Thames Tideway Strategic Study

Solutions Working Group Report

February 2005

Volume 2

Refinement Report

Thames Tideway

MAYOR OF LONDON OFWAT ENVIRONMENT AGENCY Thames Water RWE Group

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Volume 2
Refinement of the Proposed Solution

February 2005

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Glossary - *Abbreviations used in this report*

CSO	Combined Sewer Overflow
DO	Dissolved Oxygen
AMP4	(Underground) Asset Management Plan No. 4 1.04.05 - 31.03.10
STW	Sewage Treatment Works
DWF	dry weather flow
UWWTD	Urban Waste Water Treatment Directive
WFD	Water Framework Directive
CTRL	The Channel Tunnel Rail Link Project
BTKNEEC	Best Technical Knowledge Not Entailing Excessive Cost
BOD	Biological Oxygen Demand
OD	Outside Diameter
ID	Inside Diameter
TBM	Tunnel Boring Machine
NATM	the New Austrian Tunnelling Method
NOS	the Northern Outfall Sewer
SuDS	Sustainable Urban Drainage
Mm^3	Million cubic metres
CFD	Computational Fluid Dynamics

0 Executive Summary

0.1 Introduction

This Report should be read in conjunction with the main Steering Group Report and those of the Objectives Group and the Cost and Benefits Group. It is also recommended that, for reasons described herein, this report should be read ***before*** the Volume 1 of the Solutions Group report, which may be referred to for the background detail of the original investigations.

Volume 1 of the Solutions Group Report addressed the identification and assessment of potential solutions to resolve the problems associated with pollution of the tidal reaches of the river Thames (the Tideway) caused by the discharge of storm sewage from CSOs (combined sewer overflows). This adversely affects the quality of the Tideway in three main ways:

1. Discharging large quantities of aesthetically offensive sewage derived litter;
2. Causing a rapid drop in dissolved oxygen DO concentrations, which may lead to widespread fish mortality;
3. Causing a large increase in the levels of pathogens, which can lead to public health risks.

A range of strategies and potential solutions to resolve these problems were considered and evaluated in Volume 1. The recommended solution was for a storage tunnel that intercepts the CSO flows and transfers them to treatment.

The main objective of this Volume 2 report is to describe the refinement of the scope of this storage tunnel option including re-evaluation of the cost estimates and risk assessment.

0.2 The Refined Proposed Option A(ref)

A range of project changes and detailed refinements have been incorporated into the recommended option, which is now named A(ref). Some issues need further development and their inclusion will be decided upon later, possibly during the detailed design phase. These refinements improve the performance and cost effectiveness of the Volume 1 proposed solution and are discussed in more detail in section 2 below.

0.2.1 Changes to the Project

The main items of refinement that have a significant impact on the scope of the proposed storage tunnel include:

<u>Review of the CSOs to be intercepted</u>*:* This review was based upon the potential for environmental damage of discharges from each CSO. Generally those that do not cause harm due to low flow or infrequent discharge were excluded from interception. A total of 36 were retained for interception including Abbey Mills and Wick Lane, which were initially outside the scope of the feasibility study (Ref 8).

<u>*Inclusion of Abbey Mills and Wick Lane CSOs:*</u> Several options were considered to resolve the pollution associated with these two CSOs. The most cost effective is to augment the volume of storage by increasing main tunnel to 7.2m internal diameter (ID) and connecting a 5m ID transfer tunnel from Abbey Mills. This is now included in the scope (section 2.1).

<u>*Treatment and pumping regimes:*</u> Water Quality Modelling shows that to comply fully with the objectives the majority of the intercepted flow should be fully treated before discharge to the river. This led directly to the requirement for both Beckton and Crossness to be substantially up rated in their total flow to full treatment capacity. These upgrade works are now in hand and due for delivery by 2013. New pumping stations of equal capacity at both works will raise the stored flow allowing optimal use of treatment capacity and to provide adequate standby for both pumping and treatment plant.

The proposed new plant within Crossness STW has been relocated to accommodate the AMP4 upgrade works. Passing the additional intercepted flow to full treatment will increase

sludge production at Crossness by between 10 and 30%, which will require either new sludge treatment plant or additional incineration capacity.
It is also now proposed to extend the duration of pump-out from the storage tunnel to 48hours so that greater use can be made of the full treatment process(section 2.2).

0.2.2 Detailed Refinements to Design and Construction

Construction issues for tunnel connections: Previously this work had been based upon a storage tunnel diameter of 9m ID. The main consequences of constructing these connections within a 7.2m ID storage tunnel have been revisited. Interconnecting tunnels with large diameter connections would have a significant impact on cost and risk. This is avoided by restricting connecting diameters (other than the link tunnels) to 3m maximum (section 2.3.2).

Main Shaft Sites: The main shaft sites currently selected are the optimal locations based on technical considerations and the perceived availability. These are preliminary proposals and may change should there be difficulties with planning requirements or land acquisition. Potential alternatives have been investigated in outline. Improvements to the tunnel route and sequence of implementation have been considered.

The junction now required between the Abbey Mills link tunnel and the main tunnel means that a construction shaft site is now required in the Greenwich area. The position is fairly flexible at this stage (refer to section 2.3.3).

Ventilation and building requirements: The proposed storage tunnel will be continuously vented from the main shafts, where access for maintenance, cleaning and inspection will also be incorporated. Buildings of high quality and architectural merit are proposed as they will ultimately be the only evidence of this major project visible above ground level (section 2.3.6).

Internal tunnel lining: The proposed tunnel route passes through the aquifer for water abstraction sources. To protect the aquifer from contamination the current scope includes for an internal secondary lining. External groundwater pressure is comparable to that of the stored storm water. Omitting the lining would reduce the external diameter (OD) of tunnel needed for the same storage and would reduce the cost, delivery date and environmental impact of construction (2.3.7).

Hydraulic issues of choking and flushing: Elimination of choking during filling and implementation of effective flushing after drain down are the two critical hydraulic issues to ensure effective operation of the storage tunnel. These have been subject to analysis by Computational Fluid Dynamics (CFD). The results show that the stable filling of the tunnel can be achieved by limiting velocities in the connections to the main tunnel. Also emptying the tunnel in sections will re-suspend the majority of sediment to minimise the quantities of flushing waters required (refer section 2.3.11). The findings of this hydraulic study give greater confidence in robust operation of the tunnel.

Evaluation of renewable energy options: Pumping out of intercepted flow will consume approximately 7GWhrs of electrical energy per year. Three main options may be employed to improve sustainability by use of renewable energy. These are detailed in section 2.3.12.

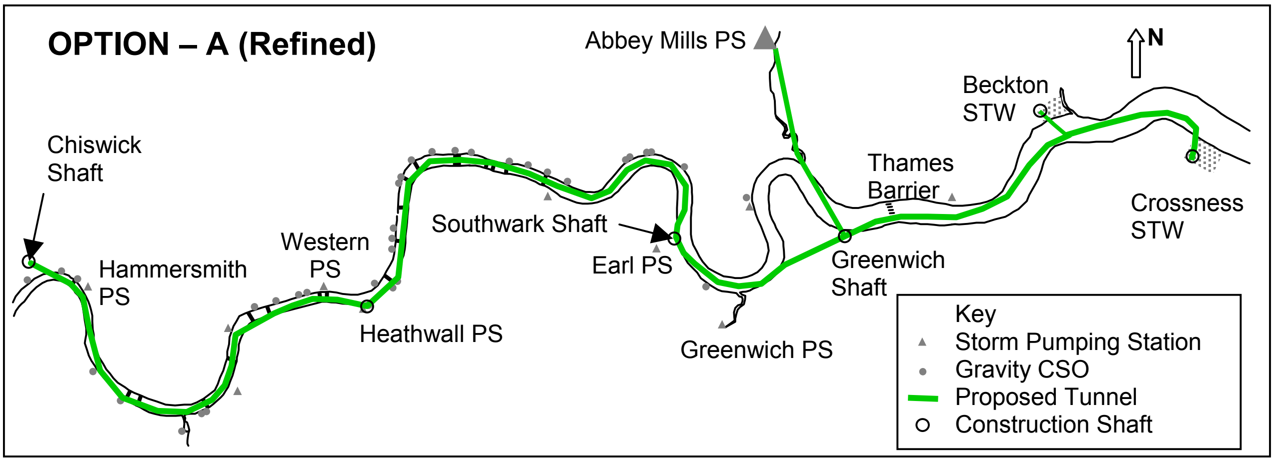
0.2.3 Description of Refined Solution A(ref)

The scope of the proposed solution includes:

- Main storage tunnel, 7.2m in diameter, 34.5km long;
- Seven main construction shafts;
- Abbey Mills link tunnel, 5m in diameter, 4.5km long;
- Beckton STW link tunnel, 3m in diameter, 1.1km long;
- Pumping station, screening and storm treatment plant at Crossness STW;
- Pumping station at Beckton STW;
- Interception of 36 unsatisfactory CSOs.

The intended method of operation is to intercept polluting flow from the 36 CSOs that have been determined to cause environmental harm. Approximately 1.5Mm^3 of polluting flow can be intercepted before the tunnel completely fills and bypass to the river would occur. Modelling shows that most rainfall events would be fully intercepted with overspills averaging just above once per year. This would represent a reduction of over 85% of the current pollution load and a 98% reduction in the number of spills.

Figure 1 - Refined Storage Tunnel Solution



The proposed storage tunnel has been subjected to a rigorous compliance testing procedure based upon four threshold limits of DO levels in the river. The results indicate robust compliance with all threshold limits with only 4 failures out of an allowed 14 in the most stringent category and none in the other three (section 2.4).

0.3 Risk assessment

The greatest risks are related to a delay in progressing the project through the planning process, and the acquisition of the required shaft sites, to prevent loss of preferred sites through development and thus to limit any further potential increase in cost.

The key risks associated with the planning process are detailed in section 3.3.3. They include refusal of planning permission or call-in for public inquiry. The main source of these planning risks is time delay. The outline programme for the planning process has been conservatively constructed and includes 18 months for a public inquiry. If approval to proceed with the proposed scheme were given early in 2005 it would be realistic to expect a successful outcome to the planning process by 2010 to allow completion of the project by 2020.

The top five risks included on the Risk Register are listed in section 3.1, together with the appropriate mitigation measures. Construction of the CSO interception structures has been evaluated together with the choice of preferred site locations and identification of alternatives.

Construction site availability is one of the major project risks. Mitigation is the proposed early acquisition of the required site areas or options to buy these sites. The main shaft sites have been selected as ideal locations. The dynamic nature of the land market in London means that some of these ideal sites may be lost and less ideal alternatives will have to be sought with the risk of a corresponding increase in cost.

Although the refinement studies have improved confidence in the scope of the proposed works more detailed evaluations would be carried out during the design phase. The level of contingency applied to the estimate remains fixed at 30% to give the most realistic estimate of the likely maximum out-turn cost. A quantitative risk review will be carried out to determine the appropriate level of contingency.

0.4 Estimated Costs

The estimated costs for the storage tunnel option have been refined on the following basis:

- A more robust method of calculation of the tunnels and structures costs;
- Revised proposals for CSO interception;
- Inclusion of Abbey Mills and Wick Lane CSOs;
- Revised pumping & treatment requirements, including detailed refinement of programme;
- Out-turn cost updated from second quarter of 2002 to third quarter 2004.

The derivation of the estimated costs is detailed in section 4.1 and summarised below:

Cost Base	**Estimated Cost (£M) Option A(Refined)**							
	Tunnels & Structures	**Screens**	**Treatment**	**Pump & Power**	**Contingency & Risk 30%**	**Resource Costs**	**Land Costs**	**Total Costs**
2002 2nd Q	936	32	22	50	312	125	50	1,527
2004 3rd Q	1,044	36	25	56	348	139	50	1,698

The estimate at 2nd quarter 2002 is included for comparison with the values in Volume 1.

The all-in unit costs have been compared with the out-turn all-in unit costs for the CTRL tunnelling contracts. Once account is taken of the different scope and requirements between these works the estimates for the storage tunnel appear to be slightly higher than CTRL. This increase reflects the cost of additional excavation for the larger external diameter (OD), as well as the additional costs associated with constructing a tunnel at greater depth.

This comparison achieves a high level of confidence that the estimated costs for construction of the proposed main storage tunnel are robust and appropriate and in addition a 30% contingency allowed.

The baseline overall and construction programmes have been reviewed in outline to consider sequential construction of the storage tunnel in three phases to spread the investment required and a more condensed programme to reduce time of implementation. Sequential construction may increase overall costs by some £200M and delay completion until 2030. Construction of tunnel sections in parallel may shorten the construction period, however this reduction is limited by the CSO connection structures becoming programme critical.

0.5 Conclusions

The conclusions are included and discussed in more detail in section 5. The principal conclusions are listed below:

- The refinement of the scope of the proposed storage tunnel represents the most effective means of resolving the pollution problems associated with discharges from the 36 CSO and fully complies with all the objectives.
- To ensure compliance with the objectives, flexibility of pump-out to both Beckton and Crossness STW must be provided.
- The greatest risk to successful implementation of the project and potential increase in costs is delayed authority to proceed causing optimal sites to be lost to redevelopment and problems with the planning process.
- Implementation of the CSO interception structures and shafts represents the most significant technical challenge. Detailed assessment is being carried out. Provided a fast-track planning process is adopted it would be technically possible to implement the eastern section of the proposed tunnel by 2012 to meet the requirements of the Olympic bid. This would resolve the problem of discharges from Wick Lane and Abbey Mills to the River Lea.
- The estimate for the proposed storage tunnel option is robust and realistic. The tunnelling costs compare well with the out-turn costs for CTRL tunnelling contracts.
- A secondary internal lining to protect the aquifer from contamination may not be necessary, particularly as the external ground pressure is comparable to that of the stored storm water. Excluding the lining would reduce cost, programme and environmental impact.

