Park to Thames) and Pyl Brook at West Barnes
Waterbody ID	GB106039022850
Current status	Poor potential
Status objective	Good by 2027
Waterbody designation	HMWB
Reasons for failure	Fish and macrophytes

			Construction								Operation				
Mitigation measures not in place	Are mitigation measures likely to be implemented by 2027?	TE2100 Policy	Jetties	Campsheds	Dredging	Dewatering	Piling	Diaphragm walls	Grouting	Tunnelling	Permanent structures	Scour protection	CSO interception	SuDS	Further assessment needed
Educate landowners on sensitive management practices (urbanisation)	Yes	N/A	X	X	X	X	X	X	X	X	X	X	X	X	X
Appropriate techniques to align and attenuate flow to limit detrimental effects of these features (drainage)	Yes	N/A	X	X	X	X	X	X	X	X	X	X	X	X	X
Retain marginal aquatic and riparian habitats (channel alteration)	Yes	N/A	X	X	X	X	X	X	X	X	X	X	X	X	X
Preserve and where possible enhance ecological value of marginal aquatic habitat, banks and riparian zone	Yes	N/A	X	X	X	X	X	X	X	X	X	X	X	X	X
Increase in-channel morphological diversity	Yes	N/A	X	X	X	X	X	X	X	X	X	X	X	X	X
Removal of hard bank reinforcement / revetment, or replacement with soft engineering solution	Yes	N/A	X	X	X	X	X	X	X	X	X	X	X	X	X

Key

✓ (red)	Potential to prevent or obstruct mitgation measure - detailed assessment required
X	No potential to prevent or obstruct mitgation measure
✓ (green)	Potential to enhance or improve mitigation measure

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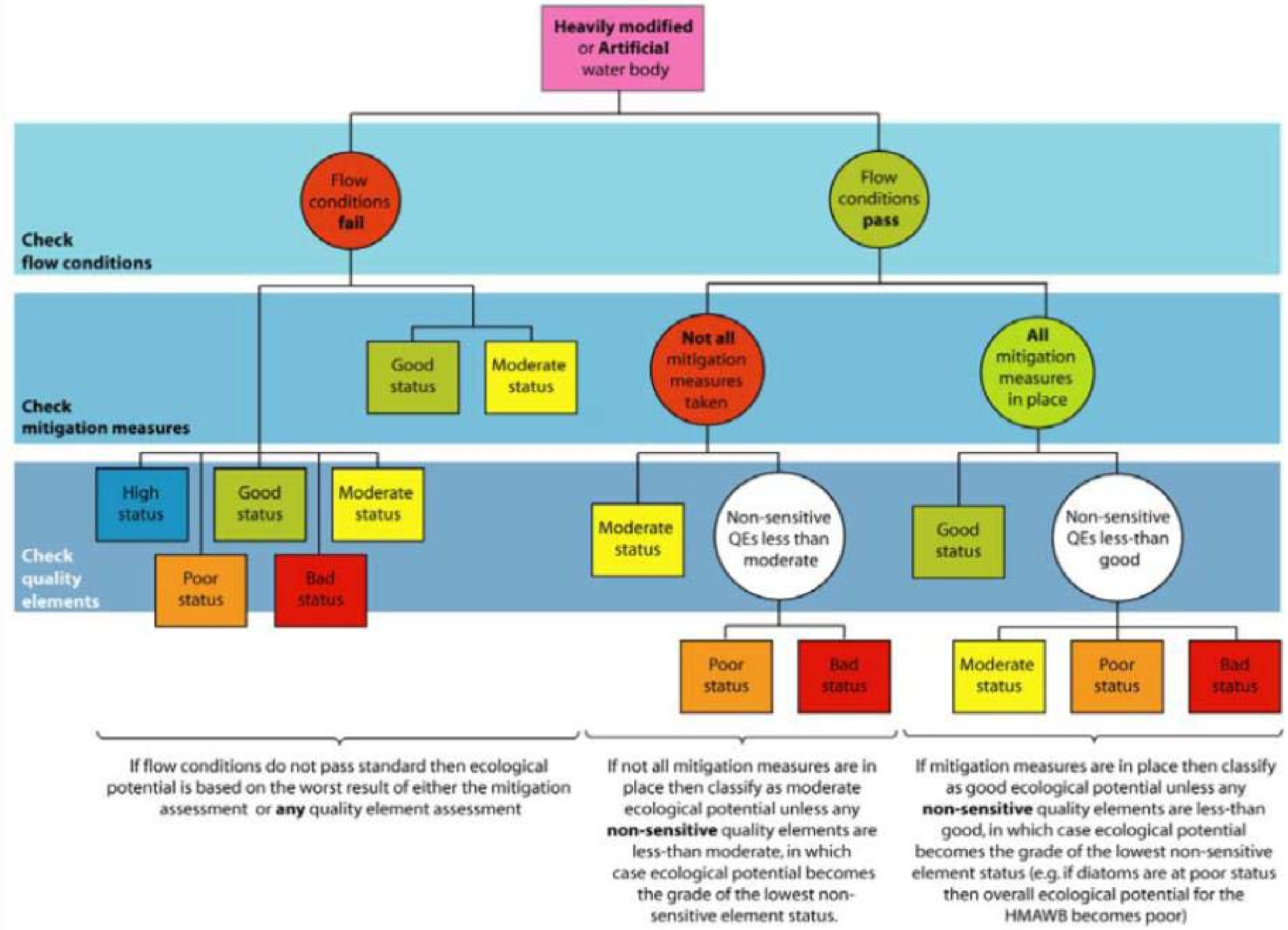
Annex D HMWB classification approach



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Annex E Morphological impacts of schemes

Type of modification		Guidance on level of WFD assessment required		
		Detailed impact assessment unlikely - follow best practise guidance	**Detailed impact assessment unlikely - follow best practise and record in the iRBM data solution**	**Detailed impact assessment may be required - use thresholds of concern as guidance. River water body length is provided in the River Basin Characterisation data set in the iRBM data solution. If no detailed assessment is undertaken follow best practise and record in the iRBM data solution**
Channel / Watercourse alteration	Watercourse alteration including - resectioning, straightening, realignment, channelisation			Calculate the length of river water body impacted. Detailed assessment should be undertaken where >2% of the river water body length is impacted.
	Channel diversions			All channel diversions will need detailed assessment.
	By pass channel/flood relief channel,			Calculate the river water body length to be by passed. Detailed assessment should be undertaken where >3% of the river water body length is bypassed.

Type of modification		Guidance on level of WFD assessment required		
		Detailed impact assessment unlikely - follow best practise guidance	**Detailed impact assessment unlikely - follow best practise and record in the iRBM data solution**	**Detailed impact assessment may be required - use thresholds of concern as guidance. River water body length is provided in the River Basin Characterisation data set in the iRBM data solution. If no detailed assessment is undertaken follow best practise and record in the iRBM data solution**
	Bank protection	Green/soft bank reinforcement or re-profiling ≤10m or ≤ one channel width in length (whichever is greater).	Green/soft bank reinforcement or re-profiling ≤50m in length.	Calculate the total length of bank protection, remembering to include the length of protection on both banks. For green/soft engineering detailed assessment should be undertaken where total length of bank protection is >5% of the river water body length. For grey/hard engineering detailed assessment should be undertaken where total length of bank protection is >3% of the river water body length.
	Bed protection		Bed reinforcement ≤10m in length downstream of closed culverts to prevent scour immediately downstream.	Calculate the length of the water body impacted. Detailed assessment should be undertaken where >1% of the water body is impacted.

Type of modification		Guidance on level of WFD assessment required		
		Detailed impact assessment unlikely - follow best practise guidance	**Detailed impact assessment unlikely - follow best practise and record in the iRBM data solution**	**Detailed impact assessment may be required - use thresholds of concern as guidance. River water body length is provided in the River Basin Characterisation data set in the iRBM data solution. If no detailed assessment is undertaken follow best practise and record in the iRBM data solution**
Defence (linear flood defence)	Embankment / flood banks			Calculate the total length of the embankment/flood bank, remembering to include the length for both banks. Detailed assessment should be undertaken where total length of embankment/flood bank is >3% of the water body length.
	Set-back embankment / flood banks			Calculate the total length of the set-back embankment/flood bank, remembering to include the length for both banks. Detailed assessment should be undertaken where total length of set-back embankment/flood bank is >5% of the water body length.
	Revetment			Calculate the total length of revetment remembering to include the length for both banks. Detailed assessment should be undertaken where the total length of revetment >3% of water body length.
	Wall			Calculate the total length of the wall, remembering to include the length for both banks. Detailed assessment should be undertaken where total length of wall is >3% of the water body length.

Type of modification		Guidance on level of WFD assessment required		
		Detailed impact assessment unlikely - follow best practise guidance	**Detailed impact assessment unlikely - follow best practise and record in the iRBM data solution**	**Detailed impact assessment may be required - use thresholds of concern as guidance. River water body length is provided in the River Basin Characterisation data set in the iRBM data solution. If no detailed assessment is undertaken follow best practise and record in the iRBM data solution**
	Set back wall			Calculate the total length of the set-back wall, remembering to include the length for both banks. Detailed assessment should be undertaken where total length of set-back wall is >5% of the water body length.
Channel / Watercourse structures	Infrastructure surrounding a outfall/intake, sluice, pipe, inlet, outlet, off-take, pumping stations			Calculate the total length of bank/bed impacted. Detailed assessment should be undertaken where >3% of the bank or bed is impacted.
	Structures such as small boat slipways, piers, jetties and platforms			Calculate the total length of bank/bed impacted. Detailed assessment should be undertaken where >5% of the bank or bed is impacted.

Type of modification		Guidance on level of WFD assessment required		
		Detailed impact assessment unlikely - follow best practise guidance	**Detailed impact assessment unlikely - follow best practise and record in the iRBM data solution**	**Detailed impact assessment may be required - use thresholds of concern as guidance. River water body length is provided in the River Basin Characterisation data set in the iRBM data solution. If no detailed assessment is undertaken follow best practise and record in the iRBM data solution**
	In stream structures such as croys, groynes, boulder placement and other flow deflectors	Boulder placement in a river occupying <10% of channel width.		Calculate the length of river over which the in stream structures will be placed. Detailed assessment should be undertaken when >2% of water body length is impacted. A threshold approach does not work particularly well for this type of structure. Consideration should be made as to whether they are the appropriate solution to the problem and advice should be sought from a geomorphologist.
	Lock			All locks require detailed assessment
	Culvert			All culverts will generally require a detailed assessment. Use a common sense approach, for example a small pipe culvert used under a footpath is unlikely to cause a significant morphological risk
Impoundment structures (including changes to	Barrage / dam (including components & installations)			All barrages and dams will need detailed assessment

Type of modification		Guidance on level of WFD assessment required		
		Detailed impact assessment unlikely - follow best practise guidance	**Detailed impact assessment unlikely - follow best practise and record in the iRBM data solution**	**Detailed impact assessment may be required - use thresholds of concern as guidance. River water body length is provided in the River Basin Characterisation data set in the iRBM data solution. If no detailed assessment is undertaken follow best practise and record in the iRBM data solution**
existing structures)	Weir / sluice- raising height of existing weir, changing capacity of impoundment or operational changes to existing structures			Calculate the length of the additional impounded water. Detailed assessment should be undertaken where the additional impounded water >1% water body length.
	Weir / sluice - removal			All weir or sluice removals will need detailed assessment
	Weir / sluice - new structure			All new weir or sluice structures will need detailed assessment.

Type of modification		Guidance on level of WFD assessment required		
		Detailed impact assessment unlikely - follow best practise guidance	**Detailed impact assessment unlikely - follow best practise and record in the iRBM data solution**	**Detailed impact assessment may be required - use thresholds of concern as guidance. River water body length is provided in the River Basin Characterisation data set in the iRBM data solution. If no detailed assessment is undertaken follow best practise and record in the iRBM data solution**
Power generation	Hydroelectric power scheme - changing height of existing weir, changing capacity of the impoundment or operational changes to existing structures			Calculate the length of the additional impounded water. Detailed assessment should be undertaken where the additional impounded water >1% water body length.
	Hydroelectric power scheme - new weir structure			All new weir / barrage / barrier structures will need detailed assessment.
	Hydroelectric power scheme			Calculate the length of the depleted reach. Detailed assessment should be undertaken where the depleted reach is >1% water body length.

Type of modification		Guidance on level of WFD assessment required		
		Detailed impact assessment unlikely - follow best practise guidance	**Detailed impact assessment unlikely - follow best practise and record in the iRBM data solution**	**Detailed impact assessment may be required - use thresholds of concern as guidance. River water body length is provided in the River Basin Characterisation data set in the iRBM data solution. If no detailed assessment is undertaken follow best practise and record in the iRBM data solution**
Fish passage	Installation of a fish pass			Consideration should first be made as to whether the impoundment could be removed or modified. Where a fish pass is the appropriate option then calculate the length of the structure. Detailed assessment should be undertaken where > 2% of the water body length is impacted.
Flood storage area	Flood storage area			All flood storage areas require detailed assessment
Capital dredge	Capital dredge			All capital dredges will require a detailed assessment
Maintenance activities	Sediment management			Calculate the length of river over which sediment is to be removed, moved or manipulated. Detailed assessment should be undertaken where >2% of the water body is impacted.

Type of modification		Guidance on level of WFD assessment required		
		Detailed impact assessment unlikely - follow best practise guidance	**Detailed impact assessment unlikely - follow best practise and record in the iRBM data solution**	**Detailed impact assessment may be required - use thresholds of concern as guidance. River water body length is provided in the River Basin Characterisation data set in the iRBM data solution. If no detailed assessment is undertaken follow best practise and record in the iRBM data solution**
	Management of woody debris			Thresholds for detailed assessment are not appropriate for the management of woody debris. Detailed assessment may be required depending on circumstances and scale of activity and expert judgement should be applied. Good practise guidance can be found in the mitigation measure manual at http://evidence.environment-agency.gov.uk/FCERM/en/SC060065/MeasuresList/M5/M5T3.aspx
Vegetation management	Removal/management of riparian vegetation			Detailed assessment is required where the asset is being managed to target condition 2 and/or if undertaking grass control at M1 or M2; weed control

Type of modification		Guidance on level of WFD assessment required		
		Detailed impact assessment unlikely - follow best practise guidance	**Detailed impact assessment unlikely - follow best practise and record in the iRBM data solution**	**Detailed impact assessment may be required - use thresholds of concern as guidance. River water body length is provided in the River Basin Characterisation data set in the iRBM data solution. If no detailed assessment is undertaken follow best practise and record in the iRBM data solution**
	Removal/management of in stream vegetation			at W1 or W2, WB1 or WB2 and tree control at TB1 or TB2 under the "Delivering consistent standards for sustainable asset management guidelines" (http://ams.ea.gov/ams_root/2009/301_350/301_09_SD05.pdf). If the vegetation management activity is not covered by the ASM standards then calculate the length of water body that vegetation is being removed from or managed. Detailed assessment in required where >5% of water body length is being impacted
Bridges and other types of crossing structure	Bridges	Minor bridges with no construction on bed or banks Temporary bridges in rivers <5m wide	Bridges with no construction on bed (e.g. no piers or in-channel supports) and ≤20m of total bank affected.	All bridges with > 20m bank affected or an in channel support require detailed assessment

Type of modification		Guidance on level of WFD assessment required		
		Detailed impact assessment unlikely - follow best practise guidance	**Detailed impact assessment unlikely - follow best practise and record in the iRBM data solution**	**Detailed impact assessment may be required - use thresholds of concern as guidance. River water body length is provided in the River Basin Characterisation data set in the iRBM data solution. If no detailed assessment is undertaken follow best practise and record in the iRBM data solution**
	Fords			Refer to thresholds for bed and bank protection as appropriate
Removal of natural barriers	Removal of natural barriers (removal of waterfalls and other in-stream natural barriers, usually to permit upstream fish migration)			All cases of natural barrier removal need detailed assessment

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[29] Environment Agency (undated). *Estuary Edges: Ecological Design Guidance.* Thames Estuary Partnership

[30] Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild

[31] The EC Freshwater Fish Directive (2006/44/EC)

[32] EC Shellfish Waters Directive (2006/113/EEC) - note that this will be repealed in 2013 by the EC Water Framework Directive

Thames Tideway Tunnel
Thames Water Utilities Limited

Application for Development Consent

Application Reference Number: WWO10001

Environmental Statement

Doc Ref: **6.2.03**

Volume 3: Project-wide effects assessment appendices

Appendix L.3: Interpretative scour report

APFP Regulations 2009: Regulation **5(2)(a)**

Hard copy available in

Box **17.3** Folder **B**
January 2013

Thames Tideway Tunnel
Creating a cleaner, healthier River Thames

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L.3 Interpretative scour report

L.3.1 The following report has its own table of contents.

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Interpretive Scour Report

February 2013

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Thames Tideway Tunnel

Interpretive Scour Report

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1 Executive summary

1.1.1 This report is intended for a readership of third part stakeholders, including the Environment Agency, Port of London Authority and the owners of bridges, tunnels and river walls that potentially could be affected by foreshore works in connection with the Thames Tunnel Project being promoted by Thames Water.

1.1.2 It draws on information provided by HR Wallingford into the potential river bed scour arising from foreshore works at nine sites which are, in order (upstream to downstream):

- Putney Embankment (temporary and permanent works)
- Carnwath Road (temporary works only)
- Chelsea Embankment (temporary and permanent works)
- Kirtling Street/ Heathwall (temporary and permanent works)
- Albert Embankment (temporary and permanent works)
- Victoria Embankment (temporary and permanent works)
- Blackfriars Bridge (temporary and permanent works)
- Chambers Wharf (temporary works only)
- King Edward Memorial Park (temporary and permanent works)

1.1.3 The report summarises the HR Wallingford work on a site by site basis and includes an overview of scour mechanisms, the methods used to estimate scour, methods and materials that are available to either prevent or mitigate scour and a provisional strategy for monitoring the river bed around foreshore structures during and after construction. The report does not offer a critical assessment of HR Wallingford's methods or results.

1.1.4 The Thames river bed can be characterised as a veneer of mobile sediments (predominantly gravels) overlying a stiff clay that is more resistant to erosion. The veneer of mobile sediments is subject to natural variations in level, responding to tides and fluvial events but the permanent foreshore works for the Thames Tunnel, and the temporary cofferdams behind which construction will take place, have the potential to cause local acceleration of the flows, which in turn may cause erosion ("scour") of the bed.

1.1.5 The issue of scour is important because it may undermine structures, remove valuable habitats or disperse sediment which when redeposited may affect navigation or smother habitats.

1.1.6 Two types of scour are considered in the report:

- Local or "abutment" scour, immediately adjacent to a structure, caused by acceleration of the flow around the structure
- General "contraction" scour as the channel responds to narrowing by the presence of the new structures.

1.1.7 Initially scour was assessed for the temporary and permanent works at each site using published methods which are based on the threshold of motion (the velocity which erodes) surface deposits, assuming the deposits are uniform cohesionless material (such as sand or gravel). This can (and did) lead to unrealistic estimates if the surface deposits are not representative of material within a few metres of the surface.

1.1.8 Accordingly, HRWallingford has re-assessed scour depths using the “erodibilty index” method that has been developed in recent years and has been previously applied to offshore wind farms and bridge projects. This method enables the erosive force (“stream power”) to be compared with the susceptibility of cohesive (clayey) soils to erosion with depth, if suitable soil properties are available from a borehole or other ground investigation technique. In general, as scour progresses and the bed becomes lower the stream power will decrease and the resistance to erosion will increase. The depth of scour is determined as the depth at which the available stream power is insufficient to erode the exposed material. The method is applicable to situations where the strength of the bed increases with depth or where a resistant layer might protect weaker materials below or is insufficient to provide such protection.

1.1.9 The erodibilty index method has tended to generate lower estimates of scour depth than the threshold of motion method which are considered by HR Wallingford to be more realistic and founded in a more robust conceptual model of the river bed.

1.1.10 For all the sites, contraction scour has been found to be less than 0.5m for both temporary and permanent works, and in most cases will be less than the natural “noise” of river bed variation. No mitigation measures are considered to be necessary.

1.1.11 Scour caused by temporary works will only be prevented as a last resort and the approach will be to monitor and mitigate only if necessary. The approach is documented in Thames Tideway Tunnel’s “Scour & Accretion Monitoring and Mitigation Plan for Temporary Works in the Foreshore” which is the subject of stakeholder consultation,

1.1.12 The design of scour protection measures to permanent structures will be by the Contractor. The studies by HR Wallingford have informed the DCO plans but the Contractor’s detailed designs will have the potential to refine what is shown on these plans. It is likely that precautionary scour limitation measures will be proposed but in cases where minimal scour is confidently predicted an allowance for scour may be included in the design of the permanent structures.

2 Introduction and Background

2.1 Introduction

2.1.1 Black & Veatch Ltd has been commissioned to prepare an interpretative report on the potential scour of the river bed caused by in-channel works associated with the Thames Tideway Tunnel Project.

2.1.2 This document, the Interpretive Scour Report, is to provide a straightforward interpretation of scour studies undertaken by HR Wallingford. These studies assess the change in river velocities caused by the proposed in-channel temporary and permanent works at eight sites in the Thames Tideway and the resultant scour that may potentially occur.

2.2 Background

The Thames Tideway Project

2.2.1 The Thames Tideway Tunnel Project, which is being promoted by Thames Water, is for the construction of a large diameter tunnel generally under the bed of the River Thames through London. The purpose of the tunnel is to intercept polluted discharges into the river from combined sewer outfalls (CSOs) and to transfer the discharges to Thames Water's sewage treatment works at Beckton. This is predicted to significantly improve the water quality of the River Thames.

The Proposed Works in the River Thames

2.2.2 In connection with the Thames Tideway Tunnel project, there are eight sites where tunnel shafts, combined sewers outfalls (CSO), interception chambers and/or temporary construction sites are proposed on the foreshore of the tidal section of the River Thames through London. The eight sites are summarised in Table 2-1 below.

2.2.3 At each of the sites, apart from Carnwath Road and Chambers Wharf, temporary works within a cofferdam[1] followed by permanent works are being proposed. The works at Chambers Wharf differ because no permanent works are proposed. The works at Carnwath Road consist of a temporary jetty, with no cofferdam, and no permanent works are required at this location.

2.2.4 Both the temporary and permanent works will protrude into the river from one or other of the banks. In all cases, the temporary works cofferdam will have a significantly larger footprint on the foreshore of the river than the permanent works.

[1] A cofferdam is a temporary structure (usually of interconnected sheet piles) which excludes the river water and enables construction to proceed in the dry. The river bed will normally be visible in the base of a cofferdam.

Table 2-1 Summary of works sites

Site Name	River Bank
Putney Embankment	South (right)
Carnwath Road	North (left)
Chelsea Embankment	North (left)
Kirtling Street/ Heathwall	South (right)
Albert Embankment	South (right)
Victoria Embankment	North (left)
Blackfriars Bridge	North (left)
Chambers Wharf	South (right)
King Edward Memorial Park	North (left)

The Scour Problem

2.2.5 The studies presented and discussed in this report address the possible additional scour, over and above the natural scour processes in the river, due to the in-channel works associated with the Thames Tideway Tunnel. The proposed works at the eight locations, whether temporary or permanent, will cause changes in flow conditions in the river, which could result in scour due to two distinct mechanisms, as follows:-

- **Local Abutment Scour** in the immediate vicinity of the proposed temporary and permanent works due to localised turbulent flow conditions
- **Contraction Scour** generally across the river channel due to faster flowing water in the channel resulting from the loss of channel width caused by the proposed temporary or permanent works

2.2.6 These scour mechanisms are reviewed in Section 3. The flow conditions used to assess the potential scour at each site are reviewed in Section 4.

2.2.7 Methods and techniques available to avoid or mitigate the effects of scour, are reviewed in Section 5.

2.2.8 The application of this general approach to scour is considered for each individual proposed site in Sections 6 – 15.

3 Scour mechanisms

3.1 Introduction

3.1.1 Scour occurs when the flow velocity in a moving body of water is greater than the critical threshold velocity required to cause movement of the bed material.

3.1.2 CIRIA Report C551 – Manual on Scour at Bridges and other Hydraulic Structures (CIRIA 2002) classifies scour as "natural", "local", or "contraction".

3.1.3 Natural scour covers the processes associated with natural factors and is part of the baseline of the Thames Tideway so is not considered as part of this study. Local scour and contraction scour result from modifications to the natural channel and are defined in the manual as follows:-

- ***Local Scour –*** *Scour that results directly from the impact of individual structural elements (for example, piers and abutments) on the flow and occurs only in the immediate vicinity of those elements.*
- ***Contraction Scour –*** *Scour affecting all or most of the channel bed in the vicinity of a bridge or other hydraulic structure, associated with higher velocities caused by narrowing of the channel*

3.1.4 The mechanisms of these two types of scour are discussed in more detail below.

3.2 Local Scour

3.2.1 Local scour is caused by the presence of structures which obstruct and change the water flow, resulting in an increase in local flow velocities and turbulence levels. The presence of a structure has three main effects:

- An increase in the local velocity as the water accelerates around the upstream end of the structure
- The development of vortices at the front face of the structure as the flow is deflected towards the bed
- The formation of 'wake' vortices behind the structure cased by the flow separation in plan as the water moves around the obstruction.

3.2.2 Figure 3-1 shows the development of these vortices and the typical flow patterns around an isolated structure or pier in flowing water and the same principles can be applied to abutments which extend from the riverbank into the flow.

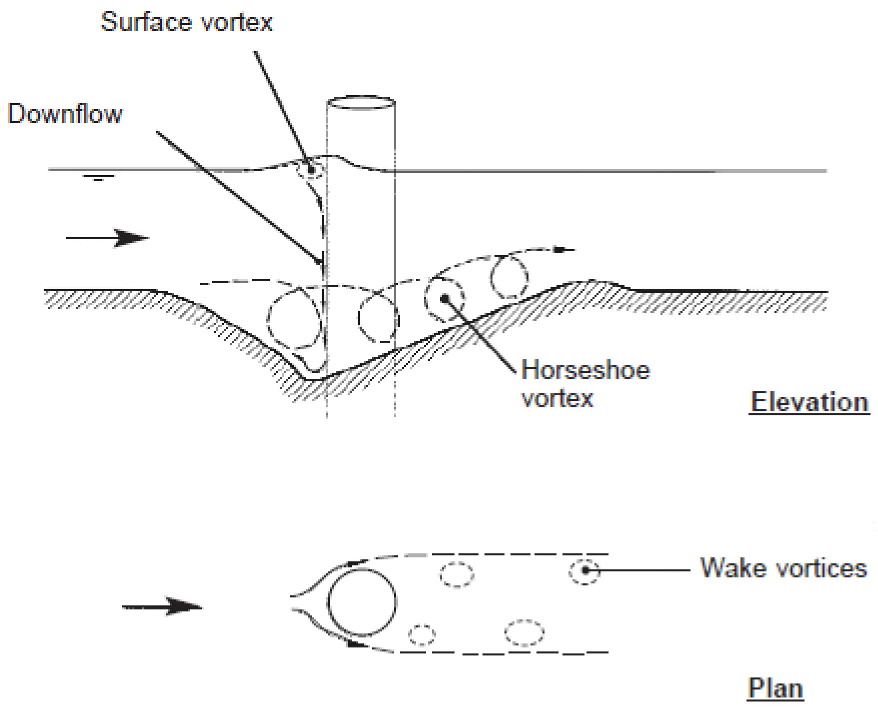

Figure 3-1 Typical flow pattern around a structure (from CIRIA, 2002)

3.3 Contraction Scour

3.3.1 Contraction scour arises due to a reduction in the cross section area of the waterway caused by introducing an object. The flow of water is not changed, but because the flow is confined to a smaller area the water velocity is forced to increase.

3.3.2 If the channel is formed in erodible material the higher velocities caused by the contraction of the channel may cause general lowering of the bed across the whole of the channel width. In practice, the parts of the channel that are deepened will be those that are most easily eroded and the maximum depth of such erosion might be considerably deeper than the calculated contraction scour which is a cross section average.

3.4 Total scour

3.4.1 The effects of different scour mechanisms are additive and therefore the total scour effect of the works will be the sum of local and contraction scour depths.

3.5 Factors affecting the depth of scour

3.5.1 In general, the works at each of the sites (with the exception of the open piled temporary pier at Kirtling Street) are temporary cofferdams and permanent reclamations which extend out from the river bank into the river channel. Scour around these types of structures is termed ‘abutment’ scour, which is a specific type of local scour. The primary factors affecting the scour depth are set out in Table 3-1 , and discussed further below.

Table 3-1 Factors affecting scour depth calculation

Scour factor	How factor affects Thames scour
Local maximum velocity	Velocity must exceed a threshold value before scour can occur - the “critical velocity” U_{cr}
Sediment size	Often this is the key factor in determining scour depth
River bed geology	Scour depth will depend on whether the river bed sediment is cohesive (such as clays) or non-cohesive (such as sands or gravels)
Distance works protrude from bank (abutment width)	Scour depth is proportional to the abutment width (although this is modified by water depth – see below)
Water depth	Scour depth is dependent on a ‘depth factor’ which is a hyperbolic function of the ratio of water depth to abutment width.
Shape of works	Scour depth is dependent on a shape factor which is related to the shape of the abutment.

Threshold velocity

3.5.2 One of the key parameters in determining the scour depth is the critical threshold velocity (U_{cr}) at which the particular sediment on the bed starts to move. The critical velocity is directly related to the average sediment size of cohesionless soils.

3.5.3 The critical velocity is also used to mark the boundary between ‘live-bed’ scour and ‘clear-water’ scour

- ‘Live-bed’ scour occurs when the velocity (U) in the channel (without the presence of additional works) is greater than the critical threshold velocity ($U>U_{cr}$), and therefore bed material is mobilised by the normal flow regime.
- ‘Clear-water’ scour occurs when the normal velocity in the channel is below the critical threshold velocity ($U<U_{cr}$), but the presence of the additional works increases local velocities so they exceed the critical velocity.

3.5.4 Overall scour depth will differ depending on whether scour is clear water or live bed scour. In live bed scour there is a supply of material from upstream that will move into the area where local scour is occurring, and may therefore reduce the overall scour depth.

River bed geology

3.5.5 Scour predictions depend directly on the composition of the river bed, and will vary depending on the sediment size, and whether the material is non-cohesive (such as sands and gravels) or cohesive (such as clays).

3.5.6 Scour depth predictions for clays are generally shallower than predictions for sands and gravels as the cohesive nature of the clay particles provides greater resistance to erosion than the individual particles in non-cohesive soils. Further discussion on the effects of the river bed geology on scour depth in relation to the sites in the Thames is included in Section 3.6.

Width of works and local water depth

3.5.7 Scour depth is related to the ratio of local water depth to the width of the works. For the large abutments being considered, scour depths are more influenced by water depth than abutment width

3.5.8 A small reduction in the amount the works protrudes from the bank may not significantly reduce the predicted scour depth, but is likely to be beneficial as it will reduce water depths and often local velocities, both of which will reduce scour, because channels tend to be shallower and velocities lower near the bank..

Shape of works

3.5.9 Scour depths are very dependent on the plan shape of the structures and so depth predictions include a shape factor. A rectangular shape has a shape factor of 3, while a streamlined shape has a factor of 0.75. Further discussion on shape factors is included in Appendix A.

3.5.10 The factor most under the control of the designer of works is the shape factor. A streamlined shape can reduce the predicted scour by a factor of four compared with a rectangular shape, though there is a risk that a streamlined shape may lead to larger velocities alongside the structure which would reduce the benefit of the streamlined shape.

3.5.11 If a streamlined shape is not achievable because of local considerations, the scour associated with a rectangular shape can be reduced by angling the walls to the bank or by rounding the corners that cause the scour. The reduction in shape factor that may be achieved by such changes is indicated in Appendix A.

3.5.12 While a streamlined or tapered shape may require a larger land take to give the same useable area, there may be benefits from the smaller area of estuary bed that will require protection against scour. This factor should be considered to minimise the area affected by the works plus the scour protection.

3.6 Scour Prediction Methods

Conceptual Model

3.6.1 Almost all the boreholes sunk in the Thames in the vicinity of the work sites indicate a relatively shallow layer of non-cohesive mobile sediments overlying stiff clay. This leads to a conceptual model of the Thames channel as a veneer of mobile sediments overlying the stiff clay which is likely to be more resistant to erosion. The boreholes suggest this veneer is between 0.4m and 3m thick and is normally composed of gravel sized material (particles in the range of 2 to 63 mm diameter).

3.6.2 One difficulty in predicting scour is that the calculation methods presented in published manuals such as CIRIA 2002 are based on uniform soils and therefore it is difficult to take account of the layered strata that are present in the Thames. Initial predictions for the work sites were therefore based either on solely non-cohesive mobile sediments, or solely cohesive sediments depending on the nature of the bed found at the specific sites.

Initial Scour Assessment

3.6.3 An initial scour assessment, which assumed uniform bed sediments with generic properties based on grab samples, was made using the methods set out in CIRIA and FHWA bridge scour guidance manuals. This produced a range of predictions which were in some cases clearly unrealistic.

Revised Detailed Scour Assessment

3.6.4 In recent years HR Wallingford and others have been developing a method of scour assessment in complex marine soils that has been applied to offshore wind turbine foundations and a number of bridges in the UK and US. The method is referred to as the “Erodibility Index (EI) Method” and enables recently acquired knowledge of the variation of the soils with depth to be included in the scour calculation.

3.6.5 These calculations use a method which compares the available stream power for erosion with the stream power required to erode the bed. Here the stream power is defined as the rate of energy dissipation against the bed and banks of a river due to frictional effects. Stream power is a function of the flow rate and bed slope and in effect says that all the potential energy of the flow is lost in bed friction and not converted to kinetic energy, i.e. the flow is not accelerating downhill. For a given flow rate stream power decreases if the depth increases.

3.6.6 The required stream power is determined from an Erodibility Index calculated from the CPT (Cone Penetration Test) measurements in cohesive soils and SPT (Standard Penetration Test) and grain size data in granular soils.

3.6.7 The results from the site investigations show that the erosion resistance of the soils tends to increase with depth. The maximum limit on the scour depth was therefore determined to be the depth at which the required stream power to erode the soil was greater than the available stream power.

3.6.8 These results should however be used with caution as they do not take into account the potential for abrasion effects due to the overlying mobile sediments.

3.6.9 A further refinement has been to consider the characterisation of the superficial gravel layer. Traditionally such a cohesionless material would be defined by "D_{50}". This is the particle diameter which splits the soil into two equal parts by weight in the particle size distribution. In practice, the finer particles will be removed from the surface without affecting the representative bed level, and the bed behaves as though defined by "D_{90}" – 90% of the soil is smaller than this diameter which in effect represents the bigger particles in the soil mix.

3.7 Timescales for development of scour

3.7.1 For local scour holes, experimental work carried out by Hoffmans and Verheij (1997) showed that there are four distinct phases of evolution for local scour holes: initiation, development, stabilisation and equilibrium.

3.7.2 Rapid erosion occurs during the initiation phase with the depth of scour increasing substantially through to the end of the development phase. During stabilisation the erosion at the base of the hole is minimal as the local velocities decrease as the hole deepens, but erosion continues at the exposed position at the top of the downstream slope, increasing the lateral extent of the scour hole. Therefore the maximum scour depth is reached early on in the progression of the scour hole, while the maximum lateral extent takes longer to develop. Once the hole has reached equilibrium the dimensions remain virtually fixed providing the hydrodynamic conditions remain the same.

3.7.3 The scour predictions are based on the flow during normal spring tides. Although it is not considered that the full scour will be able to develop in one tidal cycle, it is possible that the maximum depth (if not the maximum lateral extent) may be reached over two or three consecutive spring tides. Laboratory work by Escarameia and May (1999) for tidal conditions showed that equilibrium conditions in granular bed material is reached after 4 to 5 half tidal cycles.

3.7.4 In reality it is expected that the presence of the cohesive stiff clays will significantly increase the time-scale for development of the full predicted scour. It is therefore considered that the length of time the temporary works will be in place (estimated to be around 5 years) will not be enough for the scour to penetrate significantly into the clays.

3.8 Lateral extent of scour

Extent of local scour in absence of scour protection

3.8.1 Lateral extent of scour is very difficult to predict accurately, but is generally found to be function of scour depth and angle of repose of the material. HR Wallingford advise that in their experience downstream scour holes tend to have a slope that is around half the value of the angle of repose of the sediment. Based on an angle of repose of about 30º (loose gravel), the lateral extent of scour at the downstream edge might be around 3.7 times the predicted scour depth. (Note that as the tidal flows in the estuary are bi-directional, similar scour extents would be expected at the up-estuary and down-estuary edges of the works).

3.8.2 A laboratory study of tidal scour (Escarameia and May1999) at HR Wallingford investigated in a physical model the extent of scour in tidal flow. These tests suggested that scour could extend laterally for 3.5 times the predicted depth of scour which is similar to the current HR Wallingford experience discussed above.

3.8.3 The development of the slopes of scour holes is related to the nature of the vortices which develop around an obstruction to the flow. The slope of the upstream and side edges of the hole tend to be steeper than the downstream edge, (see Figure 3-1), and therefore the extent of scour in front of the works (parallel to the flow) is likely to be less than the extent of at the downstream edge.

3.8.4 In cohesive materials there will be different parameters influencing the lateral scour extents, and steeper slopes may be achieved than observed in non-cohesive materials. However the predicted extents of scour as given in this report have been calculated assuming non-cohesive soils, as this provides a worst case scenario.

Extent of local scour protection to avoid edge failure

3.8.5 The UK guidance (CIRIA 2002) is very reticent on the required lateral extent of scour protection. For bridge piers the guidance recommends that scour protection should extend for twice the width of the pier all around and encloses a drawing showing recommendations from a range of sources[2]. No guidance is provided which is specifically applicable to the vertical abutment walls that are proposed for the Thames Tunnel river works.

3.8.6 Escarameia and May (1999) extended their study of tidal scour to consider the lateral extent of scour protection needed to avoid scour developing at the edge of the scour protection. Their results suggested that provided the scour protection extended more than 1.5 times the pile dimension there was no movement at the edge of the protection. These results are for isolated bridge piles at small scale and assume water depth is less than the pile size. All of these factors make it difficult to apply these types of results to the scour associated with large cofferdams or reclamations.

3.8.7 We suggest that twice the predicted scour depth should be considered as a starting point for the assessment of the likely extent of scour protection works around the proposed works. As there remains a risk that the scour protection will need to be extended, a zone for permanent works in planning documents should be provided that allows a margin around the structure with its scour protection.

[2] Section 5.3.3 and Figure 5.34 of CIRIA C551 2002.

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4 Hydrodynamic conditions

4.1 Conditions chosen for scour predictions

4.1.1 Scour predictions for all the sites have been carried out based on 'normal' flow conditions consisting of a typical spring tide combined with a freshwater flow of 65m^3/s.

4.1.2 The freshwater flow is the average daily freshwater flow gauged and recorded at Teddington, which is the tidal limit of the Thames Estuary.

4.2 Discussion

4.2.1 Total flows in the estuary are the result of a combination of freshwater fluvial flow travelling downstream and tidal flows which are bidirectional, i.e. reverse according to whether on the ebb or flood.

4.2.2 Scour in tidal conditions such as the Thames Tideway differs from fluvial scour in non-tidal conditions in that in fluvial conditions scour is unidirectional and generally happens infrequently during floods, but when it does occur conditions can persist for many hours. By contrast tidal scour is bidirectional and conditions that are near to the extreme design conditions can occur quite frequently whenever large range tides occur.

4.2.3 The short duration of tidal scour means that the full depth of predicted scour is unlikely to develop in one tide cycle, but repeated large tides as occur over two or three days of spring tides are sufficient to allow the development of almost the full predicted scour.

4.2.4 In order to determine the most appropriate hydrodynamic conditions for the scour calculations, an assessment of potential conditions was carried out by HR Wallingford as part of the fluvial modelling work.

4.2.5 This assessment considered normal spring tides, the maximum tidal conditions that can occur before the Thames barrier is shut, and the mean and maximum fluvial flows. The test cases for the numerical fluvial modelling were then taken as follows:

- Typical spring tidal range with mean fluvial flow at the upstream boundary **(Normal conditions)**
- Typical spring tidal range with extreme fluvial flow at the upstream boundary **(Extreme fluvial conditions)**
- Maximum spring tidal range that can occur before the Thames Barrier is closed with mean fluvial flow at the upstream boundary **(Extreme tidal conditions)**

4.2.6 The results of the modelling showed that the flows during normal conditions (which could be expected to occur for two or three days every two weeks) are close to the extreme conditions that might be encountered less frequently. The extreme tidal velocities are typically no more than 10% greater than normal spring tide conditions.

4.2.7 As it is unlikely that there will be a long enough sequence of extreme tides to fully develop extreme tidal scour, the conditions predicted during the regular spring tides are likely to provide near design conditions, once the uncertainty inherent in scour predictions is taken into account.

4.2.8 In the upper estuary large but rare fluvial floods are likely to provide the design scour conditions. A flood flow of $800m^3/s$ was chosen for the test of extreme fluvial conditions. This is the maximum mean daily flow that was recorded at Teddington during November 1894.

4.2.9 The extreme fluvial modelling study shows that for the Putney Bridge and Chelsea Embankment sites and for one arch at Vauxhall Bridge near the Albert Embankment site, the maximum velocities in the Thames Tideway during a major fluvial flood are 20 to 40% greater than during normal conditions. Scour due to the proposed works at these locations during such major but rare fluvial events could therefore be significantly greater than predicted using the normal tidal and fluvial conditions.

4.2.10 For the Kirtling Street/ Heathwall site and for Victoria Embankment and sites further downriver, the maximum velocities during a major fluvial flood are generally within 10% of those predicted for the normal conditions used for the scour assessment. At these sites scour during a major fluvial flood seems unlikely to be significantly greater than the normal scour.

5 Potential Scour Prevention/ Mitigation Measures

5.1 Introduction

5.1.1 The potential consequences of scour are:

- Undermining of structures, leading to potential collapse
- Uncontrolled redistribution of sediments, leading to possible loss of depth or smothering of river bed habitats
- Change to river bed character, with potential loss of habitat
- Exposure of buried infrastructure

5.1.2 Figure 5-1 shows the decision tree proposed for managing the scour risk.

5.1.3 In developing a scour risk mitigation strategy it has been assumed that the plan shape of structures will be modified to minimise potential scour and that the volumes of material mobilised by scour will not be sufficient to create a navigational issue.

5.1.4 Scour caused by temporary works will only be prevented as a last resort and the approach will be to monitor and mitigate only if necessary. The approach is documented in Thames Tideway Tunnel's "Scour & Accretion Monitoring and Mitigation Plan for Temporary Works in the Foreshore" which is the subject of stakeholder consultation,

5.1.5 The design of scour protection measures to permanent structures will be by the Contractor. The studies by HR Wallingford have informed the DCO plans but the Contractor's detailed designs will have the potential to refine what is shown on these plans. It is likely that precautionary scour limitation measures similar to that shown in Figure 5-7 or Figure 5-8 will be proposed but in cases where minimal scour is confidently predicted an allowance for scour may be included in the design of the permanent structures.

5.2 Scour protection measures

5.2.1 A number of different materials are available to mitigate scour. These are discussed in detail in the scour manual (CIRIA 2002). Ultimately the final design of the scour protection will depend on a number of factors including cost, material availability, site and environmental considerations, but in principle we require a mat that extends from the toe of the introduced structure and is resistant to erosion in the area of accelerated flows. The material should be placed such that there is no significant loss of depth and should be sufficiently flexible that it can respond to scour at the edge of the mat (which might result from natural changes in the bed). This section summarises the different materials that are available and highlights those that may be suitable for use in for this project.

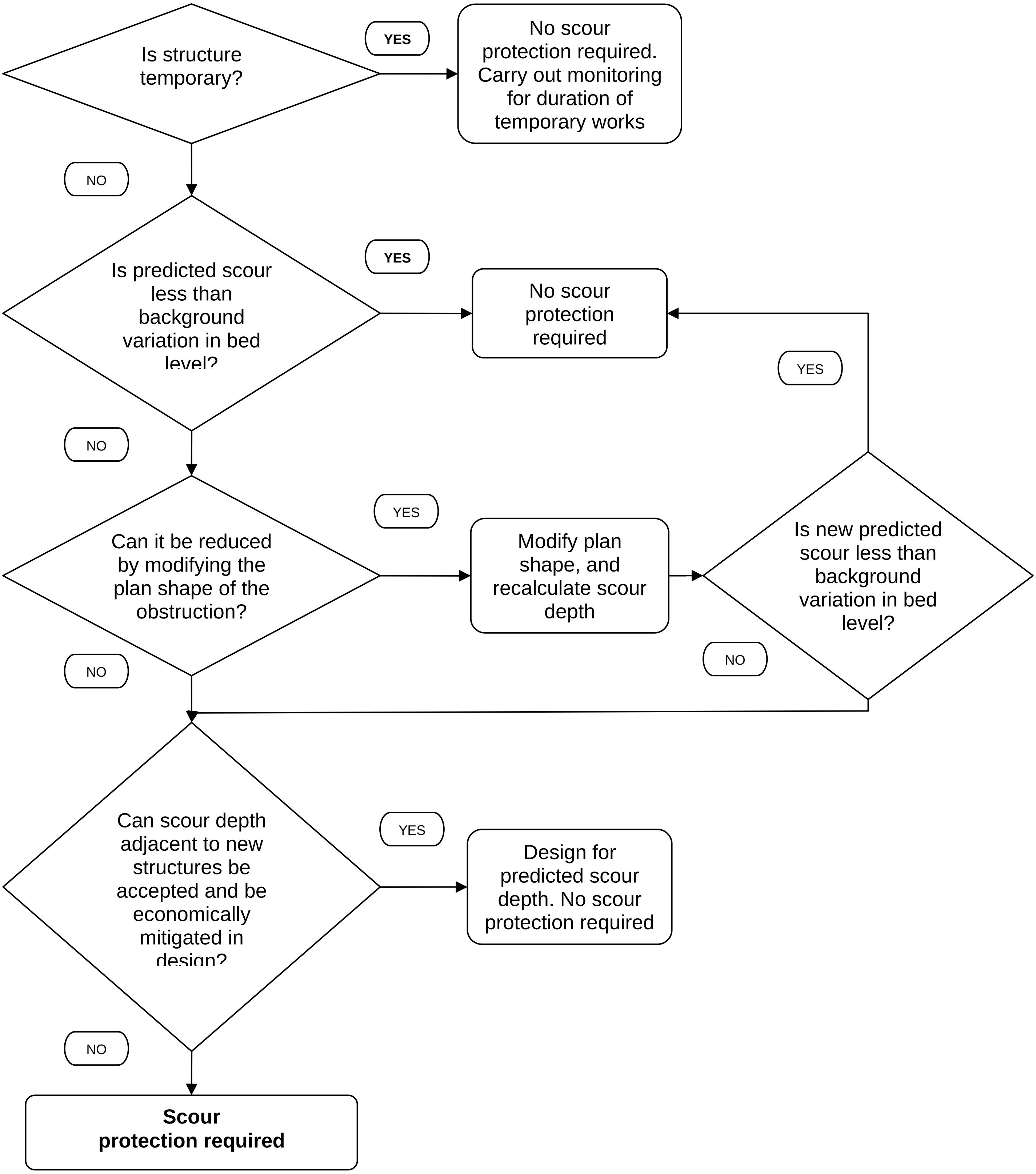

Figure 5-1: Managing scour risk

5.2.2 Table 5-1 provides a summary of the different materials that are available and the conditions under which they are appropriate for use. The materials are divided into flexible and rigid protection. In general flexible systems can accommodate more movement than rigid systems and therefore are preferred in areas with high channel instability. As the Thames has a gravel bed, levels can change typically by around ±0.5m, and this must be considered in the design of any scour protection. Rigid systems generally provide robust erosion protection, and therefore are more suitable for areas of localised high velocity and turbulence.

5.2.3 In the sections below the different types of scour protection are considered and outline sizing of the protection is provided based on equations presented in the scour manual (CIRIA 2002). Where there is a choice of equations the ones derived by Escarameia and May in the UK have been used. There are often alternative equations deriving from other research in the Netherlands or the USA that will give different results. For detailed design the scour manual (CIRIA 2002) recommends that all available equations that are based on good data should be used and expert judgement applied as to how these are combined or which to adopt in any particular circumstance. Outline calculations are included in Appendix B.

Table 5-1 Scour protection measures: selection checklist (from CIRIA, 2002)

Legend • Good/appropriate o May be appropriate × Do not use/not applicable H High M Moderate L Low	Factors: Underwater construction	Repairs	Construction cost	Maintenance cost	Restricted access/headroom	Environmental suitability	High velocity flow	Vertical stream instability	Lateral stream instability
Flexible protection									
Riprap	•	•	L	M	o	•	•	•	o
Gabion mattresses and sacks	•/o	•	M	M	o	•	o	•	o
Gabion boxes	×	•	M	M	o	•	o	o	o
Articulated concrete blocks	o	•	H	M	o	o	o	•	o
Articulated grout-filled mattresses	•	•	M	L	•	o	o	•	o
Bituminous systems	×	•	L	M	o	o	o	•	o
Biotechnical solutions	o	•	M	M	o	•	×	•	o
Rigid protection									
Rigid grout-filled bags and mattresses	•	•	M	L	•	o	•	o	o
Concrete aprons	×	•	M	L	•	o	•	×	o
Stone pitching	o	o	M	M/H	o	o	•	o	o

5.3 Rip-rap

Overview

5.3.1 Rip-rap is the term used to describe loosely placed wide-graded quarry stone, and is one of the most commonly used forms of scour protection, as the stone is often easily sourced, and is relatively easy to place providing there is sufficient space to allow for machine access. Rip-rap is also suitable for placing underwater, although placing tolerances are greater than for placing in the dry, often resulting in the need for thicker layers.

Figure 5-2 Rip rap scour protection around bridge abutments

5.3.2 Rip-rap revetments are flexible and can accommodate some movement of stones without failure and can be used for placement on non-uniform slopes.

5.3.3 However, in areas of high velocity and high turbulence (such as might be expected at some of the sites) large stone is required to provide adequate protection. This may cause issues for placement especially if it is required that the scour protection is flush with the existing foreshore and bed level as significant excavation may be required.

Sizing

5.3.4 Depth average velocities (U) in the centre of the river channel for the permanent works range between 1.17m/s (at Victoria Embankment) and 1.93m/s (at Blackfriars) in normal conditions. Velocities adjacent to the proposed structures are expected to be less.

5.3.5 The required characteristic rip-rap diameter (d_{n50}) for scour protection for the different flow velocities are shown in Table 5-2. The calculation has assumed a high level of turbulence associated with structures such as piers caissons and cofferdams. Total layer thickness has been taken as 1.8 x d_{n50} , which is appropriate for placement in the dry. Underwater placement would require a thicker layer.

Table 5-2 Required rip-rap size

Velocity (U) m/s	Required d_{n50} (mm)	Minimum required thickness (mm)
1.2	160	290
1.9	400	720

Suitability

5.3.6 The findings on the suitability of rip-rap are:

- Due to the relative ease of placement this would be a suitable solution for temporary works if monitoring of works showed that the extent of scour was greater than expected. In this case temporary scour protection would be required to be placed quickly to prevent further scour developing.
- Areas with higher flows would require larger rock. It is required that scour protection is flush with the existing bed level and this would require significant amounts of excavation and disposal of the arisings.

5.3.7 Overall rip-rap is likely to be generally suitable for scour protection around the proposed structures, but excavation to maintain existing bed levels may be an issue in some areas.

5.3.8 In areas where the existing bed is considered to be a high value habitat rip rap could be installed as a buried hard point, allowing modified bed materials, such as a larger gravel, to be placed over it.

5.4 Gabion Mattresses

Overview

5.4.1 Gabion mattresses are wire mesh baskets filled with stone. They allow for smaller stone to be used than with rip-rap under the same conditions. This is because the baskets allow the stone to move without being washed out of the protection blanket. The disadvantage compared to rip-rap is that construction and placement is generally more complicated (and therefore more costly).

Figure 5-3 Gabion basket slope protection

5.4.2 Above water the empty baskets can be placed in position and filled with stone in situ and then tied together. They can however be prefilled if underwater construction is required, although this requires the use of divers to tie the baskets.

5.4.3 One of the major concerns with gabions is the long time durability of the mesh, which can be susceptible to corrosion or abrasion, and therefore may need replacement over the design life of the permanent structure.

Sizing

5.4.4 The required characteristic stone diameter (d_{n50}) for gabion mattresses for the different flow velocities are shown in Table 5-3. The calculation has assumed a high level of turbulence associated with structures such as piers caissons and cofferdams. Total required mattress thickness has been taken as 1.8 x d_{n50}

Table 5-3 Required gabion mattresses size

Velocity (U) m/s	Required d_{n50} (mm)	Total required thickness (mm)
1.2	100	180
1.9	265	475

Suitability

5.4.5 The findings on the suitability of gabion mattresses are:

- Gabions would be most suitable for temporary works because of their short life.
- They may be suitable for some low risk permanent works in lower flows, but will be difficult to construct around more complex shapes.
- They would not be suitable for higher flows due to thickness of mattress required (generally mattresses are less than 0.5m thick)

5.4.6 Overall gabion mattresses are unlikely to be suitable for scour protection of the proposed permanent structures, but may be preferred in a few locations.

5.5 Articulated concrete blocks

Overview

5.5.1 Articulated concrete blocks are precast concrete blocks laid on a geotextile filter. They can either be individual units which interlock with adjacent blocks (interlocking blocks), or connected together using cables (cable-tied).

Figure 5-4 Articulated concrete blocks for slopes and bridge abutments

5.5.2 Cable-tied blocks are easier to lay (providing there is adequate access for machinery) but are less adaptable to complicated shapes and are difficult to use in confined spaces. Interlocking blocks are more flexible for use on complex slopes and around structures but are hand laid and are therefore labour intensive for use over large areas.

Sizing

5.5.3 The required thickness for interlocking concrete blocks for the different flow velocities are shown in Table 5-4. The calculation has assumed a high level of turbulence associated with structures such as piers caissons and cofferdams.

Table 5-4 Required thickness of concrete blocks

Velocity (U) m/s	Thickness (mm)
1.2	140
1.9	360

5.5.4 Design methods do not allow the connecting tendons to be considered for long term stability.

Suitability

5.5.5 The findings on the suitability of articulated concrete blocks are:

- Concrete blocks would be best suited to planar areas where rectangular mattresses can be laid by crane. They are most suited to low energy environments or in temporary works where engineering judgement can be applied to allow the benefits of the connecting tendons to be used.
- Blocks are less suited to underwater placement, as it is difficult to control the placement of large mats and hand placement must be done by divers. The maximum thickness of the proprietary blocks available on the market is around 300mm and therefore would only suitable for sites with lower flows.
- Generally cable-tied blocks would not be suitable due to the shape of the works; therefore individual interlocking blocks would be preferable.
- Interlocking blocks may not be suitable where large areas of scour protection are required as the blocks are hand laid.

5.5.6 Overall articulated concrete blocks are unlikely to be generally suitable for scour protection of the proposed structures, but may be preferred in a few locations.

5.6 Other Materials

5.6.1 This section covers other methods that can be used for scour protection, but are not deemed to be suitable for this project.

Grout filled mattresses

5.6.2 Bags and mattresses filled with cement grout or concrete can be a cost-effective solution for providing scour protection. They can either be pre-filled with a dry mix which hardens on contact with water, or pumped with grout or concrete once they are in place. They are especially useful for underwater construction and for temporary repairs.

Figure 5-5 Concrete mattresses for slope protection

5.6.3 Once the grout has hardened the mattresses become rigid, and therefore care must be taken in design to ensure that they are not undermined if bed levels change. They are prone to fracture in the long term as the fabric deteriorates with the time and the grout fractures under differential settlement.

5.6.4 Grout filled mattresses are not considered to be suitable for placement on the Thames foreshore, but might be considered as flexible formwork for placing small concrete infill of awkward shapes in some circumstances.

Flexible bags and mattresses

5.6.5 As an alternative to grout, bags and mattresses can also be filled with sand, which provides a more flexible erosion control system, and can be cheaper than grout filled bags where there is a plentiful sand supply. Sand filled containers are however more dependent on the strength of the outer geotextile as, unlike grout filled mattresses, damage to the containers would result in a loss of material and a failure of the protection.

5.6.6 Sand filled bags are suitable for use underwater, and can be used as a substitute for large rocks. Large geotextile bags (up to $0.5m^3$ or more) have been shown to provide heavy weight erosion protection in velocities of around 2.5m/s. Flexible bags and mattresses are considered to be suitable for urgent temporary works protection (in response to unforeseen scour development) but would not be appropriate for permanent works.

Bituminous systems

5.6.7 Bituminous systems use loose material such as sand and gravel bound with bitumen. As the bitumen binder adds cohesion and strength, much smaller stones can be used than the equivalent rip-rap or gabion revetment. Scour protection using this method can either be permeable (open-stone and sand asphalt), or impermeable (dense stone asphalt and asphaltic concrete).

Figure 5-6 Open stone asphalt erosion protection

5.6.8 Bituminous systems can provide a high resistance to erosion and are suitable for use over large areas. This method is used extensively in the Netherlands, but is not commonly used in the UK as it is often considered not to be an aesthetically pleasing solution.

5.6.9 Generally construction takes place in the dry, although it is possible to prefabricate mats for placement underwater.

5.6.10 Open stone asphalt has been shown to resist current velocities up to 7m/s. Typical layer thicknesses are around 100-150mm, with thicknesses of 250mm in areas of severe current attack.

5.6.11 These systems would not suitable for the temporary works due to the method of placement. Bituminous systems cannot be economically placed under water, except in large simple applications where preformed mats can be placed mechanically. We conclude bituminous systems would not be suitable for temporary or sub tidal works but could be employed for permanent intertidal works especially if required to cover large areas.

Biotechnical solutions

5.6.12 Biotechnical solutions make use of vegetation to stabilise river banks susceptible to erosion. They are particularly prone to damage in the early stages, before the vegetation becomes established. They are generally only suitable for low flow areas, and are therefore not considered suitable for these works.

Concrete aprons

5.6.13 Concrete aprons are a common method of providing a high level of scour resistance adjacent to fixed structures, and this method is already in use for outfalls in the Thames.

5.6.14 Concrete aprons are mainly suited for laying in the dry; for underwater construction, grout filled mattresses may be more appropriate.

5.6.15 As concrete aprons are rigid, care has to be taken in design to ensure that the system is not undermined.

5.6.16 Concrete aprons are not suitable for underwater placement which limits their potential application to permanent works constructed behind the cofferdam.

Stone pitching

5.6.17 Stone pitching is a traditional method of providing scour protection and makes use of a single layer of single sized, hand placed stone. As local stone is often used it can provide a more aesthetically pleasing solution than concrete blocks or bituminous systems. It is however very labour intensive and therefore is only really suitable for use over small areas.

5.6.18 Generally stone pitched block systems have thicknesses between 0.3 and 1m.

5.6.19 Stone pitching would not suitable for large scale or underwater placement, but is a serious option for small scale intertidal infill protection

5.6.20 Unless an aesthetically pleasing solution is required, stone pitching would probably not be suitable for the permanent works unless they are of very small scale.

5.6.21 We conclude stone pitching is generally not suitable for temporary or permanent works but may be appropriate for permanent works in specific very small intertidal areas that are visually sensitive.

5.7 Indicative cross sections for proposed scour protection

5.7.1 In areas where scour protection is judged to be required, the use of rip-rap is the preferred option. Figure 5-7 and Figure 5-8 show two indicative options; Figure 5-7 shows the rip rap layer flush with the existing bed level. Figure 5-8 shows the rip rap underlying a 1m thick layer of gravel. This option may be suitable for areas such as Putney, where the foreshore is deemed to be an important spawning ground for fish. The placed gravel is more likely to be resistant to scour than the surrounding bed material, but will provide a preferable spawning habitat than the larger rip rap.

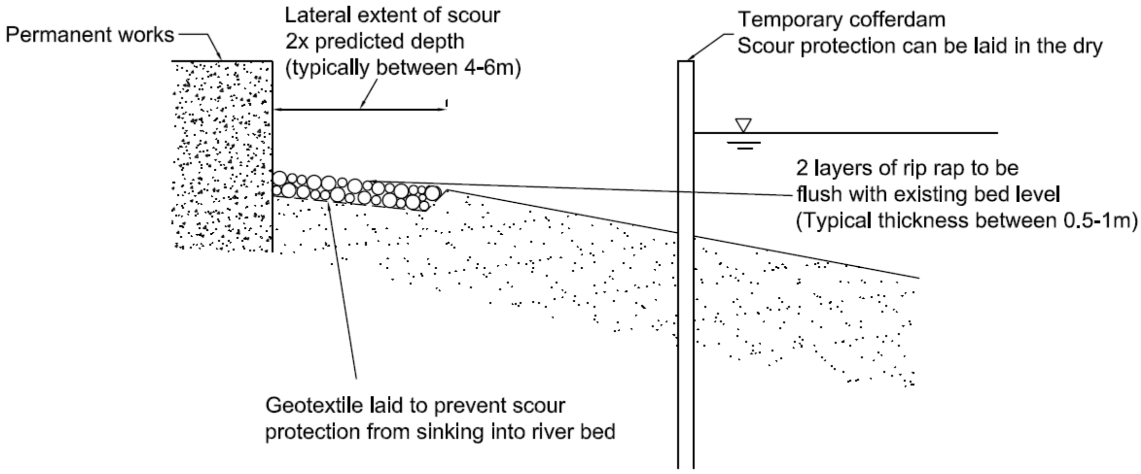

Figure 5-7 Indicative cross section for scour protection

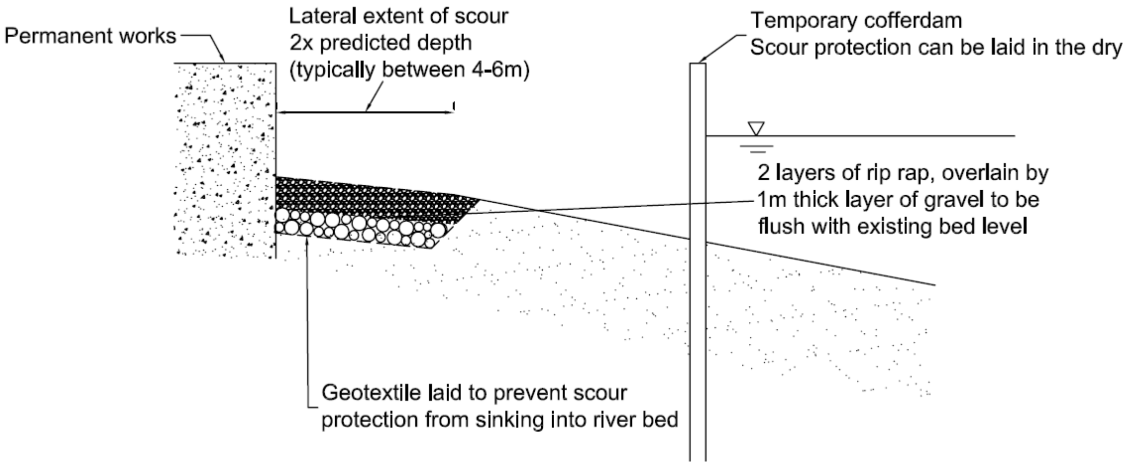

Figure 5-8 Indicative cross section for scour protection in areas of important spawning grounds

6 Predicted Scour Summary

6.1 Scour Predictions

6.1.1 The current depth predictions for local and contraction scour for each of the sites are set out in Table 6-1.

Table 6-1 Scour depth predictions to be used in design

Site	Local scour depth (metres)		Contraction scour depth (metres)	
	Temporary Works	**Permanent Works**	**Temporary Works**	**Permanent Works**
Putney Embankment	2.5	2.5	<0.1	<0.1
Carnwath Road	1.0	Not applicable	Negligible	Not applicable
Chelsea Embankment	2.8	2.8	<0.1	<0.1
Kirtling St Jetty piles	1.4	Not applicable	<0.1	Not applicable
Heathwall cofferdam	0.2*	0.2*	<0.1	<0.1
Albert Embankment	1.1	1.1	<0.1	<0.1
Victoria Embankment	0.3	0.3	<0.1	<0.1
Blackfriars Bridge	0.5	0.5	0.5	0.5
Chambers Wharf	1.0	Not applicable	<0.1	Not applicable
King Edward Memorial Park	1.0	1.0	0.5	0.2

* Note that this prediction assumes that the relatively narrow band of clay material shown in one of the boreholes remains resistant to erosion. If this layer does fails, then scour depths of up to 2.7m may occur.

6.1.2 Scour protection is being considered for the permanent works as a precautionary measure to eliminate risk of scour in the future, and limit the potential effects of the works.

6.1.3 Table 6-2 indicates the predicted maximum unmitigated lateral extent of scour for the permanent works, and the suggested width of scour protection for each of the sites.

Table 6-2 Unmitigated scour extents, and recommended width of scour protection

Site	Unmitigated scour depth	Unmitigated lateral scour extent	Suggested width of scour protection
Putney Embankment	2.5m	9.3m	5m
Chelsea Embankment	2.8m	10m	6m
Heathwall	0.2m	0.7m	0.5m
Albert Embankment	1.1m	4.1m	2m
Victoria Embankment	0.3m	1m	0.6m
Blackfriars Bridge	0.5m	2m	1m
King Edward Memorial Park	1.0m	3.7m	2m

6.1.4 The unmitigated lateral scour extent is the maximum scour that might occur if no prevention measures are taken. This has been calculated based on an assumption that the side slope of the scour hole is equal to half the angle of repose of the soil (refer to details in paragraphs 3.6.1-3.6.4).

6.1.5 The suggested width of the scour protection is roughly equal to 2 x the unmitigated scour depth. It is considered that this is the required width of protection to prevent the edge of the protection being undermined through scour action (refer to details in paragraphs 3.6.5-3.6.7). The actual design of the scour protection will be the responsibility of the contactor, and it is noted that for planning purposes the maximum limits of the zone for the permanent works should include for a conservative estimate of the likely scour protection extents, plus an additional safety margin.

7 Putney Embankment

7.1 Local conditions

7.1.1 The proposed Putney Bridge foreshore works are on the right (south) bank of the Thames under and just upriver of Putney Bridge on the outside of a long gentle bend. A plan of the proposed works is shown in Figure 7-1.

7.1.2 The temporary works (bounded by the green line) cover a total area of 4395m^2, extending a maximum of about 34m into the river. A campshed is shown towards the centre of the temporary works. The temporary works are currently shown to be constructed as a vertical sheetpiled cofferdam. This is considered to represent a worst case in respect to blockage to the flow and therefore for scour development.

7.1.3 The main permanent works (shaded grey) cover an area of approximately 560m^2 extending a maximum of 20.2m into the river. The new interception chamber beneath Putney Bridge arch covers a plan area of 40m^2 and extends a maximum of 5m into the river.

Figure 7-1 Plan of proposed works at Putney

7.1.4 The foreshore sediment on the right bank is mostly a mixture of gravel and sand. Analysis of grab samples in the area show a degree of variability in particle size distribution, with the median grain size of the sample (d_{50}) varying between 5 and 50mm. A river bed borehole offshore of the works found 0.4m of gravel overlying stiff clay. The photograph in Figure 7-2 shows the foreshore sediments in the location of the works.

Figure 7-2 View of foreshore at the location of the works, looking upstream towards Putney Pier. (Photograph provided by HRW)

7.2 Temporary works

Effect on flow regime of the temporary works

7.2.1 The temporary works (as defined by the green line on Figure 7-1) decrease the cross section of the river by up to 8% at high water

7.2.2 HR Wallingford has carried out numerical flow modelling which shows that flow velocities increase adjacent to the temporary works by a maximum of 0.4m/s immediately adjacent to the proposed works when compared to the baseline condition. The greatest changes occur on a flood tide.

7.2.3 Reductions in flow velocity occur along the river bank both upstream and downstream of the works. Accretion of finer sediments may therefore occur in these areas.

7.2.4 Figure 7-3 shows the flow velocities on a flood tide due to the temporary works. The bottom plot highlights the change in flows compared to the baseline condition, with the blue areas showing where velocities drop and the yellow areas indicating a slight increase in flow speed.

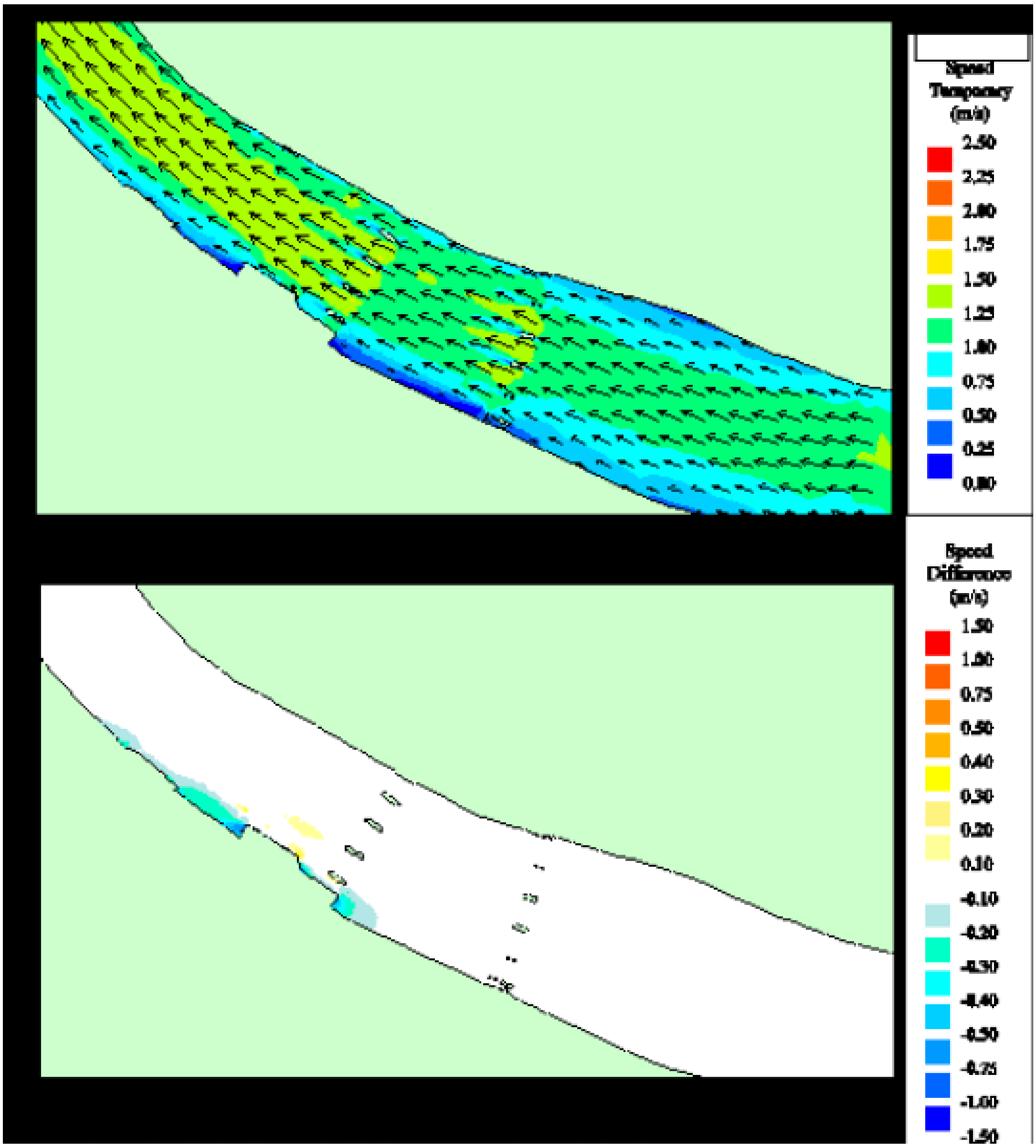

Figure 7-3 Flow velocities due to the temporary works at Putney (provided by HR Wallingford)

Local scour predictions due to temporary works

7.2.5 Scour predictions have been carried out using the Erodibility Index approach as described in Section 3.6. Scour predictions have been calculated based on a maximum depth average velocity of 0.99m/s as extracted from the numerical model at the corners of the works.

7.2.6 Scour predictions have been carried out based on the results from five different cone penetration tests that were carried out on the south bank of the river. Scour predictions vary depending on the CPT results, and also on the grain size distribution that is assumed in the calculations. Results range between 0.2m and 2.5m and without further information on the exact distribution of sediment characteristics with depth with respect to particle size distribution it is not possible to refine the results further. For the purpose of design the upper bound depth of scour of 2.5m should be assumed. It is unlikely that this scour depth can be accommodated economically in the design of the temporary works and further work in understanding the distribution of sediment types or refinement of the plan shape of the works is required if scour prevention works are to be avoided.

7.2.7 The lateral extents of scour have been calculated to be in the order of 3.6m from the riverside frontage of the works and 9.3m along the upstream and downstream face of the works. It is noted that these scour extents are based on a very simplistic assessment, which assumes that the scour extent is the same along whole length of the upstream and downstream face of the structures. In reality the depth and extent of scour will vary along the structure depending on the exact soil characteristics, and the corners of the structure adjacent to the bank will more likely be areas of deposition and accretion, rather than erosion as the flow velocities will be reduced in this area.

Scour at the Campshed

7.2.8 Scouring at the campshed has not been formally assessed, but flows around the structure are likely to be low, and it is not thought that there will be any adverse scour affects around this structure. This is supported by evidence from existing campsheds on the River Thames.

Contraction scour due to temporary works

7.2.9 Contraction scour due to the temporary works is predicted based on granular surficial sediments with a d_{50} of 5mm and a d_{95} of 30mm across the whole width of the river. Contraction scour is predicted to be negligible, and can be assumed to be less than 0.1m, and will be entirely contained within the layer of mobile sediments.

7.3 Permanent works

Effect on flow regime of the permanent works

7.3.1 The main permanent works as shown on Figure 7-1 decrease the cross section of the river up to 4% at high water.

7.3.2 The numerical modeling shows that the greatest increase in flow velocity adjacent to the permanent works is a maximum of 0.2m/s immediately adjacent to the works when compared to the baseline condition. The greatest changes occur on a flood tide.

7.3.3 Reductions in flow velocity occur along the river bank both upstream and downstream of the works. Accretion of finer sediment may therefore occur in these areas.

7.3.4 Figure 7-4 shows the flow velocities on a flood tide due to the temporary works. The bottom plot highlights the change in flows compared to the baseline condition, with the blue areas showing where velocities drop and the yellow areas indicating a slight increase in flow speed.

