London Tideway Tunnels: tackling London’s Victorian legacy of combined sewer overflows

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ABSTRACT

It takes a few millimetres of rainfall to cause the 34 most polluting combined sewer overflows (CSOs) to discharge into the River Thames. Currently, in a typical year, spillages to the tidal reaches of the River Thames occur about 60 times, with an estimated spill volume of 39 million cubic metres. Both the UK Government and the European Union have determined that the CSO discharges have an adverse environmental impact on fish species, introduce unacceptable aesthetics and elevate the health risks for recreational users of the Thames, with a frequency of discharge which is in breach of the Urban Wastewater Treatment Directive. Studies have established that the environmental objectives can be fully met on the most cost-effective basis by completing both quality improvements to treatment works and by the provision of a storage and transfer tunnel to intercept unsatisfactory CSOs. Extensive modelling has been undertaken to develop an optimised solution. In parallel with the design development a rigorous and comprehensive site selection methodology has been established to select sites and consult stakeholders and the public on the preferred sites and scheme, with the first stage of public consultation planned for later in 2010. The London Tideway Tunnels are an essential part of the delivery of improvements to the water quality of the tidal River Thames, and this ambitious, historic scheme represents a vital strategic investment in London’s infrastructure.

Key words | catchment modelling, combined sewer overflows, London Tideway Tunnels, site selection, Thames Tunnel, Urban Waste Water Treatment Directive

INTRODUCTION

In a typical year, an estimated 39 million cubic metres of untreated storm sewage is discharged directly into the tidal River Thames from London’s Victorian sewers, with an overflow frequency exceeding, on average, once a week. Thames Water has been appointed by the UK Government with addressing this issue through an ambitious and visionary scheme to control combined sewer discharges and improve water quality in the tidal River Thames. The scheme will include providing a tunnelled, combined sewage overflow (CSO) interception and storage system deep under the centre of London. It will be the most substantial CSO scheme of its type in Europe.

This paper provides an overview of why the scheme is required and the proposed solution, and outlines the development of the Thames Tunnel Project to date.

OBJECTIVES AND SYSTEM REQUIREMENTS

In common with many other European cities, London has a combined (foul sewage and stormwater) sewerage system. London’s system was masterminded by Victorian engineer Sir Joseph Bazalgette and was designed to intercept raw sewage discharging into the River Thames, while providing an overflow for diluted sewage during periods of significant rainfall to prevent flooding.

There has been a progressive extension of the collection sewerage and treatment system, with flows conveyed eastward to two principal sewage treatment works (STWs) at Crossness and Beckton, serving the southern and northern sides of the catchment respectively. Notwithstanding these improvements, the substantial growth of the London population and greater proportion of hard surfacing has increased flows to the point where there is little spare capacity in the
the sewage network as a whole. It now only takes a few millimetres of rainfall to cause some CSOs to discharge into the River Thames. Currently, spillages to the tidal reaches of the River Thames occur about 60 times per year at the most frequently overflowing CSOs. An estimated total of some 35–40 million cubic metres of polluting discharges enter the river in a typical year from the CSOs.

Both the UK Government and the European Union (EU) have determined that the CSO discharges have an adverse environmental impact on fish species, have unacceptable aesthetics and elevate the health risks for recreational users of the Thames. The Urban Waste Water Treatment Directive (UWWTD) (91/271/EEC) is the primary regulatory driver for the project. Other EU and UK legislation also form part of the legal framework within which the London Tideway Tunnels are to be designed and delivered. The Water Framework Directive (WFD) set out various ‘environmental objectives’ relating to surface water quality to be achieved by 2015, 2021 and 2027. In order to achieve these objectives in England and Wales, the Environment Agency (EA) has responsibility for the production of river basin management plans. The River Basin Management Plan for the River Thames, published in December 2009, identifies the sewage overflowing from combined sewer overflows as a main cause of pollution in the river.