0.6 Recommendations

The recommendations of the refinement of the proposed storage tunnel option are discussed in more detail in section 6. The main recommendations are listed below:

- Authority to proceed with the project to the design and planning stage should be given by spring of 2005 to minimise loss of optimal sites to redevelopment, increase in cost of alternatives and delay to completion. Approval to proceed, particularly to secure the required sites, would significantly limit exposure to risk in this area.
- Expert legal opinion is being sought to assist with issues relating to planning, environmental/legislative requirements and issues of liability.
- A quantitative risk review is arranged to determine the appropriate level of contingency

Once Authority to proceed is given:

- The implementation of CSO interception structures and shafts should be subject to more detailed investigation to assess impact and to derive alternatives means for interception where appropriate
- The interception of Wick Lane CSO should be subject to detailed investigation in the light of potential large sewer diversions to accommodate Cross Rail tunnelling works.
- Further modelling and design development is required to optimise methods for the avoidance of siltation.
- Adequate ventilation of the main storage tunnel between rainfall events is a key factor to eradicate odour nuisance. It is not clear whether natural ventilation alone will be sufficient. Therefore it is recommended that an airflow model be developed to determine the ventilation requirements. Currently the estimate includes for the installation of forced air ventilation.
- There are various modifications to the tunnel route and main shaft locations that could be incorporated to further refine and improve the proposed storage tunnel solution. These potential improvements should be considered in more detail at the design stage.

1 Introduction

1.1 The Solutions Group

The Solutions group was established at the end of 2000 with the task of developing and costing technical options to meet the objectives set. This presented a difficult challenge given the small number of such projects carried out worldwide and on a scale not experienced elsewhere in the UK. Linking the Objectives and Solutions groups were water quality models, which could be used to assist in setting objectives and testing technical options. The work carried out by the Solutions group represents the bulk of the Tideway study activity both in terms of in-house and external resource commitment.

The working group comprised:

Ben Nithsdale	Chair	**Hyder Consulting (Formerly Thames Water)**
James Smith	Project Manager	**Thames Water (Engineering)**
John Greenwood	Lead Designer	"
Susan Collins	Assistant Project Manager	"
Howard Brett	Wastewater Regulation Manager	" **(E&Q)**
Alan Lenander	Liaison Engineer	" **(Operations)**
Jon Goddard	Chief Scientist	**Environment Agency**
Peter Lloyd	Chief Scientist	"
Maxine Clement	Chief Scientist	"
Other occasional attendees		
Rachel Cunningham	Project Scientist	**Thames Water (R&T)**
Chris Douch	Asset Investment Manager	" **(Operations)**
David Wilson	Liaison Manager	" **(Property)**
Professor Adrian Saul	Scientific Consultant	**University Of Sheffield**
Barry New	Tunnelling Consultant	

As well as in-house research by both Thames Water and EA scientists the following expert consultants have also been involved in the collection and analysis of data for both the work described in Volume 1 and the refinements in Volume 2 in the following areas:

Faber Maunsell	-	Design and Construction
Cascade Consulting	-	Land and Planning
EC Harris	-	Cost Estimating
The National Energy Foundation	-	Renewable Energy research
KSB Pumps Ltd	-	Pumping and Power requirements

1.2 Background to the Reports

Since the beginning of 2000, the Thames Tideway Steering Group and its three sub-groups have each compiled reports based on the Tideway Strategic investigations carried out over the last 4-5 years. The Solutions Group evaluated a number of strategies and options and reached the point of establishing and recommending the most effective option in the summer of 2003. The draft report produced at that time is now Volume 1 of this report. The main objectives of the Strategic Study are described in detail in the Objectives Group Report.

When the study began the regulators' requirements were for options to be evaluated and the choice to implement any recommended scheme to improve to the Tideway to be justified in terms of cost/benefit analysis.

Significantly, the likely interpretation and effect of implementing the UWWTD (Urban Waste Water Treatment Directive) has been much discussed in terms of the degree to which the London sewerage networks might in any case need to be improved.

During the period between the production of the Volume 1 and Volume 2 reports various data gathering and investigation activities have continued leading to a number of technical developments and changes. As a result several aspects of the solution recommended in Volume 1 have been reconsidered in the light of new information and this has led to a number of changes in scope for the recommended option, which are explained below.

This Volume 2 report updates the Volume 1 report in respect of these changes without attempting to revise and recast the original report as if the emerging issues had been known from the start. That is why Volume 2 is a separate report and it is important not to try to compare data and costings of all the original proposed solutions in Volume 1 [except options A(low) and A(med)] with the now refined option A(ref) recommended in Volume 2. The reports should be regarded separately. Volume 1 reaches as far as choosing the preferred type of scheme and Volume 2 explains the differences and improvements made solely to that option since then.

1.3 Volume 1 - The Recommended Option

The original description of the project brief recognised several ways of polluting the Thames Tideway by the continual discharges of storm sewage including:

Introducing large quantities of sewage derived litter, sanitary wastes including, needles and plastics and fats and grease, which create aesthetically offensive conditions in the river and on the foreshore.

Causing a rapid drop in DO concentrations, which can result in widespread fish mortality.

Storm sewage discharges also cause significant increases in the levels of pathogens, which can lead to a public health risk, especially for users of the river.

Volume 1 describes the detailed analysis in detail of 4 strategic approaches to the problem of rainfall to find where the most viable solution could be provided. These strategies were:

1. Before the rainwater enters the sewerage system;
2. Within the sewerage system;
3. At the interface between the sewers and the river (i.e. the CSO outfalls);
4. In the river itself.

Analysis of a variety of methods of capturing excess flows revealed that strategies 1 and 2 would not produce an economic solution and that strategy 4 was not a strategy at all in that it could only provide amelioration of the effects which the study was designed to eliminate altogether. Therefore the likely solution was found to be best sought within strategy 3.
Under this third strategy 9 proposed solutions with a variety of sub-options were reviewed:

A: Storage Tunnel
B: Transfer Tunnel
C: Multiple Screened outlets
D: Multiple Screened outlets with Storage Tunnel
E: Storage Shafts
F: Screening at Individual CSOs
G: Displacement Tunnel
H. West London Scheme
H+ West London Scheme - enhanced version

A series of 1200 recorded storm events over a 20-year period were analysed to evaluate the volumes of discharge to the Thames. The maximum value was found to be some 4.3 million m^3. Based on this quantification most of the schemes were evaluated using three levels of intervention:

Maximum:	100%	(A storage volume of 4.28Mm^3)
Medium:	50%	(A storage volume of 2.14Mm^3)
Low:	20%	(A storage volume of 0.86Mm^3)

The major benefit of the study so far is to have determined that the character of the optimum solution is a storage tunnel under the Thames with controlled pumping out to existing and new sewage treatment facilities in east London.

The Solutions Group, including the EA, concluded that the best strategy was to aim for the most modest solution, which will achieve all the objectives, and endorsed Option A(med) or A(low) as the optimum solution.

1.4 Changing Objectives

1.4.1 The Refinements

In the light of the conclusion from Volume 1, it was decided to continue the refinement of the storage option A(low) alone rather than attempting to repeat the review of the whole array of options considered originally. If all the options were to be reviewed this would have entailed significant, probably wasted, effort and delay. Several of the original proposed options had in any case been rejected during the feasibility process and after some analysis by the Cost and Benefit team it was decided that the options would not change in their order of priority by applying these refinements.

The decision not to revisit all the original options was tempered by the fact that some of the changes now proposed had arisen from information gathered during the study which reversed some specific technical issues which had been assumed to be important at the outset.

An interim report was tabled for government in the summer of 2004 outlining progress to date. This report elicited a response that asked for some of the rejected proposals such as SuDS and Separation to be reconsidered and to look at a number of new alternative ideas and this work is now in hand.

As a result of the above factors a number of changes, including some which were specifically excluded from the study at the outset, now became part of the scope of the study including:

- Legal Considerations and Interpretation of the UWWTD and BTKNEEC.
- The CSOs were prioritised and only those causing environmental harm were to be dealt with.
- The discharges from Abbey Mills Pumping Station and the Wick Lane CSO were to be included;
- The Tideway STWs were to be upgraded and would now treat part of the stored storm flows at Beckton as well as Crossness.
- Many details of the design and construction have been improved.
- The potential impact of the programme on other projects, including the Olympics and the Thames Gateway was to be reviewed.

As a result of the changes made to date and the alterations to the project scope already included the recommended Option has been refined and is now identified as Option A(ref) (section 2.4).

1.4.2 Legal Requirements and Drivers

Initially it had been suggested that the WFD (Water Framework Directive) would be the main driver for the Tideway project. During the study it was realised that there remained a lack of clarity over the requirements of the WFD and visibility of the likely water quality consents. It was therefore decided by the Steering group to review all appropriate statutory legislation to consider other potential drivers. This highlighted the importance of the UWWTD.

The other legal issues that have emerged, relate to the potential liability for public health issues in the context of the pollution of the Thames by storm sewage. The importance of this matter continues to grow in the context of increasing public access to and use of the Thames as an amenity. Legal advice is now being sought about where such liability would lie and the degree of risk to the relevant agencies whilst the current situation prevails.

1.4.3 Prioritisation of the CSOs

The interpretation of the UWWTD concludes that only those CSOs that cause adverse environmental harm to the Tideway should be connected to the tunnel. The EA reassessed the 57 intermittent discharges and identified that only 36 are 'unsatisfactory' in terms of frequency of discharge or environmental impact and need to be intercepted (ref 8).

1.4.4 Abbey Mills

It was the above study that also concluded that Abbey Mills and Wick Lane outfalls should be included as they experience significant discharges, which reach the Tideway via the River Lee. The detailed impact of this requirement is described in section 2.1.

1.4.5 Treatment Issues

The impact of these requirements is described in section 2.2.

1.4.6 Design and Construction

The impact of these detailed improvements is described in section 2.3.

1.4.7 Impact on Risk, Cost and Programme

The impact on risk issues is discussed in section 3.

The above changes have had a significant impact on the original A (low) project cost estimate for the whole scheme both positively and negatively. Prioritising and cutting the number of CSOs to be intercepted and many of the design and construction improvements have reduced the cost of certain elements. However these are substantially offset by the very large increase in storage volume to cater for interception of the Abbey Mills CSO in particular and the required increase in pumping and treatment capacity. The cost estimates have also been subject to a more robust method of calculation. These changes are explained in detail in section 4.1.

Despite the increases in the scope of A (ref), the base programme remains unchanged with a planned delivery date of Spring 2020 (provided the authority to proceed is given by Spring 2005). Several ways of delivering the scheme have been considered as and it would certainly be possible to further optimise the programme by increasing resources and implementing more work in parallel. It might be possible to bring forward the completion date by approximately two years without incurring a significant cost penalty. This could only be achieved if approval to proceed is given early and the scheme is not delayed in the planning process. The impact on cost, programme, risks and contingency are described in detail in section 4.2.

1.5 Continuation Works - CSO and STW Monitoring

The refinement phase has seen substantial continued work on a number of items of data collection and measurement. The object was to continue to refine and calibrate the accuracy of various technical data and in some cases to capture information still outstanding. To this end various new flow monitoring was carried out on STW out falls and on CSOs in South London. The risk of the stored sewage becoming septic has been investigated and the

SCITTER rig at Acton continued to be used to collect storm water data until October 2004 when it was decommissioned. For a detailed explanation of these issues (see section 5.7.4 in Volume 1).

There is very little measured historical data on CSO discharge flows and quality parameters in particular. The principal source of data derives from the records of pump hours run from the storm pumping stations. However there are reliable records for only a few of these stations. There is also very limited data on the discharges from the STW during a rainfall event. Most records relate to daily totals.

The collection of flow and pollution parameters of actual discharges to the Tideway was used to assist with the verification of the sewerage network model and therefore improve the input data for the estuary models.

Flow meters and samplers were installed at Beckton, Crossness and Mogden STW as well as Hammersmith, Western and Falconbrook PS. The equipment was set up to record flow and take quality parameter samples. The product of the flow rate and sample concentration represents the pollution load of the discharge to the river.

It was considered important to measure the response of the main treatment process at the works to increased flow due to rainfall as well as the actual storm discharges. To achieve this at Crossness flow and sampling is required for both the east and west discharge culverts from the storm tanks and the final effluent channel. For Mogden the discharge from the storm tanks discharges into the final effluent channel before the combined flows discharge to the river, therefore flow and sampling was taken in the final effluent channel upstream and downstream of the storm tank discharge. Beckton STW does not have storm tanks, flow and sampling is therefore only required from the final effluent channel.

Hammersmith PS discharges to the river via two discharge culverts therefore two sets of flow and sampling equipment were required. Western PS and Falconbrook PS each have only one discharge culvert therefore only one set of equipment was required at each site

The following determinants were selected for analysis: Suspended Solids, Ammonia, Total Organic Nitrogen, BOD, and Chloride. Spot samples were taken every 15 minutes and all sampling collection was carried out within 12 hours of the first sample being taken and transported to the laboratory for analysis. Cumulative flow was calculated and recorded every 15 minutes from the continuous flow readings taken.

Once all results of the samples were analysed and available all sample and flow data was recorded manually onto a spreadsheet produced for each location and rainfall event.

Experience from SCITTER shows that the concentration of screened solids in the samples taken at storm pumping stations is less than for those at the Acton rig. This is an expected result as it shows that after pumping far more solids pass through a fine screen.

The sampling equipment worked well at Mogden for the August 3rd rainfall event. The difference between the final effluent and combined flow samples clearly showed that some process solids were being lost through the treatment process as the works responded to the increase in flow rate.

Some useful data has been collected, however the automation and communication problems must be overcome so that more statistically relevant data can be obtained. The generally low reliability of the flow and sampling equipment confirms the supposition that the aggressive nature of the sewage environment is not conducive to accurate and reliable measurement.