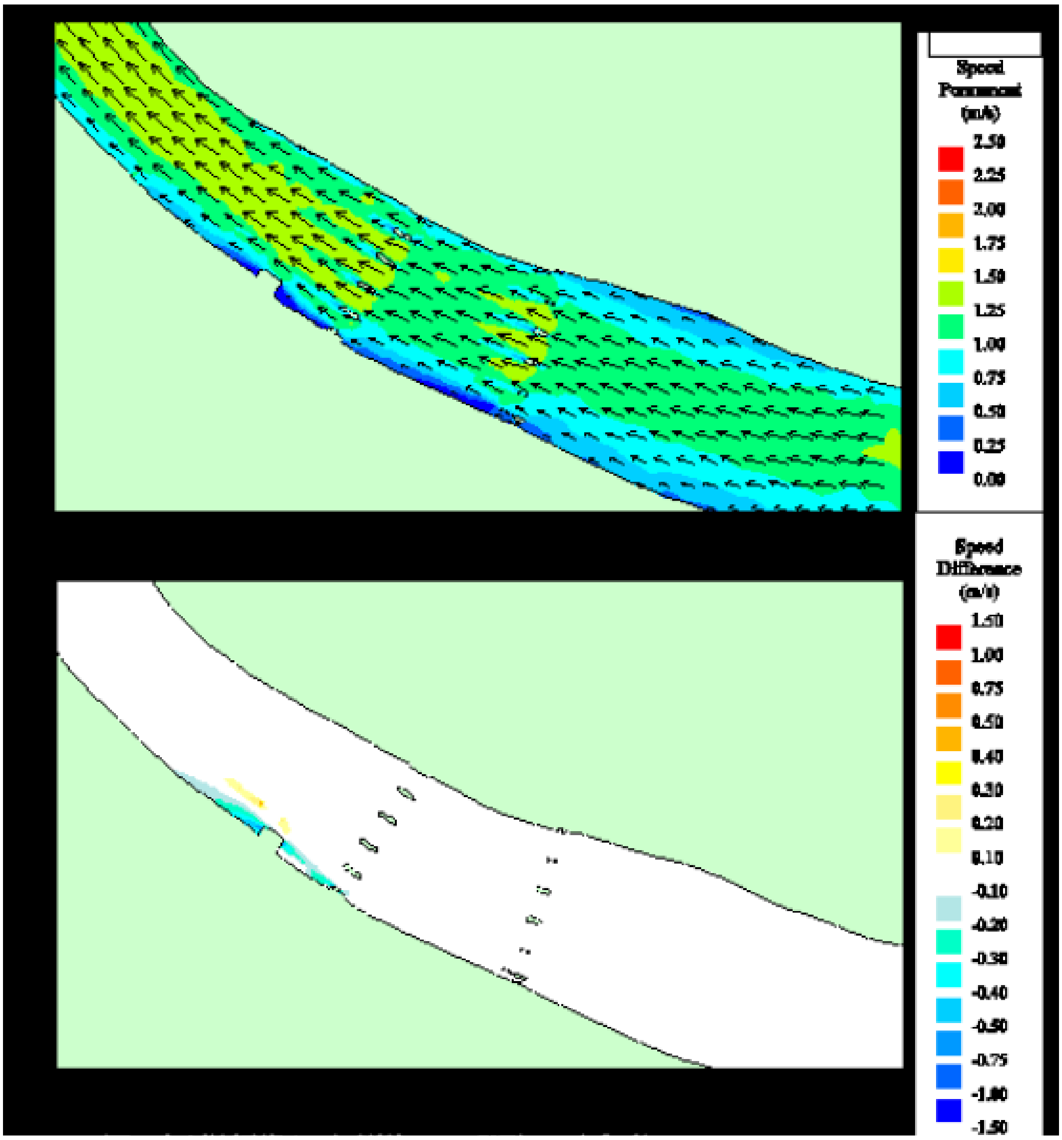

Figure 7-4 Flow velocities due to the permanent works at Putney (provided by HR Wallingford)

Local scour predictions due to permanent works

7.3.5 As for the temporary works, scour predictions have been carried out using the Erodibility Index approach as described in Section 3.6. Scour predictions have been calculated based on a maximum depth average velocity of 0.96m/s as extracted from the numerical model.

7.3.6 Scour predictions have been carried out based on the results from the five different cone penetration tests that were carried out on the south bank of the river. Depths vary depending on the CPT results, and also on the grain size that is assumed in the calculations. As for the temporary works results range between 0.2m and 2.5m and tor the purpose of design the upper bound depth of scour of 2.5m should be assumed.

7.3.7 The lateral extents of scour have been calculated to be in the order of 3.6m from the riverside frontage of the works and 9.3m along the upstream and downstream face of the works. Again it is noted that these scour extents are based on a very simplistic assessment, which assumes that the scour extent is the same along the whole length of the upstream and downstream face of the structures. In reality the depth and extent of scour will vary along the structure depending on the exact soil characteristics, and the corners of the structure adjacent to the bank will more likely be areas of deposition and accretion, rather than erosion as the flow velocities will be reduced in this area.

Contraction scour

7.3.8 Similar to the temporary case, contraction scour is predicted to be negligible, and can be assumed to be less than 0.1m, and will be entirely contained within the layer of mobile sediments.

7.4 Effects on existing structures

7.4.1 There are a number of structures within 0.5km of the proposed works at Putney including:

- Putney Bridge (spans the river at the down-river end of the works)
- Putney Pier (13m upstream)
- Fulham railway bridge (0.28km down-stream)

7.4.2 Putney Pier and Fulham Railway Bridge are out of the predicted extent of the scour due to the permanent and temporary works, and therefore will not be affected.

7.4.3 Putney Bridge is the most significant existing structure at the site, as it spans the river at the down-river end of the works and the interception chamber is situated beneath the first bridge arch.

7.4.4 The existing scour around the bridge piers is approximately 2.2m deep, and is assumed to extend into the underlying clay layer. The temporary and permanent works do not have a significant impact on the flow velocities under the bridge, and therefore it is considered that there will be negligible increase in the scour depth around the piers due to the works.

7.5 Recommendations

7.5.1 The nature of the sediments in the area is such that the scour predictions given in this report are considered to be a conservative upper bound. Therefore although the scour depth due to the temporary case (2.5m) is likely to be too great to accommodate in the design of the temporary works, it is recommended that monitoring of scour is carried out at the temporary works, to determine whether scour is developing to the predicted depths. If scour remains below the value assumed in design (say 1m), then scour protection will not be required for the temporary case.

7.5.2 It is recommended that for the permanent works scour protection should be included in the design, as it impractical to monitor for the design life. As the foreshore at Putney has been identified as an important spawning ground, scour protection similar to that shown in Figure 5-8 (rip rap underlying gravel) may be appropriate.

8 Carnwath Road

8.1 Local Conditions

8.1.1 The proposed works at Carnwath Road works are on the north (left) bank within the Wandsworth Reach of the Thames just upriver of Wandsworth bridge. Figure 8-1 shows a plan of the works.

8.1.2 The temporary works consist of a piled jetty on 0.8m diameter piles covering a total area of cover of 1480m$^{2.}$ There is a campshed in front of the jetty which extends 40m into the estuary.

8.1.3 There are no permanent works at this site.

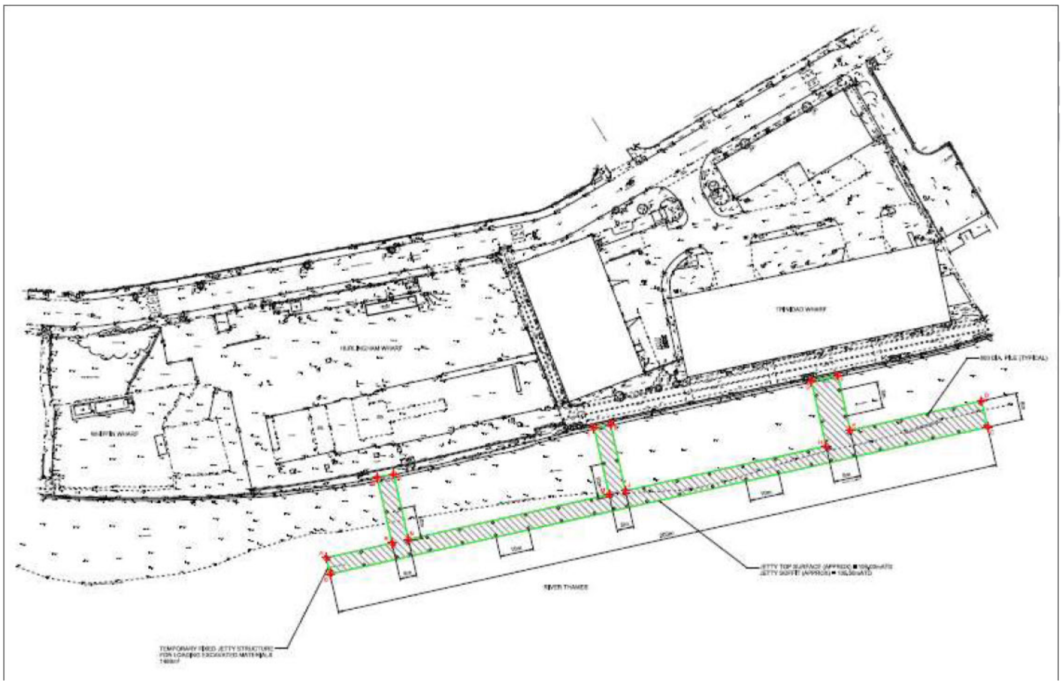

Figure 8-1 Plan of proposed works at Carnwath Road

8.1.4 The foreshore sediment in the vicinity of the works appears to be a mix of granular and muddy sediment. Two vibrocores and six CPT's were carried out in the vicinity of the works, as well as grab samples of surficial sediment which show that the foreshore is highly variable in nature with both dense and very loose soils including very soft muds. Figure 8-2 and Figure 8-3 show the variable nature of the foreshore sediment.

Figure 8-2 View of foreshore at the location of the works, looking upstream, showing granular surficial sediments. (Photograph provided by HRW)

Figure 8-3 View of foreshore at the location of the works, looking upstream, showing cohesive surficial sediments. (Photograph provided by HRW)

8.2 Temporary works

Effect on flow regime of the temporary works.

8.2.1 As the temporary works in this case consist of an open piled jetty there is no significant reduction in the cross sectional area due to the works.

8.2.2 Numerical flow modelling shows that flow velocities increase on the southern bank (the opposite bank to the works) for both flood and ebb conditions by up to 0.2m/s.

8.2.3 Up and down stream of the proposed works along the northern river bank, decreases in flows are predicted, and therefore deposition rather than erosion may occur in these locations.

8.2.4 Figure 8-4 shows the flood tide due to the temporary works. The bottom plot highlights the change in flows compared to the baseline condition, with the blue and green areas showing where velocities drop and the yellow areas indicating a slight increase in flow speed.

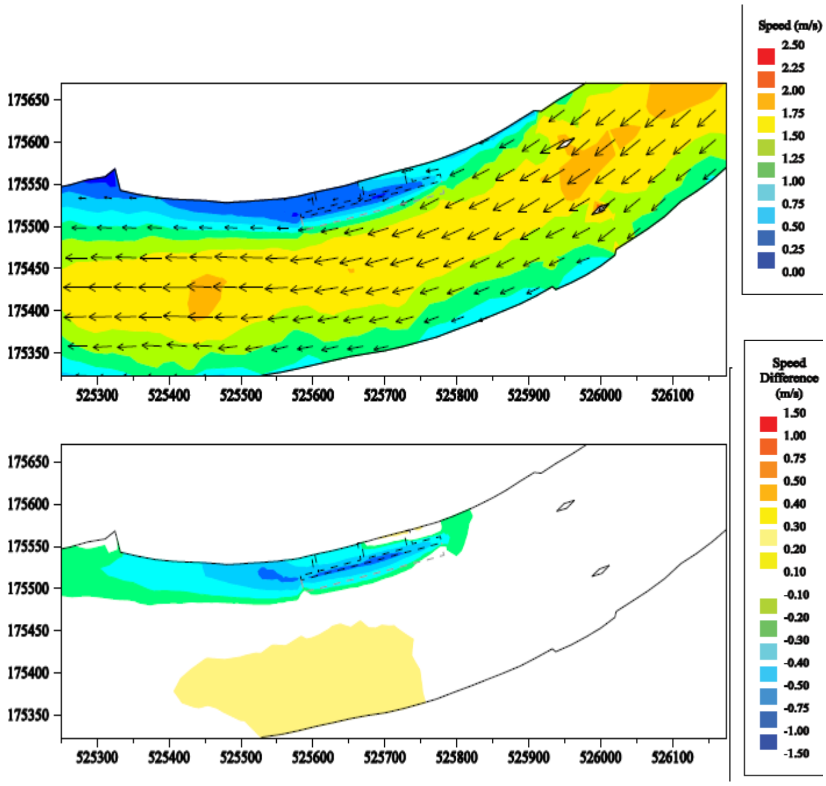

Figure 8-4 Flow velocities due to the temporary works at Carnwarth Road (provided by HR Wallingford)

Local scour predictions due to temporary works

8.2.5 Scour predictions have been carried out using the Erodibility Index approach as described in Section 3.6. Scour predictions have been calculated for a variety of different velocities (ranging between 0.72m/s to 1.01m/s) extracted from the numerical model at nine different points along the jetty.

8.2.6 Scour depths have been calculated based on the surficial samples collected closest to each of the points, and using the undrained strength of the underlying clay derived from the CPT samples together with the information from the vibrocores in the location where the substrata is predominantly granular.

8.2.7 Scour predictions are highly dependent on the exact grading characteristic of the soil. Where the underlying stratum is clay, the scour depths are limited to around 0.4 to 0.5m. For the granular substrata the limiting depth is around 0.7m. Due to the highly variable nature of the soils in this area, it may be prudent to assume a scour depth of 1m in design.

8.2.8 The top width of the scour hole around a pile has been found to be a function of the scour depth and angle of repose of the material. Assuming an angle of repose of around 30º the lateral extents downstream of the pile may extend to around 2m. The lateral extent in front of a circular pile is generally around half that of the extent behind (with a slope equal to around half the angle of repose), however it should be noted that due to the tidal nature of the estuary, flow is bi-directional and therefore it may be expected that symmetrical scour extents develop around the pile.

Scour at the campshed

8.2.9 Scouring at the campshed has not been formally assessed, but flows around the structure are likely to be low, and it is not thought that there will be any adverse scour affects around this structure. This is supported by evidence from existing campsheds on the River Thames.

Contraction scour due to temporary works

8.2.10 Contraction scour will be negligible as the open piled jetty does not restrict the cross sectional area of the channel to any significant degree.

8.3 Permanent works

8.3.1 There are no permanent works in this area.

8.4 Effect on existing structures

8.4.1 There are a number of structures along Wandsworth reach, within 1km of the works. These include:

- Hurlingham Yacht Club pontoons
- Prospect Quay pontoons
- Point Pleasant Marina
- Campsheds at the Western Riverside Waste Transfer Station
- Wandsworth Bridge
- Sainsbury Jetty

8.4.2 As the predicted scour extents are limited to local areas surrounding each pile, and any effects will only be temporary, it is not considered that the temporary works will have any effect on these structures.

8.5 Recommendations

8.5.1 The scour depth predictions at an individual pile vary between 0.4 and 0.7m. However the depth predictions are very sensitive to the exact soil grading distribution, and therefore a depth of up to 1m should be considered in design.

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9 Chelsea Embankment

9.1 Local conditions

9.1.1 The proposed Chelsea Embankment works are located on the left (north) bank of the Thames adjacent to the gardens of the Royal Hospital Chelsea. The centre of the site is approximately 250m west (upriver) of Chelsea Bridge with Albert Bridge around 950m further upriver on a long straight section of river. There are no tunnels or other major infrastructure on this reach. A plan of the proposed works is shown in Figure 9-1.

9.1.2 The temporary works (bounded by the green line) cover a total area of 5535m^2 formed from cofferdams running along the shoreline in a rectangular shape. A 45m long campshed will be situated alongside the temporary works.

9.1.3 The permanent works cover a total area of 1135m^2, extending a maximum of 23m into the river.

Figure 9-1 Plan of proposed works at Chelsea

9.1.4 The foreshore sediment on the left bank is a mixture of gravel and sand with more than two thirds of the material by weight being gravel. Analysis of grab samples in the area show a degree of variability in particle size distribution, with the median grain size of the sample varying between 5.8 and 30mm. River bed boreholes suggest that the gravel and sand deposits are 1.0-1.5m thick, overlying stiff clays, though this may vary locally. The photograph in Figure 9-2 shows the foreshore in the location of the works.

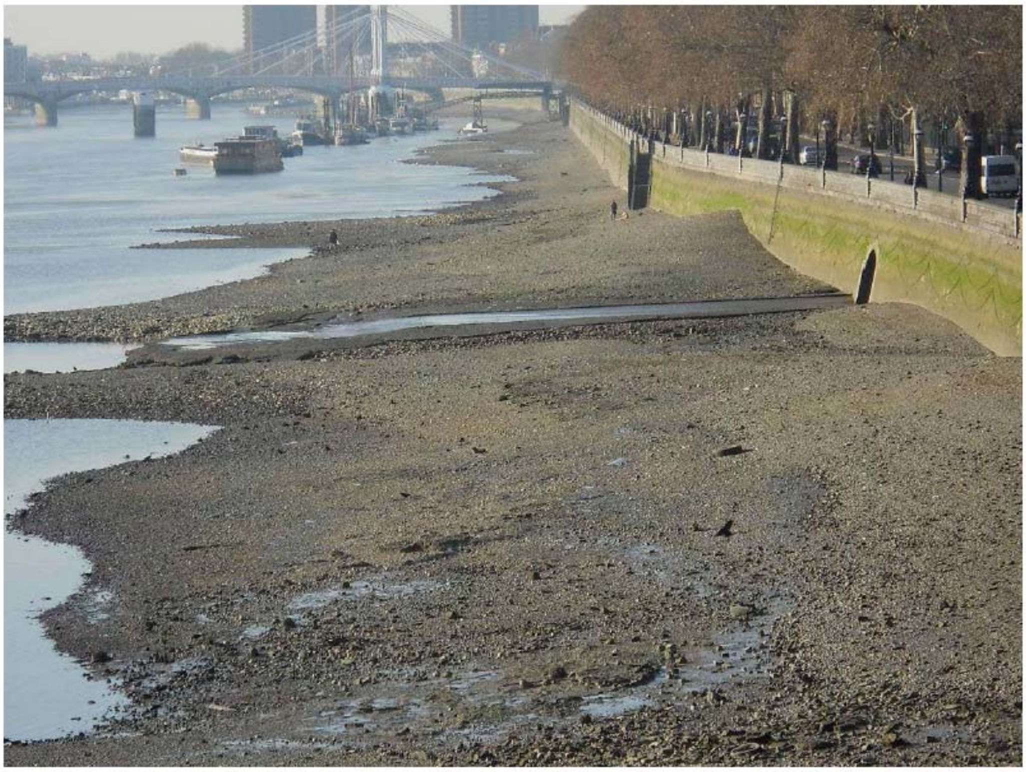

Figure 9-2 View of the foreshore at the location of the works, looking up-river, (provided by HR Wallingford)

9.2 Temporary works

Effect on flow regime of the temporary works

9.2.1 The temporary works (as defined by the green line on Figure 9-1) decrease the cross section of the river by up to 12% at high water.

9.2.2 HR Wallingford has carried out numerical modeling which shows that flow velocities increase adjacent to the temporary works by a maximum of 0.3m/s when compared to the baseline condition. The greatest changes occur on a flood tide, on the southern bank of the river across from the works.

9.2.3 Reductions in flow velocity occur along the river bank upstream and downstream of the works. Accretion of finer sediments may therefore occur in these areas.

9.2.4 Figure 9-3 shows the flow velocities on a flood tide due to the temporary works. The bottom plot highlights the change in flows compared to the baseline conditions, with the blue areas showing where velocities drop and the yellow areas indicating a slight increase in flow speed.

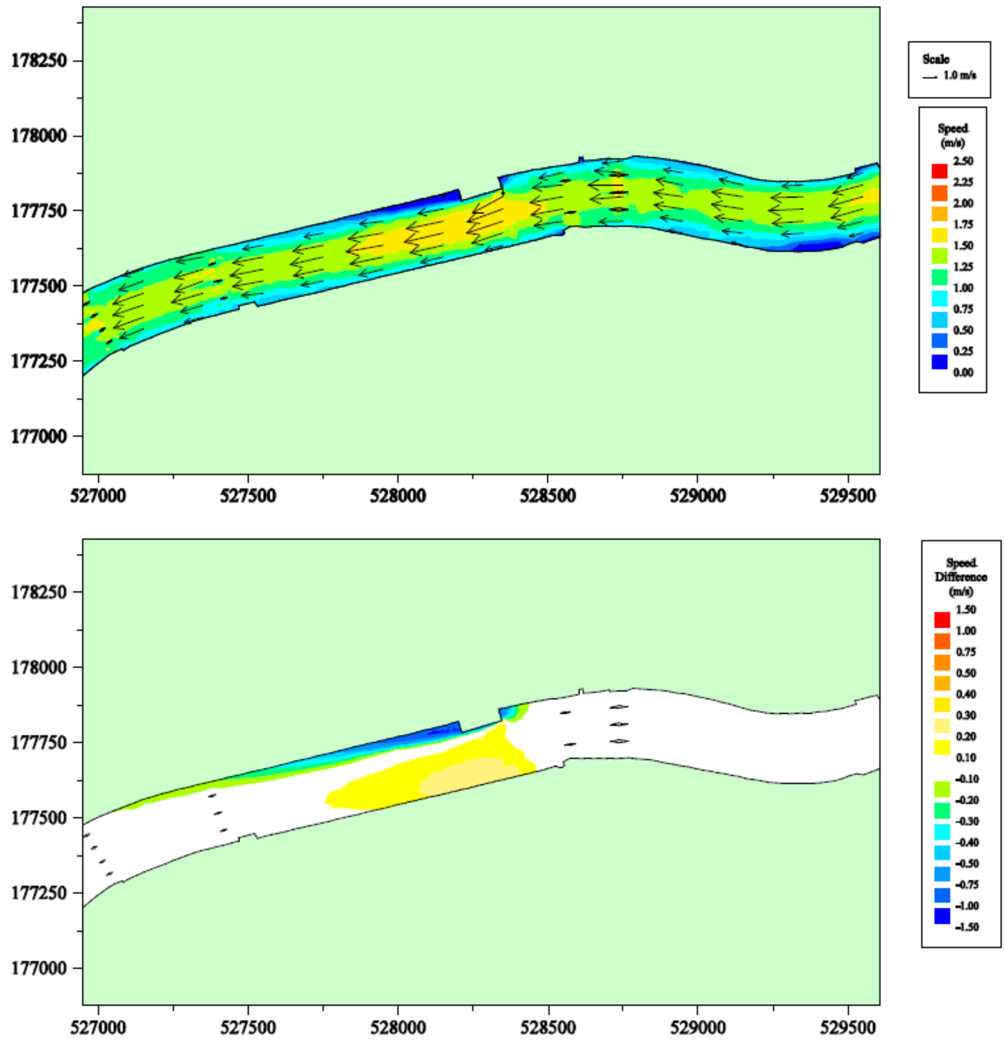

Figure 9-3 Flow velocities due to the temporary works at Chelsea (provided by HR Wallingford)

Local scour predictions due to temporary works

9.2.5 Scour depth prediction have been carried out using the Erodibility Index approach as described in Section 3.6. Scour predictions have been calculated based on a maximum depth average velocity of 1.23m/s as extracted from the numerical model at the corners of the works.

9.2.6 Scour depth predictions have been carried out based on the results from seven CPT tests that were carried out on the embankment foreshore. Scour depth predictions vary depending on CPT results, with values ranging from 0.3 to 2.1m, using CPT results in the location of the site, and up to 2.8m using CPT results from further down river. For the purpose of design the upper bound depth of scour of 2.8m should be assumed. It is unlikely that this scour depth can be accommodated economically in the design of the temporary works and further work in understanding the distribution of sediment types or refinement of the plan shape of the works is required if scour prevention works are to be avoided.

9.2.7 Lateral extents of scour may be in the order of 7.8m from the face of the temporary works (based on a scour depth of 2.1m). It is noted that this scour extent is based on a very simplistic assessment, which assumes that the scour extent is the same along the whole length of the upstream and downstream face of the structures. In reality the depth and extent of scour will vary along the structure depending on the exact soil characteristics, and the corners of the structure adjacent to the bank will more likely be areas of deposition and accretions rather than erosion as the flow velocities will be reduced in this area.

Scour at the campshed

9.2.8 Scouring at the campshed has not been formally assessed, but flows around the structure are likely to be low, and it is not thought that there will be any adverse scour affects around this structure. This is supported by evidence from existing campsheds on the River Thames.

Contraction scour due to the temporary works

9.2.9 Contraction scour predictions due to the temporary works have been based on granular surficial sediments with a d_{50} of 5.8mm and a d_{95} of 34.2mm across the whole width of the river. Contraction scour is predicted to be negligible and can be assumed to be less than 0.1m, and will be entirely contained within the layer of mobile sediments.

9.3 Permanent works

Effect of flow regime of the permanent works

9.3.1 The permanent works as shown on Figure 9-1 decrease the cross section of the river up to 7% at high water.

9.3.2 The numerical modeling shows that the greatest increase in flow velocity adjacent to the permanent works is a maximum of 0.2m/s when compared to the baseline conditions. The greatest changes occur on a flood tide.

9.3.3 Reductions in flow velocity occur along the river bank upstream and downstream of the works. Accretion of finer sediments may therefore occur in these areas.

9.3.4 Figure 9-4 shows the flow velocities on a flood tide due to the temporary works. The bottom plot highlights the change in flows compared to the baseline conditions, with the blue areas showing where velocities drop and the yellow areas indicating a slight increase in flow speed.

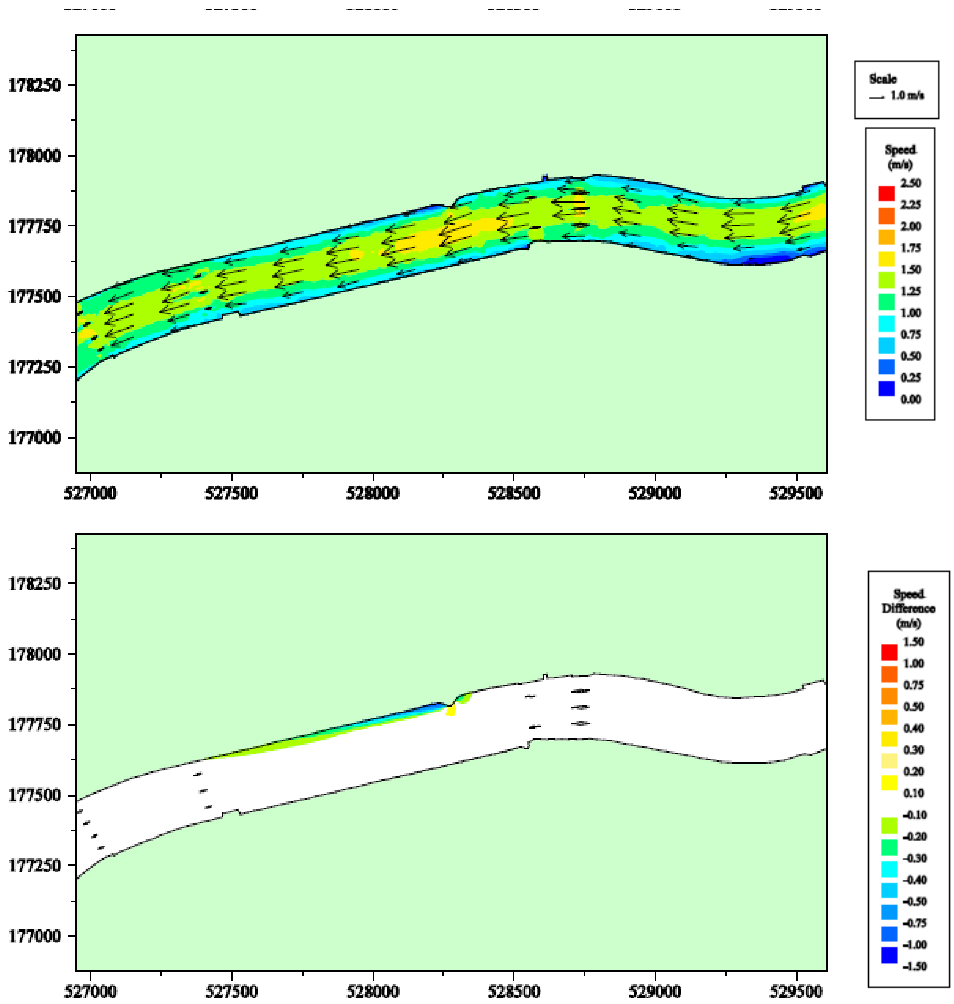

Figure 9-4 Flow velocities due to the permanent works at Chelsea (provided by HR Wallingford)

Local scour predictions due to permanent works

9.3.5 As for the temporary works scour predictions have been carried out using the Erodibility Index approach as described in Section 3.6. Scour predictions have been calculated based on a maximum depth average velocity of 1.23m/s.

9.3.6 Scour depth predictions have been carried out based on the results from seven CPT tests that were carried out on the embankment foreshore. Scour depth predictions vary depending on CPT results, with values ranging from 0.3 to 2.8m. For the purpose of design the upper bound depth of scour of 2.8m should be assumed. It is unlikely that this scour depth can be accommodated economically in the design of the temporary works and further work in understanding the distribution of sediment types or refinement of the plan shape of the works is required if scour prevention works are to be avoided.

9.3.7 Lateral extents of scour are expected to be in the order of 7.8m. Again it is noted that these scour extents are based on a very simplistic assessment, which assumes that the scour extent is the same along the whole length of the upstream and downstream face of the structures. In reality scour extents and depths will vary along the line of the structure depending on the exact soil characteristics, and the corners of the structure adjacent to the bank will more likely be areas of deposition and accretion, rather than erosion as the flow velocities will be reduced in this area.

Contraction scour

9.3.8 Similar to the temporary case, contraction scour is predicted to be negligible and can be assumed to be less than 0.1m, and will be contained entirely within the layer of mobile sediments.

9.4 Effects on existing structures

9.4.1 There are a number of structures within 0.5m of the proposed works at Chelsea including:

- Festival Gardens Pier (0.2km upstream)
- Moored vessels (0.5km upstream)
- Chelsea Bridge (0.2km downstream)
- Grosvenor Bridge (0.37km downstream)

9.4.2 The most significant existing structure is Chelsea Bridge, situated 200m downstream of the site. The numerical modeling of the bridge indicates that the additional works do not have an effect on the flow velocities at the bridge pier, and therefore it is considered that the works will not have an effect on scour at the bridge.

9.5 Recommendations

9.5.1 The nature of the sediments in the area is such that the scour predictions given in this report are considered to be a conservative upper bound. Therefore although the scour depth due to the temporary case (2.8m) is likely to be too great to accommodate in the design of the temporary works, it is recommended that monitoring of scour is carried out at the temporary works, to determine whether scour is developing to the predicted depths. If scour remains below the value assumed in design (say 1m), then scour protection will not be required for the temporary case.

9.5.2 It is recommended that for the permanent works scour protection should be included in the design, as it impractical to monitor for the design life. It is suggested that protection similar to that shown in Figure 5-7 may be appropriate.

10 Kirtling Street / Heathwall (Tideway walk)

10.1 Local conditions

10.1.1 The proposed Kirtling Street and Heathwall sites will be on the right (south) bank of the Thames on the outside of a long bend approximately midway between Vauxhall Bridge and the Grosvenor Railway Bridge. The Heathwall site will sit on top of two submerged outfalls from the Heathwall pumping station and is located approximately 100m upriver of the landfall of a cross-river electricity tunnel. Figure 10-1 and Figure 10-2 show the proposed works at Heathwall and Kirtling Street.

10.1.2 The temporary works (bounded by the green lines on the figure below) consist of a sheet piled coffer dam at Heathwall (Figure 10-1), and a temporary piled jetty structure to the west at Kirtling Street (Figure 10-2). The main temporary works at Heathwall cover a total area of 813m^2, extending a maximum of about 35m into the river. The jetty covers an area of approximately 720m^2, and is expected to be supported on 0.6m diameter piles.

10.1.3 The permanent works are contained within the Heathwall site (shaded grey in Figure 10-1), and cover an area of approximately 270m^2 extending a maximum of 19m into the river.

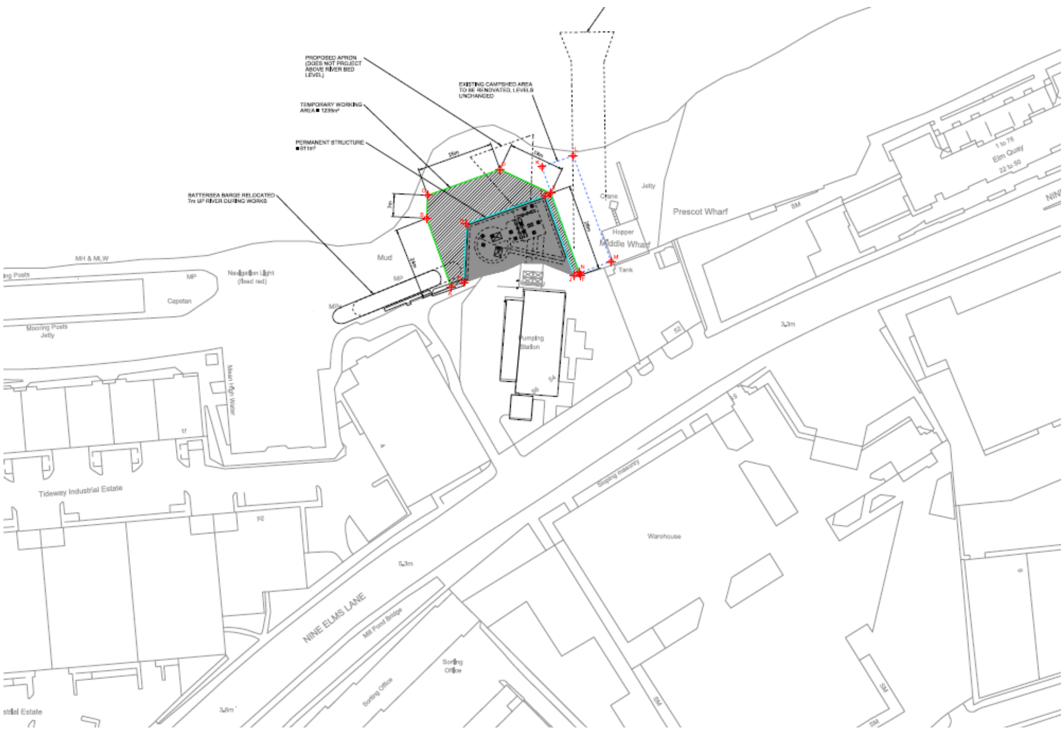

Figure 10-1 Plan of proposed works at Heathwall

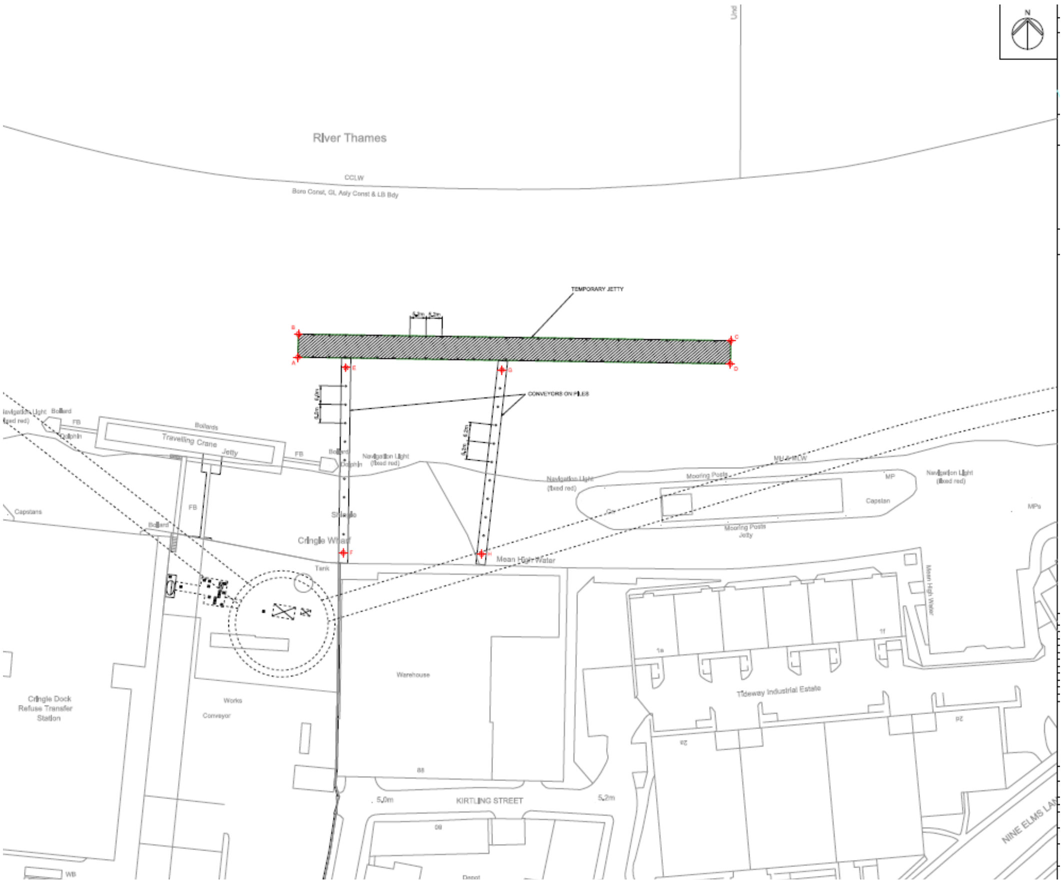

Figure 10-2 Plan of proposed works at Kirtling Street

10.1.4 The foreshore sediment on the right bank is mostly a mixture of gravel and sand. The two grab samples of sediment from this area suggest the surface material is granular with a median grain size (d_{50}) of 12mm, though a short distance upriver of the Heathwall site the foreshore surface sediment is muddy in the quiescent area around where the boats are moored. Two river bed boreholes suggest that the alluvial deposits are 1.5-2m thick, overlying stiff clays, though this may vary locally. The alluvial deposits are mainly gravel, though muddy layers were also found. A photograph showing the surface sediments in the vicinity of the works is shown in Figure 10-3.

10.1.5 With only two foreshore samples from the Kirtling Street and Heathwall sites there is inevitably some uncertainty that the two samples collected represent the range of surface sediments that might be encountered. This increases the uncertainty surrounding the scour predictions.

Figure 10-3 View of Tideway walk at the site of the works looking up river (photograph provided by HRWallingford)

10.2 Temporary works

Effect on flow regime of the temporary works

10.2.1 The main cofferdam temporary works (as defined by the green line on Figure 10-1) decrease the cross section of the river at high water.

10.2.2 HR Wallingford has carried out numerical modeling which shows that flow velocities increase adjacent to the temporary works by a maximum of 0.3m/s when compared to the baseline condition. The greatest changes occur on a spring tide. The area of increased velocity on both the spring and flood tide is on the northern bank opposite the works (on the inside of the channel bend).

10.2.3 Reductions in flow velocity occur along the river bank upstream and downstream of the works. Accretion of finer sediments may therefore occur in these areas.

10.2.4 Figure 10-4 shows the flow velocities on a flood tide due to the temporary works. The bottom plot highlights the change in flows compared to the baseline conditions, with the blue areas showing where velocities drop and the yellow areas indicating a slight increase in flow speed.

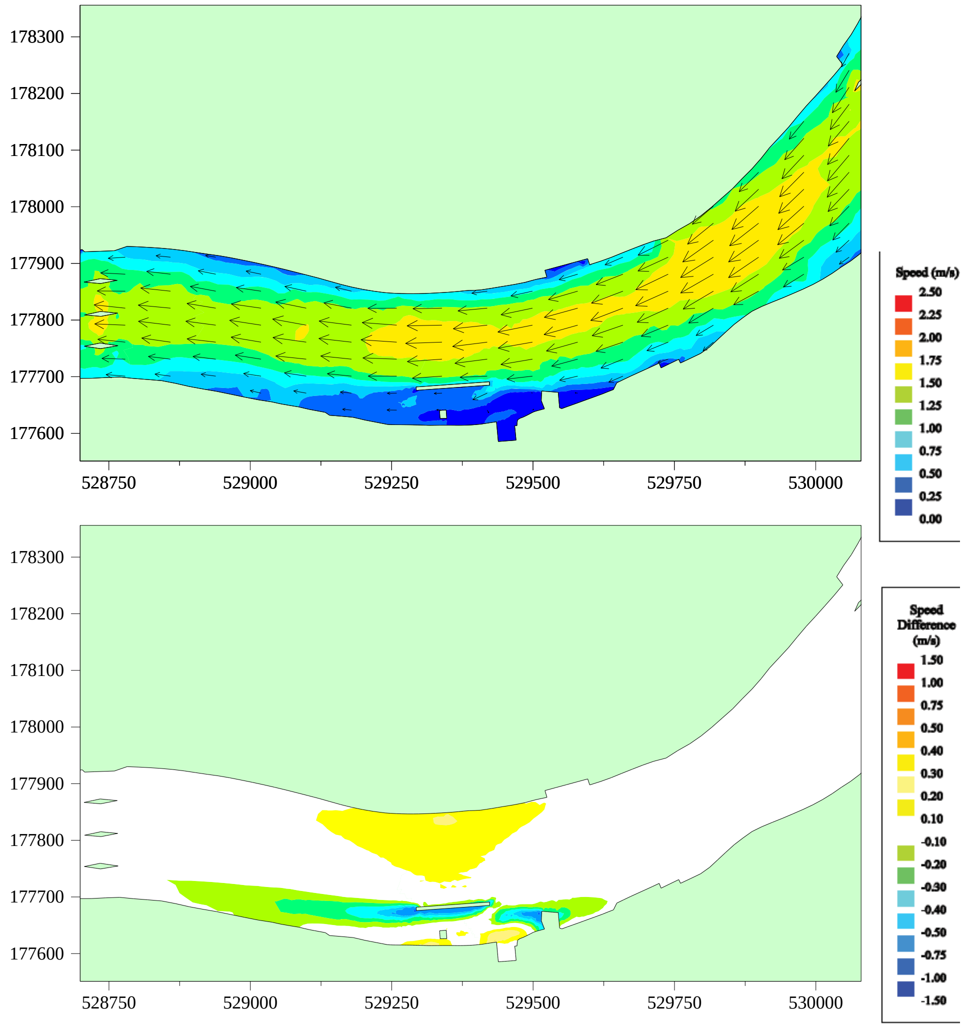

Figure 10-4 Flow velocities due to the temporary works at Kirtling street / Heathwall (provided by HR Wallingford)

Local scour predictions due to temporary cofferdam at Heathwall

10.2.5 Scour depth predictions at the temporary cofferdam at Heathwall have been carried out using the Erodibility Index approach as described in Section 3.6. Scour predictions have been calculated based on a maximum depth average velocity of 0.95m/s as extracted from the numerical model.

10.2.6 Scour depth predictions have been carried out based on the results from one CPT tests that were carried out on the embankment foreshore. Scour depth is predicted to be around 0.2m, as it is estimated that the coarser granular materials are highly resistant to scour. This prediction however is highly dependent on the exact grading characteristics and distribution of the soil, and assumes that the piling of the cofferdam does not disturb the narrow band of clay that is present in one of the boreholes. If this layer is disturbed, causing a strength reduction, actual scour depths could be higher (up to 2.7m).

10.2.7 Lateral extents of scour may be in the order of 0.4m from the face of the temporary works. It is noted that this scour extent is based on a very simplistic assessment, which assumes that the scour extent is the same along the whole length of the upstream and downstream face of the structures. In reality the depth and extent of scour will vary along the structure depending on the exact soil characteristics, and the corners of the structure adjacent to the bank will more likely be areas of deposition and accretions, rather than erosion as the flow velocities will be reduced in this area.

Local scour predictions due to temporary piled jetty at Kirtling Street

10.2.8 Potential scour depths at the piles of the jetty has been calculated using the SCIROS method (Briaud *et al*, 1999), which is dependant only on the pile diameter, flow speed and kinematic viscosity (not on the soil characteristics) and therefore is considered to be a prediction of the maximum scour depth that can occur. This approach is appropriate where the scour is expected to be contained within a granular surface layer.

10.2.9 Using this method the predicted scour depth at the jetty piles is 1.4m. Lateral extents of the scour hole are likely to be around 6.5m from both the up and down-estuary faces of the pile. The scour hole will be symmetrical due to the bi-directional nature of tidal flows (in uni-directional flows, the downstream edge of the hole is generally twice the extent of the upstream edge).

Contraction scour due to the temporary works

10.2.10 Contraction scour predictions due to the temporary works have been based on granular surficial sediments with a d_{50} of 0.42mm and a d_{95} of 15.5mm across the whole width of the river. Contraction scour is predicted to be negligible and can be assumed to be less than 0.1m, and will be entirely contained within the layer of mobile sediments.

10.3 Permanent works

Effect of flow regime of the permanent works

10.3.1 The permanent works as shown on Figure 10-1 decrease the cross section of the river up to 7% at high water.

10.3.2 The numerical modeling shows that the greatest increase in flow velocity adjacent to the permanent works is a maximum of 0.3m/s when compared to the baseline conditions. The greatest changes occur on a spring tide.

10.3.3 Reductions in flow velocity occur along the upstream and downstream of the works. Accretion of finer sediments may therefore occur in these areas.

10.3.4 Figure 10-5 shows the flow velocities on a flood tide due to the temporary works. The bottom plot highlights the change in flows compared to the baseline conditions, with the blue areas showing where velocities drop and the yellow areas indicating a slight increase in flow speed.

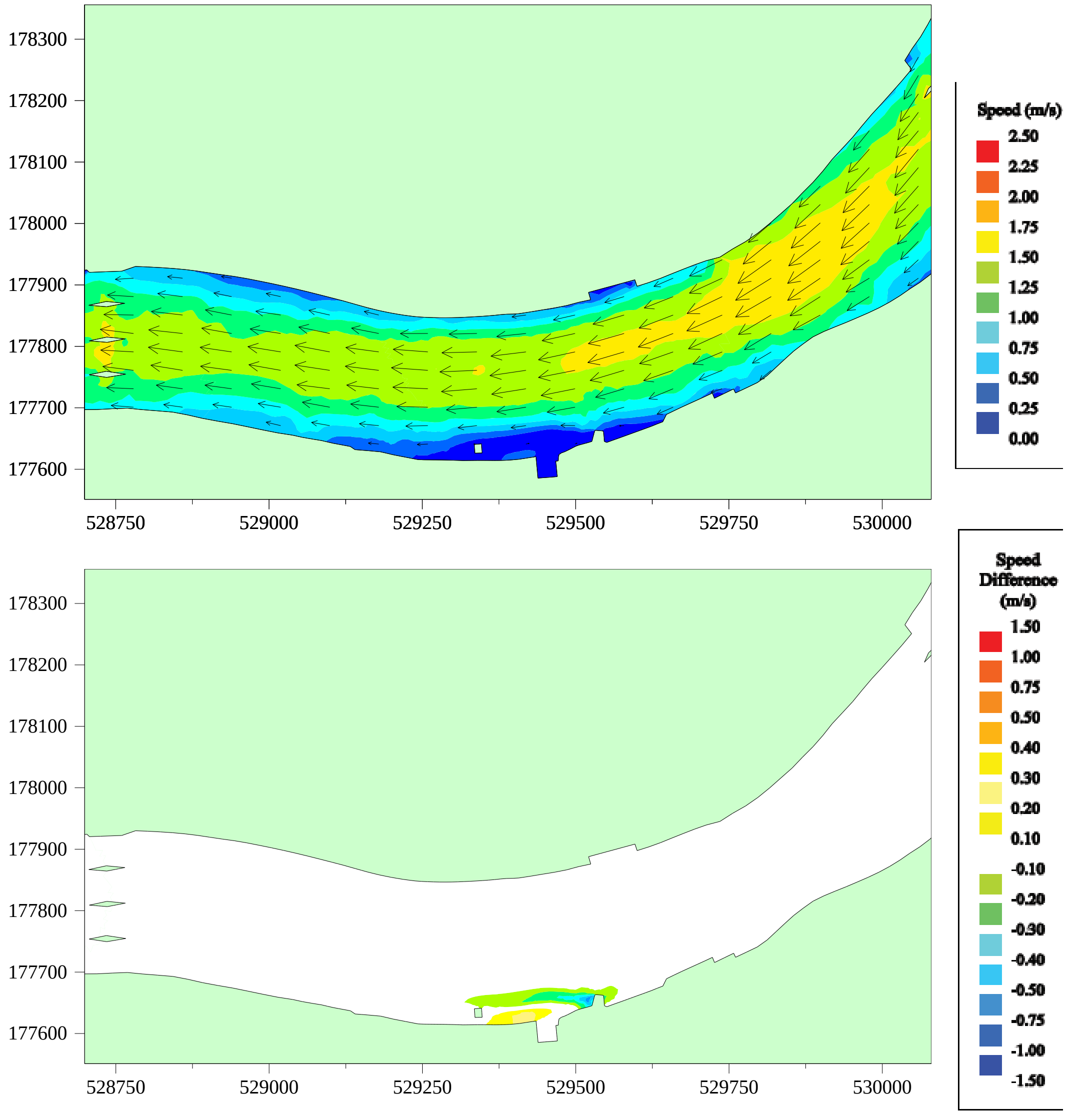

Figure 10-5 Flow velocities due to the permanent works at Kirtling Street / Heathwall (provided by HR Wallingford)

Local scour predictions due to permanent works

10.3.5 As for the temporary works scour predictions have been carried out using the Erodibility Index approach as described in Section 3.6. Scour predictions have been calculated based on a maximum depth average velocity of 0.7m/s.

10.3.6 Scour depth predictions have been carried out based on the results from one CPT test that were carried out on the embankment foreshore. As for the temporary works, scour depth are predicted to be small (of the order of 0.1-0.2m), as it is estimated that the coarser granular materials are highly resistant to scour. As noted previously this prediction is highly dependent on the exact grading characteristics and distribution of the soil.

10.3.7 Lateral extents of scour are expected to be in the order of 0.4m along the full length of the temporary works. Again it is noted that these scour extents are based on a very simplistic assessment, which assumes that the scour extent is the same along the whole length of the upstream and downstream face of the structures. In reality the depth and extent of scour will vary along the structure depending on the exact soil characteristics, and the corners of the structure adjacent to the bank will more likely be areas of deposition and accretion, rather than erosion as the flow velocities will be reduced in this area.

Contraction scour

10.3.8 Similar to the temporary case, contraction scour is predicted to be negligible and can be assumed to be less than 0.1m, and will be contained entirely within the layer of mobile sediments.

10.4 Effects on existing structures

10.4.1 There are a number of structures within 0.5m of the proposed works at the tideway foreshore including:

- Cringle wharf (0.3km up-estuary)
- Nine Elms Pier (0.1km up-estuary)
- Battersea Barge (0.02km up-estuary)
- Middle Wharf (0.03km down-estuary)
- Nine Elms Barge Roads (0.25km down-estuary)
- Electricity cable tunnel (0.1km down-estuary)
- Grosvenor Pier (0.23km down-estuary)

10.4.2 As scour depths are small due to the temporary and permanent works, it is predicted that the effect of the works on these existing structures will be negligible.

10.4.3 At the site of the proposed works there are two existing sewer outfalls, the Heathwall Pumping Station CSO and the South West Storm Relief CSO. The depth of cover to these outfalls is currently unknown, but there may be a risk of the outfalls being exposed if there is any significant lowering of the bed levels in the vicinity of the permanent or temporary structures.

10.5 Recommendations

10.5.1 The scour depth predictions for both the temporary and permanent works are around 0.2m, which is possible to accommodate within the design of the works. It is recommended that monitoring is carried out throughout the temporary works to ensure that scour depths remain within the values assumed in design (say 1m).

10.5.2 As the predicted scour depths are small, these could potentially be allowed for in the design of the permanent works. However consideration should also be given to the provision of precautionary scour protection, as it is not realistic to allow for monitoring of the works through the whole of the design life.

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11 Albert Embankment

11.1 Local conditions

11.1.1 The proposed Albert Embankment works will be on the right (south) bank of the Thames under and just downriver of Vauxhall Bridge. The upriver part of the works will extend under the southern foreshore arch of Vauxhall Bridge and immediately downriver. The downriver part will front Camelford House approximately 150m downriver of Vauxhall Bridge. The Victoria Line tube tunnels pass under the Thames about 25m upriver of Vauxhall Bridge and just upriver of the temporary works cofferdam. There are two existing CSO's through the site which discharge flow either side of Vauxhall Bridge.

11.1.2 The proposed works are contained within two sites, separated by the narrow entrance to Lack's Dock. A plan of the proposed works is shown in Figure 11-1.

11.1.3 The temporary works located down-estuary of the Vauxhall Bridge covers an area of approximately 5365m^2 and extends a maximum of 76m into the river. The temporary works located at Vauxhall Bridge, extending both up and down-estuary of the piers covers an area of approximately 2925m^2. The temporary works are bounded by green lines on the figure below.

11.1.4 The down-estuary permanent works cover an area of approximately 965m^2, extending a maximum of 16m into the river. The permanent works under the southern span of the Vauxhall Bridge cover an area of 1660m^2 and extend a maximum of 25m into the river. The permanent works are shaded in grey on the figure below.

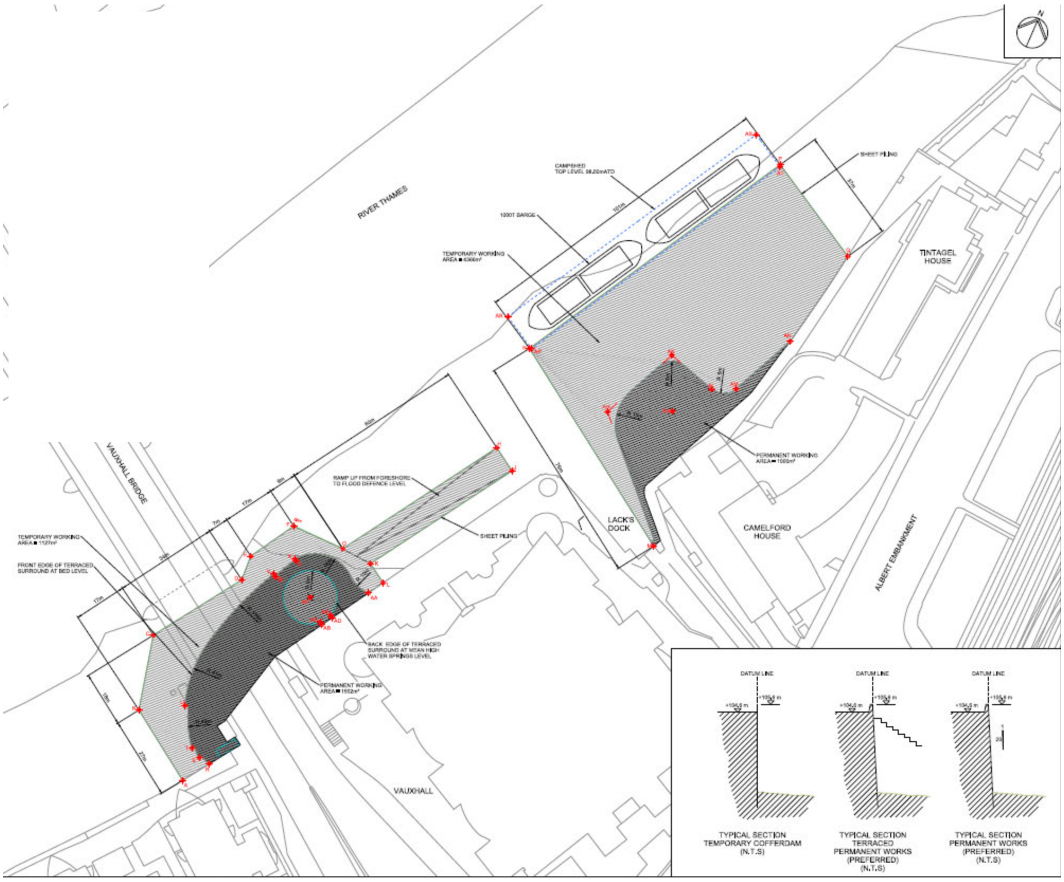

Figure 11-1 Plan of proposed works at Albert Embankment

11.1.5 The foreshore sediment on the right bank is mostly a mixture of gravel and sand. Analysis of grab samples in the area show a degree of variability in across the site, with the median grain size of the samples (d_{50}) varying between 5.3 and 75mm. There were a number of samples with a high fines content, but these have been collected from areas of surficial mud which are considered to be a transient feature, and therefore not representative of the overall sample population.

11.1.6 The two river bed boreholes closest to the works at Vauxhall Bridge indicated around 1.3m of gravel overlying stiff clay, while the boreholes closest to the Camelford House site found 2.6m of river terrace gravels overlying stiff clays. These boreholes indicate that the depth to stiff clay varies around this site and may suggest that the thickness of the overlying gravels increases with distance downriver of Vauxhall Bridge.

Figure 11-2 View of Albert Embankment south foreshore showing gravel banks and areas of mud (Photograph provided by HRW)

11.2 Temporary works

Effect on flow regime of the temporary works

11.2.1 The temporary works (as defined by the green line on Figure 11-1) decrease the cross section of the river at high water.

11.2.2 HR Wallingford has carried out numerical modeling which shows that flow velocities increase adjacent to the temporary works by a maximum of 0.2m/s when compared to the baseline condition. The greatest velocity increases occur in between the bridge piers as the flow becomes confined through the bridge arches, with the greatest changes occurring on a flood tide.

11.2.3 Reductions in flow velocity occur along the river bank upstream and downstream of the works. Accretion of finer sediments may therefore occur in these areas.

11.2.4 Figure 11-3 shows the flow velocities on a flood tide due to the temporary works. The bottom plot highlights the change in flows compared to the baseline conditions, with the blue areas showing where velocities drop and the yellow areas indicating a slight increase in flow speed.

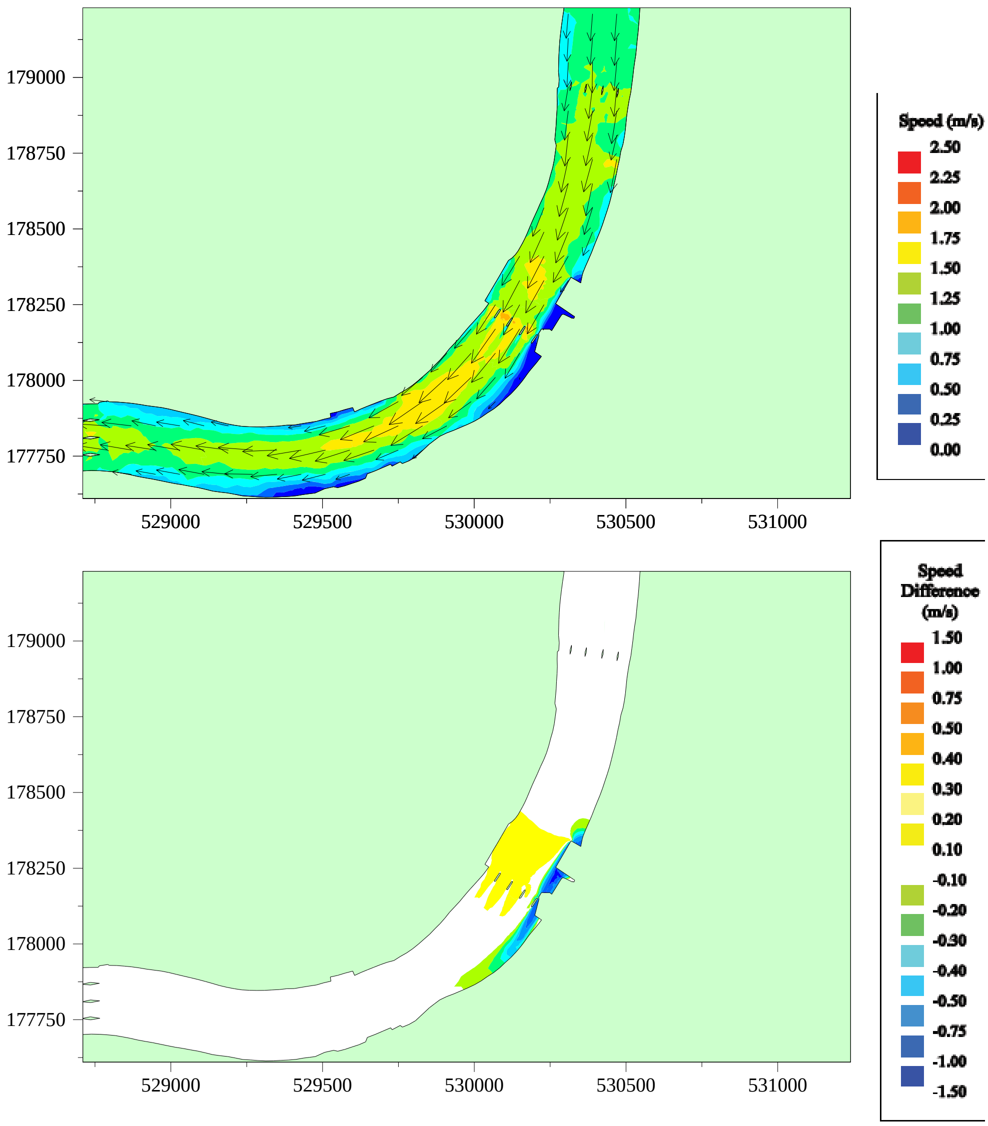

Figure 11-3 Flow velocities due to the temporary works at Albert Embankment (provided by HR Wallingford)

Local scour predictions due to temporary works

11.2.5 Scour depth prediction have been carried out using the Erodibility Index approach as described in Section 3.6. Scour predictions have been calculated based on a maximum depth average velocity of 1.08m/s at the works under the southernmost spans of Vauxhall Bridge and 1.18m/s for the up-estuary works.

11.2.6 Scour depth predictions have been carried out based on the results from four CPT tests that were carried out on the embankment foreshore. Scour depth predictions vary depending on CPT results, with values ranging from 0.4 to 1.1m. For the purpose of design the upper bound depth of scour of 1.1m should be assumed.

11.2.7 Lateral extents of scour may be in the order of 4.1m from the face of the temporary works. It is noted that this scour extent is based on a very simplistic assessment, which assumes that the scour extent is the same along the whole length of the face of the temporary structure. In reality, scour depths and extents will vary along the line of the structure depending on the exact soil characteristics, and the corners of the structure adjacent to the bank will more likely be areas of deposition and accretions rather than erosion as the flow velocities will be reduced in this area.

Scour at the campshed

11.2.8 Scouring at the campshed has not been formally assessed, but flows around the structure are likely to be low, and it is not thought that there will be any adverse scour affects around this structure. This is supported by evidence from existing campsheds on the River Thames.

Contraction scour due to the temporary works

11.2.9 Contraction scour predictions due to the temporary works have been based on granular surficial sediments with a d_{50} of 5.3mm and a d_{95} of 25mm across the whole width of the river. Contraction scour is predicted to be negligible and can be assumed to be less than 0.1m, and will be entirely contained within the layer of mobile sediments.

11.3 Permanent works

Effect of flow regime of the permanent works

11.3.1 The permanent works as shown on Figure 11-1 decrease the cross section of the river up to 4.5% at high water.

11.3.2 The numerical modeling shows that there is negligible increase in flow velocity adjacent to the permanent works compared to the baseline conditions.

11.3.3 Reductions in flow velocity occur along the river bank upstream and downstream of the works. Accretion of finer sediments may therefore occur in these areas. The greatest changes occur on a flood tide.

11.3.4 Figure 11-4 shows the flow velocities on a flood tide due to the temporary works. The bottom plot highlights the change in flows compared to the baseline conditions, with the blue areas showing where velocities drop and the yellow areas indicating a slight increase in flow speed.

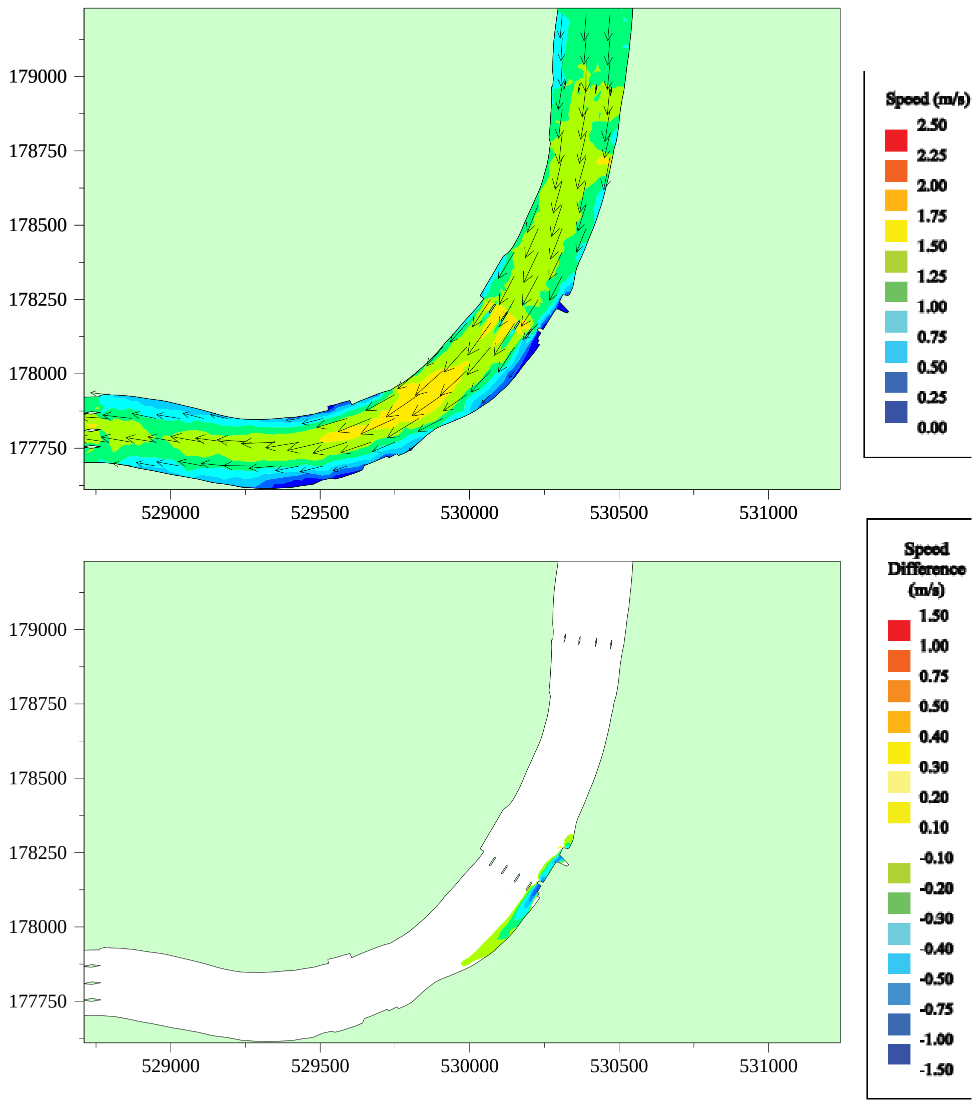

Figure 11-4 Flow velocities due to the permanent works at Kirtling Street / Heathwall (provided by HR Wallingford)

Local scour predictions due to permanent works

11.3.5 As for the temporary works scour predictions have been carried out using the Erodibility Index approach as described in Section 3.6. Scour predictions have been calculated based on a maximum depth average velocity of 1.08m/s at the works under the southernmost spans of Vauxhall Bridge and 0.99m/s for the up-estuary works.

11.3.6 Scour depth predictions have been carried out based on the results from four CPT tests that were carried out on the embankment foreshore. Scour depth predictions vary depending on CPT results, and do not vary significantly from the temporary works predictions. For the purpose of design the upper bound depth of scour of 1.1m should be assumed.

11.3.7 Lateral extents of scour are expected to be in the order of 4.1m from the face of the permanent works. Again it is noted that these scour extents are based on a very simplistic assessment, which assumes that the scour extent is the same along the whole length of the upstream and downstream face of the structures. In reality depths and extents will vary along the structure depending on the exact soil characteristics, and the corners of the structure adjacent to the bank will more likely be areas of deposition and accretion, rather than erosion as the flow velocities will be reduced in this area.

Contraction scour

11.3.8 Similar to the temporary case, contraction scour is predicted to be negligible and can be assumed to be less than 0.1m, and will be contained entirely within the layer of mobile sediments.

11.4 Effects on existing structures

11.4.1 There are a number of structures within 0.5m of the proposed works at Albert Embankment including:

- St George's Wharf (0.12km up-estuary)
- Nine Elms Barge Roads (0.5km up-estuary)
- LUL Victoria Line tunnel (0.2km up-estuary)
- Millbank Millenium Pier (0.5km down-estuary)
- Lack's Dock (at site)
- Vauxhall Bridge (at site)
- LUL Victoria line (to west of Vauxhall Bridge)

11.4.2 The majority of these structures are out of the predicted extent of the scour due to the permanent and temporary works, and therefore will not be affected.

11.4.3 The Victoria line is fully buried beneath the riverbed, out of the predicted extent of local scour. Contraction scour is not expected to occur at the site and therefore works should not impact the tunnel.

11.4.4 The Vauxhall Bridge is the most significant existing structure at the site as it spans the downstream end of the temporary and permanent works. It is considered that the works will have a negligible effect on the existing scour at the central piers (P2 and P3).

11.4.5 The current extent of the scour at the southernmost pier (P1) close to the bank is unknown, but the proximity of this pier to the works suggests that there may be a cumulative effect in scouring of the bed due to the temporary and permanent works. The existence of coarser material in this area (associated with the existing outfalls, as can just be seen between the piers in Figure 11-2), may help to limit scour potential in this area.

11.5 Recommendations

11.5.1 The upper bound scour predictions for both the temporary and permanent works are around 1m, which is possible to accommodate within the design of the works. It is recommended that monitoring is carried out throughout the temporary works to ensure that scour depths remain within the acceptable limits assumed in design.

11.5.2 It is recommended that precautionary scour protection is included in the design of the permanent works as it impractical to monitor the works over the design life.

12 Victoria Embankment

12.1 Local conditions

12.1.1 The proposed Victoria Embankment works are on the left (north) bank of the Thames around 80m upriver of the Hungerford railway and footbridge. The Bakerloo Line tube tunnels pass between the Hungerford Bridge and the proposed works site. Downriver from Hungerford Bridge past Waterloo Bridge there is a major bend. The proposed works are on the outside of this bend at its upriver limit. A plan of the proposed works in shown in Figure 12-1.

12.1.2 The temporary works (bounded by the green line) cover a total area of 3765m^2, extending a maximum of 39.2m into the river. A campshed is shown in the southeast corner of the site. The temporary works are currently shown to be constructed as a vertical sheetpiled cofferdam. This is considered to represent a worst case in respect to blockage to the flow and therefore for scour development.

12.1.3 The permanent works cover a total area of 1065m^2 extending a maximum of 26.2m into the river. The permanent works are currently shown to be constructed as a sloping vertical wall.

Figure 12-1 Plan of proposed works at Victoria

12.1.4 The foreshore sediments in the area of the works appear to be a mixture of sands, gravels, and silts, and cobbles. Two boreholes drilled at opposite ends of the site suggest variability in the soil profile, with the d_{85} value from one borehole being approximately 3 times the size of the d_{85} value from the other. Information from the boreholes and vibrocores indicates that sediment sizes decrease with depth. Analysis of twenty four grab samples taken from across the channel indicates that the surficial sediment is predominantly gravelly granular material with the median grain size d_{50} varying between 9mm and 40mm. Only a limited amount of the foreshore is exposed at low tide at Victoria, but Figure 12-2 shows a narrow section which appears to be sands and gravels.

Figure 12-2 View of foreshore at the location of the works, looking from Victoria Embankment towards Westminster. (Photograph provided by HRW)

12.2 Temporary works

Effect on flow regime of the temporary works

12.2.1 The temporary works (as defined by the green line on Figure 12-1) decrease the cross section of the river by up to 13% at high water.

12.2.2 Numerical flow modeling shows that flow velocities increase by a maximum of 0.4m/s when compared to the baseline condition. The greatest changes occur on a flood tide.

12.2.3 Reductions in flow velocity occur along the river bank both upstream and downstream of the works. Accretion of finer sediments may therefore occur in these areas.

12.2.4 Figure 12-3 shows the flow velocities on a flood tide due to the temporary works. The bottom plot highlights the change in flows compared to the baseline condition, with the blue and green areas showing where velocities drop and the yellow areas indicating a slight increase in flow speed.

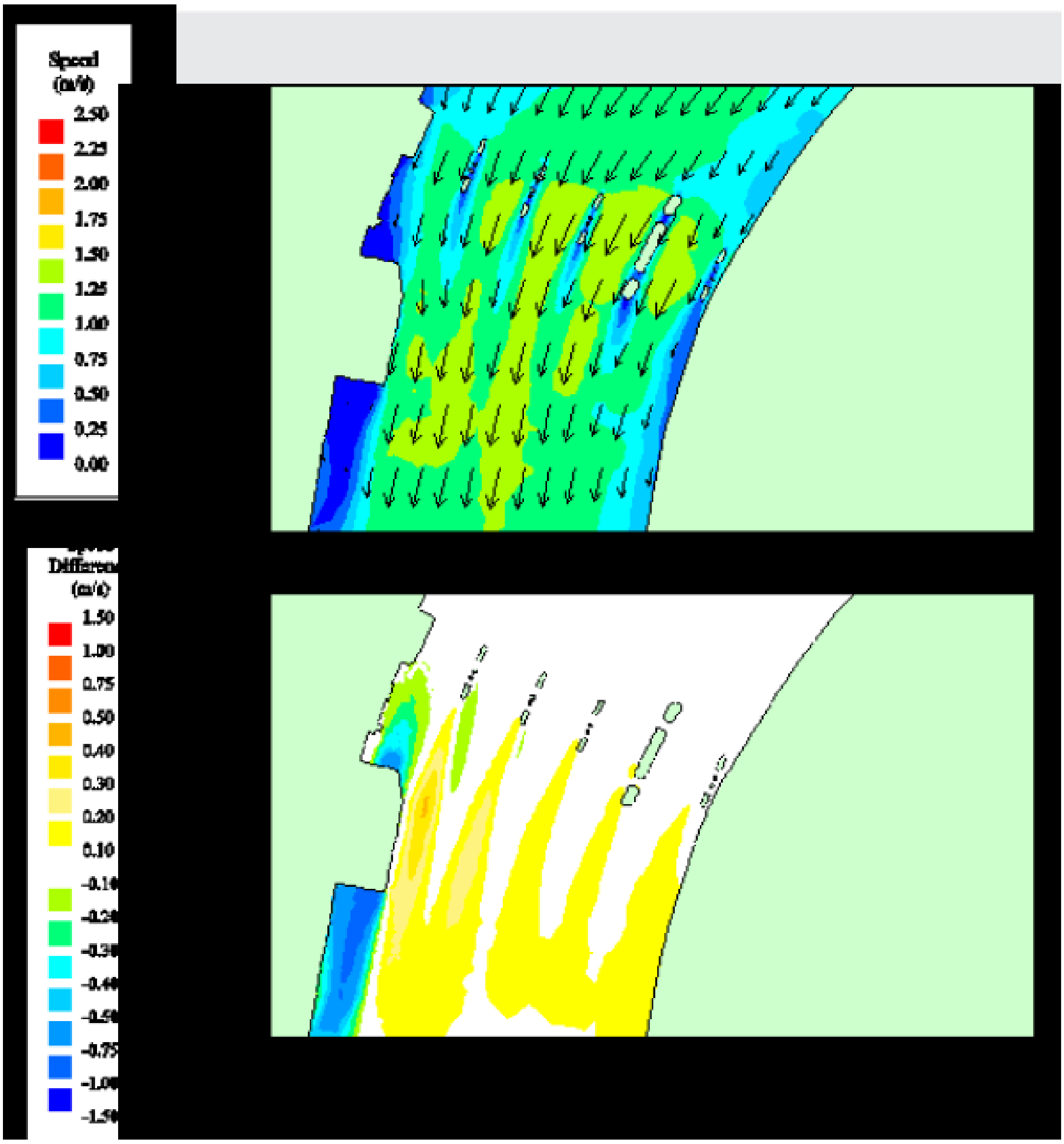

Figure 12-3 Flow velocities due to the temporary works at Victoria (provided by HR Wallingford)

Local scour predictions due to temporary works

12.2.5 Scour predictions have been carried out using the Erodibility Index approach as described in Section 3.6. Scour predictions have been calculated based on a maximum depth average velocity of 1.06m/s as extracted from the numerical model at the corners of the works.

