JACOBS BABTIE

Office of Water Services

Independent Review to assess whether there are Economic Partial Solutions to Problems caused by Intermittent Storm Discharges to the Thames Tideway – Phase1

Final Report [incorporating TTSS November 2005 Supplementary Report update]

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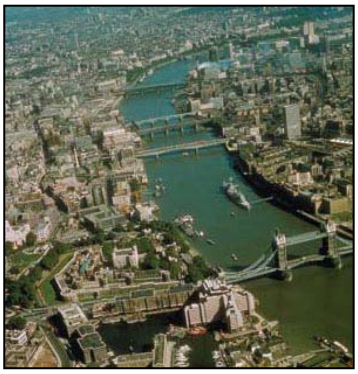

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Background

Over the past four decades there have been significant improvements in the sewerage and sewage treatment facilities that serve the London area. Consequently the water quality in the lower reaches of the River Thames has also improved significantly. However, in common with most similar urban areas, London's sewerage system relies on a series of combined sewer overflows (CSOs). These overflows discharge excess flows from the sewers to the Thames and its tributaries during times of heavy rainfall, which contributes to a deterioration in the water quality.

The Thames Tideway Strategic Study (TTSS) was commissioned by Thames Water in 2000, with a remit to assess the environmental impact of the storm sewage discharges, to consider and cost what improvements may be desirable and develop possible technical solutions.

To better define the terms of reference for the study, the TTSS team established three principal objectives to be met by any proposed solution. These are; to reduce the aesthetic pollution due to sewage-derived litter; to protect the ecology of the Tideway; and to protect the health of recreational water users. In turn, the criteria used to judge whether solutions were compliant with these objectives were; frequency of operation of CSOs; dissolved oxygen levels in the Tideway under adverse conditions; and number of 'elevated health risk days' following CSO discharges.

The TTSS team has now completed this work and has recommended construction of a major storage and transfer tunnel running for 35km, principally below the River Thames, to intercept the key CSO discharges and convey them downstream for treatment and subsequent discharge. The estimated cost of this scheme is £1.7bn at 2004 prices.

Terms of Reference

Given the scale of this project, and its likely impact on water charges, Ofwat commissioned Jacobs Babtie to undertake an independent review of the TTSS work. This report meets the requirements of Phase 1 of this review; a second phase of the commission may be progressed.

It is clear from the body of work presented and from our meetings with TTSS team members that the study was both extensive and thorough. Indeed, the introduction to the February 2005 Executive Summary report makes clear that the study aims to be robust enough to stand full scrutiny. Considerable thought has therefore been put into reviewing the arguments presented by the TTSS.

Ofwat's original brief for this review required that this report should address those key TTSS reports and documents that were available when the review commenced in August 2005. Our first report, 'TTSS Review - Phase 1 Final Report, December 2005' complied with this requirement. The issue on 29 November 2005, of the final version of the 'TTSS Supplementary Report to Government' included additional developments by the TTSS team when compared to the earlier documents. In particular, key changes included a revision to the storage capacity of the tunnel for Option H and variants thereof and a weakening of the arguments in support of this option, previously strongly favoured as a potential working solution. As a result, our brief was extended to include consideration of this new material, our responses to which are included herein.

Approach

The independent review has been undertaken by a team of Jacobs Babtie specialists who also sought the assistance of a number of external consultants who were able to offer relevant, high level opinion on various issues. Within the limited period allocated for this review, we have focused on the key factors upon which the arguments were developed and on which the solutions proposed in the TTSS report are based. For ease of assessment, this Executive Summary and this report as a whole have been structured to mirror the key elements of the TTSS Reports.

Objectives

Based on a careful review of the TTSS data and a brief visit to the Tideway, it appears that sewage-derived material only accounts for about 10% of the total litter load causing aesthetic pollution of the Tideway. As such, whilst complaints and media interest do, from time to time, generate local attention, the impact of sewage-derived material on the public at large can be said to be limited. Major capital investment to limit pollution from this source, except as part of a larger scheme, is therefore difficult to justify. This is borne out by the cost benefit studies.

Dissolved oxygen (DO) levels in the Tideway were modelled as part of the TTSS, for a representative range of storm events. Solution options were assessed as compliant when the reference DO level was maintained throughout the length of the Tideway. The arguments presented in the TTSS, and crucially in the cost benefit analysis, are centred around the issue of reducing significant fish kills. However the vast majority of fish kills will be resolved by the already funded AMP4/AMP5 sewage treatment works' improvements. No cost benefit analysis has been carried out on the sustainability issue that is the principal additional ecological benefit of the Tideway scheme. Before committing large capital investment to CSO improvement works to achieve relatively incremental improvements in DO levels over those likely to result from the AMP4/AMP5 works, re-analysis of the criteria and the cost benefit study would be prudent.

A review of the bacteriological data and the associated analysis by Professor David Kay, an acknowledged expert in the field, suggests that the available information was insufficient to draw clear conclusions and the statistical analysis was not consistent with World Health Organisation (WHO) guidelines. Furthermore the indications are that the background water quality in the Thames under dry weather flow conditions is not as good as implied by the TTSS. This has subsequently been confirmed by the TTSS team – although still using the limited dataset available. In consequence, the cost benefit analysis would appear to have been carried out on the basis of inflated benefits. Investment in reducing CSO spills is unlikely to resolve the human health issues, although a significant reduction in risk might still be derived.

Our review has indicated that the numbers of recreational water users who are likely to experience immersion and therefore be at risk is likely to be smaller than the numbers quoted in the TTSS report. It may therefore be more economic to limit the area, or stretches of the Tideway to which health risk criteria are applied. If health risk reduction is to remain a key objective, further sampling and analysis should be undertaken to support a revised cost benefit study. Furthermore, we recommend that a model of the bacteria levels in the Tideway, similar to the DO model developed for the TTSS should be commissioned and used to gain a better understanding of this issue and as a basis for the development of solutions.

Strategies

Four potential strategies to mitigate the impact of CSO discharges were identified in the TTSS and expressed in terms of the location at which a storm water management solution would be applied. Strategies 1 to 4 respectively intervene 'before the rain water enters the sewerage system', 'within the sewerage system', 'at the CSO outfall' and 'in the river itself'.

The merits of each strategy were considered by the TTSS in terms of a stand-alone solution. All but Strategy 3, 'to manage the storm water at the CSO outfall', were discarded on grounds of potential cost, disruption to life in the metropolis or, in the case of the 'in-river' strategy the fact that this only dealt with the CSO discharge after it entered the Tideway. Solutions were only developed in the TTSS on the basis of Strategy 3, dealing with the storm water 'at the CSO outfall'. As noted above, the Strategy 3 'preferred solution' comprises a single storage and transfer tunnel from west to east. In the Steering Group Supplementary Report in November 2005, TTSS recommended that limited solutions from other strategies are used to supplement Strategy 3 where these can be shown to provide additional short term or long term benefits.