2. Refinement Studies

The principal conclusion of volume 1 of the Solutions Group Report is that interception of the CSO flow to a storage tunnel and then transfer to treatment is the most economic, effective and efficient method to resolve the problem of pollution from CSO discharges. This method meets all set objectives and reduces the frequency of discharge to the river on average from approximately 60 times per year to once or twice per year. The purpose of this report is to outline further refinements to the proposed storage tunnel option. These refinements include:

2.1 The Inclusion of Abbey Mills and Wick Lane;
2.2 Review of proposed treatment regimes;
2.3 Scope, design and associated construction considerations;
2.4 The new recommended Option - A(ref).

Most of the design and Construction issues were studied by specialist external consultants or by experienced Thames Water staff. These are summarised below and supported by the reference documents listed. The updated cost estimates are detailed in section 4.

2.1 The Inclusion of Abbey Mills and Wick Lane

2.1.1 Summary

One of the principal conclusions from the revised assessment of the CSOs (ref 8) was that the discharges from Abbey Mills and Wick Lane could no longer be considered as satisfactory. The study revealed that the Beckton hydraulic model had underestimated the discharges from Abbey Mills both in terms of frequency of operation of the outfall and the volumes discharged and subsequent environmental harm caused to the Tideway should not continue despite the fine screening of the outfall.

Various options to remedy the situation were considered as described below:

2.1.2 Systems Optimisation

a. Retain more flow in Northern Outfall Sewer (NOS) for transfer to Beckton STW for treatment.

b. Retain more flow in NOS for transfer to proposed main tunnel at a location adjacent to Beckton STW

c. Spill more flow upstream to the proposed tunnel via the main sewers to free up existing capacity in the NOS to reduce pumping of flow to river at Abbey Mills.

2.1.3 Storage and Treatment at Abbey Mills

2.1.4 Connect Abbey Mills to the Main Tunnel. Either:

a. Construct a tunnel between Abbey Mills and the main tunnel at Greenwich or Crossness or Beckton with overall increase in total storage.

b. Construct a storage tank at Abbey Mills with small diameter drain down tunnel to proposed main storage tunnel.

2.1.2 Systems Optimisation

Although it was recognised that network control ideas would not produce a complete solution to the Abbey Mills PS discharges to the river, they could help to optimise the potential capacity required of any additional tunnel works or storage tank. Option a. above, has been taken into account for all current solution evaluation as the sewerage catchment model is based upon passing the full flow to Beckton STW at proposed AMP4 upgraded capacity.

Investigation of option b. has shown that in order to retain more flow in the NOS for transfer, the top water level at the Wick Lane CSO would have to be increased in the middle and high-level catchments enabling minimal reduction of pumping to river at Abbey Mills PS.

Spilling more flow upstream of Abbey Mills into the Low Level catchments instead of retention in the NOS is certainly possible under low tide conditions with outfalls intercepted to the proposed main tunnel. The volume that would otherwise be pumped at Abbey Mills would be intercepted upstream. However in heavy rain this scenario produces several undesirable effects including a considerable increase in flood risk to properties near the river especially at high tide. Also the tunnel would fill more quickly and would thus spill sooner and more often. At high tide, the outlet of the upstream gravity CSOs would be restricted causing the low level sewers repeatedly to become rapidly surcharged. This would lead to a significant increase in risk of flooding and even of structural damage to the sewers.

2.1.3 Enhanced primary treatment plant at Abbey Mills.

The option of enhanced primary treatment plant installed at Abbey Mills was also considered, based on a review of previous study work on treatment processes for storm water flows.

As the flows are intermittent biological forms of treatment cannot be sustained between rainfall events. Thus only physical forms of treatment such as enhanced sedimentation or filtration can be considered. The form of enhanced primary treatment considered is deep bed filtration, which is a relatively new process for storm water treatment; though it has been used successfully in USA (section 2.2.4). This should have the capability to reduce BOD load by approximately 60%. However the discharge from Abbey Mills represents a significant proportion of total flow to the Tideway (c30%) and the compliance modelling indicates that the majority of the intercepted flow would have to be fully treated to achieve compliance.

Therefore it is considered that this local storm treatment only option could not achieve compliance. Additionally such a high capacity plant of $50m^3$/sec capacity, which normally stands idle, will be an operational challenge to maintain in readiness for wet weather discharges. The costs of installation, at £128.7M, are significant and in excess of what would be required to connect Abbey Mills to the main storage tunnel (see below).

2.1.4 Transfer tunnel options

Three options based on transfer and/or storage, each with sub-options, were considered as described below:

Option	Description	Cost £M
1	**Transfer tunnel into main Tideway system**	
1a	5m diameter transfer tunnel from Abbey Mills to a new shaft on the main tunnel in the Greenwich Peninsula area. Increase main tunnel diameter for additional storage	117.9
1b	5m diameter transfer tunnel from Abbey Mills to Crossness Treatment works. Increase main tunnel diameter for additional storage	119.5
2	**Storage Tank and transfer tunnel**	
2a	Storage tank at Abbey Mills (200,000m^3), 5m diameter transfer to new shaft on main tunnel at Greenwich. Increase main tunnel diameter for remaining additional storage	149.1
2b	Storage tank at Abbey Mills (200,000m^3), and 6m diameter storage/transfer tunnel to Crossness. No increase in main tunnel diameter	142.5
3	**Storage tunnel Abbey Mills to Crossness**	
3a	7.8m diameter storage/transfer tunnel between Abbey Mills and Crossness. No storage tank or increase in main tunnel.	151.1
3b	Additional storage provided by storage/transfer tunnel between Abbey Mills and Crossness and main storage tunnel also increased to same diameter of 6.5m ID for consistency.	143.9

From the more reliable analysis of the discharges at Abbey Mills the design parameters are peak flow transfer of $50m^3/s$ and additional storage capacity of approximately $500,000m^3$.

Other sub-options were identified, but on examination were found to be either impractical or too costly and were rejected. For example one option proposed a large storage tank constructed at Abbey Mills of sufficient capacity for all of the additional required volume, $500,000m^3$. However there is insufficient space for such a tank at Abbey Mills as the largest tank, with a feasible depth of approximately 20m, that can be accommodated is $200,000m^3$.

2.1.5 Interception of Wick Lane

Wick Lane has been identified as an unsatisfactory CSO on the basis of current operation. It is likely that due to the proposed increase flow to full treatment at Beckton STW, discharges from Wick Lane may significantly reduce, as more flow would be retained in the NOS.

The CSO review (ref 8) also identified Wick Lane as one of the outfalls that cause environmental harm and should be included for interception. This CSO relieves excess flow from the NOS that flows direct to Beckton STW. The overflow chamber is located at Wick Lane Depot near Old Ford and discharges via twin culverts, located directly under the NOS barrels, to the River Lea. Before the culverts reach the outfall they can also receive flow from a junction with the Low Level No. 1 (Wick Lane Branch) via another overflow.

The outline proposal is to intercept the flows near Wick Lane Depot and transfer them via a tunnel to the shaft at the head of the Abbey Mills Link tunnel. The compliance test modelling included for the flows from Wick Lane. However, a more detailed assessment has not been carried out in these refinement studies as there are other factors which may impact on interception of this CSO that have yet to be resolved. It so happens that the North London Flood Relief Sewer passes directly under the depot and a cross-connexion into this sewer, which also terminates at Abbey Mills, might be possible.

The proposed Cross Rail project may entail a tunnel portal to be constructed adjacent to the southern end of Wick Lane. If so this will necessitate the diversion of the Hackney to Abbey Mills sewer and the Low Level No1 (Wick Lane Branch). The current proposal for this diversion is based upon a 2.4m diameter tunnel from Wick Lane to a new pumping station shaft at Abbey Mills. It is likely that these diversion works will be included in the necessary Parliamentary Act for Cross Rail. Should this diversion be adopted it would be more economic and practical to implement a common solution including interception of the Wick Lane CSO, should programme and budgetary constraints allow, rather than two separate solutions.

The influence of these factors will determine the appropriate method for intercepting the Wick Lane CSO. The basic options for interception are:

- Interception to dedicated tunnel from Wick Lane to Abbey Mills with connection to link tunnel leading to main storage tunnel;
- Interception to existing North London Flood Relief Sewer, including modifications to pumping station I, at Abbey Mills and connection to the link tunnel;
- Interception to proposed diversion tunnel to Abbey Mills for Low Level No 1 (Wick Lane Branch) and Hackney to Abbey Mills Sewer, including modifications to proposed pumping station and connection to link tunnel;
- Increased flow to full treatment reduces discharges to acceptable limits so interception and diversion is no longer necessary.

The actual method of interception cannot be determined at this stage, however a localised interception to either the North London Flood Relief or to the proposed diversion tunnel seems to be the most likely outcome. The scope and therefore the cost of such a localised interception are likely to be similar to those for other sites; therefore an appropriate provisional sum has been included in the estimated costs for this work.

It is planned to study the connection in more detail and to liaise with the Cross Rail team to ensure any costs arising from interference caused is charged to that project.

2.1.6 Conclusions and Recommended Option

Each of the above storage and transfer options would intercept the flows from the Abbey Mills and Wick Lane CSOs and transfer them to treatment at Crossness or Beckton STW. Most of the intercepted flow would be subject to full treatment. So all would be compliant and the appropriate option can be selected on the basis of least capital cost.

Therefore Option 1a is recommended and this is also the option that can most readily accept flows intercepted from Wick Lane. Including the Abbey Mills CSO in this way amends the scope of the proposed storage tunnel solution as described in section 2.4 below.

2.2 Treatment Issues

2.2.1 Tideway Sewage Treatment Works Upgrades

The upgrading which is now to be provided at the Tideway STWs has enabled a re-evaluation of the level of treatment to be applied to the stored sewage before discharge to the Thames. The compliance modelling has shown that storm treatment alone will be insufficient. The increased capacity designated for Crossness and Beckton will permit the majority of the stored flows to receive full biological treatment. It is proposed to balance the pump-out between the two works by providing similar pumping facilities at each site.

The general effect of passing intercepted flows to full treatment will be to extend the duration of high flow through the works. The available capacity to treat flow from the tunnel can be determined from the difference between the maximum capacity and the dwf or average flow to the works as given in the table below:

Works	**Current Flows (m^3/day)**			**AMP4 Increased Treatment Capacity**			
				Proposed (m^3/day)	**% Incr'**	**(m^3/sec)**	
	DWF	**Average**	**FFT**	**FFT**		**Over DWF**	**Over Average**
Beckton	1,009,000	1,320,930	1,419,256	1,800,000	21	9.16	5.54
Crossness	600,000	735,000	985,000	1,485,000	51	10.24	8.68

Average flows and DWF are predicted to increase with time, particularly for Beckton, through urbanisation such as the Thames Gateway development. In the long run this will impact on the level of treatment that can be afforded to the intercepted CSO flows before discharge. It is critical that maximum flexibility of pump-out to treatment is provided.

There are several factors that influence the capacity and level of the treatment required to be applied to the intercepted flows:
1. Sufficient level of treatment to reduce the polluting load of the intercepted flow before discharge to achieve compliance in the middle reaches of the river.
2. The available capacity above dwf (dry weather flow) or average flows at Beckton and Crossness STW.
3. Pump-out rate from the storage tunnel and duration of emptying cycle.
4. The capacity and effectiveness of storm treatment plant.

During, and after rainfall events inlet flow to the works will often reach maximum capacity. During these periods of high flow through the works, the intercepted flow in the main storage tunnel would be discharged via the storm treatment plant. For any given rainfall event, Crossness would typically experience a longer period of high flow through the works as the flow initially diverted to the storm tanks is returned for treatment. On the other hand, Beckton does not have storm tanks and therefore tends to experience shorter periods of high flow.

The model incorporates control flexibility to pass the flow to either of the two main works for full treatment, should capacity be available or to pass flow to the enhanced primary treatment plant (storm treatment) when capacity at the works is not available. The flow to full treatment capacity for each of the works is based on the required AMP4 upgraded rates.

2.2.2 Level of Treatment

For the initial compliance test process, it was assumed that the storage tunnel options would be emptied in 24hours. This rate of emptying was selected as a conservative measure to avoid potential problems due to onset of septicity of the intercepted flow and to ensure that the full storage volume was made available for any subsequent storm events. However this resulted in a high pump-out rate and little flow passing to full treatment because the works would also have been subject to high inlet flows at the same time. As a consequence the majority of the flow was subject only to storm treatment and failed compliance.

The duration of the emptying cycle was increased to 48 hours and the pump-out rate reduced accordingly, (see below). This process was applied to the compliance testing for the proposed storage tunnel solution (including Abbey Mills). Increasing the duration of the emptying cycle meant there was a longer period of time for the works to recover from high inlet flow and could therefore accept more flow from the tunnel. The majority of the flow was therefore subject to full treatment and the level of compliance improved dramatically.

The Objectives report indicated that the critical criterion for compliance is generally level 1 DO for the middle reach of the river close to the discharge location of both works and the treated flow from the storage tunnel. When flow to full treatment is optimal, tests show a reasonably robust level of compliance with only 4 failures recorded against an allowable 14. However, when flow to Beckton is restricted, more flow is discharged via the storm treatment plant and the number of failures increases to 12. This demonstrates the importance of passing as much intercepted flow as possible to full treatment.

2.2.3 Pump-out rate

Testing showed that compliance was not achievable with a 24 hour emptying cycle. The issues of septicity and subsequent storms was reviewed to assess how this duration could be extended so that greater use could be made of the treatment capacity at the works.

The longer storm sewage is stored the greater the production of sulphides, which create an odour nuisance. Also with time, more BOD in sediment is decomposed into soluble form, which would make physical storm treatment processes, such as deep bed filtration or ballasted sedimentation less effective at removal. From the results of research work undertaken by Sheffield University (ref 12), it was found that intercepted storm sewage could be stored in a closed environment (such as a surcharged sewer or tunnel) for up to 4 or 5days before septicity started to become a problem. This general result was also confirmed by a trial on stored storm water in the South West Storm Relief (section 1.5). However it is possible that for volumes of stored flow with large areas of exposed free surface, such as part filled sewers or tunnels, the onset of septicity may become a problem sooner than this.