Establishing a scheme to meet the need

In 2000, the Thames Tideway Strategic Study (TTSS) group was set up to assess the environmental impact of intermittent discharges of combined sewage on the Thames Tideway, to identify objectives for improvement and to propose potential solutions, having regard to costs and benefits. As part of these studies, the EA identified 57 CSOs discharging into the Thames Tideway. These were then categorised on the basis of volume and frequency of the different discharges, as well as assessing their impact on river water quality and uses. A total of 36 CSOs were identified as being unsatisfactory and therefore requiring control. Of these, 34 discharge directly into the River Thames and the other two into the River Lee. The remaining 21 CSOs were assessed by the EA as not requiring action to be taken (see Figure 1).

The TTSS investigated a wide range of potential solutions to deal with the CSO flows. Source control, partial separation, dispersed storage units and SUDS (sustainable urban drainage systems - techniques employing ponds, swales, ‘green’ roofs, detention ponds and permeable surfaces) were among options explored. None of these options were found to be suitable or cost-effective solutions. The TTSS study established that the environmental objectives, developed as part of the study, could only be fully met on the most cost-effective basis by completing both quality improvements to the treatment works and by the provision of a storage and transfer tunnel to intercept unsatisfactory CSOs.

THE SOLUTION

The proposed solution to tackling London’s CSOs comprises two major tunnel storage projects, the Lee Tunnel and Thames Tunnel (Figure 2), combined with upgrades to the five main STWs including Crossness and Beckton. The tunnels will store and transfer the majority of CSO discharges to Beckton STW for treatment until the tunnel system is full.

Catchment and water quality models have been used to develop and verify the solution. The models demonstrated that the ‘do nothing’ option was unacceptable with respect to the number of CSO discharges and dissolved oxygen levels of the river water. Model simulations showed the beneficial impact of the improvements to the five main STWs along the tidal reaches of the Thames and the effect of the implementation of the Lee Tunnel, particularly reduction of CSO discharges to the River Lee. Model simulations also showed that the Thames Tunnel was necessary to complete the required improvements, in order to reduce the number of CSO discharges to an acceptable level and to meet dissolved oxygen thresholds. Simulations have shown that the combination of improvements will reduce CSO discharges by about 96%, with on average four overflow events per year.
The Lee Tunnel will intercept the largest CSO at Abbey Mills Pumping Stations, storing flows in a 6.8 km long, 7.2 m diameter tunnel, approximately 70 m below ground. Flows will be conveyed through the tunnel to a new pumping station at Beckton, which then lifts the flows into the Beckton STW. Construction of the works is scheduled to commence in 2010 with completion in 2014.

The Thames Tunnel is proposed to intercept the 34 most polluting CSOs along the river, with the flows stored in a 7.2 m diameter tunnel extending from west London through to the Beckton STW. The main tunnel will be constructed on a gradient approaching 1:800 and will be approximately 40 m deep at its western end and 70 m deep at the eastern end. The route will pass under the majority of London’s existing buried infrastructure and will bore through three principal geological materials; London Clay in the western section, then the mixed material of the Lambeth Group and Thanet Sands Formation (i.e., gravels, sand and silty clay) up to around Tower Bridge, and then into Chalk (Figure 3).
PROGRAMME AND DELIVERY OF THE THAMES TUNNEL

The Thames Tunnel is still at an early stage of development, and has yet to commence public consultation and submission of a planning application. The overall project timescales are as follows:

- First phase public consultation: Autumn 2010
- Second phase public consultation: Summer/Autumn 2011
- Submission for planning application: Mid 2012
- Planning approval: 2013
- Main contract commencement: 2013/14
- Project completion: 2020

In 2008, Thames Water engaged CH2M HILL with Halcrow Group Ltd. to form a client-integrated London Tideway Tunnels Delivery Team (LTTDT). Framework contracts were established for the key engineering planning, environment, engineering and site investigations work streams, allowing the formation of a core team comprising team members from across the industry. The high-level organisation of Thames Tunnel team is represented in Figure 4.

The multi-disciplinary and international team is substantially co-located in a project office in central London, with external USA and UK expertise used to supplement the team’s capabilities as required. The formation of a co-located delivery team allows for effective internal and external communications, and flexibility to change in response to scheme developments.
Extensive modelling of the components and how they interact and perform was undertaken initially by Thames Water as part of the TTSS, and since mid-2008 by the LTDTD. This modelling is fundamental to and underpins all aspects of the project development.