12.2.6 Scour predictions have been carried out on based on the results of two different cone penetration tests, supplemented by information from one of the boreholes. Scour depth predictions are between 0.1 and 0.3m, indicating that the surficial granular material is able to withstand significant scour development. It should be noted that these results are highly dependent on the exact grading characteristics of the granular soil.

12.2.7 Lateral extents of scour are expected to be in the order of 1m from the face of the temporary works. It is noted that this scour extent is based on a very simplistic assessment, which assumes that the scour extent is the same along the whole length of the upstream and downstream face of the structure. In reality scour extents and depths will vary along the line of the structure depending on the exact soil characteristics, and the corners of the structure adjacent to the bank will more likely be areas of deposition and accretion, rather than erosion as the flow velocities will be reduced in this area.

Scour at the Campshed

12.2.8 Scouring at the campshed has not been formally assessed, but flows around the structure are likely to be low, and it is not thought that there will be any adverse scour affects around this structure. This is supported by evidence from existing campsheds on the River Thames.

Contraction scour due to the temporary works

12.2.9 Contraction scour preductions due to the temporary works have been based on granular surficial sediments with a d_{50} of 11mm and a d_{95} of 45mm across the whole width of the river. Contraction scour is predicted to be negligible for both ebb and flood flows.

12.3 Permanent works

Effect on flow regime of the permanent works

12.3.1 The permanent works as shown on Figure 12-1 decrease the cross section of the river up to 8% at high water.

12.3.2 The numerical modeling shows that the greatest increase in flow velocity adjacent to the permanent works is a maximum of 0.2m/s when compared to the baseline condition. The greatest changes occur on a flood tide.

12.3.3 Reductions in flow velocity occur along the river bank both upstream and downstream of the works. Accretion of finer sediment may therefore occur in these areas.

12.3.4 Figure 12-4 shows the flow velocities on a flood tide due to the temporary works. The bottom plot highlights the change in flows compared to the baseline condition, with the blue and green areas showing where velocities drop and the yellow areas indicating a slight increase in flow speed.

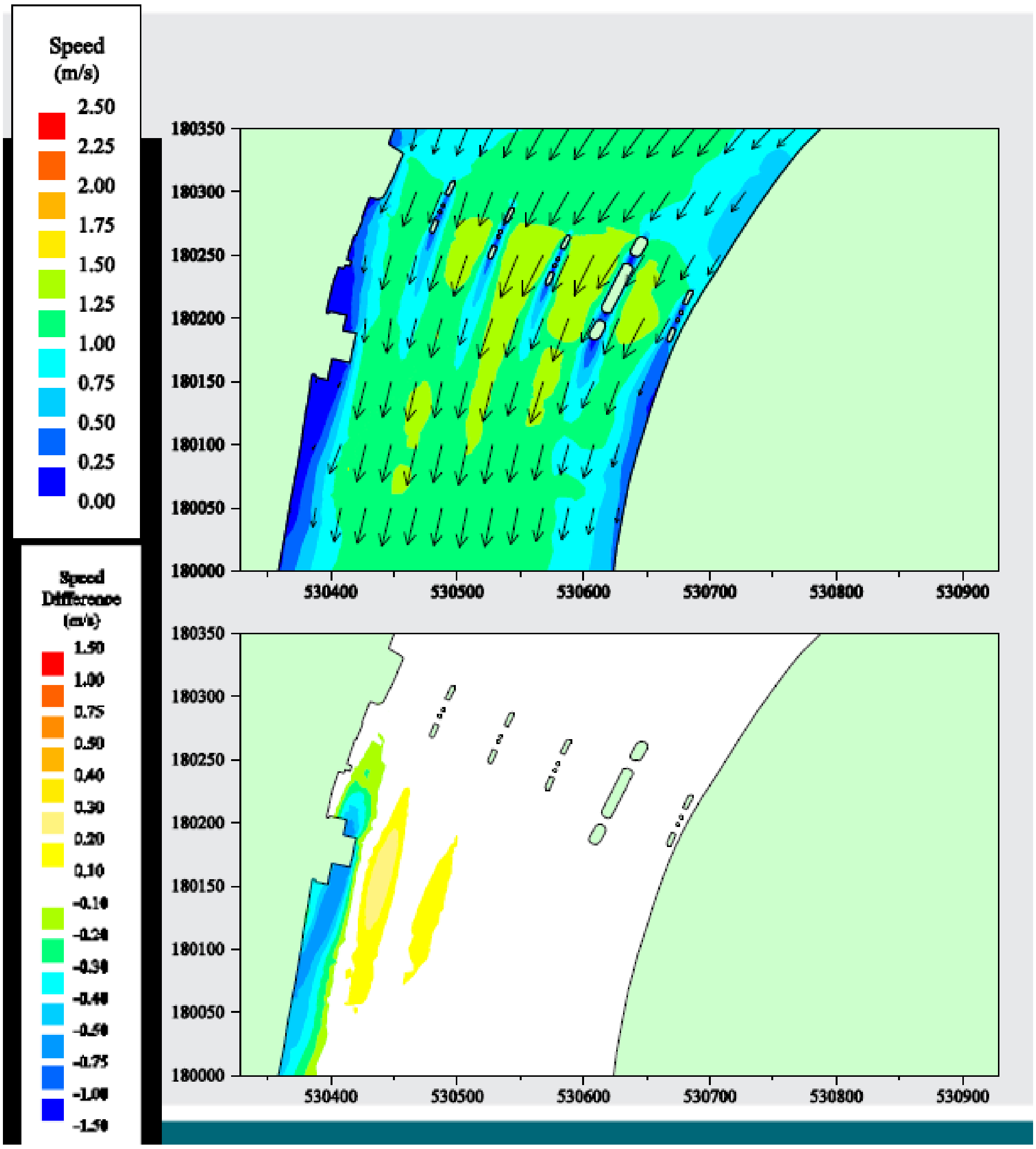

Figure 12-4 Flow velocities due to the permanent works at Victoria (provided by HR Wallingford)

Local scour predictions due to permanent works

12.3.5 As for the temporary works scour predictions have been carried out using the Erodibility Index approach as described in Section 3.6. Scour predictions have been calculated based on a maximum depth average velocity of 0.91m/s as extracted from the numerical model at the corners of the works.

12.3.6 Scour predictions have been based on the results of two different cone penetration tests, supplemented by information from one of the boreholes. Similarly to the temporary works, scour depth is predicted to vary across the site, with minimal development at the downstream end, and depths of up to 0.3m at the upstream end, indicating that the surficial granular material is able to withstand significant scour development. It should be noted that these results are highly dependent on the exact grading characteristics of the granular soil.

12.3.7 Lateral extents of scour are expected to be in the order of 1m from the face of the permanent works. It is noted that this scour extent is based on a very simplistic assessment, which assumes that the scour extent is the same along the whole length of the upstream and downstream face of the structure. In reality scour extents and depths will vary along the line of the structure depending on the exact soil characteristics, and the corners of the structure adjacent to the bank will more likely be areas of deposition and accretion, rather than erosion as the flow velocities will be reduced in this area.

Contraction scour

12.3.8 Similar to the temporary case, contraction scour is predicted to be negligible.

12.4 Effects on existing structures

12.4.1 There are a number of structures within 0.5km of the proposed works at Victoria including:

- Millenium Pier (0.3km up-stream)
- Westminster Pier (0.35km up-stream)
- Westminster Bridge (0.5km)
- Tattershall Castle (to be relocated as part of the works)
- RS Hispaniola (0.02km downstream)
- Charing Cross Rail Bridge (Hungerford Bridge) (0.2km downstream)
- Embankment Pier (0.15km downstream)
- London Underground Bakerloo and Northern Line Tunnels

12.4.2 A majority of these structures are outside the predicted extent of the scour due to the permanent and temporary works, and therefore will not be affected.

12.4.3 Figure 12-3 shows that there will be a slight increase in the flow velocities at the bridge piers due to the temporary works. However existing scour at the piers is approximately 0.5m deep, and it is considered that the slight increase in velocities will result in minimal increase to the existing scour depths.

12.4.4 The predicted scour depths due to the temporary and permanent works will have a negligible impact on the sediment cover to the underground tunnels.

12.5 Recommendations

12.5.1 The scour predictions for both the temporary and permanent works are around 0.3m, which is possible to accommodate within the design of the works. It is recommended that monitoring is carried out throughout the temporary works to ensure that scour depths remain within the values assumed in design (say 1m).

12.5.2 As the predicted scour depths are small, these could potentially be allowed for in the design of the permanent works. However consideration should also be given to the provision of precautionary scour protection, as it is not realistic to allow for monitoring of the works through the whole of the design life.

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13 Blackfriars Bridge

13.1 Local conditions

13.1.1 The proposed Blackfriars Bridge foreshore works are on a straight section of the left (north) bank of the Thames. They extend under and upriver of the Blackfriars Road Bridge. The Waterloo and City Line tube tunnels pass under the proposed works. The works are located in front of a 1960's reclamation that half fills the northern arch of the Blackfriars road and rail bridges. A plan of the proposed works in shown in Figure 13-1.

13.1.2 The main works cover a total area of 7837m^2, extending a maximum of about 46m into the river. In addition to the cofferdam area there is a temporary piled deck at the western end of the cofferdam covering an area of 2520m^2. The main temporary works are currently shown to be constructed as a vertical sheetpiled cofferdam. This is considered to represent a worst case in respect to blockage to the flow and therefore for scour development.

13.1.3 The main permanent works cover a total area of approximately 4600m^2 extending a maximum of 33.5m into the river. The permanent works include a new interception chamber beneath the most northern bridge arch of Blackfriars Road Bridge extending westwards to the drop shaft, some 175m west of Blackfriars Road Bridge.

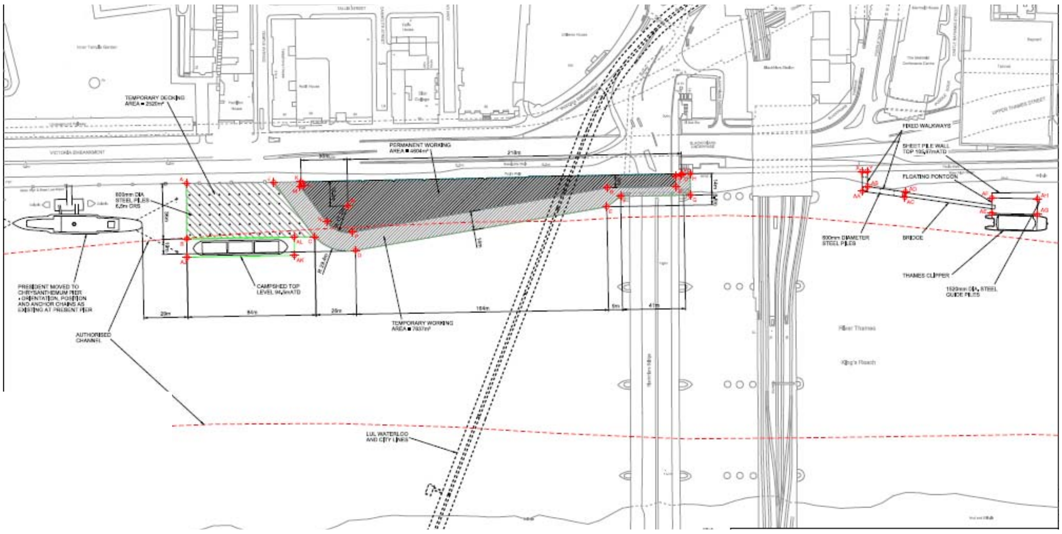

Figure 13-1 Plan of proposed works at Blackfriars

13.1.4 The foreshore in the area of the proposed works is predominantly made up of granular material, with an indication of possible silts and mud in a few locations. Analysis of grab samples in the area show a degree of variability in particle size distribution, with the median grain size d_{50} of the sample varying between 3mm and 65mm. The boreholes in the area indicate that grain size distribution is greater at depths of 1-2m (d_{50} around 13mm) than for depths of 2-3m (where d_{50} is approximately 6mm). Figure 13-2 shows the typical foreshore sediments in the location of the works.

Figure 13-2 View of foreshore at the location of the works, looking upstream. (Photograph provided by HRW)

13.2 Temporary works

Effect on flow regime of the temporary works

13.2.1 The temporary works decrease the cross section of the river by up to 19% at the widest point of the works (at high water).

13.2.2 Numerical flow modeling shows flow velocities increase adjacent to the temporary works for both flood and ebb conditions by up to 0.4m/s when compared to the baseline condition. An increase of up to 0.3m/s occurs across the whole of the river section.

13.2.3 Slight reductions in flow velocity occur along the river bank both upstream and downstream of the works. Accretion of finer sediments may therefore occur in these areas.

13.2.4 Figure 13-3 shows the flow velocities on a flood tide due to the temporary works. The bottom plot highlights the change in flows compared to the baseline condition, with the blue and green areas showing where velocities drop and the yellow areas indicating a slight increase in flow speed.

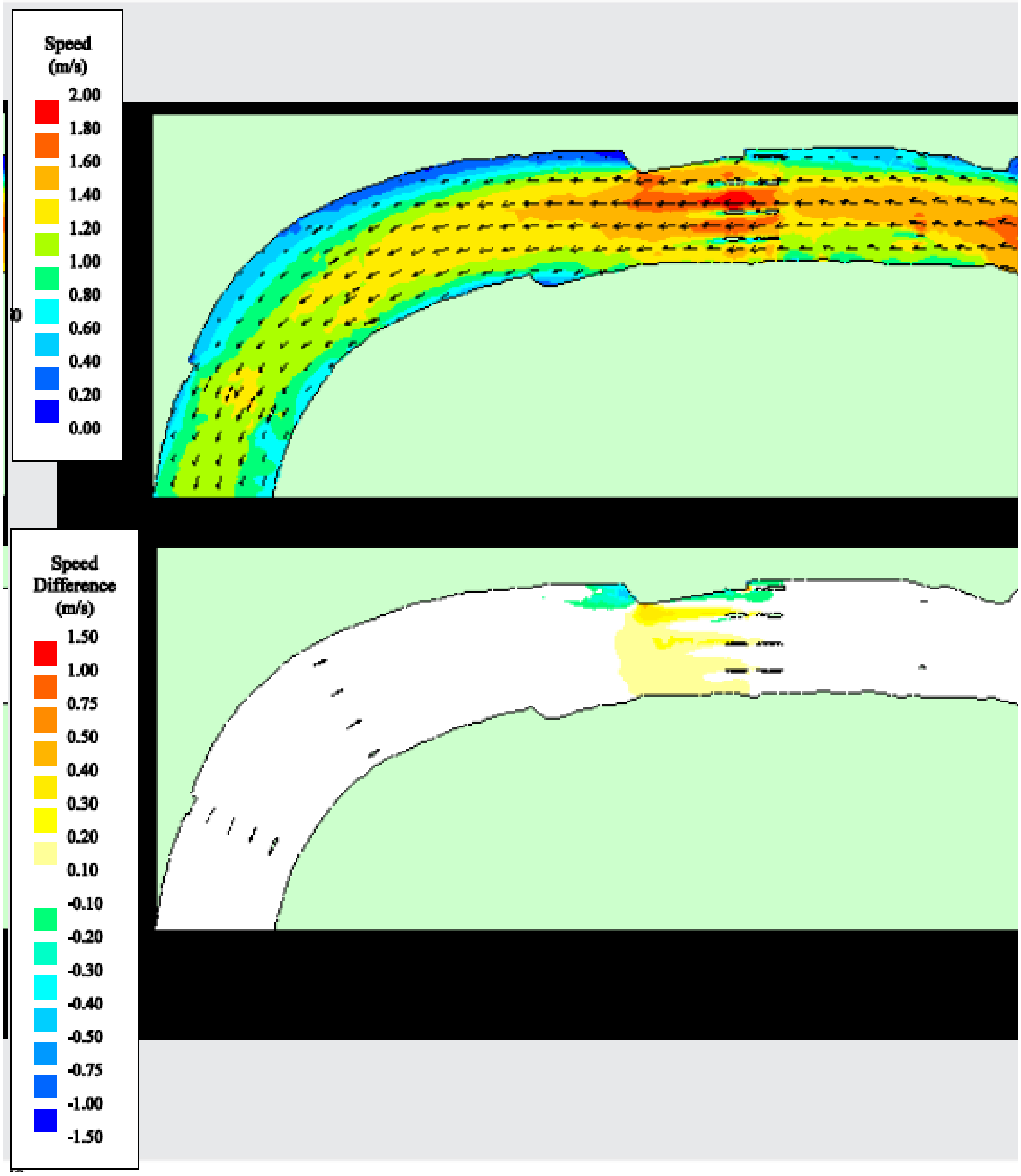

Figure 13-3 Flow velocities due to the temporary works at Blackfriars (provided by HR Wallingford)

Local scour predictions due to temporary works

13.2.5 Scour predictions have been carried out using the Erodibility Index approach as described in Section 3.6. Scour predictions have been calculated based on a maximum depth average velocity of 1.29m/s as extracted from the numerical model at the corners of the works.

13.2.6 Scour predictions are based on the results of one cone penetration test in the area. A potential scour depth of 0.5m is predicted. This is limited due to a clay layer which has a greater resistance to scouring. It should be noted that this layer is only around 0.3m thick at this depth. Extensive vessel movement and other disturbances during the construction associated with the temporary works could cause erosion of this layer, which would expose some further granular material below, which would be less resistant to scour.

13.2.7 Lateral scour extents may be in the order of 1 to 2 m from the front face of the temporary works and extending up to 2m from each end. Exact scour extents and depths will vary along the line of the structure depending on the exact soil characteristics.

Contraction scour due to temporary works

13.2.8 Contraction scour due to the temporary is works is predicted based on granular surficial sediments with a d_{50} of 0.32mm and a d_{95} of 34.2mm across the whole width of the river. Contraction scour is predicted to be in the order of 0.5m for both ebb and flood flows.

13.3 Permanent works

Effect on flow regime of the permanent works

13.3.1 The main permanent works as shown on Figure 13-1 decrease the cross section of the river up to 13% at the highest part of the works at high water.

13.3.2 The numerical modeling shows that the greatest increase in flow velocity adjacent to the permanent works is a maximum of 0.3m/s when compared to the baseline conditions, with a majority of the flow change being less than 0.2m/s. There is a slight reduction in velocities upstream and downstream of the works.

13.3.3 Figure 13-4 shows the flow velocities on a flood tide due to the temporary works. The bottom plot highlights the change in flows compared to the baseline condition, with the green areas showing where velocities drop and the yellow areas indicating a slight increase in flow speed.

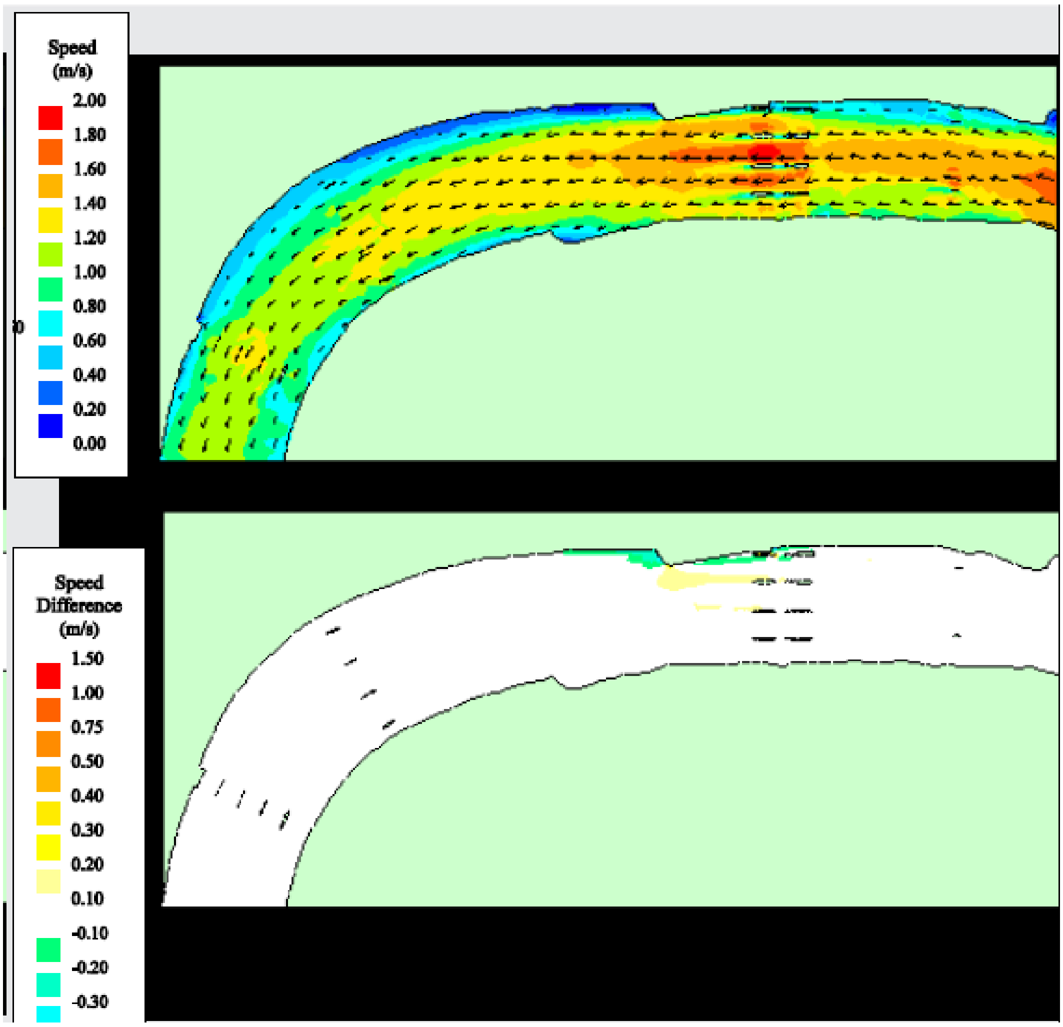

Figure 13-4 Flow velocities due to the permanent works at Blackfriars (provided by HR Wallingford)

Local scour predictions due to permanent works

13.3.4 As for the temporary works scour predictions have been carried out using the Erodibility Index approach as described in Section 3.6. Scour predictions have been calculated based on a maximum depth average velocity of 1.10m/s as extracted from the numerical model at the corners of the works.

13.3.5 As for the temporary works scour predictions are based on the results of one cone penetration test in the area, and a potential scour depth of 0.5m is predicted. This is limited due to a clay layer which has a greater resistance to scouring. It appears that the bed materials are able to withstand significant scour development, but it is noted that these results are highly dependent on the exact grading characteristics of the granular soils and how they vary across the site.

13.3.6 Lateral scour extents may be in the order of 1 to 2 m from the front face of the permanent works.

Contraction scour

13.3.7 As for the temporary works contraction scour is predicted to be in the order of 0.5m for both ebb and flood flows.

13.4 Effects on existing structures

13.4.1 There are a number of structures within 0.5km of the proposed temporary and permanent works at Blackfriars which include:

- HMS President (0.1km upstream)
- HMS Wellington (0.4km upstream)
- Chrysanthemum Pier (0.5km upstream)
- Temple Pier (0.5km upstream)
- Blackfriars Railway Bridge (50m downstream)
- Relocated Blackfriars Pier (0.2km downstream)
- Millenium Footbridge (0.4km downstream)
- London Underground Waterloo and City Line Tunnel (under site)

13.4.2 A majority of these structures are out of the predicted extent of the scour due to the permanent and temporary works, and therefore will not be affected.

13.4.3 The Blackfriars Bridge is the most significant existing structure at the site as it spans the downstream end of the temporary works and the interception chamber for the permanent works is situated in the river wall directly beneath the northernmost span of the road bridge.

13.4.4 Bathymetric surveys of the area indicate that there is actually very limited existing scour development at the bridge piers compared to what might be expected in an unconstrained bed of sediment. It is thought that this must be because scour protection has been placed around the piers. Therefore the temporary and permanent works will not have any effect on scour development at the piers of Blackfriars Bridge.

13.4.5 It is understood that the London Underground Waterloo and City line passing underneath the river to the west of Blackfriars bridge is fully buried beneath the bed, and will not be affected unless there is significant contraction scour over the tunnel section. Contraction scour is predicted to be 0.5m, and therefore is unlikely to impact on the tunnel section, but considering the difficulties in predicting scour extents and shapes this should be monitored and kept under review.

13.5 Recommendations

13.5.1 The scour predictions for both the temporary and permanent works are around 0.5m, which is possible to accommodate within the design of the works. It is recommended that monitoring is carried out throughout the temporary works to ensure that scour depths remain within the values assumed in design (say 1m).

13.5.2 As the predicted scour depths are small, these could potentially be allowed for in the design of the permanent works. However consideration should also be given to the provision of precautionary scour protection, as it is not realistic to allow for monitoring of the works through the whole of the design life

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14 Chambers Wharf

14.1 Local Conditions

14.1.1 The proposed works at Chambers Wharf works are on the right (south) bank of the Thames around 700m downriver of Tower Bridge. Downriver from the wharf there is a major bend. Chambers Wharf is on the outside of this bend at its upriver limit. Figure 14-1 shows a plan of the works.

14.1.2 The temporary works cover a total area of 8625m^2 of which around 5900m^2 extends further into the river beyond the existing quay line.

14.1.3 There are no permanent works at this site.

Figure 14-1 Plan of proposed works at Chambers Wharf

14.1.4 Two vibrocores and five CPT's were carried out in the vicinity of the works, but no grab sampling of surface sediments has been carried out. The vibrocores and CPT's indicate that the riverbed in this area consists of a thin layer of sands overlying a bed of stiff clay. Figure 14-2 shows a picture of the foreshore in the area of the works, which shows a mixed granular foreshore overlying finer sediment.

Figure 14-2 View of foreshore at the location of the works, looking upstream. (Photograph provided by HRW)

14.2 Temporary works

Effect on flow regime of the temporary works.

14.2.1 The temporary works decrease the cross section of the river by up to 11% at high water.

14.2.2 Numerical flow modelling shows that flow velocities increased on the northern bank (the opposite bank to the works) for both flood and ebb conditions by up to 0.3m/s on a flood tide.

14.2.3 Around the proposed works along the southern river bank, decreases in flows are predicted.

14.2.4 Figure 14-3 shows the flood tide due to the temporary works. The bottom plot highlights the change in flows compared to the baseline condition, with the blue and green areas showing where velocities drop and the yellow areas indicating a slight increase in flow speed.

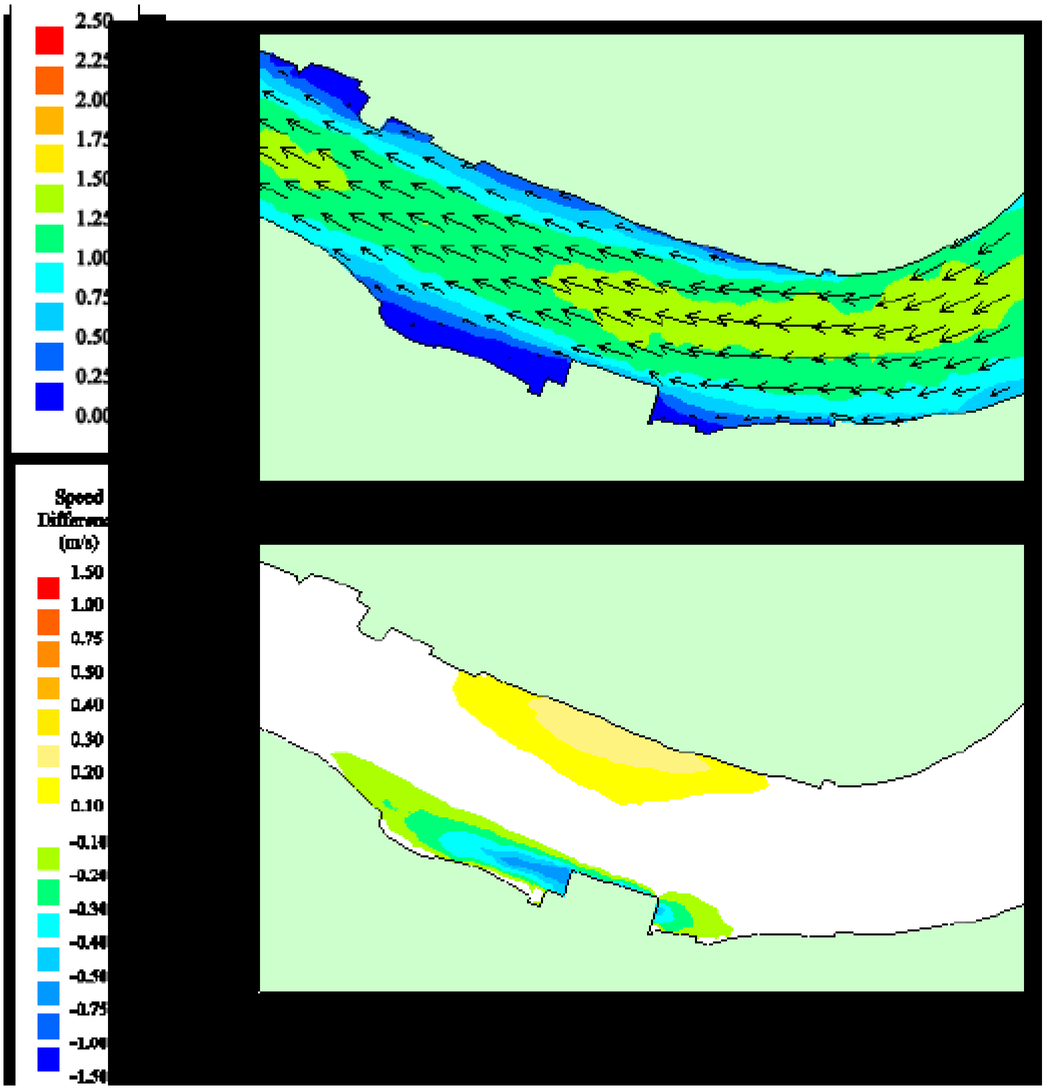

Figure 14-3 Flow velocities due to the temporary works at Chambers Wharf (provided by HR Wallingford)

Local scour predictions due to temporary works

14.2.5 Scour predictions have been carried out using the Erodibility Index approach as described in Section 3.6. Scour predictions have been calculated based on a maximum depth average velocity of 0.93m/s as extracted from the numerical model at the corners of the works.

14.2.6 Scour predictions vary depending on the assumptions made about the soil. Predictions assuming graded granular soil combined with layers of cohesive soil give minimal scour depths. Assuming fine granular soils with no additional strength from cohesion or compaction gives predictions ranging between 0.5m to 1.7m. Using a realistic granular soil grading (with coarser grains rather than a fine loose sand) gives predictions between 0.5 to 0.9m.

14.2.7 Lateral scour extents may be between 3 to 6m from the face of the temporary works. It is noted that this scour extent is based on a very simplistic assessment, which assumes that the scour extent is the same along the whole length of the upstream and downstream face of the structure. In reality scour extents and depths will vary along the line of the structure depending on the exact soil characteristics, and the corners of the structure adjacent to the bank will more likely be areas of deposition and accretion, rather than erosion as flow velocities will be reduced in this area.

Contraction scour due to temporary works

14.2.8 Contraction scour is predicted based on granular surficial sediments with a d_{50} of 5mm and a d_{95} of 35mm. Contraction scour is predicted to be minimal for both ebb and flood flows.

14.3 Permanent works

14.3.1 There are no permanent works in this area.

14.4 Effect on existing structures

14.4.1 The nearest structure to the temporary works at Chambers Wharf is Cherry Garden Pier, which is 0.2km downstream of the works. This structure is outside the predicted extent of the scour, and therefore it is considered that the works will have no adverse affect on existing structures.

14.5 Recommendations

14.5.1 The scour depth prediction based on a realistic granular soil grading is 0.9m. For design purposes a scour depth of 1m should be assumed, and monitoring should be carried out over the duration of the temporary works to ensure that scour does not develop beyond the critical level assumed in design.

15 King Edward Memorial Park

15.1 Local Conditions

15.1.1 The proposed King Edward Memorial Park (KEMP) works will be on the left (north) bank of the Thames on the outside of a long bend. The Rotherhithe tunnel passes under the river at an angle being only around 40m upriver of the proposed temporary works at the northern foreshore. The closed entrance to Shadwell Dock is 50m upriver of the Rotherhithe tunnel. The proposed works are shown in Figure 15-1.

Figure 15-1 Plan of proposed works at KEMP

15.1.2 A number of grab samples have been collected in the vicinity of the works, and these show that the foreshore sediments on the left bank upriver and downriver of the works are variable, but generally are granular, with some areas of finer material, silts and muds.

15.1.3 Two boreholes in the vicinity of the KEMP works showed sediments containing gravel or a clay and gravel mixture for 1.5 to 2.8m below the river bed overlying stiff clay.

15.1.4 Figure 15-2 shows a picture of the foreshore in the area of the works, which shows predominantly granular material with silts and muds at a lower level.

Figure 15-2 View of foreshore at the location of the works, looking down-estuary. (Photograph provided by HRW)

15.2 Temporary works

Effect on flow regime of the temporary works

15.2.1 The temporary works (as defined by the green line on Figure 15-1) slightly decrease the cross section of the river at high water.

15.2.2 HR Wallingford has carried out numerical modeling which shows that there is minimal increase in flow velocities due to the temporary works, and there is a reductions in flow velocity occur along the river bank upstream and downstream of the works. Accretion of finer sediments may therefore occur in these areas.

15.2.3 Figure 15-3 shows the flow velocities on a flood tide due to the temporary works. The bottom plot highlights the change in flows compared to the baseline conditions, with the blue and green areas showing where velocities drop.

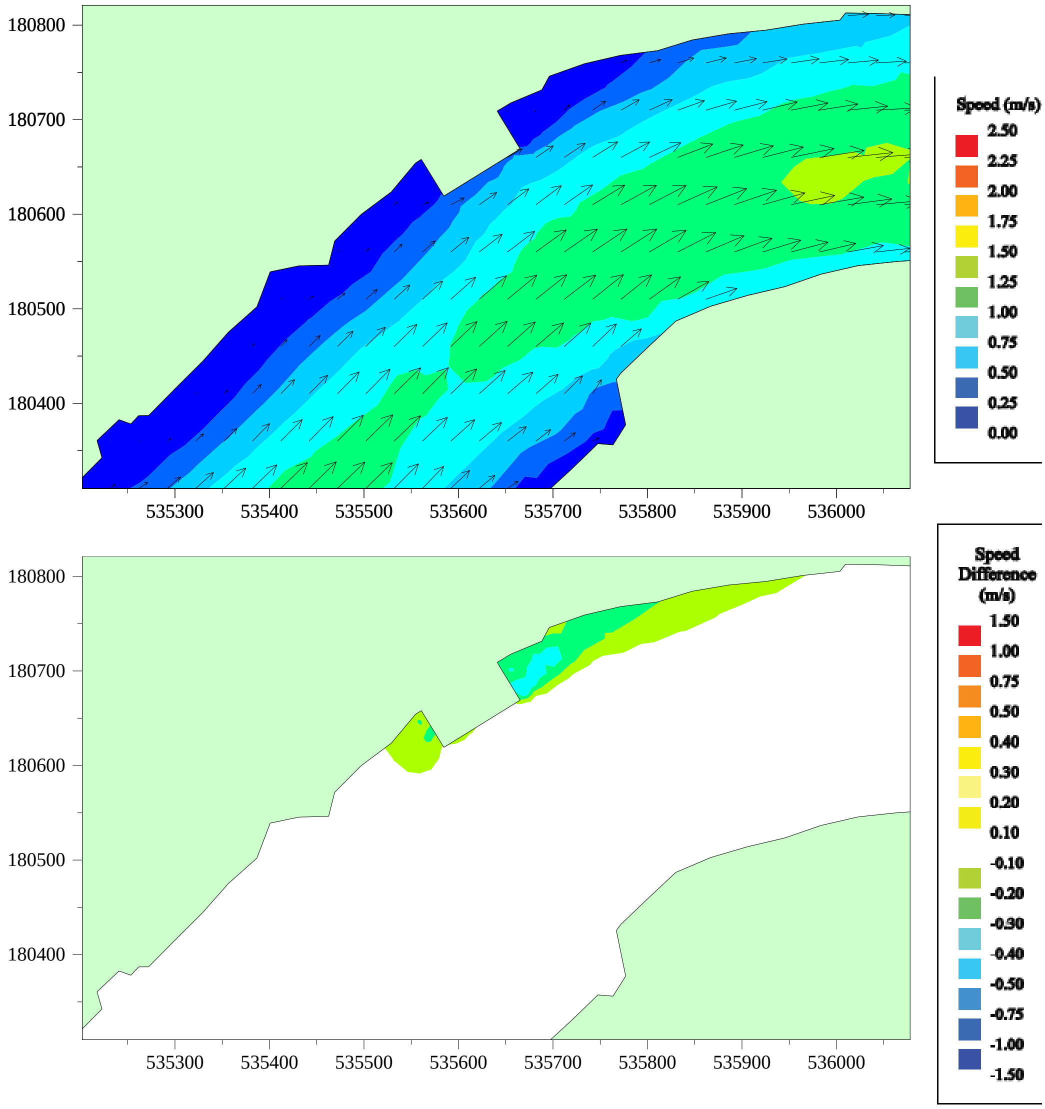

Figure 15-3 Flow velocities due to the temporary works at KEMP (provided by HR Wallingford)

Local scour predictions due to temporary works

15.2.4 Scour depth prediction have been carried out using the Erodibility Index approach as described in Section 3.6. Scour predictions have been calculated based on a maximum depth average velocity of 0.58m/s as extracted from the numerical model at the corners of the works.

15.2.5 Scour depth predictions have been carried out based on the results from SPT results from two boreholes. Predictions vary depending on the assumptions made about the strength of the top 1m of soil (no SPT readings were recorded over this depth), with values ranging from 0.1 to 1m. For the purpose of design the upper bound depth of scour of 1m should be assumed.

15.2.6 Lateral extents of scour may be in the order of 3.7m along the full length of the temporary works. It is noted that this scour extent is based on a very simplistic assessment, which assumes that the scour extent is the same along the whole length of the upstream and downstream face of the structures. In reality scour extents and depths will vary along the line of the structure depending on the exact soil characteristics, and the corners of the structure adjacent to the bank will more likely be areas of deposition and accretions, rather than erosion as the flow velocities will be reduced in this area.

Scour at the campshed

15.2.7 Scouring at the campshed has not been formally assessed, but flows around the structure are likely to be low, and it is not thought that there will be any adverse scour affects around this structure. This is supported by evidence from existing campsheds on the River Thames. As the campshed takes up a significant length of the front of face of the temporary works, then this may act to limit the potential for scour development in this area.

Contraction scour due to the temporary works

15.2.8 Contraction scour predictions due to the temporary works have been based on granular surficial sediments with a d_{50} of 1.5mm and a d_{95} of 8.0mm across the whole width of the river. For the peak ebb tide, conditions fall under live-bed contraction scour conditions, and for the peak flood tide clear-water scour conditions occur. Therefore contraction scour is only predicted to occur under flood conditions, with scour depths of up to 0.5m possible.

15.3 Permanent works

Effect of flow regime of the permanent works

15.3.1 The permanent works as shown on Figure 15-1 decrease the cross section of the river up to 6% at high water.

15.3.2 The numerical modeling shows that the greatest increase in flow velocity adjacent to the permanent works is a maximum of 0.3m/s when compared to the baseline conditions at the western end of the works. The greatest changes occur on a flood tide.

15.3.3 Reductions in flow velocity occur along the river bank upstream and downstream of the works. Accretion of finer sediments may therefore occur in these areas.

15.3.4 Figure 15-4 shows the flow velocities on a flood tide due to the temporary works. The bottom plot highlights the change in flows compared to the baseline conditions, with the blue areas showing where velocities drop and the yellow areas indicating a slight increase in flow speed.

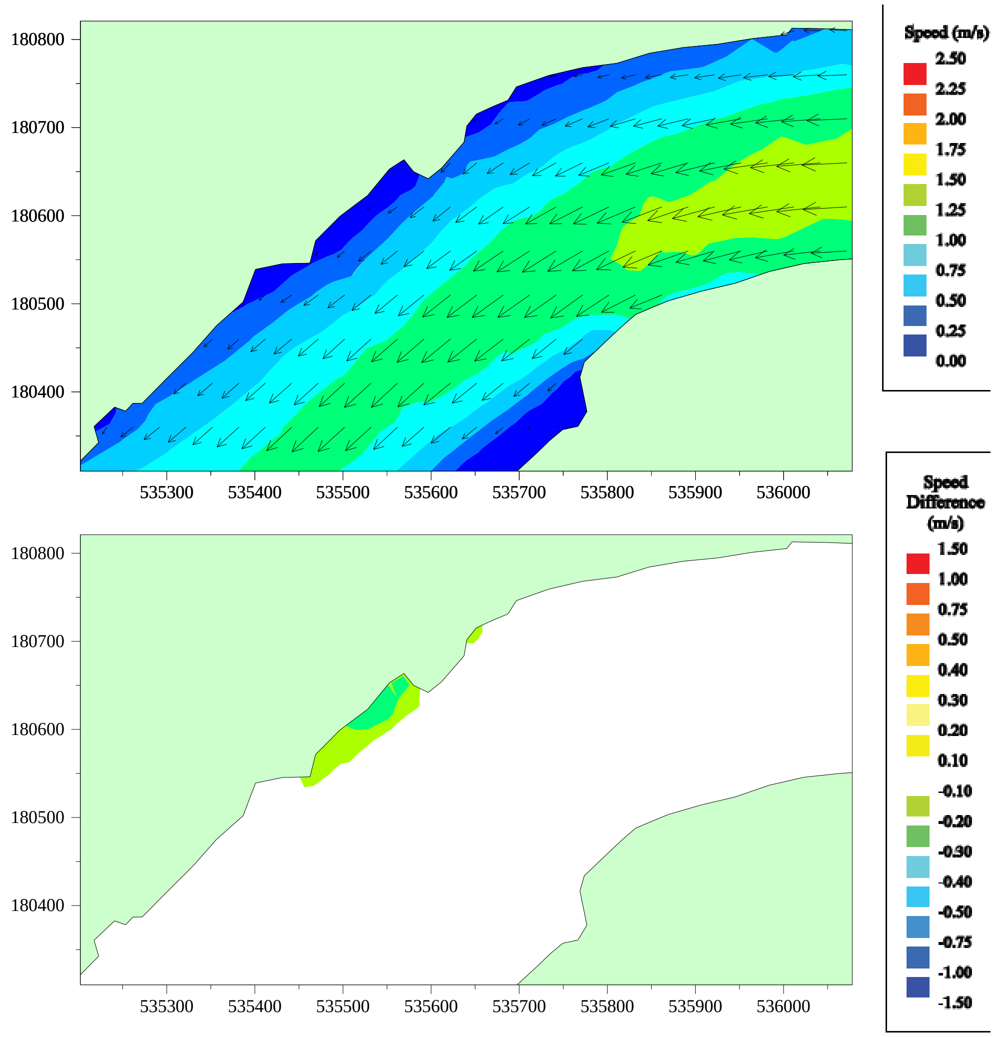

Figure 15-4 Flow velocities due to the permanent works at KEMP (provided by HR Wallingford)

15.3.5 As well as numerical modeling which gives 2D flow fields, physical modeling of the temporary works were also carried out to capture the 3D secondary currents and increased turbulence that may be expected due to the presence of the works on a river bend. Turbulence and flow separation on the river side of the temporary works was observed during the physical model testing.

Local scour predictions due to permanent works

15.3.6 As for the temporary works scour predictions have been carried out using the Erodibility Index approach as described in Section 3.6. Scour predictions have been calculated based on a maximum depth average velocity of 0.44m/s.

15.3.7 Scour depth predictions have been carried out based on the results from SPT results from two boreholes and are of a similar order to the predictions for the temporary case. Scour depth can therefore be expected to be limited to 1m.

15.3.8 Lateral extents of scour are expected to be in the order of 3.7m along the face of the permanent works. Again it is noted that these scour extents are based on a very simplistic assessment, which assumes that the scour extent is the same along the whole length of the upstream and downstream face of the structures. In reality scour extents and depths will vary along the line of the structure depending on the exact soil characteristics, and the corners of the structure adjacent to the bank will more likely be areas of deposition and accretion, rather than erosion as the flow velocities will be reduced in this area.

Contraction scour

15.3.9 Similar to the temporary case, for the peak ebb tide, conditions fall under live-bed contraction scour conditions, and for the peak flood tide clear-water scour conditions occur. Therefore contraction scour is only predicted to occur under flood conditions, with scour depths of up to 0.2m possible.

15.4 Effects on existing structures

15.4.1 There are a number of structures within 0.5km of the proposed works at KEMP including:

- Rotherhithe Tunnel (at site)
- Shadwell Basin (0.1km up-estuary)
- Free Trade Wharf jetty (0.2km down-estuary)
- Stone Stairs Barge Tier (0.2km down-estuary)
- Stone Stairs Barge Roads (0.35km down-estuary)

15.4.2 With the exception of the Rotherhithe Tunnel these structures are out of the predicted extent of the local scour due to the permanent and temporary works. However the predicted contraction scour (up to 0.5m due to the temporary works, and 0.2m due to the permanent works), may cause lowering of the bed at these structures which would be in addition to any existing local scour.

15.4.3 The location of the Rotherhithe Tunnel is evident through a rise in the bed level, with deepening of the channel either side. The rise in the bed level is likely to be due to the placement of scour protection or ballast works, placed over the tunnel to help maintain the cover to the tunnel. It is unclear whether the lowering of the bed level is due to scour response to the mound of material over the tunnel, but it does not appear that there has been any significant deepening of the bed in the vicinity of the tunnel since the 80s. It can therefore be assumed that the invert of the river channel local to the tunnel is located within the clay layer and as such is relatively resistant to further lowering. It is not expected therefore that the works will have any significant effect on the cover to the tunnel.

15.5 Recommendations

15.5.1 The upper bound scour predictions for both the temporary and permanent works are around 1m, which is possible to accommodate within the design of the works. It is recommended that monitoring is carried out throughout the temporary works to ensure that scour depths remain within the acceptable limits assumed in design.

15.5.2 To help with reducing turbulence and flow separation due to the presence of secondary currents during the temporary work it is recommended that a small training wall is included at the eastern (seaward) end of the cofferdam.

15.5.3 It is recommended that precautionary scour protection is included in the design of the permanent works as it impractical to monitor the works over the design life.

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Glossary

Term	Description
2D Mathematical model	A mathematical representation of tidal flows that considers variations in velocity in plan in two direction but assumes velocities do not change through the water column
Baseline	Conditions in the current situation.
Clay	The part of the mud fraction that has a size smaller than 0.004mm
Cobbles	Material passing through a 256mm sieve and retained on a 64mm sieve
Contraction scour	The change in waterway cross section area that occurs as the waterway adjusts to the introduction of a structure.
Erodibility index	An empirically derived measure of the resistance to erosion based on the geotechnical properties of the bed material.
Gravel	Material passing through a 64mm sieve and retained on a 2mm sieve
Local scour	Scour adjacent to a structure that arises as a result of the presence of the structure.
Main prediction	The primary local scour prediction for each part of the proposed structures based on what is considered to be a representative sediment sample
Mud	Material passing through a 0.063mm sieve
Physical model	A scale model which uses water to understand how the protype behaves. This model uses specific scaling rules that are in a particular relationship for length, velocity and flow.
Sand	Material passing through a 2mm sieve and retained on a 0.062mm sieve
Sensitivity test (prediction)	The secondary local scour prediction for each part of the proposed structures based on what is considered to be a small sediment size for the locality.
Stream power	A measure of the transfer of energy from the flowing water to the banks and bed of the channel.
Silt	The part of the mud fraction that has a size above 0.004mm
With-works	Conditions with either temporary or permanent works in place.

Appendix A Shape Factors

A.1.1 The calculations used for predicting scour depth includes a shape factor which varies the predicted local scour depth depending on the shape of the abutment. The variation in local scour associated with shape is considerable. The factor can change scour depth by a factor of four between a rectangular shape that causes maximum scour and a streamlined shape that causes the least scour. This variation assumes that the local depth and velocity of the flow around the shape does not change.

A.1.2 In practice, care should be taken to avoid unintended consequences. In previous test simulations investigated in the flow modelling it was shown that too much of an angled edge at either end of the works could ‘train’ the flow and increase the area over which currents are influenced by the works.The actual difference in scour depth may as a result be rather less than appears from a consideration of shape factor alone.

A.1.3 Shape factors are set out in the scour manual (CIRIA, 2002 Figure 4.5 and Table 4.4). A standard rectangular shape as proposed for many of the temporary cofferdams in the Thames has a shape factor of 3.0.

Tapered reclamation sides

A.1.4 If the end of a reclamation is tapered as indicated in Figure A.1 the shape factor reduces. For a taper angle of 60° (option 1.a) a shape factor of 1.5 is likely to be appropriate provided the ratio W/L is in the range 0.5<W/L<1.5. A higher shape factor of 2.0 would be appropriate if 1.5<W/L<2.5, but this is rarely the situation for the temporary works whose longest edge is usually along the river bank. If W/L<0.5, we would recommend a shape factor of 1.5 is used although this particular situation is not covered in the guidance.

A.1.5 If the cofferdam is asymmetric with a taper at only one end, the shape factor adopted should be different on the flood and ebb tide.

A.1.6 If the angle of taper for option 1 is greater than 60° as indicated for Option 1.b in Figure A.1, no reduction to the shape factor is recommended in the guidance. For option 1.b a shape factor of 3.0 should be adopted as the taper angle is unlikely to be sufficient to reduce the scour depth.

A.1.7 If the taper angle in option 1 can be reduced to between 55° and 45° a lower shape factor of 1.25 may be applied, provided W/L <0.3. For a taper angle of 45° a shape factor of 0.75 is recommended provided W/L<0.2.

Rounded reclamation ends

A.1.8 A reduced shape factor may be appropriate for a reclamation with a rounded end as shown in Figure A.2, although this situation is not explicitly covered in the guidance.

A.1.9 The guidance can be interpreted to indicate that for all cases shown in Figure A.2 a shape factor of 1.5 would be appropriate. This interpretation suggests a shape factor of 1.5 applies provided the radius of the rounding is greater than W/6. For rounding radii in the range W/6 to W/10 a shape factor of 2.25 is suggested. If the rounding radius is less than W/10 a shape factor of 3.0 appropriate for a rectangular shape should be applied as the rounding is too small to reduce scour.

Double rounded reclamation ends

A.1.10 Addition of a reverse curve at the river wall as indicated in Figure A.3 for option 3 offers no advantage or disadvantage in terms of scour depth at the outer end of the cofferdam compared with option 2. There may be other benefits of a reverse curve close to the river wall.

Figure A.1 Option 1 - Tapered Ends

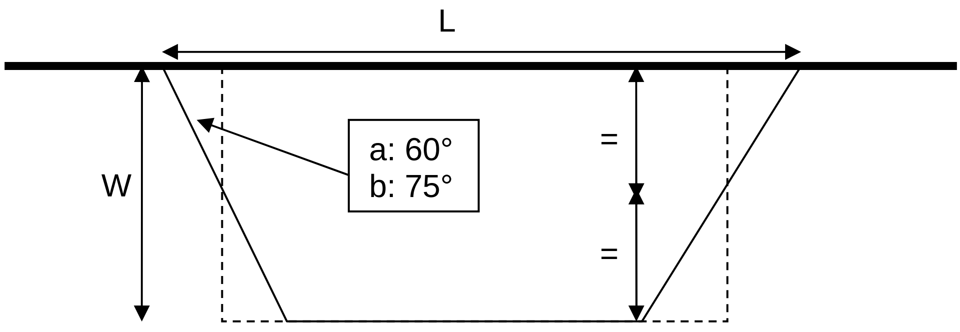


Figure A.2 Option 2 – rounded external corners

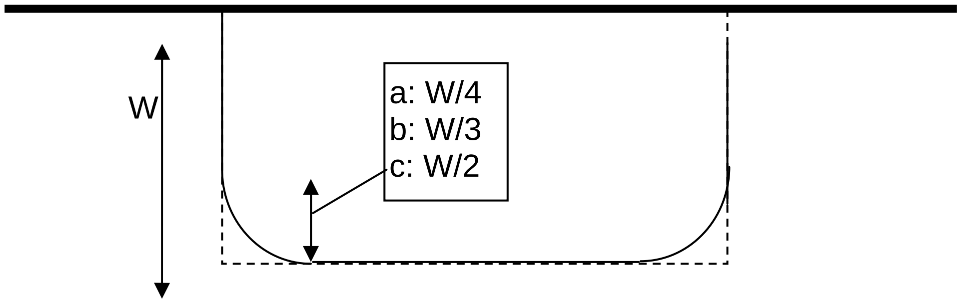
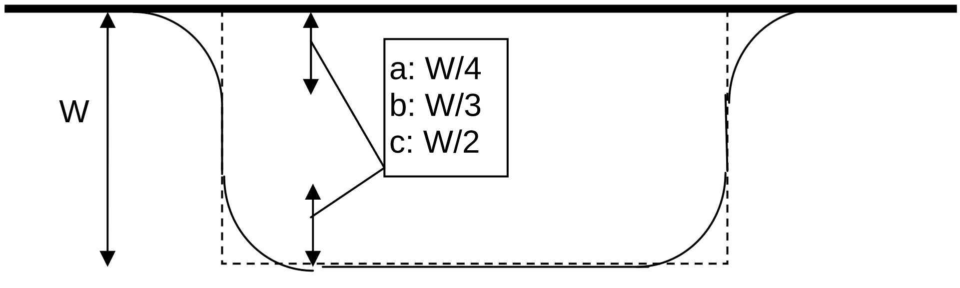


Figure A.3 Option 3 – rounded internal and external corners



Appendix B Outline scour protection calculations

B.1 Introduction

B.1.1 Outline scour protection calculations have been carried out based on the recommendations given in CIRIA C551 (2002). This manual gives three widely accepted formula for sizing rip rap and other scour protection (Escarameia and May (1992), Pilarczyk (1990) and Maynord (1995)). These equations are based mainly on laboratory research, and often give differing answers, due to limitations in the testing, over-simplification of the parameters that affect riprap stability and use of different safety factors.

B.1.2 For detailed design the recommendation is that all available formulas are used, and the final sizing chosen based on engineering judgement and depending on the consequence of failure (i.e. larger sizing where consequence of failure is high, smaller sizing where consequences are low).

B.1.3 However, for the purpose of this report (outline sizing to give a comparison between scour protection methods) only the formula of Escarameia and May has been used. This formula is the simplest of the three as it doesn't include parameters relating to water depth and channel shape (which vary depending on the site in question), and therefore provides a simple outline value that is applicable for all sites.

B.2 Calculation

B.2.1 Escarameia and May (1992) equation (*C551 eq. 5.2*)

$$d_{n50} = C_I \frac{U_b^{\,2}}{2g(s-1)}$$

- d_{n50} is the characteristic size (in m) of the stone (equivalent cube)
- C_I is a coefficient that takes into account the turbulence intensity *TI*, and differs depending on form of protection
  - o Rip rap $C_I = 12.3TI - 0.20$ *(C551 eq5.3)*
  - o Gabion mattresses $C_I = 12.3TI - 1.65$ *(C551 eq5.7)*
  - o Interlocking concrete $C_I = 9.22TI - 0.15$ *(C551 eq5.9)*
- *TI* is to be taken from C551 Table 5.4 (=0.35 relating to high levels of turbulence around structures such as piers, caissons and cofferdams)
- g is the acceleration due to gravity (=9.81 m/s^2)
- s is the specific gravity of the stone (taken as 2.4 for stone, 2.2 for concrete blocks)
- U_b is the velocity near the bed (=0.87U, where U is the depth average flow (*C551 Box 3.4)*)
  - o Maximum U = 1.9m/s U_b = 1.65m/s

- o Minimum U = 1.2m/s U_b = 1.04m/s

Table C-1: Indicative sizing of scour protection

Values	Rip rap		Gabions		Concrete blocks	
CT	4.11		2.66		3.08	
s	2.4		2.4		2.2	
U (m/s)	1.9	1.2	1.9	1.2	1.9	1.2
U_b (m/s)	1.65	1.04	1.65	1.04	1.65	1.04
D_{n50} (mm)	408	163	264	105	357	142

Thames Tideway Tunnel
Thames Water Utilities Limited

Application for Development Consent

Application Reference Number: WWO10001

Environmental Statement

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Volume 3: Project-wide effects assessment appendices

Appendix L.4: Scour monitoring and mitigation strategy

APFP Regulations 2009: Regulation **5(2)(a)**

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L.4 Scour and accretion monitoring and mitigation strategy

L.4.1 The following report has its own table of contents.

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Appendix L: Water resources – surface water

L.4 Scour and accretion monitoring and mitigation strategy for temporary works in the foreshore

Introduction

L.4.1 This document presents the draft strategy for the monitoring and mitigation of both scour and accretion during the construction phase of the Thames Tunnel. **This draft strategy only covers the construction phase** since the philosophy to mitigation for the construction and operational phases are very different as explained below.

L.4.2 It is important to note that this document must be read in conjunction with the relevant sections of the *Environmental Statement*, which include the project-wide assessments for surface water (Vol 3 Section 14) and flood risk (Vol 3 Section 15) and in particular the scour interpretative report which is presented as Volume 3 Appendix L.3. These documents provide the impacts assessments in respect of scour and accretion as well as plans which show possible extents of both (if left unmitigated). **These assessments and plans are not repeated within this draft strategy**.

L.4.3 Given the conservative nature of the modelling which has been undertaken and the degree of uncertainty associated with them, rather than providing temporary scour protection during construction, any potential scour development during this phase would be monitored and protection measures provided only when an appropriate trigger level is reached. This approach is likely to reduce the total amount of scour protection used and consequently reduce the level of encroachment on natural bed sediments. This approach is regarded as the most appropriate during construction, particularly given the views of statutory stakeholders, who wish to ensure that the impacts on the existing river bed are minimised and that existing substrates, channel depths and habitats are retained where possible.

L.4.4 This approach during the operational phase would differ substantially from the approach during construction. The operational structures within the river would have a design life of 120 years and a proactive engineered solution to scour is therefore preferable to the reactive approach identified for the temporary works. It is also important to note that observations on scour and the effectiveness of any mitigation used during construction are likely to inform the final extent and type of the scour protection for the operational structures. The operational phase would also require some element of monitoring as well as a remedial approach to any unexpected scour or accretion. **The approach to scour and accretion during the operational phase is covered within the *Engineering Design Statement*** which accompanies the application for development consent (the ‘application’).

Document structure

L.4.5 Paras L.4.9 to L.4.25 describe strategy ownership, strategy development and engagement, identifies related consents and describes how revisions to the strategy would be progressed. Paras L.4.17 to L.4.25 provide a brief introduction to the reasons for scour and accretion and the modelling work undertaken for scour at the foreshore sites.

L.4.6 Paras L.4.26 to L.4.55 describe the various types of monitoring that are proposed and provides a matrix which identifies which monitoring methods are believed to be most appropriate to each site and in respect of each type of feature.

L.4.7 Paras L.4.56 to L.4.58 provide an overview of the approach to trigger values for mitigation responses and provides a matrix of current thinking on the variables which determine how these may vary between sites and various features. Paras L.4.64 to L.4.75 then provide a review of the types of mitigation for scour during construction and provides another matrix which summarises indicative proposals for each site and feature, if scour does occur. These paragraphs also explain briefly that temporary scour mitigation would be removed at the end of the construction period, subject to the appropriate agreements

L.4.8 Paras L.4.69 to L.4.79 provide a brief description of the proposed approach to accretion.

Strategy ownership

L.4.9 It is intended that this strategy should be subject to a requirement or obligation as part of the Development Consent Order or as a side agreement with both the Port of London Authority (PLA) and the Environment Agency (EA). The responsibility for delivering the strategy would be either that of Thames Water or the relevant employer.

L.4.10 The baseline monitoring which would be required in advance of construction would be the responsibility of Thames Water or the employer, as the contractors are unlikely to be in position to undertake these surveys at that stage. Once on site construction commences, it is assumed that the responsibility for implementation for both monitoring and mitigation would be passed to the contractors by way of a contractual requirement between Thames Water (or the employer) and the contractor.

L.4.11 Once the development is operational, any monitoring and remedial mitigation that is required would be the responsibility of Thames Water (or the relevant infrastructure owner). The project operational procedures are covered within the *Engineering Design Statement* and are not part of this strategy.

Strategy development and engagement

L.4.12 This strategy has been developed by engineers and environmental staff working on behalf of Thames Water and drawing extensively on the experience and advice provided by technical specialists at both HR Wallingford and Black and Veatch.

L.4.13 An early draft of this strategy was presented to a workshop on 2nd November 2012, at which representatives of the EA, PLA and Marine Management Organisation (MMO) provided comment. Further written comments were provided by both the EA and the PLA and these have informed the preparation of the current draft, notably the preparation of the draft matrices.

L.4.14 It is considered likely that a further draft of this strategy may be required in due course.

Consents for works

L.4.15 In the event that any scour or accretion mitigation measures are required during construction, it is intended that although whilst the contractor's proposals should sit within the ambit of this strategy, the proposals would also be subject to the appropriate consents. These could include a River Works Licence (from the PLA) and a Flood Defence Consent (from the EA), unless equivalent approaches are otherwise incorporated within the Development Consent Order (DCO), as well as reach agreement with any other third party.

Revisions to the strategy

L.4.16 In undertaking the detailed design of the temporary works, the contractor may wish to revise the indicative approach given in this strategy at particular sites or in relation to recommended monitoring techniques. Any such further revisions to the strategy, beyond the development consent process, would need to be agreed with the PLA and the EA.

Background

Scour and accretion

L.4.17 There are seven proposed construction sites and three further barge handling facilities where temporary works would be installed in the river foreshore. The temporary works are likely to consist of working areas, platforms, campsheds and jetties and could be protected by sheet pile coffer dams or supported on groups of circular piles.

L.4.18 The protrusion into the river of these temporary works would affect the river regime with the potential that localised increases in flow velocity cause scour of the river bed and foreshore. The depth and extent of this potential scour has been predicted using modelling of temporary cofferdam arrangements which are considered likely to lead to slightly greater scour than a piled platform approach and so would represent a 'worst case' for assessment. The scour could affect the river bed in the immediate vicinity of the cofferdam, the adjacent river walls and any nearby third party infrastructure (such as bridge piers).

L.4.19 There is also the potential for the temporary works to cause relatively still zones at the river edges where material can settle-out and cause an increase in the river bed level. This material might be either material already in the water column or material released as a result of the works, eg, fine sediments from dredging or barging movements. It is expected that this will occur particularly on the foreshore within the sheltered zones of the temporary works.

L.4.20 The fluvial modelling indicates that at all sites deposition of suspended sediment load is most likely on the foreshore or riverbank adjacent to the temporary works and accretion in the main navigable channel is unlikely. Any river bed material scoured out at the temporary works may settle in more tranquil reaches of the river either upriver or downriver from the temporary works. Monitoring the development of scour holes can therefore give an indication of the amount of material which may be deposited elsewhere.

L.4.21 The predictions for (unmitigated) scour and deposition (accretion) are summarised in the relevant sections of the *Environmental Statement*, which include the project-wide assessments for surface water (Vol 3 Section 14) and flood risk (Vol 3 Section 15) and in particular the scour interpretative report which is presented in Vol 3 Appendix L.3. These documents provide the impacts assessments in respect of scour and accretion as well as plans which show possible extents of both (if left unmitigated). A brief summary of the scour modelling and predictions are given in the next section.

Scour modelling and predictions

L.4.22 Numerical analyses have been carried out at each of the foreshore sites to predict the scour depths resulting from the (unmitigated) proposed temporary works. These predictions assess the potential scour around the temporary works and the potential impact on any nearby existing structures such as bridge piers, jetties and river walls.

L.4.23 The local reduction of the natural cross-sectional area of the river caused by the temporary works can result in increased flow velocities and subsequently higher bed shear stress. This could mobilise the bed material and cause contraction scour across the river section. For most sites the contraction scour is predicted to be less than 0.1m for both ebb and flood tides.

L.4.24 Scour depth and extent is difficult to predict since it is based on the water depth, flow velocity, strength, type and thickness of the river bed material and the shape and extent of the temporary works. In some cases there is existing armouring and scour protection in the river bed, especially around bridge piers, which will reduce the predicted scour. Vol 3 Table L.1 indicates the predicted scour depths at each of the sites.

L.4.25 The ten sites where temporary works are proposed are:

a. Putney Embankment Foreshore, including consideration of Putney Bridge

b. Chelsea Embankment Foreshore, including consideration of nearby Chelsea Bridge

c. Heathwall Pumping Station, including the South West Storm Relief sewer outfall culvert

d. Albert Embankment Foreshore, which is divided into two temporary works sites; the interception structure site and shaft site and includes Vauxhall Bridge

e. Victoria Embankment Foreshore, including consideration of the nearby Millennium and Hungerford bridges

f. Blackfriars Bridge Foreshore, including consideration of Blackfriars bridge

g. King Edward Memorial Park Foreshore

h. Carnwath Road Riverside, which may include a new campshed and/or jetty facilities

i. Kirtling Street, which includes a jetty for barge docking facilities

j. Chambers Wharf, which would have a barge docking facility.

Vol 3 Table L.1 Predicted scour depths in the foreshore (unmitigated)

Site	Estimated potential scour depths particular locations (m)[1]			
	Temporary works abutments	Bridge piers and abutments	River wall[2]	Contraction Scour
Putney Embankment Foreshore and Putney Bridge	2.5	2[3]	<0.1	<0.1
Chelsea Embankment Foreshore and Chelsea Bridge	2.8	2[3]	<0.1	<0.1
Heathwall Pumping Station and South West Storm Relief	2.7	N/A	<0.1	<0.1
Albert Embankment Foreshore and Vauxhall Bridge Albert Embankment	1 1	2[3] N/A	<0.1 <0.1	<0.1 <0.1
Victoria Embankment Foreshore	0.3	0.5	0.3	0.3

Site	Estimated potential scour depths particular locations (m)[1]			
	Temporary works abutments	Bridge piers and abutments	River wall[2]	Contraction Scour
and Millennium Bridge, Hungerford Bridge				
Blackfriars Bridge Foreshore and Blackfriars Bridge	0.5	<0.1	<0.1	<0.5
King Edward Memorial Park Foreshore	1.5	N/A	<0.1	<0.5
Carnwath Road Riverside	1.3	N/A	<0.1	<0.1
Kirtling Street	0.5	N/A	<0.1	<0.1
Chambers Wharf	1	N/A	<0.1	<0.1

[1] Scour values are taken from Vol 3 Appendix L.3 and are the suggested design values given by HR Wallingford. They are the maxima given within any calculated range.
[2] Where scour at river walls is shown to be negligible a value of <0.1m is quoted
[3] These values are the current baseline situation; the temporary works may exacerbate the scour to a minor extent.
Note: N/A signifies that there are no bridge piers in the vicinity of the temporary works
Where scour is shown as <0.1m the potential scour is deemed to be negligible with a low likelihood of scour.

Monitoring methodologies

L.4.26 A variety of approaches and instruments can be used to monitor scour and other changes in bed level. These are described in general terms below. Three types of approach are proposed for monitoring bed levels during the construction phase of the Thames Tideway Tunnel project. These are the use of bathymetric surveys, local scour monitoring using fixed instruments and the use of visual inspection (including land surveys and photographic recording).

L.4.27 Two other methods which have been considered include the use of LIDAR techniques and the use of remote methods (unmanned vessels). Having given due consideration to the overall effectiveness of these methods they have been excluded from this draft strategy.

L.4.28 It is also acknowledged that new monitoring methods may become available before or during construction. If viable new methods do become available and are preferred by the contractor, the contractor would be expected to revise the strategy accordingly with the agreement of both the PLA and the EA.

L.4.29 The viability of the different methods varies from site to site. The preliminary recommendations for the appropriate survey methods at each site and in relation to each type of structure which have been identified by technical specialists are provided in Annex A:

Bathymetric surveys

Purpose

L.4.30 Bathymetric survey during the period when the temporary works is in place would determine any changes in the river bed level beyond those occurring naturally which may potentially be due to the effects of the temporary works. These surveys would include monitoring the changes in the bed profile at existing bridge piers and abutments and other third party structures and would be used to determine any mitigation measures to protect these existing structures. These surveys will also provide information of any significant accretion of the navigable channel to assess if dredging of the channel is required.

Baseline establishment

L.4.31 A series of baseline bathymetric surveys would be undertaken by Thames Water or its agent at each site quarterly for a two year period prior to the start of the works. The surveys would determine any variation in the bed profile resulting from natural fluvial processes or other activities in the river. The first year of baseline survey would enable the second year of baseline surveys to be refined, for example to account for any periods of peak flow identified in the first year.

L.4.32 It will be important to capture the extent of scour after high flows (tidal at spring tide, fluvial) at the end of the winter period and given due consideration for the lunar tidal cycle. For these reasons an appropriate monitoring date during March / April would need to be identified. Additional bathymetric surveys may be needed after exceptional (greater than annual return periods) fluvial events since these may cause exceptional scour.

L.4.33 In addition to, or included within the last quarterly baseline surveys, a 'whole-river' bathymetric survey would be undertaken between Hammersmith Bridge and Deptford Creek (see para. L.4.37).

L.4.34 The results would be provided to the contractor to form the baseline for their ongoing monitoring. The baseline data would also be provided to both the PLA and the EA.

Methodology

L.4.35 It is proposed that bathymetric surveys are carried-out using multi-beam sonar recording the data in analogue and digital format. It is proposed that the typical resolution of the bathymetric survey would be on a 0.5m x 0.5m grid with 0.1m vertical resolution although it may be appropriate to vary this depending on the sediments and location.

L.4.36 During the bathymetric survey the position of the boat would be accurately determined so that repeated surveys of the same river reach can be compared.

Spatial scope

L.4.37 It is proposed to undertake a single 'whole river' bathymetric survey at the outset of the construction process. This would provide the baseline to detect any 'off-site' deposition which may be attributable to the project. Modelling undertaken to date suggests that deposition would only occur in the vicinity of the new structures and no 'off-site' deposition is anticipated.

L.4.38 For the purposes of assessing effects on the navigable channel, the reach of river to be surveyed is to be agreed in advance with the PLA for each site. For the purposes of this strategy, the suggested extent of these surveys for both the navigable channel and the existing structures at each site is shown in Annex B. These survey extents would need to be revised, once the PLA has provided plans showing highly constrained sections of the channel.

Survey during construction

L.4.39 The surveys within the survey areas in the vicinity of the sites would be repeated quarterly at the same time in the calendar, established during baseline monitoring. As for the baseline monitoring, additional bathymetric surveys may be needed after exceptional (greater than annual return periods) fluvial events since these may cause exceptional scour.

Taking action

L.4.40 If bathymetric monitoring (or other monitoring) detects that scour or accretion is occurring, the response would be determined by use of appropriate 'triggers'. These are further discussed from para. L.4.56.

Fixed instrument monitoring

Purpose

L.4.41 There are a number of instruments and methods which can be employed to monitor the development of scour or accretion of the foreshore and river bed at specific locations. However within this strategy, sonar is proposed as the most appropriate was to measure changes in the bed at fixed locations for the majority of sites. In combination with bathymetry and visual inspections, this should provide a comprehensive monitoring approach.

Baseline establishment

L.4.42 Subject to agreement with relevant asset owners, it is envisaged that the devices (see para. L.4.43) would be installed on existing structures at the defined locations at least a year in advance of construction commencing in the river. This would not be possible for the new temporary cofferdams when these instruments would need to be installed once the cofferdams have been constructed.

Methodology

L.4.43 The monitoring of scour at specific locations would be carried-out by sonar devices fixed above flood level to the temporary works and adjacent river wall where scour might be anticipated. Sonar devices would be installed on brackets fixed to existing and temporary works structures and can be arranged to take readings of the river bed variations over a large area at specific locations rather than a single point. The readings can be affected by high concentrations of fine sediment in the river water.

L.4.44 Although modelling predicts limited scour at the river wall at some locations, the practical interaction of the newly installed temporary works cofferdam and the existing river wall may cause unusual local vortices. As such, it is prudent to monitor at the junction of the cofferdam and the river wall. The scour monitoring stations would be at critical points along the perimeter of the temporary works. These are at locations already identified in the studies undertaken where local flow velocities would increase due to the projection of the temporary works into the normal flow pattern. Where feasible, the specific type river bed material at the location of the monitoring point would be described and photographed. This will give an idea of the likelihood of scour occurring at these locations.

L.4.45 Following the installation of the sonar devices on the temporary works the initial reading taken at location would be the baseline reading against which the development of any potential future scour at the temporary works is to be assessed.

Spatial scope

L.4.46 The critical locations at each site are indicated in Annex B. The proposed locations for scour monitoring at the temporary works typically include the existing river walls at the start and end of the temporary works and along the length of the proposed coffer dam at protrusions or changes in plan direction.

L.4.47 At some sites the fluvial modelling indicates an increase in velocity during the ebb and flood tides on the river bank opposite the temporary works. In these cases, additional scour monitoring is proposed on the opposite bank. This would be covered by the three monthly bathymetric survey. At sites where it is feasible to install sonar devices on the opposite bank these may be used instead of or with the surveys. Sites where this is proposed are Kirtling Street and Heathwall Pumping Station, Albert Embankment Foreshore, Victoria Embankment Foreshore, Blackfriars Brdige Foreshore and Chambers Wharf.

Survey during construction

L.4.48 Ongoing monitoring and reporting at these monitoring stations would be carried-out on a weekly basis throughout the period that the temporary works is in place. As well as the taking readings of the reduced levels of the river bed at each monitoring station, the date, time and tide level is to be recorded.

Taking action

L.4.49 If fixed instrument monitoring (or other monitoring) detects that scour or accretion is occurring, the response would be determined by use of appropriate 'triggers'. These are further discussed from para L.4.56.

Land surveys and visual inspections

Purpose

L.4.50 It is acknowledged that there are certain sites at which other methods, particularly the bathymetric approach, are unlikely to be entirely suitable for monitoring some types of scour. Reasons may include the difficulty of accessing the site by boat due to the shallow depths of the river margins. For this reason and for some sites, it is likely that land based surveys will be required for those areas closer to the cofferdam or river walls.

Baseline establishment

L.4.51 The baseline surveys would be undertaken at the same frequency as the surveys they are supplementing or replacing at the relevant sites.

Methodology

L.4.52 The land surveys would use range-azimuth systems to map channel morphology. This would be undertaken at low tide and would target intertidal areas. This would be supplemented by taking photographic records of the foreshore and structures as well as visual inspection.

Spatial scope

L.4.53 The surveys would extend over the proposed survey areas (shown in Annex B) where this cannot otherwise be covered by bathymetric survey.

Survey during construction

L.4.54 The surveys would be repeated at the same frequency as the surveys they are supplementing or replacing at the relevant sites.

Taking action

L.4.55 If land surveys or visual monitoring (or other monitoring) detects that scour or accretion is occurring, the response would be determined by use of appropriate 'triggers'. These are further discussed from para L.4.56.

Scour trigger levels

L.4.56 Since scour can develop relatively quickly at temporary works and then stabilise it is suggested that trigger levels are applied to determine:

a. the need for increased frequency of monitoring (once first detected) and potentially

b. the need for mitigation measures.

L.4.57 Vol 3 Table L.2 gives an example of suggested trigger levels. When a particular threshold is reached the frequency of measurements would be increased as indicated to establish the trend of scour development before mitigation measures are carried-out.