With regard to availability of storage volume to intercept successive rainfall events, the rainfall data upon which the model runs were based was reviewed. The data was derived from 20 years of radar rainfall records and divided into rainfall events that were separated by at least 24 hours of dry weather. The rainfall model generated some 1208 rainfall events of varying intensity and duration that were fed into the catchment model to assess the resulting volumes of spill. The main risk of extending the pump-out duration is that the storage tunnel would not be empty enough to receive a rainfall event which may occur quickly afterwards.

In real life many events in the year see rain falling continuously for several days. However the modelling showed that long duration events are typically of low intensity and rarely fill the tunnel even when spread over a week or more. Pumping out the tunnel will in fact commence as soon as the rain starts to fall and at 9.6m^3/sec will remove at least 830,000m^3 of stored sewage in a day (ie half the tunnel volume). On all but a few occasions the tunnel would now be at least half empty and the subsequent event would also have to be a large event to exceed this available storage. This is predicted to be a rare coincidence and even if it did occur the first flush of the subsequent event would be intercepted so the highest polluting loads would be retained. The number of rare events which would overcome the tunnel even if pumped out over 48 hours is now calculated to be between one and two per year on average.

It was decided, therefore, that the duration of the emptying cycle could be safely increased to 48 hours.

2.2.4 Storm Treatment Plant

The storm treatment plant is required to treat flows from the storage tunnel when it is not possible to pass flows to the works for full treatment. Flows to this plant will be intermittent and as such cannot be based on a biological process. In line with the conclusions and recommendations of Solutions Group report Vol 1, the enhanced primary treatment process of deep bed filtration is considered the most appropriate physical process of storm treatment.

This recommendation is based on the successful implementation of such plant to treat storm flows in Alabama (ref 11). The plant is designed to treat about 57,000m^3/hr (15.8m^3/s) of storm sewage, which is a similar rate required for this project. The claimed performance is reductions of suspended solids from 100mg/l to 30mg/l and BOD reductions from 134mg/l to 25mg/l (approximately 80%). This was based on pilot plant trials and has been adopted as the design data for the full-scale plant. The plant is now complete and it is recommended that any operating data is reviewed when available.

As the design data for A (ref) is based on pilot trials and operating data for the complete plant at Alabama has not yet been reviewed it was thought appropriate to adopt a conservative figure of 60% reduction of BOD for the compliance test process.

Although the maximum pump-out rate is 9.6m^3/sec, it was thought appropriate, at this stage, to allow for 50% additional capacity to cover for filtration cells off stream either in backwashing mode or if shutdown for maintenance.

2.2.5 Outline arrangement of treatment plant at Crossness STW

A conceptual layout for the pumping station, generator building and treatment plant has been produced for the treatment site located in the southwest corner of Crossness STW, (refer section 8, ref 1). The treatment plant consists of constant velocity grit channels, screening plant and deep bed filters, for which outline capacities and sizes have been estimated.

As it is intended to gravitate the flow through the treatment plant to avoid complex and expensive re-pumping, the overall hydraulic head loss through the plant dictates that the grit channels will become a major elevated structure rising to a height of approximately 10m above existing ground level. However the impact of such a high structure will be balanced by the proposed building over the treatment plant units and pumping station to control odour.

2.2.6 Proposed Plant

The proposed method is generally to pump-out as much of the intercepted flow to full treatment at either or both of the works to take full advantage of the proposed AMP4 upgrades of the works. The proposed system will incorporate a wide range of flexibility so that the optimal quantity of intercepted flow can be treated. This impacts upon the required pumping plant, refer to section 2.9 below.

The proposed pump-out and treatment facilities at each site comprise:

For Beckton STW:

1. Pumping shaft, 27m diameter, located adjacent to existing inlet works on NOS.
2. Two variable speed, independent main pumps; maximum combined capacity 9.6m^3/s.
3. Discharge to head of existing grit removal plant and screening plant.

For Crossness STW:

1. Pumping shaft, 30m diameter, located adjacent to existing screening plant.
2. Two variable speed, independent main pumps; maximum combined capacity 9.6m^3/s.
3. Two flush water drain down pumps, duty/standby capacity 1.0m^3/s.
4. Discharge to additional grit removal plant and screening plant.
5. Storm treatment plant maximum capacity 15m3/s (to allow for cells off stream for backwashing) with new dedicated river outfall.
6. Discharge either to head of existing primary sedimentation tanks after screening only or to river after storm treatment.

2.3 Design and Construction

2.3.1 Tunnel Construction

For the Option A tunnel, the proposed methods of construction and difficulties to be overcome is described in considerable detail in Volume 1. This includes detailed geotechnical investigations of the strata to be excavated; ground water conditions; obstacles en route both above and below ground; TBM considerations and lining types and erection methods.

Geological Strata

A thorough review of all existing borehole data in the London area was carried out by the Geotechnical Department of Thames Water, resulting in a comprehensive database that was used to generate the geological sections for the tunnel alignment. Most features and strata are reasonably documented but, as the proposed tunnel alignment would be deeper than most previous works, significant site investigation, including deep exploratory boreholes, will be required to complete the design work necessary for such a large project.

The proposed alignment of the tunnel divides the anticipated geology into three sections:

- the first quarter of the route from the west will be in London Clay, which is widely known to be excellent tunnelling strata as experienced building the London Underground;
- the second quarter of the route would be in the Woolwich and Reading Beds, which are very variable, and the Thanet Sands, which are saturated and abrasive fine sands. Conditions are likely to be difficult at the interface of the Thanet Sands and the overlying Lambeth Group (lower strata of the Woolwich and Reading Beds) and also at the interface with the Chalk beneath. These strata are more difficult for tunnelling, but modern TBMs of the earth pressure balance type can cope with such conditions;
- the remainder, approximately half of the entire route, would be in chalk. Generally chalk is an excellent stratum for tunnelling, except where it is weathered or fractured or if bands of flint are encountered. These challenges can also be met by appropriate design of the TBM.

Groundwater

Groundwater pressures in the chalk are likely to be high as there are zones of connectivity directly between the chalk strata and the river above. However the chalk is generally of low permeability, except where faulted, and should not cause undue problems for a modern TBM.

The groundwater pressure in the Thanet sands is also likely to be high due to connectivity with the underlying chalk. These sands are fine and dense and also have low permeability and as such are less likely to be faulted and cause a significant issue for the TBM. This low permeability of the Thanet Sands may present more of a challenge for dewatering to facilitate shaft construction. It is likely that injector well point dewatering systems will be required.

Within the mixed strata of the Woolwich and Reading beds there will be perched water tables in the sand and gravel strata. These may be isolated or connected to the Thanet Sands. This should not cause significant problems for the TBM, but may be more of a challenge for shaft construction. The proposed method of shaft construction is the diaphragm wall technique, which will cut through and isolate these water-bearing layers enabling effective dewatering.

Tunnel Boring Machine

The proposed TBM should be of the closed face earth pressure balance type to tackle the anticipated variability of ground conditions in the central section of the route, the transition layers between strata and the high groundwater pressures in the chalk and Thanet Sands. Such TBMs have performed well in similar ground conditions for the CTRL running tunnels in London and under high groundwater pressures as in the river Elbe crossing in Germany. The requirements for the Tideway tunnel are thus within the limits of current technology. The TBM design will have to be developed carefully but no step-change in technology is required.

Obstructions

The proposed tunnel alignment has been passes entirely below all known obstructions such as London Underground running tunnels, GPO tunnels and bridge foundations. The only exceptions are where the proposed alignment passes over a section of the London Water Ring Main and the Thames to Lee Valley Transfer tunnel in the west section. Generally this alignment is dictated by the need to drain the storage tunnel with a consistent fall from west to east to avoid reverse gradients and intermediate pumping stations.

The tunnel depth makes the risk of hitting obstructions very low due and has the additional advantage of significantly reducing settlement at the surface. A review of the possible effect on existing tunnels and bridge foundations was carried out as part of the study of Settlement and Ground Movement (Volume 1, section 8.2.4) based on a 9m ID tunnel. Predicted settlements and ground movements for the proposed 7.2m tunnel will be proportionally less.

The proposed route of the main tunnel principally follows the river to intercept the CSOs in the most effective manner. This also has the advantage of avoiding densely built-up areas and minimising impact on buildings. Passing under built-up areas is limited to the extreme western end of the route, the Greenwich peninsular and adjacent to some main shaft locations. However the route will pass under many sensitive structures such as the bridges, existing tunnels and the river walls. The conclusions and recommendations of the Settlement study, which still hold good, include:

1. A methodology for the assessment of the impact on bridges, tunnels and river walls was developed and a preliminary assessment based on a 9m diameter main tunnel shows that the risk to strategic structures is limited and manageable
2. Most of the principal structures will require impact assessments and a significant number may require protective/mitigation works
3. Gas tunnel crossings carry very serious consequences especially that by Beverley Brook. BT tunnels require special attention and the LUL tunnels will be of great sensitivity
4. Thames Water's tunnels at the west end of route are at high risk but this should be manageable through common ownership.

The main issues affecting scope, design and associated construction considerations for refinement of the storage tunnel option were reconsidered by Faber Maunsell. These are covered in their report (ref 1), and are summarised below:

2.3.2 CSO tunnel connections
2.3.3 Review of main shafts and site compounds
2.3.4 Construction Logistics
2.3.5 Building and ventilation requirements
2.3.6 Internal lining
2.3.7 Revised route of main tunnel
2.3.8 Alternative main shaft sites
2.3.9 Pumping
2.3.10 Choking
2.3.11 Flushing
2.3.12 Renewable Energy

2.3.2 CSO tunnel connections

Previously the construction issues associated with the CSO tunnel connections had been investigated for a storage tunnel diameter of 9m. The main consequences of constructing these connections within a 7.2m diameter storage tunnel have been revisited (ref 1).

There are many technical issues to consider including geology and control of groundwater, aspect ratio between interconnecting tunnel and main tunnel diameters, temporary and permanent support to openings, launch and recovery of tunnel boring machines.

Interconnecting tunnels with diameters up to 3m do not pose exceptional logistic or construction problems, whereas larger diameter connections would create major issues, which would have a significant impact on cost and risk. Construction of these larger diameter connections would require the localised enlargement of the main tunnel, which would only be possible if the ground conditions were stable, such as in London Clay, or made stable by extensive geotechnical works.

It would be practical to drive interconnecting tunnels of up to 3m ID from either the drop shaft intercepting the CSO or from the main storage tunnel itself. In the latter case construction impact at the CSO interception site could be reduced. However for larger diameters it will only be possible to drive from the drop shaft to the main tunnel. Recovery of the TBM via the main tunnel will pose a greater challenge for larger diameters.

Hydraulic requirements for these tunnel connections have been reviewed in more detail using a computational fluid dynamic (CFD) model (section 2.3.10). The results show that for the largest intercepted flows a 3m ID connecting tunnel is sufficient to ensure inflow is relatively smooth and that choking would not occur. So the maximum required diameter of CSO connecting tunnel can be practically accommodated within the 7.2m diameter main storage tunnel irrespective of ground conditions or location.

2.3.3 Review of Main Shafts and Site Compounds

In order to progress the refinement of the storage tunnel option beyond a conceptual basis specific sites were selected for the main shafts so that the development of the design and construction issues, construction programme and cost estimate would have a realistic basis. These specific sites were chosen to facilitate a suitable tunnel route and accommodate the logistical requirements of construction. They are not final commitments as the storage tunnel concept can accommodate flexibility of the main shaft locations.

Obviously relocation of main shafts to other optimal locations would change the detail of the construction logistics and programme, but would not have a significant impact on overall estimated cost or programme. In order to divide the storage tunnel into practical lengths both for construction and operation between Heathwall and Crossness at least one and preferably two construction shafts are required. Specific locations may be determined during the next stage of project development and secured to fix route of the storage tunnel.

The previous investigation work, based on a 9m storage tunnel concluded that 25m diameter construction shafts would be required. It was hoped that by reducing the main tunnel diameter to 7.2m that smaller main shafts could be justified. However because of the depth of the excavation tunnelling best practice indicates that the main shafts remain at least 25m in diameter. The pumping shafts at Beckton and Crossness will necessarily be larger.
The minimum working site area required for constructing the shafts and tunnels remains 6000m², except in cases where some facilities can be sited in nearby locations when the actual site area could be less.

The construction requirements for the five main shafts, as well as the proposed shafts at Abbey Mills and Beckton, have been studied in detail and are summarised in the table below:

<u>Shaft</u>	Depth	Dia'	Geology	Likely method
Chiswick	33m	25m	London Clay	Underpinned or sprayed concrete. Diaphragm wall alternative
Heathwall	56m	25m	London Clay and Lambeth Beds	Underpinned or sprayed concrete. Diaphragm wall alternative. Pressure relief wells required.
Southwark	68m	25m	Alluvium and gravel on to Chalk	Diaphragm wall into sound chalk, ground treatment to control water and continue with sprayed concrete.
Greenwich	73m	25m	Alluvium and gravel on to Chalk	Diaphragm wall into sound chalk, ground treatment to control water and continue with sprayed concrete.
Crossness	85m	30m	Alluvium and gravel on to Chalk	Diaphragm wall into sound chalk, ground treatment to control water and continue with sprayed concrete.
Abbey Mills (linked)	70m	15m	London Clay, Lambeth Beds and Thanet Sand on Chalk	Caisson or Diaphragm Wall. Pressure relief wells or dewatering.
Beckton (linked)	76m	27m	Lambeth Beds and Thanet Sand on Chalk	Caisson extended with sprayed concrete. Pressure relief wells, dewatering or grouting.

2.3.4 Alternative main shaft sites

The longer that a decision to proceed is delayed, the greater the risk that optimum sites will be unavailable. The main shaft sites are the focus of the construction activity associated with the main storage tunnel and the long-term operation of the tunnel for access, maintenance and ventilation. Each shaft site would experience a temporary period of disruption due to construction and the permanent siting of the main access/ventilation building. Construction site availability is one of the top five for successful implementation of the project.

