Thames Tideway Strategic Study

Steering Group Report

February 2005

Thames Tideway

MAYOR OF LONDON

OFWAT

Environment Agency

Thames Water

RWE Group

Thames Tideway Strategic Study
Steering Group Report

Final Report
February 2005

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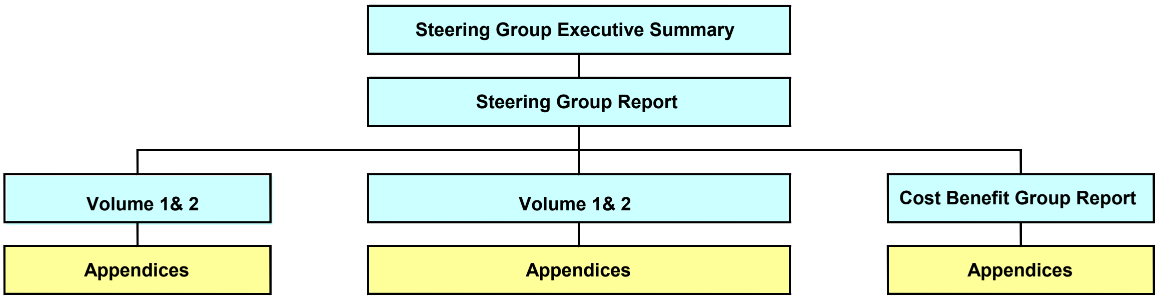
Preface

The Thames Tideway Strategic Study Reports

This is the report of the Steering Group. The Steering Group executive summary has been produced as a stand-alone document. Detailed reports from each of the Working Groups have been produced as separate documents, together with their appendices, as shown below.

Thames Tideway Strategic Study Report Structure



Chairman, Chris Binnie

Thames Tideway Strategic Study

It has been my privilege over the past four years to have chaired the Steering Group of this most important study and I am delighted that we can now publish the study reports.

The Thames Tideway Strategic Study investigated the environmental impact of wet weather discharges from 57 Combined Sewer Overflows (CSOs) and found that some discharge storm water and sewage into the River Thames on average once a week. These discharges cause offensive conditions in the river and on the foreshore, result in an elevated health risk to river users, damage the ecology of the river and occasionally kill large numbers of fish.

They occur during periods of moderate to heavy rainfall when the surface water runoff overloads the sewer system. An estimated 20 million cubic metres of untreated sewage is discharged to the river every year.

An enormous amount of work has been undertaken looking into every aspect of these CSO storm discharges to the Tideway: the causes, the impacts, the legal and policy frameworks, the possible solutions and the cost-benefit aspects. We have needed to extend our initial timetable of three years to allow for the reports to be robust and held up to full scrutiny.

I am satisfied that, based on the original remit of the Thames Tideway Strategic Study, this has been achieved and that a 35km long storage-and-transfer tunnel is the preferred solution out of many options considered. The tunnel would run beneath the Thames from Hammersmith in west London and convey the discharges from 36 of the CSOs for collection and treatment at the Crossness sewage works in east London.

Thames Water (who have provided the funding), the Environment Agency, the Department for Environment, Food and Rural Affairs (Defra) and the Greater London Authority have participated in the study; the Office for Water Services (Ofwat) has maintained an observer status. The views of a number of stakeholder groups have also been sought and considered. Now that the study has been completed, the reports have been circulated to Defra and Ofwat and are publicly available.

Given the likely 15-year timescale to deliver the preferred solution and following advice last summer from Government, it has been decided that the study should also consider extending the range of smaller-scale interim measures that could provide some short-term alleviation much sooner than the preferred solution. A separate report on these options and supplementary information concerning the tunnel solution will be produced during 2005.

I sincerely hope that decisions will be made to resolve this unfortunate legacy to London's otherwise superb sewage network designed by the great Victorian engineer, Sir Joseph Bazalgette. Bazalgette's visionary approach of combined sewers that discharge to the Thames during heavy storm rainfall, instead of flooding the streets and properties of London, is today at the root of a problem that many believe is no longer acceptable in the 21st Century.

The remit of the Steering Group does not include the promotion or the delivery of the preferred solution; that is for others to undertake once Ministers and Ofwat have decided on a way forward. I trust therefore that the work of the study will be the starting point for the realisation of the preferred solution.

Readers of these final study documents will recognise the quality of work that has been undertaken and I would like to take this opportunity to praise and to thank all of the many people who have contributed so much over the past four years.

Professor Chris Binnie
Independent Chairman, TTSS Steering Group

0. Executive Summary

0.1 Background

The Thames Tideway Strategic Study was set up, initially as a three-year project, to assess the environmental impact of intermittent discharges of storm sewage on the Thames Tideway, to identify objectives for improvement and to propose potential solutions, having regard to costs and benefits. These sewage discharges are referred to as combined sewer overflows (CSOs) and are derived from London's combined sewerage system, much of which was constructed in the mid-nineteenth century. The system as designed was not intended to convey and retain large quantities of storm sewage, and allowed instead for the large volumes of sewage generated following rainfall to be discharged direct to the river via the CSOs.

Although continuing improvements have been made to the sewerage and treatment service provided for London, the key question is whether these rainfall-derived wastewater discharges are having an adverse environmental effect on the Thames Tideway, and if so, what practicable measures can be taken to reduce this impact.

0.2 Legal Issues

Thames Water is the licensed sewerage undertaker for the London area. As such, Thames Water has a duty under the 1991 Water Industry Act to provide and maintain a system of sewers. This duty is enforceable by the Secretary of State and the industry's financial regulator, Ofwat.

In addition to this broad requirement, individual discharges of sewage effluent (both continuous and intermittent) are regulated by the Environment Agency by way of 'consent to discharge'. These consents permit the discharge of sewage effluent and are framed to manage the polluting load discharged, and are the detailed means by which UK and European policies (such as Directives) are implemented.

The Urban Waste Water Treatment Directive (UWWTD) and UK Regulations establish general standards for collecting systems (sewers) and treatment works. Compliance with these requirements is an extension of the duties under the Water Industry Act and is similarly enforceable. Government (DETR, now Defra) has produced guidance in 1997 (to accompany the Regulations), which is the basis for the UK interpretation and implementation of the Directive.

0.3 Objectives

The overarching aim of the study (which reflects the overall objective of the UWWTD) is to protect the Thames Tideway from the adverse effects of wastewater discharges. As the Directive sets general requirements, and allows the UK to decide on measures to limit pollution from storm overflows, criteria, in line with the Guidance, have been developed to reflect local needs and benefits to the environment. This leads to three principal objectives:

- To protect the ecology of the Tideway;
- To reduce the aesthetic pollution due to sewage-derived litter; and
- To protect the health of recreational water users.

There are no specific and relevant statutory requirements for water quality of the Thames, although the UWWT Regulations guidance indicates requirements as regards to the limitation of pollution due to litter (aesthetic pollution). It was therefore necessary for the study to establish appropriate water quality standards in anticipation of the Water Framework Directive (WFD), which has similar aims in terms of protecting the ecology.

A specially commissioned study of fish responses to low dissolved oxygen exposure has reinforced some empirical standards based on existing water quality data. These have been used in association with water quality models to estimate an allowable pollution load and support sustainable fish populations.

WHO standards have been used to define a bacteriological threshold above which water users are exposed to 'possible health risk'. This threshold is breached following CSO discharges giving rise to approximately 120 days of possible health risk per year. The objective for any engineering solution is to reduce, or ideally eliminate these 'health risk days' due to the storm sewage discharges.

The study has considered these three objectives as a 'package' in developing the preferred solution option, an approach supported by the 'willingness to pay' assessment.

In addition to the principal objectives, the study has also considered related topics, which would impact on such a major sewerage scheme, particularly one with a very long expected lifetime. These include the impact of climate change, alleviation of sewer flooding and population growth.

0.4 Existing Situation

The study has established that some overflows operate on a frequent basis (some as often as 60 times per year). On average some 20 million cubic metres of storm sewage are discharged annually from all the CSOs, with some individual discharges in excess of a hundred thousand cubic metres. The large quantities of storm sewage containing sewage solids and litter can create significant aesthetic impacts in the river, and increase the health risk for recreational users. The discharges also reduce the dissolved oxygen levels in the river, which on occasion has caused fish kills.

These potential impacts were brought into sharp focus by the storm event on the 3rd August 2004. Whilst the rainfall was exceptional, the substantial fish kill and aesthetic pollution resulted in unprecedented media attention and has entirely justified the existence and efforts of the study.

On behalf of the study, the Environment Agency has assessed the relative contributions of the 57 intermittent discharge points and identified that 36 of these are 'unsatisfactory' in terms of frequency of discharge and/or environmental impact. These 36 comprise the vast majority of the polluting load discharged to the Tideway, and are spatially distributed along its entire length.

The assessment of the operation of the discharges, together with a review of the requirements of the UWWT Regulations and guidance, has raised concerns that substantial parts of the collecting system and some receiving treatment works may not fully meet the requirements of the UWWTD, and associated Regulations. This issue is being considered by Government, taking into account the flexibility allowed by the Guidance and London's specific requirements.

This issue of compliance does not impact on the environmental objectives of the study, or the possible solutions identified, but would determine if action is mandatory and may influence any delivery timescale.

0.5 Potential Strategies

A number of intervention strategies and solutions have been evaluated, namely:

1. Adoption of source control and sustainable urban drainage;
2. Separation of foul and surface drainage and local storage;
3. Screening, storage or treatment at the discharge point to river; and
4. In-river treatment.

The only practicable strategy to fully meet all environmental objectives is the interception of the overflows before they meet the river, identified as strategy 3 above. Strategies 1 & 2 were assessed and discounted as either not practicable or not effective as a 'total' solution. Strategy 4 can only meet some objectives, but is expected to continue to play a role in respect of short-term measures.

0.6 Solution Options

A selection of possible scheme options has been assessed, but the preferred solution is a large diameter storage-and-transfer tunnel, with a limited rate of pump-out known as Option A (ref). This tunnel would run from Hammersmith in the west, largely under the river, to Crossness Sewage Treatment Works (STW) where a dedicated plant to handle the storm flows can be built to augment the biological treatment capacity. A link tunnel to Beckton STW is also envisaged. The flexibility that this offers will permit the maximum proportion of storm flows to be fully treated.

The proposed tunnel would be of 7.2m diameter and provide approximately 1.5 million m^3 of storage capacity; this would not preclude sewage discharges being made from the existing 36 locations at times of exceptional rainfall, but the tunnel is sized that these exceptional overflows will only occur on such a limited basis (approximately once per year) that compliance with the proposed quality standards is not threatened or compromised. If required, additional storage can be added at a future date (for instance to mitigate the impact of Climate Change) by the construction of lateral storage tanks.

The remaining discharges will continue as present, as they do not have a significant impact.

0.7 Cost Benefit Analysis

A comprehensive costs benefit analysis has been undertaken, supported by three separate studies. These comprised a stated preference survey of 1,214 Thames Water customers to evaluate the non-market benefits of the different solutions expressed through respondents' willingness-to-pay for the various environmental improvements the solutions would bring; an environmental costs desk study to evaluate the non-market environmental costs attributable to each solution; and a market benefits study to identify any benefits arising from the solutions that currently have a market value.

The cost benefit analysis revealed that a storage and transfer tunnel option, combined with improvements at the STWs, had the highest net benefits. Subsequent sensitivity testing and switching analysis demonstrated that, even though there is uncertainty around some of the assumptions underlying the Cost Benefit Analysis, the benefits would have to drop to a quarter of those assessed to change the conclusion that the net benefits are positive. A further assessment of the refined solution (Option A (ref)) has subsequently been made, and this has confirmed that this remains the most cost beneficial option.

The extent to which respondents understood the stated preference questionnaire has also subsequently been examined. The responses from this smaller scale study largely confirmed these outcomes in that, although some respondents considered the original willingness-to-pay as somewhat high, the amount that respondents were willing to pay for the Tideway improvements was of a similar order to the expected impact on bills.

In response to concerns regarding the wider context of any surveys, further work is anticipated to establish the possible costs in the context of other investment priorities both for water and environmental improvements and wider societal issues.

0.8 Environmental and Social Outcomes

The environmental outcomes clearly reflect the objectives, and are a result of a reduction of the quantity of untreated and partially treated sewage discharged to the river after completion of the preferred solution.

Specific outcomes will be: the prevention of major falls of dissolved oxygen - this benefits all the biota, but will manifest as both preventing the acute risk of fish kills and the chronic impacts on behaviour, which will enhance the sustainability of fish populations; the reduction in the quantities of pathogenic organisms - this will reduce the potential health risk to recreational water users; and a substantial reduction in the amount of sewage-derived litter deposited on the foreshore and in the river - so avoiding potential health risk and aesthetic nuisance, and supporting public enjoyment of the river.

There is expected to be scope to reduce the extent of risk of sewer flooding under some circumstances.

The project will have benefits and impacts on the development of the Thames Gateway, as the reduction of river pollution will enhance the wider environment of the Gateway development. However, it will also involve the treatment and disposal of the tunnel discharge at the Crossness sewage treatment works and this will need to be sensitively implemented alongside the future sewage treatment needs of the Thames Gateway development. The Strategic Planning Authority (GLA) sits on the Steering Group and is, in principle, supportive of the scheme.

It is clear that full implementation will take many years for the preferred technical option. It is highly desirable to initiate some shorter-term measures, if practicable and effective; to reduce the risk of fish kills and limit the extent of aesthetic pollution due to sewage derived litter.

There will, however, be some adverse impacts of the preferred solution; some may be short term, such as disruption and nuisance during the construction phase; others will be longer term such as the additional greenhouse gas emissions from power use and treatment. A major social issue will be the cost, which will be a significant increase in water bills for many years.

0.9 Costs

The capital cost of construction of the preferred option (tunnel and the associated treatment facilities) is estimated at £1.5 billion (thousand million), with an annual operating cost of £3.2 million (at 2002/3 prices). This estimate becomes £1.7 billion at 2004 prices

Provision of additional treatment capacity and improvements to the treatment standards of several sewage treatment works on the Thames Tideway have been confirmed in Thames Water's final determination of price limits for 2005 and beyond.

0.10 Impact on Customers' Bills

On completion, the average annual sewerage bill is estimated to rise by between £40 and £45 (at 2002-03 prices) over the level it would otherwise reach were the Tideway project not to be implemented. The majority of this increase will take effect steadily over the expected eight to ten year construction period. In the context of the expected 'average water and sewerage bill' by 2009/10 of £261, it would represent a rise of some 17% to over £300.