Vol 3 Table L.2 Example scour trigger levels

Scour depth detected (m)	Action
0 to 0.3	Continue weekly monitoring
0.3 to 0.6	Increase to daily monitoring
>0.6	Implement remedial measures

Note: Scour depths are below the initially recorded minimum bed level datum or the relevant level for the lunar month as detected by the monitoring established during the previous year.

L.4.58 Given the different sediments and predicted scour depths at various locations, it is judged appropriate to vary the trigger levels on a site-by-site basis. To this end, a draft matrix has been developed, included as Annex C, which summarises the relevant variables, in order to define appropriate trigger levels.

L.4.59 Within the matrix in Annex C, trigger levels for action would not be less than 0.3 m. Expert opinion suggests that a 0.3 m change between surveys is the least value that might be measured confidently and determine with confidence that this is not a natural change.

L.4.60 A variation in response in respect of either increased survey and/or action is given, depending on how vulnerable the location is. At the most vulnerable sites mitigation would be initiated immediately, whereas at less vulnerable locations, an increased level of monitoring is recommended before action is taken. Any scour approaching 0.9 m would initiate mitigation at any site.

L.4.61 A preliminary screening exercise across the river walls at the foreshore sites has identified a range of vulnerability to scour varying from medium to very high, based on wall type, age and condition of the wall.

L.4.62 Existing scour protection may reduce the vulnerability of existing river walls to scour and it is anticipated that the vulnerability of a river wall to scour could be reduced by a category if scour protection is present in front of the wall, but not to below medium vulnerability level.

L.4.63 These variables would be included in the matrix in Annex C in order to determine the trigger values for action form the river walls at each site. A similar approach would be used for bridges and similar assets.

Scour mitigation measures

Background

L.4.64 There are various mitigation measures which can be employed to reduce the development of scour holes in the river bed. This part of the strategy provides an overview of these measures that could be applied once the trigger levels for action described above are reached.

L.4.65 This part of the strategy also provides a matrix (see Annex D) which identifies, based on the current understanding of the current condition of the structures, the existing sediments and the likely extent of scour, the suggested measures at each site. These measures have been identified by technical specialists including scour specialists and engineers, having given due consideration to the flexibility and robustness of the methods.

L.4.66 The detailed approach to the implementation of measures at each location in response to any scouring would however be undertaken by the contractor under a contractual requirement and who would obtain any required consents as described above.

Types of mitigation

L.4.67 The various measures which may be appropriate in different circumstances are listed below. Plates are provided in Annex D to illustrate these mitigation types:

a. Riprap or rock fill is the simplest form of protection against scour. Rock can be laid quickly underwater to provide immediate protection in the event of rapid scour development. To form the riprap layer the scour hole would need to be trimmed by excavator to allow for the riprap layer to be benched such that the protection works do not protrude above the baseline river bed profile. The benching would be a minimum of four times the layer thickness. Geotextile filter fabric would be laid into the trimmed sour hole on to which the rock is to be laid.

b. Bags of riprap in a geotextile cord bag. These could be used in a similar manner to loose riprap bur are more easily removable for temporary works, however they are less likely to allow any development of semi-natural habitats during the construction period.

c. Proprietary articulated concrete blocks can be placed to prevent the further development of the scour hole. Since the concrete block layer has a fixed thickness, deep scour holes would need to be backfilled with granular material to provide a substrate for placing the concrete blocks. The blocks would be benched into the edges of the scour hole by a minimum four times the concrete block layer thickness and laid on a geotextile filter fabric.

d. Stone filled gabion mattresses can also be used to provide temporary scour protection. In these cases, the scour hole would be backfilled with granular material to provide the foundation for the gabion mattresses so that the mattress follows the original river profile

L.4.68 It is anticipated that the contractor’s approach would, whilst it would be informed by the judgements in the matrix, would utilise one of more of these measures in their response to a particular scour event.

L.4.69 Another alternative that has been considered but discounted would be to use a grout filled mattress which is made up of tied mats into which grout is injected. In this case, the scour hole would be backfilled with granular material prior to the laying of the geotextile fabric and mats. This technique can be susceptible to grout loss and so is not considered appropriate for remedial works in the River Thames.

L.4.70 It is noted that, in order to maintain the depth of the river channel, the PLA require bed levels to be maintained (and not raised) and for this reason, scour protection would need to be recessed into the river bed, potentially with prior excavation.

Use of rip rap

L.4.71 CIRIA C551 (CIRIA, 2002)[1] suggests that rip rap is the most appropriate scour protection material in that it is natural material and can be quickly placed below water in the event of rapid scour development. Rip rap is flexible and can fill the shape of the scour hole.

L.4.72 Within the attached matrix, rip rap of three different sizes has been identified which would more closely response to the existing sediment type, although would clearly need to be of greater particle size and / or more cohesive if scour is to be successfully mitigated.

L.4.73 These sizes are as follows:

a. Quarry run with an initial D50 of 60 mm and D85 of 90 mm.

b. Quarry run with an initial D50 of 30 mm and D85 of 60 mm.

c. Larger material, with a D of 300mm.

L.4.74 The contractor would be required to stockpile adequate scour protection material and geotextile filter fabric to allow for the development of scour holes at each site. The contractor would be required to have equipment, which can be mobilised to each site within one working week, for placing the geotextile fabric and scour protection material.

Removal of scour protection to temporary works

L.4.75 Should protection measures be required to stabilise any scour development at the temporary works during the construction phase, this protection would be removed when the temporary works are dismantled unless otherwise agreed with the PLA, the EA and any relevant asset owner (in the case of third party assets such as bridge piers).

Accretion, monitoring and mitigation

L.4.76 To ensure that the channel (both the main navigable channel and the margins) in the vicinity of the temporary works is not unduly affected by the deposition of material, monitoring of accretion would be recorded. This is to be done through the monitoring approach described above (and probably in particular the bathmetric survey) and would be compared to the recorded baseline to assess any accretion within the relevant survey area.

L.4.77 The variation in the bed profile has been recorded within the tidal Thames since 1974 although dredging finished in the 1990s. Reviewing the data from 1996-2009 for seven of the foreshore sites where temporary works are required in the foreshore suggests that the maximum variation in bed levels is about 0.5m at most locations although the average may be closer to 0.3m.

L.4.78 For this reason, a response to accretion detected within the survey area is proposed when there is accretion of 0.5m or more above the expected

[1] CIRIA C551 Manual on scour at bridges and other hydraulic structures (2002)

baseline river profiles (as defined during the baseline bathymetric surveys), attributable to the Thames Tideway Tunnel project. However in areas identified by the PLA to be critically sensitive to accretion (notably shallow sections of the navigable channel), this accretion trigger would be dropped to 0.1m (maps would be obtained from the PLA with these areas marked).

L.4.79 In the event that such accretion is detected, the contractor would be required to develop a dredging plan with the PLA. The objective would be to dredge the channel and to return it back to the expected baseline river bed profile. A bathymetric survey after the dredging would be carried-out to confirm that the dredging operation has been successful.

Annex A Summary of suggested monitoring techniques matrix

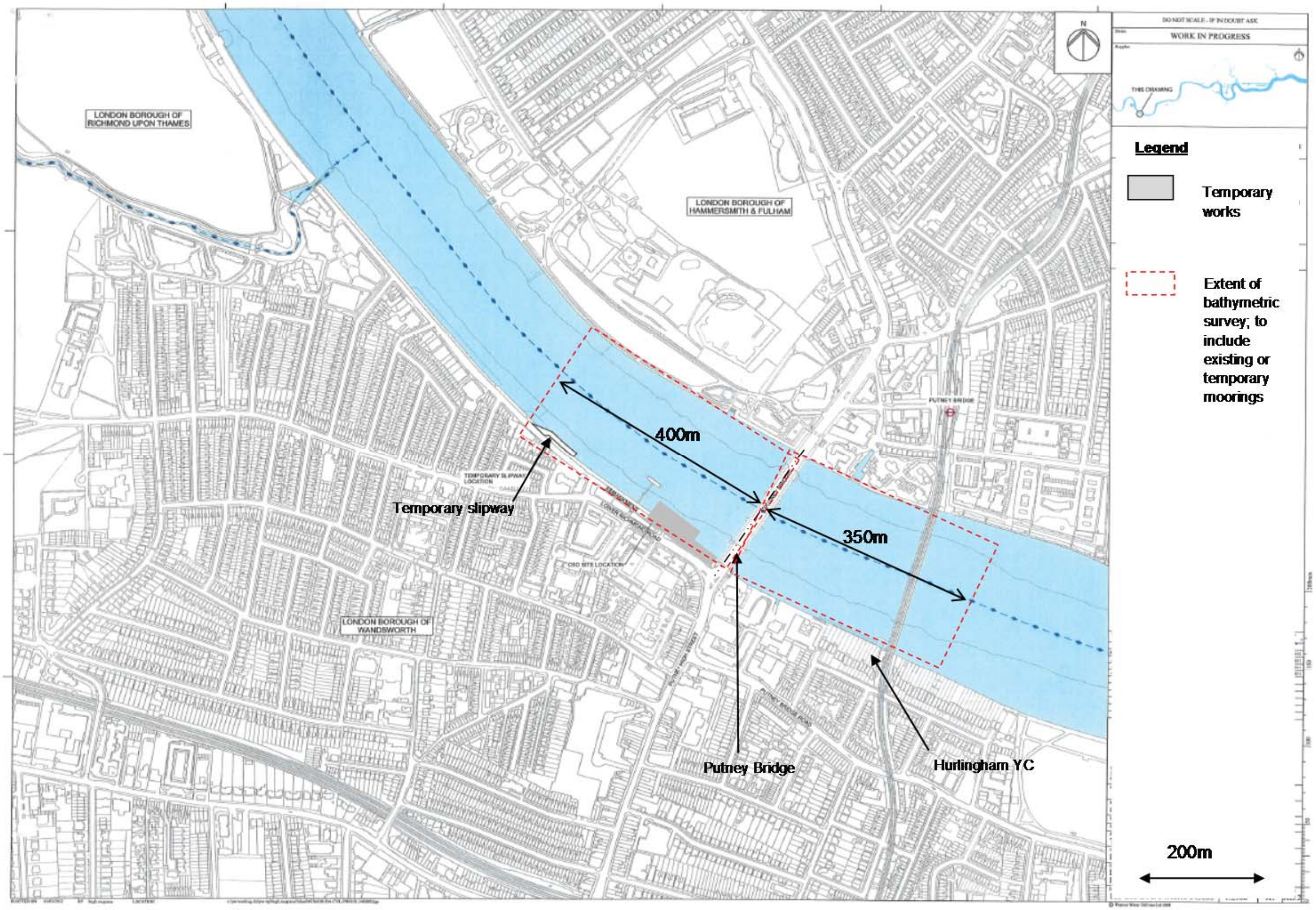
	Structure potentially affected by local scour			Area potentially affected by contraction scour	
Site	**Temporary works and abutments**	**River walls**	**Bridge piers and abutments**	**River walls and foreshore**	**River channel**
Putney Embankment and Putney Bridge	Land surveys / visual inspection / photographic recording	Land surveys / visual inspection / photographic recording	Bathymetry and Sonar	**Not applicable**	**Not applicable**
Chelsea Embankment and Chelsea Bridge	Land surveys / visual inspection / photographic recording	Land surveys / visual inspection / photographic recording	Bathymetry and Sonar	**Not applicable**	**Not applicable**
Heathwall and South West Storm Relief	Bathymetry and Land Survey	Bathymetry and Land Survey	**Not applicable**	**Not applicable**	**Not applicable**
Albert Embankment Interception and Vauxhall Bridge Albert Embankment Shaft	Land surveys / visual inspection / photographic recording	Land surveys / visual inspection / photographic recording	Bathymetry and Sonar	**Not applicable**	**Not applicable**
Victoria Embankment and Millennium Bridge, Hungerford Bridge	Bathymetry	Bathymetry	thymetry and Sor	**Not applicable**	**Not applicable**
Blackfriars and Blackfriars Bridge	Bathymetry	Bathymetry	thymetry and Sor	Bathymetry	Bathymetry
King Edward Memorial Park	Bathymetry	Bathymetry	**Not applicable**	Bathymetry	**Not applicable**
Carnwath Road	Bathymetry and Land Survey	Bathymetry and Land Survey	Bathymetry	Bathymetry and Land Survey	Bathymetry and land survey
Kirtling	Bathymetry	Bathymetry	**Not applicable**	**Not applicable**	**Not applicable**
Chambers Wharf	Bathymetry	Bathymetry	**Not applicable**	**Not applicable**	**Not applicable**

Notes:
1) For description of survey types see next sheet
2) Other forms of survey such as LiDAR and remotely controlled boats may be more appropriate near the river bank where there are existing jetties and piers.
3) The Contractor can select alternative survey techniques provided the data obtained is equivalent to that obtained with the suggested monitoring and survey methods.
4) 'Not applicable' when predicted contraction scour is less than 0.1 or there is no bridge

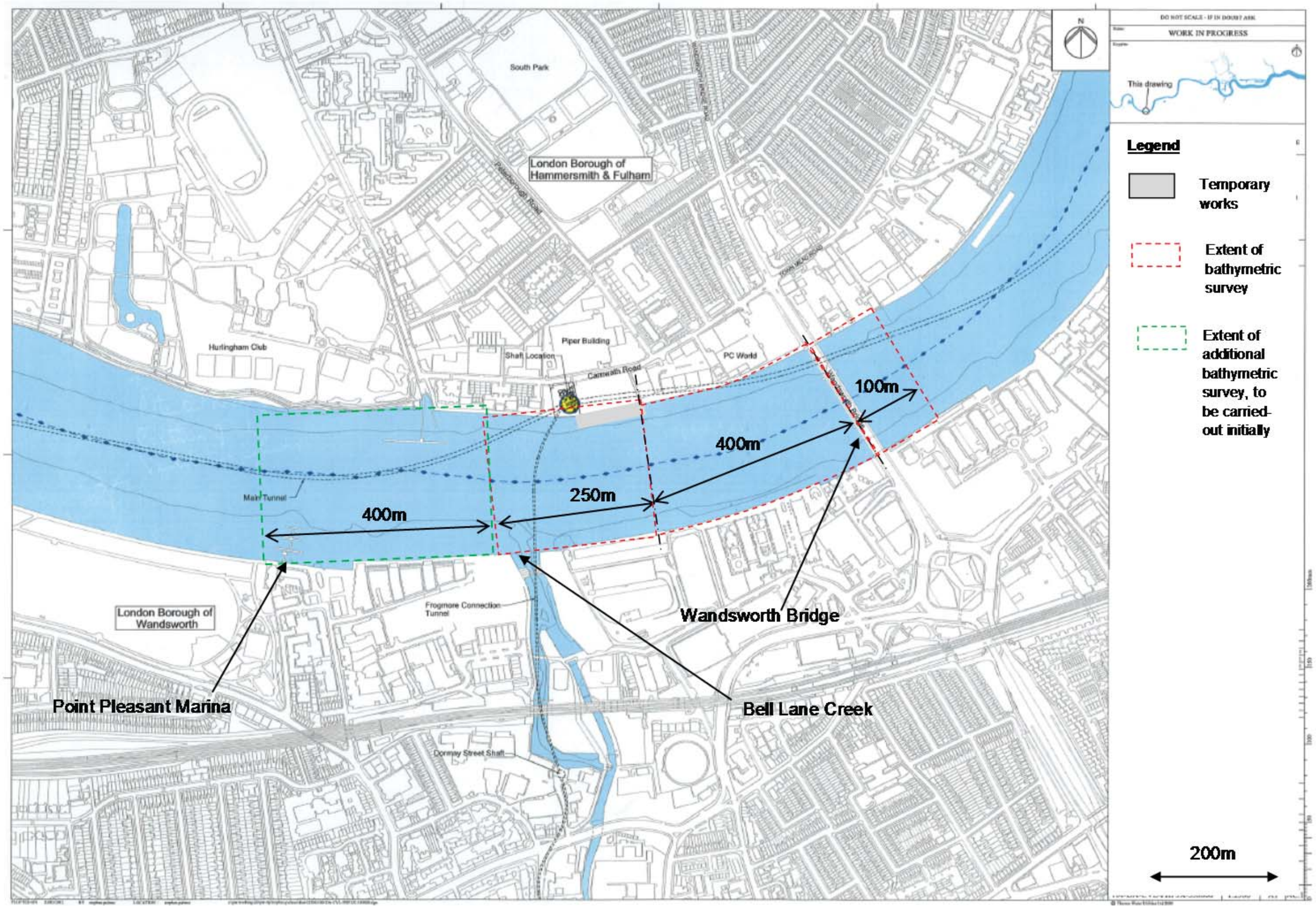
Survey Type	Description	Advantages	Limitations
Bathymetry with multibeam sonar	Rotating high resolution sonar for mapping bathymetry. Transducer can be suspended, mounted on a boat or fixed.	Provides high definition images. Can be used in high water velocities and equipped with GPS for mapping.	Stable deployment vessels required or instrumentation to correct for ships pitch and roll.
Land Surveys with range-azimuth systems	Range-azimuth systems operate similarly to survey total stations by combining an electronic distance meter (EDM) with a theodolite to document the change in channel morphology.	Can measure with high accuracy up to 10,000m with a frequency 2-10 times per second.	Initial cost
Visual Inspection-photographic recording	The data from land survey should be backed up by visual inspection and photographic records of the foreshore or structures where above the low water line.		
LiDAR	Information detected from a plane, boat, vehicle and tripod.	Very quick acquisition of large amount of data. Good accuracy and repeatability.	Careful ground truthing required. Reduced coverage under bridges or jetties. At best when used
Remotely Controlled	Unmanned vessel used to deploy instrument for bridge inspection (eg, scour depth)	Unmanned, so no persons could be injured during a storm event.	Pitch, roll and capsizing must all be monitored and knowledgeable operator must be used.

Annex B Spatial scope of bathymetric survey

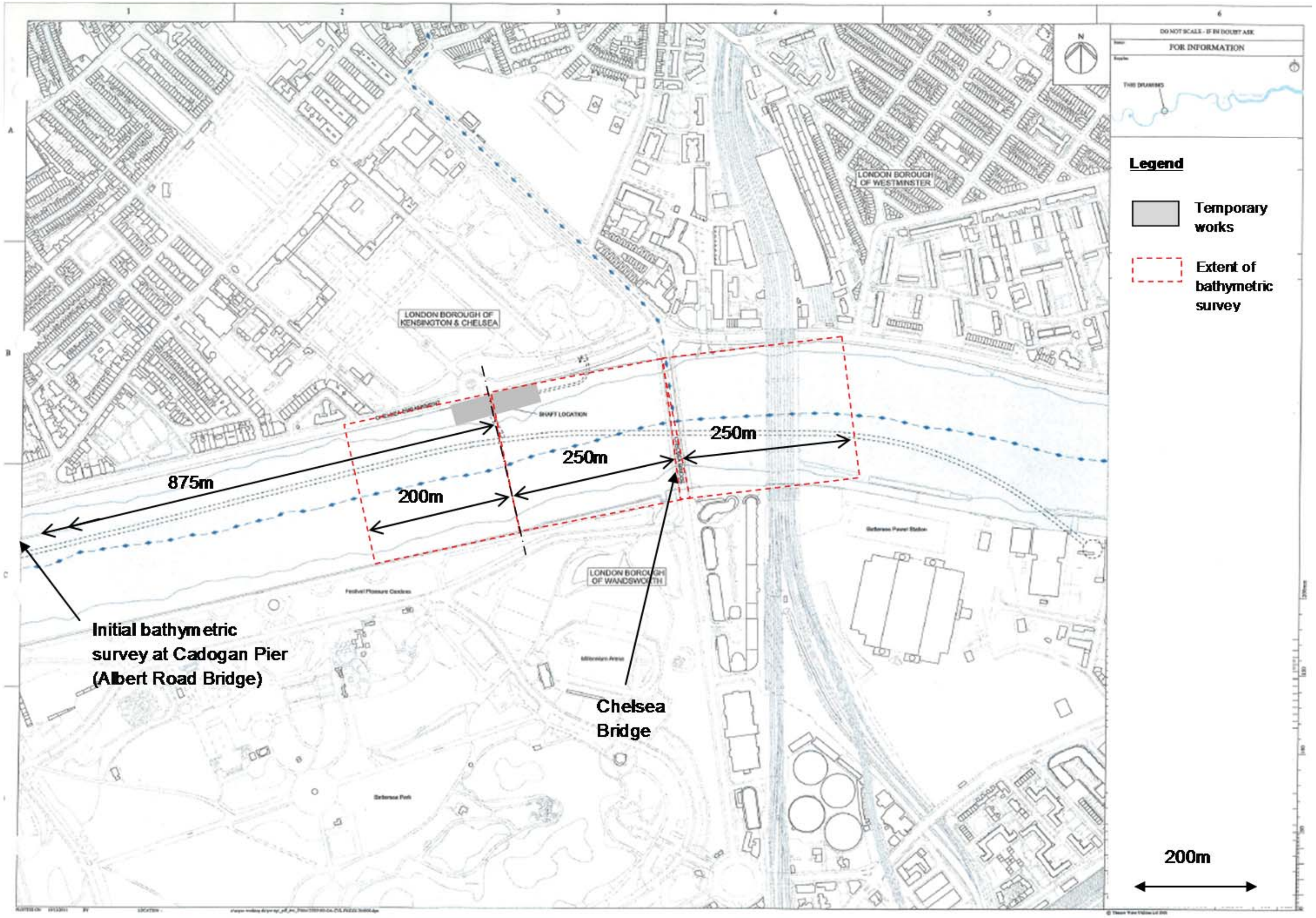
Vol 3 Plate L.1 Putney Embankment Foreshore – extent of bathymetric survey



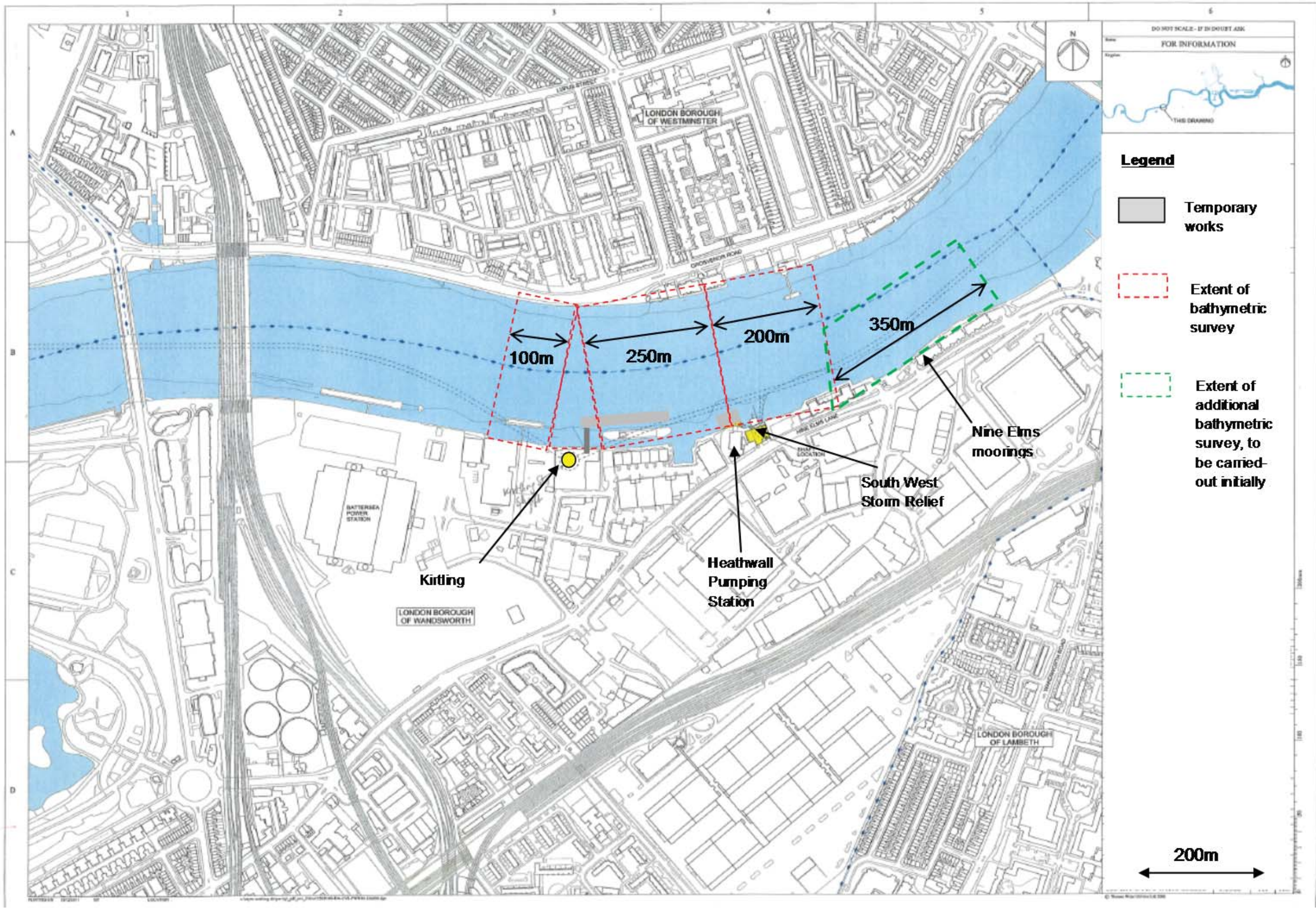
Vol 3 Plate L.2 Carnwath Road Riverside – extent of bathymetric survey



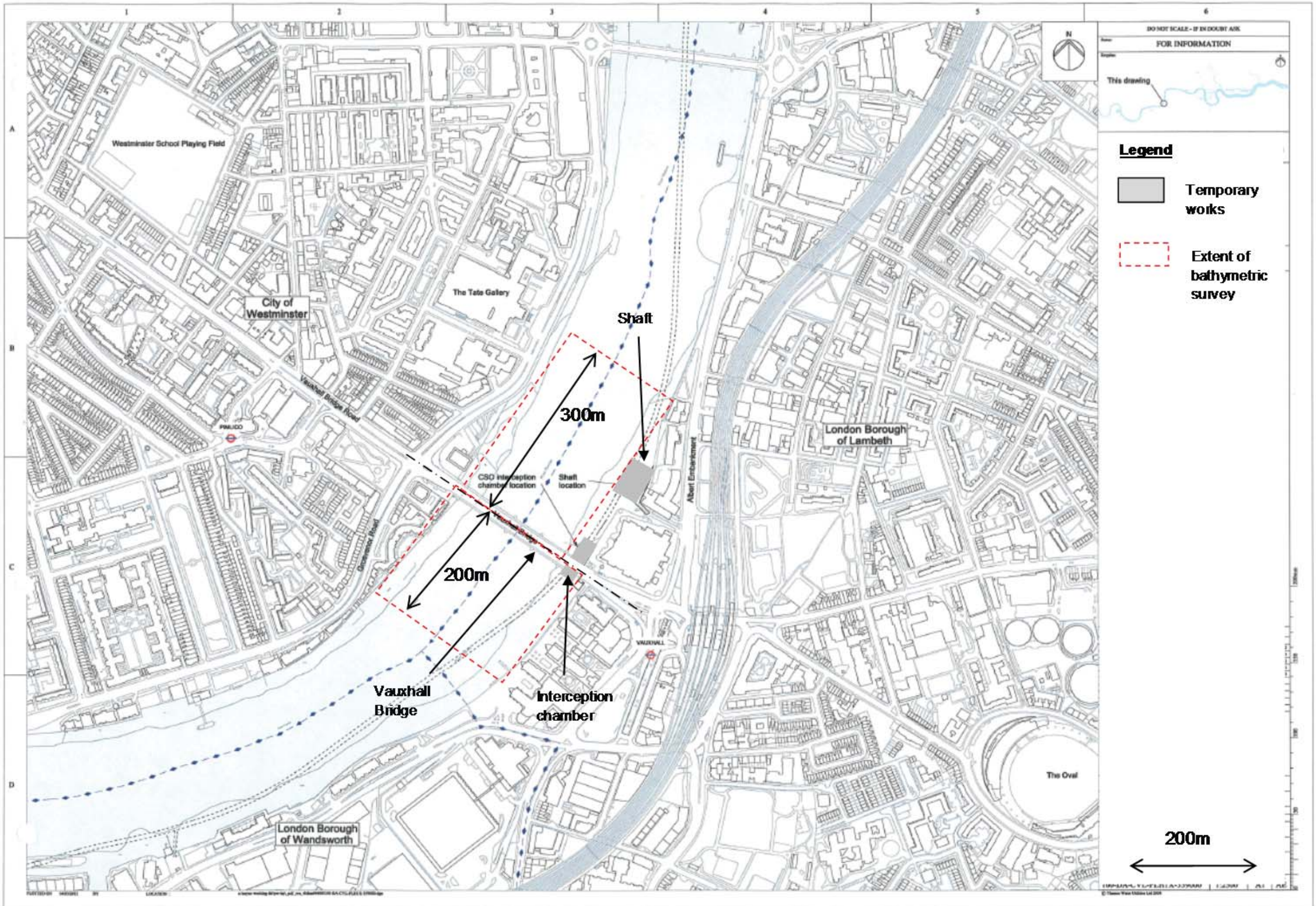
Vol 3 Plate L.3 Chelsea Embankment Foreshore – extent of bathymetric survey



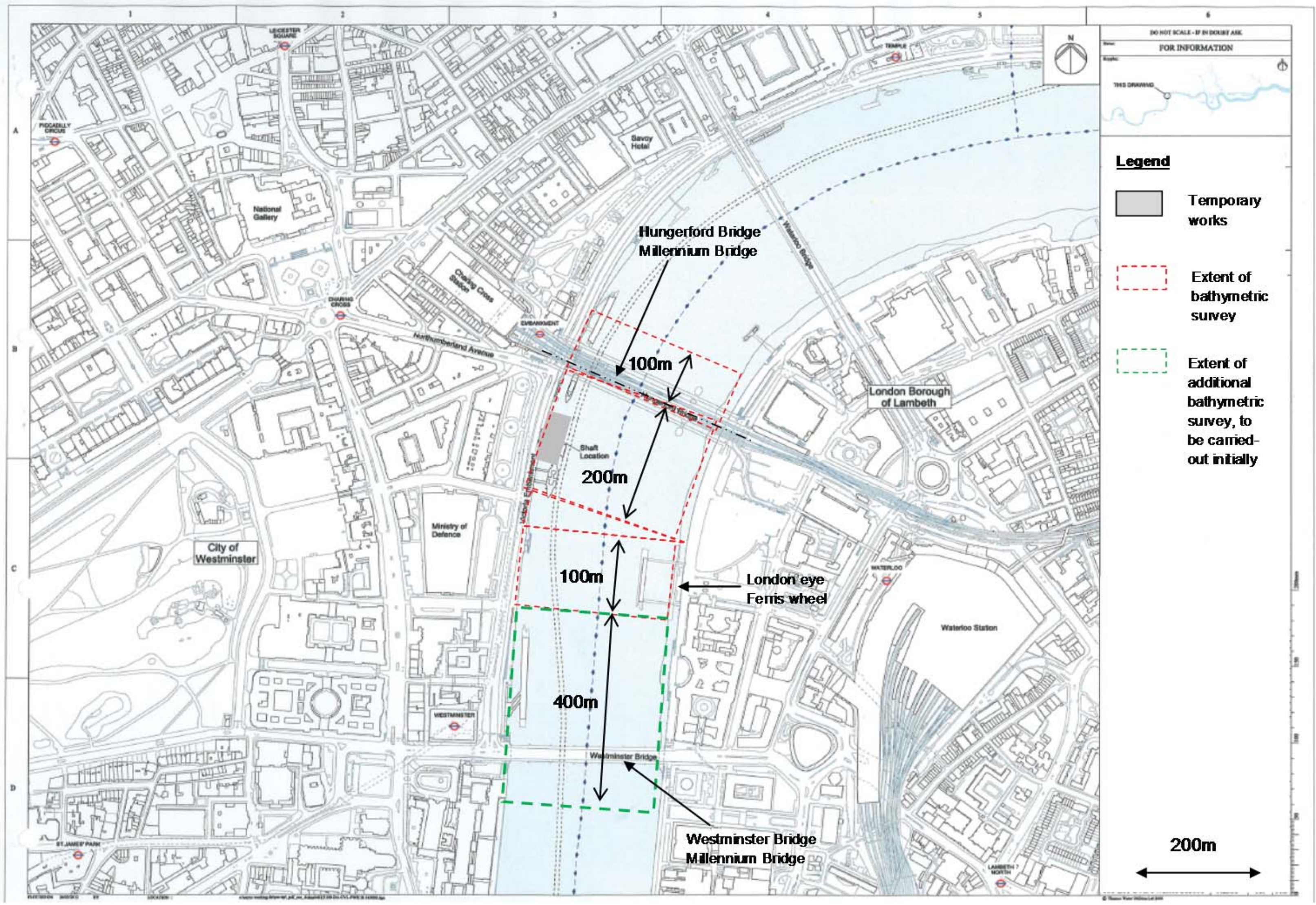
Vol 3 Plate L.4 Kirtling Street and Heathwall Pumping Station – extent of bathymetric survey



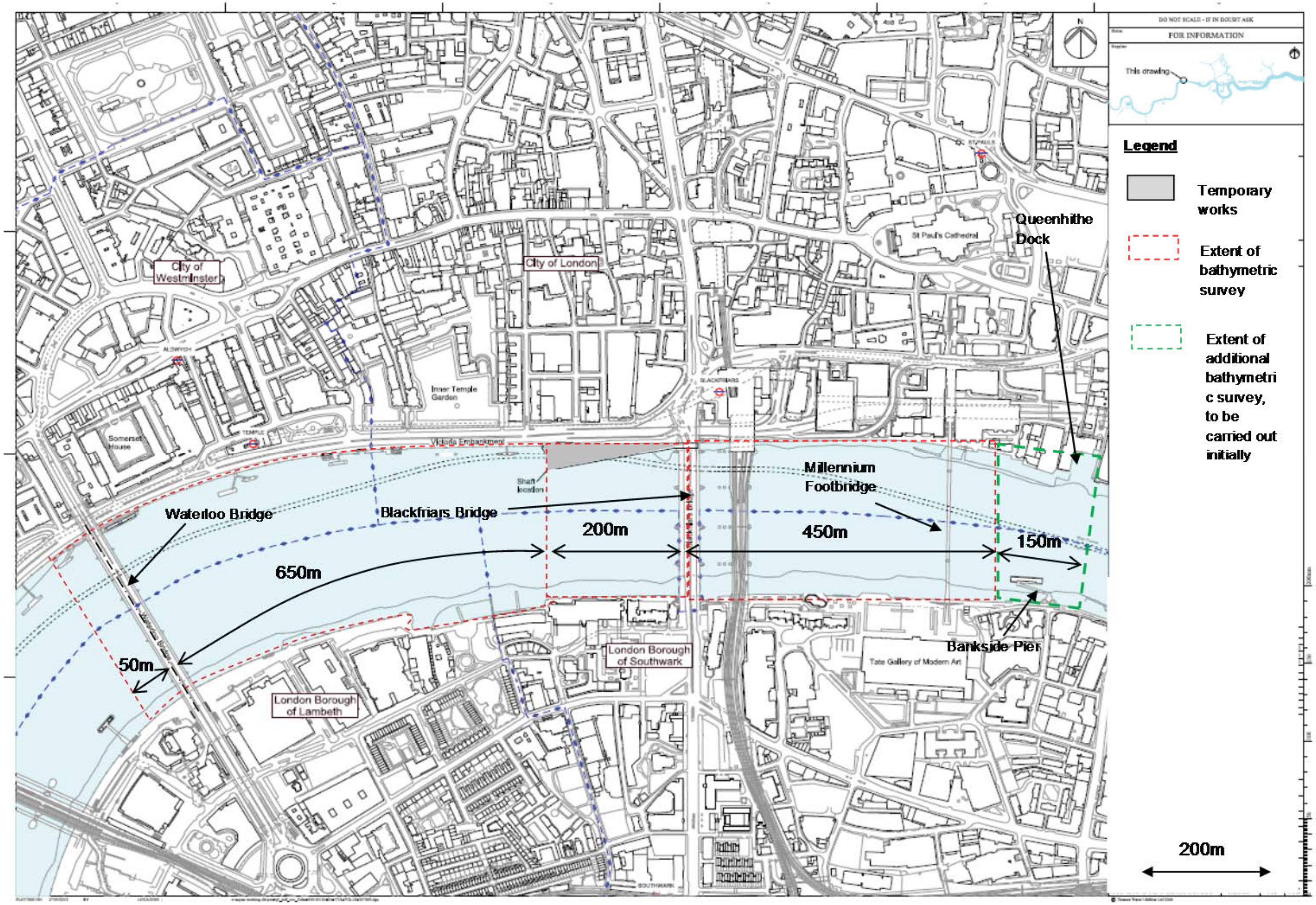
Vol 3 Plate L.5 Albert Embankment Foreshore – extent of bathymetric survey



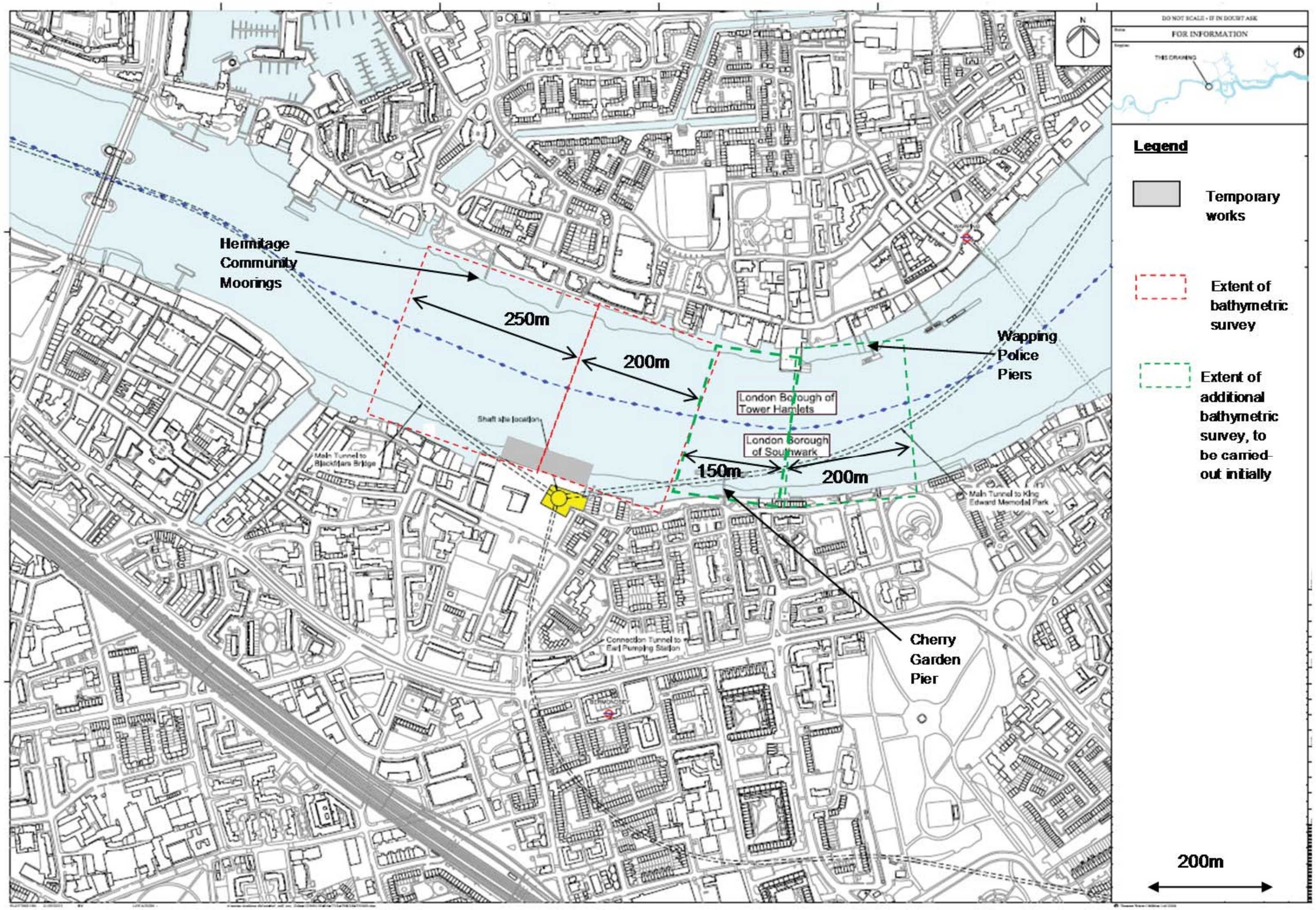
Vol 3 Plate L.6 Victoria Embankment Foreshore – extent of bathymetric survey



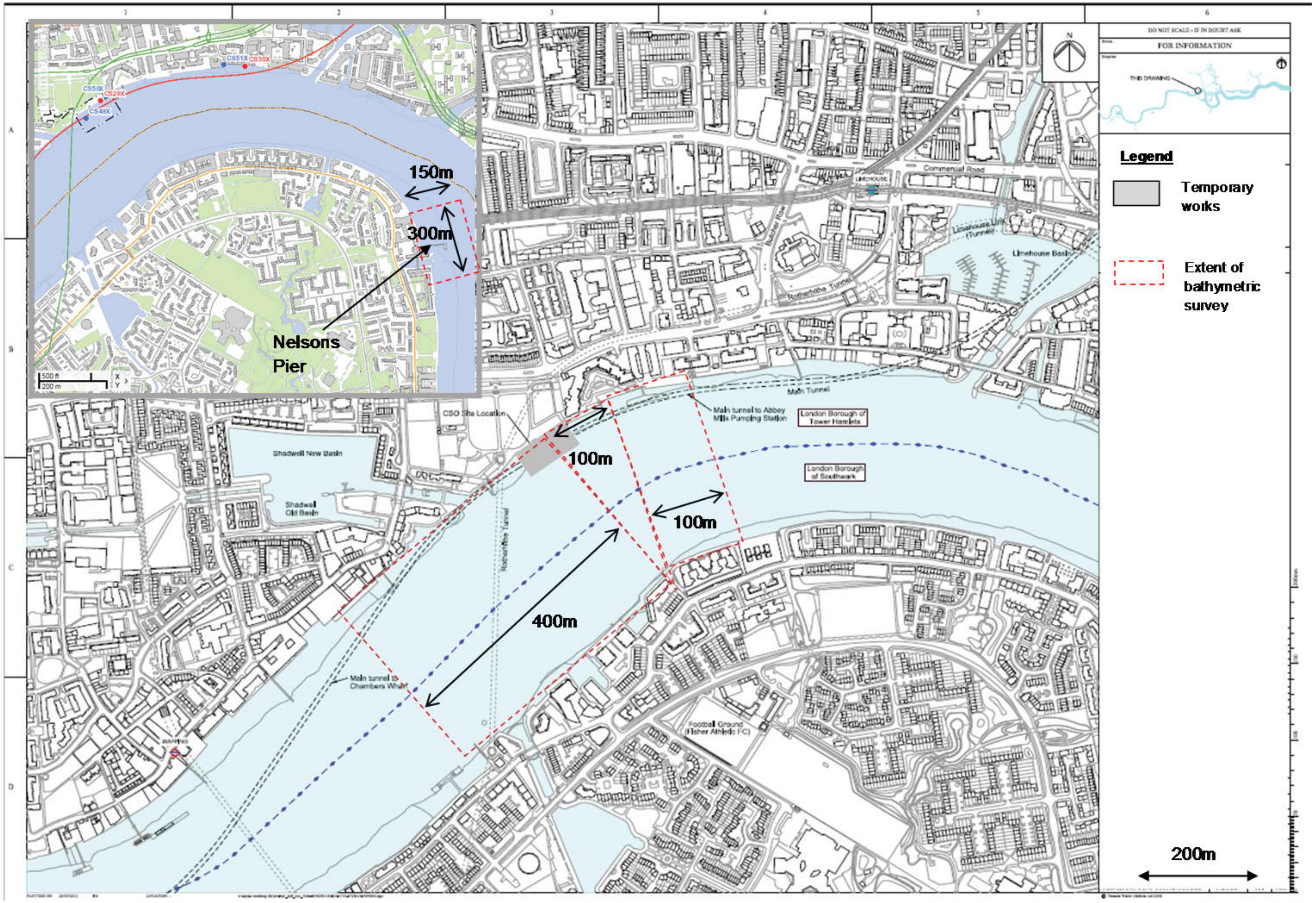
Vol 3 Plate L.7 Blackfriars Bridge Foreshore – extent of bathymetric survey



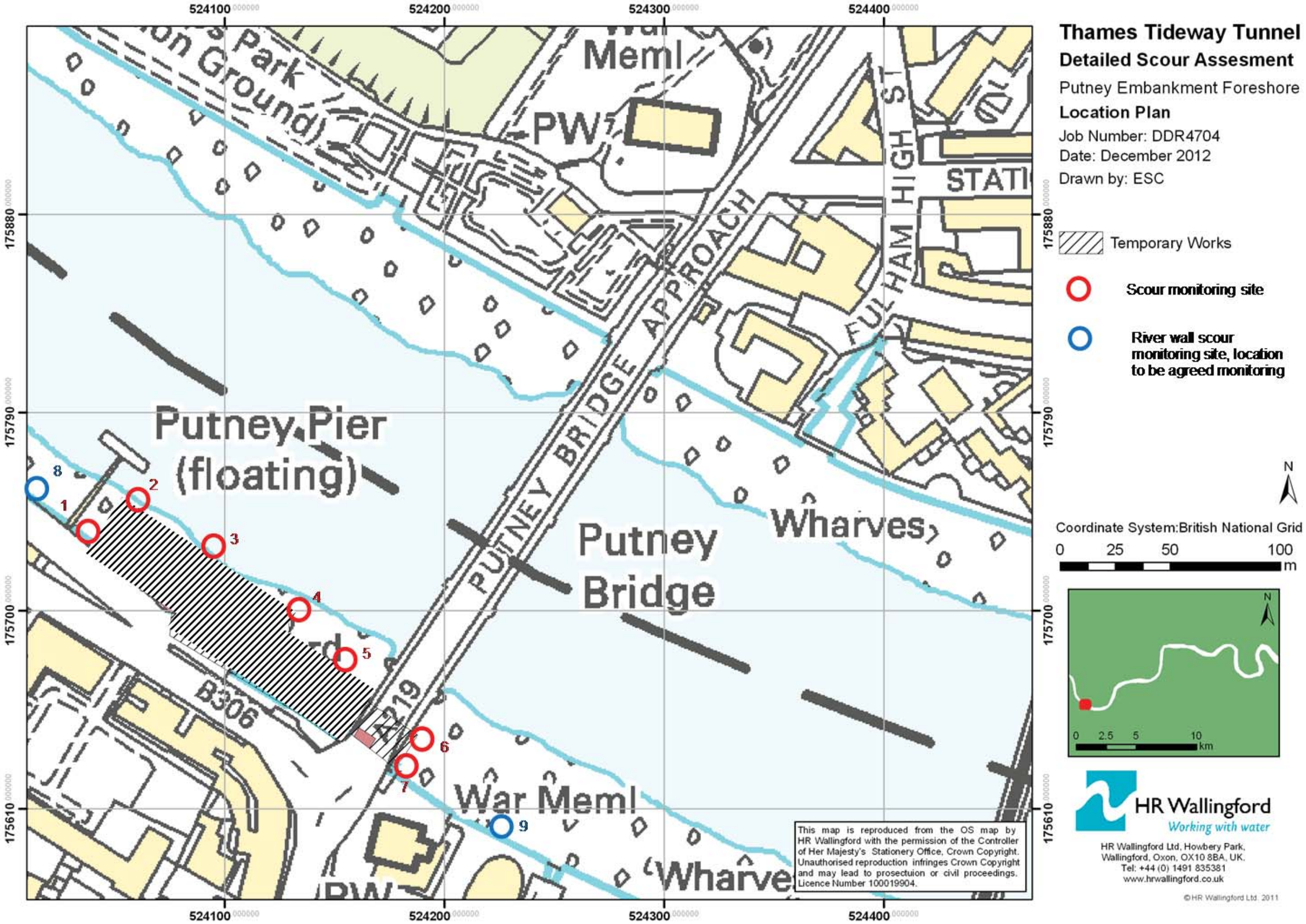
Vol 3 Plate L.8 Chambers Wharf – extent of bathymetric survey



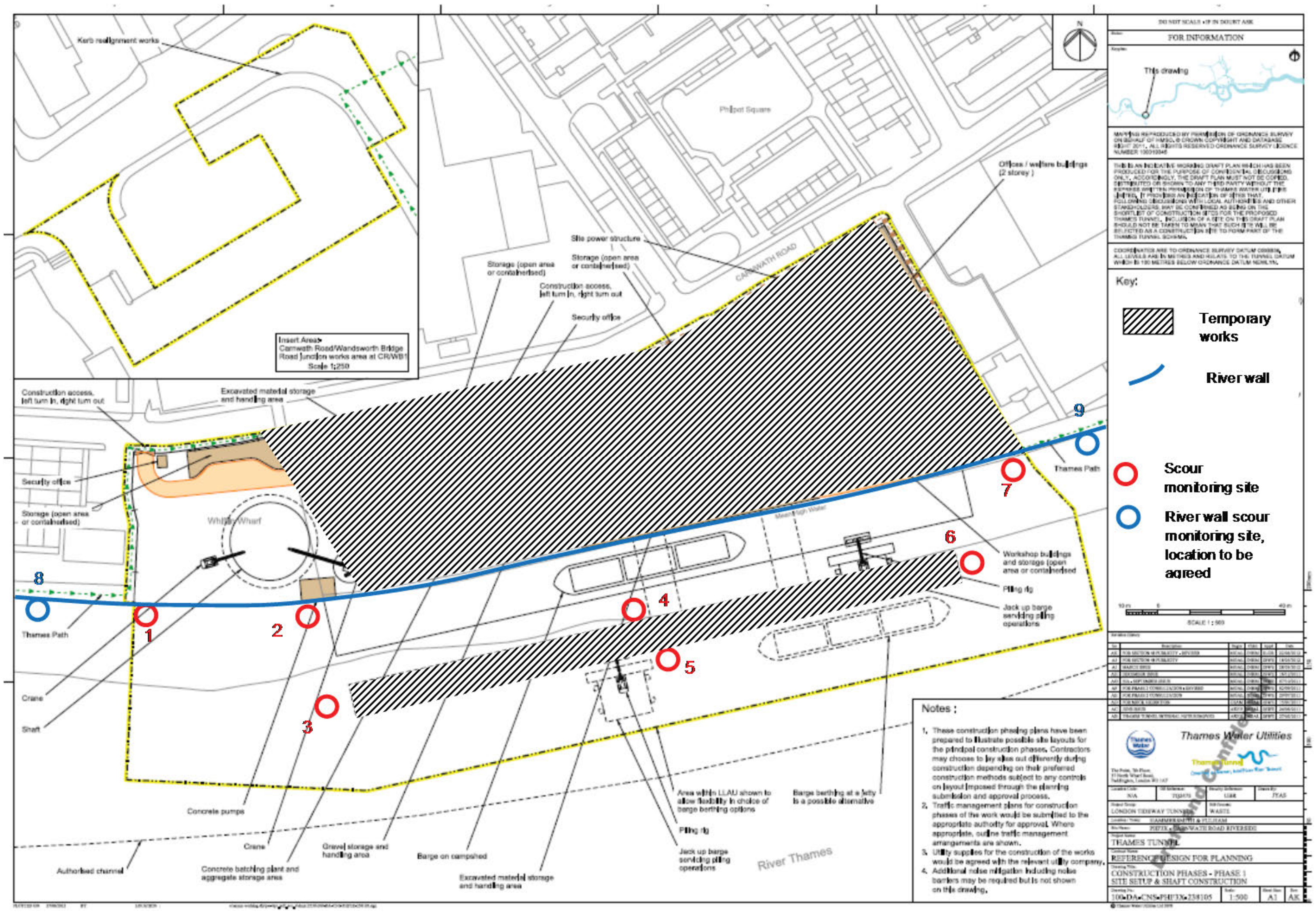
Vol 3 Plate L.9 King Edward Memorial Park Foreshore– extent of bathymetric survey



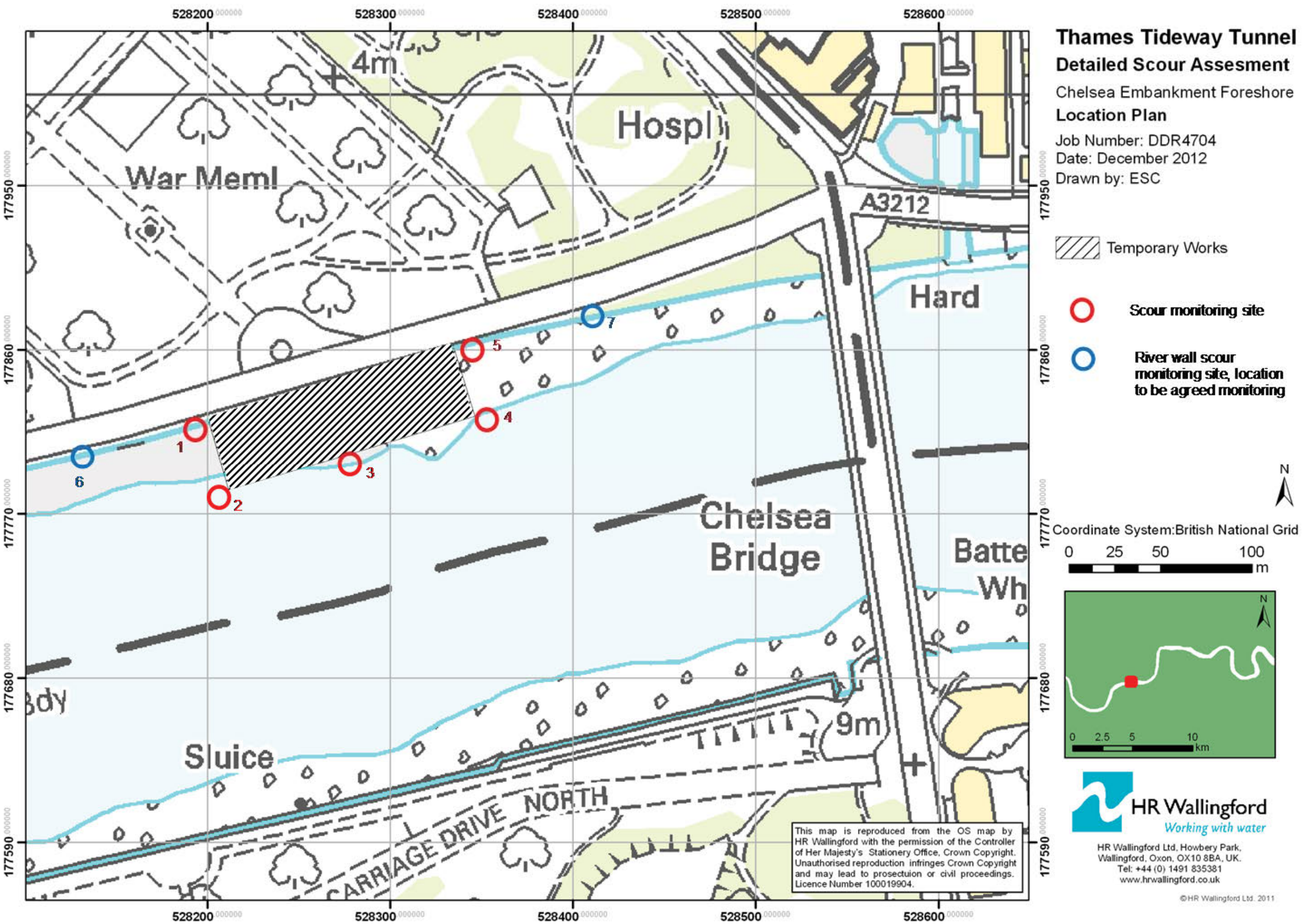
Vol 3 Plate L.10 Putney Embankment Foreshore – scour monitoring locations



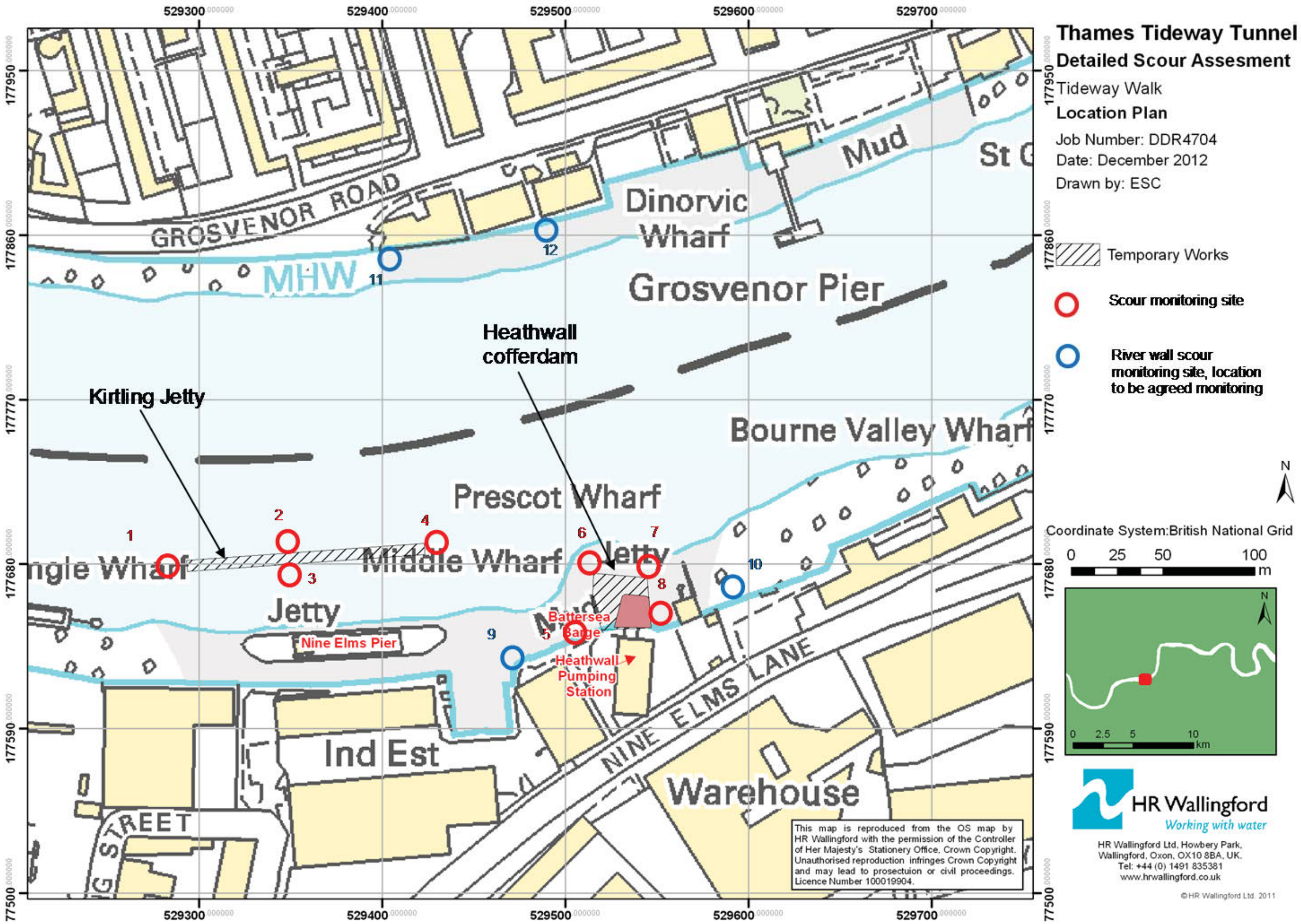
Vol 3 Plate L.11 Carnwath Road Riverside – scour monitoring locations



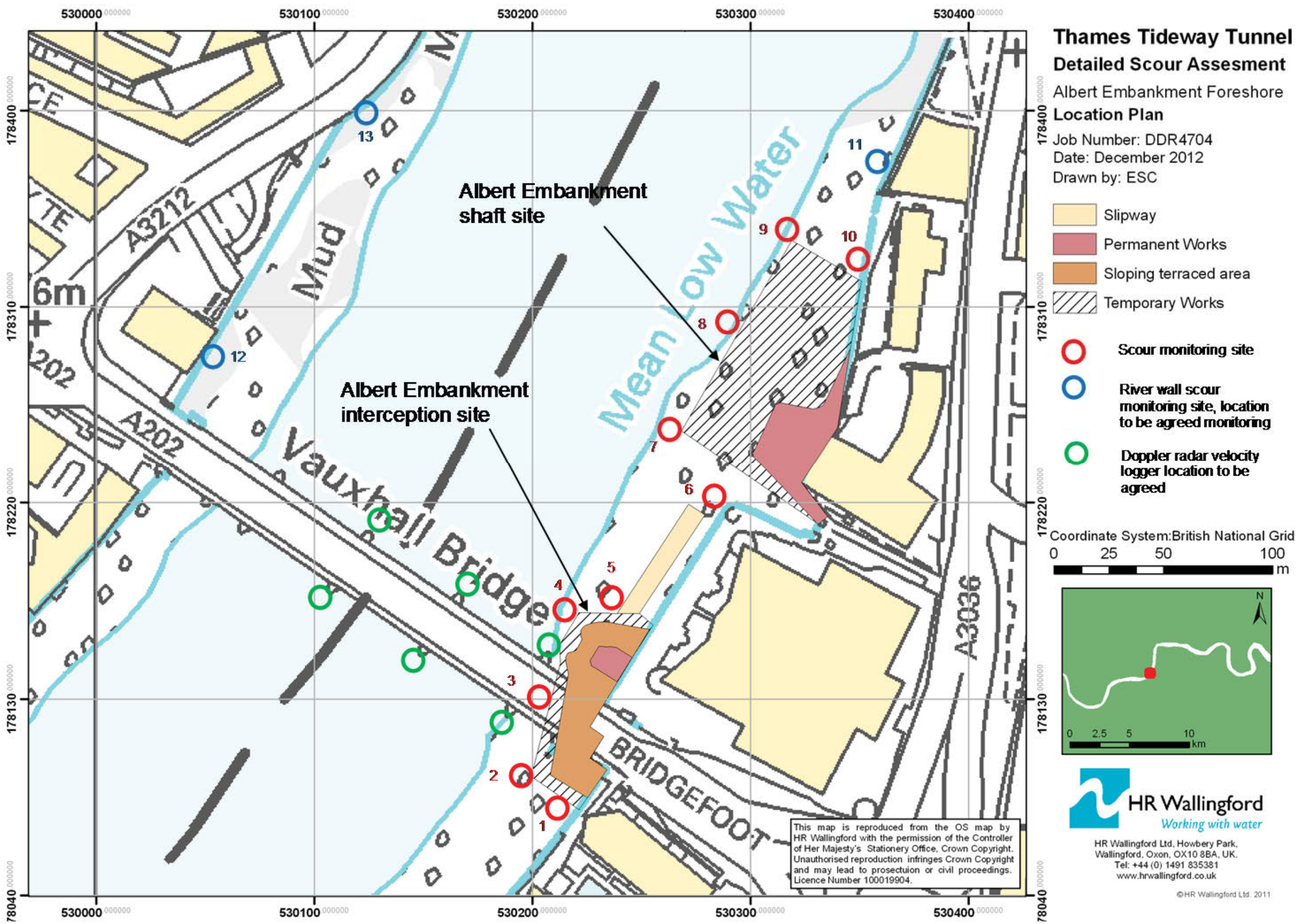
Vol 3 Plate L.12 Chelsea Embankment Foreshore – scour monitoring locations



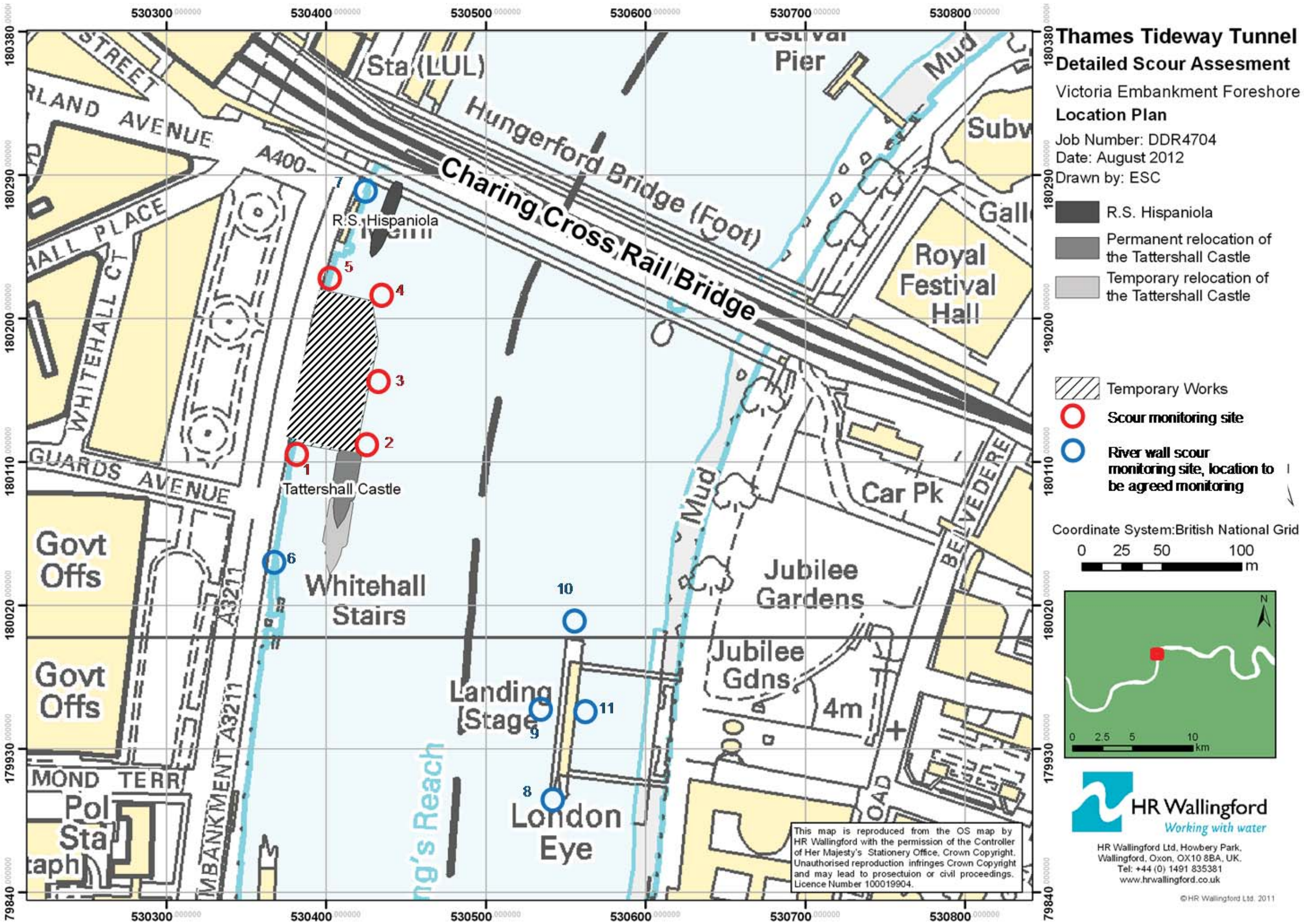
Vol 3 Plate L.13 Kirtling Street, Heathwall Pumping Station and South West Storm Relief –scour monitoring locations



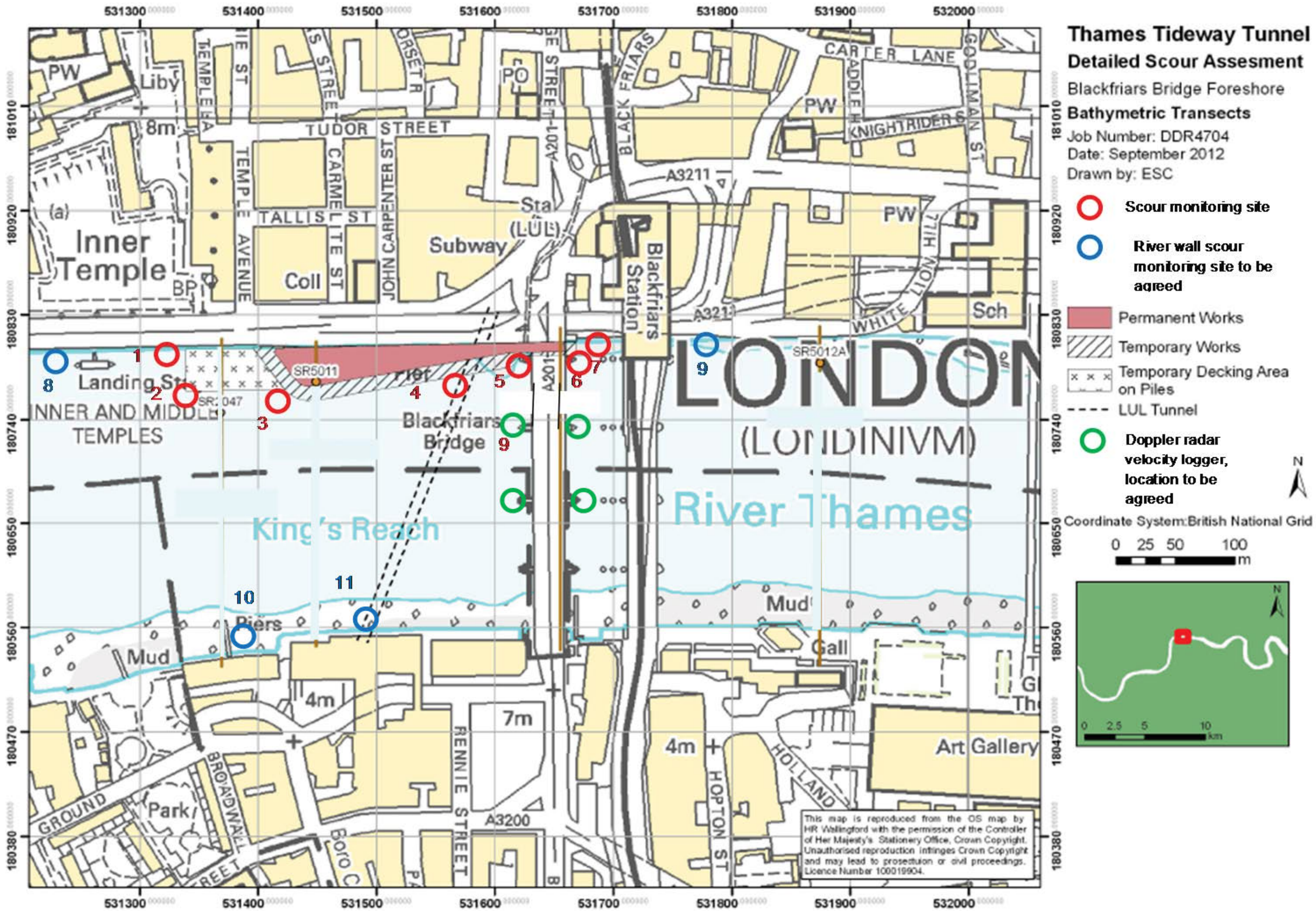
Vol 3 Plate L.14 Albert Embankment Foreshore – scour monitoring locations



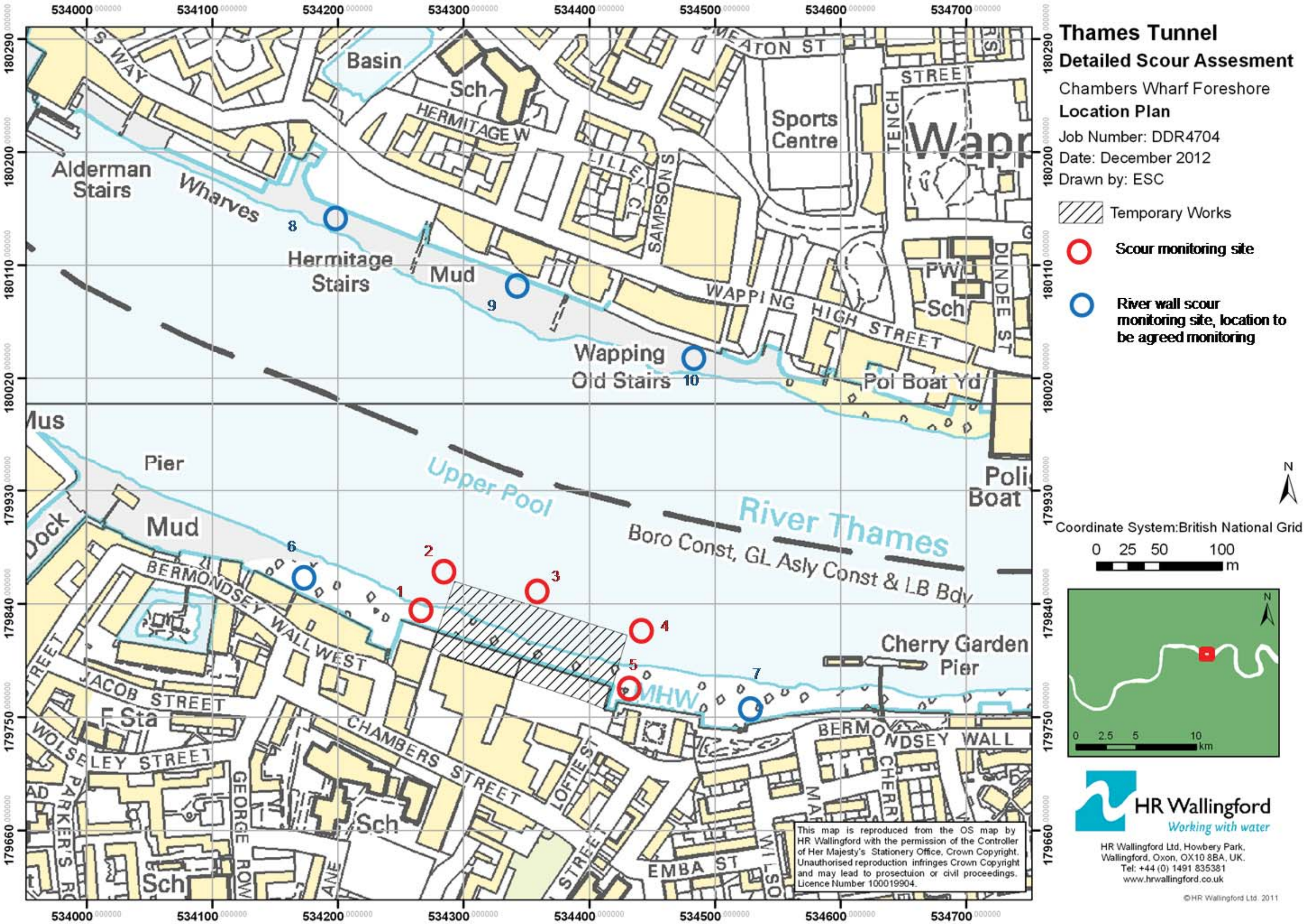
Vol 3 Plate L.15 Victoria Embankment Foreshore – scour monitoring locations



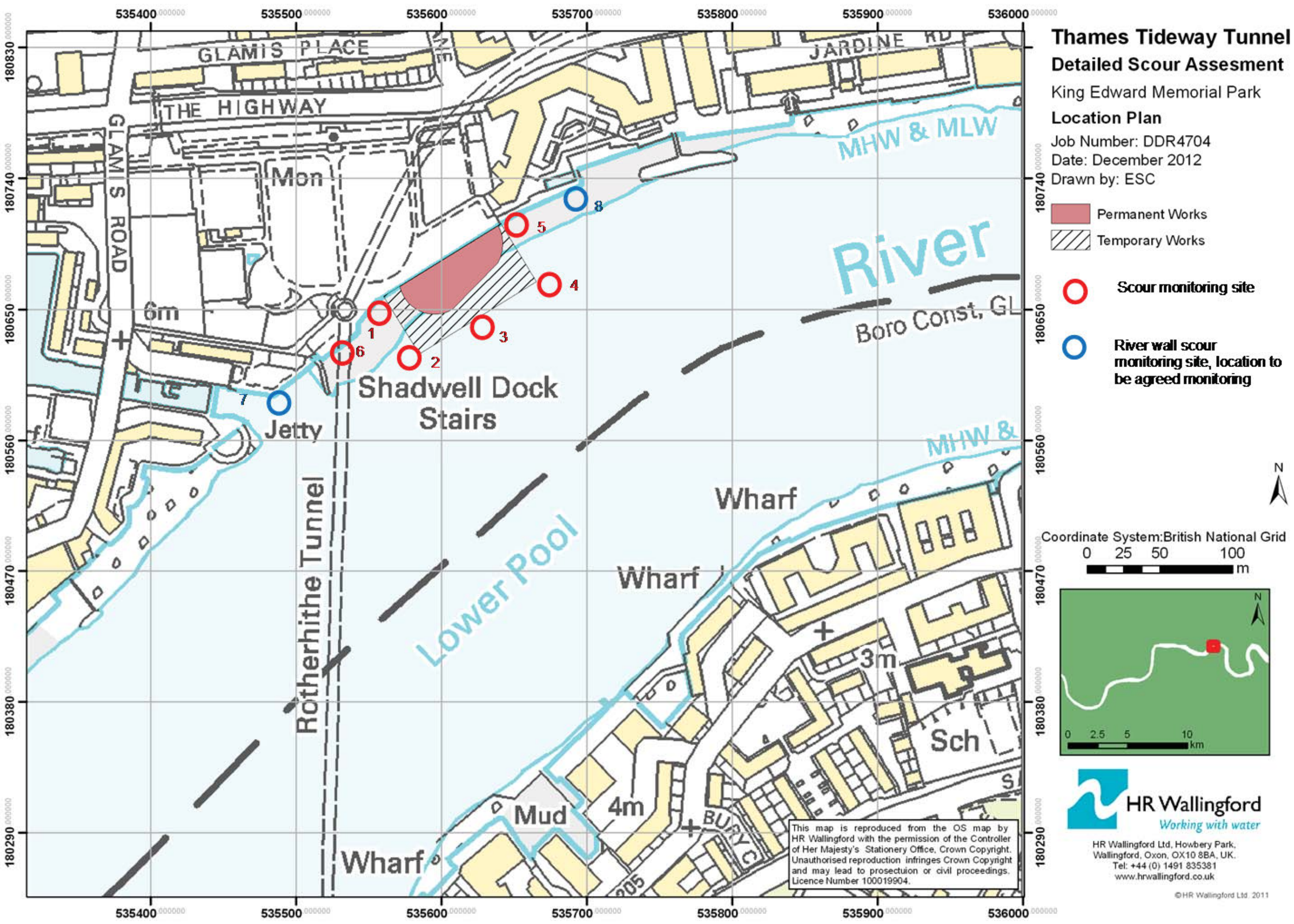
Vol 3 Plate L.16 Blackfriars Bridge Foreshore – scour monitoring locations



Vol 3 Plate L.17 Chambers Wharf – scour monitoring locations



Vol 3 Plate L.18 King Edward Memorial Park Foreshore – scour monitoring locations



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Annex C Summary of suggested monitoring parameters and trigger levels

Scour due to temporary works - Summary of Suggested Monitoring Parameters & Trigger Levels - River Walls

	River wall information						Scour information					Trigger levels	
Site	River Wall ID	Type of wall	Wall age	Condition of the river wall [1] (from EA database info)	Presence of existing armour	Vulnerability of the river wall to foreshore scour (independent of adjacent bed sediments)	Degree of predicted scour (m)	Sensitivity of estimated scour	Foreshore soil type	Rate of scour	Scour Risk Factor	Time to react	Trigger levels (m) for immediate action
Putney Embankment Foreshore	RW871-RW879, RW865, RW887, RW237 and RW554	Mass Gravity	TBC	2-3	TBC	TBC	< 0.1	medium	gravel	mid	3	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Chelsea Embankment Foreshore	RW137,RW365 and RW418	Mass Gravity	TBC	2	TBC	TBC	< 0.1	medium	gravel	mid	3	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Heathwall and South West Storm Relief	RW107,RW109,RW119,RW129,RW139,RW142,RW206 and RW557	Mass Gravity/Sheet Pile /Concrete Pile	TBC	2-3	TBC	TBC	< 0.1	high	gravel	mid	4	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Albert Embankment Foreshore	RW199-204,RW455,RW456,RW569,RW458 and RW599-601	Mass Gravity/Sheet Pile	TBC	2-3	TBC	TBC	< 0.1	medium	gravel	mid	3	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Victoria Embankment Foreshore	RW110	Mass Gravity	TBC	3	TBC	TBC	< 0.1	low	mud	low	1	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Blackfriars Bridge Foreshore	RW141, RW135,RW136 and RW413	Mass Gravity	TBC	2-3	TBC	TBC	0.5	high	gravel	mid	9	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
King Edward Memorial Parkn Foreshore	RW331-332,RW359,and RW406-407	Mass Gravity/Concrete Pile	TBC	2-3	TBC	TBC	0.5	high	mud	low	8	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Carnwath Road Riverside	RW922-926	Mass Gravity/Sheet Pile	TBC	2-3	TBC	TBC	< 0.1	medium	mixed	low	2	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Kirtling Street	RW205,RW460,RW523,and RW768	Mass Gravity/Sheet Pile	TBC	2-3	TBC	TBC	< 0.1	high	mud	low	3	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Chambers Wharf	RW653-661	Mass Gravity/Sheet Pile	TBC	2-3	TBC	TBC	< 0.1	low	mixed	low	1	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors

Based on variability in sediment samples and presence of layering in the bed shown by CPT. Also uncertainty associated with amount of data

Risk factor (1-10): 1 =low scour,low sensitivity, low rate, 10 = high scour,high sensitivity,high rate

Notes:
1) 1=very good, 2=good, 3=fair, 4=poor and 5=very poor
2) Columns shaded pink to be filled based upon river wall assessments.