<u>Chiswick Shaft</u>

Chiswick Eyot was initially selected as the location for the westernmost shaft as it was immediately adjacent to the outfall for the Acton CSO. However this is a nature conservation area and difficult to access so alternative locations have been investigated including a nearby industrial estate, Homefield Recreation Ground, the Hammersmith PS site and in the nearby river foreshore. Currently each of these sites presents its own difficulties with all except the river foreshore suffering encroachment from surrounding development.

This shaft has to cater for interception of the Acton Storm Outfall and North West Storm Relief CSOs. If the shaft were to be located in the vicinity of Hammersmith PS the alignment would be freed of the constraints imposed by the presence of the London Water Ring Main and the Thames to Lee Valley tunnels to the west and the overall depth of the tunnel could be reduced. This would reduce the depth of the whole tunnel and thus the cost of all the shafts.

Heathwall Main Shaft

The proposals for the main shaft at Heathwall PS require the acquisition of land immediately to the west of the site, which is a portion of the Tideway Industrial Estate. Negotiations are underway with the current landowners, but lest this should fail alternative arrangements have been investigated to provide a contingency plan.

Three options were considered, (section 6, ref 1) which were based on various portions of the Tideway Industrial Estate immediately adjacent to Heathwall PS becoming available. The general conclusion was that it would still be possible to construct the main shaft at Heathwall PS if insufficient additional land could be acquired but that the pumping station would have to be reconstructed, at increased cost, to facilitate the works. In part these increased costs may be off set by reduced expenditure on land acquisition.

Southwark and Greenwich Main Shafts

Rerouting of the main tunnel around Limehouse Reach means that a construction shaft would no longer be vital for construction purposes at the Southwark site. However this would increase the length of drive between Greenwich and Heathwall, refer 2.3.7 below.

There is a potential alternative site for the Greenwich shaft further to the east adjacent to the location of the Charlton CSO discharge. If the main shaft were relocated here the main tunnel drive length to Heathwall would be further increased.

2.3.5 Tunnel Construction Logistics

The potential construction logistics have been reviewed in some detail (refer section 4, ref 1) and the influences incorporated into the revised baseline construction programme (see also section 4.2).

The reduction in diameter to 7.2m increases the impact of the CSO interconnecting tunnels' construction on the main tunnel production rate, particularly if these are driven from the main tunnel itself. The working platforms required to drive the CSO interconnecting tunnels would impinge upon the conveyor system and segment transportation vehicles servicing the main tunnel drive. Whilst a drawbridge type arrangement may reduce this interference the progress rate for both the main tunnel and the CSO interception tunnels would be reduced.

Despite this there is a high level of confidence that construction of the main tunnel and shafts is within current technical capabilities and the overall programme, which is currently based on driving from the main tunnel to the interception shafts, remains the same. This has the advantage that tunnel spoil from the interconnecting tunnels will automatically be disposed of with the main tunnel spoil by river barge, which is the preferred method.

2.3.6 Building and Ventilation requirements

Ventilation of the main storage tunnel together with access arrangements for maintenance, cleaning and inspection impose significant requirements on the design of the main shafts and associated superstructure. (Section 8 of ref 1)

Storm flow can enter the tunnel at theoretical combined rates of up to 250 m^3/s, although such a high total inflow rate will rare. Air will be expelled, principally from the main shafts at the same rate as intercepted flow enters. It is not practical to provide odour control plant with such high capacity; therefore it is proposed at this stage to continuously ventilate the tunnel so that displaced air will have minimal odour.

Although it may be possible to provide this continuous ventilation by vent columns, as for the majority of existing storm sewers in London, this approach may be ineffective due to the size and depth of the proposed storage tunnel and the distance between ventilation points. It is not possible to determine whether forced ventilation will be required at this conceptual stage of project development. It is planned to produce a CFD model of the airflow in the system with the aim of demonstrating that natural ventilation will be acceptable. However a provisional sum has been included in the estimate to allow for forced ventilation.

To facilitate access for maintenance, cleaning and inspection, a lifting gantry will be required to handle man-riders, skips for removal of debris and inspection vehicles ideally at every shaft The current practice of using mobile cranes would be problematic at such depths. In addition the headworks buildings over the shafts at Beckton and Crossness will need to incorporate facilities for pump maintenance and removal.

It is proposed to include for a substantial headworks building at ground level over each of the main shafts. A conceptual layout for such a building has been developed. It is proposed that the buildings should be of high quality and architectural merit as they will ultimately be the only visible evidence of this major infrastructure project.

2.3.7 Internal lining

The proposed tunnel route passes through various strata some of which form the aquifer for water abstraction sources. The current scope for the storage tunnel includes a secondary internal lining to protect the aquifer from contamination. The detailed issues associated with a secondary internal lining are covered in detail in section 5 of ref 1, and summarised below:

- Additional structural support - The proposed primary lining is expanded or bolted concrete segments, which can withstand the geological and hydrogeological conditions to guarantee the long-term stability of the tunnel. A secondary lining is not required for structural support

- Infiltration: Although groundwater pressures may rise to a maximum of 8bar, the surrounding ground is generally of low permeability. Ingress rates of about 1.5m^3/min may be expected, however this is relatively low and does not warrant a secondary lining.

- Exfiltration: The intercepted storm water will be contaminated with sewage and any possible leakage into the chalk could have an adverse effect on the aquifer. However the internal pressure within the tunnel is unlikely to be greater than the external groundwater pressure. The risk of egress from the tunnel is very low and does not warrant the expense of a secondary internal lining.

- Scour, durability and hydraulic performance: The quality, surface finish and strength of modern concrete segments is very high and will resist the effects of scour and chemical attack. High scouring velocities only occur adjacent to tunnel connections for a short duration in the early stages of filling. Flushing may also tend to scour the invert, but is not a continuous operation. A secondary lining is not justified on these grounds

- Construction issues: Exclusion of the secondary lining will reduce the OD of the main tunnel from 8.3m to 7.8m saving 220,000m^3 of excavation. This reduction in spoil would have a significant financial and environmental benefit. Savings would also be available from a reduction in materials for the primary lining, transportation and energy costs. Another very significant saving of cost and time would be from the reduction of construction programme.

These are cogent arguments that this lining may not be necessary particularly as the groundwater pressure is higher than that of the stored storm water. Excluding the lining would enable the external diameter of the tunnel to be reduced to accommodate the same volume of storage. The cost of lining the main tunnel is included in the estimate but eliminating it would reduce cost, programme and environmental impact.

2.3.8 Revised route of main tunnel

Several detailed amendments to the route of the tunnel have been included in the refined scope of the proposed storage tunnel as a result of relocating main shafts, incorporating the Abbey Mills Link, accommodating the proposed upgrade at Crossness STW and developments adjacent to Beckton STW. These include:

- Development immediately adjacent to Beckton STW means it may no longer be possible to accommodate one of the main shafts in this location. The main tunnel route bypasses Beckton and this main shaft has been replaced with the Beckton link tunnel and the pumping station shaft adjacent to the inlet works on the NOS.

- To receive the Abbey Mills Link tunnel a main shaft is required on the eastern end of the Greenwich Peninsular. An alternative site has been identified.

- The final main shaft to house the main pumps at Crossness STW has been located in the SW corner of the site. The required screening and treatment plant will be located immediately adjacent.

The possibility of routing the tunnel around the curve of the river at Limehouse Reach rather than passing directly under the built-up area of Southwark has been investigated in outline. Initially this was avoided as the curve radius was too tight for the 9m diameter tunnel of Option A(medium). However now that the main tunnel diameter is 7.2m it is possible to accommodate this curve (ref 1, section 7.2). This avoids tunnelling under a large number of parcels of private land and although the current estimate is based on the Southwark urban route calculations show this change to be cost neutral.

2.3.9 Pumping

As discussed in 2.2 above it is proposed to provide equal pumping facilities at both Beckton and Crossness to allow for optimal flexibility of discharge to full treatment. The experienced pump supplier KSB was appointed to review previous study work (Volume 1, section 8.2.6) and to recommend an appropriate plant layout (ref 6).

The required maximum average pump-out rate of 9.6m^3/sec was derived from discharge of the maximum intercepted volume over 48hours. Smaller volumes of intercepted flow may be pumped out more quickly though 48hours is still acceptable. This implies lower pump-out rates, which may be preferred at the STWs. The required lift also covers a wide range from approximately 15m when the tunnel is full to nearly 90m when almost empty. However as capacity for full treatment is limited at each site the maximum pump-out rate could not be allowed to be much greater than the average maximum value.

This represents a very wide range of operating parameters at high capacities and the operating regime proposed by KSB is based on two equal variable speed pumps in a dry well/wet well configuration. The system curve is included in ref 6, Appendix A and the operating envelope is summarised as follows:

The maximum pump-out rate of 9.6m^3/s can be maintained with the two pumps throughout the emptying cycle from an initial lift of only 30m, gradually increasing as the tunnel empties, by increasing the speed of the pumps until the lift reaches 83m. At this point, where less than 5% of the total volume of intercepted flow remains, the pumps will be at full speed and the pump-out rate will gradually reduce to approximately 7.6m^3/s at the full lift of 90m when the tunnel is virtually empty. Despite this slight reduction in pumping capacity towards the end of the emptying cycle the time taken to empty the tunnel from full capacity is only extended by approximately half an hour.

For smaller events the pump speed can be reduced, or only one pump used to maintain lower average pump-out rates so that lower volumes of intercepted flow are still emptied in 48hours. The lowest pump-out rate achievable with one pump at full head is approximately 2.0m^3/s.

A separate set of pumps will be required for the removal of flushing flow. This flow is likely to contain high concentrations of silt and polluting load. Reducing the rate at which this flow is passed to the works for treatment as much as possible will reduce the impact of any “shock” load on the works. The current proposal is for two pumps in a duty/standby arrangement, each of equal capacity capable of pumping a maximum of $1m^3/s$. These pumps will only be required in the Crossness pumping shaft, as the main tunnel will direct the flushing flow direct to this shaft. As the Beckton pumping shaft is connected to the main tunnel by a smaller diameter link tunnel the flushing flows will not be directed to Beckton. Therefore flush water removal pumps will not be required. However some form of flushing will be required for the link tunnel. This can be provided by interception of a volume of sewerage or final effluent.

The proposed system allows the flexibility to pump out the flow either wholly to Beckton or to Crossness for treatment or in any ratio between the two.. Although all main pumps may be considered as duty pumps, the fact that in total twice the required pumping capacity is provided, means there is effectively 100% standby for both pumping and treatment.

It could be argued that more main pumping units per station would provide increased flexibility and standby. However more units of equal total capacity will occupy more space and increase the diameter of the pump-out shafts. As these shafts are so deep this would dramatically increase costs and engineering challenge, as such this approach cannot be recommended. The units as proposed provide sufficient flexibility and standby; any increase in number of units will only increase cost and complexity.

2.3.10 Tunnel Choking

One of the main conclusions made in the WS Atkins Hydraulics Study (see Volume 1, section 8.2.2) was that the controlled displacement of air from any tunnel was key to enable it to fill without choking. Large volumes of air trapped within the tunnel length could restrict the hydraulic capacity preventing successful interception of the polluting flows and causing bypass to the river. The trapped air could also be compressed, which might be dangerous.

The CFD model developed previously was used to carry out further modelling out by Thames Water R&D. The modelling work carried out and reported in Volume 1 consists of three parts:

1. CFD model of a single high inflow to the main tunnel.
2. CFD model of multiple inflows to a length of the main tunnel.
3. Small-scale physical model to validate the CFD model.

The modelling of a single large CSO inflow from the Fleet showed that the flow profile at the connection was quite smooth provided the velocities were modest. This ensured choking would not occur, again confirmed by the results from modelling a length of the tunnel with several connections, however this needed a relatively large connecting tunnel from the CSOs.

Construction difficulties associated with larger connections increase complexity, cost and risk, refer to section 2.3.2. The required range of connection sizes was therefore reviewed using the CFD model to run simulations on the following flow and connection arrangements:

Interception Tunnel diameter (m)	**Min flow rate (m^3/s)**	**Medium flow rate (m^3/s)**	**Max flow rate (m^3/s)**
2.0	6	12	18
2.5	10	20	30
3.0	14	28	42
3.5	19	38	58

The main tunnel diameter was 7.2m and the simulations were run over time to progressively fill the tunnel so that the hydraulic profiles could be assessed throughout the filling cycle, from empty to nearly full.

The results (ref 2) show that, even for maximum inflow, choking would not occur at any stage throughout the filling cycle, however the peak velocities could approach 7m/sec when the main tunnel is nearly empty, which could be of concern regarding scour. However these peak velocities rapidly diminish as the main tunnel starts to fill and are therefore of fairly short duration. Also these high peak velocities could be generated by high intercepted flows, which would occur only a few times a year. It is therefore acceptable to allow a small amount of scour for these infrequent occasions.

The main conclusion of this modelling work is that largest diameter of interconnecting tunnel to be utilised will be 3.0m which is smaller than previously considered. This factor is taken account in the review of CSO interception structures as part of the ongoing further study work.

2.3.11 Tunnel flushing

Velocity in the main body of intercepted flow will be quite low during the process of pumping out to treatment. The maximum velocity is unlikely to be greater than 0.25m/sec and for most drain down events it will be much lower. Siltation is therefore likely and a system for flushing the storage tunnel after drain down will be essential.