In our review, we considered the partial benefits which might derive from each of the strategies. We also considered a further strategy identified by Ofwat in the brief; managing the storm water by means of treatment facilities in the Tideway, located on an island or a floating barge or a bankside location.

Against this background our approach focused on identifying the latest thinking and practice in resolving pollution problems in urban waterways and on drawing parallels with other major world cities. We looked in particular at the Massachusetts Water Resource Authority's Boston Harbour Scheme. The strategies adopted in London and Boston have much in common, including the initial approach which was based on a single tunnel solution. After considerable review the Boston Harbour plan was revised and the cost substantially reduced in consequence of applying a composite solution, drawing on elements of the same four core strategies that the TTSS has investigated. As a general comment, the integrated Stormwater Management Strategy applied in Boston was very relevant and helped inform our approach to this study. However, differences in the nature of the Boston and London catchment mean that the specific solutions devised in Boston cannot be readily transplanted to the Tideway catchment, though there is an opportunity to benefit from further consideration of the lessons learnt in Boston.

We have identified a number of potential solutions drawn from all four TTSS strategies, which we believe, after further review, may produce cost effective schemes that, collectively, provide satisfactory improvements to conditions in the Tideway. We have named this Strategy 5, Integrated Stormwater Management. Strategy 5 might typically include source control or sustainable urban drainage (SUDS) solutions applied before the rainwater enters the system, separation, storage and real time control within the sewerage system. Other elements may include management of the storm water at the CSO outfall by means of storage tunnels and partial primary treatment of the stored CSO discharge, the use of skimmer craft to collect litter from the Tideway and in-river and possibly bankside re-oxygenation equipment, such as bubblers and peroxide dosing. Pressing demands from the network require that Strategy 5 must be applied as a series of staged measures. In the first instance, we consider that the most immediate and significant improvements can be achieved using solutions drawn from Strategies 3 and 4 – a similar approach to that taken by TTSS in deriving Option A(Ref.) and the interim measures. The immediate imperative to remediate the River Lee ahead of the Olympic Games in 2012 should be addressed as a matter of urgency. Notwithstanding the initial use of Strategies 3 and 4 at the other end of the timescale the application of SUDS measures should be examined and, if found viable, introduced as a long term measure. We believe our Strategy 5 approach has the benefit of reducing the focus on achieving full compliance using only a Strategy 3 solution, and enables greater emphasis to be given to locally beneficial solutions that might ultimately provide a more effective overall solution.

The evaluation of solutions designed to manage the stormwater problem within the sewerage system requires a sewerage network model capable of accurately representing the performance of the networks under storm conditions. Such a capability should be developed as an integral part of solution identification and development. We are advised that the current model is only verified under dry weather conditions.

Solutions

The evidence suggests that a combination of partial solutions could provide potentially significant savings over the current 'preferred solution'. To illustrate this, we have derived an alternative solution, Solution X.

With only a slight reassessment of the existing objectives, Solution X has the potential to deliver a significant proportion of the benefits offered by the TTSS 'preferred solution', Option A (Ref.), capturing approximately 70% of the unsatisfactory storm spills at a cost of circa 50% when compared to Option A (Ref.).

Comprising elements of TTSS's Option H (new) 7.2m dia., this solution substantially meets the existing TTSS objectives. In order to facilitate comparisons with existing TTSS proposals, Solution X has been costed using TTSS 2004 base cost data. Key components of Solution X are; a 9km long, 7.2m diameter western storage tunnel from Hammersmith to Heathwall and associated screening plant at Heathwall; new primary treatment facilities at Abbey Mills and in-river skimmers. The estimated cost of this option at 2004 prices is approximately £0.9bn and is substantially less than the £1.7bn indicative cost of Option A (Ref.). Solution X incorporates the principles of Strategy 5, incorporating as it does elements of Strategies 3 and 4 in the short to medium term with a greater emphasis on Strategies 1 and 2 in the longer term.

In carrying out this review, we have also looked at the issues surrounding the construction, operation and maintenance of the TTSS identified solutions. We have identified a number of areas where further investigations should be undertaken to assess potential technical and financial risks. Key issues identified include tunnel watertightness, flushing and ventilation.

The issues raised in this report merit discussion by Ofwat and relevant representatives of the TTSS team to confirm their validity prior to proceeding with further investigations.

Summary

We have identified an alternative scheme that, if implemented, could protect the Tideway from the adverse effects of stormwater discharges at a significantly lower cost than the 'preferred solution'. Prior to implementing the TTSS proposals, further work should be instigated to:

- refine the objective criteria and reflect this in the design criteria applied to the chosen solution;
- re-assess the benefits that will be secured through completion of the AMP4/AMP5 capital programmes and consider any further benefits which may derive from enhanced treatment at the existing works such as UV disinfection;
- assess the impact and optimum arrangement of the proposed alternative solution;
- consider in detail, the part which solutions based on source control/SUDS, in-sewer control and in-river treatment could play;
- develop a network model capable of assessing possible in-sewer solutions;
- investigate the technical issues associated with the tunnel solution;
- revisit the cost benefit study once the objectives have been confirmed;
- carry out a more detailed investigation into the technical and financial risks associated with the solutions identified in this review; and
- Commission the development of a model to assess bacteria levels in the Tideway to be used as a basis to quantify health risk issues and develop solutions.

1.0 INTRODUCTION

1.1 Thames Tideway Strategic Study

There has been an ongoing national programme of improvements to unsatisfactory storm discharges since privatisation of the water industry in 1989. As a consequence, most major conurbations have seen substantial improvements. Owing to the scale and complexities of the sewer network, London has remained an exception. There have previously been proposals to address these discharges but the cost and disruption has always been considered prohibitive. As a medium term measure, fixed and mobile oxygenation equipment has been employed 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 resulted in a thorough review of all the issues and possible options, which commenced in 2000.

The Thames Tideway Strategic Study (TTSS) was initially set up as a three year programme, 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. 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 was concerned only with the upper and middles reaches between Teddington and Purfleet. Figs 1.1 and 1.2 (previously published in the TTSS Steering Group Report of February 2005) show the Tideway area and its principal catchments and outfall locations.