0.11 Timetable for Delivery

Any major tunnel option would be a substantial undertaking and is expected to require at minimum another 5 years of pre-construction planning, promotion and land acquisition etc. Construction time will depend on the final design but is estimated at about 8 years, – and a realistic delivery timescale could be some 15 years from approval. If, for example, approval were given in 2005, this would suggest completion in 2020, assuming there is no unforeseen planning delay.

The scale of treatment works is also a major undertaking, but Thames Water believes that these can be largely completed by 2013.

0.12 Risks

The study has identified many of the potential risks to successful delivery of the proposed solution, and these fall under four main headings: Planning, Environmental, Engineering and Financial. Further work is in hand to quantify some of these risks and this will be the subject of a supplementary report, expected later in 2005.

0.12.1 Planning

The biggest uncertainty remains the planning risk, and whether the scheme has to be approved following a public inquiry. This could clearly introduce delays beyond the control of Thames Water and its contractors.

0.12.2 Environmental

The environmental risks are that the assumptions regarding (for example) water quality requirements in advance of the Water Framework Directive prove to be insufficiently stringent. Additional improvements would be required to comply with this or other future directives, re-interpretations and revisions, such as obligations arising from the revised Bathing Water Directive. Similarly, the impact of climate change may be to demand that discharges are made less frequently or to a higher quality. The nature of the proposed solution means that these climate change requirements can be accommodated in the future if necessary.

0.12.3 Engineering

Implementation of a major project, such as a 35-km long storage-and-transfer tunnel, is not without risk and challenge, especially in relation to the construction of the interception structures and the proposed depth of the shafts and tunnels. Several studies were carried out by consultants and experts in their field in support of selection and development of the proposed solution to ensure that it is technically robust. Potential risks have been considered throughout the feasibility study and are well documented together with proposals for mitigation. These risks will continue to be reviewed during the detailed design and pre-construction activities.

The ground conditions which may be expected are also well documented. This is not to say that there is no engineering risk, but that at this early stage, the initial concerns have been addressed and contingency included. The considered view is that the engineering risks associated with construction and operation are manageable and within current limits of technology.

0.12.4 Financial

The financial risks are a combination of generic, such as changes to the taxation regime or cost of borrowing, and those specific to the project.

0.13 Conclusion

The Thames Tideway Strategic study has investigated, researched and assessed the operation and environmental impact of wastewater discharges from the collecting system and treatment works on the river. Objectives and possible solutions have been developed which have been subject to cost benefit analysis.

This work indicates that parts of the London collecting and treatment system require improvement to meet one or more of the objectives.

The study has established that the environmental objectives can only be fully met at least-cost by completing both the quality improvements to the treatment works discharges and by provision of a storage-and-transfer tunnel. (Option A ref)

It is for Government to decide whether the preferred option identified by the Study proceeds and at what pace. The Steering Group has received a request for additional investigations to be carried out to inform this decision and to consider smaller scale measures that could bring earlier improvements to the Tideway. This work is underway and will be reported on during 2005.

An outline delivery timetable for the storage-and-transfer tunnel has been developed and confirms that a five-year period of detailed engineering design and planning would be required. Construction could take a further 8-10 years, so overall solution delivery within 15 years is believed feasible.

1. Introduction

1.1 Background to the Project

Water industry investment, and the related changes to water and sewerage charges, are determined by a regular review process (the 'Periodic Review'). These are currently on a five-year cycle. At the last review of water prices in 1999, the Government made it clear that it wished to see the national issue of unsatisfactory storm discharges finally resolved. There has been an ongoing national programme of improvement since privatisation of the water industry in 1989, which has been accelerated over the last ten years and, as a consequence, most major conurbations have had a substantial improvement programme in place or completed. London remained the exception and it was agreed that a review should be carried out of the storm sewage discharges to the tidal River Thames.

There have previously been proposals to address these discharges (such as on the adoption of the UWWTD in 1991) but the cost and disruption has always been considered prohibitive. As a short-to-medium term measure, mobile oxygenation (the Thames "Bubbler") vessels have been deployed to reduce the risk of major fish kills. However, the combination of the adoption of the Water Framework Directive (WFD) and increasing pressure on what are seen as 'unsatisfactory' storm sewage discharges has meant that a thorough review of issues and possible options (and their costs) was timely. The Thames Tideway Strategic Study (TTSS) was set up as a three year project to assess the environmental impact of intermittent discharges of storm sewage on the Thames Tideway, to identify objectives for improvement and to propose potential solutions, having regard to cost benefit. These sewage discharges are referred to as combined sewer overflows (CSOs) and are derived from London's sewerage system. The Thames Tideway is defined as the tidal stretch of the River Thames from Teddington to the seaward limit of the Thames estuary at the Isle of Sheppey, a distance of 111km, but the study is concerned only with the upper and middles reaches between Teddington and Purfleet.

1.2 The Sewerage System

London's sewerage system dates back to before the 19th century and is designed on the "combined" principle; whereby a single set of sewers convey both foul sewage and rainwater run-off to sewage treatment works (STWs) for treatment, prior to discharge to the river. This differs from the more modern "separate" drainage system where there are two sets of sewers, one to convey foul sewage only and the other to collect rainwater for direct discharge to a watercourse. It is normal practice for combined sewerage systems to incorporate overflows in the system, which allows excess flows to discharge directly to a river to prevent flood risk to properties. This is the case with the London sewerage system which, to alleviate flooding, has of necessity been extended over the years and now incorporates 57 CSOs to the Tideway (See main map, Figure 1).

Discharges from the CSOs contain a mixture of sewage and run-off and may be very polluting in nature. Under conditions of heavy rainfall, which has a "flushing" effect in the sewers, the discharges can also contain large quantities of re-suspended sediment, litter and grease washed from the sewers, which can be deposited on the foreshore and give rise to public complaint.

As might be expected, the size and complexity of London's sewage system make it a special case. The original watercourses in London have long since been incorporated into the sewerage system, which means that during periods of rainfall, the massive volume of run–off generated from the large impermeable land area has to be drained to the sewers. (Figure 2)

Over the years, societal changes and the rise in impermeable area have increased the frequency of operation of the CSOs and the quantity of storm sewage discharged, to the point where, on average, discharges from the catchment occur as often as 60 times per year and are frequently caused by moderate rainfall.

The biggest CSO discharges arise from pumping stations, some of which pump the entire contents of the sewer to the river. In these circumstances, this means that although the sewage may be diluted to varying degrees by rainwater, everything that is in the sewer is discharged to the river. For the larger rainfall events, total storm sewage volumes in excess of a million cubic metres per event can be discharged to the river.

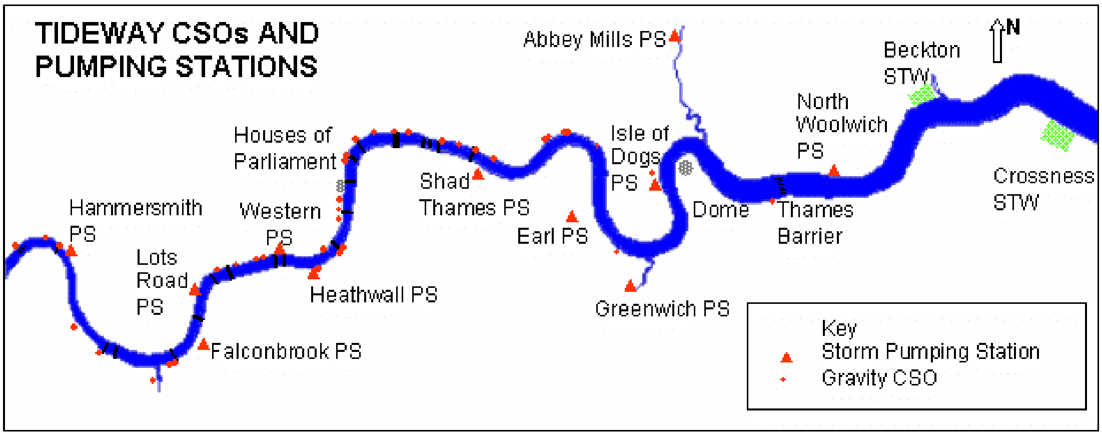


Figure 1 – Tideway Storm Sewage – Outfall locations

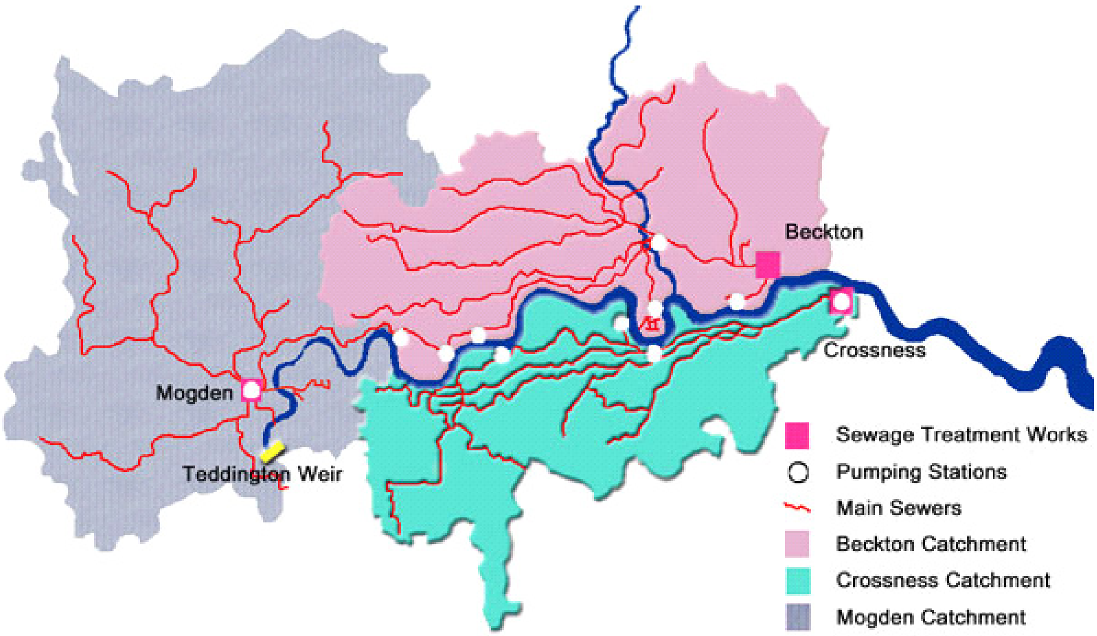


Figure 2 – Sewerage catchments contributing to CSO discharges (Beckton and Crossness plus Mogden for information).

1.3 The Thames Tideway

The Thames river basin does not generate large river flows and these are further reduced by abstractions in the lower reaches of the freshwater river to be used as a potable supply for London. The estuary does not therefore receive large flows of freshwater to provide dilution and protection from pollution. As a consequence of this, there is a very slow seaward movement and water can take three months to travel through the estuary from Teddington to Southend. This makes the upper and middle reaches of the Tideway particularly vulnerable to pollution, since a polluted body of water will not be quickly flushed through the river and will exert its full effect during its residence time in the estuary. The tidal effect will move water up to 15 km on each flood and ebb tide but as little as half a kilometre per day towards the sea.

This can create long slicks of polluted water and also allows solid material to be washed onto the foreshore during the ebb tide where it can be very conspicuous.

1.4 The Sewage Treatment Works (STW) Discharges

Water quality in the Tideway during dry weather is dominated by the discharges from five sewage treatment works operated by Thames Water Utilities, which include the largest works in the country. The principal works are those shown in figure 2 – Mogden, Beckton and Crossness – with contributions further downstream from Riverside and Long Reach STWs.

Although these works operate well under stable dry weather conditions, as with any sewage works, they have a limited capacity to treat the higher flows which arrive at the works during wet weather, and for historic reasons this capacity is less than the norm for sewage works discharging to freshwater. The excess flow arriving at the works passes through storm tanks and so receives a lower standard of treatment, as these provide sedimentation only. These storm tank discharges are generally made at the same time as the CSO discharges and are themselves a significant contribution to polluting load. As the study proceeded, investigations into the performance of these STWs revealed that additional capacity was required and that improvements in both dry and wet weather performance were required if future objectives, designed to protect fish life in the Tideway, were to be met.

1.5 The CSO Discharges

The impact of the intermittent CSO discharges during wet weather is dependent on river conditions, but it can adversely affect the water quality of the Tideway in three main ways:

1. By introducing large quantities of sewage derived solid material into the river that can give rise to offensive conditions both in the river and on the foreshore (Fig 3 & 4);

Figure 3 & 4 - Overflows in operation and sewage-derived litter

2. By producing a fall in dissolved oxygen (DO) concentrations that can drop sufficiently low to result in fish mortality (Fig 5 & 6);

Figure 5 & 6 - Effect of very low dissolved oxygen concentrations: fish kill and dead fish fry

3. By introducing large numbers of pathogenic organisms into the river, which increases the health risk to recreational river users (Fig 7 & 8).

Figure 7 & 8 - Recreational use of the Tideway

The poorer quality discharges made from the STWs during wet weather will generally coincide with the operation of the CSOs and so exacerbate reduction in dissolved oxygen (DO).

To ameliorate the adverse effects of these discharges on DO, and to help protect against a major fish kill, Thames Water and the Environment Agency have an agreement to deploy two oxygenation barges – "Bubbler" and "Vitality" – together with limited land-based hydrogen peroxide dosing plant, to add oxygen to the river during critical times in order to maintain DO levels. This agreement has been in place for many years and although it has largely been considered successful, it was clearly inadequate to prevent the well-publicised fish kill that followed the exceptional storm event of August 2004.

In any event, no preventative or ameliorative actions have been taken to address the potential health risks and the creation of offensive conditions which result from the discharge of sewage and the related solid materials.

1.6 August 3rd 2004

The exceptional weather conditions of August 2004 illustrated most graphically the vulnerability of the Tideway to storm sewage discharges. The resulting aesthetic pollution and fish kill brought widespread media attention and has raised the awareness and the public profile of both the issue of storm discharges and the Strategic Study.

A joint Thames Water /Environment Agency report identified that the fish kill was due to the combination of storm discharges from Mogden STW and the CSOs at the head of the Beckton catchment (principally Hammersmith pumping station). Unfortunately it is not possible to deploy the oxygenation vessels this far upstream, and it was not possible to maintain adequate dissolved oxygen concentrations.

There was in any case no mechanism to deal with either the sewage-derived solids or the potential health risks, and these issues were also widely reported.

1.7 Wider Implications

Although the terms of reference for the TTSS are specifically concerned with the problems of the intermittent discharges, it is important to be aware of other related issues, which may have implications on the project.