CATCHMENT MODELLING

The tunnels will work in conjunction with other components to control CSOs on both the north bank of the river within the catchment system served by Beckton STW, and the south bank of the river within the catchment system served by Crossness STW. A model represents the two catchments on either side of the river and includes all major sewers and cross connections. The model combines proposed CSO control options and the existing sewerage network, and consists of approximately 1,100 subcatchments to determine rainfall-runoff from land surfaces and flow generation from population, and about 5,400 pipes to convey the generated flow to the treatment works or to the rivers as CSO discharges. The model is also used to develop the operating rules required for pumping stations and treatment works, control of flow to the tunnel system and CSO discharges to the rivers.

Primary characteristics of the two catchments producing flows requiring controls are given in Table 1 below. The sewerage network is very large and complicated, with numerous cross-connections and overflow diversion structures between interceptor sewers flowing largely from the west to the STWs in the east, and storm relief sewers (SRS) flowing south (in the Beckton catchment) or north (in the Crossness catchment) and discharging into the river. The existing network has many Victorian age sewers, particularly the major interceptors north and south of the river and storm relief sewers. Diversion structures can either be internal to allow balancing of flow between major interceptor sewers, or at the river and direct flow to the river when interceptor capacity is reached. The system also includes ten large pumping stations for lifting flow for transport to treatment or discharge to the rivers. These sewers and pump stations remain integral components of the existing and future sewerage system.

There are numerous variables affecting the flow in the sewer system. For example, time of day variations are seen in dry weather flow (DWF) and seasonal conditions will affect runoff when it rains. Within the catchments, there are parts of the system where the peak DWF approaches the maximum hydraulic capacity of the sewers so that a small amount of rain will cause overflows. Therefore, as DWF increases with population and service area growth, there is progressively less surplus capacity in the sewers to take storm flow, and if no improvements are made, the frequency, duration and volume of CSO discharges will increase.

The catchment is so large that there can be very intense rainfall in one area and no rainfall in other areas. There is therefore no single set of rainfall events that adequately describes the range of system responses and CSO discharges that can arise. Therefore, a ‘typical year’ was developed from statistical analysis of 34 years of available rainfall records to include how rainfall can vary both spatially and in volume across the large Tideway catchment. The typical year rainfall has been utilised to assess the frequencies and volumes of CSO discharges with respect to meeting the requirements under the UWWTD.

With the addition of the Lee Tunnel, no spills at Abbey Mills occur during the typical year. The previously estimated spills from Abbey Mills are transferred into the Lee Tunnel storage. Most storms are captured, and stored flow is treated at Beckton STW when capacity is available. However, three larger storms in the typical year fill the Lee Tunnel storage and overflow through the Beckton CSO. The Lee Tunnel and treatment works improvements do not control overflows to the River Thames, hence the need for the Thames Tunnel.

There has been considerable development of solutions since 2007. Studies and evaluation of tunnel route options are ongoing and will be the subject of public consultation, planned for autumn 2010. The route options provide different tunnels lengths, which affects the storage volume and hence the system performance (primarily the overflow frequency and volume). The length of tunnel also affects the number of tunnel construction drive sites, which is significant on the construction time and number of major construction sites required to build the works. Options will be assessed against spill frequency and volume, and the consequence of the residual discharges on dissolved oxygen (DO) standards in the River Thames.

Compliance with the specified dissolved oxygen (DO) standards in the river is a key measure for comparing performance of the Thames Tunnel alignment options. These DO standards have been set by the EA as indicators of ecological conditions in the river to meet the requirements of the WFD. Compliance is based on modelling of the tidal Thames with simulation of 154 Compliance Test Procedure (CTP) summer events that were selected to stress the river system and produce large CSO discharges. The results of the DO modelling show that all route options evaluated are compliant with all DO standards.
The catchment modelling has been used to optimise the number of CSOs that require shaft interception sites and those that can be controlled by other means. By making a number of strategic connections from the Thames Tunnel works onto the existing interception sewers, it is possible to use existing sewer capacity created by these connections to pass storm overflows to an alternative CSO interception location. This has the advantage of reducing the overall number of CSO interception sites and works required. Further studies are required to refine the method of flow control for each CSO, but preliminary findings are that 10 or more CSOs can be controlled, significantly reducing the number of CSOs needing to be directly intercepted. This leads to a reduction in the number of work sites required and therefore has a significant reduction in the potential impact and also cost of the scheme. The use and selection of sites is discussed in more detail below.