Scour due to temporary works - Summary of Suggested Monitoring Parameters & Trigger Levels - Bridge Piers & Abutments

	Structure information				Scour Information					Trigger levels	
Site	Type of structure	Condition of the existing structure	Presence of existing armour	Vulnerability of the structure to foreshore scour (independent of adjacent bed sediments)	Degree of baseline scour (m)	Sensitivity of estimated scour	Foreshore soil type	Rate of scour	Scour Risk Factor	Time to react	Trigger levels (m) for immediate action
Putney Embankment Foreshore	Putney Bridge	TBC	TBC	TBC	2	medium	gravel	mid	8	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Chelsea Embankment Foreshore	Chelsea Bridge	TBC	TBC	TBC	2	medium	gravel	mid	8	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Albert Embankment Foreshore	Vauxhall Bridge	TBC	TBC	TBC	2	medium	gravel	mid	8	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Victoria Embankment Foreshore	Westminster Bridge	TBC	TBC	TBC	0.5	low	mud	low	2	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
	Hungerford Bridge	TBC	TBC	TBC	0.5	low	mud	low	2	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
	Golden Jubilee Footbridge	TBC	TBC	TBC	0.5	low	mud	low	2	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Blackfriars Bridge Foreshore	Millennium Footbridge	TBC	TBC	TBC	< 0.1	high	gravel	mid	4	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
	Blackfriars Rail Bridge	TBC	TBC	TBC	< 0.1	high	gravel	mid	4	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
	Blackfriars Road Bridge	TBC	TBC	TBC	< 0.1	high	gravel	mid	4	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors

Sensitivity of estimated scour: Based on variability in sediment samples and presence of layering in the bed shown by CPT. Also uncertainty associated with amount of data

Scour Risk Factor: Risk factor (1-10): 1 =low scour,low sensitivity, low rate, 10 = high scour,high sensitivity,high rate

1) Columns shaded pink to be filled based upon bridge assessments.

Scour due to temporary works - Summary of Suggested Monitoring Parameters & Trigger Levels - Temporary Works Abutments

	Structure information			Scour information					Trigger levels	
Site	Structure	Construction method	Vulnerability of the temp structure to foreshore scour (independent of adjacent bed sediments)	Degree of predicted scour (m)	Sensitivity of estimated scour	Foreshore soil type	Rate of scour	Scour Risk Factor	Time to react	Trigger levels (m) for immediate action
Putney Embankment Foreshore	Cofferdam	TBC	TBC	2.5	medium	gravel	mid	7	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Chelsea Embankment Foreshore	Cofferdam	TBC	TBC	2.8	medium	gravel	mid	8	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Heathwall and South West Storm Relief	Cofferdam	TBC	TBC	2.7	high	gravel	mid	8	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Albert Embankment Foreshore	Cofferdam	TBC	TBC	1	medium	gravel	mid	4	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Victoria Embankment Foreshore	Cofferdam	TBC	TBC	0.3	low	mud	low	1	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Blackfriars Bridge Foreshore	Cofferdam	TBC	TBC	0.5	high	gravel	mid	4	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
King Edward Memorial Park Foreshore	Cofferdam	TBC	TBC	1.5	high	mud	low	5	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Carnwath Road Riverside	Jetty	TBC	TBC	1.3	medium	mixed	low	4	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Kirtling Street	Jetty	TBC	TBC	0.5	high	mud	low	3	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors
Chambers Wharf	Cofferdam	TBC	TBC	1	low	mixed	low	2	TBC based on combination of vulnerability and scour risk factors	TBC based on combination of vulnerability and scour risk factors

Sensitivity of estimated scour: Based on variability in sediment samples and presence of layering in the bed shown by CPT. Also uncertainty associated with amount of data

Scour Risk Factor: Risk factor (1-10): 1 =low scour,low sensitivity, low rate, 10 = high scour,high sensitivity,high rate

1) Suggested summary to be reviewed and updated by the contractor when extent of temporary works confirmed.

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Annex D Summary of suggested mitigation measures

Scour due to temporary works - Summary of Suggested Mitigation Measures Matrix

	Structure potentially affected by local scour			Structure potentially affected by contraction scour [1]	
Site	**Temporary works and abutments**	**River walls**	**Bridge piers and abutments**	**River walls**	**Bridge piers and abutments**
Putney Embankment Foreshore and Putney Bridge	Riprap 1	Riprap 1	Riprap 3	Not applicable	Not applicable
Chelsea Embankment Foreshore and Chelsea Bridge	Riprap 2	Riprap 2	Riprap 3	Not applicable	Not applicable
Heathwall Pumping Station and South West Storm Relief	Riprap 2	Riprap 2	Not applicable	Not applicable	Not applicable
Albert Embankment Foreshore and Vauxhall Bridge	Riprap 1	Riprap 1	Riprap 3	Not applicable	Not applicable
Victoria Embankment and Millennium Bridge, Hungerford Bridge	Riprap 2	Riprap 2	Riprap 3	Not applicable	Not applicable
Blackfriars Bridge Foreshore and Blackfriars Bridge	Riprap 1	Riprap 1	Riprap 3	Riprap 1	Riprap 1
King Edward Memorial Park Foreshore	Riprap 1	Riprap 1	Not applicable	Riprap 1	Not applicable
Carnwath Road Riverside	Riprap 1	Riprap 1	Riprap 2	Not applicable	Not applicable
Kirtling Street	Riprap 2	Riprap 2	Not applicable	Not applicable	Not applicable
Chambers Wharf	Riprap 1	Riprap 1	Not applicable	Not applicable	Not applicable

Notes:

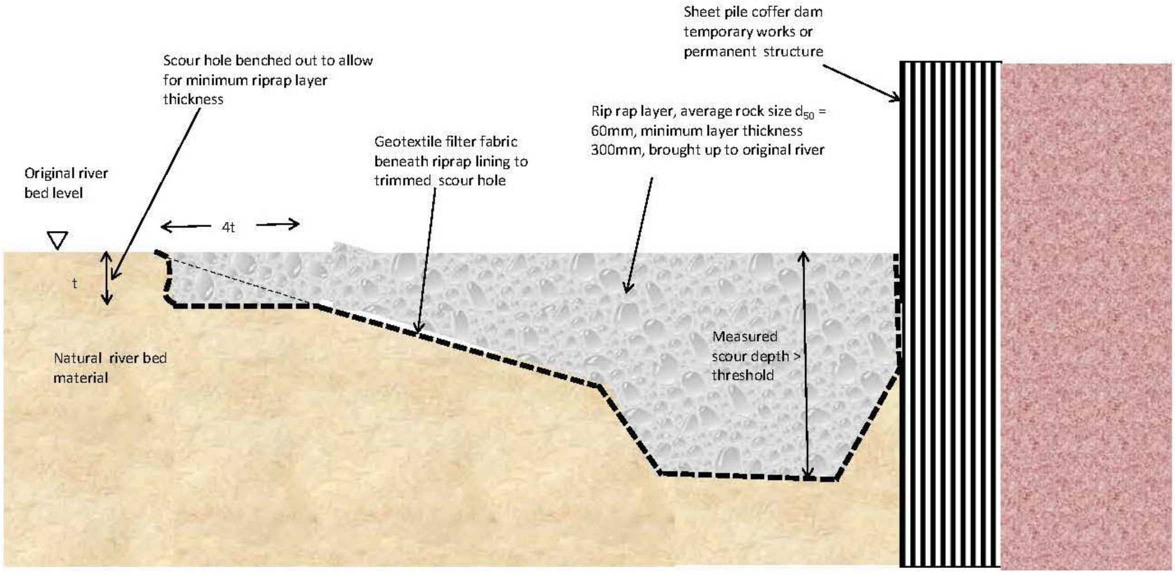
1)Contraction scour is predicted at Blackfriars and King Edward Memorial Park only

2)The contractor may decide to vary the mitigation measures depending upon availability and the size and speed of scour development.

3) Table continues on next page.

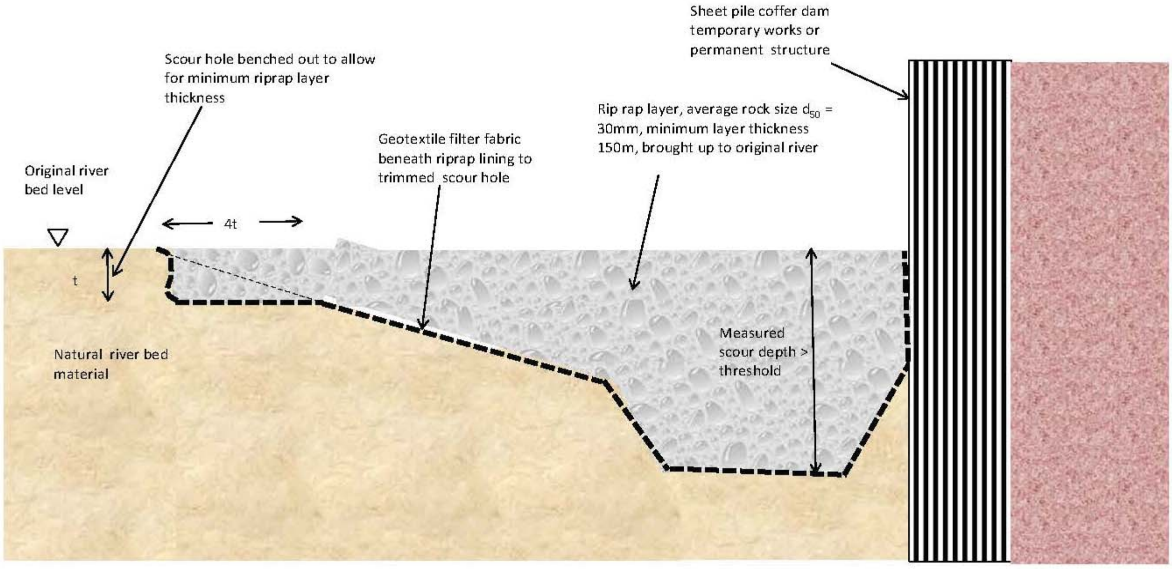
Decision parameters						
Foreshore soil type	Scour depth at temporary works (m)	Maximum design current used for the assessment (m/s)	Upper end of envelope of observed sediment found at site		Variability present in bed sampling Range of D50 observed(mm)	Layers observed in CPT / boreholes with potential to increase scour
			D50 (mm)	D85 (mm)		
gravel	2.5	1	60	80	Y, 4-60	N
gravel	2.8	1.3	30	60	Y, 7-30	N
gravel	2.7	1	13	28	Little data	Y
gravel	1	1.2	70	90	Y, 5-70	N
mud	0.3	1.1	42	50	N, 25-50	N
gravel	0.5	1.3	70	90	Y, 1.5-80	N
mud	1	0.6	55	75	Y, 1.5-55	No data
mixed	1.3	1	75	90	Y, 10-75	N
mud	0.5	1	13	28	Little data	Y
mixed	1	1.1	13	80	N, 5-13	Y

Scour Mitigation With Riprap 1 - Illustrative Sheet 1



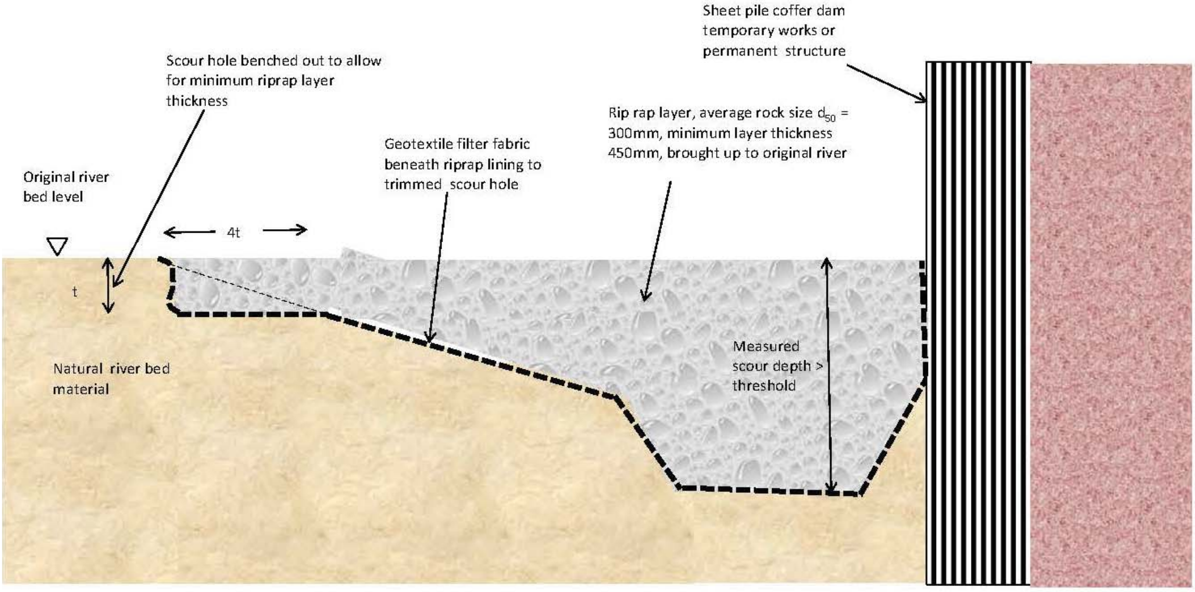
Description:	A layer (minimum layer tickness 300 mm) of natural rock or large gravel uniformly graded , laid on geotextile filter fabric . Quarry run with an initial D50 of 60 mm and D85 of 90 mm. Any material of size less than 10 mm discarded.
Method:	The scour hole is trimmed and reprofiled by excavator to form a benching for the protective layer. Geotextile filter fabric is laid on the trimmed scour hole either above or below water. If below water it needs to weighted down or pegged to the ground. Rip rap rock fill is laid on the filter fabric either above or below water level . The surface profile of the riprap is at the original river bed profile.
Suitability:	This is the best form of protection since it uses mostly natural material and has a well proven record over hundreds of years world wide. Rockfill is readily flexible and can be laid to fill any shape of scour hole. The right size and density of rock needs to be used. The Contractor can maintain a stockpile of rock and may deliver these reasonably quickly, within 2 days but a collapse could still occur.

Scour Mitigation With Riprap 2 - Illustrative Sheet 2



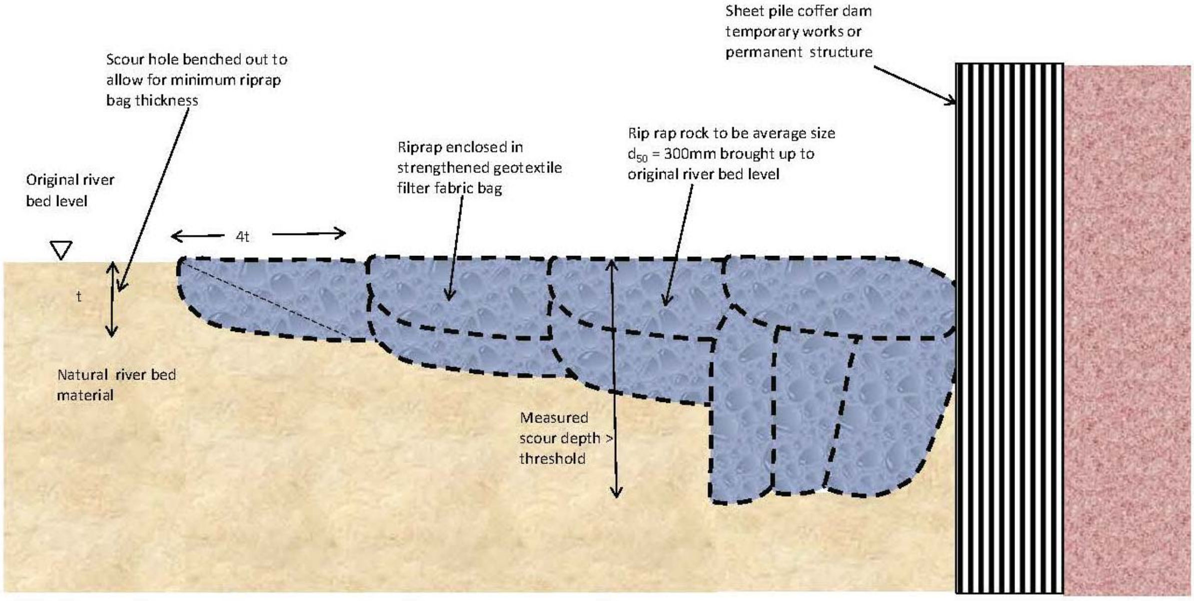
Description:	A layer (minimum layer tickness 150 mm) of natural rock or large gravel uniformly graded , laid on geotextile filter fabric . D50 of 30 mm and D85 of 60 mm. Any material of size less than 10 mm discarded.
Method:	The scour hole is trimmed and reprofiled by excavator to form a benching for the protective layer. Geotextile filter fabric is laid on the trimmed scour hole either above or below water. If below water it needs to weighted down or pegged to the ground. Rip rap rock fill is laid on the filter fabric either above or below water level . The surface profile of the riprap is at the original river bed profile.
Suitability:	This is the best form of protection since it uses mostly natural material and has a well proven record over hundreds of years world wide. Rockfill is readily flexible and can be laid to fill any shape of scour hole. The right size and density of rock needs to be used. The Contractor can maintain a stockpile of rock and may deliver these reasonably quickly, within 2 days but a collapse could still occur.

Scour Mitigation With Riprap 3 - Illustrative Sheet 3



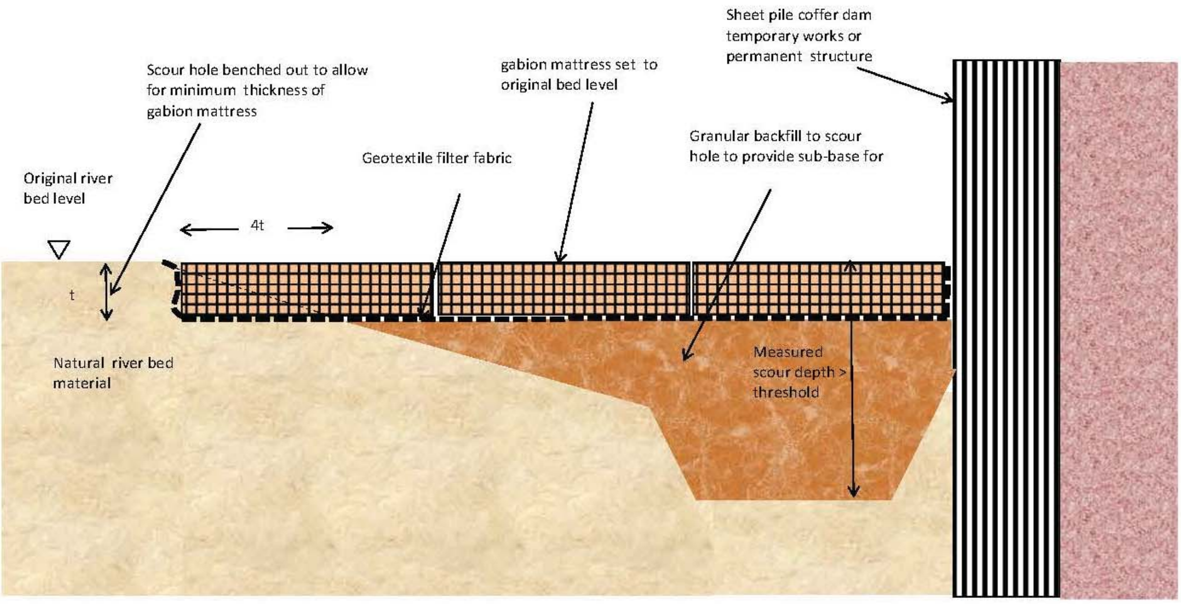
Description:	A layer of natural rock uniformly graded with an average rock diameter of 300mm and a minimum layer thickness of 450mm, laid on geotextile filter fabric .
Method:	The scour hole is trimmed and reprofiled by excavator to form a benching for the protective layer. Geotextile filter fabric is laid on the trimmed scour hole either above or below water. If below water it needs to weighted down or pegged to the ground. Rip rap rock fill is laid on the filter fabric either above or below water level . The surface profile of the riprap is at the original river bed profile.
Suitability:	This is the best form of protection since it uses mostly natural material and has a well proven record over hundreds of years world wide. Rockfill is readily flexible and can be laid to fill any shape of scour hole. The right size and density of rock needs to be used. The Contractor can maintain a stockpile of rock and may deliver these reasonably quickly, within 2 days but a collapse could still occur.

Scour Mitigation With Rock Filled geotextile bags - Illustrative Sheet 4



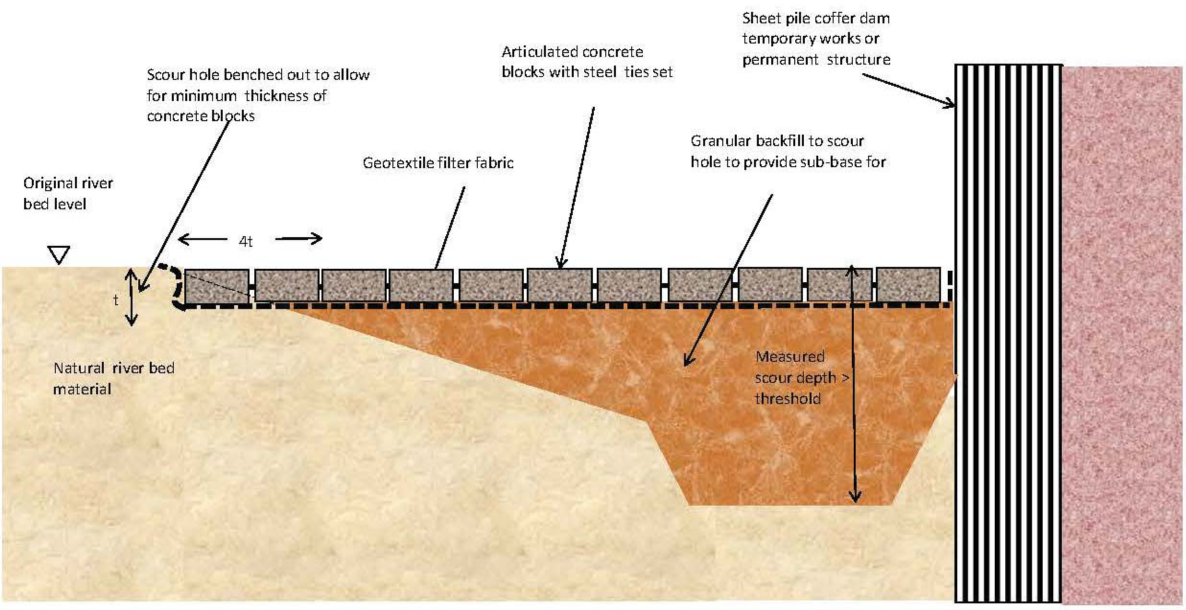
Description:	Natural rock uniformly graded with an average rock diameter of 300mm is encased in strengthened geotextile fabric is placed into the scour hole.
Method:	The scour hole is trimmed and reprofiled by excavator to form a benching for the protective layer. The rock filled strengthened geotextile bags are placed into the trimmed scour hole by excavator, which can be done below water. The surface profile of the bags is set as close as feasible to the original river bed profile, but can be lumpy.
Suitability:	This is a good form of protection since it uses mostly natural material and is able to fill any shaped scour hole. The strengthened bags are new technology and can rip open during handling depending on the rock size, shape and weight. The right size and density of rock needs to be used. Easier to place below water when compared with laying a geotextile fabric layer below water.

Scour Mitigation With Stone Filled Gabion Mattress - Illustrative Sheet 5



Description:	Gabion mattresses made of galvanised steel wire baskets 300mm thick containing rock with an with average size of about 200mm are placed on geotextile filter fabric over compacted backfill.
Method:	The scour hole is trimmed and reprofiled by excavator to form a benching for the protective layer. The trimmed hole is back filled with compacted granular backfill to form a substrate for the gabion mattress (difficult to do below water). Geotextile filter fabric is laid on the backfilled scour hole either above or below water. If below water it needs to weighted down or pegged to the ground. Ready filled gabion mattresses are laid on the filter fabric either above or below water level by crane. The surface profile of the gabion mattresses is to be at the original river bed profile.
Suitability:	This is a good form of temporary protection since it is reasonably flexible to accommodate the scour hole shape. The wires are subject to damage and corrosion and rocks can fall out of the mattress. The right size and density of rock needs to be used. The gabion mattress can settle into the backfill if not well compacted.

Scour Mitigation With Articulated Concrete Blocks - Illustrative Sheet 6



Description:	Proprietary articulated concrete blocks (either interlocking or fixed by cables) about 300mm thick are placed on a geotextile filter fabric laid over the backfilled scour hole.
Method:	The scour hole is trimmed and reprofiled by excavator to form a benching for the protective layer. The trimmed hole is back filled with compacted granular backfill to form a substrate for the concrete blocks (difficult to do below water). Geotextile filter fabric is laid on the backfilled scour hole either above or below water. If below water it needs to weighted down or pegged to the ground. Concrete block mat is laid on the filter fabric either above or below water level by crane. The surface profile of the concrete blocks is to be at the original river bed profile.
Suitability:	This is the not a good form of protection for temporary works situations and is generally used in permanent works designs. The articulated concrete blocks can settle into the scour hole if the backfill is not properly co The Contractor cannot easily maintain a stockpile of articulated concrete block mats because the size of the scour hole will not be known in advance. The mats would have to be tailored to suit the scour hole shape; as such, the reaction time to protect the temporary structure would probably be nearer a week during which time a collapse of the cofferdam could occur.

Thames Tideway Tunnel
Thames Water Utilities Limited

Application for Development Consent

Application Reference Number: WWO10001

Environmental Statement

Doc Ref: **6.2.03**

Volume 3: Project-wide effects assessment appendices

Appendix M: Water resources - flood risk

APFP Regulations 2009: Regulation **5(2)(a)**

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Thames Tideway Tunnel
Creating a cleaner, healthier River Thames

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Thames Tideway Tunnel

Environmental Statement

Volume 3 Project-wide effects assessment appendices

Appendix M: Water resources − flood risk

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Thames Tideway Tunnel
Thames Water Utilities Limited

Application for Development Consent

Application Reference Number: WWO10001

Environmental Statement

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Volume 3: Project-wide effects assessment appendices

Appendix M.1: CSO foreshore works fluvial modelling

APFP Regulations 2009: Regulation **5(2)(a)**

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Creating a cleaner, healthier River Thames

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Appendix M: Water resources – flood risk

M.1 Combined sewer overflow foreshore works fluvial modelling – overall impact on the tidal Thames

M.1.1 The following report has its own table of contents.

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HR Wallingford
Working with water

Thames Tunnel

Combined Sewer Overflow Foreshore Works Fluvial Modelling – Overall impact upon the Tidal Thames

EX 6322 R7
100-RG-MDL-WALLI-000015-AG

December 2012

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Summary

Thames Tideway Tunnel

Combined Sewer Overflow Foreshore Works Fluvial Modelling - Overall impact upon the Tidal Thames

Report EX 6322 100-RG-MDL-Walli-000015-AG
December 2012

HR Wallingford was commissioned by the Thames Tideway Tunnel Team (TTT) to undertake flow modelling and simulations of river conditions to assess the cumulative impacts of the proposed works for the interception of selected combined sewer overflows (CSOs) as part of the proposed Thames Tideway Tunnel. A set of simulations have been completed to investigate the effect of the proposed CSO works on tidal propagation and water levels. Tidal levels in the area are a complex interrelationship of the incoming tide and the fluvial input at the landward limit of the Thames Tideway. Most of the scenarios chosen were at the limiting conditions for the closure of the Thames Barrier. A final test case of a Thames Barrier closure was included to cover the range of likely conditions.

Tidally dominated cases
The works act to impede the tidal flow, during both the flood and ebb phases. This acts to reduce the tidal high water in the landward reaches by approximately 50 mm. Some small increases (a few mm) are predicted in the area around the Thames Barrier. All the predicted increases are reduced considerably for the permanent works cases. Low Water levels due to the tide in the landward reaches are increased by up to 50 mm. Landward of Richmond the level of Low Water is controlled by the Richmond Half Tide Weir.

Fluvially dominated cases
Up to and including the 1:100 year flow case no increase in maximum water level is predicted. For the largest fluvial flow without Barrier closure (1051 m^3/s) small increases in peak levels (up to 7 mm) are predicted for the temporary works case only. In the landward reaches Low Water level is dominated by the fluvial flow. For the 1:100 year flow the temporary works increase the level of Low Water by up to 50 mm. The predicted effects are reduced considerably for the permanent works cases.

Flood storage
As both the temporary and permanent works, up to and including the 1:100 year fluvial flow case, reduce the highest water levels which might occur without closure of the Thames Barrier being triggered there is no need to provide additional flood storage to mitigate the presence of the works in the tidal Thames.

Closure of the Thames Barrier
The predicted effects of the works on tidal levels are insufficient to require alteration of the present approach to the closing of the Thames Barrier.

Peak water levels landward of the Thames Barrier are predicted to increase during a high fluvial flow case with the Thames Barrier closed. It should be noted that these increases are from a low peak level due to the exclusion of the tide by the Barrier.

Contents

Figures

Appendix

1. Introduction

HR Wallingford was commissioned by the Thames Tideway Tunnel Team (TTT) to undertake flow modelling of river conditions at proposed works for the interception of selected combined sewer overflows (CSOs) as part of the proposed Thames Tideway Tunnel project. These works will redirect existing combined sewer flows into bespoke individual drop shafts and from thence into the proposed Thames Tideway Tunnel.

The nature of the required works to enable the redirection of the CSOs to the Thames Tideway Tunnel means that some activity on the surface is necessary. The numerous constraints on the works have meant that at some locations these engineering activities will take place on the river embankment and the adjacent inter- and sub-tidal foreshores. Engineering works within the river brings the additional challenges of the potential for the works to change the flow, sediment transport and morphological regime in the vicinity. The number and detail of the works on the foreshore is under consideration by TTT during the on-going site selection and outline design processes.

Numerical modelling at individual CSO sites has been undertaken using a 2D model of the Thames Estuary to provide detailed information on the changes to the local flow and likely implications for sediment transport and morphology. These predicted impacts were put into context by completing a historical morphological review of the estuary around each site.

Cumulative impacts of the whole project will be of interest to the regulatory authorities such as the Environment Agency (EA) in terms of changes to flood risk and the Port of London Authority (PLA) for navigation. To address this and other issues, a programme of numerical modelling to identify the potential cumulative impacts of all the proposed works was undertaken as described in this report.

The report contains four further sections. Section 2 describes the modelling setup and scenarios chosen, with the results being presented in Section 3. The implications of the modelling results are discussed in Section 4 and the conclusions of the study are presented in Section 5.

2. Hydrodynamic modelling

2.1 WORKS INCLUDED IN THE MODELLING

Figure 1 shows the CSO sites that have been included in the cumulative modelling. At each location of temporary works a combination of differing structures is envisaged including; an area enclosed by cofferdam; a piled jetty structure; a piled platform extending into the river or a floating pontoon. Table 1 details the location and the type of construction proposed.

The sites at which permanent works are proposed are a subset of those proposed for temporary works. Table 1 also lists the permanent works included in the simulation of the overall impacts of the permanent works. The locations of the proposed permanent works simulated, being a subset of the locations for temporary works are also shown on Figure 1. The permanent works are made up of a range of sizes of reclamation some fronted by terraced areas of sea bed, some with near vertical walls. The detailed design of the various permanent works has been refined a number of times to balance the internal engineering needs of the works with the likely impact on the river and other aspects including visual amenity. Considerable consultation has also been fed into the design development for the permanent works.

Table 1 Temporary works included in the model layout

CSO name	London Borough	Temporary works	Permanent works
Putney Bridge	Wandsworth	Solid structure	✓
Chelsea Embankment	Kensington and Chelsea	Solid structure	✓
Kirtling St / Heathwall	Wandsworth	Solid structure, piled structure and floating pontoon	✓ - Heathwall
Albert Embankment	Lambeth	Solid structure	✓
Victoria Embankment	Westminster	Solid structure	✓
Blackfriars Bridge	City of London	Solid structure and piled structure	✓
Chambers Wharf	Southwark	Solid structure	x
King Edward Memorial Park	Tower Hamlets	Solid structure	✓

The drawings of the works as supplied by TTT for inclusion in the modelling are provided in this report as Appendix 1.

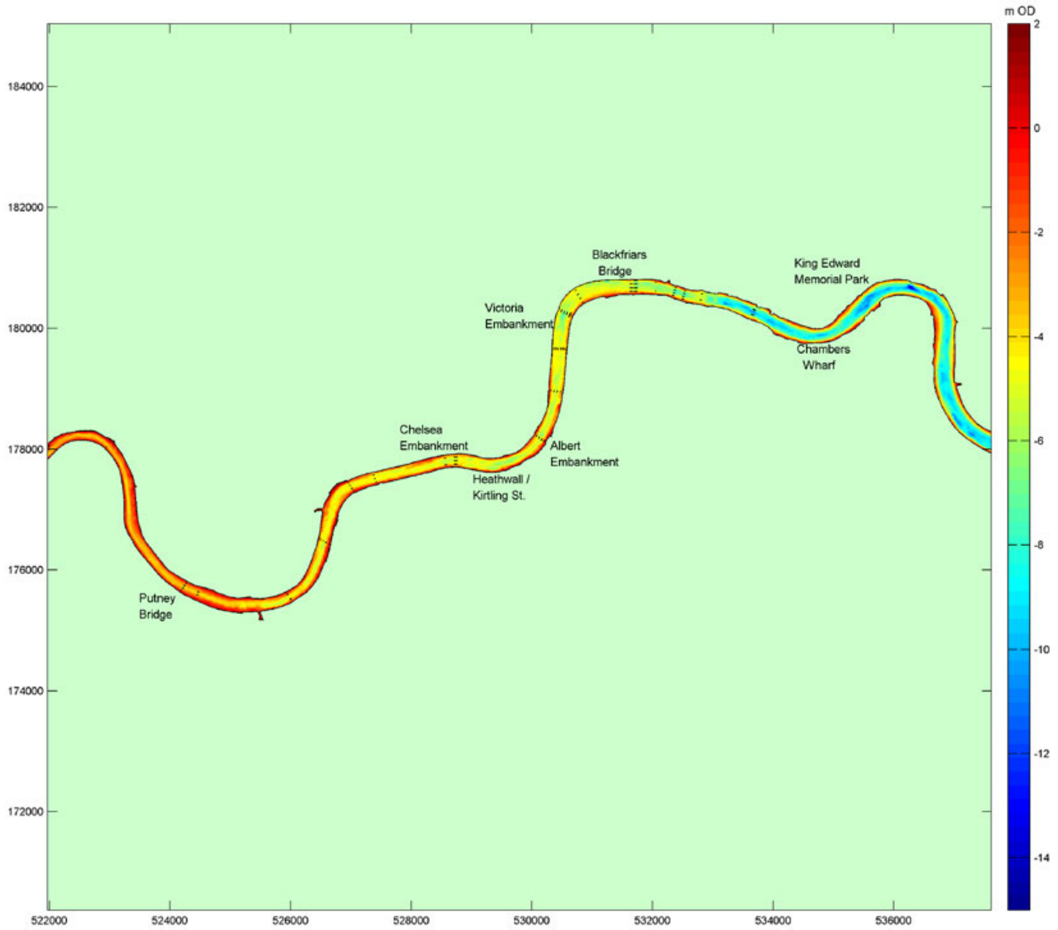

Figure 1 Locations of works included in the model layout

2.2 MODEL SETUP

2.2.1 Model used

The modelling tool used for the Thames Base model was TELEMAC2D. TELEMAC2D, developed by EDF-LNHE solves the depth-averaged shallow water equations using a finite element triangular grid. This triangular grid allows the model mesh resolution to continually vary in space resulting in accurate representation of features such as the various bridge piers and the river wall. The model mesh can be focussed on the particular area of interest to resolve structures in the flow such as the proposed permanent and temporary works.

The Thames Base model was set up by HR Wallingford in 2004 on behalf of the Port of London Authority and Environment Agency to provide a model of known provenance to aid the two organisations in their regulatory responsibilities.

2.2.2 Mesh

The mesh used by the Thames Base model in the study area was refined to fit around the proposed structures. As all the structures were to be included in the same model significant refinement of the model grid at all the sites was not practical and so the mesh sizes were generally no finer than 10 m around all of the structures to allow general representation of the structures. In some locations, for example around the pontoons, the model mesh size was reduced further to approximately 5 m. Figure 2 shows some detail of the mesh in the area between Battersea and Lambeth. This general level of refinement is the same as that used in the establishment and calibration of the model hence no impairment in its accuracy for simulation of the present conditions or prediction of the effects of the works was expected. It is considered that the mesh refinement used is satisfactory for the intended purpose of the model, i.e. to show the overall impact of the works.

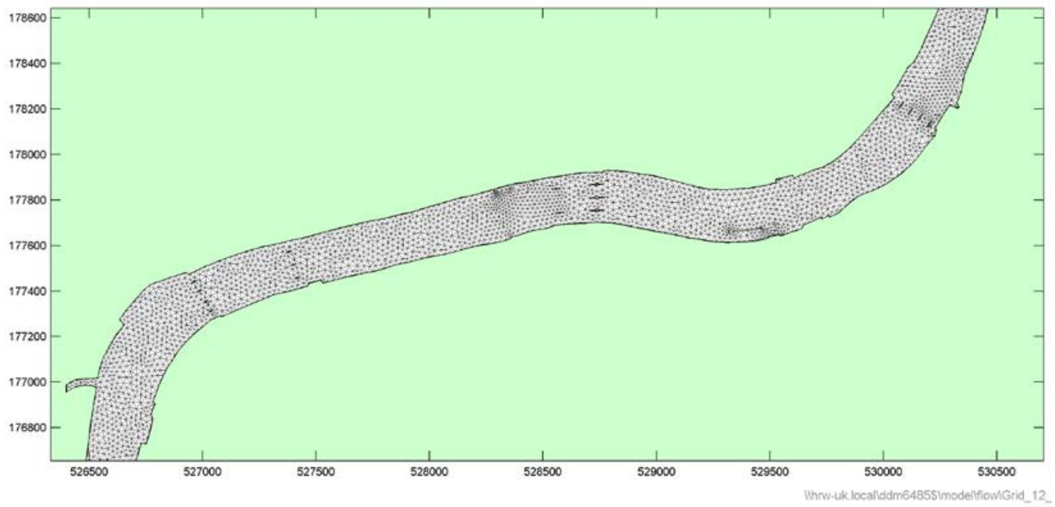

Figure 2 Detail of model mesh used in the simulations

2.2.3 Bathymetry data

The bathymetry database of the Thames Base model was extracted from the bathymetric data published by the Port of London Authority. All depths were reduced from Chart Datum to a common datum of Ordnance Datum (Newlyn), the conversion value of which changes along the length of the Thames Estuary.

2.2.4 Model calibration and validation

The model has been successively validated against a wide set of tidal level, current and total discharge data. The model establishment and first set of calibration results are presented in HR Wallingford (2004). More recently the model has been validated against the estuary wide survey undertaken in late 2004 as part of the Environment Agency's TE2100 studies (HR Wallingford, 2006a). The model bathymetry was updated in 2009 and maintenance of the model's accuracy confirmed by a validation exercise, comparing the updated model results against the 2004 survey data (HR Wallingford, 2009).

The validation exercise presented in HR Wallingford (2006a) for TE2100 focussed on high water levels as TE2100 was primarily a flood management study. An objective statistical measure, the Mean Absolute Error (MAE), was used to judge the model's representation of high water during a series of 6 spring tides. This measure of model accuracy suggested the model generally represented high water levels with an accuracy of about 0.05 m for spring tide conditions.

The MAE method was also applied to the model representation of the whole tide giving a value of 0.1 – 0.2 m through central London (HR Wallingford, 2009). This mean error represents 2-3 per cent of the tidal range at each comparison tide gauge. Further landward where the fresh water flow tends to dominate the lower half of the tide the MAE is worse being 0.4 m at the Richmond tide gauge - although this is still only 8 per cent of the tide range at this site.

The overall level of accuracy is considered good for a tidal flow model of 100 km of estuary. It should be noted that these accuracy measures consider the model's representation of the observed tide, used as baseline conditions for the present study. However this level of accuracy also gives confidence in the prediction of the effect of the works on the tide.

2.2.5 Model boundary conditions

The simulations require setting of upstream and downstream boundary conditions. The model domain covers the whole length of the tidal Thames Estuary so the tidal elevation at Southend-on-Sea and flow at Teddington define the downstream and upstream boundary conditions respectively. Data for the tidal elevation boundary comes from those observed at the Port of London Authority's tide gauge on Southend Pier. The freshwater flow data is as extracted from the long term gauged flow at Kingston held within the National River Flow Archive:
(http://www.nwl.ac.uk/ih/nrfa/station_summaries/039/001.html).

2.3 CHOICE OF HYDRODYNAMIC CONDITIONS

Any investigation of peak water levels in the Thames Tideway has to take account of the operation of the Thames Barrier which was designed to prevent large storm surges with the potential to exceed the flood defences propagating into the Thames Estuary upstream of the barrier. To minimise flood risk the Thames Barrier is operated to a closure rule based upon the exceedence of combinations of predicted high water level at Southend and river flows measured at Kingston. Following discussions with the Environment Agency (EA) a set of scenarios of tide level / fluvial combinations were chosen to show the effect of the works on water levels at the limiting conditions for closure of the Thames Barrier. These were considered to be the most extreme cases, likely to demonstrate the largest effect of the works. To complete the range of scenarios studied a case with the Thames Barrier closing was included in the modelling.

The chosen tide /fluvial flow cases were as follows:

a) HW Southend 3.85 OD(N) + mean daily flow at Teddington (65 m^3/s)
b) HW Southend 3.85 OD(N) + 0 flow at Teddington
c) HW Southend 2.75 OD(N) + 1:100 year flow (800 m^3/s)

d) HW Southend 2.75 OD(N) + 0 flow at Teddington
e) Mean tide (HW at Southend 2.4 m OD(N))+ daily flow at Teddington (65 m^3/s)
f) Mean spring tide (HW at Southend 2.9 m OD(N) + largest flow for Barrier open for this tide (~ 736 m^3/s)
g) Most extreme fluvial flow for Barrier open (1051 m^3/s + HW Southend 2.35 OD(N)
h) Barrier closure case - 13-14th December 2000. HW Southend up to 3.4 OD(N) + flow up to 450 m^3/s.

The reasoning for the choices was as follows:

Cases a and c examine the effect on water levels for the low fluvial flows and high tides and high fluvial flows and low tides respectively; extreme ends of the current Thames Barrier Operating rules.

Cases b and d are included to provide an understanding of the impact fluvial flows have on water levels.

Case e is included to provide average flow conditions so that the impact on aquatic life can be better understood.

Case f was as requested by the Environment Agency. It represents the largest flow for which the barrier will remain open for a mean spring tide (HW 2.9 m OD(N) at Southend).

Case g was requested by the Environment Agency. It represents the largest flow for which the Thames Barrier will remain open. For reference it is also is slightly more extreme than a climate change case for 2070 conditions.

Case h shows the effect of the works if the Thames Barrier is closed. In the case of a Barrier closure the water levels landward of the Barrier are controlled by the details of its operation and so for this case a real period was simulated – for which the Barrier operation is known.

The available tidal records were inspected to identify suitable observed tides to meet the target HW levels at Southend. The selected tides are described in Table 2.

Table 2 Tidal conditions chosen for test cases

Test	Predicted HW Southend m OD(N)	River flow (m^3/s)	Recorded HW Southend m OD(N)	Date of recorded HW	Time HW (GMT)
A	3.85	65	3.85	29/10/1996	13:30
B	3.85	0	3.85	29/10/1996	13:30
C	2.75	800	2.76	04/09/2001	01:30
D	2.75	0	2.76	04/09/2001	01:30
E	2.40	65	2.42	02/09/2001	00:10
F	2.90	736	2.91	16/09/2001	11:20
G	2.35	1051	2.35	17/08/2001	22:10
H	2.92	400-450	3.33	14/12/2000	02:00

3. Simulation results

3.1 BASELINE CONDITIONS

Figure 3 shows a longitudinal section of maximum water levels as simulated. For reference the flood defence level and the sites of the proposed CSO interception works are included. Chainages are shown consistent with the flood defence level data provided by the EA and are relative to an origin point on the downstream side of Molesey Lock.

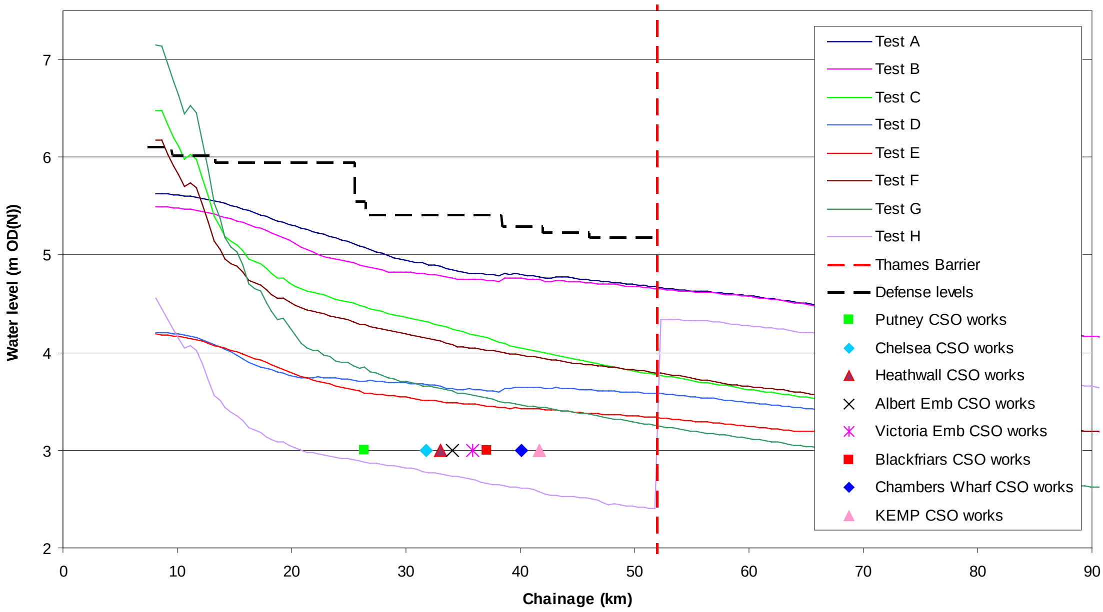

Figure 3 Baseline predicted maximum water level for scenario tests

The plot indicates that larger tidal conditions dominate the maximum water levels seawards of Richmond Weir (Chainage 13 km). Landward of this point the highest water levels are associated with extreme fluvial flows. Comparison of Tests c and d show that the extreme fluvial flow conditions influences to some extent the peak water levels seawards of the Thames Barrier.

It should be noted that for Tests c, e and g some out-of-bank flow would be likely which is not included in the setup of the model. Hence the maximum water level predicted should be regarded as an over prediction in the most landward reaches of the Thames Tideway.

Figure 4 shows the minimum water levels for the baseline simulations. Minimum water levels in the Thames Tideway landward of Richmond Weir are maintained to a minimum level of 1.72 m OD (N) by the operation of the weir. From Figure 4 it can be seen that the weir operation is not controlling low water levels for the higher fluvial flow cases. It is considered that fluvial flows of more than about 250 m^3/s maintain low water at or above the required level.

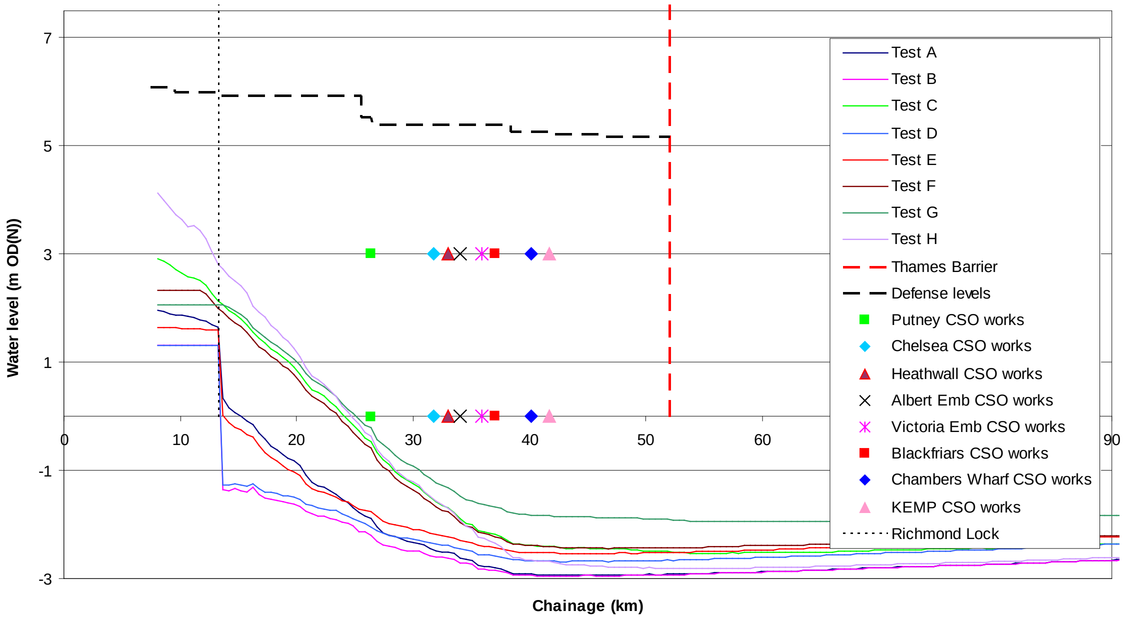

Figure 4 Baseline predicted minimum water level for scenario tests

3.2 SCENARIO TESTS

Simulation results are presented as a long section of maximum or minimum water level, time history of water level at Westminster Pier and tables of maximum and minimum water level plus largest predicted changes to water level occurring during the tidal period.

3.2.1 Test a

Test a examines the situation for a high tidal level and mean daily fluvial flow. The conditions are HW Southend 3.85 OD(N), flow at Teddington 65 m^3/s.

Figure 5 shows the effect of the temporary and permanent works on maximum water level along the length of the Thames Tideway for the baseline, temporary and permanent works cases. The level is plotted against the left hand y axis with the differences in water level plotted against the right hand axis.

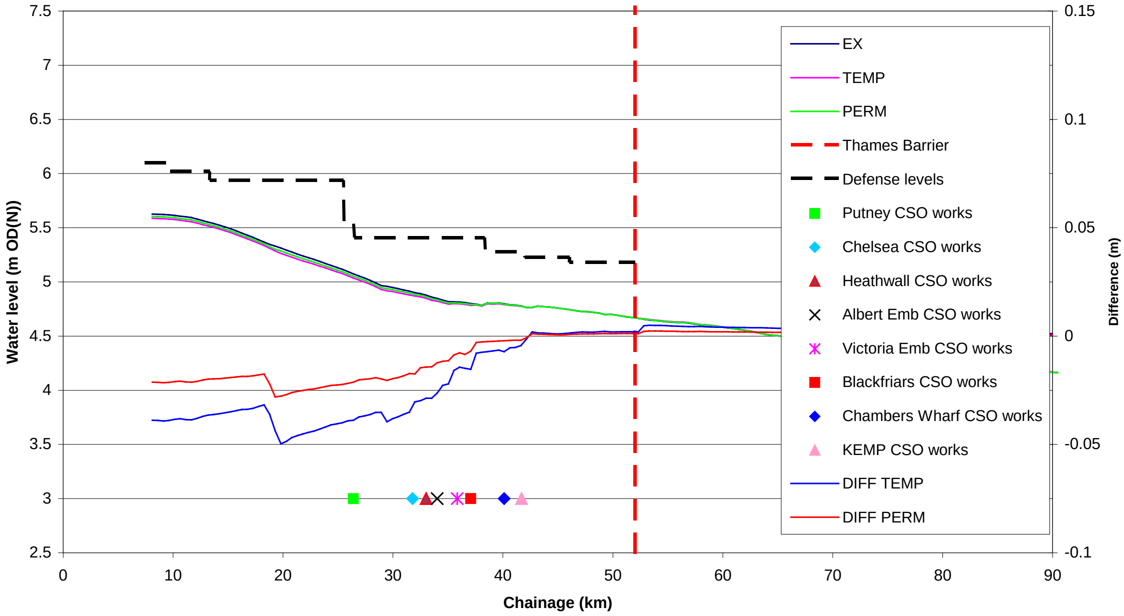

Figure 5 Maximum water level for Test a

The predicted effect of the works on maximum water levels at all the tide gauges landward of the Thames Barrier are tabulated below in Table 3.

Table 3 Predicted maximum water levels at tide gauges, Test a

	Maximum level (m OD(N))		Difference in maximum level (m)	Maximum level (m OD(N))		Difference in maximum level (m)
	Baseline	Temporary works		Baseline	Permanent works	
Richmond	5.580	5.542	-0.038	5.580	5.560	-0.021
Chelsea	4.915	4.880	-0.035	4.915	4.898	-0.017
Westminster	4.860	4.831	-0.029	4.860	4.846	-0.014
Tower	4.802	4.795	-0.007	4.802	4.800	-0.002
Charlton	4.685	4.687	0.002	4.685	4.687	0.001

These results show that the incoming tide is affected by the developments reducing the maximum water level in the area of and landwards of the works. The largest change shown is a reduction in peak water levels of the order of 0.05 m. The effect of the temporary works on reducing peak water levels is larger due to the larger structures that pose a larger obstruction to the flow.

A very small increase in peak water levels with temporary works, of the order of 0.002 m, is shown at Charlton. Seawards of Charlton and the Thames Barrier increases are predicted of up to 0.005 m (Table 4). For the permanent works the increase at Charlton is 0.001 m with the largest increase 0.002 m in the area seaward of the Thames Barrier.

Table 3 provides data at points along the Thames Tideway. To ensure all changes in peak water level are captured Table 4, below show the maximum (most positive) and minimum (most negative) changes.

Table 4 Predicted maximum water levels in tidal reaches, Test a

River reach (inclusive downstream)	Maximum peak water level difference in reach (m)		Minimum peak water level difference in reach (m)	
	Temporary works	Permanent works	Temporary works	Permanent works
Teddington- Richmond	-0.038	-0.021	-0.039	-0.022
Richmond- Chelsea	-0.032	-0.017	-0.050	-0.028
Chelsea- Westminster	-0.029	-0.014	-0.030	-0.017
Westminster- Tower	-0.007	-0.002	-0.026	-0.012
Tower- Charlton	0.002	0.001	-0.007	-0.002
Charlton- Tilbury	0.005	0.002	0.002	0.001

Care should be taken when considering Table 4 as the 'largest' effect is the minimum difference in reaches where peak water level is reduced and is the maximum difference in reaches where peak water level in increased. The extracted results for the reaches confirm the changes shown at the tide gauge locations and provide the overall envelope of change in peak water level.

A longitudinal plot of minimum water level is shown in Figure 6 with the values tabulated at the tide gauges in Table 5.

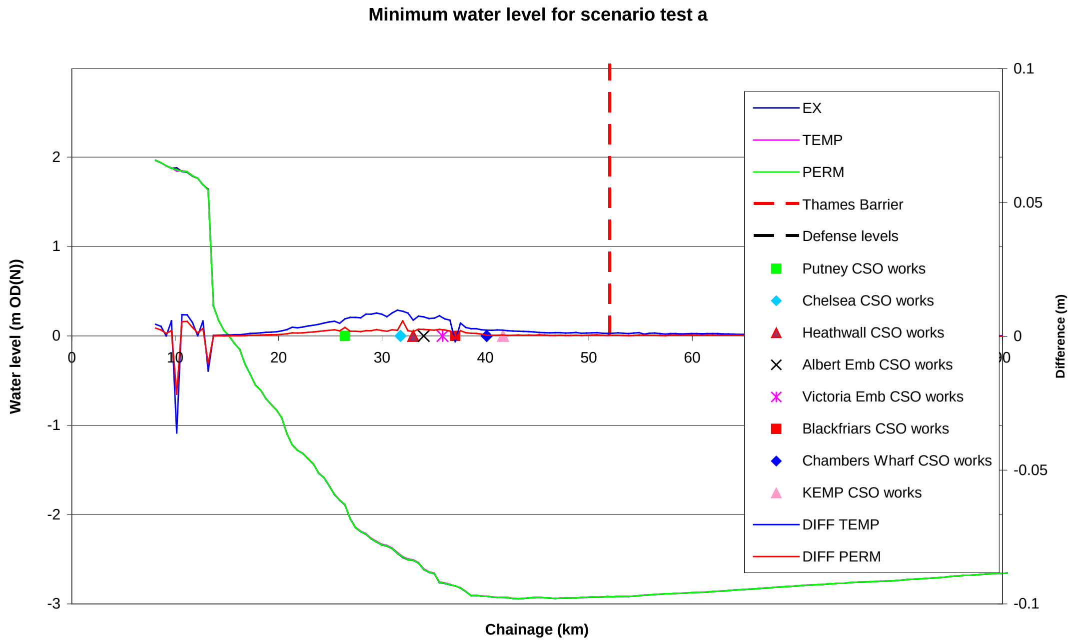

Figure 6 Minimum water level for Test a

The effect of the works in reducing the tidal influence is shown by a small increase in low water levels. The largest change is of the order of 0.01 m in central London. Above Westminster the tidal influence decreases leaving the low water level controlled by the fluvial flow. In line with this change in behaviour the increase in low water level predicted reduces to near zero at Richmond Weir. Landward of Richmond Weir the low water is controlled by the operation of the weir
The reduced blockage effect of the permanent works induces a weaker effect on the tide (in comparison to temporary measures) such that changes in low water are predicted to be less than 0.003 m.

Table 5 Predicted minimum water levels at tide gauges, Test a

	Minimum level (m OD(N))		Difference in minimum level (m)	Minimum level (m OD(N))		Difference in minimum level (m)
	Baseline	Temporary works		Baseline	Permanent works	
Richmond	1.764	1.764	0.000	1.764	1.765	0.001
Chelsea	-2.435	-2.425	0.010	-2.435	-2.433	0.002
Westminster	-2.544	-2.536	0.008	-2.536	-2.541	0.003
Tower	-2.906	-2.903	0.003	-2.906	-2.905	0.001
Charlton	-2.924	-2.924	0.001	-2.924	-2.923	0.001

The above results show the effect of the works at the top and bottom of the tide. Further detail of the through-tide variation in water level is shown in Figure 7.

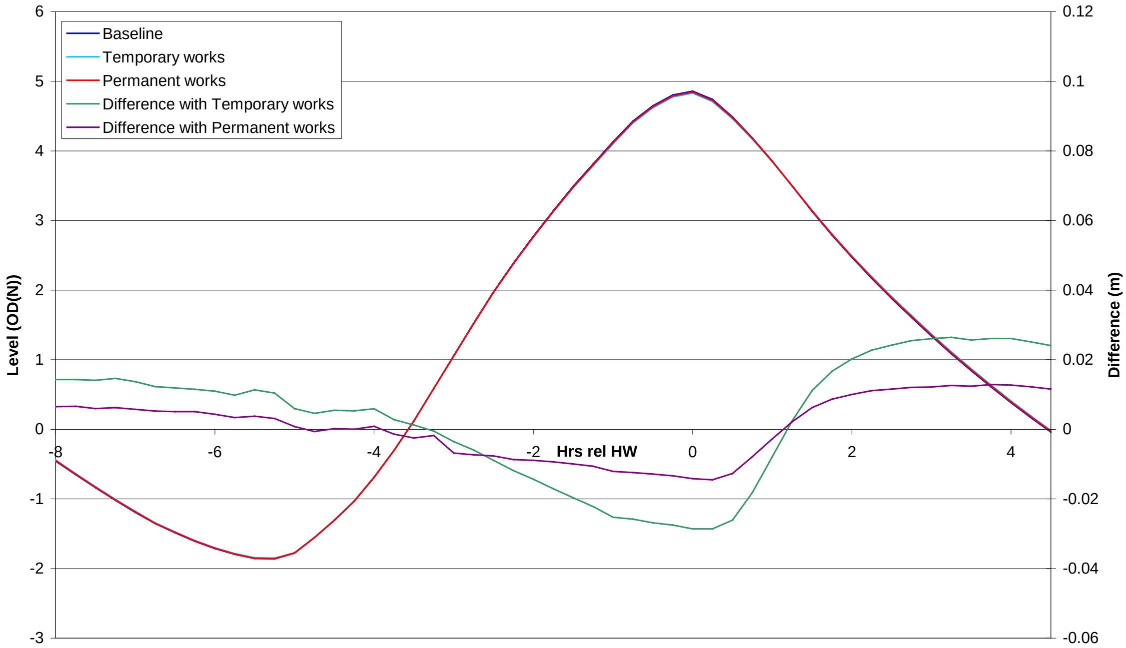

Figure 7 Predicted effect of works on the tide at Westminster Pier, Test a

Figure 7 shows the effect of the works in impeding the tide such that the tide both rises and falls slightly later. This means water levels are suppressed during the flood tide and increased during the ebb. The impedance effect is linked to the tidal currents and so it is greatest near mid tide when currents are highest and low at slack water when currents are low – though the consequence of the impedance in reducing the tide range remains. The largest changes shown at Westminster are approximately 0.03 m – an increase during the ebb tide and a decrease during the flood tide. To provide similar information at all the tide gauges, the maximum effect of the works on tidal levels throughout the tidal period was extracted – either to increase or decrease water levels due to the changed tide phasing. These results are presented in Table 6.

Table 6 Through-tide effect of works on water level at tide gauges, Test a

	Largest through tide effect on tide curve – Temporary works		Largest through tide effect on tide curve – Permanent works	
	Increase (m)	Decrease (m)	Increase (m)	Decrease (m)
Richmond	0.025	-0.074	0.011	-0.062
Chelsea	0.046	-0.044	0.015	-0.019
Westminster	0.026	-0.029	0.013	-0.015
Tower	0.023	-0.030	0.012	-0.018
Charlton	0.012	-0.021	0.005	-0.009

The results show no changes in water level greater than about 0.075 m at any point during the tide. The largest increase is 0.046 m during the ebb tide at Chelsea for the temporary works which reduces to 0.015 m for the permanent works.

3.2.2 Test b

Test b examines the situation for a high tidal level and no fluvial flow. Comparison of this tests with test a shows the sensitivity of water levels to fluvial flow. The conditions are HW Southend 3.85 OD(N), flow at Teddington 0 m^3/s.

The simulated peak water levels for test b are shown in Figure 8.

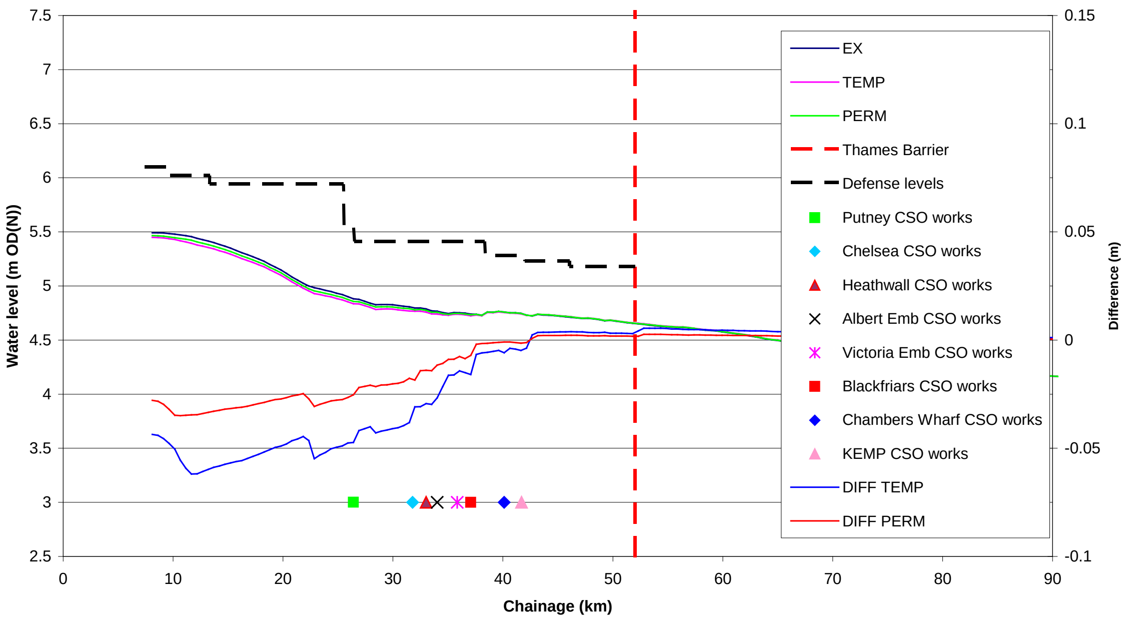

Figure 8 Maximum water levels for Test b

The trend of the plotted results are similar to those from Test a. Peak water levels at the landward reaches of the Tidal Thames are shown to be sensitive to fluvial flow. The differences in peak water level between Tests a and b are predicted to increase upstream. At Richmond the peak water level for the no-fluvial flow case (test b) is approximately 0.15 m lower than the case with typical fluvial flow (test a). The works impede the tide for Tests a and b to the same order of magnitude. From Tests a and b it may be concluded for low/typical flows the effect of the works on reducing peak water levels is insensitive to fluvial flow. At Richmond, where fluvial flows would be expected to influence the tidal propagation some differences are noted. The predicted effect of the works on maximum water levels at all the tide gauges landward of the Thames Barrier are tabulated below in Table 7.

Table 7 Predicted maximum water levels at tide gauges, Test b

	Maximum level (m OD(N))		Difference in maximum level (m)	Maximum level (m OD(N))		Difference in maximum level (m)
	Baseline	Temporary works		Baseline	Permanent works	
Richmond	5.441	5.379	-0.062	5.441	5.406	-0.034
Chelsea	4.807	4.769	-0.038	4.807	4.789	-0.018
Westminster	4.771	4.741	-0.030	4.771	4.757	-0.014
Tower	4.758	4.753	-0.005	4.758	4.757	-0.001
Charlton	4.668	4.671	0.003	4.668	4.670	0.002

The data extracted for the tidal reaches is shown in Table 8. This confirms the effects shown at the tide gauges. The largest decrease in peak water level is 0.062 mm in the reach Teddington to Richmond. The largest increase in water level is 0.006 m occurring somewhere between Charlton and Tilbury.

Table 8 Predicted maximum water levels in tidal reaches, Test b

River reach (inclusive downstream)	Maximum peak water level difference in reach (m)		Minimum peak water level difference in reach (m)	
	Temporary works	Permanent works	Temporary works	Permanent works
Teddington- Richmond	-0.044	-0.028	-0.062	-0.035
Richmond- Chelsea	-0.038	-0.018	-0.061	-0.034
Chelsea- Westminster	-0.029	-0.014	-0.031	-0.019
Westminster- Tower	-0.005	-0.001	-0.027	-0.012
Tower- Charlton	0.004	0.002	-0.006	-0.001
Charlton- Tilbury	0.006	0.003	0.003	0.001

The effect of the works on minimum water level is shown in Figure 9 with the values tabulated at the tide gauges in Table 9.

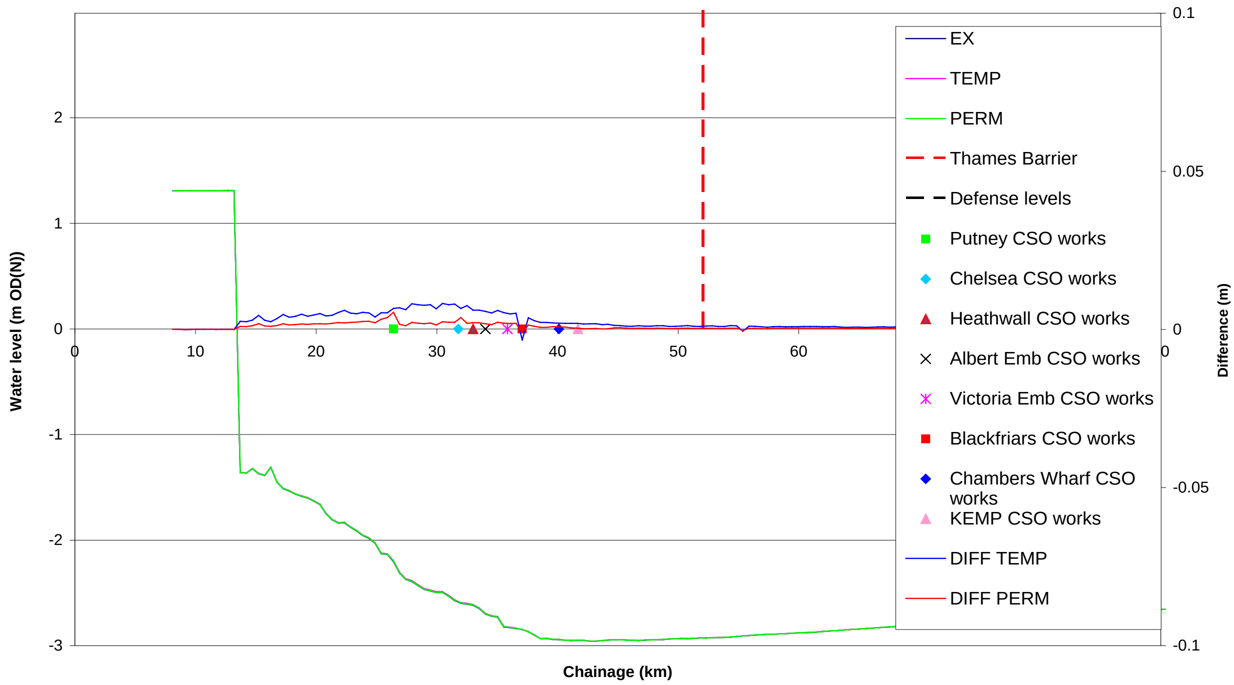

Figure 9 Minimum water levels for Test b

Table 9 Predicted minimum water levels at tide gauges, Test b

	Minimum level (m OD(N))		Difference in minimum level (m)	Minimum level (m OD(N))		Difference in minimum level (m)
	Baseline	Temporary works		Baseline	Permanent works	
Richmond	1.310	1.310	0.000	1.310	1.310	0.000
Chelsea	-2.572	-2.564	0.008	-2.572	-2.570	0.002
Westminster	-2.647	-2.641	0.006	-2.641	-2.645	0.002
Tower	-2.932	-2.930	0.002	-2.932	-2.931	0.001
Charlton	-2.933	-2.933	0.001	-2.933	-2.933	0.000

The effect of the works on minimum water level is extremely similar to that shown for Test a. Further detail of the through tide variation in water level is shown in Figure 10 and Table 10.