The implementation of a solution could represent a significant increase in capacity of the sewerage system, which could have the potential to reduce the risk of sewer flooding and assist sewer maintenance and cleansing programmes. In particular this additional capacity could be an important feature of disaster recovery plans to increase the resilience of London's sewerage system in critical areas. These potential synergies must be investigated and developed further to ensure optimal investment and to maximise realisation of benefits and improvements.

The current operation of the Thames Barrier to improve flood protection during periods of tidal surge or high upland flow has a significant influence on the Tideway river levels, mixing and water quality dynamics. With changing use of the Barrier, there are likely to be potential effects on the operation of any implemented scheme, and whilst these effects are not believed to be material, this issue is kept under review through liaison between Environment Agency departments.

The project has prompted a review of the longer-term suitability of the current water quality objectives (and associated standards) of the Tideway. To achieve the full benefit of addressing the intermittent discharges, improvements to the continuous discharges are also required.

In order for the CSO solution to achieve compliance with all objectives throughout its intended life span, consideration has to be given to the various changes that will occur with time which will affect the ability of the solution to perform adequately. The nature of CSO discharges will alter significantly according to a range of changes including socio-economic to demographic and climatic which in turn will impact on the design specifications required of the solution now, to meet these future changes.

The earliest that any solution could be operational is about 2020. The existing main sewer interceptors are already about 130 years old and any new scheme would be expected to last about 200 years. The furthest ahead that sufficiently reliable climate scenarios was available is 2080 so this was set as the objective to check that the selected scheme was sufficiently future proof.

The substantial population growth in the Thames Gateway should not impact materially on the proposed solution, since the development area will not contribute to the existing CSO discharges and the additional capacity planned at the receiving sewage treatment works will mitigate the environmental impact of the effluent discharge. There is also significant additional housing planned within the catchment area. The impact of this development will be relatively small since the scale of the solution is related to the rainfall runoff and hence the impervious area – which, in a mature urban catchment, is unlikely to change as a result of redevelopment. Indeed, it is possible that the adoption of more sustainable drainage practices may reduce the peak flows discharged to sewer, but the impact is expected to be very small and will only take place over a protracted timescale.

1.8 The Project Structure

1.8.1 The Steering Group and Working Groups

A project Steering Group under the independent chairmanship of Professor Chris Binnie has guided the project. Membership of the Steering Group includes Defra, the Environment Agency, Thames Water and the Greater London Authority with Ofwat represented in an observer status. Reporting to the Steering Group are three working groups on Objectives, Solutions and Cost Benefit (Figure 9).

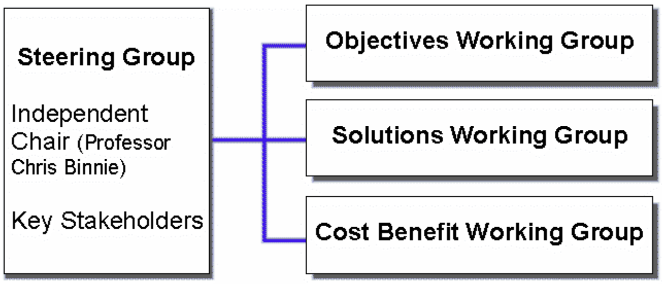


Figure 9 – Tideway Working Group structure

1.8.2 The Working Groups

The role of the **Objectives Group** was to review current and likely future legislation and to consider appropriate objectives to be applied to the Tideway. Suitable standards were then to be defined which would form a basis for the design of potential solutions.

The **Solutions Group** was responsible for identifying strategic options and potential solutions that would be likely to comply with the objectives, carrying out sufficient preliminary design studies to ensure feasibility and costing of each solution.

The potential solutions were then tested for compliance by means of river and sewer modelling techniques and evaluated for compliance with the objectives. This work was carried out by a sub-group of the Objectives Group.

The **Cost Benefit Group** had the function of submitting the potential solutions to cost benefit analysis to determine those that gave the most favourable returns.

1.8.3 Progression of Project

The overall progression of the project can be summarised as:-

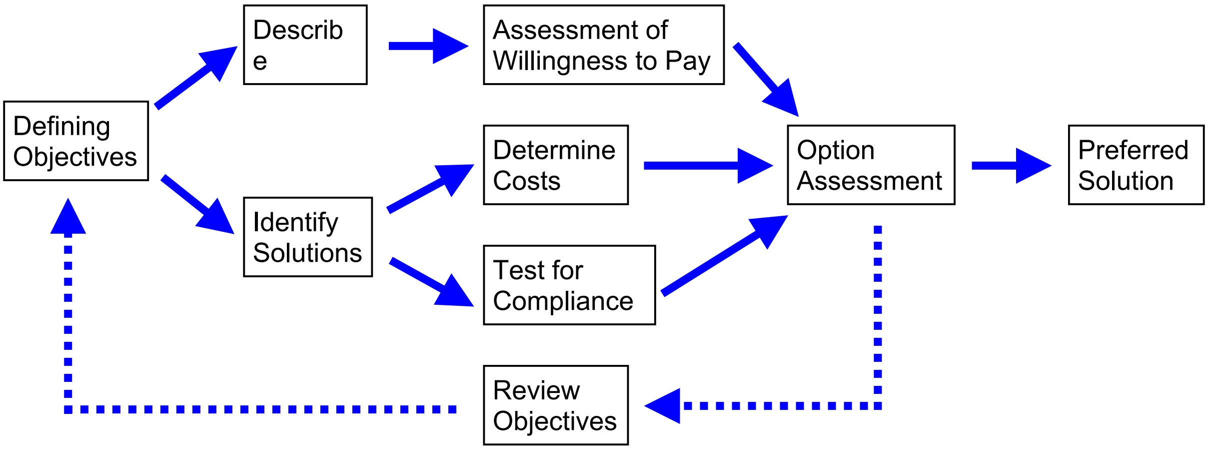


Figure 10 – Project progression

1.9 Project revisions

Inevitably, with a project of this scope, there have been some changes to the initial assumptions made as the project has progressed. The most significant of these was the re-assessment by the Environment Agency of which of the existing CSO discharges are 'unsatisfactory' and hence the inclusion of the discharge from Abbey Mills Pumping Station.

One consequence of these changes, and the continued refinement of the various outputs, is a degree of inconsistency between the early parameters for option selection and those for the study's preferred solution. Whilst this is true for the derivation of solutions, it is more obvious in the sections on cost benefit and compliance testing.

Whilst this inconsistency does make comparisons more difficult, it does not in any way invalidate the overall conclusions nor impact on selection of the preferred solution.

1.10 Water Industry Regulation and Investment

Thames Water is the licensed sewerage undertaker for the London area. As such, Thames Water has a duty under the 1991 Water Industry Act to provide and maintain a system of sewers. This duty is enforceable by the Secretary of State and the industry's financial regulator, Ofwat.

In addition to this broad requirement, individual discharges of sewage effluent (both continuous and intermittent) are regulated by the Environment Agency by way of 'consent to discharge'. These consents permit the discharge of sewage effluent and are framed to manage the polluting load discharged, and are the detailed means by which UK and European policies (such as Directives) are implemented.

New or revised consents generally require investment to meet the new requirements, so this also involves the industry's financial regulator, the Office of Water Services ("Ofwat"). Investment by the water industry is financed through long-term borrowing, but ultimately paid for by water customers. The industry is closely regulated by Ofwat and on a five-yearly cycle –

described as the periodic review – this body dictates the overall charges to customers. The charges are linked to a package of measures to maintain or improve assets, commonly termed the Asset Management Plan (AMP). These ‘AMPs’ also presume five-year cycles and ‘AMP3’ finishes in March 2005, to be followed by ‘AMP4’ in April 2005. The project has been running in parallel with the periodic review process, and price limits for the five years following April 2005 have recently (December 2004) been set.

2. Defining the Objectives

The process of defining the objectives has been an iterative process, whereby an increasing knowledge of the operation of London's sewerage system and the corresponding relevance of the Water Framework Directive (WFD), the Urban Waste Water Treatment Directive (UWWTD) and Guidance, has meant objectives have had to be changed or adapted to make them more appropriate

The Thames Tideway Strategy is working towards a broad aspirational aim:

"To reduce the impact of intermittent sewage discharges, and to further improve water quality in the Thames Tideway, to benefit the ecosystem and facilitate use and enjoyment of the river."

The Group considered all existing statutory requirements, which might be relevant to the achievement of this objective; and concluded that the Urban Waste Water Treatment Directive and the Water Framework Directive were of particular importance.

2.1 Water Framework Directive

The Water Framework Directive was adopted and transposed into UK regulations in 2004. It aims to achieve *good ecological status* or *good ecological potential* for all water bodies by 2015. However, the classification schemes that will be based on biological, hydromorphological, chemical and physico-chemical quality elements have yet to be developed.

2.2 Urban Waste Water Treatment Directive

This is the principal legislative instrument for controlling waste water discharges to the Tideway. In the absence of greater certainty regarding the future provisions of the WFD, it was considered to be of critical importance that full account was taken of the requirements of this Directive when deriving objectives for the Tideway. The overarching objective of the Directive is:

"*To protect the environment from the adverse effects of urban waste water*"

There are five key requirements that are relevant to the Tideway. The requirements and the corresponding extracts from the UWWTD are as follows:

1. **The sewerage system must convey waste water to the STWs for treatment**: *"Urban waste water entering collecting systems shall before discharge be subject to secondary treatment or an equivalent treatment."* (Article 4)

2. **Sewer overflows may occur under conditions of unusually heavy rainfall:** *"Given that it is not possible in practice to construct collecting systems and treatment plants in a way such that all waste water can be treated during situations such as unusually heavy rainfall, Member States shall decide on measures to limit pollution from storm water overflows."* (Footnote)

3. **Measures shall be taken to limit the pollution from sewer overflows:** see footnote in 2 above

4. **The STWs must perform sufficiently under all normal local climatic conditions :** *"Urban waste water treatment plants are designed, constructed, operated and maintained to ensure sufficient performance under all normal local climatic conditions:"* (Article 10)

5. **The sewerage system and the measures taken to limit pollution from the CSOs, must be undertaken in accordance with the best technical knowledge not entailing excessive costs:** *"The design, construction and maintenance of collecting systems shall be undertaken in accordance with the best technical knowledge not entailing excessive costs, notably regarding:*

    - *Volume and characteristics of urban waste water,*
    - *Prevention of leaks,*
    - *Limitation of pollution of receiving waters due to storm water overflows"* (Annex 1 A)

The task of the Objectives Group was to develop appropriate objectives to ensure that these specific requirements and the overarching objective of the Directive are met.

2.3 Assessment of CSO Discharges

The history of the frequency of operation of the CSOs and the adverse environmental effect that the discharges produce raised questions regarding the sufficiency of measures to meet the requirements of the UWWTD.

In order to gain a more comprehensive picture of the operation and impact of the CSOs, a detailed assessment was made of each of the 57 outfalls. This assessment utilised information relating to historical records, visual observations and modelling data. The detailed results of the study are provided in Appendix 1 of the Objectives Group report, but the main conclusions are:

- Of the 57 CSOs, 36 cause significant adverse environmental impact;
- Of these, 28 discharge more frequently than 12 times per year, and 20 discharge more frequently than 36 times per year;
- Within the 36 causing an adverse impact, 35 cause significant aesthetic pollution.

From this additional information, it became apparent that the principal means to achieve the environmental objectives would be to reduce the frequency of operation of the CSOs and to take more effective measures to limit pollution. A benefit of this approach would be to remove any doubts about meeting the requirements of the UWWTD.

2.4 Reduction in Frequency of Operation

The Directive acknowledges that, during situations such as unusually heavy rainfall, it might not be possible to treat all waste water and that storm overflows may occur. No definition is given in either the Directive or the Guidance as to what might be considered as unusually heavy rainfall. The occurrence of frequent, prolonged and intense rainfall in the London area is not unusual. There are, however, several rainfall events per year that are of sufficient intensity or duration to be considered as unusual. Therefore, it seems reasonable to consider "unusual" as something that might occur several times per year, but not several times per month.

Given the existing high frequency of discharges from many of the CSOs, it is necessary to reduce the frequency with which discharges occur.

2.5 Limitation of Pollution from the CSOs

The Directive requires Member States to decide on measures to limit pollution derived from CSOs; and the UK provides details of what these measures might be in the Guidance document.

Appendix 8 (i) of the Guidance proposes the use of a formula for calculating minimum acceptable forward flow at overflow points in the sewerage system. This formula (referred to as Formula A) takes account of the contributing population, dry weather flow and trade effluent flow in the sewer. Although this formula is widely used as a design parameter for CSO operation, it was never intended for use in a large complex network such as London. It is of interest to note, however, that London's system fails to meet the broad principles of Formula A by a wide margin; and that to comply with the formula, would require the enlargement of every one of the 10 intercepting sewers, as well as many of the trunk sewers. This would clearly not be the most cost-effective method of dealing with the CSO problem.

Where the use of Formula A is inappropriate, section 5.5.2 of Appendix 8 (ii) of the Guidance allows for flexibility on a case by case basis. Since the principal objective of the Directive is to prevent adverse environmental impact from the discharge of waste water, it would be compatible with these aims, if the measures taken to limit pollution were to be defined in terms of an acceptable level of impact from the CSO discharges. Standards were therefore derived to cover the three areas of environmental and social impact caused by these discharges:

- to reduce the aesthetic pollution due to sewage-derived litter;
- to protect the ecology of the Tideway; and
- to protect the health of river users.

2.5.1 Limitation of Aesthetic Impact from Sewage Derived Solids

An estimated 10,000 tonnes of screenable sewage derived solids is discharged by the CSOs to the Tideway each year.

The assessment of the impact of the CSO discharges showed that 35 caused significant aesthetic pollution and the Guidance states that unsatisfactory CSOs should receive screening prior to discharge in order to limit the pollution caused.

Objective: To reduce the frequency of operation and limit pollution from those discharges which cause significant aesthetic pollution, to the point where they cease to have a significant adverse impact.

2.5.2 Limitation of Ecological Damage

In the absence of WFD standards, or other recognised criteria, the TTSS group developed a series of DO standards that will deliver a sustainable fish population in the Tideway.

The standards were developed from considerable amounts of data collected from a network of Automatic Quality Monitoring Stations (AQMS) along the Tideway that continuously record water quality information such as DO. These were derived in accordance with the recommended methodology of the Urban Pollution Management Manual, for addressing intermittent discharges, with DO concentrations defined in terms of a return period and duration.

These standards are more realistic than single percentile-based standards commonly used in setting river quality objectives and are shown in table 1 below.