### SHAFT SITE REQUIREMENTS AND SITE SELECTION

The sites required for the project can be broadly split into those required for the interception of the CSOs and sites required for construction of the main tunnel shafts. The locations of CSO sites will be governed by the locations of the existing category 1 and 2 CSOs (Figure 1). A typical CSO interception site is shown diagrammatically in Figure 5.

It is anticipated that CSO sites will range in area from 1,500 m² for small CSO interceptions in ‘good’ ground.

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#### Table 1 | Characteristic summary of the Beckton and Crossness catchments (existing conditions)

<table>
<thead>
<tr>
<th>Description</th>
<th>Beckton STW catchment</th>
<th>Crossness STW catchment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drainage area (km²)</td>
<td>326</td>
<td>230</td>
</tr>
<tr>
<td>Population – 2005</td>
<td>3,428,000</td>
<td>1,814,000</td>
</tr>
<tr>
<td>STW capacity – 2005 (m³/s)</td>
<td>17.33</td>
<td>9.0</td>
</tr>
<tr>
<td>Peak diurnal (m³/s)</td>
<td>17.2</td>
<td>7.2</td>
</tr>
<tr>
<td>Daily volume (million m³)</td>
<td>1.28</td>
<td>0.5</td>
</tr>
<tr>
<td>Type of system</td>
<td>Fully combined system in the centre and towards the west, with partially to fully separated system towards the perimeter:</td>
<td>Fully combined system in the centre with partially to fully separated system towards the perimeter:</td>
</tr>
<tr>
<td></td>
<td>• 53% combined system</td>
<td>• 18% combined system</td>
</tr>
<tr>
<td></td>
<td>• 47% partially to fully separated system</td>
<td>• 37% partially separated</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 44% fully separated</td>
</tr>
<tr>
<td>Topography</td>
<td>Generally falls towards the river north to south with a more gradual fall from west to east</td>
<td>Generally falls towards the river south to north with a more gradual fall from west to east</td>
</tr>
<tr>
<td>Length of main gravity sewers¹ (km)</td>
<td>633</td>
<td>423</td>
</tr>
<tr>
<td>CSOs ²</td>
<td>Gravity 35</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Pumped 6</td>
<td>5</td>
</tr>
</tbody>
</table>

¹Based on Beckton and Crossness model which includes all main trunk sewers.
²Note 57 CSOs were identified by the Environment Agency categorisation, however Frogmore SR has two distinct CSOs (Bell Lane Creek and Buckhold Rd), hence the total of 58 CSOs.
conditions (e.g., London Clay) to 7,500 m² if long connection tunnel drives or large drop shaft diameters are required (by diaphragm wall techniques) in the Chalk. It is anticipated that the construction period at CSO construction sites will typically be two years.

To construct the 7.2 ID main tunnel, three types of sites will be required; drive, intermediate and reception. A drive shaft site would be used to insert and then drive the TBM, and hence deal with excavated material and the primary lining of the main tunnel. A main tunnel reception shaft site would be used to remove the TBM from the tunnel at the end of a drive, and a main tunnel intermediate shaft site would be used to gain direct access to the tunnel bore during construction and/or operational phases. Main tunnel shafts are anticipated to be typically 20 m in internal diameter, with depths ranging between 40 m in west London and up to 75 m at the downstream, eastern end. However, some shafts may need to be 30 m diameter if they receive flows from more than one CSO connection tunnel.

The number of tunnel drives and the number and type of shafts on the main tunnel will be dependent on a balance between system storage requirements (and hence length of tunnel), the available location of suitable shaft sites, geology, programme, planning, environment, health and safety, risk and cost considerations. The horizontal alignment of the main tunnel will generally follow the River Thames as an efficient route to connect the CSOs, maximise the potential to use the river for construction transport, and minimise the physical structures that the tunnel will pass beneath and therefore the number of third parties affected by the tunnel.

It is anticipated that main tunnel drive shafts sites will ideally be 18,000 m² to 20,000 m² in area, with an anticipated construction period of typically six to seven years. Depending on the tunnel drive strategy chosen, between three and five main tunnel drives are anticipated.