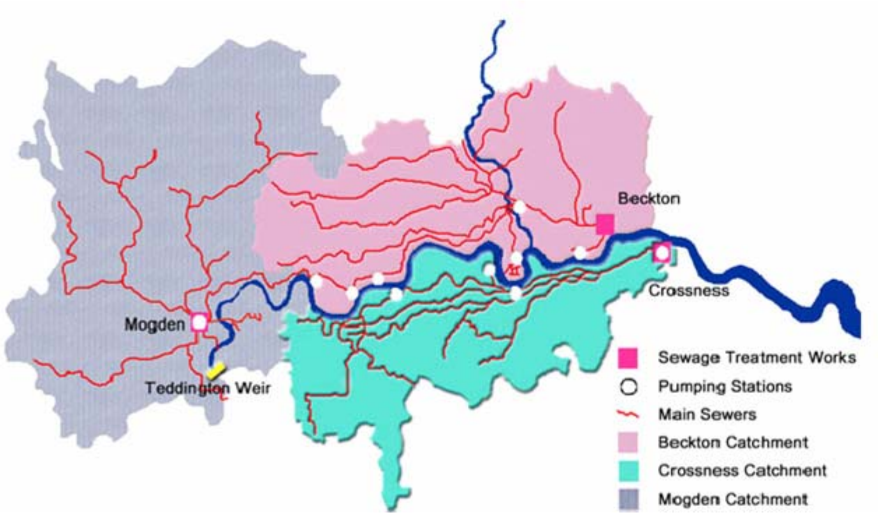

Fig 1.1 Tideway Area and Principal Catchments

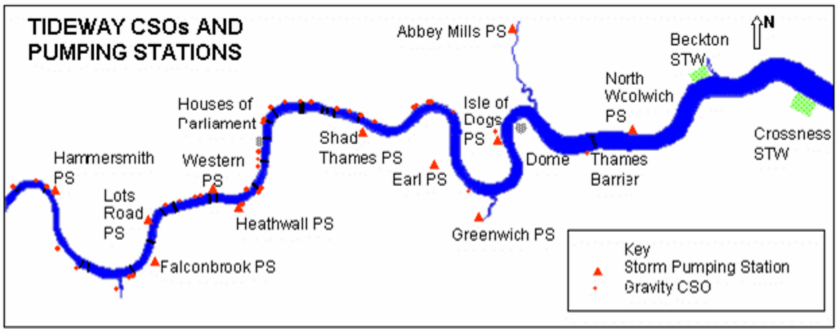

Fig 1.2 – Thames Tideway Storm Sewage Outfall Locations

The TTSS has now been completed and a 35km long storage and transfer tunnel has been identified as the preferred solution. This would run from Hammersmith to Crossness, intercepting most storm flows from 36 of the 57 combined sewer overflows (CSOs) along the Tideway and delivering them for (at least) enhanced primary treatment before discharge to the estuary. Between one and two spills are still expected to occur each year.

Thames Water, the Environment Agency, the Department for Environment, Food and Rural Affairs (Defra) and the Greater London Authority have all participated in the TTSS study. The Office of Water Services (Ofwat) attended Project Steering Group meetings in the capacity of 'observer'.

1.2 The Need for Review

The estimated capital cost of the preferred solution identified in the TTSS report is £1.7 billion at 2004 prices, with a delivery time of some 15 years. As a result of the significance, magnitude and impacts of the proposal, Ofwat identified the need to undertake a "review of the outputs of the Thames Tideway Strategies Study (TTSS) Report with a view to identifying possible strategies/schemes that may, in terms of costs and benefits, compare favourably with the options identified as the 'preferred solution' by the TTSS. This will necessitate outline costings of any option(s) identified."

The review is envisaged as comprising two phases, this report forming Phase 1. Depending on the outcome of the Phase 1 review, a second Phase may be commissioned. It is currently envisaged that the broad aim would be to develop an alternative scheme identified in Phase 1 as offering potential, to the point where quantitative comparison can be reliably made with the 'preferred option'.

The Brief for the review is given in full in Appendix 1 and the objectives and scope of work are summarised below.

1.3 The Phase 1 Objectives

Paraphrasing Ofwat's brief, the objective of Phase 1 is to review the work carried out in the course of the TTSS and to identify any alternative strategies or solutions, which will meet the objectives of the TTSS Study either not considered or considered insufficiently in the TTSS and which offer a realistic prospect, upon development, of being able to partially achieve the benefits at lower unit cost than the TTSS recommended solution.

The objectives established by the TTSS study refers to the targets for reducing aesthetic impact by reducing spill frequency, percentage reduction in days of elevated health risk and dissolved oxygen standards against which all identified TTSS Options were tested. The proposed strategies/solutions may address the objectives independently.

Alternative strategies should include the feasibility of providing treatment of storm flows at or upstream of the CSOs on the Tideway or at in-river treatment installations (permanent barges/islands) or by utilising foreshore space. Furthermore, strategies/solutions must take due account of the constraints imposed by available space and determine the approximate space required for each element of any scheme identified as offering a potential (partial) solution.

Outline cost estimates are to be derived for any option identified as potentially offering an economic (partial) solution compared with the TTSS's preferred solution.

1.4 Scope of Work

As required by Ofwat, the Phase 1 review was to include the following:

- Review, (a) the suite of main TTSS reports, (b) any subsidiary reports and other references listed in the appendices to the main TTSS reports which are considered relevant and (c) the latest version of the supplementary clarifications report made available to Jacobs Babtie (version 7.1) and any relevant subsidiary reports.

- Identify any explicit or implicit assumptions that impose unnecessary constraints on the solution options considered. Should schemes, identified as representing a potential partial solution, rely on alternative assumptions, then these assumptions should be identified and justified.

- Identify any gaps in the work undertaken in the course of the TTSS where further study may help to identify cost-effective partial solutions. Any recommendations for further studies should be explained and justified.

- Consider the feasibility of providing treatment of storm flows at or upstream of the CSOs on the Tideway or at in-river installations or by utilising foreshore space.

- Schemes that only improve a proportion of the 36 CSOs intercepted by the 'preferred solution' may be considered. A sub-set of the Tideway CSOs may be selected as the focus of the Phase 1 feasibility study.

The original intention of Ofwat's brief as reproduced above was that this report should address those key TTSS reports and documents that were available when the review commenced in August 2005. This material included draft version 7.1 (August 2005) of the 'TTSS Steering Group – Supplementary Report' as referenced in 'a' above. The draft Supplementary Report was one of the key documents reviewed by us and had a major impact on our findings. These were first published in our report 'TTSS Review - Phase 1 Final Report' which was issued in early December 2005.

On 29 November 2005, immediately prior to the issue of our December 2005 report, the TTSS team published a final version of their Supplementary Report now retitled 'Supplementary Report to Government'. This report exhibits a number of differences in its findings when compared with draft version 7.1. In particular, key changes included a revision to the storage capacity of the tunnel for Option H (although the same does not appear to have been applied to Option A(Ref.)) and a weakening of the arguments in support of this option, previously strongly favoured as a potential working solution. As a result, we were invited by Ofwat to revise our December 2005 report to take into consideration the new material and arguments presented in the November final Supplementary Report. Our responses to these changes are presented herein as fully integrated text within this revised issue of our TTSS Review - Phase 1 Final Report. Whilst this revised report is written to stand alone, reference to our December 2005 report may prove beneficial in informing the reader of the nature of the on-going changes in approach to the resolution of water quality issues arising from stormwater discharges to the Tideway.

Whilst not forming a formal part of the brief, this report has been extended to take cognisance of the needs of the 2012 Olympic Games which will be largely held within the Tideway catchment area.