Dissolved Oxygen (mg/l)	Return Period (years)	Duration (tides)
4	1	29
3	3	3
2	5	1
1.5	10	1
Note: The objectives apply to any continuous length of river $\geq$ 3 km. Duration means that the DO must not fall below the limit for more than the stated number of tides. A tide is a single ebb or flood. Compliance will be assessed using the network of AQMS stations.		

Table 1 DO Standards for the Tideway

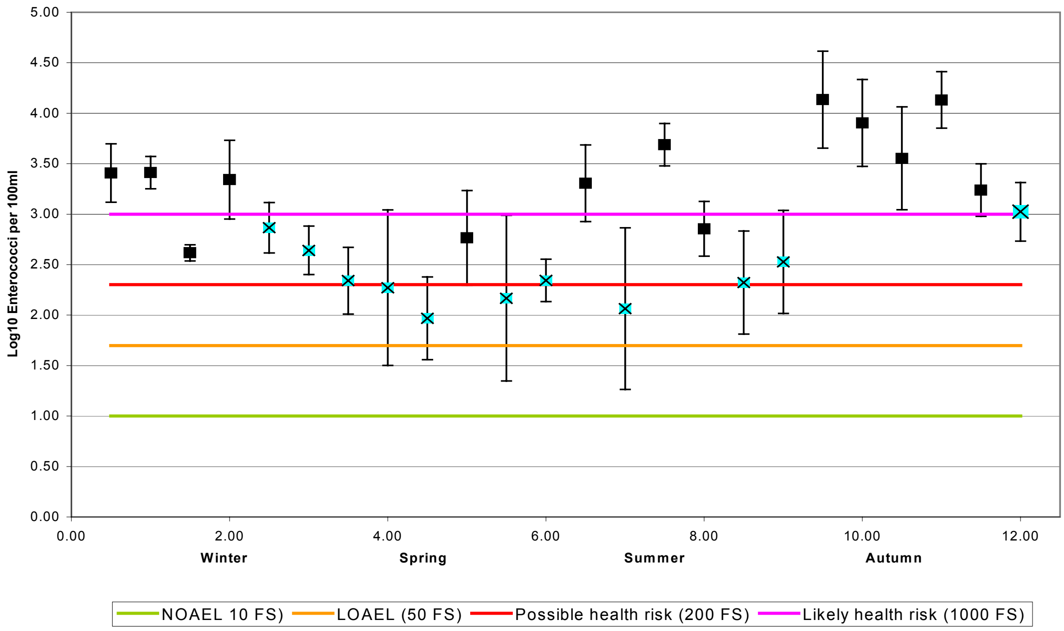
Suitability of these standards was confirmed by research into the dissolved oxygen requirements of a range of fish species found in the Tideway.

Objective: To limit ecological damage by complying with the DO standards specified in table 1

2.5.3 Limitation of Adverse Effects on Health Risk

The section of the Tideway considered by the TTSS is not a designated water under the EC Bathing Water Directive, yet 3000-5000 people practice water-based recreation on the Tideway each week and it is important that due consideration is given to the protection of all river users, including those working in this environment.

Two-weekly surveys were carried out between 1999 and 2002 to determine the impact of CSO spills on pathogen levels in the Tideway. Figure 11 shows data from surveys carried out in 2002 plotted against WHO standards. Data marked as blue squares are samples that were taken during dry periods when there were no discharges up to 2 days prior to sampling. These points fall below the '*Possible Health Risk'* threshold. This is despite the large volumes of treated sewage effluent discharging from the sewage treatment works. The black squares represent sampling occasions during wet weather, and indicate that potential health risks for people who are immersed and/or swallow polluted water is elevated as a result of CSO discharges.



Where FS is 95%ile faecal streptococci (equivalent to enterococci on y-axis) per 100ml of sample

Figure 11 Enterococci concentrations in Tideway during 2002

The surveys also demonstrated that pathogen levels remain at high risk to human health for approximately 2 days after a discharge. With weekly discharges from CSOs, this equates to approximately 120 days of elevated risk per year as a result of CSO discharges. The London Port Health Authority, which is responsible for matters concerning public health in the Tideway, has stated that "the present situation regarding the CSO discharges represents a potentially serious threat to public health."

Objective: To help protect river users by substantially reducing the number of 'elevated health risk' days following CSO discharges.

2.6 Implications of BTKNEEC

Annex 1 of the UWWTD states that '*The design, construction and maintenance of collecting systems shall be undertaken in accordance with the best technical knowledge not entailing excessive costs (BTKNEEC), notably regarding:*

- *Volume and characteristics of waste water,*
- *Prevention of leaks,*
- *Limitation of pollution of receiving waters due to storm water overflows'*

This provision is seeking to ensure that the best possible technical knowledge is used to prevent environmental damage being caused from waste water discharges, up to the point where further improvements to the level of technical knowledge applied leads to an excessive cost compared to that of a lower level. It is a comparative test and does not allow a scheme to be discounted solely on grounds of cost, but when considering alternative schemes, account must therefore be taken of the need to evaluate costs in the context of the technical knowledge being applied

Objective: To comply fully with the requirements of BTKNEEC.

2.7 Climate Change

Any solution to the CSO problem must have sufficient flexibility to accommodate the anticipated effects of climate change. Given that the current drainage system of London has lasted 130 years, it is anticipated that an engineered solution will have a similar life and so needs to accommodate the likely climatic impacts predicted by the latest models. Although the combined drainage area of London is already fully developed, account must also be taken of any foreseeable socio-economic or demographic changes that could impact on solution options.

Objective: To ensure that a solution has sufficient flexibility to accommodate future effects brought about by climate change and other factors.

2.8 Summary of Objectives

The proposed objectives can be summarised as:

- **To reduce the frequency of operation of those discharges that cause significant aesthetic pollution or to limit the pollution caused, to the point where they cease to have a significant adverse impact.**

- **To limit ecological damage by complying with the DO standards specified in table 3, which were developed from historic water quality data, supported by fish studies and based on UPM standards.**

- **To help protect river users by substantially reducing the number of 'elevated health risk' days following CSO discharges.**

- **To comply fully with the requirements of BTKNEEC.**

- **To ensure that a solution has sufficient flexibility to accommodate future effects brought about by climate change and other factors.**

3. Identifying the Solutions

3.1 Scope

The Solutions Group investigated the strategies and options to reduce the adverse effects on the tidal waters of the River Thames, caused by the discharge of storm sewage via CSOs from the gravity sewers and pumping stations of central London. The recommended solution was tested against the requirements from the Objectives Group and was refined so as to comply fully with the required objectives.

3.1.1 Link to objectives

The complex nature of the Tideway and the interconnected nature of the many points of discharge has meant that the conventional improvement of individual discharges to achieve objectives ceases to be a practicable approach. Rather, it has been recognised that the network capacity should be approached as a whole and that either the discharges are to be made much less frequently (at the same quality) or their polluting impact is to be greatly lessened if discharging at a comparable frequency. This realisation led to the investigation of appropriate strategies as listed below.

3.1.2 Overseas comparison

A desktop assessment of overseas projects and experience was made. As a broad generality, where there are comparable problems elsewhere in the world, then the approach taken has been to intercept the polluting flows followed by storage and transfer to treatment. Projects in place include Chicago, New York, Paris, Hong Kong, Tokyo, Osaka and many others are in preparation like Bangkok, Bilbao, Toronto, Dublin and Glasgow. Whilst this is a useful indication, it clearly does not preclude the application of different approaches tailored to local (and perhaps unique) circumstances.

3.2 Strategies

A number of strategies were considered to achieve the long-term objective of sufficient and permanent improvements in the water quality of the upper and middle tidal reaches of the river Thames. These strategies may be grouped into four potential areas along the route of storm water from rainfall to flow in the river:

1. Before the rain water enters the sewerage system
   e.g. source control; Sustainable urban Drainage System (SDS)

2. Within the sewerage system
   e.g. separation, in-line storage (attenuation), new on or off-line storage tanks

3. At the interface between the sewers and the river (i.e. the CSO outfalls)
   e.g. screening to remove litter; new storage; return flows to treatment

4. In the river itself
   e.g. more injected oxygen from river craft or riverside hydrogen peroxide dosing of discharges

3.3 Evaluation of Strategies

3.3.1 Strategy 1

The catchment is very mature and serves a very densely urbanised environment, which is at least 45% impermeable. It is therefore very difficult to apply source control techniques to the majority of the sewerage catchment, although there may be limited opportunity in the uppermost reaches of the catchment. However, any extra storage provided in these reaches would be least effective in terms of the level of pollution intercepted. This water contains little or no suspended solids and reaches the river when continued spillage has the least effect on water quality. It would therefore offer very limited benefit.

SUDS techniques have been successfully employed in many new developments and involve the use of permeable surfaces to allow water to infiltrate into the ground and storage systems to collect and store excess water in lagoons, where evaporation and ground infiltration take place. Incorporation of these techniques into existing highly developed areas is not normally possible due to the excessive costs involved in replacing ground surfaces and the lack of available land to provide for storage and attenuation of flows. There are also severe constraints on the use of these systems where the underlying strata are impervious as in London.

The widespread retrofitting of SUDS techniques in central London is not considered to be technically feasible, and this was confirmed by an independent consultant's report. (Solutions Volume 1) Even if the retrofitment is practicable, the installations require a discharge route, and disposal routes for surface water flows are scarce or not available, because in most cases the natural land drainage (rivers) have become the sewers. Therefore, the strategy of preventing storm water from flowing through the sewerage system by source control or SUDS techniques is not considered viable.

3.3.2 Strategy 2

The construction of an entirely new separate sewerage system would only be possible at extreme cost and disruption over a very long timescale. It is also unlikely to provide a complete solution to the storm pollution problems of the Tideway, as surface water runoff will include its own pollutants. It also cannot be guaranteed that the systems will remain separate over an extended period due to continual redevelopment and misconnections.

The existing system, although sufficient for dry weather flow, becomes overloaded very quickly during rainfall events. Therefore there is very limited opportunity to utilise attenuation within the sewerage system. The construction of on or off-line storage in discrete units throughout the existing system would be very disruptive. A far larger volume would have to be created as the CSO flows become relatively insensitive to changes further away from the river. Emptying of these additional storage volumes would be problematic as the drain-down flows would accumulate and overload the existing system. Hence dedicated additional sewer capacity would have to be provided to accommodate these flows.

Therefore Strategy 2, which includes separation, attenuation within the sewerage system or attenuation in new on or off-line tanks, is also not regarded as generally viable.

3.3.3 Strategy 3

It has been concluded that only solutions developed within Strategy 3 could realise the objectives by providing intervention at the interface between the sewers and the river.

Potential solutions within Strategy 3 have been investigated and costs estimated in outline. This exercise has revealed that there are only a few practical engineering solutions, which are likely to realise the desired levels of improvement at reasonable cost. Several of the potential solutions have been evaluated.

3.3.4 Strategy 4

Strategy 4 cannot be considered a preventative strategy in that once the sewage has reached the river, the polluting effects can only be ameliorated. This reflects the current practice of oxygenation which does not address the aesthetic and health risk issues. As such, it cannot meet the adopted environmental objectives. However, this is being re-examined as part of a wider review to determine what short-term measures may have some beneficial effect.

3.3.5 Strategy assessment

The following Table 2 describes how the various strategies were assessed, showing disadvantages and costs

Strategy	Description	Disadvantages	Cost
1. Before the System	Source Control SUDS	Lack of suitable surface sites Fragmented storage not efficient	Not feasible to cost
2. In the System	In/off–line attenuation tanks Separation	Fragmented storage not efficient Cost Disruption	£5bn - £12bn
3. At the CSOs	Storage and transfer to treatment	Preferred Option	£1.5bn - £4bn
4. In the River	Oxygenation Dosing	Litter/Health Risks Unaffected Current Practice -Not a true Strategy	

Note £1bn = £1,000,000,000

Table 2 – Assessment of potential solution strategy

3.4 Potential Solutions

Development of the proposed solution was carried out in two stages:

1. Investigation of a wide range of potential solutions to determine the most appropriate solution;
2. Refine proposed solution.

Between these two steps the scope changed appreciably by the inclusion of two other major discharges and the assessment of some of the minor discharges as no longer needing to be addressed.

3.4.1 Stage 1: Determine appropriate solution

The concept of interception at the CSO locations to storage and then transfer to treatment represents the most promising solution and it is notable that it is broadly this approach that has been adopted to solve similar problems elsewhere in the world. A wide range of potential solutions under the umbrella of this strategy was assessed.

A series of 1200 recorded storm events over a 20-year period was analysed to evaluate the values 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 solution options comprise three key elements:

1. **Interception of the flow** – Control of interception of the flow and bypass to the river.

2. **Storage and/or transfer of flow –** This entails retention of the flow and/or transfer for screening or treatment.

3. **Treatment** – Treatment consists of screening to remove larger sewage solids as a minimum. For potential solutions that include storage, primary treatment can also be applied. Secondary treatment may only be viable up to a limited capacity.

All the potential solutions described below are based on a combination of these three key elements and most of them are designed for the three different levels of intervention. With the exception of Option H, all solutions include for the interception of all the CSOs between Hammersmith in the west and Crossness STW in the east. Whilst this view has subsequently been reappraised such that only a selection of the discharges need to be addressed, the relative contributions from the CSOs is such that tackling those of greatest concern still requires a large storage and/or transfer capacity. Put another way, the removal of the CSOs of lesser concern does little to reduce scope of the solution required. This is explained in Volume 2 of the Solutions Group report.

A: **Storage** – CSO flows intercepted along the Tideway, stored within a tunnel and pumped out at controlled rate for treatment.

B: **Transfer** – CSO flows intercepted to a tunnel and carried downstream to a high capacity pumping station and screening plant for discharge to the lower reaches of the Thames.

C: **Multiple Screened outlets** – multiple, purpose built pumping and screening stations would be connected via a collection and distribution tunnel, which would intercept flows from the CSOs.

D: **Multiple Screened outlets with storage** – a hybrid of A and C, incorporating a second tunnel to store the first flush of storm water that would be stored and pumped out for treatment at the sewage works.

E: **Storage Shafts** – large storage shafts constructed in the foreshore of the CSOs incorporating a static screen whereby two thirds of storm water is screened and returned to the river and the remainder is pumped back into the sewerage system for treatment.

F: **Screening at Individual CSOs** – installation of screening plant immediately adjacent to or upstream of the CSO discharge locations.

G: **Displacement** – option based on a conduit normally left full and discharging to a large wetlands area.

H: **West London Scheme** – initially formulated as the first phase of Option A, targeting at the western end of the Tideway to achieve the greatest benefits from a given level of investment.