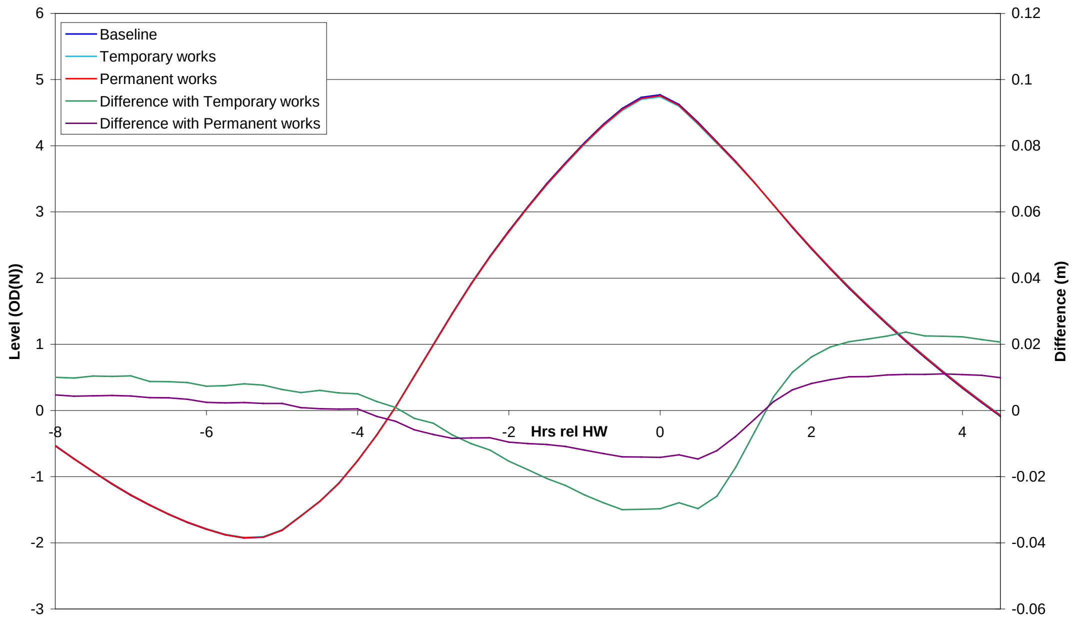

Figure 10 Predicted effects of works on the tide at Westminster Pier, Test b

Table 10 Through-tide effect of works on water level, Test b

	Largest through tide effect on tide curve – Temporary works		Largest through tide effect on tide curve – Permanent works	
	Increase (m)	Decrease (m)	Increase (m)	Decrease (m)
Richmond	0.022	-0.095	0.010	-0.054
Chelsea	0.041	-0.047	0.013	-0.020
Westminster	0.024	-0.030	0.011	-0.015
Tower	0.024	-0.033	0.012	-0.019
Charlton	0.012	-0.021	0.005	-0.010

These results confirm the general insensitivity of the effect of the works to the fluvial flow, for the tidally dominated areas. The temporary works have a larger influence than the permanent due to the size of the structures and the resultant blockage of the flow. The largest increase in water level is again shown at Chelsea where 0.041 m is shown for the temporary works during the ebb tide. This effect reduces to 0.013 m for the permanent works.

3.2.3 *Test c*

Test c includes the 1:100 year fluvial flow combined with a water level for which the Thames Barrier would remain open. The conditions are HW Southend 2.75 m OD(N), fluvial flow 800 m^3/s.

Figure 11 shows the peak water levels predicted for baseline, temporary works and permanent works cases.

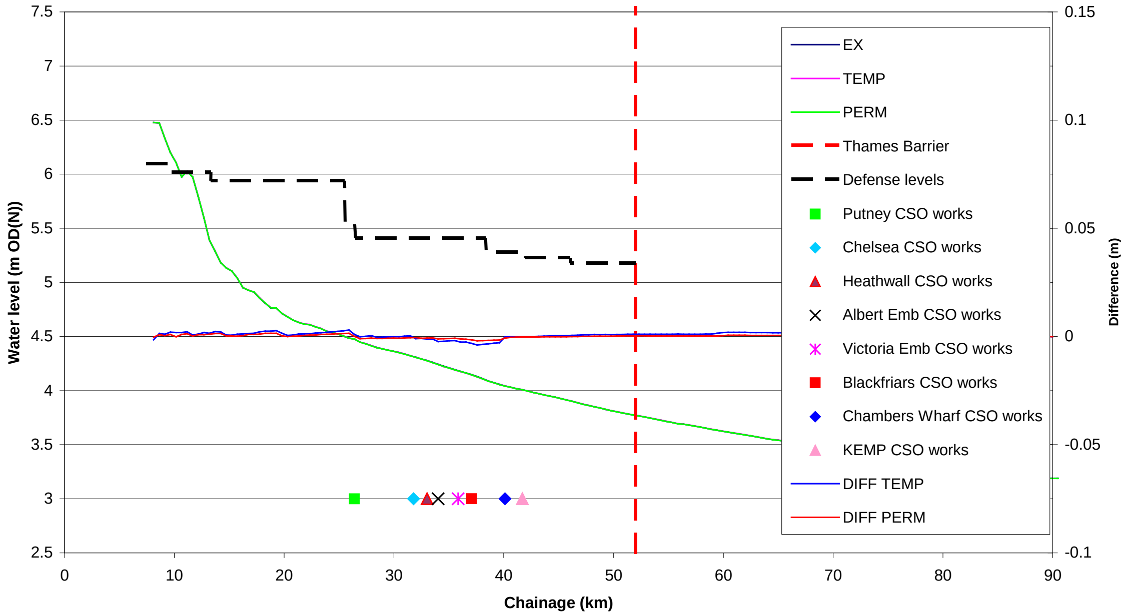

Figure 11 Maximum water levels for Test c

The predicted effect of the works on maximum water levels at all the tide gauges landward of the Thames Barrier are tabulated below in Table 11.

Table 11 Predicted maximum water levels at tide gauges, Test c

	Maximum level (m OD(N))		Difference in maximum level (m)	Maximum level (m OD(N))		Difference in maximum level (m)
	Baseline	Temporary works		Baseline	Permanent works	
Richmond	5.789	5.790	0.001	5.789	5.789	0.001
Chelsea	4.323	4.324	0.000	4.323	4.323	-0.001
Westminster	4.260	4.259	-0.001	4.260	4.259	-0.001
Tower	4.074	4.071	-0.003	4.074	4.073	-0.002
Charlton	3.795	3.796	0.001	3.795	3.795	0.000

Changes in peak water levels due to the development for Test c are small as shown in Figure 11. Table 11 shows a very small effect, with the largest change being a reduction of 0.003 m. The differences in peak water level due to the works are very small.

The results at the identified tidal reaches are provided in Table 12. The largest increase anywhere in the tidal Thames is 0.003 m for the Temporary works and 0.002 m for the Permanent works.

Table 12 Predicted maximum water levels in tidal reaches, Test c

River reach (inclusive downstream)	Maximum peak water level difference in reach (m)		Minimum peak water level difference in reach (m)	
	Temporary works	Permanent works	Temporary works	Permanent works
Teddington- Richmond	0.002	0.001	-0.002	0.000
Richmond- Chelsea	0.003	0.002	0.000	-0.001
Chelsea- Westminster	-0.001	0.000	-0.001	-0.001
Westminster- Tower	-0.002	-0.001	-0.004	-0.002
Tower- Charlton	0.001	0.000	-0.003	-0.002
Charlton- Tilbury	0.002	0.001	0.001	0.000

A longitudinal plot of minimum water level is shown in Figure 12 with the value tabulated at the tide gauges in Table 13.

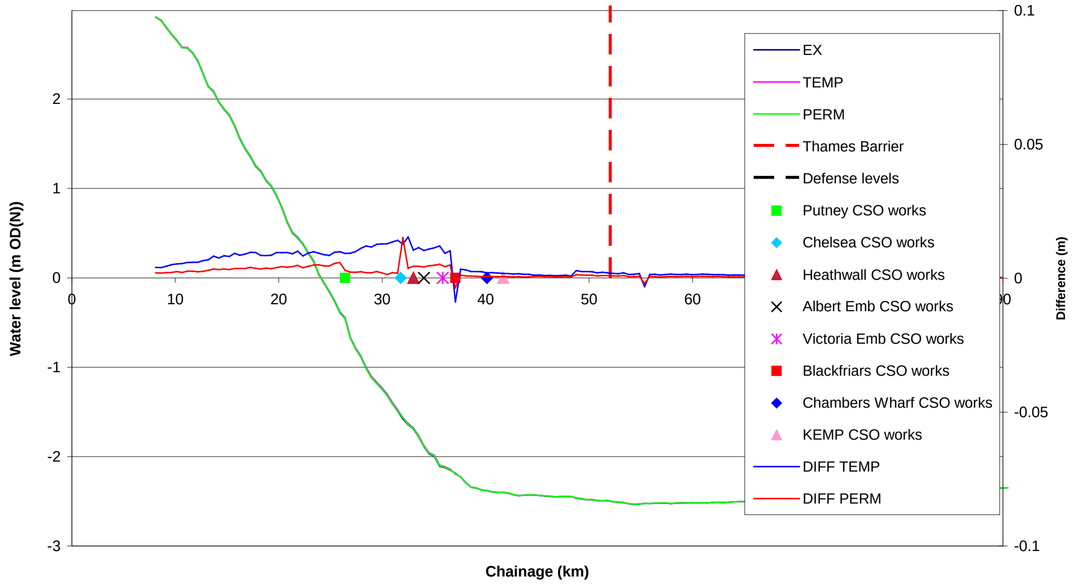

Figure 12 Minimum water levels for Test c

Figure 12 shows a general increase in minimum water level under these conditions. The high fluvial discharge condition dominates the low water level in the area landward from central London. The plot shows the works impede the transit of the large fluvial flow which leads to raised low water levels.

Table 13 Predicted minimum water levels at tide gauges, Test c

	Minimum level (m OD(N))		Difference in minimum level (m)	Minimum level (m OD(N))		Difference in minimum level (m)
	Baseline	Temporary works		Baseline	Permanent works	
Richmond	2.428	2.434	0.006	2.428	2.430	0.002
Chelsea	-1.490	-1.475	0.014	-1.490	-1.488	0.002
Westminster	-1.778	-1.767	0.011	-1.767	-1.774	0.004
Tower	-2.353	-2.351	0.002	-2.353	-2.352	0.001
Charlton	-2.492	-2.492	0.002	-2.492	-2.491	0.001

The above results show the effect of the works at the top and bottom of the tide. Further detail of the through tide variation in water level is shown in Figure 13.

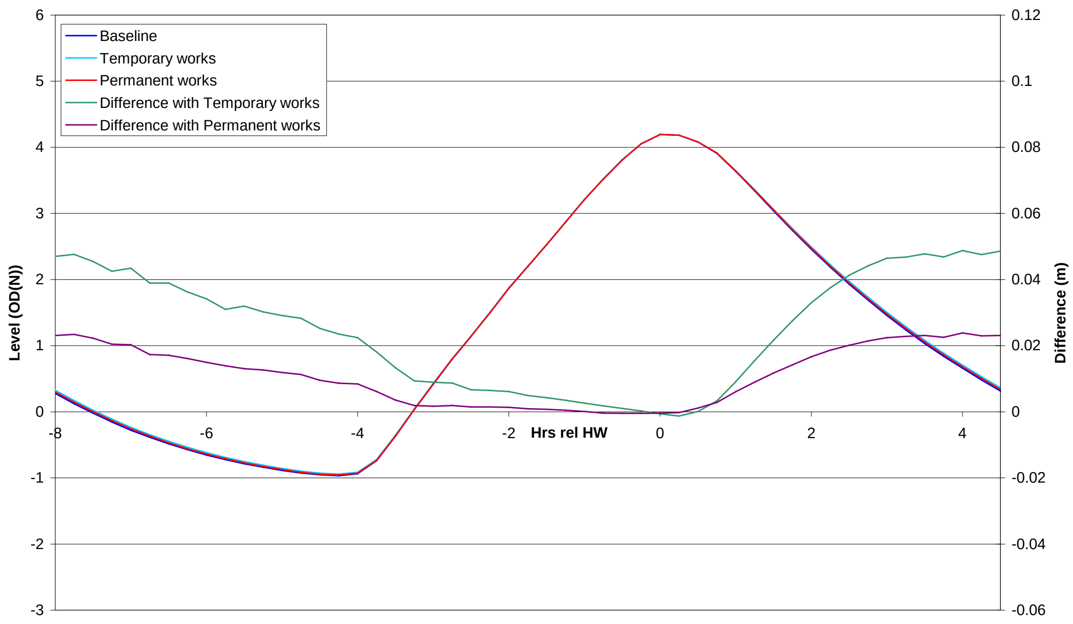

Figure 13 Predicted effects of works on the tide at Westminster Pier, Test c

Table 14 includes the maximum effect of the works on tidal levels throughout the tidal period – either to increase or decrease water levels due to the changed tidal phasing.

Table 14 Through-tide effect of works on water level, Test c

	Largest through tide effect on tide curve – Temporary works		Largest through tide effect on tide curve – Permanent works	
	Increase (m)	Decrease (m)	Increase (m)	Decrease (m)
Richmond	0.015	-0.001	0.008	-0.001
Chelsea	0.079	0.000	0.026	-0.001
Westminster	0.049	-0.001	0.024	0.000
Tower	0.010	-0.015	0.004	-0.009
Charlton	0.006	-0.013	0.002	-0.005

3.2.4 *Test d*

Test d provides further evidence of the sensitivity of water level to fluvial flow. Tidal conditions are the same as Test c. The conditions are HW Southend 2.75 mOD(N) with no fluvial flow.

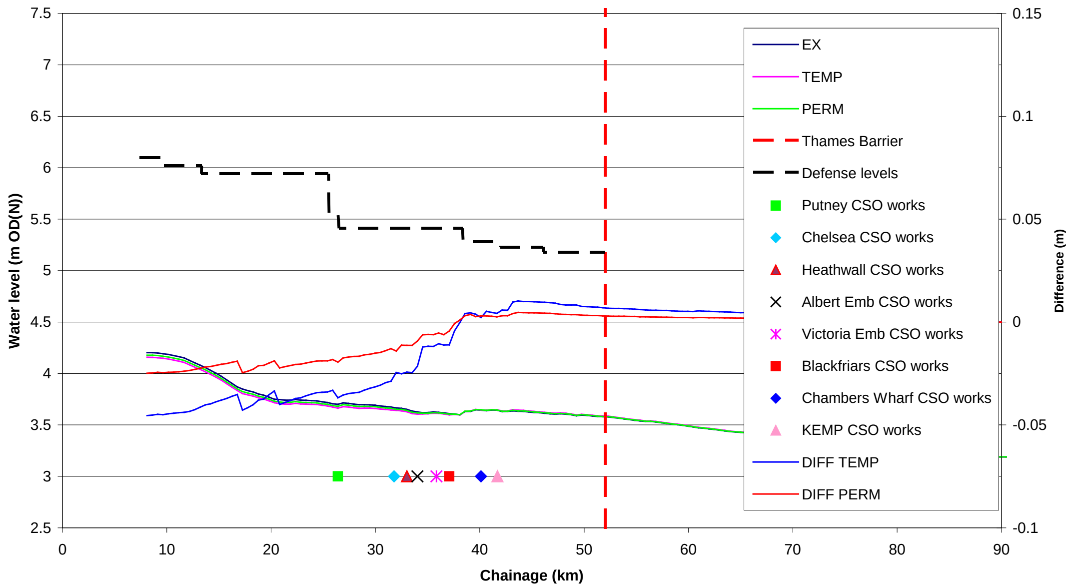

Figure 14 Maximum water levels for Test d

Test d is identical to Test c but without the fluvial discharge and shows the same pattern of effect as Tests a and b with the tide impeded by the works. Without the large fluvial flow the situation is again tidally dominated. It is worth noting that the scale of effect remains very similar to Tests a and b, considering the reduced tide range used for this test.

The predicted effect of the works on maximum water levels at all the tide gauges landward of the Thames Barrier are tabulated below in Table 15.

Table 15 Predicted maximum water levels at tide gauges, Test d

	Maximum level (m OD(N))		Difference in maximum level (m)	Maximum level (m OD(N))		Difference in maximum level (m)
	Baseline	Temporary works		Baseline	Permanent works	
Richmond	4.127	4.083	-0.043	4.127	4.103	-0.024
Chelsea	3.674	3.646	-0.029	3.674	3.661	-0.013
Westminster	3.635	3.610	-0.025	3.635	3.623	-0.011
Tower	3.632	3.637	0.005	3.632	3.636	0.004
Charlton	3.587	3.587	0.007	3.587	3.590	0.003

Changes in peak water levels due to the development for Test d show the same pattern as Tests a and b. Table 16 extends the results presented above to show the effects of the works in the identified tidal reaches. This confirms the type of scale of effects as shown at the tide gauge locations. The largest decrease in peak water level is 0.045 m in the landward reaches for the Temporary works case. For the permanent works case the comparable reduction is 0.024 m. The largest increase in peak water level for the Temporary works case is predicted as 0.01 m in the reaches between Tower and Charlton. With the Permanent works in place the largest increase is 0.005 in the same reach.

Table 16 Predicted maximum water levels in tidal reaches, Test d

River reach (inclusive downstream)	Maximum peak water level difference in reach (m)		Minimum peak water level difference in reach (m)	
	Temporary works	Permanent works	Temporary works	Permanent works
Teddington- Richmond	-0.043	-0.024	-0.045	-0.025
Richmond- Chelsea	-0.029	-0.013	-0.043	-0.025
Chelsea- Westminster	-0.024	-0.011	-0.025	-0.014
Westminster- Tower	0.005	0.004	-0.022	-0.009
Tower- Charlton	0.010	0.005	0.002	0.003
Charlton- Tilbury	0.007	0.003	0.002	0.001

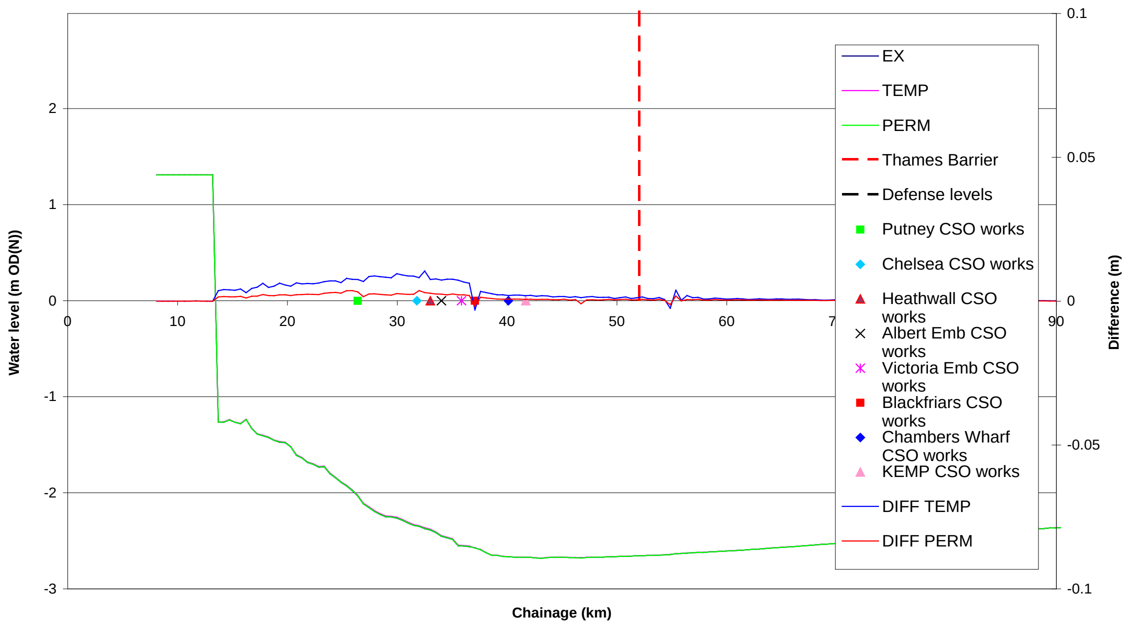

Figure 15 Minimum water levels for Test d

Figure 15 shows a general increase in minimum water level under these conditions. The values are tabulated at the tide gauge sites in Table 17.

Table 17 Predicted minimum water levels at tide gauges, Test d

	Minimum level (m OD(N))		Difference in minimum level (m)	Minimum level (m OD(N))		Difference in minimum level (m)
	Baseline	Temporary works		Baseline	Permanent works	
Richmond	1.310	1.310	0.000	1.310	1.310	0.000
Chelsea	-2.340	-2.331	0.009	-2.340	-2.337	0.002
Westminster	-2.415	-2.407	0.008	-2.415	-2.412	0.003
Tower	-2.652	-2.649	0.002	-2.652	-2.651	0.001
Charlton	-2.662	-2.660	0.001	-2.662	-2.661	0.001

The predicted raising of low water is less than 0.010 m for the temporary works case and 0.03 m for the permanent works case.

Further detail of the through tide variation in water level is shown in Figure 16.

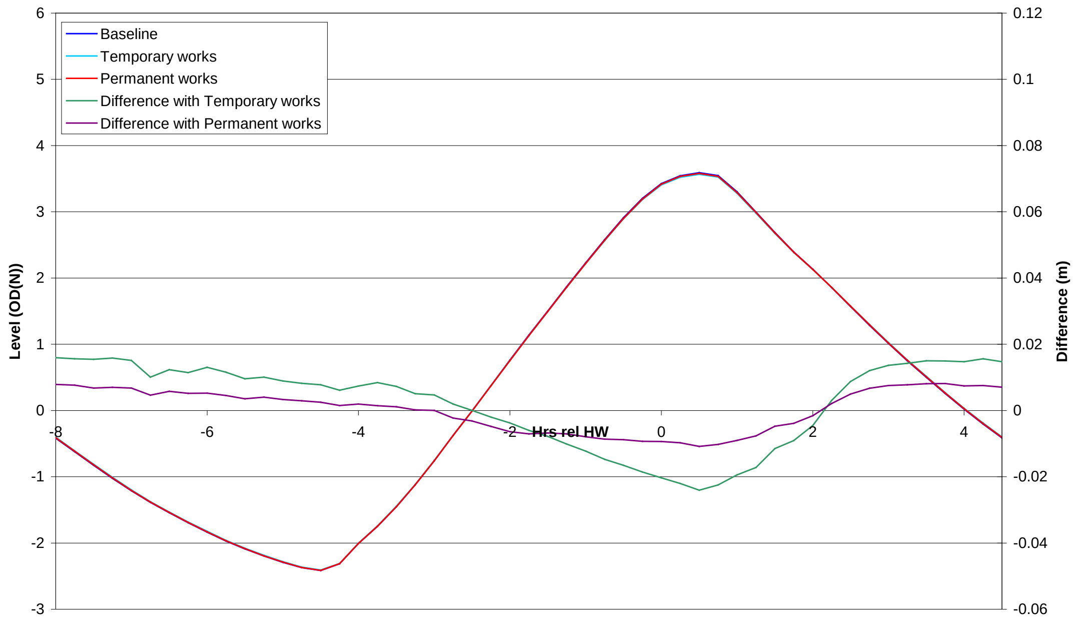

Figure 16 Predicted effects of works on the tide at Westminster Pier, Test d

Table 18 includes the maximum effect of the works on tidal levels throughout the tidal period – either to increase or decrease water levels due to the changed tide phasing.

Table 18 Through-tide effect of works on water level at tide gauges, Test d

	Largest through tide effect on tide curve – Temporary works		Largest through tide effect on tide curve – Permanent works	
	Increase (m)	Decrease (m)	Increase (m)	Decrease (m)
Richmond	0.009	-0.070	0.004	-0.038
Chelsea	0.032	-0.038	0.009	-0.016
Westminster	0.017	-0.024	0.009	-0.011
Tower	0.018	-0.024	0.009	-0.013
Charlton	0.009	-0.017	0.004	-0.007

Test d shows reduced water level from mid flood to mid ebb around high water, which indicate the tidal impedance of the works. In Test d the works seem to have a smaller effect overall than in Test c. These results again show the sensitivity of the tidal propagation to the balance of tide range and fluvial input.

3.2.5 Test e

Tests e is a mean tide range with mean daily fluvial flow. It is included to provide average flow conditions so that the impact on aquatic life can be better understood. The conditions are HW Southend 2.4 mOD(N), fluvial flow at Teddington 65 m^3/s. The predicted peak water levels for baseline conditions and with the works in place are shown in Figure 17 and tabulated in Table 19.

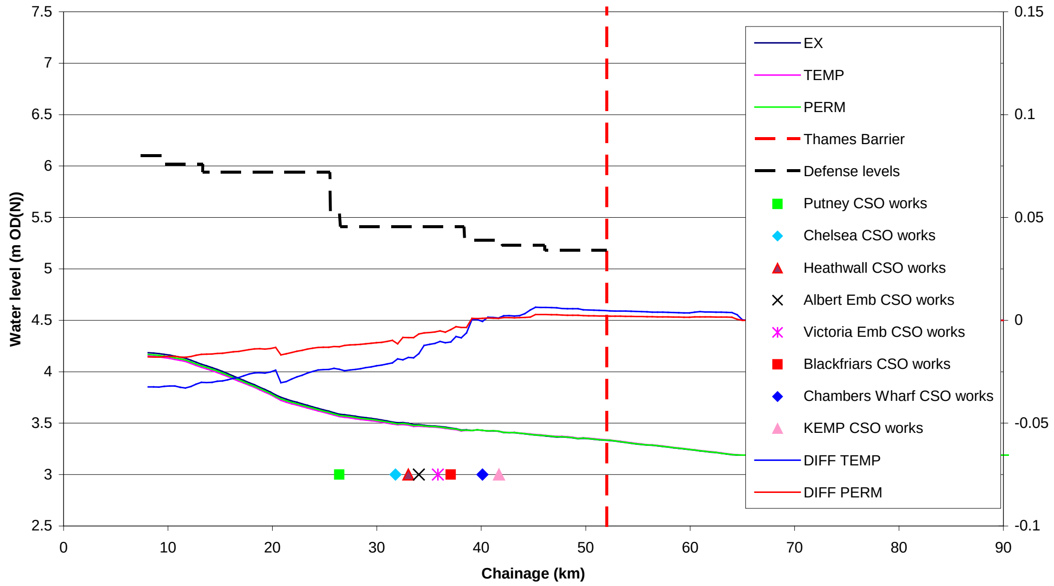

Figure 17 Maximum water levels for Test e

Figure 17 shows changes in peak water levels along the long section of the Thames. The patterns of differences in peak flows for Test e are very similar to Test a (Figure 5). Comparison of Tests a and c suggest the effect of the works are not very sensitive to tide range for mid to higher range tides –when the when the works are occupying some of the flow cross section. The effect of the works on the peak water levels are tabulated in Table 19 below.

Table 19 Predicted maximum water levels at tide gauges, Test e

	Maximum level (m OD(N))		Difference in maximum level (m)	Maximum level (m OD(N))		Difference in maximum level (m)
	Baseline	Temporary works		Baseline	Permanent works	
Richmond	4.113	4.080	-0.032	4.113	4.095	-0.018
Chelsea	3.512	3.491	-0.021	3.512	3.502	-0.010
Westminster	3.486	3.468	-0.018	3.486	3.478	-0.008
Tower	3.428	3.428	0.000	3.428	3.429	0.001
Charlton	3.343	3.348	0.005	3.343	3.345	0.002

Table 19 shows the differences landward of the Thames Barrier for Test e are very similar to Test a, although values actual peak values are slightly smaller associated with the smaller tide range. In this case (as for test d) some small increases are predicted in the area around and seawards of the Thames Barrier, up to 0.005 m for the Temporary works and 0.002 m for the permanent works.

The predicted changes to peak water levels for the whole tidal Thames are given in Table 20. These results confirm the nature and scale of changes predicted at the tide gauge locations. The temporary works result in a largest reduction of peak water level of 0.033 m between

Teddington and Richmond with the largest increase in peak water level 0.006 between Tower and Charlton. For the permanent works the largest changes are at the same locations although the magnitudes are roughly halved.

Table 20 Predicted maximum water levels in tidal reaches, Test e

River reach (inclusive downstream)	Maximum peak water level difference in reach (m)		Minimum peak water level difference in reach (m)	
	Temporary Works	**Permanent works**	**Temporary works**	**Permanent works**
Teddington- Richmond	-0.032	-0.018	-0.033	-0.018
Richmond- Chelsea	-0.021	-0.010	-0.031	-0.017
Chelsea- Westminster	-0.018	-0.008	-0.019	-0.011
Westminster- Tower	0.000	0.001	-0.016	-0.007
Tower- Charlton	0.006	0.003	-0.001	0.001
Charlton- Tilbury	0.005	0.002	0.000	0.000

To show the sensitivity to tide range of the predicted effect of the works on minimum water level these values were extracted for Test e. As for Test a, the minimum water level above Richmond Lock is set by the operation of the half tide weir at that location.

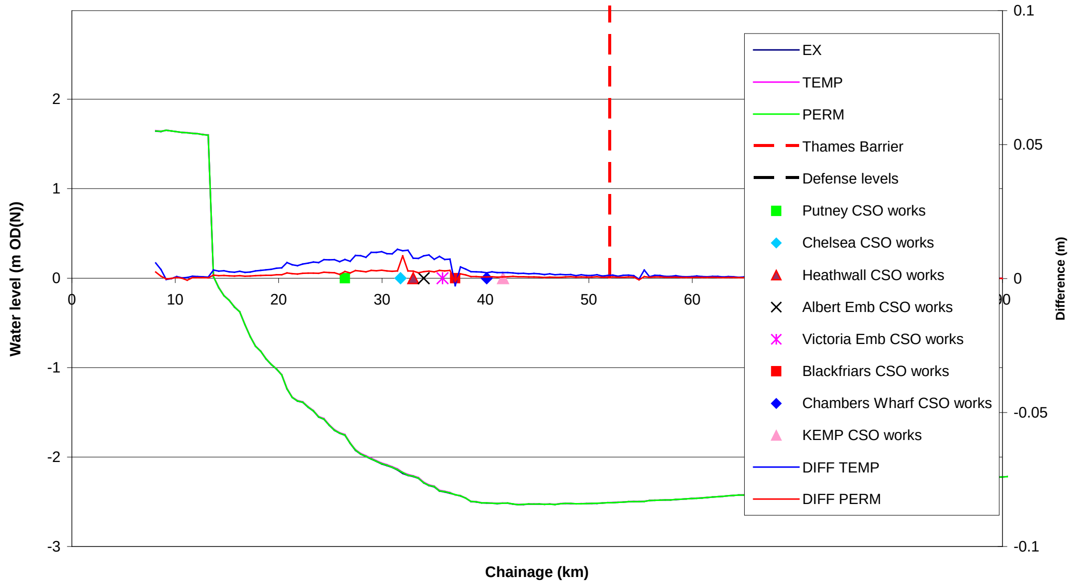

Figure 18 Minimum water levels for Test e

In this case the effect of the works on low water is less than that predicted for Test a. This reduced effect is a function of the smaller tide range in Test e with an associated reduced effect on impeding the tide. For the permanent works the effect of the works is less than 0.003 m. Tabulated results to match Figure 18 are shown in Table 21 below.

Table 21 Predicted minimum water levels at tide gauges, Test e

	Minimum level (m OD(N))		Difference in minimum level (m)	Minimum level (m OD(N))		Difference in minimum level (m)
	Baseline	Temporary works		Baseline	Permanent works	
Richmond	1.614	1.615	0.001	1.614	1.615	0.000
Chelsea	-2.144	-2.133	0.011	-2.144	-2.141	0.003
Westminster	-2.237	-2.230	0.008	-2.230	-2.235	0.002
Tower	-2.501	-2.499	0.002	-2.501	-2.500	0.001
Charlton	-2.518	-2.518	0.001	-2.518	-2.517	0.001

How these results are reflected through the tide is shown by Figure 19 and Table 22 below.

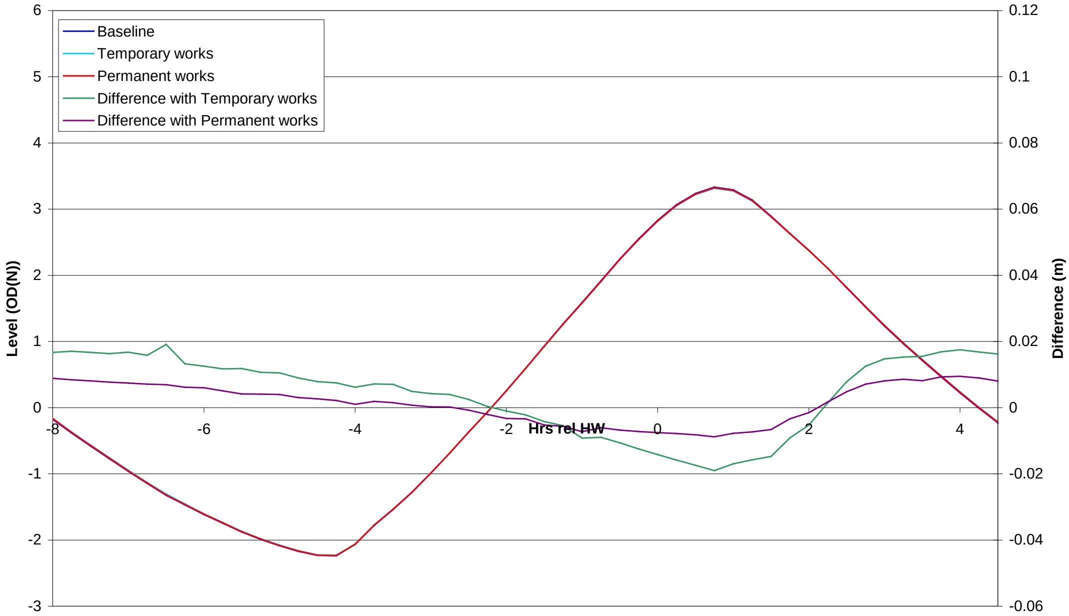

Figure 19 Predicted effects of works on the tide at Westminster Pier, Test e

Table 22 Through-tide effect of works on water level, Test e

	Largest through tide effect on tide curve – Temporary works		Largest through tide effect on tide curve – Permanent works	
	Increase (m)	Decrease (m)	Increase (m)	Decrease (m)
Richmond	0.008	-0.072	0.004	-0.025
Chelsea	0.032	-0.029	0.010	-0.012
Westminster	0.019	-0.019	0.010	-0.009
Tower	0.014	-0.022	0.007	-0.012
Charlton	0.008	-0.015	0.003	-0.006

The through-tide effect of the works on the tide at Westminster is comparable to Test a where the tidal range was larger. The behaviour is also similar to Test b and d. The largest differences in water level at Westminster occur during the ebb tide (where the levels are higher than in the existing case) and at the times near high waters (where the levels are lower than in the existing case). These changes are no larger than 0.02 m.

The largest differences in through tide level are predicted at Richmond and are decreases of 0.072 m (temporary works) and 0.025 m (permanent works). For the temporary and permanent works the increase and decrease in water level are broadly of a comparable magnitude.

3.2.6 *Test f*

Test f was put forward by the Environment Agency as the largest fluvial flow for which mean spring tides would not result in closure of the Thames Barrier. The conditions are HW Southend 2.9 mOD(N), fluvial flow 736 m^3/s. Figure 20 presents the maximum water level for the baseline, temporary and permanent works cases.

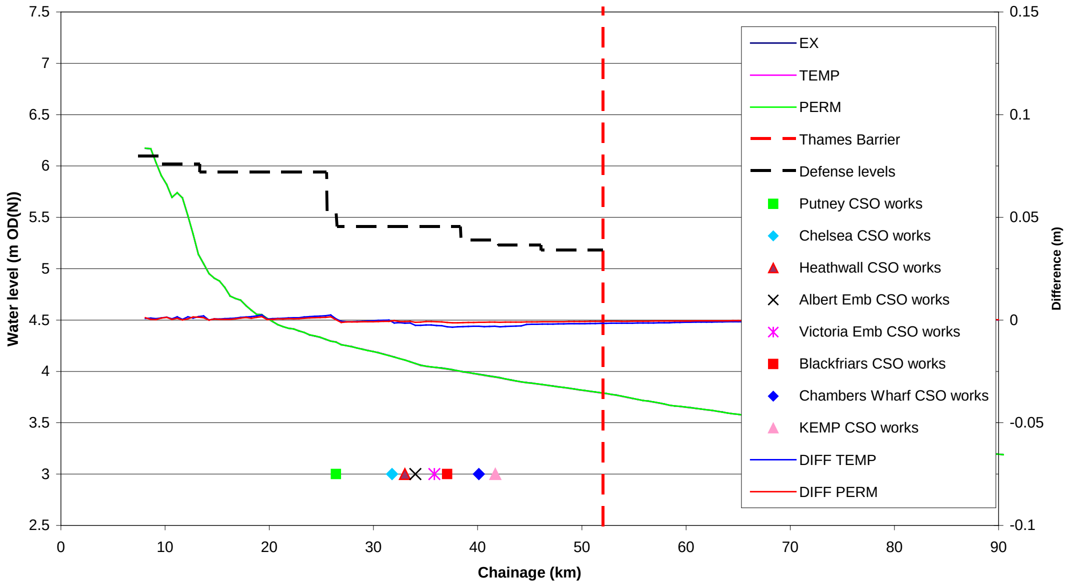

Figure 20 Maximum water levels for Test f

Figure 20 shows that changes to peak water levels due to the development are small throughout the Thames. The predicted effect of the works on peak water levels at all tide gauges landward of the Thames Barrier are tabulated below in Table 23. Test f can be compared to Test c (800 m^3/s flow). The changes in peak water level for Test f are very similar to Test c is as much as the effect of the development is very small (greatest difference is a reduction of 0.003 m). For the permanent works case the peak water levels are generally reduced by 0.001 m with the exception of Richmond which shows an increase in peak water level of 0.001 m.

Table 23 Predicted maximum water levels, Test f

	Maximum level (m OD(N))		Difference in maximum level (m)	Maximum level (m OD(N))		Difference in maximum level (m)
	Baseline	Temporary works		Baseline	Permanent works	
Richmond	5.517	5.518	0.002	5.517	5.517	0.001
Chelsea	4.154	4.154	0.000	4.154	4.154	-0.001
Westminster	4.094	4.093	-0.001	4.094	4.093	-0.001
Tower	3.989	3.986	-0.003	3.989	3.988	-0.001
Charlton	3.807	3.805	-0.002	3.807	3.806	-0.001

These results are shown to be broadly representative of the whole Thames Tideway in Table 24. The largest increase in peak water level from the temporary works is 0.002 m (2 mm) which stayed the same for the permanent works. Some areas of decreased peak water level are shown in the Reaches between Westminster and Tower. The largest decrease shown in this area is 0.003 m for the temporary works and 0.001 m for the permanent works.

Table 24 Predicted maximum water levels in tidal reaches, Test f

River reach (inclusive downstream)	Maximum peak water level difference in reach (m)		Minimum peak water level difference in reach (m)	
	Temporary works	Permanent works	Temporary works	Permanent works
Teddington- Richmond	0.002	0.001	0.000	0.000
Richmond- Chelsea	0.002	0.002	-0.001	-0.001
Chelsea- Westminster	-0.001	0.000	-0.002	-0.001
Westminster- Tower	-0.002	-0.001	-0.003	-0.001
Tower- Charlton	-0.002	-0.001	-0.003	-0.001
Charlton- Tilbury	0.000	0.000	-0.002	-0.001

Table 25 and Figure 21 show the effects of the works on minimum water level.

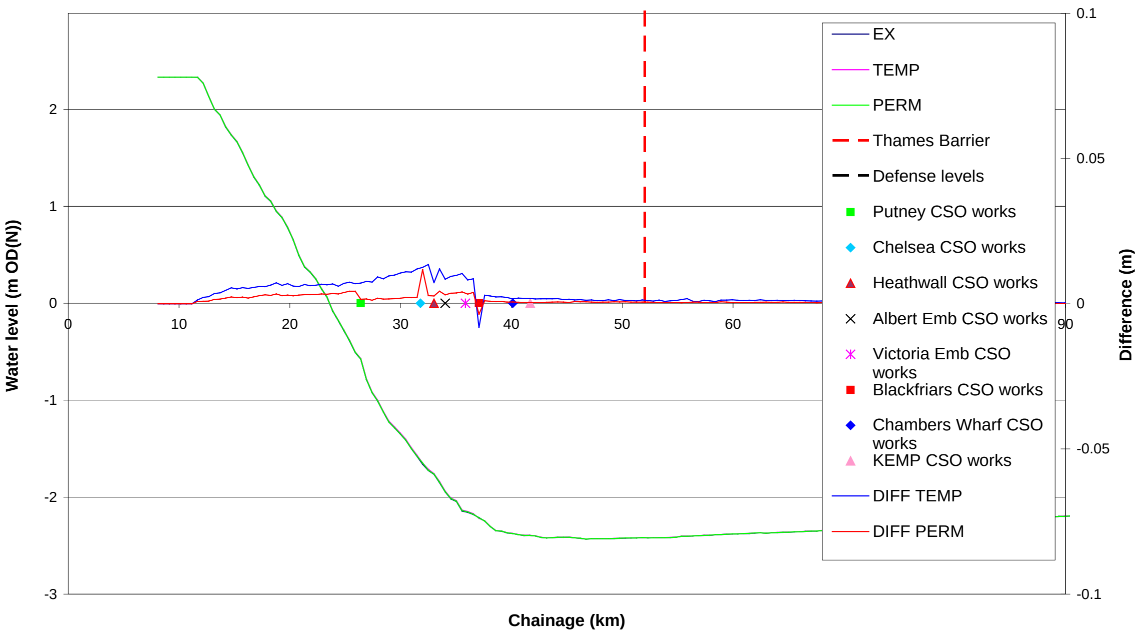

Figure 21 Minimum water levels for Test f

Table 25 Predicted minimum water levels at tide gauges, Test f

	Minimum level (m OD(N))		Difference in minimum level (m)	Minimum level (m OD(N))		Difference in minimum level (m)
	Baseline	Temporary works		Baseline	Permanent works	
Richmond	2.269	2.271	0.002	2.269	2.270	0.001
Chelsea	-1.580	-1.568	0.012	-1.580	-1.578	0.002
Westminster	-1.850	-1.838	0.012	-1.838	-1.845	0.004
Tower	-2.351	-2.348	0.002	-2.351	-2.350	0.001
Charlton	-2.421	-2.421	0.001	-2.421	-2.420	0.001

A general increase in minimum water level is predicted for this case with the largest magnitude of change being 0.012 m at Westminster and Chelsea for the temporary works case. For the permanent works case this effect reduced markedly to 0.004 m increase at Chelsea.

Further detail of the through tide variation in water level is shown in Figure 22.

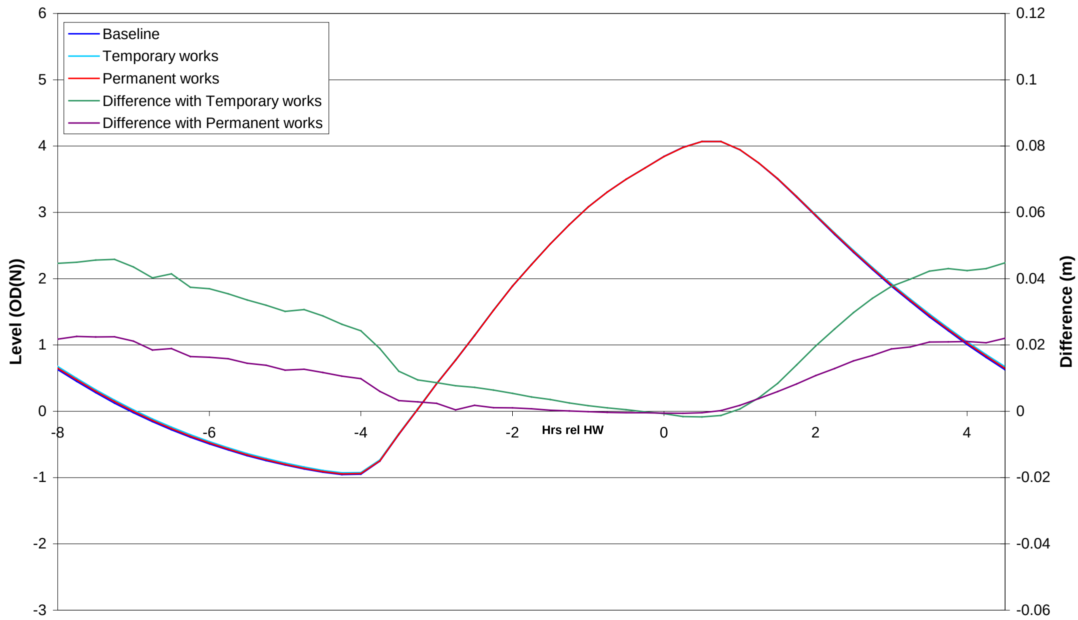

Figure 22 Predicted effects of works on the tide at Westminster Pier, Test f

Figure 22 shows that water levels during Test f at Westminster remain higher through the tide with the development in place. Water levels are higher with temporary structures during the ebb tide (the effect of the permanent structures is again smaller than the temporary one). The levels at high waters are very similar. This again shows the different effect which can occur depending on the tidal/fluvial flow combination modelled. Table 26 includes the maximum effect of the works on tidal levels throughout the tidal period – either to increase or decrease water levels due to the changed tide phasing.

Table 26 Through-tide effect of works on water level, Test f

	Largest through tide effect on tide curve – Temporary works		Largest through tide effect on tide curve – Permanent works	
	Increase (m)	Decrease (m)	Increase (m)	Decrease (m)
Richmond	0.015	-0.001	0.008	-0.001
Chelsea	0.072	-0.001	0.024	0.000
Westminster	0.046	-0.002	0.023	-0.001
Tower	0.011	-0.014	0.004	-0.008
Charlton	0.007	-0.012	0.002	-0.004

Table 26 shows that the effect at ebb tide (shown as increased level) is greater for the temporary works. Increases in water level can be up to 0.07 m as shown at Chelsea for the temporary works, reducing to 0.02 for the permanent works.

3.2.7 Test g

Case g was requested by the Environment Agency. It represents the largest flow for which the Thames Barrier will remain open. From the available tidal records a tide has been chosen with a low enough high water at Southend which would allow the Thames Barrier to remain open. The conditions are HW Southend 2.35 mOD(N), fluvial flow 1051 m^3/s. This flow is an extreme case with a return period of more than 500 years (HR Wallingford, 2006b). Figure 23 shows the maximum water level achieved during the simulation.

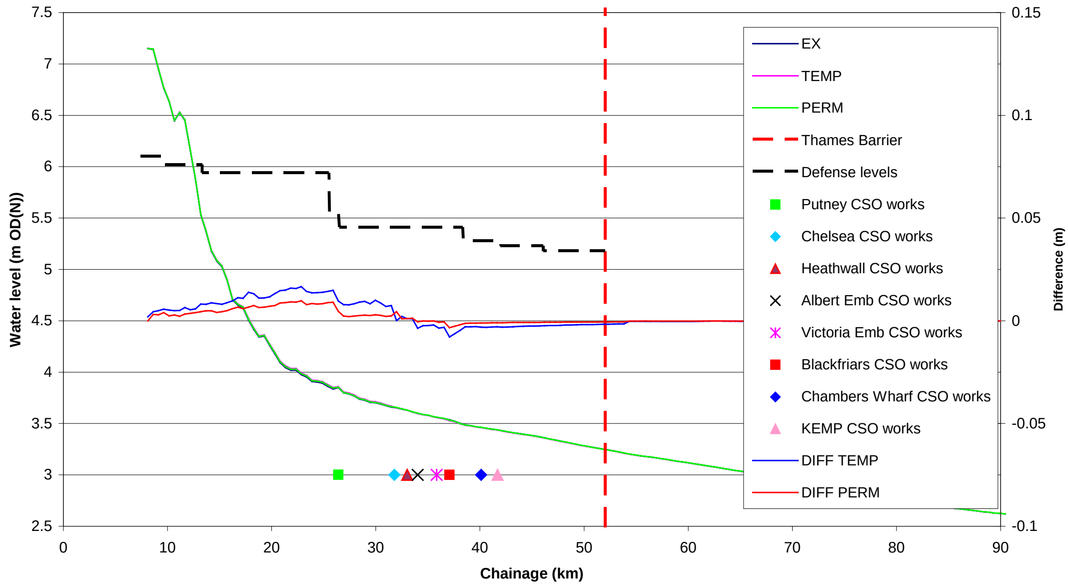

Figure 23 Maximum water levels for Test g

In Test g the fluvial flow further dominates the predicted peak water level. Peak levels upstream of Chelsea are increased with the works in place as the works impede the seawards transit of the large fluvial flow. Downstream of Chelsea peak levels are slightly lower with the works. Permanent works pose a smaller blockage hence the effect of these on the peak levels is smaller.

The predicted effect of the works on maximum water levels at all the tide gauges landward of the Thames Barrier are tabulated below in Table 27.

Table 27 Predicted maximum water levels at tide gauges, Test g

	Maximum level (m OD(N))		Difference in maximum level (m)	Maximum level (m OD(N))		Difference in maximum level (m)
	Baseline	Temporary works		Baseline	Permanent works	
Richmond	6.158	6.164	0.005	6.158	6.162	0.004
Chelsea	3.660	3.668	0.007	3.660	3.663	0.002
Westminster	3.613	3.614	0.001	3.613	3.614	0.001
Tower	3.479	3.476	-0.003	3.479	3.478	-0.001
Charlton	3.269	3.267	-0.002	3.269	3.268	-0.001

In common with the plot the results of the table show an increase in peak water level between Westminster and Richmond due to the temporary works. Seawards of Westminster reductions are predicted. The permanent works have a similar effect on the peak water levels though with a smaller magnitude of change associated with the smaller structures in the permanent case. Table 28 shows that the results presented at the tide gauge locations are representative of the results along the reaches of the Tidal Thames.

Table 28 Predicted maximum water levels in tidal reaches, Test g

River reach (inclusive downstream)	Maximum Water Level difference in reach (m)		Minimum Water Level difference in reach (m)	
	Temporary works	Permanent works	Temporary works	Permanent works
Teddington- Richmond	0.006	0.004	0.002	0.000
Richmond- Chelsea	0.017	0.010	0.006	0.002
Chelsea- Westminster	0.002	0.004	0.000	0.001
Westminster- Tower	-0.002	0.000	-0.008	-0.003
Tower- Charlton	-0.002	-0.001	-0.003	-0.001
Charlton- Tilbury	0.000	0.000	-0.002	-0.001

Figure 24 and Table 29 show the effect of the works on minimum water levels. A general increase in minimum water levels, which in combination with the predicted increase in maximum levels suggests the works act to increase the mean water level slope in the landward reaches of the Tideway. The largest change in minimum water level for the temporary works case is more than 0-.01 m near the Chelsea tide gauge site. For the permanent works case the general magnitude of increase in water level is less than for the temporary case, with exception of a small spike in increased minimum water level at Chelsea which again reaches a peak of the order of 0.01 m, similar to that for the temporary works case.

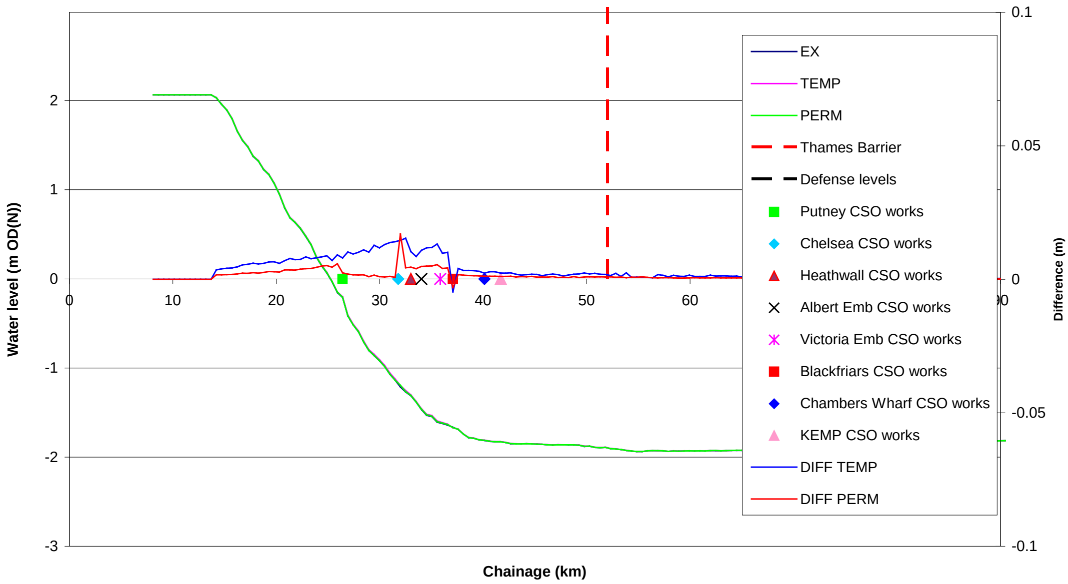

Figure 24 Minimum water levels for Test g

Table 29 Predicted minimum water levels at tide gauges, Test g

	Minimum level (m OD(N))		Difference in minimum level (m)	Minimum level (m OD(N))		Difference in minimum level (m)
	Baseline	Temporary works		Baseline	Permanent works	
Richmond	3.296	3.297	0.001	3.296	3.297	0.001
Chelsea	-1.461	-1.450	0.010	-1.461	-1.461	0.000
Westminster	-1.785	-1.778	0.007	-1.778	-1.783	0.003
Tower	-2.605	-2.603	0.002	-2.605	-2.605	0.000
Charlton	-2.791	-2.791	0.001	-2.791	-2.791	0.000

A slight increase in minimum water level is predicted for this case with the largest magnitude of change being 0.010 m at Westminster and Chelsea for the temporary works case. For the permanent works case this effect reduced to 0.003 m increase at Westminster.

Further detail of the through tide variation in water level is shown in Figure 25.

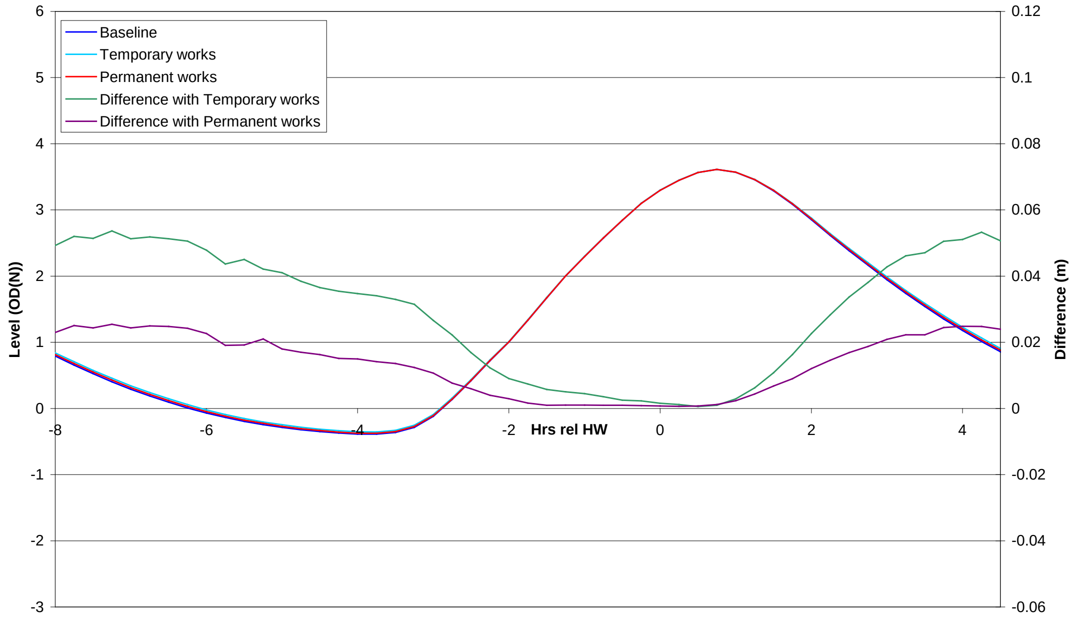

Figure 25 Predicted effects of works on the tide at Westminster Pier, Test g

The pattern of effect is of very similar order of magnitude to Test f both in terms of the differing effect between ebb and flood phases of the tide and the different behaviours of the temporary and permanent works. Table 30 includes the maximum effect of the works on tidal levels throughout the tidal period – either to increase or decrease water levels due to the changed tide phasing.

Table 30 Through-tide effect of works on water level, Test g

	Largest through tide effect on tide curve – Temporary works		Largest through tide effect on tide curve – Permanent works	
	Increase (m)	Decrease (m)	Increase (m)	Decrease (m)
Richmond	0.012	0.000	0.008	-0.001
Chelsea	0.086	0.004	0.027	0.001
Westminster	0.054	0.001	0.025	0.001
Tower	0.009	-0.012	0.003	-0.007
Charlton	0.005	-0.011	0.002	-0.004

The result of this analysis of the effect of the works during the tide is extremely similar to those produced by Test f.

3.2.8 Test h

Test h simulated a set of actual tides including a closure of the Thames Barrier. The fluvial flow during the period was 400 – 450 m^3/s with HW at Southend up to 3.4 mOD(N). Figure 26 shows the maximum water level with peak water levels at the tide gauges in the area tabulated in Table 31.

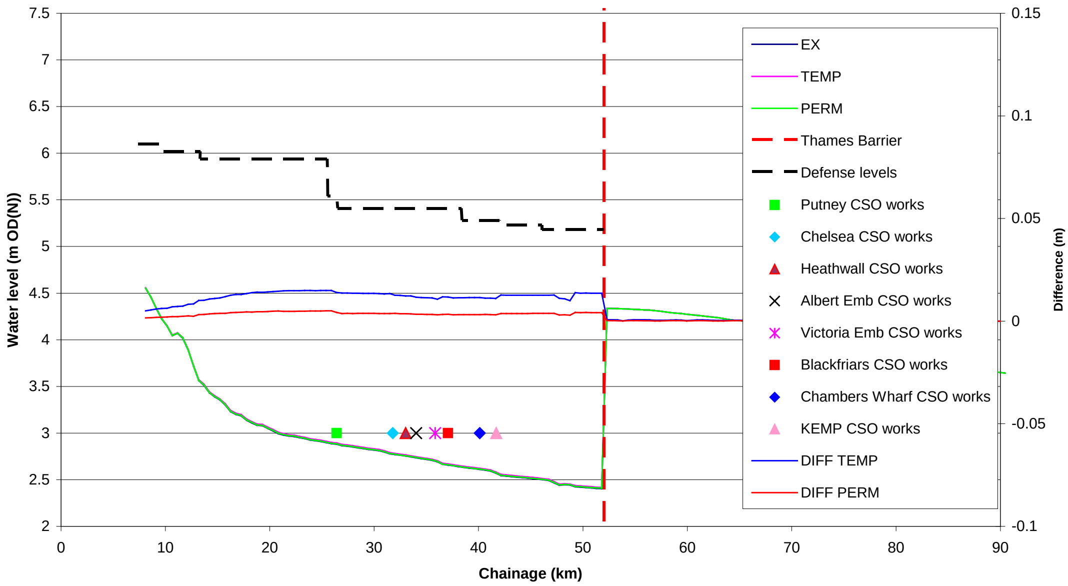

Figure 26 Maximum water levels for Test h

Table 31 Predicted maximum water levels at tide gauges, Test h

	Maximum level (m OD(N))		Difference in maximum level (m)	Maximum level (m OD(N))		Difference in maximum level (m)
	Baseline	**Temporary works**		**Baseline**	**Permanent works**	
Richmond	3.888	3.897	0.008	3.888	3.891	0.003
Chelsea	2.777	2.791	0.013	2.777	2.781	0.004
Westminster	2.745	2.757	0.012	2.745	2.748	0.004
Tower	2.625	2.636	0.011	2.625	2.628	0.003
Charlton	2.412	2.426	0.014	2.412	2.416	0.004

In common with Figure 26 the results of the table shows an increase in peak water level at all the tide gauge sites for the temporary works. The permanent works have a similar effect on the peak water levels though with a smaller magnitude of change associated with the smaller structures in the permanent works case. Table 32 confirms the effect of the works on peak level extracted at the tide gauge sites as broadly representative of the data throughout the reaches of the Tideway.

Table 32 Predicted maximum water levels in tidal reaches, Test h

River reach (inclusive downstream)	Maximum Water Level difference in reach (m)		Minimum Water Level difference in reach (m)	
	Temporary Works	Permanent works	Temporary works	Permanent works
Teddington- Richmond	0.008	0.003	0.005	0.002
Richmond- Chelsea	0.015	0.005	0.008	0.002
Chelsea- Westminster	0.013	0.004	0.012	0.004
Westminster- Tower	0.012	0.003	0.011	0.003
Tower- Charlton	0.014	0.004	0.010	0.003
Charlton- Tilbury	0.014	0.004	0.000	0.000

The effects of the works on minimum water levels are presented in Figure 27 and Table 33.

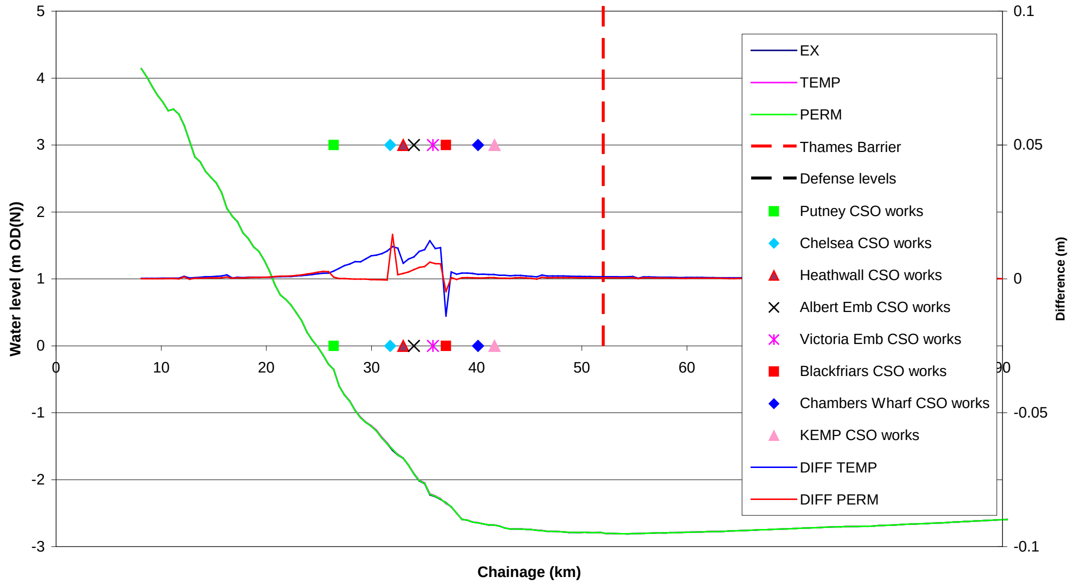

Figure 27 Minimum water levels for Test h

Table 33 Predicted minimum water levels at tide gauges, Test h

	Maximum level (m OD(N))		Difference in maximum level (m)	Maximum level (m OD(N))		Difference in maximum level (m)
	Baseline	Temporary works		Baseline	Permanent works	
Richmond	3.296	3.297	0.001	3.296	3.297	0.001
Chelsea	-1.461	-1.450	0.010	-1.461	-1.461	0.000
Westminster	-1.785	-1.778	0.007	-1.778	-1.783	0.003
Tower	-2.605	-2.603	0.002	-2.605	-2.605	0.000
Charlton	-2.791	-2.791	0.001	-2.791	-2.791	0.000

Figure 27 and Table 33 indicate that low water levels are increased as well as high water levels. This is as might be expected for the structures taking up some of the tidal volume without any effect on tidal propagation as shown by the other test cases.

The through tide variation in the effect of the works on tidal level is provided by Figure 28 and Table 34.

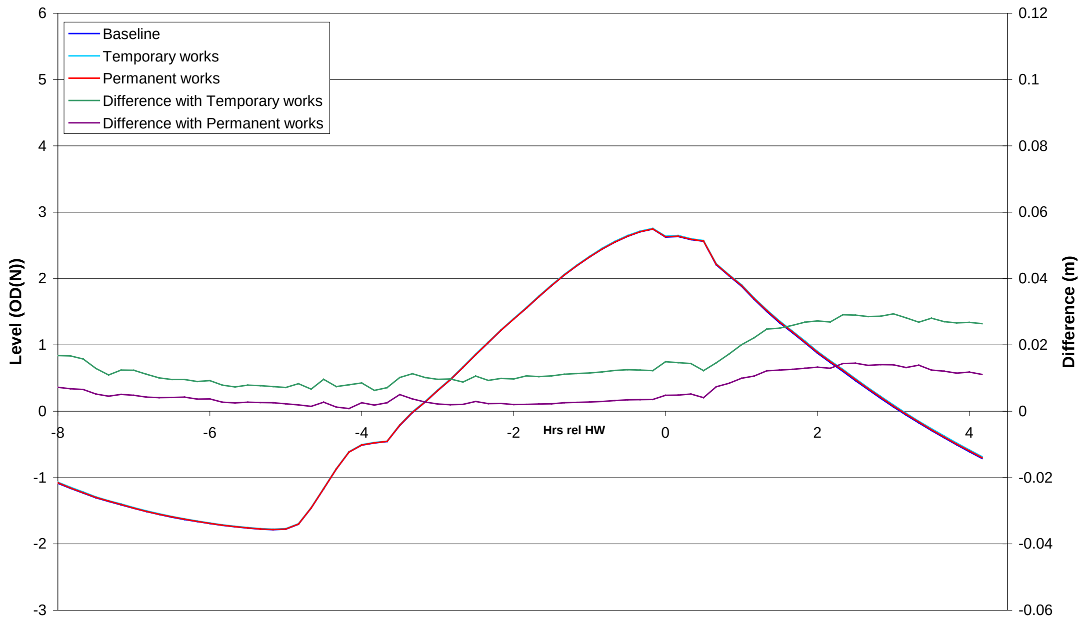

Figure 28 Predicted effects of works on the tide at Westminster Pier, Test h

Table 34 Through-tide effect of works on water level, Test h

	Largest through tide effect on tide curve – Temporary works		**Largest through tide effect on tide curve – Permanent works**	
	Increase (m)	**Decrease (m)**	**Increase (m)**	**Decrease (m)**
Richmond	0.008	0.000	0.003	0.000
Chelsea	0.046	0.006	0.013	-0.001
Westminster	0.029	0.005	0.014	0.001
Tower	0.016	-0.009	0.005	-0.006
Charlton	0.015	-0.008	0.005	-0.003

3.3 ENVELOPE OF PREDICTED CHANGE IN MAXIMUM WATER LEVEL

To provide a summary of the model predictions for maximum water level the maximum predicted water level has been extracted from all the scenario tests completed. Comparison between the maximum water level predicted for the simulations with the temporary and permanent works were then compared with the baseline conditions. Figure 29 shows a long section of the combined results as was plotted in the main text of the report.

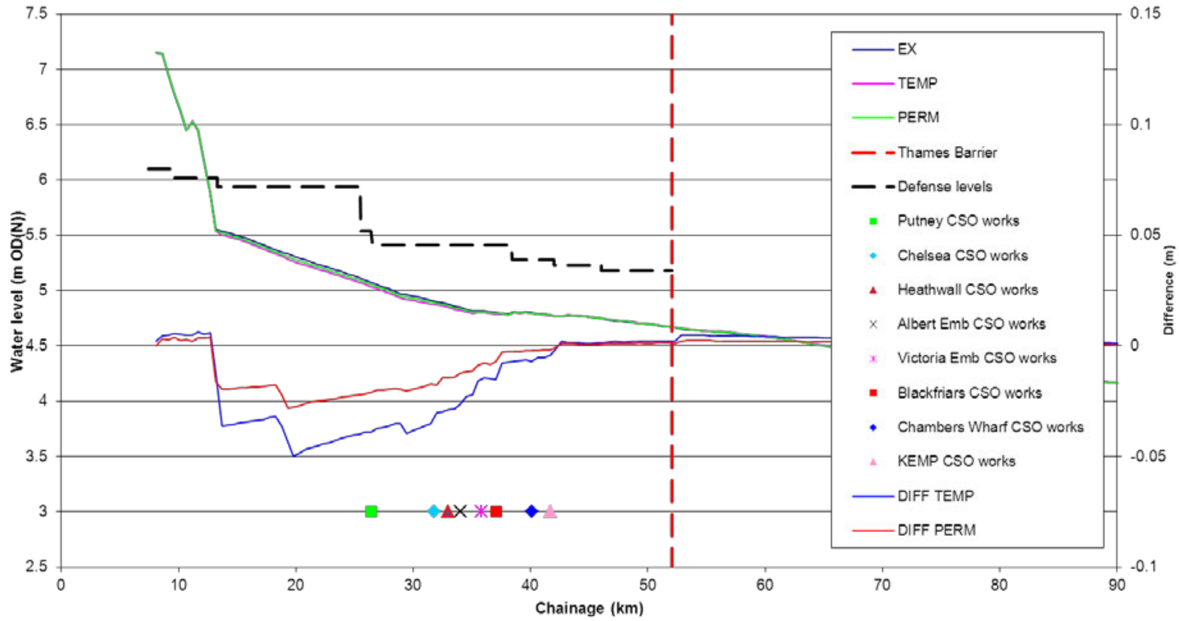

Figure 29 Maximum water levels, all tests

Numerical results for the maximum water level and change in maximum water level for the works have been extracted at the sites of tide gauges along the length of the Tidal Thames (Table 35) and summarised for particular reaches to make sure the largest predicted changes are captured. (Table 36).

Table 35 Predicted maximum water level at tide gauges, all tests

	Maximum level (m OD(N))		Difference in maximum level (m)	Maximum level (m OD(N))		Difference in maximum level (m)
	Baseline	Temporary Works		Baseline	Permanent works	
Richmond	6.158	6.164	0.005	6.158	6.162	0.004
Chelsea	4.915	4.880	-0.035	4.915	4.898	-0.017
Westminster	4.860	4.831	-0.029	4.860	4.846	-0.014
Tower	4.802	4.795	-0.007	4.802	4.800	-0.002
Charlton	4.685	4.687	0.002	4.685	4.687	0.001

Table 36 Predicted maximum water levels in tidal reaches, all tests

River reach (inclusive downstream)	Maximum Water Level difference in reach (m)		Minimum Water Level difference in reach (m)	
	Temporary Works	Permanent works	Temporary Works	Permanent works
Teddington-Richmond	0.006	0.004	0.002	0.000
Richmond-Chelsea	0.006	0.004	-0.050	-0.028
Chelsea-Westminster	-0.029	-0.014	-0.030	-0.017
Westminster-Tower	-0.007	-0.002	-0.026	-0.012
Tower-Charlton	0.002	0.001	-0.007	-0.002
Charlton-Tilbury	0.005	0.002	0.002	0.001

In summary the areas from Richmond landward are the same as test g (the largest fluvial case) and the areas seaward of Richmond are the same as test a (the largest tide case).

4. Discussion

4.1 DISCUSSION OF MODEL RESULTS

The tide curve in the Thames Tideway is a result of the complex interaction of the incoming tide and the fluvial input from landward. This interaction becomes increasingly biased towards the fluvial input landward of Westminster where friction effects restrict any further lowering of low water. Landward of Westminster the tidal high water continues to increase whereas the low water level is a function of the fluvial flow.

The proposed works are of a sufficient size to impede flow passing them, somewhat like the water level difference seen across a bridge (the head difference). Furthermore in a tidal situation the amount of energy loss across a structure may change the tidal 'signal' which then alters the propagation further along the estuary.

The peak water levels, being a function of the interacting tide and fluvial flow can be influenced by the works. In general it may be considered that the works impede the fluvial flow going seawards, with the potential to decrease or increase (depending upon location and conditions) water levels and impede the tidal flow moving landward. It is the interaction of these two effects which the simulations have explored. Therefore the works alter the balance of the tide with the fluvial inputs, and the simulations have shown that the effect of the works can be different for the fluvially or tidally dominated cases. Some difference is also shown between the temporary and permanent works, again as there are differences in the predicted effect on the tidal and fluvial flows.

For the landward reaches the general effects of the works in impeding the tide is predicted to have negligible effect or reduce peak water levels up to and including the 800 m^3/s fluvial flow case (Test c) which is considered to be the 1:100 year fluvial flow. In the case of the Temporary works, for this fluvial flow condition, the effects of the works in impeding the incoming tide and the outgoing fluvial flow are approximately balanced. For the higher flow case (Test g) a small increase in peak water level at Richmond (0.007 m) is predicted for the Temporary works.

Further seawards, some simulations show small increases and some show small decreases in maximum levels. In either case the effects are very small, a few mm.

The general effects of the works on minimum water levels are more straightforward. In the landward reaches the low water is a function of fluvial flow and so any impeding of a large fluvial flow is shown to increase minimum water level. In the tidally dominated cases the impeding of the incoming tide does increase minimum water level, though this effect diminishes landwards as the fluvial flow increasingly dominates low water level. Above Richmond the minimum water level is set by the operation of the Richmond Half Tide Weir.

4.2 IMPLICATIONS FOR FLOOD STORAGE

The Thames Tideway, landward of the Thames Barrier can be regarded as a volume available for flood storage either to contain incoming surges or large fluvial inputs. Any structures in the tidal Thames could usually be assumed to reduce the available volume for flood storage. The minimum volume available for flood storage relates to the value between the flood defence level and the maximum water level. This volume is of interest as it must be sufficient to contain any other flows into the tidal Thames without flooding occurring.

The simulations undertaken have shown that for all conditions for which the Thames Barrier will be open, up to and including the 1:100 year flow (800 m^3/s), the works impede the incoming tide sufficiently to decrease peak water levels in the area landwards of the Thames Barrier where flood storage is most critical. Hence with the works in place the volume of flood storage occupied by the works is more than replaced by the effect of the works in reducing peak water level.

The volume of water moving in and out through the line of the Thames Barrier has been calculated from the model results to be of the order of 50 Mm^3 for a spring tide. The temporary works themselves occupy a volume of up to 200,000 m^3, of the order of 0.5 % of the total. A calculation of the tidal volume with the works included suggests the effect of the works reduces the maximum tidal volume in the area by nearly 400,000 m^3 associated with the reduction in tide range. As shown above, half of this reduction is a direct effect of the footprint of the works themselves. However a further 200,000 m^3 of water volume reduction is shown due to the tidal effect.