1.5 Method of Approach

In undertaking our review, we have followed the same logic as that adopted by TTSS, i.e. we have sought; to examine the objectives; to consider viable strategies; and then to assess a range of feasible options by which a solution might be achieved. The structure of this report reflects this logic. Our intended methodology was set out in our tender submission, inter alia to identify a set of partial solutions which would substantially meet the objectives, albeit less completely than the TTSS scheme, but at lower cost. In this way, we would satisfy the requirements of the Brief identified in sections 1.2 and 1.3 above.

In our review we have addressed the issues identified in the Brief and in our tender submission. However, during the course of our review, facts emerged which led us to challenge some of the principles on which the conclusions of the TTSS reports are based. Most notably:-

- It became apparent that there may be inconsistencies in the presentation of some of the data used in the development of the TTSS objectives and on which the strategies, cost benefit analysis, solutions review and the selection of the 'preferred solution' are based. These should be the subject of further investigation and;

- The TTSS team primarily focused on single, 'whole catchment' strategies. Whilst given some attention in the TTSS reports, we believe that more attention could have been given to what we have called 'Strategy 5', the adoption of a 'basket' of improvement strategies applied partially, over a period of time, to suit local conditions and requirements across the Tideway area.

With the agreement of Ofwat, we revised the methodology, focus of the study and the content of this report in order to capture these key issues and to explore some of their consequences. In particular, we have diverted our efforts to focus more on the objectives and strategies elements of the TTSS than was originally intended.

In turn, and to comply with the limited timescales and budgetary constraints of the study, we have varied the levels of our inputs to the development of partial solutions and to the review of those solutions developed by TTSS, particularly where the parameters on which these are based are now themselves the subject of further review.

1.6 The Review Team

This independent review of the Thames Tideway Strategic Study was undertaken by a team lead by Jacobs Babtie. The team comprised experienced wastewater engineers and scientists from Jacobs Babtie supported by acknowledged experts brought into the team because of their relevant specialist knowledge and skills. These included:-

- Dr Andrew Turnpenny of Jacobs Babtie. Andrew undertook the fish trials for the TTSS team to determine the susceptibility of various fish species to reduced dissolved oxygen concentrations following major CSO events. He sits on the EA's Water Framework Directive Group of Fisheries Experts for Transitional Waters. His principal role has been to advise on TTSS's ecological objective.

- Paul Dempsey is the Pollution Management Programme Manager within WRc. He developed and applied the compliance test procedure to evaluate the impact of the strategies to improve the Thames Tideway. Paul's principal role within the team has been to advise on the modelling work undertaken for the TTSS.

- Dennis Doherty is Jacobs' Lead Design Manager for the East Boston Branch Sewer Relief Project for the Massachusetts Water Resource Authority. Dennis' role was to bring knowledge of experience gained in the implementation of CSO improvement works in Boston to the team.

- Professor Richard Ashley is Managing Director of Pennine Water Group, a centre dedicated to research into water and wastewater. Based at the Universities of Sheffield and Bradford, Richard and his team have provided advice on alternative strategies, in particular the application of SUDS.

- Professor David Kay is Professor of Environment and Health at University of Wales and Director of the Centre for Research into Environment and Health. David worked with the World Health Organisation in developing the guideline standards that are quoted in the TTSS analysis. David's role has been to advise on TTSS's human health objective.

2.0 OBJECTIVES REVIEW

2.1 Introduction

The TTSS was set up to assess the environmental impact of intermittent discharges from combined sewer overflows (CSOs) on the Thames Tideway, to identify objectives for improvement and to propose solutions, having regard to costs and benefits. The overarching aim was to protect the Thames Tideway from the adverse effects of stormwater discharges from CSOs.

Three ‘high level’ principal objectives were defined for the TTSS as follows;

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

There are no specific and relevant statutory requirements for the water quality of the Thames, so aesthetic pollution criteria were developed by the TTSS team to bring the Tideway broadly into line with the perceived requirements of the Urban Waste Water Treatment Directive (UWWTD) and water quality criteria were established in anticipation of the Water Framework Directive (WFD). Finally, criteria aimed at minimising the risks to the health of those coming into direct contact with the water were developed on the basis of World Health Organisation (WHO) standards.

A large volume of analytical work was carried out to support these objectives and to derive well defined standards against which the strategies and solutions subsequently developed could be judged for compliance.

In general terms, these are;

- To reduce the frequency of operation and limit pollution from discharges which cause significant aesthetic pollution, to the point where they cease to have significant adverse impact;
- To limit ecological damage by complying with appropriate dissolved oxygen (DO) standards and;
- To help protect river users by substantially reducing the number of ‘elevated health risk’ days following CSO discharges.

The Brief for this Independent Review of the TTSS report envisaged the work being carried out on the basis of the “Objectives established for the study”. However, in our proposal to Ofwat to undertake this review, we recognised a need to reconsider the objective criteria, which, in turn, underpin the cost benefit analysis and thereby, the validity of the conclusions.

Our objective review has sought to check the qualitative and quantitative support for the criteria used to assess the environmental impacts, and to qualify how their achievement would lead to improved conditions in the Tideway. We have drawn on expert opinion, particularly in relation to the ecological and health objectives, in carrying out this review.

2.2 Aesthetics

The complicated and reticular configuration of the sewer and overflow network in London causes particular problems that are largely unique to the city. In particular, the hydraulic arrangements of the networks generally make it impracticable to readily fit chambers with the weirs/ baffles/ screens which are the key features of modern ‘satisfactory’ CSOs and which facilitate gross solids to be retained in the sewer or captured by screening plant. Thus, this particular approach to the reduction of aesthetic pollution, often applied elsewhere as a simple and rapid retrofit solution is not well suited to the CSOs spilling to the Tideway. As a result, most existing Tideway CSOs continue to spill all of the solids presented to them.

The TTSS Objectives Working Group Final Report states;

> “It has been calculated that approximately 10,000 tonnes of sewage-derived solids (including paper, condoms, faecal material, sanitary towels and syringes) is discharged from the CSOs into the river every year”.

TTSS indicates that this quantity represents approximately 10% of the total litter in the Tideway.

The report ‘An Assessment of the Frequency of Operation and Environmental Impact of the Tideway CSOs’ identifies 25 of the 57 CSOs in question as causing adverse aesthetic impact; discharges from two of these occur less often than 12 times per year, and one less than twice per year. A further 10 CSOs that fail the criteria for inclusion on the list – spilling less frequently and / or of proportionately low spill volume are included because of Environment Agency (EA) / Thames Water observations, or a history of public complaint.

On the 31 August 2005 Jacobs Babtie toured the Thames Tideway from Greenland Pier to Acton, as guests of the EA on their water quality monitoring launch ‘Thames Guardian’. During the course of the tour, undertaken on a dry day, several days after the most recent rainstorms, floating debris was seen in several locations. Fig 2.1 refers. The slicks that the TTSS describes in its reports were observed, and on close inspection it was clear that some of the debris contained in them was sewage-derived. However, our opinion is that it would not be immediately apparent to a casual observer that the debris was any more than windblown litter and vegetation – a fact reflected in public survey responses obtained during the TTSS.