H+ Was also developed, as a variant of the West London Scheme, as a combination of measures based on H that would enable compliance with the litter objective.

Although these potential solutions are listed with apparent equal status, it should be noted that some only address part of the objectives. Options B, C and F are essentially only screening and make virtually no contribution to improved water quality. Option H is effectively only the western half of Option A and does not intercept any polluting flows in the middle reach of the river. Option H+ is a variant of H to include known litter issues in the middle reaches.

3.4.2 Feasibility Assessment and Compliance Testing

Options A to H were initially assessed for feasibility, and it rapidly became apparent that options E, F & G were not practicable to construct (see table 6 below). No further development of these options was carried out. The compliance testing then proceeded in two phases; firstly, the potential solutions that were initially identified as being feasible by the Solutions Group were assessed to determine compliance with the three components of the objectives. These solutions were Options A (low, medium and maximum), Option B (maximum), Option C (maximum), Option D (maximum), Option H and Option H+. This initial work fed into the cost-benefit assessment and helped identify Option A (low) as the most promising solution (This phase also identified the need to make improvements at the treatment works to achieve full compliance with the proposed objectives). Secondly, the testing was applied iteratively to refine the 'package' of solutions, including the transfer of Abbey Mills PS flows to storage, to ensure that the optimum solution that meets all requirements was eventually selected and costed.

3.5 Phase 1 testing

3.5.1 Reduction of sewage-derived litter

The reduction of litter is linked to BTKNEEC rather than an absolute measure. However, some benchmark of anticipated reduction was required, and the measure of performance used to determine compliance with this objective was the requirement that at least 80% of the annual discharge should be improved to the equivalent of 6mm mesh screening. All of the potential solutions utilise 6mm screens to achieve the removal of solid material and calculations were made for each solution to determine whether this objective would be achieved. Table 3 gives the results of these calculations, from which it can be seen that all solutions, excepting the partial Option H meet this objective. If Option H is augmented with additional screening schemes into Option H+, it can give borderline compliance with this objective.

Potential Options							
A low	A med	A max	B max	C max	D Max	H	H+
81%	97%	100%	100%	100%	100%	48%	79%

Table 3 - Percentage reduction in sewage derived litter for each potential solution

3.5.2 Microbiological quality & health risk

Although no objective has been defined in terms of compliance with microbiological quality standards, an assessment has been made, for each feasible solution, of the reduction in days when the river is subjected to increased levels of health risk due to the operation of the CSOs. It has been calculated that, on average, with the CSOs discharging at their present frequency, elevated health risks occur for 120 days per year. This assessment has taken into account the different levels of recreational activity that take place in different reaches of the river and has applied weighting factors to arrive at a figure, which gives the mean reduction in health risk days for each solution. Potential Option C is a screening-only option, which doesn't provide any treatment and therefore fails to provide any reduction in health risk. Potential Option B, whilst not providing treatment, does convey the CSO discharges away from the key recreational reaches and Options A and D achieve this as well as providing for treatment of the discharge.

Potential Option							
A low	A med	A max	B max	C max	D max	H	H+
95%	99%	100%	78%	0%	95%	26%	26%

Table 4 - Percentage reduction in health risk days

3.5.3 Compliance with Dissolved Oxygen standards

Compliance testing against these standards involved extensive use of mathematical modelling of DO concentrations in the Tideway, and the compliance testing procedure was designed primarily to test differences in compliance with the DO standards between proposed solutions. Two estuary water quality models were used in the compliance test procedure; Quests 1D and Tideway-2DV developed by WRc and HR Wallingford respectively. In addition, a Thames Water sewerage model based on InfoWorks was used to produce flow and quality distributions for the CSO discharges that were fed into the estuary models.

For the period 1989-2002, the largest rainfall events were identified (total 62) and modelled in accordance with a standardised procedure. Using the return periods of the DO standards, the number of allowable breaches of each standard between 1989-2002 was calculated. By examining the modelled DO profile in the river after each event, it was determined whether a standard had been breached for each solution. The results of all the events for each solution were aggregated to see if the allowable breaches had been surpassed, hence determining DO standard compliance.

3.5.4 Improvements to STWs – proposed AMP4 standards

The initial compliance modelling indicated that improvements would be required to the STWs in order to achieve compliance with the standards, and that dealing with CSO discharges in isolation would not be sufficient to ensure full compliance. There were two suggested areas of improvement for the STWs.

- A reduction in dry weather loads (oxygen demand) from the STWs discharging to the middle reaches.
- A reduction in oxygen demand due to increased treatment capacity at the STWs (which has the effect of a reduction in the amount of storm sewage discharged).

To achieve both of these requirements, the Environment Agency proposed a revised set of standards for inclusion at the periodic review. For the purposes of this report, these standards are referred to as AMP4 conditions as distinct from the existing standards, which are referred to as current conditions.

3.5.5 Key Points from phase 1 compliance testing

- Options A (low, medium and maximum), give compliance with all of the objectives provided that the AMP4 improvements to the sewage treatment works are in place and either secondary treatment of the tunnel discharge or improvements to Long Reach are provided.
- Option B complies with the sewage litter objective, provides a worthwhile reduction in health risk and with AMP4 improvements, was assessed as marginally failing one of the DO standards in the middle reaches. However, due to the impact of the tunnel discharge having no treatment provision within this design, this option was not modelled further because, at this stage, results from the cost benefit study suggested that even if Option B was fully compliant, it would not be ranked highly in cost benefit terms.

- Option H gives marginal compliance with the DO objectives with AMP4 and Long Reach improvements but performs less well on the litter and health risk objectives, and did not achieve DO standard compliance in the middle reaches where it can offer no CSO improvement . This solution could be up-graded to Option H+ and would then marginally comply with the sewage litter objective.
- Option C complies with the sewage litter objective but gives no reduction in health risk. As a screening-only option, option C affords little improvement in regard DO standards and is therefore non-compliant with the DO objectives.
- For Option A (low), there is no worthwhile improvement as regards dissolved oxygen to be obtained by increasing the tunnel size beyond the low level of intervention. There is however some differentiation in terms of litter and health risk reduction.
- STW improvements (AMP4 + Long Reach) are essential to approach compliance with the adopted DO standards and are almost sufficient to achieve compliance with DO objectives without any CSO scheme. However, this cannot address litter or microbiological requirements, and failures of DO standard 1 (4mg/l) still occur unless a CSO solution is also implemented.

	Compliance with Aesthetics Objective	**% Reduction in Health Risk Days**	**Compliance with DO Standards (AMP4)**
Baseline	NO	0	NO
Option A	YES	95	YES†
Option B	YES	78	Marginal‡
Option C	YES	0	NO
Option D	YES	95	Marginal‡
Option H	NO*	26	Marginal

Table 5 - Summary of compliance testing

Note that the above table assumes that the 'AMP4 standards' for STWs have been implemented. Additionally:

† Option A requires either secondary treatment of tunnel discharge or Long Reach improvements to comply with DO standards

‡ Options B, D and H require either secondary treatment of tunnel discharge or Long Reach improvements to achieve marginal compliance with DO standards

All potential solutions were subject to risk assessment. It was concluded that, with the exception of interception of CSO flows to a storage tunnel, all other strategies and potential solutions were found to have significant or insurmountable engineering challenges or were far more expensive and disruptive to implement. Option A, the storage tunnel, is the only feasible approach as it does not involve any insurmountable issues and offers the best compliance at reasonable cost.

The principal disadvantages of the other options are listed below in Table 6:

Option	Disadvantages	Cost
B	Extreme peak power requirements Screening only, treatment infeasible due to high flow rates Does not comply with DO or pathogen objectives	£1.2bn – £2.7bn
C	High disruption in central London Screening only, in underground bunkers Operation difficult and costly Does not comply with DO or pathogen objectives	£1.5bn - £4.5bn
D	High disruption in central London Twin tunnel, high cost Complex interception arrangements Operation difficult and costly Does not comply with DO objectives	£1.9bn - £5.0bn
E	Extreme environmental impact on river foreshore Operation difficult and costly Connecting tunnel required anyway	£1.5bn - £3.5bn
F	Intolerable disruption at most locations Extreme cost Screening only Does not comply with DO or pathogen objectives	Approx £12bn
G	No suitable site available for constructed wetlands Extreme hydraulic difficulties, requiring pump assist High energy use	Approx £2.7bn
H	Treatment site in London Remaining CSOs discharge unscreened and untreated Does not comply with DO or pathogen objectives	£1.3bn

Table 6 – Principal disadvantages of the other options

4. Cost Benefit – Evaluation Studies

The Cost Benefit Working Group was originally set up to design and manage a series of studies to enable the relative assessment of the cost and benefits of the different CSO solution options identified by the Solutions Group. The remit of the group was subsequently extended to consider both CSO solution options and the Sewage Treatment Works improvements, and, given the uncertainty over the statutory driver, to consider the absolute value of benefits relative to costs.

All members of the Cost Benefit Working Group (representatives from Thames Water, Defra, Environment Agency, Ofwat, Eftec (Independent Environmental Economics Consultant) and the GLA) participated in the group in their technical capacity and not as representatives of their particular organisations. Ofwat's involvement with the group was in observer status only.

The group has commissioned three separate studies to inform the cost benefit assessment. These are:

1. a stated preference survey to evaluate the non-market benefits of the different solutions as represented by respondents' willingness to pay (WTP) for each of the three environmental improvements afforded by CSO (and STW) solutions, namely, reductions in sewage litter, number of days on which risk to human health is elevated and potential fish kills.

2. an environmental costs study to identify the non-market environmental costs attributable to the different solutions and express these, as far as possible, in monetary terms using benefits transfer

3. a market evaluation study to identify any benefits arising from the solutions that currently have a market value, through literature review and stakeholder consultation.

Wherever possible, all costs and benefits were expressed quantitatively and in monetary terms. However, in some cases, particularly some environmental costs, monetisation or even quantification was not possible. Where this is the case, qualitative assessments of costs and benefits were compared alongside the monetised values to assess their likely significance. These assessments were carried out using the net present value (NPV), being the difference in benefits and costs discounted to a present-day value.

The results of the three studies, along with financial costs estimated by the Solutions Group, have then been utilised in a cost benefit analysis (CBA), including a comprehensive set of sensitivity tests. Sensitivity tests undertaken included:

- Varying the discount rate (e.g. 3.5% as applied by the Environment Agency; 6% being an approximation to current cost of capital; and a 10% upper bound);
- Inclusion of uncertainty surrounding the WTP estimates and affected population as part of a Monte Carlo analysis;
- Options with short construction periods using 3-6 year WTP estimates and longer construction periods using 10-20 year WTP estimates rather than using the aggregated data for all options;
- Excluding health risks to test the importance of this benefit category;
- Assuming WTP value starts in the first year of operation rather than year 1 of the strategy;
- The options that consistently appeared at the top of the ranking were investigated further using more detailed cost profiles.

The results of this analysis are given in Table 7 below.

Summary of CBA report NPV results for all options assessing all WTP results and impacts		
Options	Range of NPV £bn	All WTP – all impacts £bn
		Best estimate
A (max)	-0.88 – 3.82	3.82
A(max)+ STW	-0.51 – 4.43	4.43
A(med)	-0.08 – 4.58	4.58
A(med) + STW	0.29 – 5.18	5.18
A(low)	0.05 – 4.48	4.48
A(low) + STW	0.39 – 5.06	5.06
B(max)	-0.90 – 2.80	2.80
B(max) + STW	-0.54 – 3.40	3.40
C(max)	-2.76 – -2.08	-2.08
C(max) + STW	-2.58 – -1.47	-1.47
C(med)	-1.03 – -0.37	-0.37
C(med) + STW	-0.84 – 0.24	0.24
C(low)	-0.48 – 0.07	0.07
C(low) + STW	-0.29 – 0.68	0.68
H	0.03 – 1.59	1.45
H + STW	0.89 – 2.45	2.04
H*	0.53 – 2.15	1.88
H* + STW	1.29 – 3.23	2.64
STW ONLY	0.40 – 1.14	0.81

Discount Rate = 3.5%

Key	
(green)	*Highest NPV value*
(yellow)	*All NPV Values above zero*
(magenta)	*Negative NPV Values*

Source: Thames Tideway – Cost Benefit Analysis, Eftec, October 03. Table 7.7, page 37

Table 7 - Summary of CBA report NPV results for all options assessing all WTP results and impacts

The CBA study ran in parallel to the Solutions Group work. Detailed evaluation by the Solutions Group ruled out most of the options due to insurmountable engineering difficulties. Other options were comparatively too costly or did not deliver the water quality objectives. Irrespective of these findings, variants of Option A (either medium or low, as both were very close) combined with improvements at the STWs, had the highest net benefits. The medium level of intervention had a greater NPV than the low level of intervention but the optimum tunnel size, to be calculated during the detailed planning phase of the project (following ministerial approval), is likely to be between the two levels of intervention.

Switching analysis was also undertaken to estimate by how much costs have to increase, or benefits have to decrease, for the currently plausible options to become unattractive, (i.e. positive NPV become zero or benefits and costs equalise). For the composite options (CSO plus AMP4 STW upgrade) Options A(med) and A(low), costs have to increase by 146 % and 289 % respectively or benefits have to decrease by 59 % and 74 % respectively before the NPVs become zero. This demonstrates that even though there is uncertainty around some of the assumptions underlying the Cost Benefit Analysis, the cost and benefit estimates would need to change significantly to change the conclusion that net benefits are positive.

Due to both the high costs of these proposed solutions and the fact that the majority of the benefits to be gained will be environmental and therefore, by their very nature, difficult to estimate with a high degree of accuracy, further confidence was sought in the results of the CBA. An academic panel (Professor David Pearce, Professor Ken Willis and Professor Ian Bateman) was appointed to advise the working group on the need for, and scope of, additional studies. On the advice of the Panel, a cognitive testing (face to face interviews in which a respondent first undertakes the questionnaire and is then questioned on the reasons behind their responses) exercise was commissioned. This examined whether respondents in the stated preference study had fully understood the context and the choices they were asked to make to help with the interpretation of the willingness to pay results and the resulting CBA. Although this exercise was only carried out for 24 respondents and the results therefore are not statistically significant, some useful qualitative conclusions can be drawn. Respondents appeared to understand the questionnaire, and that the improvements being discussed would result in a rise in water bills to fund the chosen solution. In terms of the relatively high WTP, most respondents provided “non-use” justification for their WTP values

Although these conclusions cannot be taken to suggest any degree of quantitative accuracy around the absolute values derived from the Stated Preference study, they do provide additional information regarding the values expressed by respondents to the original WTP study and, taken together with the original study results they confirm that respondents in general appear to attach significant value to the improvements which would result from the Tideway Strategy. Indeed, none of the analysis the Group has undertaken has indicated that the value of the benefits of the Tideway Strategy are significantly lower than the costs and point more towards the reverse. However, it is not possible to eliminate all elements of uncertainty. It is important therefore that when the results of the CBA are considered alongside other inputs into the decision-making process they are not used in a mechanistic way but with due regard to the uncertainties, which apply to both costs and benefits.