Large quantities of sediment would, over time, decompose producing noxious and potentially explosive gases. When the tunnel fills during subsequent rainfall events large quantities of such gases could be discharged into the air adjacent to the main shafts causing potential danger and odour nuisance. The rate of discharge would be too large to treat with odour control systems. It is important that this sediment is effectively removed following drain down. The fumes arising from any decomposing sediment and biological matter that remain could be controlled by the proposed tunnel ventilation system (refer to section 2.3.6)

Two flushing systems are under investigation using a CFD model of the whole tunnel. The first is based on introducing river water, initially stored in the westernmost shaft and released quickly to flush the entire length of the tunnel. This process would be repeated until the tunnel is clear of sediment. Such a large use of river water (up to 100,000m^3) may meet abstraction limitations in the upper Tideway. This is being investigated but is time-consuming because of the substantial computing power required

.
Another system uses baffle walls and control gates at each main shaft, so that volumes of intercepted flow (or river water) can be released sequentially to flush lengths of the tunnel. A final flush with river water would be necessary to complete the operation.

Early results indicate that high velocities could be generated and sustained which should re-suspend sediment and transport it along the tunnel for pump-out. It appears likely that the sequential emptying of the tunnel will prove to be, overall, the most effective means of flushing the tunnel. It is a matter of hydraulic control to optimise the process.

2.3.12 Options for Renewable energy

The target for utilisation of renewable energy for major projects in London is currently 10%. A review of the potential applications has been carried out with the National Energy Foundation (ref 5). Preliminary findings are that the most favourable potential options are wind generators, bio fuels and sludge incineration.

Recovery of hydro-energy from the intercepted flows is not recommended, as it is very unlikely to be cost effective. The plant and installation required will be very expensive and difficult to maintain, and the flows are too intermittent and short in duration to make this approach viable.

Other possibilities such as photo-voltaic cells will be too expensive and heat recovery from the intercepted flows, by heat pump, will be of no value as the main treatment works no longer require large quantities of heat for the treatment process.

The main issues associated with the three favourable options are:

1. ***Wind Generators;*** A single large generator located at Beckton or Crossness is likely to generate approximately 3 to 4 GWhrs per year, which is in approximately 50% of the typical estimated annual energy consumption of 7GWhrs. However there are specific challenges to the use of wind generators at these two sites. It is understood that permission has recently been refused for a wind generator at Beckton due to the proximity of the City Airport. It is also understood from previous investigations that due to the proximity of the nature reserve to Crossness, installation of wind generation may not be acceptable at this site.

2. ***Bio fuel Usage;*** It is proposed to generate the required power for the pumping plant on site. There are several options for running this generation plant on bio fuels alone or a mixture with diesel. It is possible therefore that virtually all the energy could be from renewable sources

3. ***Sludge Incineration;*** The intercepted flow may generate approximately 10,000tonnes of dry solids per year. As well as providing an effective means of sludge disposal, incineration of this sludge will release calorific energy, which can be used for power generation. Preliminary calculations indicate that between 30% and 50% of the estimated annual energy consumption could be generated in this manner. However a substantial increase in incineration capacity at Crossness would be required for this option.

Optimisation of the appropriate use of renewable energy usage is the critical issue to improve sustainability and reduce the environmental impact of operation of the proposed storage tunnel option. Further development of the potential for utilisation of renewable energy is recommended.

2.4 The Refined Recommended Option A(ref)

Taking account of all the above factors the scope and content of the refined option is as follows:

1. A main storage tunnel, 7.2m internal diameter, 34.5km long providing 1,405,000m^3 storage;
2. Seven main construction shafts including the pumping shafts;
3. Abbey Mills link tunnel, 5m in diameter, 4.5km long providing 88,500m^3 storage;
4. Beckton STW link tunnel, 3m in diameter, 1.1km long providing 7,500m^3 storage;
5. A new 9.6 m^3/s pumping station at Beckton STW and connexion to the main works inlet;
6. A new 9.6 m^3/s pumping station at Crossness with connexion to the works inlet, a new storm treatment plant with screening rated at 15.6m^3/s capacity and a new dedicated overflow to the Thames for the treated storm sewage;
7. Interception of 36 unsatisfactory CSOs.

3. Risk

3.1 Risk Register

The risk assessment processes employed throughout this study are described in detail in Section 7.3, volume 1 of the Solutions Group Report 1. Initially this was used to select the most appropriate solution and then to assist refinement of the preferred option. Potential risks, their context and the proposed measures of mitigation are discussed and summarised in ref 10. Risks particular to the planning process are detailed in section 3.3.2 below.

The current risk register has been reviewed and updated and is included in ref 1. The top five risks, together with the associated mitigation measures are assessed to be:

Item	Risk	Mitigation
1	Difficulties in obtaining insurance	Early discussions with Insurance companies. Self insure
2	Construction site availability	Early acquisition of required site areas or take out option for purchase
3	Groundwater encountered during shaft construction	Construction technique chosen to suit presence of groundwater Allow for dewatering system
4	Intake structure at Hammersmith	Research alternative site due to planning risk (protected site)
5	Difficulties in site locations for CSO tunnels constructed from surface	Intercept sewers away from river (increase in CSO tunnel length)

Regarding the above items of risk the following observations are pertinent:

1. A code of practice has been developed by the British Tunnelling Society and the Association of British Insurers, which includes measures for appropriate insurance cover on a risk, based approach.

2. It has been recognised for some time that early acquisition of the proposed sites will reduce this risk. A site adjacent to Heathwall PS has already been acquired. The other sites have been identified and preliminary negotiations are underway with the current landowners.

3. Mitigation of this risk will require significant site investigation to develop the required construction method. A significant allowance for site investigation is included in the current estimated cost.

4. Investigations into alternative sites are already in progress as part of the current refinement of the proposed storage tunnel solution (refer to section 2.3.4).

Alternative CSO interception locations would require significant and detailed investigation and study and a suitable allowance has been included in the estimated project cost.

3.2 Construction Overrun

The main impact of construction overrun is the additional cost of maintaining the site establishment, management and operative resource costs. From the current budget estimate the time related cost for these items is approximately £1M per month. At this stage it can be assumed that the cost of resolving such problems are covered by the contingency sum.

It is useful to reflect on the performance of recently completed tunnelling projects to place such risk in context:

1. ***Channel Tunnel Rail Link (CTRL) tunnelling contracts;*** All main tunnelling contracts for CTRL were completed within programme and to budget. Two minor problems were encountered which had an insignificant impact on overall performance.

2. ***Jubilee Line Extension (JLE);*** All main running tunnel works progressed well. The main problems which caused the programme and budget costs to considerably over-run were late design changes and the cessation of works due to the Heathrow Tunnel collapse (construction in NATM). It is not proposed to utilise this method of construction except for isolated enlargement of shafts in stable ground.

3. ***Channel Tunnel;*** The main tunnelling works were completed generally to time and budget. The main cost over-runs were due to major changes to rolling stock specification to cover greater fire risk protection measures

3.3 Land acquisition and planning risks

3.3.1 Introduction

Several studies on land availability, acquisition, appropriate planning process and preliminary environmental impact assessments have been undertaken (ref 3), which includes an outline programme. The main planning risks are summarised below.

Early acquisition of the required sites for the main shafts is a critical element enabling the planning process to be linear. If the shaft sites are identified but not acquired or optioned for purchase, they may not be available at the end of the planning process. Alternative locations would then be sought and the route and design of the tunnel might change and the planning process would have to start again. This could cause delays of several years. Acquisition of the sites by private treaty and not compulsory purchase might help to minimise the risk of a public inquiry being invoked.

The most favourable option for the planning process appears to be by the lead authority route. Expert consideration by a Queen's Counsel experienced in planning law is being carried out to substantiate this view.

3.3.2 Potential planning risks

The main planning risk is time delay and when the planning process is in the hands of the inspectorate or the Secretary of State, Thames Water would lose control of the programme. Even if a public inquiry was invoked the overall planning process could still be completed with a successful outcome by 2010 so that construction could commence at the start of 2010.

The table below identifies the principal items of risk associated with the planning process and includes measures of mitigation that could be adopted to reduce risk and ensure a successful outcome:

Ref	Item	Mitigation/Comment
1	Scheme requires planning permission	Application for planning permission included in proposed programme
2	Scheme requires Environmental Impact assessment (EIA)	Requirement for EIA identified and included in proposed programme
3	Planning applications for scheme elements are submitted to relevant planning authorities individually and one or more refuses permission	Application to individual planning authorities is not recommended
4	Planning application is submitted to a lead authority who coordinates responses from individual authorities and one or more refuses permission	Lead authority is a recommended approach, but is dependant upon all affected boroughs agreeing the approach and could be vulnerable to a single objection. However, if one authority took, it would be

		open for that authority to determine the application irrespective of an objection. This would not be desirable.
5	The Mayor's office directs refusal of one or more applications to boroughs	Thames water would appeal leading to a Public Inquiry. The Mayor would consider the application(s) on the grounds that the scheme is of strategic importance. He would only direct refusal if the scheme was contrary to policies in the London Plan.
6	Thames Water appeal against refusal, Public Inquiry is held and Inspector recommends dismissing appeal	The planning inspector would determine an application on its merits and an appeal would be dismissed if, on balance, the planning negatives outweighed the positives (judged against policy)
7	Planning application is deemed to be a departure from local plans, or a significantly controversial scheme, and is called in by Secretary of State (ODPM/DEFRA) for Public Inquiry	Public Inquiry process included in proposed programme
8	Technical or non-technical objector requests Secretary of State (SoS) to call application in for Public Inquiry and SoS does so	Public Inquiry process included in proposed programme
9	Planning inspector recommends refusal and SoS refuses permission	*There is no planning recourse if the SoS upholds the inspector's decision. The procedure for making the decision could be challenged on a point of law via judicial review, and a decision could be reversed if an authority or the SoS has been shown to have acted incorrectly (for example, by not following the correct procedure).*
10	Planning Inspector recommends approval and SoS refuses (for political reasons)	SoS would need robust political case to refuse

3.3.3 Land acquisition risks

Construction site availability is one of the main project risks and is best mitigated by early acquisition of the required site areas or options for them. A small site adjacent to Heathwall PS has successfully been acquired to facilitate construction of one of the main shafts and interception of the CSOs at this site. Negotiations for further acquisition at Heathwall and of the remaining main shaft sites are underway.

Negotiations have brought to light serious issues relating to the proposed main shaft sites at Southwark and Greenwich which were targeted early in 2004. The Greenwich site recently acquired planning permission for redevelopment and it is understood that the Southwark site will soon get planning permission. This shows the dynamic nature of the land market in London and why it poses such a challenge to the successful implementation of this project. An extensive proposed commercial development borders Hammersmith PS on three sides and may severely restrict options for interception of this CSO.

Until the planning phase of the project is approved it is not possible to negotiate modification to these proposed developments to facilitate the project or to fund the necessary compensation. It is highly likely that these optimal sites for the main shafts will be lost and alternatives will have to be sought. As any other site will be less than optimal it is very likely that there will be a corresponding increase in cost.

4 Estimated Costs & Programme

These estimates originate in the Solutions Group report Volume 1 - sections 8.2.14 and 8.2.15 and have been reviewed at stages throughout the investigation. The estimates for the storage tunnel option have been reviewed during this refinement stage on the following basis:

1. Use of a more robust method of calculation of tunnels and structures costs;
2. Revised proposals for CSO interception;
3. Inclusion of Abbey Mills CSO;
4. Changes to Proposed Design and Construction;
5. Present the estimate updated from second quarter of 2002 to third quarter 2004.

To assist with selection of the appropriate solution including Abbey Mills, expert tunnelling contractor Amec prepared estimates for the various options, later verified by quantity surveyors E C Harris (see section 4.1.3).

The results of the changes to the scope and content of A(low) [and A(med)] which lead to the new recommended option A(ref) are shown in table 4 at the end of this section. To improve confidence and demonstrate the estimates are robust and appropriate, they have been compared with the outturn costs for CTRL tunnelling works (Appendix A).

4.1 Costs

4.1.1 Costs Re-estimated Using a More Robust Calculation

The estimates for construction used in the Solutions Group Report Volume 1 are based on those produced for solutions A to E in March 2002. The medium level of intervention is the reference estimate for each solution and those for the low and maximum levels were extrapolated. These were reviewed by EC Harris who concluded that the upper bound values were reasonable. However they pointed out that the lower levels of intervention were under-estimated by reducing costs of the interception structures, implying that these were smaller. This is wrong as the structures must cater for peak flows, whatever the level of interception and will therefore be approximately the same size and cost.

More robust construction estimates for solutions A(low), A(medium), G and H were developed based on the preliminary drawings by Faber Maunsell and the detailed programme developed by Amec. Considering the programme of works, the resources, materials and duration for each element of work this method of calculation is much more systematic and accurate. The improved estimate for A(low) was based on a main storage tunnel diameter of 6m and for A(med) of 9m for comparison as below:

Solution	**Halcrow Estimates Volume 1**	**EC Harris Revised Volume 2**	**Difference**	
A(low)	£763M	£849M	+ £86M	+11%
A(medium)	£1058M	£987M	- £71M	-7%

4.1.2 Revised Proposals for CSO Interception

The estimates for A(low) and A(med) allowed for the interception of all existing CSOs discharging directly into the Thames. The detailed review categorised each CSO on the basis of estimated environmental damage (Refer Table 11 in ref 8). To assist this process estimates were prepared for A(low) allowing for the inclusion of different sets of categories to compare the costs. Ultimately Option A(ref) allows for the interception of the recommended 36 unsatisfactory CSOs.

4.1.3 Including the Abbey Mills Link

One of principal conclusions drawn from the revised assessment was that the Abbey Mills CSO could no longer be considered as satisfactory. The options considered with the estimated costs are as described in section 2.1. The estimate for the option based on treatment plant at Abbey Mills was calculated in the previous Treatment Study report (refer Solution Group Report Vol 1, section 8.2.5). All the other estimates were assessed by Amec as part of the feasibility process. The estimate for the preferred option (1A) was reviewed and verified by EC Harris.

The Preferred Option: Referring to section 2.1.4 it is seen that 1a is the most economic option to incorporate interception of the Abbey Mills CSO and is therefore the proposed main refinement to the storage tunnel option. Note that a high proportion of the cost of tunnelling is incurred in launching and recovering of the TBM. This means that the location of the junction of the two tunnels (i.e. the Greenwich shaft) can be flexible without incurring a cost penalty. The required volume of storage is achieved by increasing the diameter of the main storage tunnel from 6m to 7.2m.