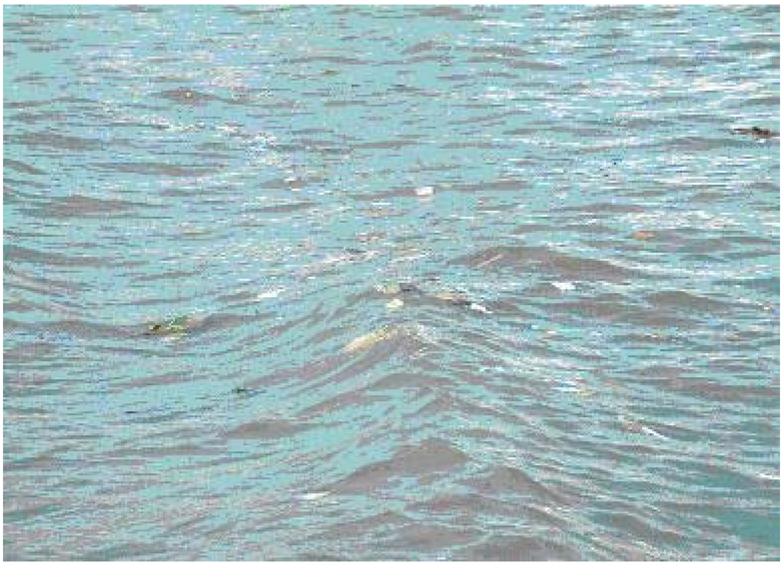

Fig 2.1: Floating litter & leaf debris forming a slick near Dove Pier

In addition to the slicks, litter was seen to have accumulated on the banks of the Tideway as illustrated in Fig 2.2. However, much of this is coarse debris which is likely to have originated from sources other than the CSO discharges.

Fig 2.2: Litter accumulated on the banks of the Tideway

Much of the bankside of the Tideway is overlooked from adjoining residential and commercial buildings or is accessible to the public, albeit access to the actual waterside is made only infrequently. Numerous leisure vessels provide visitors to London with river tours. Thus bankside litter deposits may be considered a very visible and aesthetically unattractive feature from a public standpoint.

In reviewing the TTSS reports, we have been unable to ascertain how the quantity of 10,000 tonnes per annum of sewage-derived solids referred to above has been arrived at, although we understand this is based on application of reasonable engineering judgement to the available data. It does not appear to be an unreasonable estimate. Our own calculations indicates between 4,000 tonnes and 11,000 tonnes – although between 40% and 50% of this could be inorganic 'grit' that will settle quickly and cause little aesthetic nuisance.

The 10% proportion of the total litter referred to previously as being sewage derived is understood to have been supplied by the Tidy Britain Group, we presume based on analysis following their litter pick campaigns on the tideline. It would be useful to have the derivation of this figure since it is key to the development of the cost benefit case for the scheme.

Referring to our tour of the Tideway, it was clear that some of the observed solids may not have been derived from sewer discharges, and were certainly not 'sewage solids' in the traditional sense, for example crisp packets and drinks bottles along with many branches and leaves. From discussions with the Port of London Authority (PLA) we understand that they recover a considerable volume of floatable wind-blown and tipping derived litter from the river and bankside - some 500 dry tonnes is collected from the Tideway each year.

The sewerage network for central London includes many former watercourses. Parks and public open spaces discharge to the sewerage network in storms. It might therefore be expected that a proportion of the solids that discharge from the CSOs is not necessarily what would be defined as sewage-derived solids. These solids might typically include leaves, branches and other surface debris which are unlikely to cause a particular aesthetic nuisance.

Reference is made in the TTSS reports to the Screening Investigation Test Trial and Evaluation Rig 'SCITTER' but there does not appear to be a detailed analysis of solids nor a re-evaluation of total CSO discharges. TTSS Appendix 13a - Summary Paper on Litter Disposal estimates the volume of screenings from Abbey Mills (where the screens are said by TTSS to be working ineffectually) as 3,200 tonnes per year representing nearly 33% of the 10,000 tonnes of sewage-derived solids said to be discharging from the CSOs each year.

Whilst the broad estimate of sewage-derived solids quantities appears reasonable, we have been unable to find clear evidence or calculations to support the quantities, spatial occurrence and assertions as regards sewage-derived solids that specifically cause significant aesthetic pollution. A more rigorous approach would undoubtedly provide greater insight into the nature of aesthetic pollution in the networks and Tideway and would better inform decision making in how to address this issue. To add to this, a good example of the benefits of such an approach was the very thorough river quality modelling exercise undertaken by the TTSS team which proved key to identifying the impact of sewage works wet weather spills and the Abbey Mills discharge that would not otherwise have been considered.

Whilst we recognise the practical difficulty in ascertaining a detailed quantitative assessment in a project of this scale, we consider it would be beneficial to quantify the coarseness of data available in support of this objective - there is a recognised procedure for assessing the impact of CSOs, FR0466 'User Guide for Assessing the Impact of CSOs', developed by the Foundation for Water Research on behalf of the then National Rivers Authority (now the EA). This approach does not appear to have been adopted in the TTSS.

With regard to the public impact of sewage-derived aesthetic pollution, 'The Market Benefits of Options for the Thames Tideway', report produced by eftec and appended to the TTSS Cost Benefit Working Group Report states;

> "…although reducing CSO events would be associated with reduced amounts of sewage litter, this is currently only a small (10 per cent) proportion of the total litter and debris in the Tideway at any one time, and what there is, appears to be invisible much of the time, at least as far as individual perceptions are concerned.
>
> This is one of the findings of the SP (TTSS's stated preference survey) as well as being the view expressed by consultees from the London property market. We might expect certain-river users to notice a difference, in particular those who come into close contact with the water, such as rowers, houseboat owners and those who frequently walk by the river. However, in general the public are unlikely to detect much visible difference, and this includes owners of riverside property who, as we have just argued, tend to partake in river-based activities from a greater 'distance'. The aesthetic water quality indicator employed in the hedonic studies examined above was some measure of clarity. The Thames is a tidal river downstream from Teddington, and levels of suspended silt and mud in the water are naturally high and always will be. Reducing CSO events will not have any impact in this regard.
>
> **Therefore, little aesthetic change in the water is to be expected due to Tideway Strategy options, and this, together with the low correlation between riverside residence and involvement in river-based water sports, suggests that any impact of the Tideway options on property prices is likely to be minor**."
> [emboldment of last sentence by eftec].

The need for significant sewerage infrastructure investment to deliver a low level of perceived qualitative benefit, and remove a low percentage of the total litter is therefore open to challenge.

During the consultation period for this report, this assertion has been challenged by the Environment Agency who cite various complaints received from members of the public and highlighted by the press or campaign groups such as Surfers Against Sewage and Rowers Against Thames Sewage as evidence of the need to address the litter problem. Our opinion is that this needs to be set in the context of the improvements which may be derived and the cost of achieving them.