5. Overall Option assessment

5.1 Option Assessment (following phase 1)

The final stage of option assessment was to combine the rankings from the CBA assessment with a technical and compliance assessment to generate an overall assessment. This is shown in the table below.

Option	Solutions Feasibility	Cost Benefit Analysis (Ranking in order of preference, showing discount rates)				Compliance	Comments
			3.5%	6%	10%		
A	Less technical challenge	max	3	3	3	All 3 objectives met	Most favourable, flexible to meet objectives.
		med	1	1	2		
		low	2	2	1		
B	Very high power requirements	max	4	4	4	Complies with aesthetics objective, reduces health risk. Assessed as marginally failing DO objective	Infeasible, peak power requirements too high
		min	Not technically feasible				
		low	Not technically feasible				
C	High disruption, High land requirements	max	-‘ve NPV	-‘ve NPV	-‘ve NPV	Complies with aesthetics objective, no reduction in health risk. Assessed as marginally failing DO objective	Unlikely that land can be acquired.
		med	-‘ve NPV	-‘ve NPV	-‘ve NPV		
		low	7	-‘ve NPV	-‘ve NPV		
D	High cost of twin tunnel.	Possible				Complies with all three objectives	Higher cost than A for no extra benefit.
E	Impact on foreshore High cost	Not technically feasible				Not assessed	High environmental impact. Unproven technology. Higher cost than A for no extra benefit
F	Extreme disruption, Very high cost	Not technically feasible				Not assessed	High environmental impact. Unproven technology. Higher cost than A for no extra benefit
G	High energy requirements, Large wetlands required.	Not technical feasible				Not assessed	No site available for wetlands.

H	Similar to A with shorter tunnel Partial or staged option. Technically feasible	6	6	6	Fails aesthetics objective, gives some reduction in health risk. Marginally complies with DO objective.	Favourable partial and or staged solution
H+	Solution H augmented with screening at additional sites. Technically feasible. Full solution	5	5	6	Marginally complies with aesthetics objective. Otherwise identical to H	As for H

Table 8 – Solution summary table

Options E, F and G are rejected as technically infeasible and impractical with excessive costs.
Option D provides identical benefits to Option A but at greater cost.
Option C is a screening only option that does not comply with all objectives, and gives poor cost benefit and has unattainable land requirements.
Discount rates: a financial measure that reflects the greater 'value' of money in the present (rather than in the future). Most analyses expect to operate at approximately 6% p.a. – the other percentages are included to indicate any sensitivity to this assumption

It is immediately apparent that Option A (be it low or medium) is the only option which meets all objectives at reasonable cost. It is for this reason that Option A alone was further developed when it became clear that the Abbey Mills Pumping Station also needed to be addressed as part of the overall scheme.

5.2 Development of Solution to match revised scope

It is very important to realise that the development of the solution was carried out after the main body of the technical investigations had been carried out and the most likely approach had already been selected. The revised scope mainly comprises the inclusion of the Abbey Mills flows and the exclusion of some of the CSOs through the prioritisation process designed to ensure the solution addresses the environmental requirements and is consistent with the requirements of the UWWTD. Considering the process by which the preferred approach was selected, it was clear from a basic review that any refinement was not going to change the order of priority of the various solutions analysed, and for this reason the application of the detailed changes in terms of revised scope of construction and the consequential increase in cost was applied to Option A (low) only; none of the other options were re-scoped and re-costed. Thus the capital and operating costs of the preferred approach (now described as the refined solution, Option A (ref)) and the performance achieved cannot be compared with similar data for the other options detailed in the first volume of the Solutions Group report which would otherwise all need to be expanded to the refined level.

Initially, Option A (low) was based on interception of flow from the 54 CSOs that spill directly into the Thames. However, many of these CSOs spill very small or negligible amounts of polluting flow to the river, so that they are considered by the EA to have insignificant environmental impact. It has been determined that interception of these is not necessary to comply with the objectives. The result of this review is that the number of CSOs to be intercepted has been reduced to 36.

Similarly, the Abbey Mills Pumping Station, which discharges into Channelsea Creek (part of the tidal section of the River Lee), was initially excluded from interception as its discharge is currently the subject of improvement, by way of implementing fine screening. However, the modelling has now shown that this discharge still has a significant and adverse environmental impact.

Several options were investigated in dealing with the Abbey Mills CSO on the pumping station site itself. These included the installation of surface storage and storm treatment plant on the land available. These were all found to be very expensive and subject to high engineering and operational risk compared with connecting the flows to the main tunnel. The most appropriate and cost effective solution is to include the shortest possible transfer tunnel to the proposed main tunnel, which is increased in diameter to provide the additional storage required for the Abbey Mills CSO. The consequences of this additional flow for the treatment facilities at Crossness have been accommodated bearing in mind the proposed works extensions.

This phase of the study also allowed for other refinements to the proposed scheme, such as the relocation of proposed main shafts to accommodate current land availability, environmental and planning issues. For example, the successful acquisition of land adjacent to Heathwall Pumping Station now allows for one of the proposed main construction shafts to be relocated here.

Initially it had been suspected that the tunnel size proposed for Option A (low) might have been at risk of choking during filling, which could have impaired its interception capacity. The hydraulic limitations of rapid filling of the tunnel were subject to more detailed analysis using computational fluid dynamics and physical modelling. This additional work has shown that provided the main tunnel is at least 6m in diameter this problem is avoided.

5.3 The Refined Solution

The preferred solution to reduce the adverse effects caused by the discharge of storm sewage from the CSOs is a storage tunnel from Hammersmith to Crossness STW that generally follows the course of the Thames. Polluting flow from all the unsatisfactory CSOs is intercepted, stored within the tunnel and pumped out to a storm water treatment works at Crossness. Also included is a link tunnel from Abbey Mills to the main storage tunnel, connected at the main shaft at Greenwich and a link tunnel to Beckton STW. Following the change of scope, this proposal is now described as Option A(ref), but it offers a comparable degree of environmental protection (in terms of the frequency with which storm events will exceed the storage capacity) as the A(low) concept. This permits the application of the earlier cost benefit assessment to the revised proposal.
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;
- Pumping station at Beckton;
- Interception of 36 unsatisfactory CSOs.

This is represented in figure 12 below:

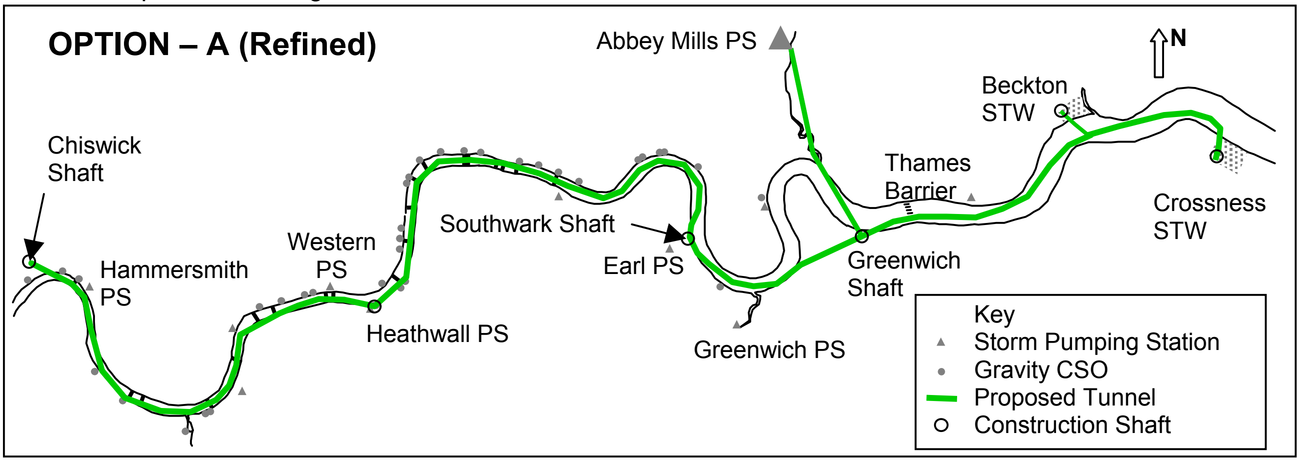


Figure 12 – Proposed Solution Option A (ref)

It is proposed to take advantage of the planned upgrades of Crossness and Beckton STWs by passing as much flow as possible from the tunnel to full treatment; this includes the proposal to pump out the tunnel over 48, not 24, hours. However it will not be possible to accommodate the maximum pump-out rate and there will be occasions, particularly during extended periods of rainfall, when the treatment works will only be able to accept limited flows from the storage tunnel.

A dedicated storm treatment facility is therefore also required. The proposed storm treatment is deep bed filtration, which is an enhanced primary treatment process. It is a robust and physical process that readily accommodates the intermittent flow that removes fine solids and a significant proportion of the polluting load.

If constructed, Option A (ref) could be regarded as an integral part of the sewerage system, in the form of another trunk intercepting sewer providing additional capacity and reducing the frequency of operation of the CSOs. The high flows that would previously have been discharged to the river will be contained within the system and will flow through the new sewer to the STWs for treatment. CSO discharges will still spill from the system but at a much-reduced frequency, approximately once per year, which will not produce environmental damage.

Option A (ref) is a means of combining all the unsatisfactory CSO discharges together into one discharge, which is treated to a standard to limit pollution to an acceptable level.

Option A (ref) offers the following advantages: -

- Because it intercepts the unsatisfactory CSO discharges at the point of outfall to the river, it will be effective under all flow patterns that may occur in the sewerage system due to different rainfall events and tidal conditions;
- Storage is provided in a single structure, allowing maximum flexibility for most effective use of this capacity by all the unsatisfactory CSOs;
- Storage is provided to allow sufficient attenuation of flows to reduce pumping and energy requirements and enable the whole of the intercepted flow to receive treatment;
- Flexibility in treatment options is provided with access to both Crossness and Beckton STWs;
- The use of the one structure to intercept, store and transfer is highly efficient in terms of overall cost;
- Constructing the sewer in tunnel form allows for negotiating the various service structures and tunnels. Tunnelling costs are significantly cheaper than other forms of construction;
- The route of the tunnel prevents excessive disruption to London;
- At any future date, if any of the existing CSOs, which are not connected to the tunnel, cause problems, they can be connected cost-effectively and with minimum disruption;
- If flows increase due to climate change, this option can be extended by the addition of parallel tunnel storage.

5.4 Phase 2 compliance testing

The decision to include the Abbey Mills Pumping Station as part of the overall improvements, coupled to a better understanding of the likely sewer flows (which itself followed refinement of the sewer modelling parameters) prompted a further round of compliance testing. This would help demonstrate which components of the package were key in securing compliance with each of the four DO standards (Table 1: Section 2.5.2). By this stage, the clearly preferred option was the storage/transfer tunnel and this was taken as the baseline assumption for the additional testing.

In addition to testing this revised solution, it proved desirable to assess the differing STW improvement benefits separately; specifically, that the benefit of the improved effluent quality (which is considered non-statutory) can be identified in addition to the increased flow to full treatment, which is considered statutory.

An example of the modelled outputs is shown below (Figure 13). This graph is a composite of five modelling runs which, based on the same rainfall event, indicates for each solution or combination the predicted dissolved oxygen concentrations. (These concentrations are shown as a profile along the Thames, corrected to remove the complication of tidal movement, and by convention are distances by reference to London Bridge).

This illustrates clearly the massive fall in dissolved oxygen (at approximately 10km below London Bridge) that is currently experienced and how effective the combined measures of Option A (ref) and STW improvements would be. For this event, the target DO concentration is just met by the full suite of measures.

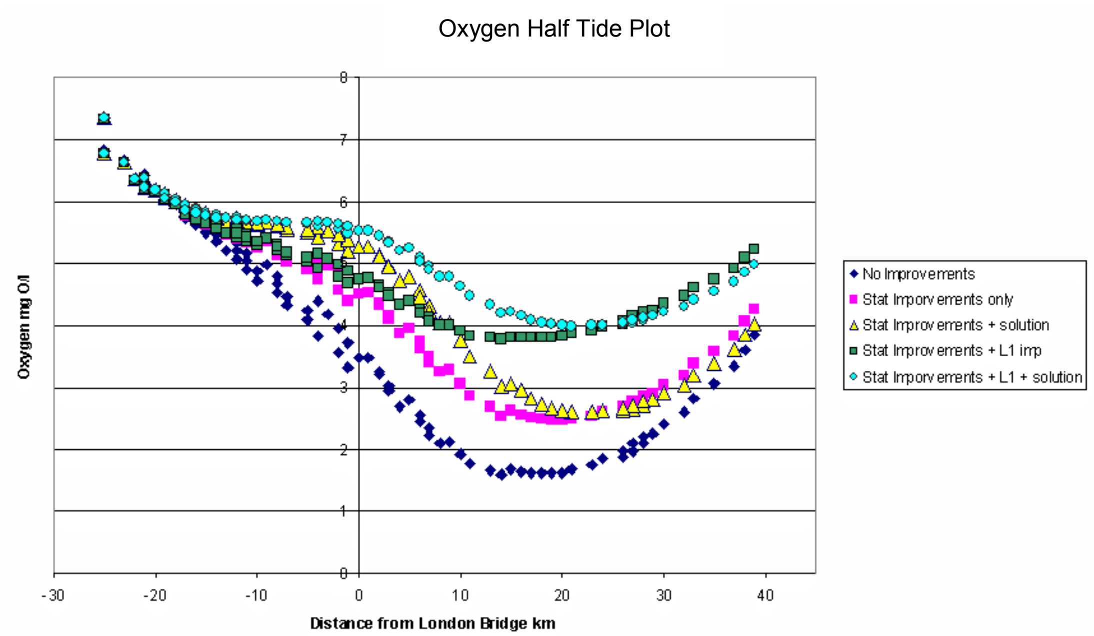


Figure 13 - Effects of statutory STW improvements, additional STW enhancements and inclusion of the tunnel solution.

5.5 Summary of phase 2 testing

The outputs of the modelling runs (i.e. the individual DO plots in Figure 13) have been combined for all of the 62 rainfall events to establish compliance against the objective standards, bearing in mind that these standards are not absolute but refer to frequency and duration (See 2.5.2).