The exception to the predicted reduction in maximum water level is Test g which represents the largest flow for which the Thames Barrier will remain open (1051 m^3/s). This test case shows that for an extreme flow the structures will to some extent impede outgoing fluvial flow, however, as this flow has a return period of more than 500 years (HR Wallingford, 2006b) it is considered that a flow of such a return period is beyond the range of conditions which are appropriate to be used in the assessment of the need for flood storage.

The implications of these results for flood storage is that whilst the structures remove volume potentially available for flood storage, the effect of the works on the tide has the net result of an increase in volume available for flood storage around high water. Therefore, without a loss of volume available for flood storage, there is not a need to provide additional flood storage to mitigate for the presence of the proposed CSO interception structures in the Thames Tideway.

It should be further noted that the Thames Tideway Tunnel itself provides up to 1 Mm^3 of storage for water which would otherwise have entered the Thames Tideway from the CSOs during storm overflow events. Whilst the timing of a storm event accessing the additional volume in the Thames Tideway Tunnel would not necessarily coincide with a high water level in the Tideway due to fluvial inputs or a surge, the Tunnel does have the effect of reducing the total water input under these circumstances.

4.3 THE THAMES BARRIER

Seven of the scenarios tested were at the limiting tide level / fluvial flow combinations for the Thames Barrier to be open. The Barrier closure rule is that with no fluvial flow, the Barrier should be closed for predicted high waters of 3.85 m OD(N) or more at Southend (Test a). For higher fluvial flows this closure level reduces, for example, for the 1:100 fluvial flow of 800 m^3/s the Barrier should be closed for predicted High Water at Southend of greater than 2.75 m OD(N) (Test c).

An analysis of the Thames Barrier closures undertaken as part of the development of the flood defence levels (Halcrow, (2002)) has shown that, in practice, the Thames Barrier is closed adopting a precautionary principle with barrier closures generally being initiated for predicted high waters at Southend between 0.2 and 0.4 m below that suggested by the closure rule for the equivalent fluvial flow. This ‘extra’ precaution is due to the decision to close being a human decision rather than adherence to a set rule.

The completed simulations have included some cases were the water level at Charlton (near the Thames Barrier) have increased. The largest increase predicted was 7 mm (Test d). This very small change is insufficient to require changes to the way the Thames Barrier is operated.

Once the Thames Barrier is closed the tide is excluded and currents in the landward reaches reduce greatly. In this situation the blockage effect of the works is likely to reduce greatly such that the peak water level achieved in the landward reaches is only changed by the presence of the works taking up volume which otherwise would be filled by the fluvial flow.

Test h predicted this effect as an increase in peak water level of 0.015 m in the landward reaches for a 400 m^3/s fluvial flow and a 5 hour Thames Barrier closure. It should be noted that the increase in peak level predicted is from a low starting point, governed by the Barrier closure. Seawards of the Barrier no effect of the works on peak water level was predicted.

4.4 TIDE RANGE AND DEPOSITION

The study as presented above has been focussed on the effect of the works on maximum or minimum water level conditions rather than a detailed assessment of sediment transport. However the results suggest that in general the tide range will be reduced due to the works and this may have some effect on sediment transport and deposition. Some information on the potential changes in the ability of the water body to suspend sediment can be assessed from the available results by looking at changes in predicted peak current. In this case the most precautionary view can be taken from the largest tide condition run – test a.

Figure 2 shows the peak mid channel current and change in peak current from the works predicted for test a.

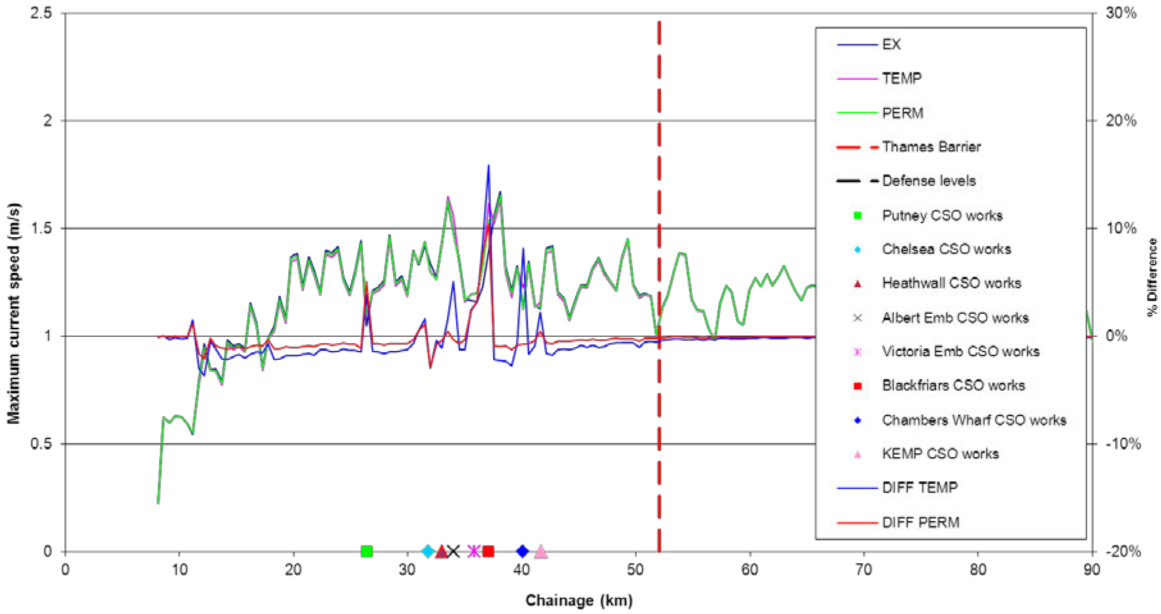

Figure 30 Maximum current speed mid channel, test a

A general 2% reduction in peak currents is predicted for this large spring tide case. This is mid channel and so excludes any localised areas of low currents in the immediate vicinity of the works. Areas of mid-channel speed increase are shown at the sites of the works as predicted by the detailed modelling.

The suspended solids concentration in the area of change (seawards of the Thames Barrier) is known to be variable seasonally with typical tide average values of 100 mg/l in summer (low flow) periods and 50 mg/l in winter (high flow) periods. The volume of water in the area is of the order of 50 Mm^3 therefore the average amount of sediment in suspension in the area landward of the Thames Barrier is up to approximately 5000 Tonnes in summer conditions (2% of the total suspended sediment for the whole Thames Estuary, Odd and Owen, 1972).

Typical empirical formulae relate the average suspended sediment concentration to the peak current to the power of 3. From this type of relationship the average suspended sediment concentration may be expected to reduce by 6% for a 2% reduction in peak current. This suggests that up to 300 Tonnes of sediment may be released from suspension in the area due to the tide range reduction associated with the works. An assessment of the sediment budget of the Thames Estuary has calculated the range of the input of fine sediment in to the Tideway from fluvial sources (River Thames + tributaries) as between 100,000 and 190,000 dry tonnes per year (HR Wallingford, 2006c). Therefore the deposition of 300 Tonnes of fine material due to the effect of the works on tide range is considered insignificant in the context of the natural variation in the suspended sediment regime of the tidal Thames.

4.5 CHECK OF PREDICTIONS AGAINST OTHER MODELLING METHODOLOGIES

The effect of blockages impeding the tide is generally held to be true for large blockages; however the scale of predicted effect of the proposed CSO interception works in reducing peak tidal water levels was not an intuitive result. To explore the results further and provide further confidence in the conclusions from the 2D modelling, further modelling was undertaken including a schematic version of the temporary works at Blackfriars (Fleet CSO) and using the 1D Isis model of the Thames. This 1D model was set up as a tool for the Environment Agency to use for management of flood risk in the Thames and it was extensively used for the Thames Estuary Flood Risk Management study (TE2100). At an early stage in TE2100 an inter-comparison of the 1D and 2D models was performed to allow use of the 1D model for the extensive modelling of flood management options that was required for the TE2100 project (HR Wallingford, 2006b) whilst the 2D modelling supported the more detailed estuary process studies.

The modelled conditions in the 1D model were for a typical spring tide with mean daily fluvial flow (65 m/s^3). The Temporary works at Blackfriars were included by using a calculation of energy loss due to contraction and expansion of flow (Bernoulli losses). The definition of the loss parameters is a function of the form of the contraction and expansion (e.g. its angle to the flow). For the tests undertaken this parameter was first given a “best estimated” value based on the information from the 2D model and the drawings of the works. Thereafter, the same tests were performed with the loss parameter firstly set to zero (no energy loss due to the structure), and secondly set to a theoretical maximum value. Peak water levels were extracted on either side of the works and then further afield, 10 km either side of the site. Table 35 shows the results of these tests.

Table 35 Isis model - predicted maximum water levels for schematic Blackfriars temporary works test case, typical spring tide, 65 m^3/s fluvial flow

	Level m OD(N)			
		Temporary works included as Bernoulli loss elements		
	Baseline conditions	Best estimate	Zero loss	Theoretical Maximum
Upstream	4.265	4.235	4.273	4.215
Downstream	4.261	4.256	4.265	4.254
10 km Upstream	4.333	4.301	4.334	4.276
10 km Downstream	4.164	4.176	4.171	4.180

The modelling with the Bernoulli losses using a best estimate of the loss parameter shows a reduction of peak water level of about 30 mm landward with the temporary works in place. In this case, the effect of the reduction in conveyance due to the losses has a greater impact on water level than the loss of volume. The scale of effect is very close to that predicted by the 2D model. The effect is maintained at the site some 10 km further landward.

With the maximum theoretical loss parameters the water level difference is about 50 mm.
These results provide confidence that the 2D model predictions of reduced peak water level due to the proposed works is of the correct order.

5. Conclusions

A set of tide/flow scenarios at the limiting conditions for closure of the Thames Barrier have been run.

Tidally dominated cases
The works act to impede the tidal flow, during both the flood and ebb phases. This acts to reduce the tidal high water in the landward reaches by up to approximately 50 mm for the temporary works case. Some small increases are predicted in the area around the Thames Barrier. All the predicted increases are reduced considerably for the permanent works cases. Low Water levels due to the tide in the landward reaches are increased by up to 50 mm. Landward of Richmond the level of Low Water is controlled by the Richmond Half Tide Weir.

Fluvially dominated cases
Up to and including the 1:100 year flow case no increase in maximum water level is predicted. For the largest fluvial flow without Barrier closure (1051 m^3/s) small increases in peak levels (up to 7 mm) are predicted for the temporary works case only. In the landward reaches Low Water level is dominated by the fluvial flow. For the 1:100 year flow the temporary works increase the level of Low Water by up to 50 mm. The predicted effects are reduced considerably for the permanent works cases.

Flood storage
As both the temporary and permanent works, up to and including the 1:100 year fluvial flow case, reduce the highest water levels which might occur without closure of the Thames Barrier being triggered there is no need to provide additional flood storage to mitigate the presence of the works in the tidal Thames.

Closure of the Thames Barrier
The predicted effects of the works on tidal levels are insufficient to require alteration of the present approach to the closing of the Thames Barrier.

Peak water levels landward of the Thames Barrier are predicted to increase by approximately 15 mm during a high fluvial flow case with the Thames Barrier closed. It should be noted that these increases are from a low peak level due to the exclusion for the tide by the Barrier.
.

6. References

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HR Wallingford (2009). Thames 2D Base Model. Model update and validation. Report EX 5994.

Odd, N.V.M. and M. W. Owen, 1972. A two-layer model of mud transport in the Thames Estuary. Proc. Instn. Civ. Engrs, Supplement (ix) Paper 7517 S.

Appendix

Drawings

1	2	3	4	5	6

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Status: FOR INFORMATION

Keyplan:

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COORDINATES ARE TO ORDNANCE SURVEY DATUM OSGB36. ALL LEVELS ARE IN METRES AND RELATE TO A LOCAL HEIGHT DATUM WHICH IS 100 METRES BELOW ORDNANCE DATUM NEWLYN.

KEY :

- TEMPORARY SHEET PILING
- PERMANENT RE-ALIGNED RIVER WALL
- PERMANENT FORESHORE WORKS
- TEMPORARY FORESHORE WORKING AREA

10 m 0 40 m

SCALE 1 : 500

SITE CO-ORDINATES			
TEMPORARY WORKS			
A	E. 528200.64	N. 177820.33	
B	E. 528266.03	N. 177783.08	
C	E. 528238.04	N. 177790.90	
D	E. 528241.07	N. 177781.13	
E	E. 528284.05	N. 177794.46	
F	E. 528281.12	N. 177803.93	
G	E. 528346.21	N. 177823.61	
H	E. 528334.66	N. 177860.83	
PERMANENT WORKS			
I	E. 528215.08	N. 177824.42	
J	E. 528236.76	N. 177826.26	
K	E. 528257.61	N. 177820.07	
L	E. 528277.23	N. 177819.70	
M	E. 528286.05	N. 177828.72	
N	E. 528300.46	N. 177845.96	
O	E. 528320.30	N. 177856.53	

Revision History

Iss	Description	Dsgnr	Chkd	Appd	Date
AA	FOR INFORMATION	TCRE	AGIL	DDOL	17/06/2011

Thames Water Utilities

The Point, 7th Floor,
37 North Wharf Road,
Paddington, London W2 1AF

Thames Tideway Tunnel
Creating a cleaner, healthier River Thames

Location Code:	OS Reference:	Security Reference:	Drawn By:
N/A	TQ2675	UBR	ELEE

Project Group: LONDON TIDEWAY TUNNELS
Sub Process: WASTE
Location / Town: KENSINGTON & CHELSEA - CS14X - RANELAGH
Site Name: C14XJ - CHELSEA EMBANKMENT FORESHORE 2 (T.B.C)
Project Name: THAMES TUNNEL
Contract Name: FLUVIAL MODELLING
Drawing Title: FORESHORE WORKSITE LAYOUT C14XJ - CHELSEA EMBANKMENT

Drawing No.:	Scale:	Sheet Size:	Rev:
100-DA-CNS-C14XJ-254010	1:500	A1	AA

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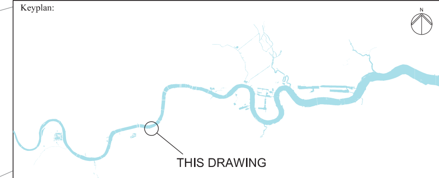
Status: FOR INFORMATION

Keyplan:



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COORDINATES ARE TO ORDNANCE SURVEY DATUM OSGB36. ALL LEVELS ARE IN METRES AND RELATE TO A LOCAL HEIGHT DATUM WHICH IS 100 METRES BELOW ORDNANCE DATUM NEWLYN.

KEY :

— TEMPORARY SHEET PILING
— PERMANENT RE-ALIGNED RIVER WALL
— PERMANENT FORESHORE WORKS
— TEMPORARY FORESHORE WORKING AREA

SITE CO-ORDINATES			
TEMPORARY WORKS			
A	E. 529520.12	N. 177643.77	
B	E. 529514.58	N. 177657.74	
C	E. 529515.42	N. 177674.83	
D	E. 529544.55	N. 177672.42	
E	E. 529546.90	N. 177645.22	
PERMANENT WORKS			
F	E. 529526.54	N. 177645.34	
G	E. 529531.01	N. 177662.34	
H	E. 529532.48	N. 177663.38	
I	E. 529544.25	N. 177662.41	
J	E. 529545.53	N. 177661.13	
K	E. 529546.90	N. 177645.22	

10 m 0 40 m

SCALE 1 : 500

Revision History

Iss	Description	Dsgnr	Chkd	Appd	Date
AA	FOR INFORMATION	AGIL	TCRE	DDOL	30/06/2011

Thames Water Utilities

Thames Tideway Tunnel
Creating a cleaner, healthier River Thames

The Point, 7th Floor,
37 North Wharf Road,
Paddington, London W2 1AF

Location Code:	OS Reference:	Security Reference:	Drawn By:
N/A	TQ2877	UBR	GJOR

Project Group: LONDON TIDEWAY TUNNELS
Sub Process: WASTE
Location / Town: WANDSWORTH - CS16X - HEATHWALL PS
Site Name: C16XB - SITE CS16X - FORESHORE
Project Name: THAMES TUNNEL
Contract Name: FLUVIAL MODELLING
Drawing Title: FORESHORE WORKSITE LAYOUT C16XB - HEATHWALL PS

Drawing No.:	Scale:	Sheet Size:	Rev:
100-DA-CNS-C16XB-256010	1:500	A1	AA

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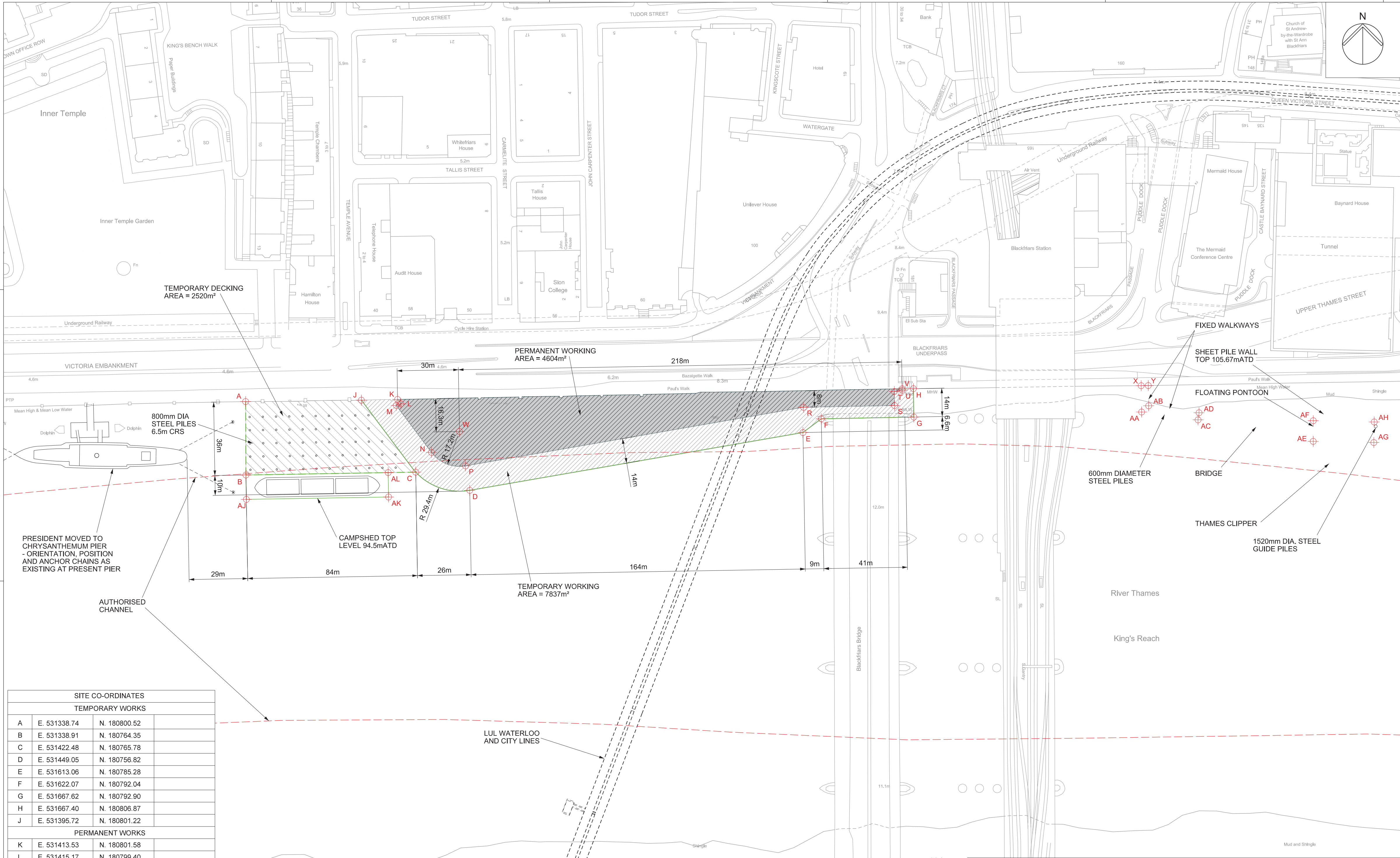
COORDINATES ARE TO ORDNANCE SURVEY DATUM OSGB36. ALL LEVELS ARE IN METRES AND RELATE TO THE TUNNEL DATUM WHICH IS 100 METRES BELOW ORDNANCE DATUM NEWLYN.



NOTES

1. ALL LEVELS ARE IN METRES ABOVE TUNNEL DATUM. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED
2. WORKING AREA SHOWN FOR ILLUSTRATIVE PURPOSES ONLY.
3. DRAWING PURPOSE TO ENABLE INITIAL FLUVIAL MODELLING.
4. SETTING OUT SITE CO-ORDINATES ARE TO ORDNANCE SURVEY GRID.

KEY :

- TEMPORARY SHEET PILED COFFERDAM WALL
- EDGE OF WORKING PLATFORM
- PERMANENT RE-ALIGNED RIVER WALL
- PERMANENT FORESHORE WORKS
- TEMPORARY FORESHORE WORKING AREA (SOLID FILL)
- TEMPORARY DECKING WORKING AREA (ON PILES)

BOAT / BARGE DIM'S (m)	LENGTH	BREADTH	DRAFT
PRESIDENT	79.9	10.7	3.4
1000 TONNE BARGE	61.7	9.5	1.8

SITE CO-ORDINATES			
TEMPORARY WORKS			
A	E. 531338.74	N. 180800.52	
B	E. 531338.91	N. 180764.35	
C	E. 531422.48	N. 180765.78	
D	E. 531449.05	N. 180756.82	
E	E. 531613.06	N. 180785.28	
F	E. 531622.07	N. 180792.04	
G	E. 531667.62	N. 180792.90	
H	E. 531667.40	N. 180806.87	
J	E. 531395.72	N. 180801.22	
PERMANENT WORKS			
K	E. 531413.53	N. 180801.58	
L	E. 531415.17	N. 180799.40	
M	E. 531412.89	N. 180798.63	
N	E. 531430.23	N. 180775.49	
P	E. 531446.94	N. 180768.85	
R	E. 531613.33	N. 180797.70	
S	E. 531658.15	N. 180798.55	
T	E. 531658.02	N. 180805.45	
U	E. 531661.87	N. 180806.12	
V	E. 531661.86	N. 180806.82	
W	E. 531444.00	N. 180785.80	
PIER			
X	E. 531779.51	N. 180808.35	
Y	E. 531783.01	N. 180808.41	
AA	E. 531779.74	N. 180795.38	
AB	E. 531783.20	N. 180798.44	
AC	E. 531807.51	N. 180791.53	
AD	E. 531807.99	N. 180795.00	
AE	E. 531864.18	N. 180780.95	
AF	E. 531864.21	N. 180791.10	
AG	E. 531894.00	N. 180780.33	
AH	E. 531894.21	N. 180790.49	
CAMPSHED			
AJ	E. 531339.11	N. 180752.36	
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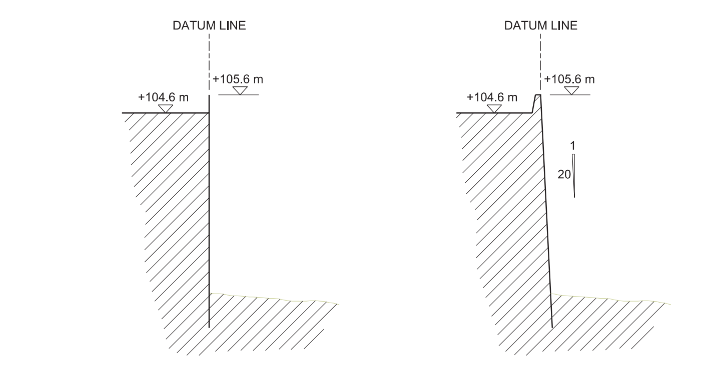
AL	E. 531408.90	N. 180765.55	



TYPICAL SECTION TEMPORARY COFFERDAM (N.T.S)

TYPICAL SECTION PERMANENT WORKS (PREFERRED) (N.T.S)

10 m 0 100 m

SCALE 1 : 1000

Revision History

Iss	Description	Dsgnr	Chkd	Appd	Date
AD	CAMPSHED ADDED	DWIK	RGUE	SDYE	20/07/2012
AC	REVISED LAYOUT	DWIK	RGUE	SDYE	31/05/2012
AB	REVISED LAYOUT	SWIL	MYAT	DDOL	07/07/2011
AA	FIRST ISSUE	SWIL	MYAT	DDOL	13/04/2011

Thames Water Utilities

Thames Tideway Tunnel
Creating a cleaner, healthier River Thames

The Point, 7th Floor,
37 North Wharf Road,
Paddington, London W2 1AF

Location Code:	OS Reference:	Security Reference:	Drawn By:
N/A	TQ3079	UBR	APUR

Project Group: LONDON TIDEWAY TUNNELS

Sub Process: WASTE

Location / Town: CITY OF LONDON - CS27X - FLEET MAIN

Site Name: PCL1X - BLACKFRIARS BRIDGE FORESHORE

Project Name: THAMES TUNNEL

Contract Name: REFERENCE DESIGN FOR PLANNING

Drawing Title: BLACKFRIARS BRIDGE FORESHORE - PCL1X FLUVIAL MODELLING - (option 5)

Drawing No.:	Scale:	Sheet Size:	Rev:
100-DA-CNS-PCL1X-267025	1:1000	A1	AD

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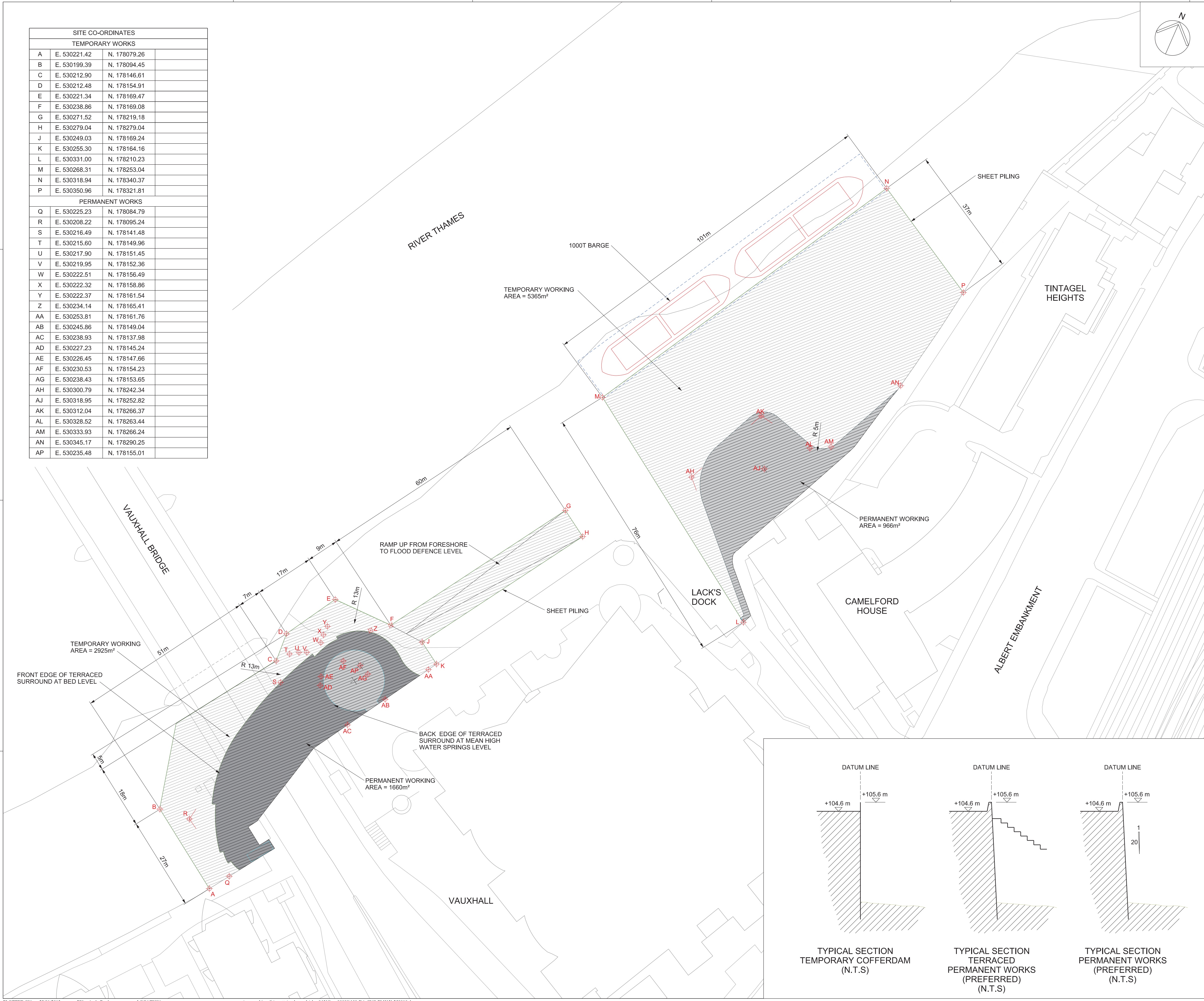
SITE CO-ORDINATES			
TEMPORARY WORKS			
A	E. 530221.42	N. 178079.26	
B	E. 530199.39	N. 178094.45	
C	E. 530212.90	N. 178146.61	
D	E. 530212.48	N. 178154.91	
E	E. 530221.34	N. 178169.47	
F	E. 530238.86	N. 178169.08	
G	E. 530271.52	N. 178219.18	
H	E. 530279.04	N. 178279.04	
J	E. 530249.03	N. 178169.24	
K	E. 530255.30	N. 178164.16	
L	E. 530331.00	N. 178210.23	
M	E. 530268.31	N. 178253.04	
N	E. 530318.94	N. 178340.37	
P	E. 530350.96	N. 178321.81	
PERMANENT WORKS			
Q	E. 530225.23	N. 178084.79	
R	E. 530208.22	N. 178095.24	
S	E. 530216.49	N. 178141.48	
T	E. 530215.60	N. 178149.96	
U	E. 530217.90	N. 178151.45	
V	E. 530219.95	N. 178152.36	
W	E. 530222.51	N. 178156.49	
X	E. 530222.32	N. 178158.86	
Y	E. 530222.37	N. 178161.54	
Z	E. 530234.14	N. 178165.41	
AA	E. 530253.81	N. 178161.76	
AB	E. 530245.86	N. 178149.04	
AC	E. 530238.93	N. 178137.98	
AD	E. 530227.23	N. 178145.24	
AE	E. 530226.45	N. 178147.66	
AF	E. 530230.53	N. 178154.23	
AG	E. 530238.43	N. 178153.65	
AH	E. 530300.79	N. 178242.34	
AJ	E. 530318.95	N. 178252.82	
AK	E. 530312.04	N. 178266.37	
AL	E. 530328.52	N. 178263.44	
AM	E. 530333.93	N. 178266.24	
AN	E. 530345.17	N. 178290.25	
AP	E. 530235.48	N. 178155.01	



TYPICAL SECTION TEMPORARY COFFERDAM (N.T.S)

TYPICAL SECTION TERRACED PERMANENT WORKS (PREFERRED) (N.T.S)

TYPICAL SECTION PERMANENT WORKS (PREFERRED) (N.T.S)

NOTES

1. ALL LEVELS ARE IN METRES ABOVE ORDNANCE DATUM. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED
2. WORKING AREA SHOWN FOR ILLUSTRATIVE PURPOSES ONLY.
3. DRAWING PURPOSE TO ENABLE INITIAL FLUVIAL MODELLING.
4. SETTING OUT SITE CO-ORDINATES ARE TO ORDNANCE SURVEY GRID.

KEY :

- TEMPORARY SHEET PILED COFFERDAM WALL
- PERMANENT RE-ALIGNED RIVER WALL
- PERMANENT FORESHORE WORKS AT FLOOD DEFENCE LEVEL
- PERMANENT FORESHORE WORKS SLOPING TERRACED AREA
- TEMPORARY FORESHORE WORKING AREA (SOLID FILL)

BOAT / BARGE DIM'S (m)	LENGTH	BREADTH	DRAFT
1000 TONNE BARGE	61.7	9.5	1.8

10 m 0 40 m

SCALE 1 : 500

Revision History

Iss	Description	Dsgnr	Chkd	Appd	Date
AB	REVISED LAYOUT	SWIL	MYAT	DDOL	06/07/2011
AA	REVISED LAYOUT	AG	DA	GT	28/04/2010

Thames Water Utilities

The Point, 7th Floor,
37 North Wharf Road,
Paddington, London W2 1AF

Location Code:	OS Reference:	Security Reference:	Drawn By:
N/A	TQ3077	UBR	APUR

Project Group: LONDON TIDEWAY TUNNELS

Sub Process: WASTE

Location / Town: LAMBETH - CS1920X - CLAPHAM & BRIXTON SR

Site Name: PLH1X - ALBERT EMBANKMENT FORESHORE

Project Name: THAMES TUNNEL

Contract Name: FLUVIAL MODELLING

Drawing Title: ALBERT EMBANKMENT FORESHORE - PLH1X FLUVIAL MODELLING

Drawing No.:	Scale:	Sheet Size:	Rev:
100-DA-CNS-PLH1X-259010	1:500	A1	AB

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1	2	3	4	5	6

SITE CO-ORDINATES		
TEMPORARY WORKS		
A	E. 535640.98	N. 180708.97
B	E. 535665.38	N. 180669.11
C	E. 535584.59	N. 180619.19
D	E. 535560.19	N. 180659.01
E	E. 535671.65	N. 180658.88
F	E. 535590.86	N. 180608.96
PERMANENT WORKS		
G	E. 535638.95	N. 180707.71
H	E. 535641.94	N. 180691.67
J	E. 535638.67	N. 180682.06
K	E. 535607.67	N. 180650.18
L	E. 535579.53	N. 180652.30
M	E. 535571.26	N. 180665.79
N	E. 535594.33	N. 180661.29

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4. SETTING OUT SITE CO-ORDINATES ARE TO ORDNANCE SURVEY GRID.

KEY :

- TEMPORARY SHEET PILED COFFERDAM WALL
- PERMANENT RE-ALIGNED RIVER WALL
- PERMANENT FORESHORE WORKS
- TEMPORARY FORESHORE WORKING AREA (SOLID FILL)

BOAT / BARGE DIM'S (m)	LENGTH	BREADTH	DRAFT
1000 TONNE BARGE	61.7	9.5	1.8

10 m 0 40 m

SCALE 1 : 500

Revision History

Iss	Description	Dsgnr	Chkd	Appd	Date
AC	TEMPORARY COFFERDAM MODIFIED	REVI	DDOL	DDOL	07/07/2011
AB	PERMANENT FORESHORE WORKS REMOVED	REVI	DDOL	DDOL	23/03/2011
AA	FOR INFORMATION	REVI	DDOL	DDOL	25/02/2011

Thames Water Utilities

Thames Tideway Tunnel — Creating a cleaner, healthier River Thames

The Point, 7th Floor, 37 North Wharf Road, Paddington, London W2 1AF

Location Code:	OS Reference:	Security Reference:	Drawn By:
N/A	TQ3479	UBR	MBRI

Project Group: LONDON TIDEWAY TUNNELS — Sub Process: WASTE

Location / Town: TOWER HAMLETS - CS29X - NORTH EAST SR

Site Name: PTH1X - KING EDWARD MEMORIAL PARK

Project Name: THAMES TUNNEL

Contract Name: FLUVIAL MODELLING

Drawing Title: FORESHORE WORKSITE LAYOUT - OPTION 2 PTH1X - KING EDWARD MEMORIAL PARK

Drawing No.:	Scale:	Sheet Size:	Rev:
100-DA-CNS-PTH1X-269011	1:500	A1	AC

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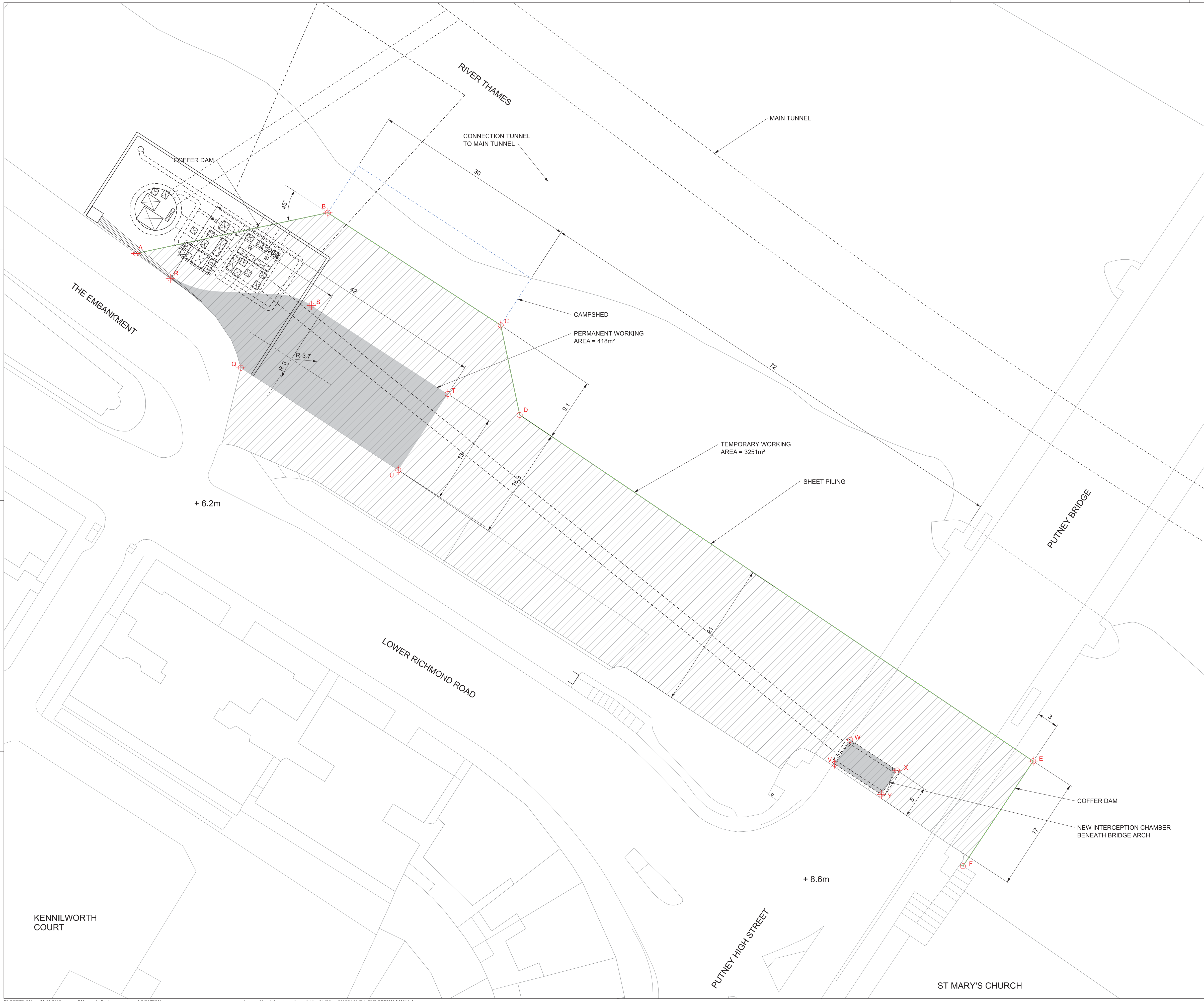
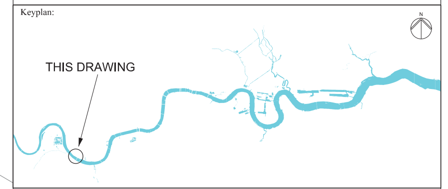


Do not scale - if in doubt ask

Status: FOR INFORMATION

Keyplan:



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NOTES

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2. WORKING AREA SHOWN FOR ILLUSTRATIVE PURPOSES ONLY.
3. DRAWING PURPOSE TO ENABLE INITIAL FLUVIAL MODELLING.
4. SETTING OUT SITE CO-ORDINATES ARE TO ORDNANCE SURVEY GRID.

SITE CO-ORDINATES			
TEMPORARY WORKS			
A	E. 524059.47	N. 175716.16	
B	E. 524086.95	N. 175721.99	
C	E. 524111.70	N. 175705.90	
D	E. 524114.43	N. 175693.05	
E	E. 524187.93	N. 175643.51	
F	E. 524177.87	N. 175628.49	
PERMANENT WORKS			
Q	E. 524074.50	N. 175699.80	
R	E. 524064.41	N. 175712.58	
S	E. 524084.62	N. 175708.72	
T	E. 524104.12	N. 175696.05	
U	E. 524097.04	N. 175685.15	
V	E. 524159.49	N. 175643.11	
W	E. 524161.73	N. 175646.55	
X	E. 524168.43	N. 175642.19	
Y	E. 524166.20	N. 175638.75	

KEY :

— TEMPORARY SHEET PILING

— PERMANENT RE-ALIGNED RIVER WALL

— PERMANENT FORESHORE WORKS

— TEMPORARY FORESHORE WORKING AREA

10 m 0 10 m

SCALE 1 : 250

Revision History

Iss	Description	Dsgnr	Chkd	Appd	Date
AC	REVISED LAYOUT	ASMR	JSWE	DDOL	01/07/2011
AB	REVISED LAYOUT	AB	DA	GT	22/10/2010
AA	FOR INFORMATION	AG	DA	DA	28/04/2010

Thames Water Utilities

The Point, 7th Floor,
37 North Wharf Road,
Paddington, London W2 1AF

Thames Tideway Tunnel
Creating a cleaner, healthier River Thames

Location Code:	OS Reference:	Security Reference:	Drawn By:
N/A	TQ2475	UBR	HMCG

Project Group: LONDON TIDEWAY TUNNELS
Sub Process: WASTE
Location / Town: WANDSWORTH - CS06X - PUTNEY BRIDGE
Site Name: PWH1X - PUTNEY BRIDGE FORESHORE
Project Name: THAMES TUNNEL
Contract Name: FLUVIAL MODELLING
Drawing Title: FORESHORE WORKSITE LAYOUT PWH1X - PUTNEY BRIDGE

Drawing No.:	Scale:	Sheet Size:	Rev:
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Status: FOR INFORMATION

Keyplan:

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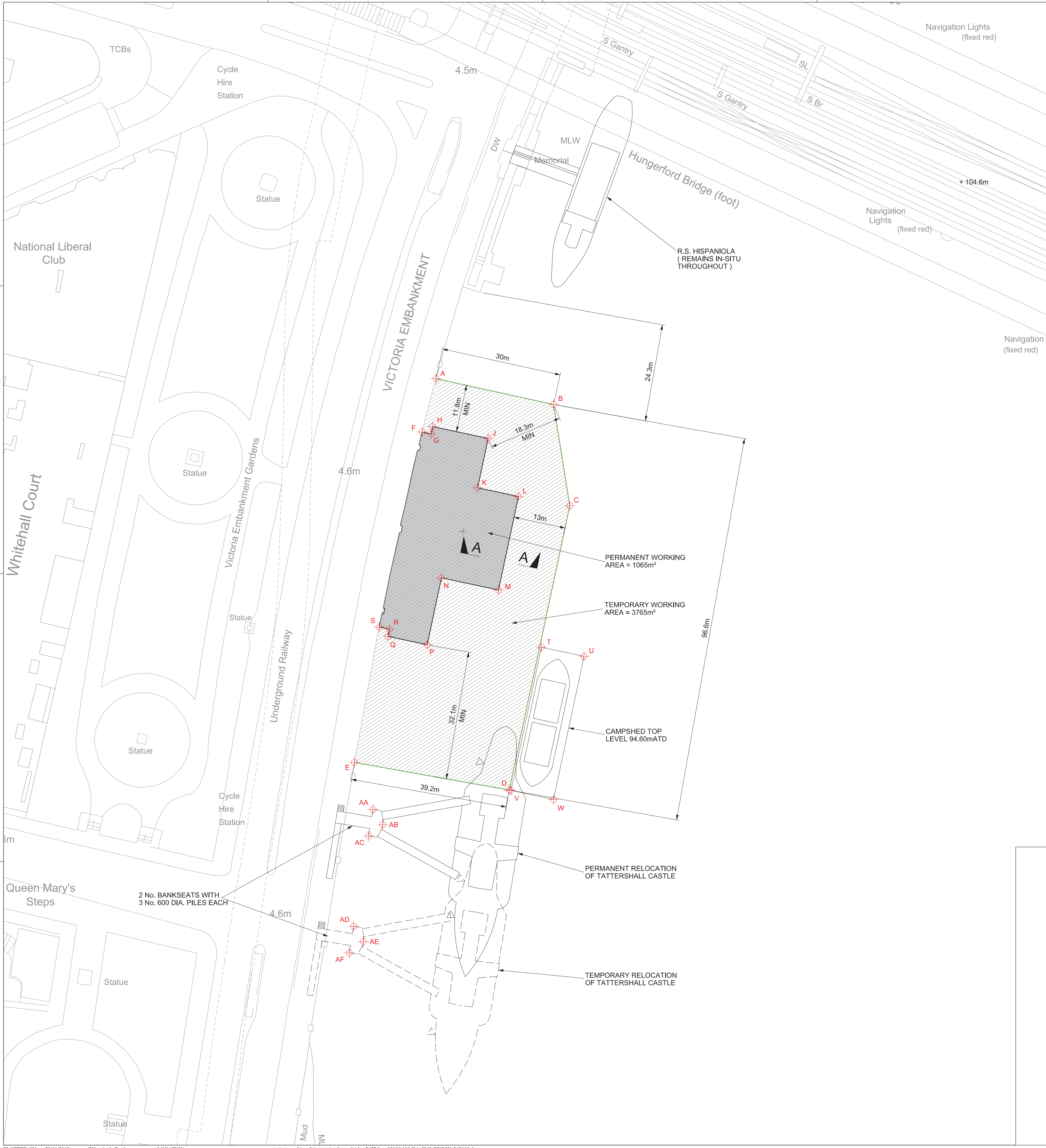
COORDINATES ARE TO ORDNANCE SURVEY DATUM OSGB36.
ALL LEVELS ARE IN METRES AND RELATE TO THE TUNNEL DATUM WHICH IS 100 METRES BELOW ORDNANCE DATUM NEWLYN.



NOTES

1. ALL LEVELS ARE IN METRES ABOVE TUNNEL DATUM. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED
2. WORKING AREA SHOWN FOR ILLUSTRATIVE PURPOSES ONLY.
3. DRAWING PURPOSE TO ENABLE INITIAL FLUVIAL MODELLING.
4. SETTING OUT SITE CO-ORDINATES ARE TO ORDNANCE SURVEY GRID.

KEY :

- TEMPORARY SHEET PILED COFFERDAM WALL
- PERMANENT RE-ALIGNED RIVER WALL
- PERMANENT FORESHORE WORKS
- TEMPORARY FORESHORE WORKING AREA (SOLID FILL)

BOAT / BARGE DIM'S (m)	LENGTH	BREADTH	DRAFT (LOADED)
350 TONNE BARGE	28.65	7.29	2.1

SITE CO-ORDINATES			
TEMPORARY WORKS			
A	E 530,399.46	N 180,217.72	
B	E 530,428.76	N 180,211.28	
C	E 530,432.79	N 180,186.03	
D	E 530,417.71	N 180,115.14	
E	E 530,379.12	N 180,122.01	
PERMANENT WORKS			
F	E 530,395.99	N 180,204.42	
G	E 530,398.22	N 180,203.94	
H	E 530,398.61	N 180,205.76	
J	E 530,412.44	N 180,202.81	
K	E 530,409.83	N 180,190.51	
L	E 530,419.99	N 180,188.35	
M	E 530,415.03	N 180,165.02	
N	E 530,400.80	N 180,168.05	
P	E 530,397.25	N 180,151.36	
Q	E 530,387.48	N 180,153.44	
R	E 530,387.86	N 180,155.25	
S	E 530,385.26	N 180,155.80	
CAMPSHED			
T	E 530,425.73	N 180,150.74	
U	E 530,436.34	N 180,148.49	
V	E 530,418.14	N 180,115.04	
W	E 530,428.74	N 180,112.79	
PERMANENT BANKSEAT PILES			
AA	E 530,383.74	N 180,110.31	
AB	E 530,386.15	N 180,106.51	
AC	E 530,382.65	N 180,103.69	
TEMPORARY BANKSEAT PILES			
AD	E 530,378.93	N 180,081.16	
AE	E 530,381.34	N 180,077.36	
AF	E 530,377.83	N 180,074.54	

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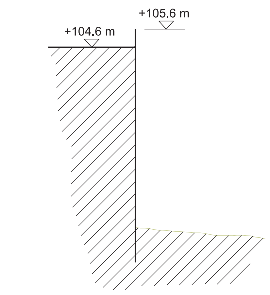
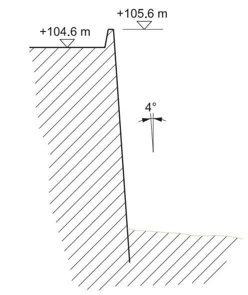
SCALE 1 : 500



TYPICAL SECTION
TEMPORARY COFFERDAM
(N.T.S)



TYPICAL SECTION A-A
PERMANENT WORKS
(N.T.S)

Revision History

Iss	Description	Dsgnr	Chkd	Appd	Date
AA	SUPERSEDES 100-DA-CNS-PWR2X-263010	SWIL	RGUE	AGIL	29/06/2012

Thames Water Utilities

Thames Tideway Tunnel
Creating a cleaner, healthier River Thames

The Point, 7th Floor,
37 North Wharf Road,
Paddington, London W2 1AF

Location Code: N/A	OS Reference: TQ3079	Security Reference: UBR	Drawn By: DBOX

Project Group: LONDON TIDEWAY TUNNELS
Sub Process: WASTE
Location / Town: WESTMINSTER - CS22X - REGENT STREET
Site Name: PWR3X - VICTORIA EMBANKMENT FORESHORE
Project Name: THAMES TUNNEL
Contract Name: REFERENCE DESIGN FOR PLANNING
Drawing Title: FLUVIAL MODELLING

Drawing No.:	Scale:	Sheet Size:	Rev:
100-DA-CNS-PWR3X-263010	1:500	A1	AA

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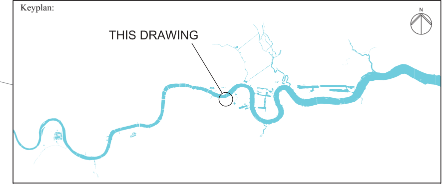
PLOTTED ON 23/01/2013 BY Andy.Purdy LOCATION : c:\pw working dir\pw-ttp\andy.purdy\dms04534\100-DA-CNS-S76SK-200010.dgn

Do not scale - if in doubt ask

Status: FOR INFORMATION

Keyplan:



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NOTES

1. ALL LEVELS ARE IN METRES ABOVE ORDNANCE DATUM. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED
2. WORKING AREA SHOWN FOR ILLUSTRATIVE PURPOSES ONLY.
3. DRAWING PURPOSE TO ENABLE INITIAL FLUVIAL MODELLING.
4. SETTING OUT SITE CO-ORDINATES ARE TO ORDNANCE SURVEY GRID.

SITE CO-ORDINATES			
TEMPORARY WORKS			
A	E. 534280.09	N. 179818.27	
B	E. 534292.64	N. 179857.80	
C	E. 534430.15	N. 179815.12	
D	E. 534412.93	N. 179756.30	
E	E. 534394.18	N. 179763.54	
F	E. 534288.26	N. 179797.53	
G	E. 534274.86	N. 179805.61	
H	E. 534279.12	N. 179818.58	
PERMANENT WORKS			

KEY :

— TEMPORARY SHEET PILING

— PERMANENT RE-ALIGNED RIVER WALL

— PERMANENT FORESHORE WORKS

— TEMPORARY FORESHORE WORKING AREA

— DECKING

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SCALE 1 : 500

Revision History

Iss	Description	Dsgnr	Chkd	Appd	Date
AA	FIRST ISSUE - FOR INFORMATION	REVI	DDOL	DDOL	08/04/2011

Thames Water Utilities

Thames Tideway Tunnel
Creating a cleaner, healthier River Thames

The Point, 7th Floor,
37 North Wharf Road,
Paddington, London W2 1AF

Location Code:	OS Reference:	Security Reference:	Drawn By:
N/A	TQ3479	UBR	MBRI

Project Group: LONDON TIDEWAY TUNNELS
Sub Process: WASTE
Location / Town: SOUTHWARK - S76SK - CHAMBERS WHARF
Site Name: S76SK - CHAMBERS WHARF
Project Name: THAMES TUNNEL
Contract Name: FLUVIAL MODELLING
Drawing Title: FOORESHORE WORKSITE LAYOUT S76SK - CHAMBERS WHARF

Drawing No.:	Scale:	Sheet Size:	Rev:
100-DA-CNS-S76SK-200010	1:500	A1	AA

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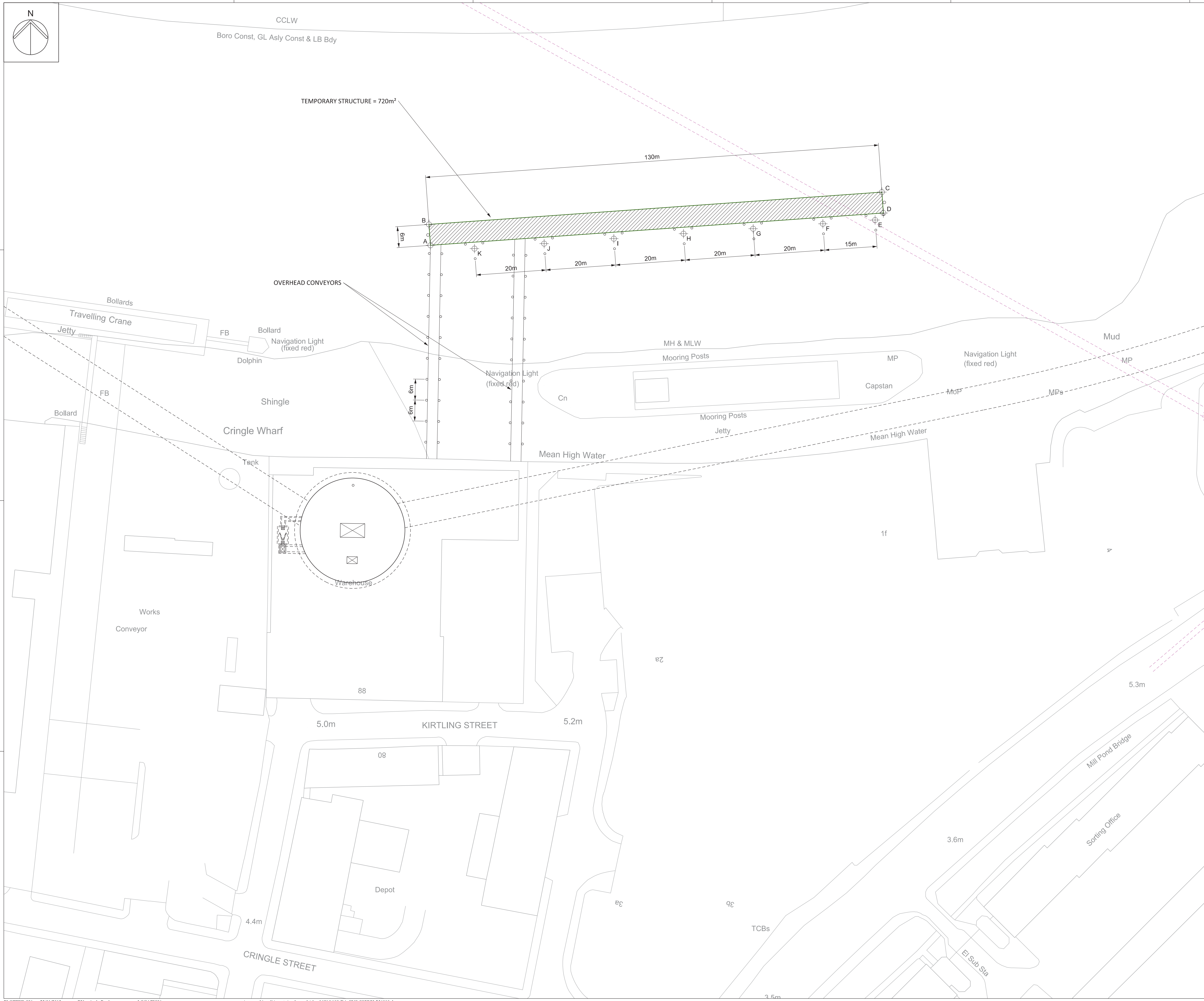

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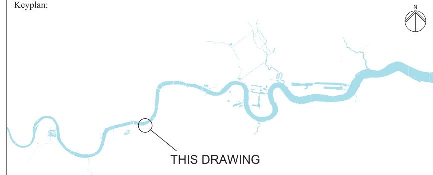
Status: FOR INFORMATION

Keyplan:



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COORDINATES ARE TO ORDNANCE SURVEY DATUM OSGB36. ALL LEVELS ARE IN METRES AND RELATE TO A LOCAL HEIGHT DATUM WHICH IS 100 METRES BELOW ORDNANCE DATUM NEWLYN.

KEY :

- TEMPORARY SHEET PILING
- PERMANENT RE-ALIGNED RIVER WALL
- PERMANENT FORESHORE WORKS
- TEMPORARY FORESHORE WORKING AREA
- 3No 600mm DIA PILE GROUP SETTING OUT (5, 5, 5)

SITE CO-ORDINATES			
TEMPORARY WORKS			
A	E. 529293.62	N. 177675.87	
B	E. 529293.19	N. 177681.86	
C	E. 529422.86	N. 177691.10	
D	E. 529423.29	N. 177685.12	
E	E. 529420.93	N. 177683.11	
F	E. 529405.96	N. 177682.04	
G	E. 529386.01	N. 177680.62	
H	E. 529366.06	N. 177679.20	
I	E. 529346.11	N. 177677.78	
J	E. 529326.17	N. 177676.35	
K	E. 529306.22	N. 177674.93	

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SCALE 1 : 500

Revision History

Iss	Description	Dsgnr	Chkd	Appd	Date
AA	FOR INFORMATION	AGIL	TCRE	DDOL	28/06/2011

Thames Water Utilities

Thames Tideway Tunnel
Creating a cleaner, healthier River Thames

The Point, 7th Floor,
37 North Wharf Road,
Paddington, London W2 1AF

Location Code:	OS Reference:	Security Reference:	Drawn By:
N/A	T2877	UBR	GJOR

Project Group: LONDON TIDEWAY TUNNELS

Sub Process: WASTE

Location / Town: WANDSWORTH

Site Name: S93WH - KIRTLING STREET

Project Name: THAMES TUNNEL

Contract Name: FLUVIAL MODELLING

Drawing Title: FORESORE WORKSITE LAYOUT PWH9X - KIRTLING STREET

Drawing No.:	Scale:	Sheet Size:	Rev:
100-DA-CNS-S93WH-256010	1:500	A1	AA

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Working with water

HR Wallingford is an independent engineering and environmental hydraulics organisation. We deliver practical solutions to the complex water-related challenges faced by our international clients. A dynamic research programme underpins all that we do and keeps us at the leading edge. Our unique mix of know-how, assets and facilities includes state of the art physical modelling laboratories, a full range of numerical modelling tools and, above all, enthusiastic people with world-renowned skills and expertise.

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www.hrwallingford.com

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Certificate No. EMS 558310

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Thames Tideway Tunnel
Thames Water Utilities Limited

Application for Development Consent

Application Reference Number: WWO10001

Environmental Statement

Doc Ref: **6.2.03**

Volume 3: Project-wide effects assessment appendices

Appendix M.2: Asset freeboard and settlement summary

APFP Regulations 2009: Regulation **5(2)(a)**

Hard copy available in

Box **17.3** Folder **B**
January 2013

Thames Tideway Tunnel
Creating a cleaner, healthier River Thames

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M.2 Asset freeboard and settlement summary

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Asset ID	EA_ALT_REF	River Reach	Location Description	Impact type	Defence Crest Height (mAOD)	Statutory defence height (mAOD)	1 in 200 year water level 2107 (mAOD)	Available freeboard now (m)	Maximum vertical settlement (mm)	Maximum vertical settlement (m)	Remaining freeboard after settlement (m)	max. decrease in water levels - temporary (m)	Available freeboard after max. decrease in water levels and max settlement - temporary (m)	max. decrease in water levels - permanent (m)	Available freeboard after max. decrease in water levels and max settlement - permanent (m)	max. increase in water levels - temporary (m)	Available freeboard after max. increase in water levels and max settlement - temporary (m)	max. increase in water levels - permanent (m)	Available freeboard after max. increase in water levels and max settlement - permanent (m)	Is overtopping predicted in 1 in 200 year event?		Significant? (based on settlement below statutory level)?
																				Temporary	Permanent	
RW425	82/001	Richmond- Chelsea	Chiswick Mall, Chiswick (left bank)	Main Tunnel passing under	5.940	5.540	5.100	0.840	0.000	0.000	0.840	0.038	0.878	0.018	0.858	0.017	0.823	0.010	0.830	NO	NO	NOT SIGNIFICANT
RW488	N001/01	Richmond- Chelsea	Chiswick Mall, Chiswick (left bank)	Main Tunnel passing under	5.540	5.540	5.100	0.440	0.000	0.000	0.440	0.038	0.478	0.018	0.458	0.017	0.423	0.010	0.430	NO	NO	NOT SIGNIFICANT
RW487	N001/02	Richmond- Chelsea	Chiswick Mall, Chiswick (left bank)	Main Tunnel passing under	5.540	5.540	5.100	0.440	0.520	0.001	0.439	0.038	0.477	0.018	0.457	0.017	0.422	0.010	0.429	NO	NO	SIGNIFICANT
RW424	N001/03	Richmond- Chelsea	Chiswick Mall, Chiswick (left bank)	Main Tunnel passing under	5.540	5.540	5.100	0.440	6.610	0.007	0.433	0.038	0.471	0.018	0.451	0.017	0.416	0.010	0.423	NO	NO	SIGNIFICANT
RW818	N001/04	Richmond- Chelsea	Chiswick Mall, Chiswick (left bank)	Main Tunnel passing under	5.540	5.540	5.100	0.440	23.000	0.023	0.417	0.038	0.455	0.018	0.435	0.017	0.400	0.010	0.407	NO	NO	SIGNIFICANT
RW819	N002	Richmond- Chelsea	Chiswick Mall, Chiswick (left bank)	Main Tunnel passing under	5.570	5.540	5.100	0.470	26.070	0.026	0.444	0.038	0.482	0.018	0.462	0.017	0.427	0.010	0.434	NO	NO	NOT SIGNIFICANT
RW820	N003	Richmond- Chelsea	Chiswick Mall, Chiswick (left bank)	Main Tunnel passing under	5.570	5.540	5.100	0.470	17.410	0.017	0.453	0.038	0.491	0.018	0.471	0.017	0.436	0.010	0.443	NO	NO	NOT SIGNIFICANT
RW821	N004/01	Richmond- Chelsea	Chiswick Mall, Chiswick (left bank)	Main Tunnel passing under	5.540	5.540	5.100	0.440	15.360	0.015	0.425	0.038	0.463	0.018	0.443	0.017	0.408	0.010	0.415	NO	NO	SIGNIFICANT
RW822	N004/02	Richmond- Chelsea	Chiswick Mall, Chiswick (left bank)	Main Tunnel passing under	5.540	5.540	5.100	0.440	15.540	0.016	0.424	0.038	0.462	0.018	0.442	0.017	0.407	0.010	0.414	NO	NO	SIGNIFICANT
RW823	N005	Richmond- Chelsea	Chiswick Mall, Chiswick (left bank)	Main Tunnel passing under	5.970	5.540	5.100	0.870	5.910	0.006	0.864	0.038	0.902	0.018	0.882	0.017	0.847	0.010	0.854	NO	NO	NOT SIGNIFICANT
RW824	N006	Richmond- Chelsea	Chiswick Mall, Chiswick (left bank)	Main Tunnel passing under	5.980	5.540	5.100	0.880	1.420	0.001	0.879	0.038	0.917	0.018	0.897	0.017	0.862	0.010	0.869	NO	NO	NOT SIGNIFICANT
RW470	86/402	Richmond- Chelsea	St Paul's School Playing fields, Barnes (right bank)	Main Tunnel passing under	5.980	5.540	5.100	0.880	25.900	0.026	0.854	0.038	0.892	0.018	0.872	0.017	0.837	0.010	0.844	NO	NO	NOT SIGNIFICANT
RW236	86/501/02	Richmond- Chelsea	St Paul's School Playing fields, Barnes (right bank)	Main Tunnel passing under	6.030	5.540	5.080	0.950	0.000	0.000	0.950	0.038	0.988	0.018	0.968	0.017	0.933	0.010	0.940	NO	NO	NOT SIGNIFICANT
RW477	86/302	Richmond- Chelsea	Just seaward of Hammersmith bridge, Barnes (right bank)	Main Tunnel passing under	6.090	5.540	5.080	1.010	0.000	0.000	1.010	0.038	1.048	0.018	1.028	0.017	0.993	0.010	1.000	NO	NO	NOT SIGNIFICANT
RW111	86/301/01	Richmond- Chelsea	River frontage, nr Riverview gardens, Barnes (right bank)	Main Tunnel passing under	6.090	5.540	5.080	1.010	2.270	0.002	1.008	0.038	1.046	0.018	1.026	0.017	0.991	0.010	0.998	NO	NO	NOT SIGNIFICANT
RW113	86/301/02	Richmond- Chelsea	River frontage, nr Riverview gardens, Barnes (right bank)	Main Tunnel passing under	6.080	5.540	5.080	1.000	23.760	0.024	0.976	0.038	1.014	0.018	0.994	0.017	0.959	0.010	0.966	NO	NO	NOT SIGNIFICANT
RW363	N081/01	Richmond- Chelsea	footpath frontage, opposite Hammersmith construction site (left bank)	connection tunnel passing under	5.790	5.540	5.080	0.710	10.920	0.011	0.699	0.038	0.737	0.018	0.717	0.017	0.682	0.010	0.689	NO	NO	NOT SIGNIFICANT
RW421	N081/02	Richmond- Chelsea	footpath frontage, opposite Hammersmith construction site(left bank)	connection tunnel passing under	5.790	5.540	5.080	0.710	9.180	0.009	0.701	0.038	0.739	0.018	0.719	0.017	0.684	0.010	0.691	NO	NO	NOT SIGNIFICANT
RW362	N082	Richmond- Chelsea	footpath frontage, opposite Hammersmith construction site(left bank)	connection tunnel passing under	5.800	5.540	5.080	0.720	0.840	0.001	0.719	0.038	0.757	0.018	0.737	0.017	0.702	0.010	0.709	NO	NO	NOT SIGNIFICANT
RW231	S001/01	Richmond- Chelsea	Beverley Brook confluence, Barn Elms, (right bank)	connection tunnel passing under	6.050	5.540	5.080	0.970	0.210	0.000	0.970	0.038	1.008	0.018	0.988	0.017	0.953	0.010	0.960	NO	NO	NOT SIGNIFICANT
RW476	S001/02/01	Richmond- Chelsea	Embankment, Wandsworth (right bank)	connection tunnel passing under	5.540	5.540	5.080	0.460	3.620	0.004	0.456	0.038	0.494	0.018	0.474	0.017	0.439	0.010	0.446	NO	NO	SIGNIFICANT
RW232	S001/02/02	Richmond- Chelsea	Embankment, Wandsworth (right bank)	connection tunnel passing under	5.940	5.540	5.080	0.860	2.220	0.002	0.858	0.038	0.896	0.018	0.876	0.017	0.841	0.010	0.848	NO	NO	NOT SIGNIFICANT
RW233	S001/02/03	Richmond- Chelsea	Embankment, Wandsworth (right bank)	connection tunnel passing under	5.890	5.540	5.080	0.810	0.640	0.001	0.809	0.038	0.847	0.018	0.827	0.017	0.792	0.010	0.799	NO	NO	NOT SIGNIFICANT
RW865	S005/05/01	Richmond- Chelsea	Putney Pier (right bank)	connection tunnel passing under	5.540	5.540	5.060	0.480	5.900	0.006	0.474	0.038	0.512	0.018	0.492	0.017	0.457	0.010	0.464	NO	NO	SIGNIFICANT
RW237	S005/05/02	Richmond- Chelsea	Putney Pier (right bank)	connection tunnel passing under	5.540	5.540	5.060	0.480	14.640	0.015	0.465	0.038	0.503	0.018	0.483	0.017	0.448	0.010	0.455	NO	NO	SIGNIFICANT
RW922	N111/01	Richmond- Chelsea	Carnwarth Road (left bank)	Main Tunnel passing under	7.430	5.410	5.040	2.390	17.950	0.018	2.372	0.038	2.410	0.018	2.390	0.017	2.355	0.010	2.362	NO	NO	NOT SIGNIFICANT
RW923	N111/02	Richmond- Chelsea	Carnwarth Road (left bank)	connection tunnel passing under	5.890	5.410	5.040	0.850	42.750	0.043	0.807	0.038	0.845	0.018	0.825	0.017	0.790	0.010	0.797	NO	NO	NOT SIGNIFICANT
RW924	N112	Richmond- Chelsea	Carnwarth Road (left bank)	Main Tunnel passing under	6.000	5.410	5.040	0.960	22.240	0.022	0.938	0.038	0.976	0.018	0.956	0.017	0.921	0.010	0.928	NO	NO	NOT SIGNIFICANT
RW925	N113	Richmond- Chelsea	Carnwarth Road (left bank)	Main Tunnel passing under	5.410	5.410	5.040	0.370	17.270	0.017	0.353	0.038	0.391	0.018	0.371	0.017	0.336	0.010	0.343	NO	NO	SIGNIFICANT
RW926	N114	Richmond- Chelsea	Carnwarth Road (left bank)	Main Tunnel passing under	5.410	5.410	5.040	0.370	14.770	0.015	0.355	0.038	0.393	0.018	0.373	0.017	0.338	0.010	0.345	NO	NO	SIGNIFICANT
RW927	N115	Richmond- Chelsea	Carnwarth Road (left bank)	Main Tunnel passing under	5.860	5.410	5.040	0.820	19.190	0.019	0.801	0.038	0.839	0.018	0.819	0.017	0.784	0.010	0.791	NO	NO	NOT SIGNIFICANT
RW928	N116	Richmond- Chelsea	Wandsworth Bridge (left bank)	Main Tunnel passing under	5.860	5.410	5.040	0.820	7.820	0.008	0.812	0.038	0.850	0.018	0.830	0.017	0.795	0.010	0.802	NO	NO	NOT SIGNIFICANT
RW929	N117	Richmond- Chelsea	Wandsworth Bridge (left bank)	Main Tunnel passing under	5.410	5.410	5.040	0.370	5.070	0.005	0.365	0.038	0.403	0.018	0.383	0.017	0.348	0.010	0.355	NO	NO	SIGNIFICANT
RW805	N118	Richmond- Chelsea	Wandsworth Bridge (left bank)	Main Tunnel passing under	6.080	5.410	5.040	1.040	1.540	0.002	1.038	0.038	1.076	0.018	1.056	0.017	1.021	0.010	1.028	NO	NO	NOT SIGNIFICANT
RW806	N119	Richmond- Chelsea	Wandsworth Bridge (left bank)	Main Tunnel passing under	5.950	5.410	5.040	0.910	0.920	0.001	0.909	0.038	0.947	0.018	0.927	0.017	0.892	0.010	0.899	NO	NO	NOT SIGNIFICANT
RW808	N120	Richmond- Chelsea	Wandsworth Bridge (left bank)	Main Tunnel passing under	6.110	5.410	5.040	1.070	0.160	0.000	1.070	0.038	1.108	0.018	1.088	0.017	1.053	0.010	1.060	NO	NO	NOT SIGNIFICANT
RW809	N121	Richmond- Chelsea	Wandsworth Bridge (left bank)	Main Tunnel passing under	5.890	5.410	5.040	0.850	0.000	0.000	0.850	0.038	0.888	0.018	0.868	0.017	0.833	0.010	0.840	NO	NO	NOT SIGNIFICANT
RW570	W032	Richmond- Chelsea	Armoury Way - Bell Lane Creek (Left bank)	connection tunnel passing under	5.910	5.410	5.040	0.870	9.100	0.009	0.861	0.038	0.899	0.018	0.879	0.017	0.844	0.010	0.851	NO	NO	NOT SIGNIFICANT
RW577	W033	Richmond- Chelsea	Armoury Way - Bell Lane Creek (Left bank)	connection tunnel passing under	5.410	5.410	5.040	0.370	12.740	0.013	0.357	0.038	0.395	0.018	0.375	0.017	0.340	0.010	0.347	NO	NO	SIGNIFICANT
RW224	W034	Richmond- Chelsea	Armoury Way - Bell Lane Creek (Left bank)	connection tunnel passing under	5.410	5.410	5.040	0.370	16.610	0.017	0.353	0.038	0.391	0.018	0.371	0.017	0.336	0.010	0.343	NO	NO	SIGNIFICANT
RW484	W035-36	Richmond- Chelsea	Sudlow Road - Bell Lane Creek (Left bank)	connection tunnel passing under	5.900	5.410	5.040	0.860	19.960	0.020	0.840	0.038	0.878	0.018	0.858	0.017	0.823	0.010	0.830	NO	NO	NOT SIGNIFICANT
RW465	W037-44	Richmond- Chelsea	Sudlow Road - Bell Lane Creek (Left bank)	connection tunnel passing under	5.900	5.410	5.040	0.860	0.960	0.001	0.859	0.038	0.897	0.018	0.877	0.017	0.842	0.010	0.849	NO	NO	NOT SIGNIFICANT
RW225	W045/01	Richmond- Chelsea	Sudlow Road - Bell Lane Creek (Left bank)	connection tunnel passing under	5.890	5.410	5.040	0.850	2.460	0.002	0.848	0.038	0.886	0.018	0.866	0.017	0.831	0.010	0.838	NO	NO	NOT SIGNIFICANT
RW461	W045/02	Richmond- Chelsea	Sudlow Road - Bell Lane Creek (Left bank)	connection tunnel passing under	5.890	5.410	5.040	0.850	15.780	0.016	0.834	0.038	0.872	0.018	0.852	0.017	0.817	0.010	0.824	NO	NO	NOT SIGNIFICANT
RW226	S061/02/01	Richmond- Chelsea	Enterprise Way - Bell Lane Creek (Left bank)	connection tunnel passing under	6.550	5.410	5.040	1.510	9.250	0.009	1.501	0.038	1.539	0.018	1.519	0.017	1.484	0.010	1.491	NO	NO	NOT SIGNIFICANT
RW462	W046	Richmond- Chelsea	Enterprise Way - Bell Lane Creek (Left bank)	connection tunnel passing under	6.500	5.410	5.040	1.460	6.690	0.007	1.453	0.038	1.491	0.018	1.471	0.017	1.436	0.010	1.443	NO	NO	NOT SIGNIFICANT
RW227	W047/01	Richmond- Chelsea	Enterprise Way - Bell Lane Creek (Left bank)	connection tunnel passing under	6.500	5.410	5.040	1.460	3.380	0.003	1.457	0.038	1.495	0.018	1.475	0.017	1.440	0.010	1.447	NO	NO	NOT SIGNIFICANT
RW228	W047/02	Richmond- Chelsea	Enterprise Way - Bell Lane Creek (Left bank)	connection tunnel passing under	5.410	5.410	5.040	0.370	11.810	0.012	0.358	0.038	0.396	0.018	0.376	0.017	0.341	0.010	0.348	NO	NO	SIGNIFICANT
RW463	W048	Richmond- Chelsea	Enterprise Way - Bell Lane Creek (Left bank)	connection tunnel passing under	6.090	5.410	5.040	1.050	11.740	0.012	1.038	0.038	1.076	0.018	1.056	0.017	1.021	0.010	1.028	NO	NO	NOT SIGNIFICANT
RW219	S062	Richmond- Chelsea	River Wandle (Right bank)	connection tunnel passing under	5.880	5.410	5.040	0.840	4.470	0.004	0.836	0.038	0.874	0.018	0.854	0.017	0.819	0.010	0.826	NO	NO	NOT SIGNIFICANT
RW208	S074/01	Richmond- Chelsea	York Place (right bank)	connection tunnel passing under	5.370	5.410	5.040	0.330	5.880	0.006	0.324	0.038	0.362	0.018	0.342	0.017	0.307	0.010	0.314	NO	NO	N/A - defence level currently less than statutory height
RW218	S074/02	Richmond- Chelsea	Bridges Court (right bank)	connection tunnel passing under	5.410	5.410	5.040	0.370	4.630	0.005	0.365	0.038	0.403	0.018	0.383	0.017	0.348	0.010	0.355	NO	NO	SIGNIFICANT
RW217	S075/01/01	Richmond- Chelsea	Bridges Court (right bank)	connection tunnel passing under	5.410	5.410	5.040	0.370	7.420	0.007	0.363	0.038	0.401	0.018	0.381	0.017	0.346	0.010	0.353	NO	NO	SIGNIFICANT
RW414	N141/02	Richmond- Chelsea	Cremorne Wharf (left bank)	connection tunnel passing under	5.410	5.410	5.020	0.390	11.720	0.012	0.378	0.038	0.416	0.018	0.396	0.017	0.361	0.010	0.368	NO	NO	SIGNIFICANT
RW535	N141/03	Richmond- Chelsea	Cremorne Wharf (left bank)	connection tunnel passing under	5.410	5.410	5.020	0.390	20.500	0.021	0.370	0.038	0.408	0.018	0.388	0.017	0.353	0.010	0.360	NO	NO	SIGNIFICANT
RW479	N141/04	Richmond- Chelsea	Cremorne Wharf (left bank)	connection tunnel passing under	5.410	5.410	5.020	0.390	19.680	0.020	0.370	0.038	0.408	0.018	0.388	0.017	0.353	0.010	0.360	NO	NO	SIGNIFICANT
RW419	N142	Richmond- Chelsea	Cremorne Wharf (left bank)	connection tunnel passing under	5.570	5.410	5.020	0.550	4.540	0.005	0.545	0.038	0.583	0.018	0.563	0.017	0.528	0.010	0.535	NO	NO	NOT SIGNIFICANT
RW371	N143	Richmond- Chelsea	Cremorne Wharf (left bank)	connection tunnel passing under	6.060	5.410	5.020	1.040	2.440	0.002	1.038	0.038	1.076	0.018	1.056	0.017	1.021	0.010	1.028	NO	NO	NOT SIGNIFICANT
RW365	N152/02	Chelsea-Westminster	Chelsea Bridge	Main Tunnel passing under	5.410	5.410	5.010	0.400	26.060	0.026	0.374	0.029	0.403	0.014	0.388	0.013	0.361	0.004	0.370	NO	NO	SIGNIFICANT
RW766	S116/01	Chelsea-Westminster	Cringle Wharf (right bank)	Main Tunnel passing under	5.830	5.410	4.990	0.840	1.610	0.002	0.838	0.029	0.867	0.014	0.852	0.013	0.825	0.004	0.834	NO	NO	NOT SIGNIFICANT
RW767	S116/02	Chelsea-Westminster	Cringle Wharf (right bank)	Main Tunnel passing under	5.690	5.410	4.990	0.700	5.060	0.005	0.695	0.029	0.724	0.014	0.709	0.013	0.682	0.004	0.691	NO	NO	NOT SIGNIFICANT
RW768	S117/01	Chelsea-Westminster	Cringle Wharf (right bank)	Main Tunnel passing under	5.690	5.410	4.990	0.700	24.040	0.024	0.676	0.029	0.705	0.014	0.690	0.013	0.663	0.004	0.672	NO	NO	NOT SIGNIFICANT
RW523	S117/02	Chelsea-Westminster	Cringle Wharf (right bank)	Main Tunnel passing under	5.820	5.410	4.990	0.830	37.910	0.038	0.792	0.029	0.821	0.014	0.806	0.013	0.779	0.004	0.788	NO	NO	NOT SIGNIFICANT
RW205	S118	Chelsea-Westminster	Cringle Wharf (right bank)	Main Tunnel passing under	5.880	5.410	4.990	0.890	33.720	0.034	0.856	0.029	0.885	0.014	0.870	0.013	0.843	0.004	0.852	NO	NO	NOT SIGNIFICANT
RW460	S119/01	Chelsea-Westminster	Cringle Wharf (right bank)	Main Tunnel passing under	5.880	5.410	4.990	0.890	11.220	0.011	0.879	0.029	0.908	0.014	0.893	0.013	0.866	0.004	0.875	NO	NO	NOT SIGNIFICANT
RW106	S119/02	Chelsea-Westminster	Cringle Wharf (right bank)	Main Tunnel passing under	5.880	5.410	4.990	0.890	3.020	0.003	0.887	0.029	0.916	0.014	0.901	0.013	0.874	0.004	0.883	NO	NO	NOT SIGNIFICANT
RW459	S119/03	Chelsea-Westminster	Cringle Wharf (right bank)	Main Tunnel passing under	5.880	5.410	4.990	0.890	2.480	0.002	0.888	0.029	0.917	0.014	0.902	0.013	0.875	0.004	0.884	NO	NO	NOT SIGNIFICANT
RW206	S119/05	Chelsea-Westminster	Middle Wharf (right bank)	Main Tunnel passing under	5.880	5.410	4.990	0.890	0.400	0.000	0.890	0.029	0.919	0.014	0.904	0.013	0.877	0.004	0.886	NO	NO	NOT SIGNIFICANT
RW129	S119/06	Chelsea-Westminster	Middle Wharf (right bank)	Main Tunnel passing under	5.880	5.410	4.990	0.890	0.690	0.001	0.889	0.029	0.918	0.014	0.903	0.013	0.876	0.004	0.885	NO	NO	NOT SIGNIFICANT
RW119	S119/07	Chelsea-Westminster	Middle Wharf (right bank)	Main Tunnel passing under	5.880	5.410	4.990	0.890	0.700	0.001	0.889	0.029	0.918	0.014	0.903	0.013	0.876	0.004	0.885	NO	NO	NOT SIGNIFICANT
RW139	S119/08	Chelsea-Westminster	Middle Wharf (right bank)	Main Tunnel passing under	5.880	5.410	4.990	0.890	1.090	0.001	0.889	0.029	0.918	0.014	0.903	0.013	0.876	0.004	0.885	NO	NO	NOT SIGNIFICANT
RW109	S119/09	Chelsea-Westminster	Middle Wharf (right bank)	Main Tunnel passing under	5.880	5.410	4.990	0.890	1.510	0.002	0.888	0.029	0.917	0.014	0.902	0.013	0.875	0.004	0.884	NO	NO	NOT SIGNIFICANT
RW103	S120/01	Chelsea-Westminster	Middle Wharf (right bank)	Main Tunnel passing under	5.840	5.410	4.990	0.850	2.410	0.002	0.848	0.029	0.877	0.014	0.862	0.013	0.835	0.004	0.844	NO	NO	NOT SIGNIFICANT
RW107	S120/02	Chelsea-Westminster	Middle Wharf (right bank)	Main Tunnel passing under	5.840	5.410	4.990	0.850	23.940	0.024	0.826	0.029	0.855	0.014	0.840	0.013	0.813	0.004	0.822	NO	NO	NOT SIGNIFICANT
RW142	S121	Chelsea-Westminster	Prescott Wharf (right bank)	connection tunnel passing under	5.840	5.410	4.990	0.850	30.510	0.031	0.819	0.029	0.848	0.014	0.833	0.013	0.806	0.004	0.815	NO	NO	NOT SIGNIFICANT
RW557	S122	Chelsea-Westminster	Prescott Wharf (right bank)	Main Tunnel passing under	5.970	5.410	4.990	0.980	25.680	0.026	0.954	0.029	0.983	0.014	0.968	0.013	0.941	0.004	0.950	NO	NO	NOT SIGNIFICANT
RW769	S123	Chelsea-Westminster	Prescott Wharf (right bank)	Main Tunnel passing under	6.360	5.410	4.990	1.370	7.900	0.008	1.362	0.029	1.391	0.014	1.376	0.013	1.349	0.004	1.358	NO	NO	NOT SIGNIFICANT
RW770	S124	Chelsea-Westminster	Prescott Wharf (right bank)	Main Tunnel passing under	6.480	5.410	4.990	1.490	4.290	0.004	1.486	0.029	1.515	0.014	1.500	0.013	1.473	0.004	1.482	NO	NO	NOT SIGNIFICANT
RW771	S125/01	Chelsea-Westminster	Prescott Wharf (right bank)	Main Tunnel passing under	7.330	5.410	4.990	2.340	2.390	0.002	2.338	0.029	2.367	0.014	2.352	0.013	2.325	0.004	2.334	NO	NO	NOT SIGNIFICANT
RW772	S125/02	Chelsea-Westminster	Bourne Valley Wharf (right bank)	Main Tunnel passing under	7.330	5.410	4.990	2.340	4.020	0.004	2.336	0.029	2.365	0.014	2.350	0.013	2.323	0.004	2.332	NO	NO	NOT SIGNIFICANT
RW773	S126/01	Chelsea-Westminster	Bourne Valley Wharf (right bank)	Main Tunnel passing under	6.270	5.410	4.990	1.280	5.880	0.006	1.274	0.029	1.303	0.014	1.288	0.013	1.261	0.004	1.270	NO	NO	NOT SIGNIFICANT
RW774	S126/02	Chelsea-Westminster	Bourne Valley Wharf (right bank)	Main Tunnel passing under	6.270	5.410	4.990	1.280	2.570	0.003	1.277	0.029	1.306	0.014	1.291	0.013	1.264	0.004	1.273	NO	NO	NOT SIGNIFICANT
RW775	S127	Chelsea-Westminster	Bourne Valley Wharf (right bank)	Main Tunnel passing under	5.820	5.410	4.990	0.830	1.100	0.001	0.829	0.029	0.858	0.014	0.843	0.013	0.816	0.004	0.825	NO	NO	NOT SIGNIFICANT
RW776	S128	Chelsea-Westminster	Bourne Valley Wharf (right bank)	Main Tunnel passing under	UNKNOWN	5.410	4.990	UNKNOWN	0.140	0.000	UNKNOWN	0.029	UNKNOWN	0.014	UNKNOWN	0.013	UNKNOWN	0.004	UNKNOWN	NO	NO	UNKNOWN
RW781	S129/01/01	Chelsea-Westminster	Bourne Valley Wharf (right bank)	Main Tunnel passing under	5.820	5.410	4.990	0.830	1.380	0.001	0.829	0.029	0.858	0.014	0.843	0.013	0.816	0.004	0.825	NO	NO	NOT SIGNIFICANT
RW782	S129/01/02	Chelsea-Westminster	St George's Wharf (right bank)	Main Tunnel passing under	5.820	5.410	4.990	0.830	1.330	0.001	0.829	0.029	0.858	0.014	0.843	0.013	0.816	0.004	0.825	NO	NO	NOT SIGNIFICANT
RW755	S129/01/03	Chelsea-Westminster	St George's Wharf (right bank)	Main Tunnel passing under	5.820	5.410	4.990	0.830	0.240	0.000	0.830	0.029	0.859	0.014	0.844	0.013	0.817	0.004	0.826	NO	NO	NOT SIGNIFICANT
RW756	S129/01/04	Chelsea-Westminster	Somerset Wharf (right bank)	Main Tunnel passing under	5.820	5.410	4.990	0.830	0.040	0.000	0.830	0.029	0.859	0.014	0.844	0.013	0.817	0.004	0.826	NO	NO	NOT SIGNIFICANT
RW757	S129/01/05	Chelsea-Westminster	Somerset Wharf (right bank)	Main Tunnel passing under	5.820	5.410	4.990	0.830	0.020	0.000	0.830	0.029	0.859	0.014	0.844	0.013	0.817	0.004	0.826	NO	NO	NOT SIGNIFICANT
RW758	S129/02	Chelsea-Westminster	Chester Wharf (right bank)	Main Tunnel passing under	5.410	5.410	4.990	0.420	0.040	0.000	0.420	0.029	0.449	0.014	0.434	0.013	0.407	0.004	0.416	NO	NO	SIGNIFICANT
RW759	S130/01	Chelsea-Westminster	Chester Wharf (right bank)	Main Tunnel passing under	5.630	5.410	4.990	0.640	0.080	0.000	0.640	0.029	0.669	0.014	0.654	0.013	0.627	0.004	0.636	NO	NO	NOT SIGNIFICANT
RW760	S130/02	Chelsea-Westminster	Eagle Wharf (right bank)	Main Tunnel passing under	5.630	5.410	4.990	0.640	0.010	0.000	0.640	0.029	0.669	0.014	0.654	0.013	0.627	0.004	0.636	NO	NO	NOT SIGNIFICANT
RW589	S130/03	Chelsea-Westminster	Eagle Wharf (right bank)	Main Tunnel passing under	5.630	5.410	4.990	0.640	0.360	0.000	0.640	0.029	0.669	0.014	0.654	0.013	0.627	0.004	0.636	NO	NO	NOT SIGNIFICANT
RW588	S130/04	Chelsea-Westminster	Eagle Wharf (right bank)	Main Tunnel passing under	5.630	5.410	4.990	0.640	0.570	0.001	0.639	0.029	0.668	0.014	0.653	0.013	0.626	0.004	0.635	NO	NO	NOT SIGNIFICANT
RW458	S131/03	Chelsea-Westminster	Vauxhall Bridge (right bank)	Main Tunnel passing under	5.410	5.410	4.980	0.430	9.340	0.009	0.421	0.029	0.450	0.014	0.435	0.013	0.408	0.004	0.417	NO	NO	SIGNIFICANT
RW201	S132	Chelsea-Westminster	Vauxhall Bridge (right bank)	Main Tunnel passing under	5.410	5.410	4.980	0.430	9.700	0.010	0.420	0.029	0.449	0.014	0.434	0.013	0.407	0.004	0.416	NO	NO	SIGNIFICANT
RW200	S133/01/01	Chelsea-Westminster	Albert Embankment (right bank)	Main Tunnel passing under	5.320	5.410	4.980	0.340	13.280	0.013	0.327	0.029	0.356	0.014	0.341	0.013	0.314	0.004	0.323	NO	NO	N/A - defence level currently less than statutory height
RW569	S133/01/02	Chelsea-Westminster	Albert Embankment (right bank)	Main Tunnel passing under	5.320	5.410	4.980	0.340	4.010	0.004	0.336	0.029	0.365	0.014	0.350	0.013	0.323	0.004	0.332	NO	NO	N/A - defence level currently less than statutory height