By combining the main tunnel and CSO shaft sites, it is possible to further reduce the number of construction sites required. However, the delivery of the project is still likely to require some 20 to 30 construction sites, located through London and broadly along the route of the River Thames.

The route will pass through up to 14 London local planning authorities. The potential work sites will vary in nature and location, but are likely to include river foreshore as well as land based sites, sites with planning development aspirations by others, and (where no other suitable alternatives are available) public open space. Despite routing the main tunnel principally along the River Thames, the works will pass under or adjacent to numerous third-party tunnels, bridges, buildings, water abstraction wells, utilities and other structures, including listed and heritage structures. Major pan-London stakeholders include the Greater London Authority, local planning authorities, Environment Agency, Transport for London, Port of London Authority, English Heritage, English Nature, police and security services. As well as these pan-London stakeholders, the project will need to engage with the public, community groups, developers, landowners, and Thames Water customers whose payments ultimately will fund the project. As a result, the selection of sites and engagement of stakeholders at all levels, in a process that
is fair, transparent and properly takes into account people's views and concerns, is a major undertaking.

A rigorous and comprehensive approach has been developed by LTTDT to identify and select the most suitable sites required for the construction and operation of the main tunnel and CSO interceptions. This is captured in a Site Selection Methodology, which was agreed following consultation with local authorities and other pan-London stakeholders. The Site Selection Methodology, which was finalised in May 2009, draws upon best practice and reflects the principles and requirements of relevant planning policy and sustainability. A multi-disciplinary approach was used, drawing upon the technical knowledge and expertise of engineering, planning, environmental, property and community specialists. It allows for the screening of potential options for sites through a series of stages, progressively increasing the level of detail considered at each stage, from a long list to a shortlist, to more detailed information for the selection of a preferred list of sites. After public consultation, a final selection of sites will be made.

The initial search area for suitable construction sites covered an area of land 500 m either side of the River Thames. This was because the tunnel needs to broadly follow the route of the River Thames to connect to the CSOs, which are located along the riverbanks. The search area also includes areas of land close to the CSOs, so that potential sites can be identified for the connection of the CSOs into the main tunnel.

In tandem with the shortlisting of sites, the engineering team examined tunnel drive options. This applied an approach of geographical grouping of main tunnel shaft sites into zones. From each zone it was then possible to identify and assess the tunnel drive options for constructing the main tunnel. For each of the final shortlisted sites, a review and assessment can then be made, and considered against possible engineering tunnel drive options for the entire scheme, to produce a 'preferred list' of sites.

During 2010, the project will undertake a 12-week consultation of the public, local communities, relevant London local authorities and other stakeholders on the development of the project to date. The consultation will present the 'preferred scheme', consisting of an overall preferred main and connection tunnel routes and preferred sites for construction and operation. The other shortlisted sites and routes that were considered but not selected as preferred sites will also be made available during consultation for comment.

Based on the feedback from this consultation, the LTTDT will amend and develop the final proposals for the overall tunnel route, tunnel alignment and preferred site selections. A second public consultation on the selected sites, selected route and tunnel alignment will be then undertaken, and the design further refined prior to the submission of the proposal for planning approval.

**ONGOING DESIGN DEVELOPMENT**

There remain numerous technical work products, design development and technical challenges still to be fully designed, most notably:

- transient and pneumatic: the effects of rapid filling and how to reduce the risk from large events while maintaining CSO controls and localised events;
- CSO drop shaft design: computer and physical modelling of drop structures to select structures that can pass, and drop, the high flows predicted;
- odour and ventilation: determining the potential for odour releases and determining the best means of minimising the effects of air releases, including if necessary odour treatment facilities;
- tunnel construction: construction at depth in water bearing strata and logistics including disposal of tunnel excavated material and opportunities for use of river transport.

**CONCLUSION**

The London Tideway Tunnels are an essential part of the delivery of improvements to the water quality of the tidal River Thames, and this ambitious, historic scheme represents a vital strategic investment in London’s infrastructure. The proposed solution is visionary, providing a single, London-wide CSO collection solution in keeping with Sir Joseph Bazalgette’s original bold concept, and a benchmark for future European CSO schemes.

**REFERENCES**