The current proposed solution of tunnel Option A (ref), plus the statutory STW enhancements complies with the objectives identified for litter reduction and reduction of health risk days. These improvements also enable compliance with the majority of the dissolved oxygen standards, with the exception of the 4 mg/l standard.

Inclusion of the STW 'L1' improvements in addition to Option A (low) and statutory STW improvements achieves compliance against the 4mg/l standard as well as full compliance with all other standards.

This is shown as below (Figure 14). (Note that this is a compliance test showing numbers of permitted exceedences and not a plot of dissolved oxygen).

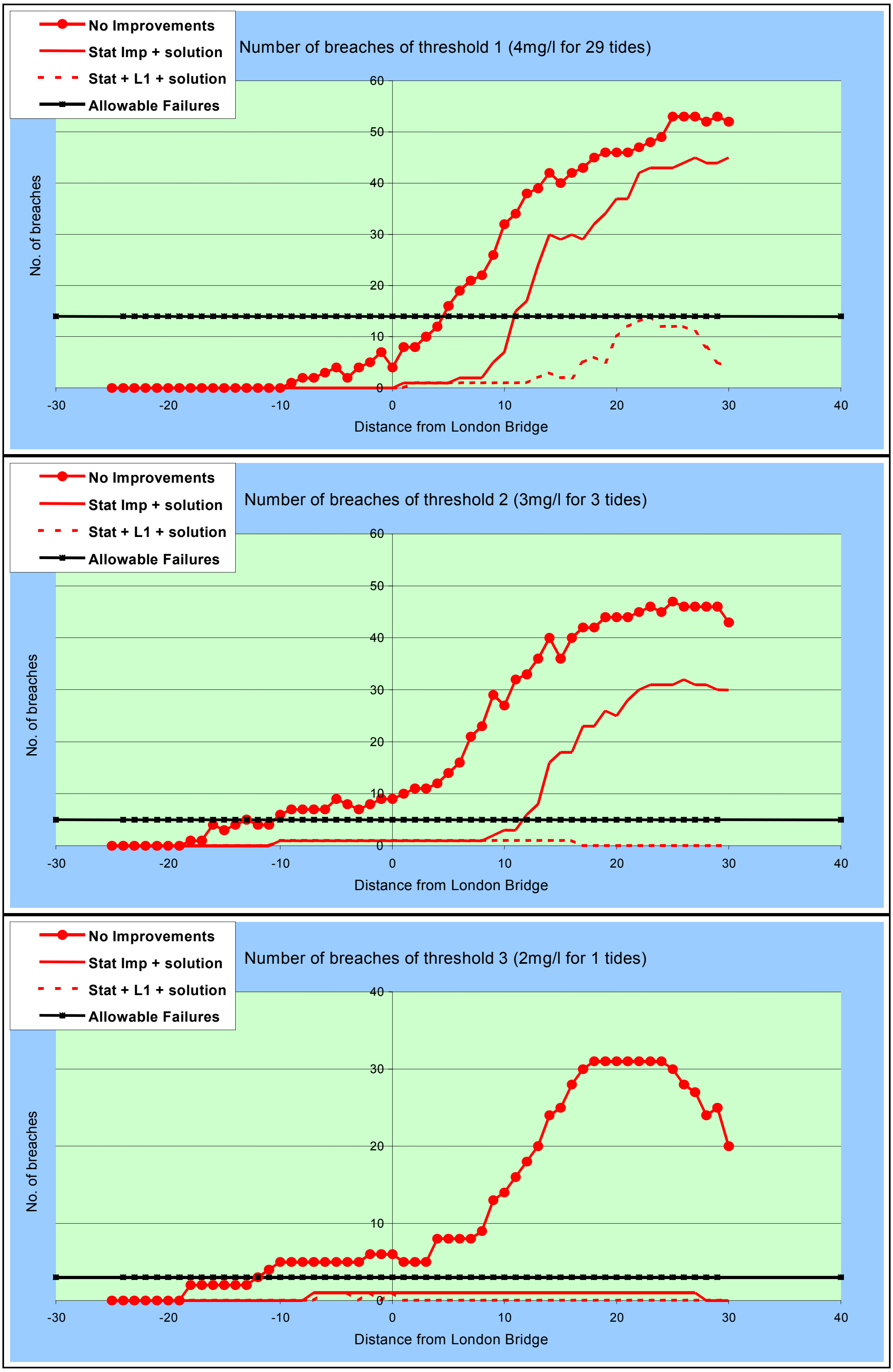


Figure 14 - Compliance plots showing impact of statutory STW improvements and L1 drivers, in addition to CSO solution

Full compliance with all objectives can be achieved only by the combination of Option A (ref), a storage-and-transfer tunnel with both the statutory and discretionary STW improvements,

5.6 Cost benefit Assessment

The preceding CBA work (described above) showed CSO Option A(ref) to be the option with the greatest potential of implementation. Since these original analyses, the design of this option has been further refined and the compliance test procedure, from which the impact on fish populations is derived, has been enhanced. Ofwat has also made provision for funding of the proposed improvements at the STWs so that these can now be considered to be part of the baseline for assessment. In addition some changes have been agreed to some of the assumptions adopted in the CBA.

Table 9: Revised Cost Benefit Analysis for Option A(ref)

Version of option and CBA	PV Benefits (£ billion)	PV Costs (£ billion)	NPV (£ billion)	BCR (ratio)
A(ref) (3.5% discount rate)	5.7	1.2	4.5	5
A(ref) & STW (3.5% discount rate)	6.8	1.7	5.1	4
Revised A(ref) (hyperbolic rate)	8	1.3	6.7	6

All costs quoted at 2002/3 prices

The results show that the above mentioned changes lead to even better results for A(ref) in terms of NPV and BCR: while costs increase by a small margin, benefits increase (due entirely to changing estimates for potential fish kills) by a larger amount.

5.7 Engineering Risks

Assessment of the engineering risks has been made in parallel with the development of the various options. Topics considered in technical reports include:

- Ground movement
- Underground structures
- Groundwater pollution
- High groundwater pressure
- Construction site availability
- Insurance of the works
- Spoil disposal
- High and fluctuating energy demand
- Choking of tunnel
- Septicity of sewage
- Siltation/deposition of solids
- High and costly energy use

All the rejected Options include technical and/or planning risks that could have prevented them from actually being physically constructed or operated.

Option A (ref) has emerged as the best solution in part because there are no insurmountable technical risks of this kind. The technical risks, which have been identified, could have a financial impact and this has been catered for in the large contingency allowance of 30%.

5.8 Cost Estimates

The overall budget costs for the proposed storage tunnel solution are based on late 2002 figures, and are detailed below:

Estimated Cost @ 2002							
Tunnels & Structures	**Screens**	**Treatment**	**Pump & Power**	**Contingency & Risk 30%**	**Resource Costs**	**Land Costs**	**Total Costs**
£936m	£32m	£22m	£50m	£312m	£125m	£50m	£1,527m

Table 10 – Estimated costs

This cost base (2002) has been retained for comparison with Thames Water's Business Plan for the 2005-2010 period, but the comparable total at 2004 costs is approximately £1,700 million

These costs will not be incurred evenly over the duration of the project, but would be programmed as follows, assuming 5-year funding tranches:

- 1st tranche (years 1-5) £65m
- 2nd tranche (years 6-10) £975m
- 3rd tranche (years 11-15) £487m

The budget costs for tunnels and structures have been developed using the robust and systematic method of working from a detailed programme of works using the resources, materials and duration required for each element of the works. These budget estimates have also been also compared with the current tunnelling costs for the Channel Tunnel Rail Link (CTRL).

The contract for the tunnelled approach to the terminal at St. Pancras within the CTRL project, in essence comprises twin tunnels of 8.15m external diameter and 17.5km long; the equivalent to a single line 35km in length. The outturn cost of this contract was £380M, which translates to unit costs of £10.9M/km or £208.00 per m^3 excavated. The budget for the Tideway Tunnel has to be modified to make it comparable with this contract, which involves a number of assumed differences in factors at all stages of the implementation from insurance costs to spoil disposal. The modified budget is £544.1M (before contingency) for 34.5km of tunnel of 8.9m external diameter, which equates to £15.8M/km or £253 per m^3 of excavation. Given the differences between the two projects in scope and purpose such figures are more than reasonably comparable and indicate the financial estimates for the Tideway scheme can be considered reliable.

The Tunnel Boring Machines used on CTRL are of similar size to those proposed to construct the refined option and an example is shown below:

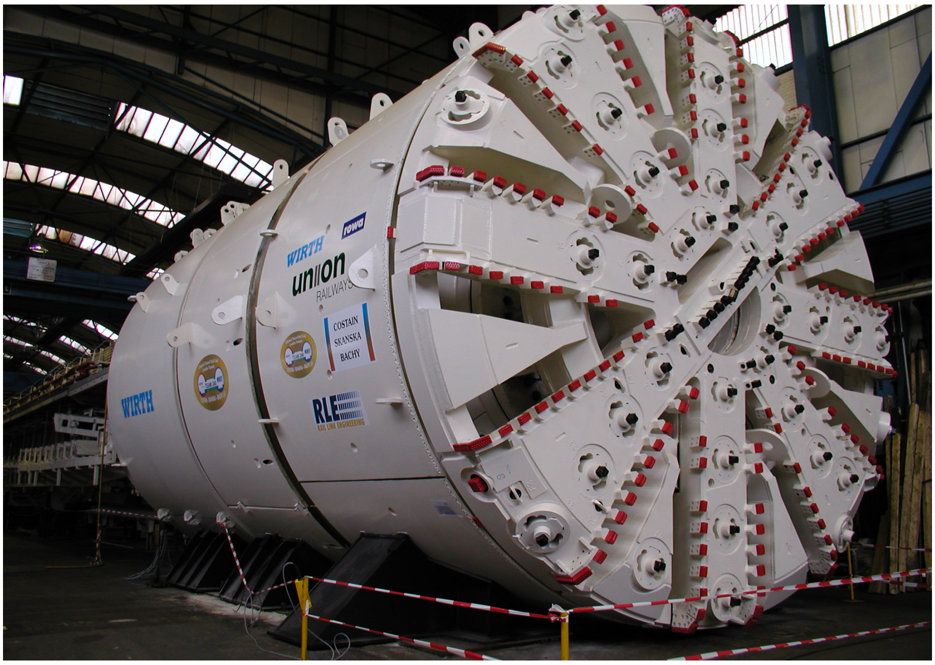


Figure 15: example of Tunnel Boring Machine (source: CTRL)

The budget costs for screens, treatment and pump and power have been developed from out-turn costs of similar projects.

These budget estimates include a general contingency of 30%, which is deemed appropriate at this stage of the investigation to represent the following:

- Items of a more detailed nature that have yet to be investigated
- Items that have been neglected or omitted
- Potential additional cost to items already included but subject to additional cost by realisation of risk
- Loss of optimal locations for shaft construction

The proposed AMP4 improvements for the main STWs are excluded from the above figures.

6. Sewage Treatment Works Improvements

At an early stage, the modelling sub-group identified that addressing the CSOs in isolation was insufficient to achieve the quality objectives adopted (see compliance testing, Section 3.5, above) The capacity of the STWs was deemed inadequate and that considerably more flow was needed to be treated at the three major STWs. The following improvements were confirmed as obligations for Thames Water in the recent 'final determination' of price limits for the period 2005 and beyond:

STW Name	**Current Consent Standards (mg/l)**					**Proposed Consent Standards (mg/L)**		
	Suspended Solids	BOD	Ammonia	BOD Summer	Ammonia Summer	BOD Summer	Ammonia Summer	Increased Flow to Full Treatment (m^3/d)
Beckton		22	6	6	1	5	1	1,800,000
Crossness		25	16	10	7	5	1	1,485,000
Mogden		23	7	11	1	11*	1*	1,075,000
Long Reach		50	53	20	25	15	15	
Riverside	45	20	10	15	20	7	7	

Table 11 – Improvements included in Thames Water's Business Plan

Key:

BOD - Biochemical Oxygen Demand

** - unchanged from current standards*

These improvements were also carried through into the cost benefit analysis.

7. Risks

The study has identified many of the potential risks to successful delivery of the proposed solution, and these fall under four main headings: Planning, Environmental, Engineering and Financial. Equally, the risks of a 'do nothing' option should also be considered. These are:

- Continued environmental damage, human health risk and poor aesthetics
- Negative impact on London's 'brand', e.g. Olympic bid
- Negative impact on Thames Water's brand
- Negative impact on regeneration of land adjacent to Tideway

7.1 Planning and Land Issues

The key risks associated with the planning process include refusal of planning permission or call-in for public inquiry. The main implication 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 is 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 principal risks are considered more fully in the Solutions Group report (Volume 2), together with the appropriate mitigation measures. Construction of the CSO interception structures has been subject to preliminary investigation and requires further assessment of site locations with identification of alternatives. Further investigation in more detail is now in hand.

Construction site availability is one of the top five project risks. The proposed mitigation is early acquisition of the required site areas or options for these sites. The main shaft sites have been selected as ideal locations, but these locations are generic and there is a large element of flexibility in terms of specific sites. Nonetheless, he 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 if there are substantial delays in scheme approval. Finding alternative sites inevitably increases the risk of a corresponding increase in cost.

7.2 Environmental

The principal environmental risks are that the objectives selected prove inappropriate (either too stringent or too lax, or omitted altogether) or that external pressures will impose different requirements on the UK during the life of the project. For instance, the study has had to anticipate the requirements for water quality that will be imposed under the Water Framework Directive. Whilst it is evident that the study's Working Groups are content with the proposed standards, it is possible that external pressures may dictate that higher standards be imposed, although the quality requirements of the WFD should be defined well before any major construction (and hence expenditure) is committed. Similarly, the Bathing Water Directive is currently under revision, and it has been a long-recognised desire by some in Europe to identify and give statutory protection to recreational users.

7.2.1 Future effects including climate change

Since the earliest a tunnel could be operational is about 2020 and it would be likely to have a life of some 200 years it was decided to assess how the scheme might operate under future conditions.

7.2.1 Demographic changes

It is accepted that the population in London will increase within the projected lifespan of the project and that hard standing areas may increase development areas. However, it is thought unlikely to significantly impact on the performance of the tunnel in capturing and mitigating the extra urban run-off created as a result since much of the area identified for development has already previously been developed and/or is outside the Beckton and Crossness sewerage systems.