The scope of the proposed works for A(ref) (section 2.4)now includes:

1. Main storage tunnel, 7.2m in diameter, 34.5km long.
2. Seven main construction shafts.
3. Abbey Mills link tunnel, 5m in diameter, 4.5km long.
4. Beckton STW pumping shaft and link tunnel 3m in diameter, 1.1km long.
5. Pumping, screening and treatment plant at Crossness based on 15.6m^3/s capacity.
6. Interception of 36 unsatisfactory CSOs.

<u>Notes</u>

<u>*Screens, Treatment, Pump & Power*</u>: Including Abbey Mills in the main scheme will increase intercepted flows by approximately 50% and the pumping and treatment capacity will need to be proportionally increased. The estimates for screens, treatment, pumping and power have been developed from out-turn costs of similar projects by experienced consultants. Previous estimates have been revisited and increased to accommodate this increase in capacity.

<u>*Tunnels & Structures:*</u> EC Harris have reviewed the estimates for Tunnels and Structures based upon a revised more detailed scope and work programme. A detailed breakdown and comparison of both phases, together with the original budget estimate for A(low) calculated in November 2002, is included in reference 4.

<u>*Contingency and Risk:*</u> The allocation of 30% contingency was established following a review of previous risk registers for projects involving significant underground works. This contingency value should be considered to represent the following items:

- More detailed items that have yet to be investigated, e.g. CSO interception structures
- Items that have been neglected or omitted at this stage
- Potential additional cost to items already included but subject to additional cost by a risk being actually realised in the event
- Potential additional cost due to relocation of main shafts to other reasonably optimal sites

Therefore all items of risk and all contingency sums against any work element that is not quantifiable at this stage are covered by this allowance with the exception of excessive additional cost caused by loss of optimal main shaft site due to redevelopment. There is still significant detailed design and investigation work to be carried out, particularly during the design phase. It is therefore recommended that the contingency allowance of 30% on the four main work items be retained at this stage.

A quantitative risk review will be undertaken to review the appropriate level of contingency.

<u>*Land Costs:*</u> Estimates include for the further acquisition of land adjacent to Heathwall PS and the Southwark, Chiswick and Greenwich shafts, together with allowances for temporary occupation of construction working sites and associated compensation costs. Most of the

CSO interception structures will only require temporary occupation of public open space or roads during construction. Some interception structures require the permanent acquisition of land, the costs of which are also included under this section. Estimates for land acquisition have been provided by land surveyors and for compensation from Cascade Consulting.

Resource Costs: This item includes for costs associated with design, including feasibility study, initial investigation, outline and detailed design, planning and environmental studies, Impact Assessment, specialist consultants, project management, construction supervision and procurement.

4.1.4 Other Refinement Modifications

In light of the refinements, the construction programme and the cost estimates were reviewed. The changes of scope to the Tunnels and Structures include increasing the diameter of main shaft at Crossness to 30m and the Beckton shaft to 27m with provision of a building for ventilation. Minor shafts at Heathwall to facilitate CSO interception were included.

These changes have an impact on the following elements:

Power supply and Usage: The latest programme for the duration of CSO tunnel drives is slightly longer than the previous programme. As a consequence power usage has increased.

TBMs: The extended duration of CSO tunnel drives entails a nominal increase in spares and maintenance.

Site Management: The programme review has reduced the resources required.

Main Shafts: Increasing the diameter of the Crossness shaft and adopting a more expensive diaphragm wall method of construction has increased the estimated cost for this element.

CSO Shafts & Structures: This element has increased because of the increase in size of the Beckton Shaft. Consequently diaphragm wall construction is proposed.

Spoil Disposal: There is a nominal increase in spoil disposal costs due to the increased diameter of the shafts at Beckton and Crossness.

Wick Lane CSO: A provisional sum of £5M, based upon an approximate average cost for interception, is included within the Tunnels and Structures element to cover these works.

Estimates for Screens, Treatment, Pumping and Power have also been refined. Screens estimates are based on a 10m^3/sec capacity plant at Crossness and Treatment costs based on a deep bed filtration plant of 15m^3/sec capacity, which allows 50% redundancy to cover for cells off-line for breakdown or maintenance. The Pumping and Power estimate has increased substantially as duplicate pumping stations are now proposed at Beckton and Crossness.

4.1.5 Cost Estimate Updated to 2004

Estimates to date have been assessed to the second quarter of 2002 in line with Volume 1. EC Harris have reviewed the Civil Engineering Construction cost indices to update these costs to the third quarter of 2004 indicating an increase of 11.6%. It is reasonable to apply this increase to Tunnels & Structures, Screens, Treatment and Pumping and Power elements of the estimate as these are based on a significant proportion of civil engineering content. Contingency, Risk and Resource Costs are percentages and therefore increase by the same proportion.

4.1.6 Comparison with CTRL Outturn Costs

A detailed comparison with a similar tunnelling project: the Channel Tunnel Rail Link, has been carried out (see appendix A). Out-turn costs for CTRL are very close to the contract values. The all-in unit rate for CTRL amounts to £10.86M per km, compared with £11.59M per km for Tideway, which is thus 7% higher approximately. This is largely due to the additional excavation for the larger OD and the additional costs associated with constructing a tunnel at greater depth. This comparison realises a high level of confidence that the estimated costs for construction of the proposed main storage tunnel are robust and appropriate.

The Recommended Option – Evolution of Cost Estimates

Option	**Estimated Cost (£M) for Storage Options**										
	Tunnel Diameter m	**Tunnel Volume (000 m^3)**	**Tunnels & Structures**	**Screens**	**Treatment**	**Pump & Power**	**Contingency & Risk 30%**	**Resource Costs**	**Land Costs**	**Total Costs**	**Comments**
A Medium (2002 prices)	9.0	*2,140	1058	60	26	40	355	142	94	1,775	Volume 1 – August 2003
A Low (2002 prices)	6.0	*860	763	32	20	25	252	101	94	1,287	Volume 1 – August 2003
A Medium (2002 prices)	9.0	*2,140	987	60	26	40	334	134	94	1,675	Improved Calculation - May 04
A Low (2002 prices)	6.0	*860	849	32	20	25	278	111	94	1,409	Improved Calculation - May 04
A Refined (2002 prices)	7.2	**1,500	901	48	30	38	305	122	50	1494	Report to Government - June 04
A Refined (2002 prices)	**7.2**	****1,500**	**936**	**32**	**22**	**50**	**312**	**125**	**50**	**1,527**	**Volume 2 - February 05. Cost increase due to twin pumping facilities**
A Refined (2004 prices)	7.2	**1,500	1044	36	25	56	348	139	50	1,698	Volume 2 - January 05

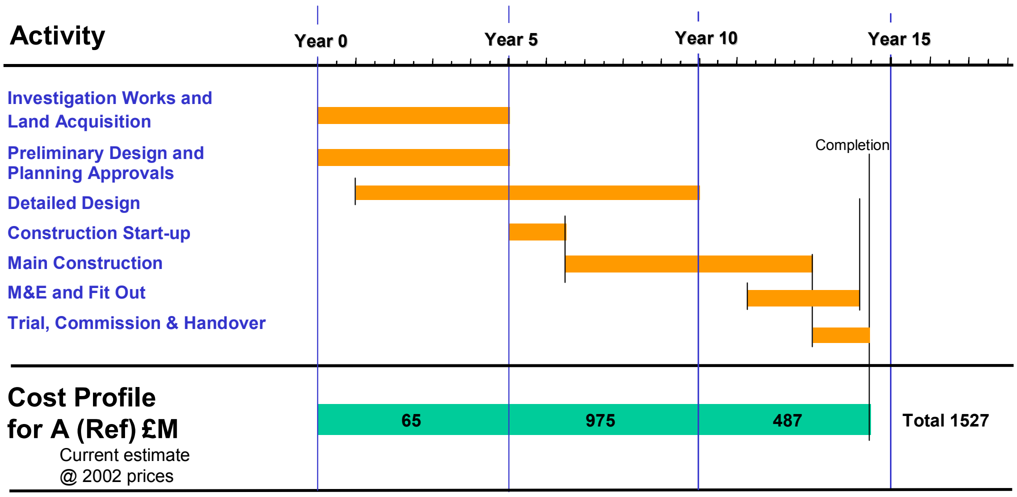
Note - * Tunnel Storage only **Total Storage including Shafts

Thus the cost of the refined Option A(ref) is £1.698B at a cost-base at the 3rd quarter of 2004 and is considered robust.

4.2 Project Programme

4.2.1 *The Overall programme*

Outline Generic Programme - Solution A (ref)

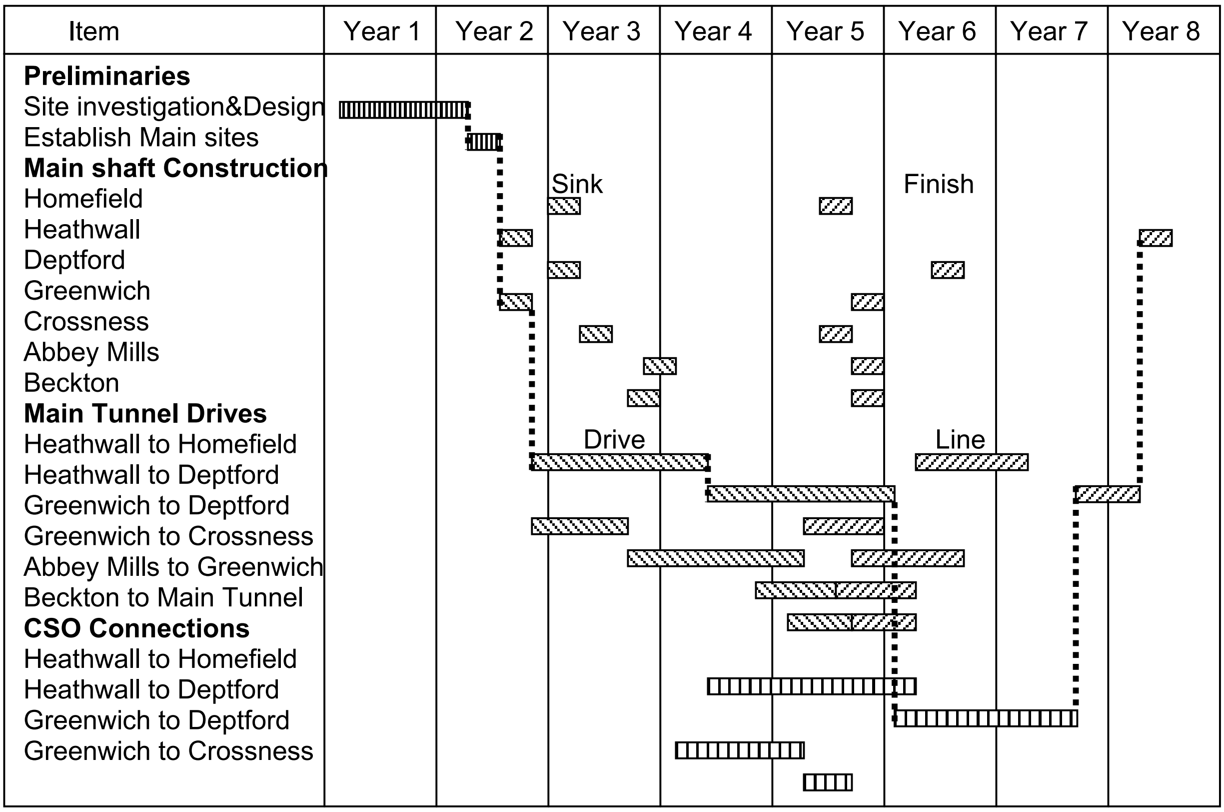


NB Construction Start-up includes: site establishment & the acquisition of TBMs
Main Construction includes: tunnelling, treatment plant and interception structures

4.2.2 *The Tunnel Construction Programme*

The construction programme for the proposed storage tunnel is the critical path activity and was reviewed throughout the refinement stage. The final detail version is included in ref 1.

A simplified bar chart for this baseline programme is included below:



This programme is based upon the main shafts at Heathwall and Greenwich being drive shafts for the main tunnel sections sequentially in both directions. Thus two main tunnel drives are under construction together. The order of work for each tunnel section is:

1. Drive shaft excavated to required depth;
2. Main tunnel drive construction and construction of reception shaft;
3. CSO connections driven from main tunnel to drop shafts;
4. Clean and line tunnel;
5. Shaft finishes.

Combining all these elements makes the critical path for this construction process, as indicated by the dotted line:

1. Drive shafts at Heathwall and Greenwich;
2. Main tunnel drive Heathwall to Chiswick;
3. Main tunnel drive Heathwall to Deptford;
4. CSO connections on Heathwall to Deptford section;
5. Lining to Heathwall to Deptford main tunnel section;
6. Finishes to Heathwall shaft.

It should possible to condense this programme by constructing three main tunnel drives together but this would cause both sets of CSO connections on the longest sections to be on the critical path, thus limiting the overall reduction in construction time.

5 Conclusions

5.1 General

The originally proposed storage tunnel solution as refined in this report remains the only complete solution that can meet all the required objectives. This is Option A(ref).

The review (ref 8) of the potential for environmental damage confirms that only 36 CSOs need to be intercepted. Typically those having low flow or infrequent discharge may be excluded. However the discharges from Abbey Mills and Wick Lane, which were initially outside the scope of this study should be included for interception and treatment.

The most economic and effective manner to include the discharges from Abbey Mills and Wick Lane is to provide a transfer tunnel from Abbey Mills to the main storage tunnel and to augment the volume of the main storage by increasing its diameter from 6.0m to 7.2m.