RW456	S133/02/01	Chelsea-Westminster	Albert Embankment (right bank)	Main Tunnel passing under	5.840	5.410	4.980	0.860	15.830	0.016	0.844	0.029	0.873	0.014	0.858	0.013	0.831	0.004	0.840	NO	NO	NOT SIGNIFICANT
RW199	S133/02/02	Chelsea-Westminster	Albert Embankment (right bank)	Main Tunnel passing under	5.840	5.410	4.980	0.860	24.450	0.024	0.836	0.029	0.865	0.014	0.850	0.013	0.823	0.004	0.832	NO	NO	NOT SIGNIFICANT
RW455	S134	Chelsea-Westminster	Albert Embankment (right bank)	Main Tunnel passing under	5.830	5.410	4.980	0.850	30.630	0.031	0.819	0.029	0.848	0.014	0.833	0.013	0.806	0.004	0.815	NO	NO	NOT SIGNIFICANT
RW204	S135	Chelsea-Westminster	Albert Embankment (right bank)	Main Tunnel passing under	5.830	5.410	4.980	0.850	26.190	0.026	0.824	0.029	0.853	0.014	0.838	0.013	0.811	0.004	0.820	NO	NO	NOT SIGNIFICANT
RW203	S136	Chelsea-Westminster	Albert Embankment (right bank)	Main Tunnel passing under	5.830	5.410	4.980	0.850	6.990	0.007	0.843	0.029	0.872	0.014	0.857	0.013	0.830	0.004	0.839	NO	NO	NOT SIGNIFICANT
RW202	S137	Chelsea-Westminster	Albert Embankment (right bank)	Main Tunnel passing under	5.830	5.410	4.980	0.850	9.170	0.009	0.841	0.029	0.870	0.014	0.855	0.013	0.828	0.004	0.837	NO	NO	NOT SIGNIFICANT
RW500	S138/01	Chelsea-Westminster	Albert Embankment (right bank)	Main Tunnel passing under	5.830	5.410	4.980	0.850	9.310	0.009	0.841	0.029	0.870	0.014	0.855	0.013	0.828	0.004	0.837	NO	NO	NOT SIGNIFICANT
RW110	N190	Westminster - Tower Brid	Westminster Bridge/Pier (left bank)	Main Tunnel passing under	5.490	5.410	4.970	0.520	17.800	0.018	0.502	0.012	0.514	0.004	0.506	0.007	0.495	0.002	0.500	NO	NO	NOT SIGNIFICANT
RW540	N192	Westminster - Tower Brid	Victoria Embankment Gardens, Somerset House, Temple (left bank)	Main Tunnel passing under	5.490	5.410	4.960	0.530	3.550	0.004	0.526	0.012	0.538	0.004	0.530	0.007	0.519	0.002	0.524	NO	NO	NOT SIGNIFICANT
RW413	N193	Westminster - Tower Brid	Temple Avenue (left bank)	Main Tunnel passing under	5.490	5.410	4.960	0.530	40.990	0.041	0.489	0.012	0.501	0.004	0.493	0.007	0.482	0.002	0.487	NO	NO	NOT SIGNIFICANT
RW135	N195	Westminster - Tower Brid	Blackfriars Bridge (left bank)	Main Tunnel passing under	5.410	5.410	4.940	0.470	2.150	0.002	0.468	0.012	0.480	0.004	0.472	0.007	0.461	0.002	0.466	NO	NO	SIGNIFICANT
RW141	N194	Westminster - Tower Brid	Blackfriars Station (left bank)	Main Tunnel passing under	5.740	5.410	4.930	0.810	4.930	0.005	0.805	0.012	0.817	0.004	0.809	0.007	0.798	0.002	0.803	NO	NO	NOT SIGNIFICANT
RW136	N203	Westminster - Tower Brid	White Lion Hill (left bank)	Main Tunnel passing under	5.740	5.410	4.930	0.810	0.750	0.001	0.809	0.012	0.821	0.004	0.813	0.007	0.802	0.002	0.807	NO	NO	NOT SIGNIFICANT
RW646	S265	Tower Bridge - Charlton	Bermondsey Wall West (right bank)	Main Tunnel passing under	5.810	5.280	4.920	0.890	0.130	0.000	0.890	0.014	0.904	0.005	0.895	0.002	0.888	0.001	0.889	NO	NO	NOT SIGNIFICANT
RW647	S266	Tower Bridge - Charlton	Bermondsey Wall West (right bank)	Main Tunnel passing under	5.850	5.280	4.920	0.930	0.720	0.001	0.929	0.014	0.943	0.005	0.934	0.002	0.927	0.001	0.928	NO	NO	NOT SIGNIFICANT
RW648	S267	Tower Bridge - Charlton	Bermondsey Wall West (right bank)	Main Tunnel passing under	5.800	5.280	4.920	0.880	0.950	0.001	0.879	0.014	0.893	0.005	0.884	0.002	0.877	0.001	0.878	NO	NO	NOT SIGNIFICANT
RW649	S268	Tower Bridge - Charlton	Bermondsey Wall West (right bank)	Main Tunnel passing under	6.020	5.280	4.920	1.100	1.840	0.002	1.098	0.014	1.112	0.005	1.103	0.002	1.096	0.001	1.097	NO	NO	NOT SIGNIFICANT
RW650	S269	Tower Bridge - Charlton	Bermondsey Wall West (right bank)	Main Tunnel passing under	5.920	5.280	4.920	1.000	2.680	0.003	0.997	0.014	1.011	0.005	1.002	0.002	0.995	0.001	0.996	NO	NO	NOT SIGNIFICANT
RW651	S270	Tower Bridge - Charlton	Bermondsey Wall West (right bank)	Main Tunnel passing under	5.410	5.280	4.920	0.490	4.050	0.004	0.486	0.014	0.500	0.005	0.491	0.002	0.484	0.001	0.485	NO	NO	NOT SIGNIFICANT
RW652	S271	Tower Bridge - Charlton	Bermondsey Wall West (right bank)	Main Tunnel passing under	5.410	5.280	4.920	0.490	4.640	0.005	0.485	0.014	0.499	0.005	0.490	0.002	0.483	0.001	0.484	NO	NO	NOT SIGNIFICANT
RW653	S272	Tower Bridge - Charlton	Chambers Street (right bank)	Main Tunnel passing under	5.410	5.280	4.920	0.490	3.330	0.003	0.487	0.014	0.501	0.005	0.492	0.002	0.485	0.001	0.486	NO	NO	NOT SIGNIFICANT
RW654	S273	Tower Bridge - Charlton	Chambers Street (right bank)	Main Tunnel passing under	5.730	5.280	4.920	0.810	6.990	0.007	0.803	0.014	0.817	0.005	0.808	0.002	0.801	0.001	0.802	NO	NO	NOT SIGNIFICANT
RW655	S274/01	Tower Bridge - Charlton	Chambers Street (right bank)	Main Tunnel passing under	5.640	5.280	4.920	0.720	9.620	0.010	0.710	0.014	0.724	0.005	0.715	0.002	0.708	0.001	0.709	NO	NO	NOT SIGNIFICANT
RW656	S274/02	Tower Bridge - Charlton	Chambers Street (right bank)	Main Tunnel passing under	5.640	5.280	4.920	0.720	13.870	0.014	0.706	0.014	0.720	0.005	0.711	0.002	0.704	0.001	0.705	NO	NO	NOT SIGNIFICANT
RW657	S274/03	Tower Bridge - Charlton	Chambers Street (right bank)	Main Tunnel passing under	5.640	5.280	4.920	0.720	25.240	0.025	0.695	0.014	0.709	0.005	0.700	0.002	0.693	0.001	0.694	NO	NO	NOT SIGNIFICANT
RW658	S274/04	Tower Bridge - Charlton	Chambers Street (right bank)	Main Tunnel passing under	5.640	5.280	4.920	0.720	27.810	0.028	0.692	0.014	0.706	0.005	0.697	0.002	0.690	0.001	0.691	NO	NO	NOT SIGNIFICANT
RW659	S274/05	Tower Bridge - Charlton	Chambers Street (right bank)	Main Tunnel passing under	5.640	5.280	4.920	0.720	26.290	0.026	0.694	0.014	0.708	0.005	0.699	0.002	0.692	0.001	0.693	NO	NO	NOT SIGNIFICANT
RW660	S275/01	Tower Bridge - Charlton	Chambers Street (right bank)	Main Tunnel passing under	5.760	5.280	4.920	0.840	21.260	0.021	0.819	0.014	0.833	0.005	0.824	0.002	0.817	0.001	0.818	NO	NO	NOT SIGNIFICANT
RW661	S275/02	Tower Bridge - Charlton	Chambers Street (right bank)	Main Tunnel passing under	5.760	5.280	4.920	0.840	20.320	0.020	0.820	0.014	0.834	0.005	0.825	0.002	0.818	0.001	0.819	NO	NO	NOT SIGNIFICANT
RW662	S276	Tower Bridge - Charlton	Chambers Street (right bank)	Main Tunnel passing under	5.760	5.280	4.920	0.840	5.760	0.006	0.834	0.014	0.848	0.005	0.839	0.002	0.832	0.001	0.833	NO	NO	NOT SIGNIFICANT
RW663	S277	Tower Bridge - Charlton	Bermondsey Wall East (right bank)	Main Tunnel passing under	5.770	5.280	4.920	0.850	4.830	0.005	0.845	0.014	0.859	0.005	0.850	0.002	0.843	0.001	0.844	NO	NO	NOT SIGNIFICANT
RW664	S278	Tower Bridge - Charlton	Bermondsey Wall East (right bank)	Main Tunnel passing under	5.760	5.280	4.920	0.840	4.180	0.004	0.836	0.014	0.850	0.005	0.841	0.002	0.834	0.001	0.835	NO	NO	NOT SIGNIFICANT
RW665	S279	Tower Bridge - Charlton	Bermondsey Wall East (right bank)	Main Tunnel passing under	5.760	5.280	4.920	0.840	5.830	0.006	0.834	0.014	0.848	0.005	0.839	0.002	0.832	0.001	0.833	NO	NO	NOT SIGNIFICANT
RW666	S280	Tower Bridge - Charlton	Bermondsey Wall East (right bank)	Main Tunnel passing under	5.760	5.280	4.920	0.840	5.820	0.006	0.834	0.014	0.848	0.005	0.839	0.002	0.832	0.001	0.833	NO	NO	NOT SIGNIFICANT
RW512	S281	Tower Bridge - Charlton	Bermondsey Wall East (right bank)	Main Tunnel passing under	5.760	5.280	4.920	0.840	5.740	0.006	0.834	0.014	0.848	0.005	0.839	0.002	0.832	0.001	0.833	NO	NO	NOT SIGNIFICANT
RW506	S282	Tower Bridge - Charlton	Bermondsey Wall East (right bank)	Main Tunnel passing under	5.730	5.280	4.920	0.810	4.630	0.005	0.805	0.014	0.819	0.005	0.810	0.002	0.803	0.001	0.804	NO	NO	NOT SIGNIFICANT
RW457	S283	Tower Bridge - Charlton	Bermondsey Wall East (right bank)	Main Tunnel passing under	5.750	5.280	4.920	0.830	4.510	0.005	0.825	0.014	0.839	0.005	0.830	0.002	0.823	0.001	0.824	NO	NO	NOT SIGNIFICANT
RW173	S284	Tower Bridge - Charlton	Bermondsey Wall East (right bank)	Main Tunnel passing under	5.750	5.280	4.920	0.830	2.620	0.003	0.827	0.014	0.841	0.005	0.832	0.002	0.825	0.001	0.826	NO	NO	NOT SIGNIFICANT
RW172	S285	Tower Bridge - Charlton	Bermondsey Wall East (right bank)	Main Tunnel passing under	5.280	5.280	4.920	0.360	2.230	0.002	0.358	0.014	0.372	0.005	0.363	0.002	0.356	0.001	0.357	NO	NO	SIGNIFICANT
RW171	S286	Tower Bridge - Charlton	Bermondsey Wall East (right bank)	Main Tunnel passing under	5.770	5.280	4.920	0.850	2.770	0.003	0.847	0.014	0.861	0.005	0.852	0.002	0.845	0.001	0.846	NO	NO	NOT SIGNIFICANT
RW170	S287	Tower Bridge - Charlton	Bermondsey Wall East (right bank)	Main Tunnel passing under	5.770	5.280	4.920	0.850	1.340	0.001	0.849	0.014	0.863	0.005	0.854	0.002	0.847	0.001	0.848	NO	NO	NOT SIGNIFICANT
RW169	S288	Tower Bridge - Charlton	Bermondsey Wall East (right bank)	Main Tunnel passing under	5.760	5.280	4.920	0.840	1.140	0.001	0.839	0.014	0.853	0.005	0.844	0.002	0.837	0.001	0.838	NO	NO	NOT SIGNIFICANT
RW183	S290	Tower Bridge - Charlton	Bermondsey Wall East (right bank)	Main Tunnel passing under	5.280	5.280	4.920	0.360	0.320	0.000	0.360	0.014	0.374	0.005	0.365	0.002	0.358	0.001	0.359	NO	NO	SIGNIFICANT
RW403	N313	Tower Bridge - Charlton	Wapping Wall (left bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	0.140	0.000	0.410	0.014	0.424	0.005	0.415	0.002	0.408	0.001	0.409	NO	NO	SIGNIFICANT
RW410	N317	Tower Bridge - Charlton	Wapping Wall (left bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	3.820	0.004	0.406	0.014	0.420	0.005	0.411	0.002	0.404	0.001	0.405	NO	NO	SIGNIFICANT
RW112	N318/01	Tower Bridge - Charlton	Wapping Wall (left bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	4.850	0.005	0.405	0.014	0.419	0.005	0.410	0.002	0.403	0.001	0.404	NO	NO	SIGNIFICANT
RW357	N318/02	Tower Bridge - Charlton	Wapping Wall (left bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	5.220	0.005	0.405	0.014	0.419	0.005	0.410	0.002	0.403	0.001	0.404	NO	NO	SIGNIFICANT
RW409	N319	Tower Bridge - Charlton	Wapping Wall (left bank)	Main Tunnel passing under	5.760	5.280	4.870	0.890	4.950	0.005	0.885	0.014	0.899	0.005	0.890	0.002	0.883	0.001	0.884	NO	NO	NOT SIGNIFICANT
RW356	N320/01	Tower Bridge - Charlton	Wapping Wall (left bank)	Main Tunnel passing under	5.800	5.280	4.870	0.930	5.830	0.006	0.924	0.014	0.938	0.005	0.929	0.002	0.922	0.001	0.923	NO	NO	NOT SIGNIFICANT
RW118	N320/02	Tower Bridge - Charlton	Wapping Wall (left bank)	Main Tunnel passing under	5.800	5.280	4.870	0.930	5.810	0.006	0.924	0.014	0.938	0.005	0.929	0.002	0.922	0.001	0.923	NO	NO	NOT SIGNIFICANT
RW140	N320/03	Tower Bridge - Charlton	Wapping Wall (left bank)	Main Tunnel passing under	5.800	5.280	4.870	0.930	6.120	0.006	0.924	0.014	0.938	0.005	0.929	0.002	0.922	0.001	0.923	NO	NO	NOT SIGNIFICANT
RW151	N320/04	Tower Bridge - Charlton	Wapping Wall (left bank)	Main Tunnel passing under	5.800	5.280	4.870	0.930	6.430	0.006	0.924	0.014	0.938	0.005	0.929	0.002	0.922	0.001	0.923	NO	NO	NOT SIGNIFICANT
RW408	N321/01	Tower Bridge - Charlton	Glamis Road (left bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	9.400	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	SIGNIFICANT
RW355	N321/02/01	Tower Bridge - Charlton	Glamis Road (left bank)	Main Tunnel passing under	5.280	5.230	4.870	0.410	9.610	0.010	0.400	0.014	0.414	0.005	0.405	0.002	0.398	0.001	0.399	NO	NO	NOT SIGNIFICANT
RW354	N321/02/02	Tower Bridge - Charlton	Glamis Road (left bank)	Main Tunnel passing under	5.280	5.230	4.870	0.410	5.600	0.006	0.404	0.014	0.418	0.005	0.409	0.002	0.402	0.001	0.403	NO	NO	NOT SIGNIFICANT
RW353	N321/02/03	Tower Bridge - Charlton	Glamis Road (left bank)	Main Tunnel passing under	5.280	5.230	4.870	0.410	9.400	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	NOT SIGNIFICANT
RW122	N321/02/04	Tower Bridge - Charlton	Glamis Road (left bank)	Main Tunnel passing under	5.280	5.230	4.870	0.410	9.420	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	NOT SIGNIFICANT
RW108	N321/02/05	Tower Bridge - Charlton	Glamis Road (left bank)	Main Tunnel passing under	5.280	5.230	4.870	0.410	9.370	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	NOT SIGNIFICANT
RW359	N322	Tower Bridge - Charlton	Shadwell Dock Stairs (left bank)	Main Tunnel passing under	5.440	5.230	4.870	0.570	9.050	0.009	0.561	0.014	0.575	0.005	0.566	0.002	0.559	0.001	0.560	NO	NO	NOT SIGNIFICANT
RW407	N323/01	Tower Bridge - Charlton	Shadwell Dock Stairs (left bank)	Main Tunnel passing under	5.690	5.230	4.870	0.820	21.630	0.022	0.798	0.014	0.812	0.005	0.803	0.002	0.796	0.001	0.797	NO	NO	NOT SIGNIFICANT
RW332	N323/02	Tower Bridge - Charlton	Shadwell Dock Stairs (left bank)	Main Tunnel passing under	5.690	5.230	4.870	0.820	43.200	0.043	0.777	0.014	0.791	0.005	0.782	0.002	0.775	0.001	0.776	NO	NO	NOT SIGNIFICANT
RW331	N323/03	Tower Bridge - Charlton	Shadwell Dock Stairs (left bank)	Main Tunnel passing under	5.690	5.230	4.870	0.820	41.070	0.041	0.779	0.014	0.793	0.005	0.784	0.002	0.777	0.001	0.778	NO	NO	NOT SIGNIFICANT
RW406	N324/01	Tower Bridge - Charlton	Shadwell Dock Stairs (left bank)	Main Tunnel passing under	5.730	5.230	4.870	0.860	8.410	0.008	0.852	0.014	0.866	0.005	0.857	0.002	0.850	0.001	0.851	NO	NO	NOT SIGNIFICANT
RW115	N324/02	Tower Bridge - Charlton	Jardine Road (left bank)	Main Tunnel passing under	5.730	5.230	4.870	0.860	4.950	0.005	0.855	0.014	0.869	0.005	0.860	0.002	0.853	0.001	0.854	NO	NO	NOT SIGNIFICANT
RW145	N324/03	Tower Bridge - Charlton	Jardine Road (left bank)	Main Tunnel passing under	5.730	5.230	4.870	0.860	5.470	0.005	0.855	0.014	0.869	0.005	0.860	0.002	0.853	0.001	0.854	NO	NO	NOT SIGNIFICANT
RW149	N324/04	Tower Bridge - Charlton	Jardine Road (left bank)	Main Tunnel passing under	5.730	5.230	4.870	0.860	8.060	0.008	0.852	0.014	0.866	0.005	0.857	0.002	0.850	0.001	0.851	NO	NO	NOT SIGNIFICANT
RW124	N325	Tower Bridge - Charlton	Jardine Road (left bank)	Main Tunnel passing under	6.280	5.230	4.870	1.410	5.310	0.005	1.405	0.014	1.419	0.005	1.410	0.002	1.403	0.001	1.404	NO	NO	NOT SIGNIFICANT
RW130	N326	Tower Bridge - Charlton	Jardine Road (left bank)	Main Tunnel passing under	6.580	5.230	4.870	1.710	6.410	0.006	1.704	0.014	1.718	0.005	1.709	0.002	1.702	0.001	1.703	NO	NO	NOT SIGNIFICANT
RW114	N327/01	Tower Bridge - Charlton	Jardine Road (left bank)	Main Tunnel passing under	8.720	5.230	4.870	3.850	6.220	0.006	3.844	0.014	3.858	0.005	3.849	0.002	3.842	0.001	3.843	NO	NO	NOT SIGNIFICANT
RW144	N327/02	Tower Bridge - Charlton	Jardine Road (left bank)	Main Tunnel passing under	8.720	5.230	4.870	3.850	5.450	0.005	3.845	0.014	3.859	0.005	3.850	0.002	3.843	0.001	3.844	NO	NO	NOT SIGNIFICANT
RW335	N328	Tower Bridge - Charlton	Jardine Road (left bank)	Main Tunnel passing under	5.700	5.230	4.870	0.830	5.280	0.005	0.825	0.014	0.839	0.005	0.830	0.002	0.823	0.001	0.824	NO	NO	NOT SIGNIFICANT
RW334	N329	Tower Bridge - Charlton	Jardine Road (left bank)	Main Tunnel passing under	5.700	5.230	4.870	0.830	2.330	0.002	0.828	0.014	0.842	0.005	0.833	0.002	0.826	0.001	0.827	NO	NO	NOT SIGNIFICANT
RW412	N330/01	Tower Bridge - Charlton	Narrow Street (left bank)	Main Tunnel passing under	5.750	5.230	4.870	0.880	3.430	0.003	0.877	0.014	0.891	0.005	0.882	0.002	0.875	0.001	0.876	NO	NO	NOT SIGNIFICANT
RW333	N330/02	Tower Bridge - Charlton	Narrow Street (left bank)	Main Tunnel passing under	5.750	5.230	4.870	0.880	3.620	0.004	0.876	0.014	0.890	0.005	0.881	0.002	0.874	0.001	0.875	NO	NO	NOT SIGNIFICANT
RW533	N330/03	Tower Bridge - Charlton	Narrow Street (left bank)	Main Tunnel passing under	5.750	5.230	4.870	0.880	3.720	0.004	0.876	0.014	0.890	0.005	0.881	0.002	0.874	0.001	0.875	NO	NO	NOT SIGNIFICANT
RW539	N331	Tower Bridge - Charlton	Narrow Street (left bank)	Main Tunnel passing under	5.720	5.230	4.870	0.850	4.060	0.004	0.846	0.014	0.860	0.005	0.851	0.002	0.844	0.001	0.845	NO	NO	NOT SIGNIFICANT
RW532	N332	Tower Bridge - Charlton	Narrow Street (left bank)	Main Tunnel passing under	5.280	5.230	4.870	0.410	4.610	0.005	0.405	0.014	0.419	0.005	0.410	0.002	0.403	0.001	0.404	NO	NO	NOT SIGNIFICANT
RW531	N333	Tower Bridge - Charlton	Narrow Street (left bank)	Main Tunnel passing under	5.280	5.230	4.870	0.410	5.460	0.005	0.405	0.014	0.419	0.005	0.410	0.002	0.403	0.001	0.404	NO	NO	NOT SIGNIFICANT
RW538	N334	Tower Bridge - Charlton	Narrow Street (left bank)	Main Tunnel passing under	5.280	5.230	4.870	0.410	6.000	0.006	0.404	0.014	0.418	0.005	0.409	0.002	0.402	0.001	0.403	NO	NO	NOT SIGNIFICANT
RW530	N335	Tower Bridge - Charlton	Narrow Street (left bank)	Main Tunnel passing under	5.280	5.230	4.870	0.410	6.340	0.006	0.404	0.014	0.418	0.005	0.409	0.002	0.402	0.001	0.403	NO	NO	NOT SIGNIFICANT
RW529	N336-337	Tower Bridge - Charlton	Narrow Street (left bank)	Main Tunnel passing under	5.280	5.230	4.870	0.410	6.850	0.007	0.403	0.014	0.417	0.005	0.408	0.002	0.401	0.001	0.402	NO	NO	NOT SIGNIFICANT
RW537	N338	Tower Bridge - Charlton	Narrow Street (left bank)	Main Tunnel passing under	5.280	5.230	4.870	0.410	8.330	0.008	0.402	0.014	0.416	0.005	0.407	0.002	0.400	0.001	0.401	NO	NO	NOT SIGNIFICANT
RW528	N339	Tower Bridge - Charlton	Narrow Street (left bank)	Main Tunnel passing under	5.280	5.230	4.870	0.410	8.670	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	NOT SIGNIFICANT
RW536	N340	Tower Bridge - Charlton	Narrow Street (left bank)	Main Tunnel passing under	5.280	5.230	4.870	0.410	9.190	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	NOT SIGNIFICANT
RW502	N341	Tower Bridge - Charlton	Narrow Street (left bank)	Main Tunnel passing under	5.280	5.230	4.870	0.410	9.500	0.010	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	NOT SIGNIFICANT
RW508	N342/01	Tower Bridge - Charlton	Narrow Street (left bank)	Main Tunnel passing under	5.710	5.230	4.870	0.840	9.690	0.010	0.830	0.014	0.844	0.005	0.835	0.002	0.828	0.001	0.829	NO	NO	NOT SIGNIFICANT
RW505	N342/02	Tower Bridge - Charlton	Narrow Street (left bank)	Main Tunnel passing under	5.710	5.230	4.870	0.840	10.490	0.010	0.830	0.014	0.844	0.005	0.835	0.002	0.828	0.001	0.829	NO	NO	NOT SIGNIFICANT
RW513	N343/01	Tower Bridge - Charlton	Narrow Street (left bank)	Main Tunnel passing under	5.720	5.230	4.870	0.850	7.920	0.008	0.842	0.014	0.856	0.005	0.847	0.002	0.840	0.001	0.841	NO	NO	NOT SIGNIFICANT
RW514	N343/02	Tower Bridge - Charlton	Narrow Street (left bank)	Main Tunnel passing under	5.720	5.230	4.870	0.850	4.110	0.004	0.846	0.014	0.860	0.005	0.851	0.002	0.844	0.001	0.845	NO	NO	NOT SIGNIFICANT
RW507	N343/03	Tower Bridge - Charlton	Narrow Street (left bank)	Main Tunnel passing under	5.720	5.230	4.870	0.850	1.980	0.002	0.848	0.014	0.862	0.005	0.853	0.002	0.846	0.001	0.847	NO	NO	NOT SIGNIFICANT
RW402	LC045	Tower Bridge - Charlton	Limehouse - Narrow Street, Northey Street	Main Tunnel passing under	5.390	5.230	4.870	0.520	9.560	0.010	0.510	0.014	0.524	0.005	0.515	0.002	0.508	0.001	0.509	NO	NO	NOT SIGNIFICANT
RW294	LC094	Tower Bridge - Charlton	Limehouse - Narrow Street, Northey Street	Main Tunnel passing under	5.230	5.230	4.870	0.360	0.910	0.001	0.359	0.014	0.373	0.005	0.364	0.002	0.357	0.001	0.358	NO	NO	SIGNIFICANT
RW386	N344	Tower Bridge - Charlton	Limehouse - Narrow Street, Northey Street	Main Tunnel passing under	5.230	5.230	4.870	0.360	0.690	0.001	0.359	0.014	0.373	0.005	0.364	0.002	0.357	0.001	0.358	NO	NO	SIGNIFICANT
RW402	LC086	Tower Bridge - Charlton	Limehouse - Narrow Street, Northey Street	Main Tunnel passing under	5.390	5.230	4.870	0.520	9.560	0.010	0.510	0.014	0.524	0.005	0.515	0.002	0.508	0.001	0.509	NO	NO	NOT SIGNIFICANT
RW395	LC087	Tower Bridge - Charlton	Limehouse Cut (left bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	0.680	0.001	0.359	0.014	0.373	0.005	0.364	0.002	0.357	0.001	0.358	NO	NO	SIGNIFICANT
RW343	LC088	Tower Bridge - Charlton	Limehouse Cut (left bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	7.470	0.007	0.353	0.014	0.367	0.005	0.358	0.002	0.351	0.001	0.352	NO	NO	SIGNIFICANT
RW342	LC089	Tower Bridge - Charlton	Limehouse Cut (left bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	8.670	0.009	0.351	0.014	0.365	0.005	0.356	0.002	0.349	0.001	0.350	NO	NO	SIGNIFICANT
RW341	LC090	Tower Bridge - Charlton	Limehouse Cut (left bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	9.460	0.009	0.351	0.014	0.365	0.005	0.356	0.002	0.349	0.001	0.350	NO	NO	SIGNIFICANT
RW394	LC078	Tower Bridge - Charlton	Limehouse Cut (left bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	11.340	0.011	0.349	0.014	0.363	0.005	0.354	0.002	0.347	0.001	0.348	NO	NO	SIGNIFICANT
RW393	LC079	Tower Bridge - Charlton	Limehouse Cut, Copenhagen Place (left bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	10.230	0.010	0.350	0.014	0.364	0.005	0.355	0.002	0.348	0.001	0.349	NO	NO	SIGNIFICANT
RW340	LC080	Tower Bridge - Charlton	Limehouse Cut, Copenhagen Place (left bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	10.780	0.011	0.349	0.014	0.363	0.005	0.354	0.002	0.347	0.001	0.348	NO	NO	SIGNIFICANT
RW339	LC081	Tower Bridge - Charlton	Limehouse Cut, Copenhagen Place (left bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	10.810	0.011	0.349	0.014	0.363	0.005	0.354	0.002	0.347	0.001	0.348	NO	NO	SIGNIFICANT
RW392	LC082	Tower Bridge - Charlton	Limehouse Cut, Copenhagen Place (left bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	9.260	0.009	0.351	0.014	0.365	0.005	0.356	0.002	0.349	0.001	0.350	NO	NO	SIGNIFICANT
RW338	LC083	Tower Bridge - Charlton	Limehouse Cut, Copenhagen Place (left bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	9.140	0.009	0.351	0.014	0.365	0.005	0.356	0.002	0.349	0.001	0.350	NO	NO	SIGNIFICANT
RW337	LC084	Tower Bridge - Charlton	Limehouse Cut, Copenhagen Place (left bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	10.450	0.010	0.350	0.014	0.364	0.005	0.355	0.002	0.348	0.001	0.349	NO	NO	SIGNIFICANT
RW336	LC085	Tower Bridge - Charlton	Limehouse Cut, Copenhagen Place (left bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	10.420	0.010	0.350	0.014	0.364	0.005	0.355	0.002	0.348	0.001	0.349	NO	NO	SIGNIFICANT
RW348	LC069	Tower Bridge - Charlton	Limehouse Cut, Copenhagen Place (left bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	10.650	0.011	0.399	0.014	0.413	0.005	0.404	0.002	0.397	0.001	0.398	NO	NO	SIGNIFICANT
RW347	LC070	Tower Bridge - Charlton	Limehouse Cut, Thomas Road (left bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	8.710	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	SIGNIFICANT
RW346	LC071	Tower Bridge - Charlton	Limehouse Cut, Thomas Road (left bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	8.660	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	SIGNIFICANT
RW345	LC072	Tower Bridge - Charlton	Limehouse Cut, Thomas Road (left bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	10.150	0.010	0.400	0.014	0.414	0.005	0.405	0.002	0.398	0.001	0.399	NO	NO	SIGNIFICANT
RW318	LC073	Tower Bridge - Charlton	Limehouse Cut, Thomas Road (left bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	9.860	0.010	0.400	0.014	0.414	0.005	0.405	0.002	0.398	0.001	0.399	NO	NO	SIGNIFICANT

RW317	LC074	Tower Bridge - Charlton	Limehouse Cut, Thomas Road (left bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	10.470	0.010	0.400	0.014	0.414	0.005	0.405	0.002	0.398	0.001	0.399	NO	NO	SIGNIFICANT
RW316	LC075	Tower Bridge - Charlton	Limehouse Cut, Thomas Road (left bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	10.490	0.010	0.400	0.014	0.414	0.005	0.405	0.002	0.398	0.001	0.399	NO	NO	SIGNIFICANT
RW315	LC076	Tower Bridge - Charlton	Limehouse Cut, Thomas Road (left bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	10.530	0.011	0.399	0.014	0.413	0.005	0.404	0.002	0.397	0.001	0.398	NO	NO	SIGNIFICANT
RW391	LC077	Tower Bridge - Charlton	Limehouse Cut, Thomas Road (left bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	9.350	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	SIGNIFICANT
RW314	LC063	Tower Bridge - Charlton	Limehouse Cut, Thomas Road (left bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	9.350	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	SIGNIFICANT
RW390	LC064	Tower Bridge - Charlton	Limehouse Cut, Hawgood Street (left bank)	Main Tunnel passing under	5.330	5.280	4.870	0.460	9.280	0.009	0.451	0.014	0.465	0.005	0.456	0.002	0.449	0.001	0.450	NO	NO	NOT SIGNIFICANT
RW329	LC065	Tower Bridge - Charlton	Limehouse Cut, Hawgood Street (left bank)	Main Tunnel passing under	5.330	5.280	4.870	0.460	9.220	0.009	0.451	0.014	0.465	0.005	0.456	0.002	0.449	0.001	0.450	NO	NO	NOT SIGNIFICANT
RW328	LC066	Tower Bridge - Charlton	Limehouse Cut, Hawgood Street (left bank)	Main Tunnel passing under	5.330	5.280	4.870	0.460	9.240	0.009	0.451	0.014	0.465	0.005	0.456	0.002	0.449	0.001	0.450	NO	NO	NOT SIGNIFICANT
RW389	LC067	Tower Bridge - Charlton	Limehouse Cut, Hawgood Street (left bank)	Main Tunnel passing under	5.330	5.280	4.870	0.460	10.810	0.011	0.449	0.014	0.463	0.005	0.454	0.002	0.447	0.001	0.448	NO	NO	NOT SIGNIFICANT
RW327	LC068	Tower Bridge - Charlton	Limehouse Cut, Hawgood Street (left bank)	Main Tunnel passing under	5.330	5.280	4.870	0.460	9.160	0.009	0.451	0.014	0.465	0.005	0.456	0.002	0.449	0.001	0.450	NO	NO	NOT SIGNIFICANT
RW326	LC057	Tower Bridge - Charlton	Limehouse Cut, Hawgood Street (left bank)	Main Tunnel passing under	5.330	5.280	4.870	0.460	10.700	0.011	0.449	0.014	0.463	0.005	0.454	0.002	0.447	0.001	0.448	NO	NO	NOT SIGNIFICANT
RW388	LC058	Tower Bridge - Charlton	Limehouse Cut, Yeo Street (left bank)	Main Tunnel passing under	5.330	5.280	4.870	0.460	10.650	0.011	0.449	0.014	0.463	0.005	0.454	0.002	0.447	0.001	0.448	NO	NO	NOT SIGNIFICANT
RW325	LC059	Tower Bridge - Charlton	Limehouse Cut, Yeo Street (left bank)	Main Tunnel passing under	5.330	5.280	4.870	0.460	9.120	0.009	0.451	0.014	0.465	0.005	0.456	0.002	0.449	0.001	0.450	NO	NO	NOT SIGNIFICANT
RW387	LC060	Tower Bridge - Charlton	Limehouse Cut, Yeo Street (left bank)	Main Tunnel passing under	5.330	5.280	4.870	0.460	9.120	0.009	0.451	0.014	0.465	0.005	0.456	0.002	0.449	0.001	0.450	NO	NO	NOT SIGNIFICANT
RW324	LC061	Tower Bridge - Charlton	Limehouse Cut, Yeo Street (left bank)	Main Tunnel passing under	5.330	5.330	4.870	0.460	9.160	0.009	0.451	0.014	0.465	0.005	0.456	0.002	0.449	0.001	0.450	NO	NO	SIGNIFICANT
RW401	LC062	Tower Bridge - Charlton	Limehouse Cut, Yeo Street (left bank)	Main Tunnel passing under	5.330	5.330	4.870	0.460	9.160	0.009	0.451	0.014	0.465	0.005	0.456	0.002	0.449	0.001	0.450	NO	NO	SIGNIFICANT
RW323	LC055	Tower Bridge - Charlton	Limehouse Cut, Yeo Street (left bank)	Main Tunnel passing under	5.330	5.330	4.870	0.460	10.600	0.011	0.449	0.014	0.463	0.005	0.454	0.002	0.447	0.001	0.448	NO	NO	SIGNIFICANT
RW400	LC056	Tower Bridge - Charlton	Limehouse Cut, St Andrews Way (left bank)	Main Tunnel passing under	5.330	5.330	4.870	0.460	10.420	0.010	0.450	0.014	0.464	0.005	0.455	0.002	0.448	0.001	0.449	NO	NO	SIGNIFICANT
RW322	LC051	Tower Bridge - Charlton	Limehouse Cut, St Andrews Way (left bank)	Main Tunnel passing under	5.330	5.330	4.870	0.460	8.890	0.009	0.451	0.014	0.465	0.005	0.456	0.002	0.449	0.001	0.450	NO	NO	SIGNIFICANT
RW321	LC052	Tower Bridge - Charlton	Limehouse Cut, Towcester Road (left bank)	Main Tunnel passing under	5.330	5.330	4.870	0.460	8.490	0.008	0.452	0.014	0.466	0.005	0.457	0.002	0.450	0.001	0.451	NO	NO	SIGNIFICANT
RW399	LC053	Tower Bridge - Charlton	Limehouse Cut, Towcester Road (left bank)	Main Tunnel passing under	5.330	5.330	4.870	0.460	9.040	0.009	0.451	0.014	0.465	0.005	0.456	0.002	0.449	0.001	0.450	NO	NO	SIGNIFICANT
RW398	LC054	Tower Bridge - Charlton	Limehouse Cut, Towcester Road (left bank)	Main Tunnel passing under	5.330	5.330	4.870	0.460	8.940	0.009	0.451	0.014	0.465	0.005	0.456	0.002	0.449	0.001	0.450	NO	NO	SIGNIFICANT
RW320	LC050	Tower Bridge - Charlton	Limehouse Cut, Towcester Road (left bank)	Main Tunnel passing under	5.330	5.330	4.870	0.460	10.420	0.010	0.450	0.014	0.464	0.005	0.455	0.002	0.448	0.001	0.449	NO	NO	SIGNIFICANT
RW319	RL091	Tower Bridge - Charlton	Limehouse Cut, A12 (left bank)	Main Tunnel passing under	5.330	5.330	4.870	0.460	10.470	0.010	0.450	0.014	0.464	0.005	0.455	0.002	0.448	0.001	0.449	NO	NO	SIGNIFICANT
RW397	RL092	Tower Bridge - Charlton	Limehouse Cut, A12 (left bank)	Main Tunnel passing under	5.720	5.330	4.870	0.850	9.180	0.009	0.841	0.014	0.855	0.005	0.846	0.002	0.839	0.001	0.840	NO	NO	NOT SIGNIFICANT
RW330	RL093	Tower Bridge - Charlton	Limehouse Cut, A12 (left bank)	Main Tunnel passing under	5.720	5.330	4.870	0.850	9.160	0.009	0.841	0.014	0.855	0.005	0.846	0.002	0.839	0.001	0.840	NO	NO	NOT SIGNIFICANT
RW396	RL094	Tower Bridge - Charlton	Limehouse Cut, A12 (left bank)	Main Tunnel passing under	5.740	5.330	4.870	0.870	9.120	0.009	0.861	0.014	0.875	0.005	0.866	0.002	0.859	0.001	0.860	NO	NO	NOT SIGNIFICANT
RW499	RL095	Tower Bridge - Charlton	Limehouse Cut, A12 (left bank)	Main Tunnel passing under	UNKNOWN	5.330	4.870	UNKNOWN	10.740	0.011	UNKNOWN	0.014	UNKNOWN	0.005	UNKNOWN	0.002	UNKNOWN	0.001	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN
RW515	RL096	Tower Bridge - Charlton	Limehouse Cut, A12 (left bank)	Main Tunnel passing under	UNKNOWN	5.490	4.870	UNKNOWN	4.410	0.004	UNKNOWN	0.014	UNKNOWN	0.005	UNKNOWN	0.002	UNKNOWN	0.001	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN
RW503	unknown	Tower Bridge - Charlton	Limehouse Cut, A12 (left bank)	Main Tunnel passing under	UNKNOWN	5.490	4.870	UNKNOWN	2.500	0.003	UNKNOWN	0.014	UNKNOWN	0.005	UNKNOWN	0.002	UNKNOWN	0.001	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN
RW593	LC033	Tower Bridge - Charlton	Limehouse Cut, A12 (left bank)	Main Tunnel passing under	UNKNOWN	UNKNOWN	4.870	UNKNOWN	10.690	0.011	UNKNOWN	0.014	UNKNOWN	0.005	UNKNOWN	0.002	UNKNOWN	0.001	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN
RW282	LC034	Tower Bridge - Charlton	Limehouse Cut (right bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	5.700	0.006	0.354	0.014	0.368	0.005	0.359	0.002	0.352	0.001	0.353	NO	NO	SIGNIFICANT
RW249	LC035	Tower Bridge - Charlton	Limehouse Cut (right bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	7.850	0.008	0.352	0.014	0.366	0.005	0.357	0.002	0.350	0.001	0.351	NO	NO	SIGNIFICANT
RW480	LC036	Tower Bridge - Charlton	Limehouse Cut (right bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	8.820	0.009	0.351	0.014	0.365	0.005	0.356	0.002	0.349	0.001	0.350	NO	NO	SIGNIFICANT
RW283	LC037	Tower Bridge - Charlton	Limehouse Cut (right bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	8.850	0.009	0.351	0.014	0.365	0.005	0.356	0.002	0.349	0.001	0.350	NO	NO	SIGNIFICANT
RW284	LC025	Tower Bridge - Charlton	Limehouse Cut (right bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	8.890	0.009	0.351	0.014	0.365	0.005	0.356	0.002	0.349	0.001	0.350	NO	NO	SIGNIFICANT
RW285	LC026	Tower Bridge - Charlton	Limehouse Cut, Copenhagen Place (right bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	8.990	0.009	0.351	0.014	0.365	0.005	0.356	0.002	0.349	0.001	0.350	NO	NO	SIGNIFICANT
RW286	LC027	Tower Bridge - Charlton	Limehouse Cut, Copenhagen Place (right bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	8.980	0.009	0.351	0.014	0.365	0.005	0.356	0.002	0.349	0.001	0.350	NO	NO	SIGNIFICANT
RW287	LC028	Tower Bridge - Charlton	Limehouse Cut, Copenhagen Place (right bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	8.850	0.009	0.351	0.014	0.365	0.005	0.356	0.002	0.349	0.001	0.350	NO	NO	SIGNIFICANT
RW288	LC029	Tower Bridge - Charlton	Limehouse Cut, Copenhagen Place (right bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	8.900	0.009	0.351	0.014	0.365	0.005	0.356	0.002	0.349	0.001	0.350	NO	NO	SIGNIFICANT
RW289	LC030	Tower Bridge - Charlton	Limehouse Cut, Copenhagen Place (right bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	8.900	0.009	0.351	0.014	0.365	0.005	0.356	0.002	0.349	0.001	0.350	NO	NO	SIGNIFICANT
RW290	LC031	Tower Bridge - Charlton	Limehouse Cut, Copenhagen Place (right bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	8.730	0.009	0.351	0.014	0.365	0.005	0.356	0.002	0.349	0.001	0.350	NO	NO	SIGNIFICANT
RW291	LC032	Tower Bridge - Charlton	Limehouse Cut, Copenhagen Place (right bank)	Main Tunnel passing under	5.230	5.230	4.870	0.360	8.770	0.009	0.351	0.014	0.365	0.005	0.356	0.002	0.349	0.001	0.350	NO	NO	SIGNIFICANT
RW481	LC018	Tower Bridge - Charlton	Limehouse Cut, Copenhagen Place (right bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	8.730	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	SIGNIFICANT
RW292	LC019	Tower Bridge - Charlton	Limehouse Cut, Dod Street (right bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	8.750	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	SIGNIFICANT
RW293	LC020	Tower Bridge - Charlton	Limehouse Cut, Dod Street (right bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	8.790	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	SIGNIFICANT
RW250	LC021	Tower Bridge - Charlton	Limehouse Cut, Dod Street (right bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	8.790	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	SIGNIFICANT
RW279	LC022	Tower Bridge - Charlton	Limehouse Cut, Dod Street (right bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	8.690	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	SIGNIFICANT
RW280	LC023	Tower Bridge - Charlton	Limehouse Cut, Dod Street (right bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	8.680	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	SIGNIFICANT
RW379	LC024	Tower Bridge - Charlton	Limehouse Cut, Dod Street (right bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	8.680	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	SIGNIFICANT
RW281	LC015	Tower Bridge - Charlton	Limehouse Cut, Dod Street (right bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	8.550	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	SIGNIFICANT
RW380	LC016/01	Tower Bridge - Charlton	Limehouse Cut, Cotall Street (right bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	9.650	0.010	0.400	0.014	0.414	0.005	0.405	0.002	0.398	0.001	0.399	NO	NO	SIGNIFICANT
RW307	LC016/02	Tower Bridge - Charlton	Limehouse Cut, Cotall Street (right bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	9.650	0.010	0.400	0.014	0.414	0.005	0.405	0.002	0.398	0.001	0.399	NO	NO	SIGNIFICANT
RW381	LC017	Tower Bridge - Charlton	Limehouse Cut, Cotall Street (right bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	8.540	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	SIGNIFICANT
RW308	LC010	Tower Bridge - Charlton	Limehouse Cut, Cotall Street (right bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	8.490	0.008	0.402	0.014	0.416	0.005	0.407	0.002	0.400	0.001	0.401	NO	NO	SIGNIFICANT
RW309	LC011	Tower Bridge - Charlton	Limehouse Cut, Broomfield Street (right bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	8.470	0.008	0.402	0.014	0.416	0.005	0.407	0.002	0.400	0.001	0.401	NO	NO	SIGNIFICANT
RW382	LC012	Tower Bridge - Charlton	Limehouse Cut, Broomfield Street (right bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	8.470	0.008	0.402	0.014	0.416	0.005	0.407	0.002	0.400	0.001	0.401	NO	NO	SIGNIFICANT
RW310	LC013	Tower Bridge - Charlton	Limehouse Cut, Broomfield Street (right bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	9.270	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	SIGNIFICANT
RW383	LC014/01	Tower Bridge - Charlton	Limehouse Cut, Broomfield Street (right bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	8.250	0.008	0.402	0.014	0.416	0.005	0.407	0.002	0.400	0.001	0.401	NO	NO	SIGNIFICANT
RW311	LC014/02	Tower Bridge - Charlton	Limehouse Cut, Broomfield Street (right bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	9.270	0.009	0.401	0.014	0.415	0.005	0.406	0.002	0.399	0.001	0.400	NO	NO	SIGNIFICANT
RW312	LC008	Tower Bridge - Charlton	Limehouse Cut, Broomfield Street (right bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	7.980	0.008	0.402	0.014	0.416	0.005	0.407	0.002	0.400	0.001	0.401	NO	NO	SIGNIFICANT
RW384	LC009	Tower Bridge - Charlton	Limehouse Cut, Barchester Street (right bank)	Main Tunnel passing under	5.280	5.230	4.870	0.410	8.010	0.008	0.402	0.014	0.416	0.005	0.407	0.002	0.400	0.001	0.401	NO	NO	NOT SIGNIFICANT
RW313	LC007	Tower Bridge - Charlton	Limehouse Cut, Barchester Street (right bank)	Main Tunnel passing under	5.280	5.280	4.870	0.410	7.950	0.008	0.402	0.014	0.416	0.005	0.407	0.002	0.400	0.001	0.401	NO	NO	SIGNIFICANT
RW385	LC005	Tower Bridge - Charlton	Limehouse Cut, Morris Street (right bank)	Main Tunnel passing under	5.330	5.330	4.870	0.460	7.790	0.008	0.452	0.014	0.466	0.005	0.457	0.002	0.450	0.001	0.451	NO	NO	SIGNIFICANT
RW297	LC006	Tower Bridge - Charlton	Limehouse Cut, Docklands Light Railway (right bank)	Main Tunnel passing under	5.330	5.330	4.870	0.460	7.730	0.008	0.452	0.014	0.466	0.005	0.457	0.002	0.450	0.001	0.451	NO	NO	SIGNIFICANT
RW298	LC004	Tower Bridge - Charlton	Limehouse Cut, Docklands Light Railway (right bank)	Main Tunnel passing under	5.330	5.330	4.870	0.460	7.600	0.008	0.452	0.014	0.466	0.005	0.457	0.002	0.450	0.001	0.451	NO	NO	SIGNIFICANT
RW372	LC002/02	Tower Bridge - Charlton	Limehouse Cut, Uamvar Street (right bank)	Main Tunnel passing under	5.330	5.330	4.870	0.460	7.900	0.008	0.452	0.014	0.466	0.005	0.457	0.002	0.450	0.001	0.451	NO	NO	SIGNIFICANT
RW299	LC003	Tower Bridge - Charlton	Limehouse Cut, Teviot Street (right bank)	Main Tunnel passing under	5.330	5.333	4.870	0.460	8.340	0.008	0.452	0.014	0.466	0.005	0.457	0.002	0.450	0.001	0.451	NO	NO	N/A - defence level currently less than statutory height
RW373	LC002/01	Tower Bridge - Charlton	Limehouse Cut, Teviot Street (right bank)	Main Tunnel passing under	5.330	5.330	4.870	0.460	9.860	0.010	0.450	0.014	0.464	0.005	0.455	0.002	0.448	0.001	0.449	NO	NO	SIGNIFICANT
RW300	BC001	Tower Bridge - Charlton	Limehouse Cut, Gillender Street (right bank)	Main Tunnel passing under	5.330	5.330	4.870	0.460	8.910	0.009	0.451	0.014	0.465	0.005	0.456	0.002	0.449	0.001	0.450	NO	NO	SIGNIFICANT
RW301	BC002/01	Tower Bridge - Charlton	Limehouse Cut, A12 (right bank)	Main Tunnel passing under	5.330	5.330	4.870	0.460	8.910	0.009	0.451	0.014	0.465	0.005	0.456	0.002	0.449	0.001	0.450	NO	NO	SIGNIFICANT
RW377	BC002/02	Tower Bridge - Charlton	Limehouse Cut, A12 (right bank)	Main Tunnel passing under	5.500	5.330	4.870	0.630	0.520	0.001	0.629	0.014	0.643	0.005	0.634	0.002	0.627	0.001	0.628	NO	NO	NOT SIGNIFICANT
RW306	BC002/04	Tower Bridge - Charlton	Limehouse Cut, A12 (right bank)	Main Tunnel passing under	5.830	5.330	4.870	0.960	3.150	0.003	0.957	0.014	0.971	0.005	0.962	0.002	0.955	0.001	0.956	NO	NO	NOT SIGNIFICANT
RW305	BC002/05	Tower Bridge - Charlton	Limehouse Cut, A12 (right bank)	Main Tunnel passing under	5.830	5.330	4.870	0.960	2.470	0.002	0.958	0.014	0.972	0.005	0.963	0.002	0.956	0.001	0.957	NO	NO	NOT SIGNIFICANT
RW376	BC002/06	Tower Bridge - Charlton	Limehouse Cut, A12 (right bank)	Main Tunnel passing under	5.830	5.330	4.870	0.960	2.000	0.002	0.958	0.014	0.972	0.005	0.963	0.002	0.956	0.001	0.957	NO	NO	NOT SIGNIFICANT
RW304	BC002/07	Tower Bridge - Charlton	Limehouse Cut, A12 (right bank)	Main Tunnel passing under	5.830	5.330	4.870	0.960	0.320	0.000	0.960	0.014	0.974	0.005	0.965	0.002	0.958	0.001	0.959	NO	NO	NOT SIGNIFICANT
RW303	BC003/01	Tower Bridge - Charlton	Limehouse Cut, A12 (right bank)	Main Tunnel passing under	5.830	5.330	4.870	0.960	0.530	0.001	0.959	0.014	0.973	0.005	0.964	0.002	0.957	0.001	0.958	NO	NO	NOT SIGNIFICANT
RW302	LC001	Tower Bridge - Charlton	Limehouse Cut, A12 (right bank)	Main Tunnel passing under	5.830	5.330	4.870	0.960	0.900	0.001	0.959	0.014	0.973	0.005	0.964	0.002	0.957	0.001	0.958	NO	NO	NOT SIGNIFICANT
RW374	BC049	Tower Bridge - Charlton	Limehouse Cut, A12 (right bank)	Main Tunnel passing under	5.330	5.333	4.870	0.460	2.480	0.002	0.458	0.014	0.472	0.005	0.463	0.002	0.456	0.001	0.457	NO	NO	N/A - defence level currently less than statutory height
RW101	BC050/01	Tower Bridge - Charlton	Twelve Trees Cres.	Main Tunnel passing under	UNKNOWN	UNKNOWN	4.870	UNKNOWN	10.680	0.011	UNKNOWN	0.014	UNKNOWN	0.005	UNKNOWN	0.002	UNKNOWN	0.001	UNKNOWN	NO	NO	UNKNOWN
RW497	CS949/02	Tower Bridge - Charlton	Twelve Trees Cres.	Main Tunnel passing under	UNKNOWN	UNKNOWN	4.870	UNKNOWN	9.110	0.009	UNKNOWN	0.014	UNKNOWN	0.005	UNKNOWN	0.002	UNKNOWN	0.001	UNKNOWN	NO	NO	UNKNOWN
RW239	unknown	Tower Bridge - Charlton	Twelve Trees Cres.	Main Tunnel passing under	5.490	5.490	4.870	0.620	10.660	0.011	0.609	0.014	0.623	0.005	0.614	0.002	0.607	0.001	0.608	NO	NO	SIGNIFICANT
RW510	unknown	Tower Bridge - Charlton	Twelve Trees Cres.	Main Tunnel passing under	5.490	5.490	4.870	0.620	2.920	0.003	0.617	0.014	0.631	0.005	0.622	0.002	0.615	0.001	0.616	NO	NO	SIGNIFICANT
RW501	CS916/01	Tower Bridge - Charlton	Twelve Trees Cres.	Main Tunnel passing under	5.490	5.490	4.870	0.620	1.360	0.001	0.619	0.014	0.633	0.005	0.624	0.002	0.617	0.001	0.618	NO	NO	SIGNIFICANT
RW274	CS916/02	Tower Bridge - Charlton	Channelsea River, Mill Meads	Main Tunnel passing under	5.490	5.490	4.870	0.620	10.590	0.011	0.609	0.014	0.623	0.005	0.614	0.002	0.607	0.001	0.608	NO	NO	SIGNIFICANT
RW243	CS917/01	Tower Bridge - Charlton	Channelsea River, Mill Meads	Main Tunnel passing under	5.730	5.490	4.870	0.860	7.500	0.008	0.853	0.014	0.867	0.005	0.858	0.002	0.851	0.001	0.852	NO	NO	NOT SIGNIFICANT
RW244	CS917/02	Tower Bridge - Charlton	Channelsea River, Mill Meads	Main Tunnel passing under	5.730	5.490	4.870	0.860	0.520	0.001	0.859	0.014	0.873	0.005	0.864	0.002	0.857	0.001	0.858	NO	NO	NOT SIGNIFICANT
RW247	CS917/03	Tower Bridge - Charlton	Channelsea River, Mill Meads	Main Tunnel passing under	5.480	5.490	4.870	0.610	9.050	0.009	0.601	0.014	0.615	0.005	0.606	0.002	0.599	0.001	0.600	NO	NO	N/A - defence level currently less than statutory height
RW246	CS918	Tower Bridge - Charlton	Channelsea River, Mill Meads	Main Tunnel passing under	5.490	5.490	4.870	0.620	8.280	0.008	0.612	0.014	0.626	0.005	0.617	0.002	0.610	0.001	0.611	NO	NO	SIGNIFICANT
RW278	CS948/02	Tower Bridge - Charlton	Channelsea River, Mill Meads	Main Tunnel passing under	5.490	5.490	4.870	0.620	10.050	0.010	0.610	0.014	0.624	0.005	0.615	0.002	0.608	0.001	0.609	NO	NO	SIGNIFICANT
RW277	CS948/03	Tower Bridge - Charlton	Channelsea River, Mill Meads	Main Tunnel passing under	5.490	5.490	4.870	0.620	9.030	0.009	0.611	0.014	0.625	0.005	0.616	0.002	0.609	0.001	0.610	NO	NO	SIGNIFICANT
RW245	CS949/01	Tower Bridge - Charlton	Channelsea River, Mill Meads	Main Tunnel passing under	5.490	5.490	4.870	0.620	9.000	0.009	0.611	0.014	0.625	0.005	0.616	0.002	0.609	0.001	0.610	NO	NO	SIGNIFICANT
RW276	PC800/02	Tower Bridge - Charlton	Channelsea River, Mill Meads	Main Tunnel passing under	5.730	5.490	4.870	0.860	0.380	0.000	0.860	0.014	0.874	0.005	0.865	0.002	0.858	0.001	0.859	NO	NO	NOT SIGNIFICANT
RW241	PC801	Tower Bridge - Charlton	Channelsea River, Mill Meads	Main Tunnel passing under	5.730	5.490	4.870	0.860	7.950	0.008	0.852	0.014	0.866	0.005	0.857	0.002	0.850	0.001	0.851	NO	NO	NOT SIGNIFICANT
RW242	DC038	Tower Bridge - Charlton	Channelsea River, Mill Meads	Main Tunnel passing under	5.480	5.490	4.870	0.610	10.540	0.011	0.599	0.014	0.613	0.005	0.604	0.002	0.597	0.001	0.598	NO	NO	N/A - defence level currently less than statutory height
RW482	DC039	Tower Bridge - Charlton	Deptford Creek, Norman Road (right bank)	connection tunnel passing under	5.230	5.230	4.830	0.400	1.650	0.002	0.398	0.014	0.412	0.005	0.403	0.002	0.396	0.001	0.397	NO	NO	SIGNIFICANT
RW272	DC040	Tower Bridge - Charlton	Deptford Creek, Norman Road (right bank)	connection tunnel passing under	5.680	5.230	4.830	0.850	6.140	0.006	0.844	0.014	0.858	0.005	0.849	0.002	0.842	0.001	0.843	NO	NO	NOT SIGNIFICANT
RW271	DC012/01	Tower Bridge - Charlton	Deptford Creek, Norman Road (right bank)	connection tunnel passing under	5.680	5.230	4.830	0.850	8.280	0.008	0.842	0.014	0.856	0.005	0.847	0.002	0.840	0.001	0.841	NO	NO	NOT SIGNIFICANT
RW638	DC012/02	Tower Bridge - Charlton	Deptford Creek, Creekside (left bank)	connection tunnel passing under	5.670	5.230	4.830	0.840	2.220	0.002	0.838	0.014	0.852	0.005	0.843	0.002	0.836	0.001	0.837	NO	NO	NOT SIGNIFICANT
RW639	DC013	Tower Bridge - Charlton	Deptford Creek, Creekside (left bank)	connection tunnel passing under	5.670	5.230	4.830	0.840	6.030	0.006	0.834	0.014	0.848	0.005	0.839	0.002	0.832	0.001	0.833	NO	NO	NOT SIGNIFICANT
RW629	DC014/01	Tower Bridge - Charlton	Deptford Creek, Creekside (left bank)	connection tunnel passing under	5.650	5.230	4.830	0.820	6.030	0.006	0.814	0.014	0.828	0.005	0.819	0.002	0.812	0.001	0.813	NO	NO	NOT SIGNIFICANT
RW628	DC014/02	Tower Bridge - Charlton	Deptford Creek, Creekside (left bank)	connection tunnel passing under	5.650	5.230	4.830	0.820	7.830	0.008	0.812	0.014	0.826	0.005	0.817	0.002	0.810	0.001	0.811	NO	NO	NOT SIGNIFICANT
RE630	DC015/01	Tower Bridge - Charlton	Deptford Creek, Creekside (left bank)	connection tunnel passing under	6.160	5.230	4.830	1.330	6.330	0.006	1.324	0.014	1.338	0.005	1.329	0.002	1.322	0.001	1.323	NO	NO	NOT SIGNIFICANT
RE631	DC015/02	Tower Bridge - Charlton	Deptford Creek, Creekside (left bank)	connection tunnel passing under	6.160	5.230	4.830	1.330	6.330	0.006	1.324	0.014	1.338	0.005	1.329	0.002	1.322	0.001	1.323	NO	NO	NOT SIGNIFICANT
RE632	DC016/01	Tower Bridge - Charlton	Deptford Creek, Creekside (left bank)	connection tunnel passing under	5.690	5.230	4.830	0.860	2.440	0.002	0.858	0.014	0.872	0.005	0.863	0.002	0.856	0.001	0.857	NO	NO	NOT SIGNIFICANT
RE633	DC016/02	Tower Bridge - Charlton	Deptford Creek, Creekside (left bank)	connection tunnel passing under	5.680	5.230	4.830	0.850	1.470	0.001	0.849	0.014	0.863	0.005	0.854	0.002	0.847	0.001	0.848	NO	NO	NOT SIGNIFICANT
RE441		Tower Bridge - Charlton	Deptford Creek, Creekside (left bank)	connection tunnel passing under	5.680	5.230	4.830	0.850	0.810	0.001	0.849	0.014	0.863	0.005	0.854	0.002	0.847	0.001	0.848	NO	NO	NOT SIGNIFICANT

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