Aesthetic pollution is related to many urban activities and our experience elsewhere is that when better informed, the public are less likely to blame the water undertaker for pollution. We therefore consider it important that efforts should be made to educate the public as to the relatively minor proportion of sewage-derived material present in the Tideway when compared to the much larger quantities of litter derived from other sources, and the generally ‘murky’ outlook of the Thames that will always persist because of natural processes. Furthermore, such a campaign of education should emphasise the fact that most of this litter will remain irrespective of any amount of investment in the sewerage system.

Conclusion: Reducing aesthetic pollution in the Tideway is a credible objective. However our initial review of the arguments presented in the TTSS reports appears to indicate that whilst there is without doubt impact from the sewage solids discharges, the evidence to support investment on the scale proposed is limited. Further analysis of the quantitative and qualitative impact of sewage-derived material is needed before any potential benefit from this objective can be considered as ‘proven’.

Recommendation: Before committing to any investment to meet this objective a more robust impact assessment and quantitative criteria should be provided.

2.3 Ecology

This element of the study was undertaken in collaboration with Dr Andrew Turnpenny of Jacobs Babtie. A summary of Andrew’s observations on the TTSS reports is included herein as Appendix 2.1.

In the 1960’s, the fish population in the Tideway stood at virtually nil species recorded, such was the low level of water quality at that time. The situation has improved significantly since then with more than 120 species having been recorded in recent years. This is due largely to significant investment by Thames Water and its predecessors. As a result, the Thames is now regarded as an example of the extent to which polluted rivers can be improved. The aquatic population appears to have largely reached a plateau after a long period of developing and diversifying. The river is still subject to ecological impacts from our use of its water, in particular, the TTSS identifies that some of the more sensitive species, such as the salmonids, which swim upstream to breed beyond the tidal Thames, may be limited by low DO levels.

The TTSS considers that the current intermittent discharges in wet weather from the sewage treatment works and CSOs are a major factor limiting the status of fish populations. It identified a number of factors, supported by river quality modelling and a field and laboratory study into the oxygen requirements of fish, which impact on the ecology in the Tideway. These include:-

- Low flows (caused primarily by upstream water abstraction needs) and high temperatures leading to natural degradation of DO levels in the summer and potential eutrophication;

- Oxygen consumption by treated effluent loads discharged from the sewage works into the Tideway;

- Oxygen consumption by treatment works mixed liquors (MLSS) discharged as a result of capacity constraints at Mogden works;

- Oxygen consumption by storm sewage loads discharged intermittently from sewage treatment works into the Tideway;
- Oxygen consumption by storm sewage loads discharged intermittently from the CSOs in the Tideway;
- Potential unverified impacts of 'sediment oxygen demand' (SOD) from re-suspended solids, particularly in the middle reaches.

As a result of the modelling and fish studies, the TTSS has proposed absolute limits applied uniformly across the river, which must not be breached over a series of return periods. See Table 2.1 below. These standards have been set to ensure that the visible fish kills that have occurred in the past will be largely eliminated, and that other impacts on the lifecycle of the various species in the river arising from reduced DO levels, such as increased susceptibility to infection, and depressed rates of feeding and reproduction, are greatly reduced. The strategies and solutions reported in the TTSS were then ranked against their respective abilities to achieve these DO standards.

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 ≥ 3km. 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 would be assessed using the network of AQMS stations.		

Table 2.1 – DO Standards for the Tideway as proposed by TTSS

Whilst discharges from the CSOs undoubtedly affect the ecology of the Tideway, it is important that the substantial impact of discharges from the sewage treatment works should not be overlooked. Having set out to develop a CSO upgrading scheme to prevent DO problems in the Tideway, the TTSS team found during the course of the study that discharges from the sewage treatment works have, for most of the time, an overriding impact on DO levels in the Tideway. In particular, the TTSS Objectives Working Group Report Volume 2, Modelling Report states;

> "The 2003 CTP [Compliance Testing Procedure] runs had shown that without including proposed AMP4 / AMP 5 improvements, the estuary was failing the DO standards even under no storm conditions."

To address this issue, Thames Water will make a significant investment in AMP4/AMP5 to increase the treatment capacity at the existing works reducing their impact so that the likelihood of large fish kills will be greatly reduced. We note that the AMP4 / AMP 5 sewage treatment works improvements at Mogden, do not include the provision of tertiary polishing processes such as are proposed for the works' at Beckton and Crossness. This is despite the fact that Mogden sewage treatment works discharges into the more sensitive areas of the upper Tideway. Appendix D of the TTSS Cost Benefit Working Group Report refers.

The TTSS presents some useful figures that demonstrate the relative benefits on fish mortality to be gained from improvement works to both sewage treatment works and CSOs. Table 2.2 below is based on extracts from Table 3 and Table 7 of the TTSS Cost Benefit Working Group Report.

Upgrading Option	Modelled fish kills per annum (CSO related)	Modelled fish kills per annum (Total)	Percentage improvement
Nil; Current situation	2.7	8	N.A.
Sewage Treatment Works upgrades only	0.36	1.53	81-87%
A low /A (Ref.) only, ie. the recommended solution	2.2	Pro-rata assumption of 7.5	6-19%
Sewage Treatment Works upgrades plus A low /A (Ref.)	0.2	Pro-rata assumption of 1.37	83-93%

Table 2.2 Impact of Sewage Treatment Works and CSO Upgrading on Fish Mortality

Clarification of the data is provided by the following statement in the above report:-

> " In terms of Fish Population, the observed number of potential fish kills per year, as used in the stated preference survey, is eight [i.e. the maximum under current conditions]. However these are driven by a number of factors not related to CSO discharges. Therefore mathematical modelling was used to estimate the number of fish kills arising from CSO discharges alone. The resulting estimate [i.e. the modelled kills] was 2.7 kills per year and this is the baseline used for comparison of the performance of the CSO only solutions"

Further issues raised by our consultation with Dr Turnpenny but not discussed in the TTSS are;

- The most stringent of the TTSS standards are designed to avoid visible fish kills; this requires higher standards than if the criterion was just to create sustainable fish populations. A sustainable fish population of some longer-lived species may be maintained at a mortality rate significantly higher than the 10% per annum chosen to set the TTSS ecological objective. This is often the case in fisheries harvested commercially.

- Laboratory studies carried out on Tideway fish have shown that some fish species show a strong avoidance of low DO levels, suggesting that many larger fish would react to a DO sag by swimming away in search of more well-oxygenated areas. Following the severe August 2004 storm, fish counts in the lower reaches appeared to increase significantly, suggesting fish from the upper and middle reaches may have migrated downstream to find better conditions. It is not known if these fish would subsequently have returned to their pre-storm habitat, or whether this behaviour may apply to the weaker-swimming fry population which would be less likely to outrun an event. Certain species do not in any case react to avoid hypoxia.