7.2.2 Climate change

Consideration was given to the effects of climate change on the frequency and intensity of future rainfall events, changed environmental conditions in the river, primarily due to raised temperature, sea level rise, and reduced natural river flow into the upper Tideway. The furthest ahead data that was sufficiently reliable was for 2080.

Whilst the results are based on current models and analysis and they cannot be taken as predictions, they can be taken as indicative. Rising sea level and changed storm patterns do not adversely affect compliance. Reduced fresh water river flow makes the natural conditions in the upper Tideway significantly worse but the tunnel scheme reduces CSO discharge here to such an extent that there are still no failures. Reduced river flow marginally improves conditions in the middle estuary. Anticipated changed environmental conditions, primarily increased river temperature, would lead to failure of the 4mg standard in the middle Tideway. However this cannot be improved significantly by increased tunnel storage volume, only by improved sewage treatment works effluent. Solution A would still remain compliant with the critical fish mortality standard of 3mg/l.

Lastly, the consequences of future higher environmental standards may be to require that discharges are made less frequently. These requirements can be accommodated by the tunnel solution by linking in further CSOs and/or by constructing further storage in a parallel tunnel. If higher quality discharges are required for the tunnel effluent then there would be a need to uprate or extend the Crossness Sewage treatment works.

7.3 Engineering and Financial

The principal engineering risks have been identified above, and it is believed that the remaining risks are manageable and can be accommodated within the quoted contingency. It is equally believed that the cost estimates are adequately robust as they are comparable with other projects such as CTRL.

7.4 Possible Delivery Timetable for Tunnel option

As identified above, satisfying the planning process and the acquisition of suitable sites will take several years; after consultation with planning experts, a period of 5 years was adopted as practicable. There will be some overlap between obtaining planning permission and the detailed design, and the detailed design will be running in parallel with early construction. Tunnel construction is expected to take some 8 years, and a further period of minor works for completion and commissioning. Given the uncertainties, an overall project timescale of 15 years is realistic, and this can be illustrated as shown in figure 16.

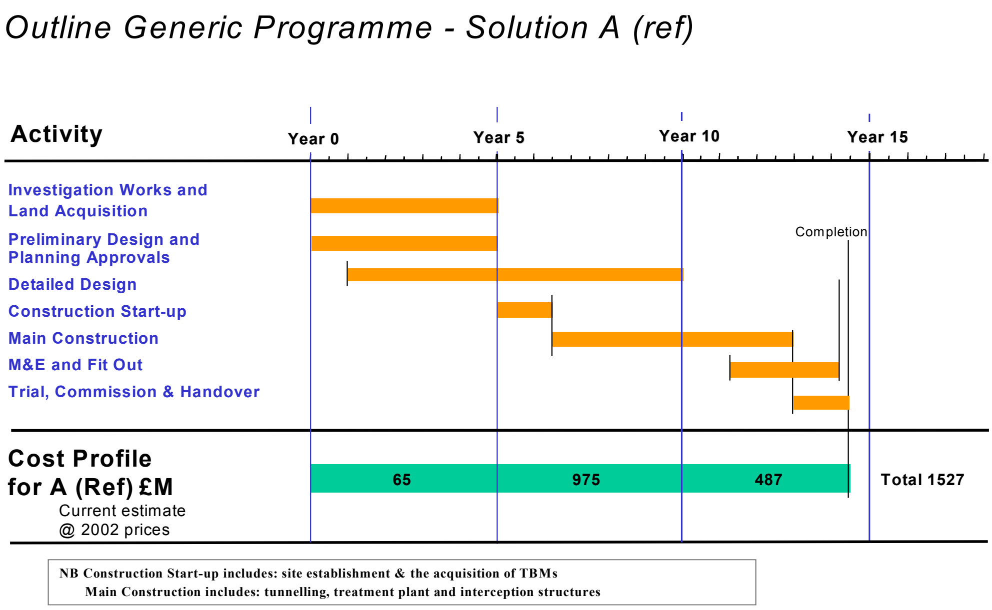


Figure 16. Potential outline programme – Solution A (ref)

8. Cost implications for Thames Water Customers

An attempt to forecast the total impact on customers' bills – the average household sewerage bill – if a project associated with the Tideway was to go ahead has been made.

The modelling has been carried out using Ofwat's Aquarius 3 model as used for Thames Water's Strategic Business Plan (SBP) submission. To link the project with possible prices, it was assumed that the project would follow usual industry financing cycles, and commence in 2005. Since the project was not included in the last price determination (December 2004), the consequences must therefore be seen as illustrative.

Option A(ref) has been agreed as appropriate. This has an estimated capital expenditure cost of £1,494m (2002 prices) and annual operating expenditure of £3.2m. The modelling result was that household bills would need to rise by a total of approximately £43 p.a. (2002/03 prices) by the time the scheme had been fully implemented. This is consistent with past estimates of some £40 p.a. total cost. Given the uncertainties around any modelling of this nature, it is probably appropriate to quote a range of impact of, say, £40-45, rather than the specific £43 figure.

It would be expected that this rise would be implemented in annual increments over the presumed 15 years of implementation, at a rate, which reflected the expenditure incurred. However, should the scheme proceed, then these estimates cannot anticipate the actual increases in bills over the next fifteen years which will be subject to other external forces. As has recently been announced, Thames Water bills will rise on average by 22% over the next five years. Adding the modelled costs to the planned charges would suggest an additional increase compared to 2009/10 of some 17% on the anticipated combined water and sewerage bill of £261, to just over £300.

9. Stakeholder Consultation

During the Study period the agreed communications strategy was to ensure that all Thames Tideway stakeholders and interested parties were kept informed of the progress of the Study and all questions were answered.

To this end, a comprehensive stakeholder database was created to include Thames Tideway riparian local authorities and ward councillors, statutory consultees, angling and other sports and recreation groups using the Thames Tideway, Members of Parliament, national and local environment groups and societies as well as interested members of the public. Environment correspondents of the national and London-based newspapers and professional trade press have also been included on the stakeholder database.

During the study period, three stakeholder reports have been produced: 2001 Annual Report; 2002 Annual Report and; 2003-2004 Report. Copies of these reports with an accompanying letter/press release from the TTSS Chairman have been dispatched to all stakeholders. Each mailing encouraged stakeholders to contact the study group either to ask questions or to request meetings/presentations on the progress of the Study to their respective organisations. Some of these offers were taken up, details of which listed below in Table 12.

Year	Mailings	Presentations
2002	2001 Annual Report (July)	WaterVoice (Sept)
		Port of London Authority (Oct)
		London Borough of Hounslow – Chiswick Area Committee (Dec)
2003	2002 Annual Report (June)	WaterVoice (June)
		London Assembly Environment Committee (Sept)
		Institute of Fisheries Management (Mar)
2004	2003-04 Report (Nov)	EA Advisory Groups - Regional Environment Protection Advisory Committee (REPAC) and Regional Fisheries Ecology Recreation Advisory Committee (RFERAC) (July)
		London Assembly Health and Public Safety Services Committee (Sept)
		GLA scrutiny (Sept)
		London Borough of Hounslow – Chiswick Area Committee (Nov)
		PLA Consultative Forum (Nov)
		WaterVoice (Dec)
		Thames Estuary Partnership (TEP) Annual Forum (Dec)
		River User Group 8 (Shepperton to Teddington Weir) (Dec)
		AMP Conference, Regents Park (Dec)
2005		GLA Water Resources Working Group (Jan)
		Elmbridge Borough Council Environment Committee (Jan)

Table 12 – Stakeholder consultations

A project telephone information enquiry line was established and a number of calls have been managed and responded during the study period.

Although the communications strategy for the TTSS was deliberately reactive rather than pro-active, all stakeholders were kept fully informed throughout the Study period and given the opportunity to ask questions and find out more information. A number of stakeholders such as Thames 21, the London Port Health Authority and others have also contributed to the study, helping to ensure a fully informed report on the issues of CSO storm discharges and their effect on those groups' particular interests.

It would be a fair summary to report that although all stakeholders who responded have been unanimous in their support of developing a solution to the CSO storm discharges to the Tideway, there has been muted interest in the subject by the majority of identified stakeholders. Early efforts by the Environment Agency to generate media interest have produced some limited editorial coverage. Inevitably it was going to be "disaster scenario" such as a major sewage discharge that caused either a public health scare or large numbers of fish killed that would raise public awareness about the problem and the potential solutions.

August 3rd 2004 was the catalyst for this as it coincided with the traditionally quiet news period of the summer holidays coupled with the fact that there was a highly visible manifestation (dead fish) of the impact of discharges from Mogden STW and the CSOs in the west London area. The outcome of the widespread media publicity has helped – perhaps in the only way it could – to raise public and stakeholder awareness and to generate support for the proposed solution to be implemented as soon as possible.

Further stakeholder consultation will be undertaken at the time of, and during the period after the publication of the study reports.

10. Conclusions

- Large quantities of storm sewage containing sewage solids and sewage-derived litter are discharged to the Tideway by the CSOs, creating significant aesthetic impacts in the river and increasing the health risk for recreational users. The discharges also reduce the dissolved oxygen levels in the river, which can cause fish kills. Discharges from the sewerage catchment occur some 60 times per year, on average.

- The existing strategy to ameliorate the adverse effects of CSOs on DO concentrations, to prevent fish kills by injecting oxygen into the river using the two oxygenation barges – “Bubbler” and “Vitality” – and land-based hydrogen peroxide dosing plant has been largely effective, although clearly inadequate when dealing with exceptional conditions. This has always been recognised as an interim strategy and it does not address the sewage-derived litter and health risk issues. However, it is clear that it will need to continue for the foreseeable future, until a longer-term solution can be implemented. Additional short-term measures such as litter collection and further oxygenation should be considered and if practicable, implemented and their effectiveness assessed.

- The frequency of the overflow discharges from both the collecting system and treatment works has prompted a re-appraisal of the requirements of the UWWT Directive, the associated Regulations and their implementing guidance.

- Following a re-assessment by the Environment Agency, 36 CSOs have been identified, following investigation and modelling, as unsatisfactory by virtue of their adverse effect on the environment.

- To establish the extent of any improvements required, a set of objectives has been formulated which should ensure compliance with current and anticipated statutory environmental requirements and will provide protection to the fish population in the Tideway. Compliance with the objectives will also improve the amenity and recreational value of the river.

- To achieve compliance with the full suite of objectives, it is necessary to reduce the impact of the CSO discharges. A number of potential solutions have been identified and evaluated to determine whether they are operationally practicable and would comply with the objectives. They have also been subjected to cost benefit analysis.

- To meet the proposed objectives, it is also necessary to both enlarge the capacity of and improve the discharge quality from the sewage treatment works. The first element, is an increase in treatment capacity at three STWs, whilst the second involves improved treatment quality standards at two of these three works plus a further two sites. These treatment works improvements are provided for in Thames Water’s price limits post 2005, and it is expected that, with one exception, the improvements will be completed by 2012.

- The only CSO solution that satisfies all hydraulic and operational requirements, shows modelled compliance with the objectives and maximises net benefit is Option A(ref). This involves the construction of a 7.2 metre diameter storage-and-transfer tunnel between Hammersmith and Crossness STW to provide storage and attenuation prior to pumping out for treatment and discharge to the river.

- Such a long life scheme needs where possible to be future proof. Demographic changes are unlikely to have much affect. Rising sea level, changed storm patterns, and reduced natural river flows would not affect compliance. Increased temperature would have an effect on the Tideway water quality but the CSO/tunnel flows would have only a limited influence on this and the solution would be to improve STW effluent quality. If ever needed, the storage could be increased by constructing a parallel storage tunnel. Thus the scheme appears to be largely future proof.

- There is considerable housing growth planned for South East England, in particular the Thames Gateway development and infill growth within Greater London. The impact of this potential growth will need to be reviewed as proposals become clearer, although the majority of the planned growth is not expected to impact on the sections of the existing sewer network being considered in the study. The substantial increases in capacity at the major sewage treatment works (Mogden, Beckton and Crossness STWs) will in any case mitigate any adverse effects.

- An outline delivery timetable for Option A(ref) has been developed, and confirms that a period of more detailed engineering design, scheme planning and promotion would be needed, and that this would take about five years. This would include evaluation of the practical issues of land acquisition, planning permissions and detailed environmental impact assessments, as well as a continuing review of the broad issues of climate change and population growth. Construction could begin as little as five years after inception, subject to successful planning approvals, and could take some 8 years to complete. Overall solution delivery within 15 years is believed feasible.

- The results of the Cost Benefit Analysis has aided the option selection process by providing a range of net present values per option to represent the costs and benefits associated with an option. Subsequent sensitivity and switching analysis confirmed that, even though there is uncertainty around some of the assumptions used in the CBA, the cost and benefit estimates would have to change considerably to alter the conclusion that the net benefits delivered by Option A(ref) are positive.

- A cognitive testing exercise, designed to explore the uncertainty surrounding the benefits, confirmed that respondents in general appear to attach significant value to the improvements, which would result from implementation of the Tideway project. However, it is quite possible that a further round of cost/benefit assessments will be requested.

- The capital cost of Option A(ref) is approximately £1.7 billion (£1,698 million). The estimated annual operating cost of this option is some £3.4 million, all at 2004 cost base.

- This cost will be borne by Thames Water's sewerage customers, and the impact on their bills has been calculated using the approved Ofwat model. This calculation indicates an incremental bill increase rising to a total of £43 per annum extra on completion, although this should realistically be seen as a range from £40 to £45.

- Projects of this nature and scale are subject to several different sorts of risk; primary ones in this instance are political/regulatory, planning and engineering risks. Whilst some (such as planning risk) remain intangible, the engineering risks have been broadly assessed and addressed within the engineering studies. The proposed solution is therefore considered to be a robust option.

Glossary

AMP4	Asset Management Plan 4 (2005-2010)
BOD	Biochemical Oxygen Demand
BTKNEEC	Best Technical Knowledge Not Entailing Excessive Cost
CBA	Cost Benefit Analysis
CSO	Combined Sewer Overflow
Defra	Department for Environment, Food and Rural Affairs
DETR	Department for Environment, Transport and the Regions (relevant duties now part of DEFRA)
DO	Dissolved Oxygen
EA	Environment Agency
EC	European Community
GLA	Greater London Authority
NPV	Net Present Value
Ofwat	Office of Water Services
SP	Stated Preference
STW	Sewage Treatment Works
SDS	Sustainable (urban) Drainage System
TTSS	Thames Tideway Strategic Study
UWWT[D][R]	Urban Waste Water Treatment [Directive] [Regulation]
WFD	Water Framework Directive
WHO	World Health Organisation
WQ	Water Quality
WTP	Willingness to Pay