5.2 Treatment and Pumping

To ensure compliance with the objectives set for DO levels in the river the majority of the intercepted flow must be fully treated before discharge. Over the next ten years it is proposed to upgrade Beckton and Crossness STW, increasing the flow to full treatment of both works. It is proposed to utilise this spare capacity over average flows to treat the intercepted flow from the storage tunnel. This can be achieved by extending the pump-out from the storage tunnel to 48 hours so that flexible use can be made of both Beckton and Crossness STWs.

To achieve this flexibility, similar pumping stations should be provided at each site. This will allow optimum use of full treatment and storm treatment capacity and to provide adequate standby in terms of both pumping plant and treatment process.

In the future because of planned development, average flows to the works will increase thus eroding this spare capacity and reduce the flexibility of the works to treat intercepted flow from the tunnel. Eventually it may prove necessary to further upgrade Beckton and Crossness STWs to maintain treatment capacity.

5.3 Choking and Flushing

The results of the CFD analysis show that for a main tunnel diameter of 7.2m, interconnecting tunnels up to 3m in diameter would not pose exceptional logistic or construction problems. Fortuitously the largest intercepted flow can be accommodated by a 3m diameter, interconnecting tunnel without risk of tunnel choking.

During pump-out the horizontal velocities in the main tunnel will be very low allowing settlement of solids. An effective flushing process will be essential to remove the sediment to prevent the accumulation of noxious and potentially dangerous fumes from the decomposition of biological matter. Flushing of the main tunnel is under investigation using a CFD model.

Early results indicate that high velocities can be generated to re-suspend sediment. The likely preferred method is to empty the tunnel in sections so that volumes of intercepted flow are released sequentially to flush the tunnel. More analysis is required in this area of study.

5.4 Risk

The approval to proceed presents the biggest risk of programme delay and the potential for escalating cost as optimum sites to facilitate the construction of this project are lost to residential and commercial developments.

The project will require planning permission as it is very unlikely to be allowed under permitted development rights. There are various options for the Planning process, but the most favourable appears to be by appointment of a lead authority as it will impact on several

London Boroughs. It is likely that such a large project would be subject to Public Inquiry, however the proposed programme for the Planning process, land acquisition and EIA includes sufficient float to accommodate a public inquiry.

Early acquisition of the required sites for the main shafts is critical for fixing the main route, and therefore the design of the tunnel, to ensure that the Planning and EIA process would be linear. However if Planning approval were granted for a route where the availability of the main shaft sites was uncertain, the adoption of alternative sites could cause the route to fundamentally change. This may invalidate the approval and invoke a repeat of the Planning process, causing a delay of several years.

The principle risks associated with construction of the main tunnel and shafts have been identified using a comprehensive qualitative risk register and are well understood at this stage. The Engineering risks are identifiable and are considered manageable within current technology. However implementation of the CSO interception structures and shafts represents the most significant area of technical challenge and uncertainty.

5.5 Estimated Costs and Contingency

The estimated costs for the proposed storage tunnel option are robust and realistic. The tunnelling costs compare favourably with the out-turn costs for CTRL tunnelling contracts. The refinement studies have improved confidence in the scope of the required works and therefore estimation of out-turn costs.

However it should be appreciated that there are still areas of uncertainty at this stage, which will not be reduced until more detailed evaluations are carried out in the design phase. The contingency applied to the budget costs is thus maintained at 30%. The quantitative risk review will determine the likely range of out-turn costs and confirm the appropriate level of contingency. **The cost estimate for Option A(ref) is £1.698B at current prices.**

5.6 Programme Issues

The baseline programme for the proposed storage tunnel is generally based on two main tunnel drives being carried out simultaneously from separate drive shafts. This gives an overall construction time of approximately 7.5years.

The thorough study of construction logistics has given a detailed understanding of the interdependency of the various work streams. It would be possible to accelerate the programme by constructing three main tunnel dives simultaneously. However this would cause the CSO connections work stream to become critical, thus limiting the potential reduction in construction time overall.

It is technically conceivable to implement the eastern section of the proposed tunnel to meet the requirements of the Olympic bid to resolve the problem of discharges from Wick Lane and Abbey Mills to the River Lea. However it cannot be constructed in time for 2012 if subject to normal planning process.

5.7 Internal Lining

The secondary internal lining may not be necessary to protect the aquifer from contamination, particularly as the external ground water pressure is higher than that of the stored storm water. Excluding the lining would reduce cost, programme and environmental impact.

5.8 Options for Renewable Energy

Pumping out of the intercepted flow will consume a significant quantity of energy, approximately 7GWhrs per year. There are three main options that can be employed to improve sustainability by use of renewable energy sources. These are wind generators, bio fuels for power generation and sludge incineration. Other options such as recovery of hydro-energy or heat recovery from intercepted flows and photovoltaic cells were considered but rejected as they were either too expensive or infeasible.

6. Recommendations

6.1 General

The principal recommendation is that approval be granted to progress the storage tunnel option A(ref), to design, planning, EIA and land acquisition stage. This would allow the Tideway Team to further develop this refined option into the optimal solution, Secure the main shaft sites and obtain planning approval.

6.2 Risk and Contingency

Timely approval to proceed will facilitate acquisition of the required sites for the main shafts and will considerably reduce the risk of escalating cost due to the loss of optimal sites to redevelopment and the risk of delay during the Planning process.

The implementation of the CSO interception structures and shafts represents the most significant remaining area of technical challenge and uncertainty. he proposals for interception are being reviewed and will be reported on shortly. A quantitative risk review is arranged to determine the likely range of out-turn costs and confirm the appropriate level of contingency with more accuracy.

6.3 Treatment

Compliance testing clearly indicates that the majority of the intercepted flow must be fully treated before discharge to the river. This general increase in flow to full treatment during and following wet weather will have a significant impact on the processes at Beckton and Crossness STW. In particular sludge production will increase, probably by 10,000 tonnes dry solids per year. This represents just under 10% of the annual sludge production for Beckton.

The capacity of the sludge treatment stream at both works will require enhancement to meet this new demand. This increase in sludge production can be viewed as an opportunity to produce more fuel for the incinerators and hence generate more power. However the impact of this increase in capacity has not been determined and requires more detailed evaluation.

6.4 Flushing

Sedimentation in the main tunnel is a critical factor in effective long-term operation. Although current analysis of this issue suggests that it will not be a problem, it is recommended that the CFD analysis be continued and that in addition alternative methods to evaluate flushing and cleansing the tunnel be developed, potentially utilising physical scale models.

6.5 Tunnel Ventilation

It is proposed to ventilate the tunnel continuously so that displaced air will be free of odour. Although it may be possible to provide this continuous ventilation by vent columns, as for the majority of existing storm sewers in London, this approach may be ineffective due to the size and depth of the proposed storage tunnel and the distance between ventilation points. It is recommended that an airflow model of the system be created to reveal whether natural ventilation will be acceptable or what capacity of forced air ventilation may be necessary.

7 Appendices and References

Appendix A –

Cost Estimate - Comparison with CTRL - Thames Water Engineering - Sept 2004

References:

Technical Studies

Ref	Title	Consultant or Author	Date
1	Tideway – Refinement of Option A	Faber Maunsell	August 2004
2	Connections – CFD Modelling	Thames Water R&T	November 2004
3	Land & Planning Reports	Cascade	2004
4	Budget Costs phases 5 to 7	EC Harris	2004
5	Renewable Energy Options	National Energy Foundation	October 2004
6	Pumping Study	KSB	December 2004
7	Tideway Storm Event Sampling	Thames Water R&T	December 2004

Supporting Documents

Ref	Title	Consultant or Author	Date
8	CSO Interception Review	Environment Agency	April 2004
9	Interim/Smaller Scale Measures to Alleviate the Environmental Damage Caused by the CSO Discharges	Environment Agency	September 2004
10	Key risks considered in developing a solution for London's combined sewer overflows (CSOs)	Environment Agency	June 2004
11	Use of Tetra Deep-Bed Filtration for Treatment of Wet Weather Overflows	Slack D, Fleming H, Hart J Of Severn Trent Services,	
12	Investigating and modelling the development of septic sewage in filled sewers – a feasibility study	Robert Bachmann, Adrian J Saul, Robert Edyvean of Sheffield University	2004

Appendix A - Comparison with CTRL Outturn Costs

General comparison with CTRL

The predicted tunnelling costs have been compared with the actual contract values for the CTRL Project (London Tunnels). These started in 2002, were recently completed and provide very recent cost data appropriate to such works in the UK.

The Tideway tunnel has much in common with CTRL particularly in the general scale and complexity of the Civil Engineering work required. Both tunnels pass through broadly similar strata in the Thames Basin and similar technologies such as earth pressure balance TBMs are likely to be applied especially at the western end of the Tideway where the depths of the tunnels are similar. The eastern section of the proposed storage tunnel lies deep in the chalk and the CTRL data is likely to be less relevant.

The Tideway tunnel is 7.2m ID (8.7m OD) and 34.5km long. For comparison the CTRL tunnel to St Pancras comprises 17.5km of twin tunnels (total length 35km) each approximately 7.15m ID (8.15m OD) split into three principal contracts as shown below:

Contract/location/Contractor	Principal Works	Approx' Value
C220 - London Portal to Stratford Box. Nishimatsu/Cementation/Skanska JV	15km of bored tunnel with cross passages and two major vent shafts	£145M
C240 - Stratford Box to Barrington Road (Newham). Costain/Skanska/Bachy-Soletanche JV	9.4km of bored tunnel and two major vent shafts	£120M
C250 - Barrington Road to Ripple Lane (Dagenham). Edmund Nuttall/Wayss & Freytag/Kier	10.6km of bored tunnel, 500m of cut-and-cover tunnel structure and one major vent shaft.	£115M
Totals	35km bored tunnel, five large vent shafts and 29 cross passages.	**£380M**

The significant differences between the CTRL tunnels and the proposed Tideway tunnel to be considered when making comparisons between the two projects are given below:

- The proposed main storage tunnel is similar in length and diameter to CTRL, but is generally much deeper. The difference in OD represents 13% additional excavation.
- CTRL tunnel construction is based on 6 drives, carried out more or less in parallel. This efficient approach was possible because of the twin tunnel configuration and therefore offers considerable time and cost savings. Opportunity for parallel working is much more limited for the Tideway tunnel, which is based on two drives being carried out in parallel.
- Because the spoil from the CTRL tunnels is being used as fill on development land close to the pitheads disposal costs are low. Whereas disposal and transportation costs for spoil from the Tideway tunnel will be much higher.
- These are Contractors values for construction of the tunnel works. The costs for design and project management, carried out by Rail Link Engineering, are not included.
- The CTRL estimates given include for 5 large shafts, 29 cross passages, a 500m long cut-and-cover section, track bed and drainage works. The Tideway tunnel needs more substantial works for interception structures, shafts and interconnecting tunnels. The five main construction shafts for Tideway average nearly twice the depth of those for CTRL.
- The Tideway tunnel will be mainly under the riverbed. Advantages in avoiding risks from overlying structures (except the bridges and tunnels) are offset by the geology and hydrology being maybe more difficult.
- The Stratford Box required substantial and permanent dewatering. Thus the CTRL tunnels did not have to include dewatering. The Tideway tunnel is likely to be subject to high-pressure groundwater, particularly for tunnel breakouts.

The Tideway tunnel has a secondary lining plus Screening, Treatment, Pumping and Power, which the CTRL tunnels do not have. This represents a significant extra cost and extension of programme.

Detailed Comparison

EC Harris compared the project costs for the CTRL with the estimate for the Tideway 'Tunnels and Structures'. Cost items that were not covered by the CTRL contracts were stripped out so that a direct comparison could be made, as summarised in the table below:

Item	Tideway - Phase 6 (£k)	Stripped-Out Costs - (£k)	Comments refer below
Site Investigation	9,000	0	1
Main Management and Compound	32,494	25,000	2
Power Supply and Usage	46,597	20,800	3
Jetties	19,525	0	4
TBMs (Main and CSO Drives	49,283	18,000	5
Site Management	55,237	40,000	6
Main Shafts	50,989	26,000	7
Main Tunnel Drives	321,977	245,564	8
CSO Shafts & Structures	97,873	0	9
CSO Tunnel Drives	37,627	0	9
Abbey Mills CSO Shaft & Structure	6,430	0	10
Abbey Mills CSO Tunnel drive	29,633	0	10
Spoil Disposal (inc Landfill Tax)	22,720	0	11
Sub Total	**779,387**	**375,364**	
HO and Management Fee	62,350	24,399	12
Grand Total (excl' Contingency)	**841,738**	**399,763**	

Notes

1. Site Investigation costs covered elsewhere, assumed by Client
2. Main management and compound costs for tunnel and main shafts only retained.
3. Power supply and usage for interconnecting tunnels excluded
4. CTRL spoil disposal to development land, jetties for river transportation not required
5. Main TBMs only required. TBMs for interconnecting tunnels excluded
6. Site management for main tunnel and shafts only retained
7. Shafts are almost twice total depth of CTRL tunnels, approximately 50% cost retained
8. CSO shafts, tunnels and structures excluded
9. Abbey Mills CSO shaft, tunnel and structure excluded
10. Cost of disposal of spoil excluded to reflect CTRL arrangements
11. Reduced to 6.5% to represent tendered rates
12. The following items have been stripped out of the Tideway tunnel costs:

Item	Cost Reduction - (£k)
Forward probing	1,380
Extra gasket provision increased water pressures	6,900
Head interventions for longer drive lengths	10,140
Internal Lining	47,639
Waterproofing membrane	3,150
Total reduction in main tunnel costs	76,413

Conclusions:

Out-turn costs for CTRL are very close to the contract values. The all-in unit rate for CTRL amounts to £10.86M per km, compared with £11.59M per km for Tideway, which is thus 7% higher approximately. This is largely due to the additional excavation for the larger OD and the additional costs associated with constructing a tunnel at greater depth.

This comparison realises a high level of confidence that the estimated costs for construction of the proposed main storage tunnel are robust and appropriate.