- Allied with the avoidance noted above, there is anecdotal evidence of the phenomenon of fish seeking ‘refuge’ in harbours and off-line waters where some hydraulic separation can often be found, although we accept that current opportunities for this in the Tideway are limited. The development of off-line refuges to cope with CSO discharges is being pursued by the Environment Agency elsewhere, for example on the River Trent.

Whilst much emphasis is given by TTSS to the avoidance of fish kills, in particular in the Cost Benefit Analysis, the 2, 3 and 4 mg/l DO standards are also a key part of the TTSS proposals. These standards, whilst still allowing some low levels of fish mortality, primarily aim to protect the impact of depleted DO levels on the fishery lifecycle. They have been set using laboratory analysis and reference to best practice elsewhere. Whilst, there is no doubt that these improvements will enhance the ecological quality of the Tideway, we consider there is scope to apply these standards less rigorously or to apply them spatially to reflect the sensitivity of local fish populations or their ability to swim away from areas deficient in oxygen. In extreme circumstances, whilst this might lead to reduced growth and activity of fish populations, DO standards could be applied locally, as opposed to globally, in such a way that fish mortality targets would not be compromised Where this is feasible, such local relaxations of DO have the potential to facilitate the development of lower priced solutions.

From our discussions with the TTSS team, we understand that the emphasis on fish kills appears to be, in part, to give a simple indicator of solution performance that members of the public partaking in the cost benefit analysis study could readily identify with. However, because of the programmed improvements at AMP4/AMP5, since little change in fish kill reduction will be achieved by any of the Tideway CSO solutions, this appears to undermine the validity of the cost benefit exercise.

Much has been made of the fish kill resulting from the storms in August 2004 and the media and political attention this subsequently attracted. However key to this incident was an extraordinary inundation of Mogden Sewage Treatment Works and the resulting spills from its storm tanks. Statistically we understand this incident was a 1 in 60 year probability event, and that Thames Water, as previously stated, has already committed expenditure in AMP4/AMP5 that will reduce the probability of such an event reoccurring in the future.

Conclusion: Reducing the impact of oxygen depleting discharges from CSO spills in the Tideway is a credible objective. However, the data presented to us in the TTSS reports appear to suggest that discharges from major sewage treatment works into the Tideway currently have, overall, a greater impact on oxygen depletion than those arising from CSO spills during major storm events. Major investment at Mogden, Crossness and Beckton sewage treatment works planned for the AMP4/AMP5 period will substantially address overall problems of DO depletion in the Tideway and will bring with it a significant reduction in fish kill levels. With substantial improvements in Tideway DO levels already budgeted for, it is important to ensure that further, incremental, improvements are achieved in a cost effective way. Key to this is the need to consider challenging the standards proposed by the TTSS team especially where it can be shown that the application of slightly less onerous standards may still deliver noticeable environmental improvements but at lesser unit cost.

Furthermore, the manner in which the DO criteria are applied uniformly along the Tideway does not allow for the variations in ecological risk in different stretches of the river and in not taking account of fish behaviour may be setting an unnecessarily high standard.

Recommendation: Before committing to a large capital investment to achieve a relatively small incremental improvement above and beyond the DO improvements which will be delivered by the programmed AMP4 / AMP5 works, re-analysis of the criteria and cost benefit study would be prudent. It may be practicable to set revised DO compliance standards that do not set such a high level of environmental quality but which better reflect the sensitivity of the local fish populations. The ability of the larger, more ecologically valuable fish to actively avoid areas of hypoxia should be properly investigated and considered within the solution.

2.4 Human Health

Through surveys, the TTSS has established that there are significant numbers of recreational users of the Tideway – 3000-5000 persons per week. A proportion of these might be exposed to elevated levels of bacterial contamination in the two days following CSO discharges. These users are primarily located in two distinct clusters of approximately equal size: in the upper reaches upstream of Vauxhall; and in the London Docklands area. Because of the facility to isolate the London Docklands hydraulically from the main Tideway, this body of water can be considered as being controlled. As a result, we understand that the TTSS team does not consider users of the London Docklands waters to be at undue risk from CSO spills. This leaves 1500-2500 users per week in the upper reaches of the Tideway. The presence of storm sewage effluent in the Tideway after CSO spills creates an elevated risk to the health of those river users that come into direct contact with it.

The TTSS report identifies 19 of the 57 CSOs in question as causing adverse health impact; discharges from two of these occur less often than 12 times per year, and one less than twice per year.

Existing legislation in relation to health risk in the water environment is limited to the EU Bathing Water Directive. Whilst this does not apply to the Tideway it does indicate principles that might be applied:-

Ensure bacteriological quality is maintained at a defined level in the designated water

Limit the number of spills to the designated waters

In attempting to set an acceptable defined limit for bacteriological quality, the TTSS team has elected to adopt World Health Organisation (WHO) standards to benchmark the existing quality and estimate what impact the proposed improvements may make. The data analysis carried out as part of the TTSS to establish broad comparison with WHO Guidelines initially implied near compliance with the WHO's 'possible health risk' standard (i.e. 200 colony forming units or cfu per 100ml) during dry weather throughout the Tideway. The analysis used to establish this was reviewed for us by Professor David Kay, a recognised expert in the field who worked with the WHO in developing the guideline standards. Professor Kay's statistical methodologies are in fact directly referenced in parts of the TTSS. Professor Kay's notes summarising the key findings of his review are included as Appendix 2.2. He found that the analysis was incorrect and overstated the prevailing dry weather quality.

The TTSS team has now reviewed the calculations and has provided revised bacteriological qualities as follows:-

- Dry weather 95%ile – 1,000 cfu per 100ml
- Wet weather 95%ile – 28,000 cfu per 100ml

The Environment Agency has kindly provided the raw data used to determine these qualities but we have not had the opportunity in the timescale of this review to undertake a thorough assessment of it. Unfortunately, this raw data comprises only 24 days of data in total, and once split into 'dry days' and 'wet days' is, in our opinion, not statistically viable.

Whilst these figures indicate a dramatic difference between dry day and wet day water quality, the following points need to be made:-

The dry day quality deteriorated five fold from the original TTSS reports, such that it now falls at the point defined by the WHO standards as 'Likely Health Risk' - as predicted by Prof. Kay.

The data makes no differentiation between sources of bacteriological contamination so that wet day quality will include significant bacteriological load from the sewage treatment works storm overflows, and possibly surface water inputs.

The TTSS reports acknowledge a correlation between the DO sag profile and the bacteriological quality. River quality modelling established that additional treatment at Mogden works is the key to achieving the DO standard throughout the Tideway. It may follow that modelling of the bacteriological impacts of the discharges in the

Tideway might generate a similar finding which, in turn, may lead to the identification of alternative strategies that will deliver significant benefits. One example could be the use of UV disinfection to reduce the levels of bacterial contamination resulting from sewage treatment works' discharges. However given the nature of the urban watercourse under consideration, it may be unrealistic to seek to achieve the aspiration of WHO Bathing Water Quality Guidelines under either wet or dry antecedent conditions in the Tideway.

Bathing water standards are used in the TTSS as a surrogate standard that would apply to recreational waters such as the Tideway. However we note that the predominant water usage is rowing, and that 'immersion' would be expected to be infrequent during such an activity. The actual number of individuals statistically subject to direct exposure is therefore somewhat less than the 3000-5000 per week quoted in the TTSS report (many of whom are, in any case, in the controlled environment of the Docklands)

The TTSS team has used 'elevated health risk days' as a concept to enable some level of comparison to be made between the different levels of protection provided by each option. In its assessment, the TTSS estimates an average of 60 days per annum when spills occur from the set of 57 Tideway CSOs and has allocated weighted health risk days to each of these notional spills. This method of allocation of health risk days takes no account of the distribution and volume of the individual spills. Thus, for example, the CSO at Fleet is given undue prominence when compared to the Environment Agency's criteria for adverse health risk in the Tideway. As stated above in the context of fish kills, this approach appears to have been adopted in order to give a reasonably simple indicator by which cost benefit analysis respondents can access the value of improvements. Whilst we agree that it is a valid approach, its application appears to prejudice against partial solutions that might significantly reduce the level of health risk by tackling the most polluting CSOs whilst still permitting spills from smaller overflows.

As the promise of the river water being largely free of health risk following implementation of the preferred solution underpins the 'willingness to pay' findings, the validity of the Cost Benefit Analysis is likely to be undermined. This issue is addressed in more detail in Section 5 of this report. Secondly, it would appear unlikely that any modification of the CSO regime will have the result originally sought by the TTSS which was to achieve the microbiological standard outlined in the WHO 'Guidelines for the Safe Recreational Water Environment (2003)' which are based on the health effects of contact recreational activities.

Conclusion: Reducing the level of health risk from CSO spills in the Tideway is a credible objective. However the data presented to us in the TTSS indicates that the direct impacts of the CSOs, and consequently the benefits to be derived should the preferred solution be implemented, are optimistic. In essence, we would expect to see a spatial modelling analysis similar to the work carried out to establish the DO benefits to give a robust indication of the impact of the treatment works and CSO discharges on the Tideway. The DO model was used to great effect by the TTSS team in developing its solutions. The absence of such a model means that it is not possible to effectively endorse, or indeed criticise, the human health concepts presented by TTSS and nor is it possible to provide a rigorous definition and understanding of the level and extent of the health risk problem. Without such an understanding, it is very difficult to develop, with any confidence, a robust and cost effective solution.

The cost benefit analysis led respondents to believe that the prevailing bacteriological water quality is good, and only the CSO spills cause it to fail TTSS's human health objectives. This is not correct.

Recommendations: We recommend that if health risk reduction based on the apparent wet day/ dry day approach is to remain a key objective of the TTSS, then further sampling and analysis work be carried out to define the wet day and dry day water quality in comparison with the WHO Guidelines. This would require sufficient samples to underpin a credible 95 percentile calculation for any reach of interest. An alternative objective following the same broad aims might be to present the objective in terms of the projected reduction of the disease burden in preference to health risk days, since this term is misleading in the context of what we expect to be the prevailing bacteriological quality of the Thames. We recommend that a spatial model of the bacterial contamination of the Tideway similar in scope to that developed for the DO assessment should be developed and used as the basis for any solution.

2.5 Other TTSS Objectives

The TTSS identifies two other objectives with which we concur, although, strictly we might consider them to be simply good practice. These are;

- 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.
- We believe a further objective, should be that the solution should be developed in the context of a strategic water environment management strategy for the Thames Tideway and its associated catchment.

We are of the opinion that any solution should not seek solely to mitigate the CSO discharges if it is found that improvements elsewhere can provide equivalent benefits at reduced cost. This would require the chosen solution to demonstrate value for money in terms of its delivery of improvements in proportion to pollution in the Tideway from other sources, not just the unsatisfactory intermittent discharges from the CSOs themselves.

We believe that whilst the three principal objectives all correctly identify that the CSOs have a detrimental impact, the TTSS does not (perhaps because it was not in the original remit) go far enough to show the context of these in relation to the overall water quality in the Tideway.

The solutions developed should be tested against the cost of providing enhanced treatment at the sewage works, or aeration in the Tideway that might provide continuous elevation of water quality and flexibility to mitigate wider problems than just those associated with CSO discharges.

This further objective would also provide weighting to catchment solutions that provide additional benefits such as mitigation of foul flooding or development of new or improved green spaces.

In addition to the above, any chosen scheme should also enable early action with regard to tackling the principal current adverse environmental impacts and be developed in close integration with all other improvements to the sewerage and sewage treatment system.

2.6 Proposed Alternative Objectives

Having reviewed and commented above on the effectiveness of TTSS's stated objectives to capture the water quality needs of the Thames Tideway in respect of stormwater discharges, we offer below possible alternative objectives that we feel go some way to resolving our concerns. If applied in a manner focused to the specific needs of the Tideway, either locally or globally, we believe these alternative objectives will facilitate the development of a wider range of potential solutions still capable of delivering significant benefits at lower cost.

Reduce Aesthetic Pollution

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

The TTSS Steering Group Supplementary report considers the benefits derived from various options in terms of the percentage of flow captured, assuming flow captured equates proportionally to solids captured. This approach is pragmatic in that it accepts that some practicable options will deliver significant benefits without necessarily capturing all the discharges having an aesthetic impact as required by the stated objective. We propose the following alternative wording that would encompass this pragmatic approach and permit partial solutions and ameliorating measures in the river to form a compliant element of a solution package.

JB Proposed Aesthetic Objective: To reduce the mass of offensive sewage solids present in the Tideway significantly such that sewage solids cease to have a significant adverse impact.

In taking this approach, we are not rejecting the need to reduce sewage pollution from stormwater discharges but rather recognising that enhanced visual benefits might equally be achieved through the deployment of fine skimmer craft to target all floating waste in the river to supplement any tunnel solution which by its nature can only ever target the smaller proportion of the total waste that is sewage derived.

Protect the Ecology

Existing TTSS Ecological Objective: To limit ecological damage by complying with appropriate dissolved oxygen (DO) standards.

The TTSS proposes that selected DO standards be applied to stretches of the river over fixed time periods, as detailed in Table 2.1 previously.

To a large extent, the DO objectives tackle distinctly different ecological issues. The key driver behind the setting of the 1.5mg/l DO objective is fish mortality – the regular instances of fish kills of a scale that can have a significant population impact. To reflect this overriding significance, we propose that a revised, two stage, ecological objective should be developed, the first stage being dedicated exclusively to the management of fish kill issues. Our proposed primary objective is as follows:-

JB Proposed Primary Ecological Objective: To limit ecological damage by significantly reducing the number of significant events of fish mortality caused by wet weather discharges by the global application of appropriate primary DO standards.

Taking into consideration the body of work undertaken as part of the TTSS, we propose that the 1.5mg/l DO standard from Table 2.1 be adopted as the primary standard. This is reproduced below as Table 2.3:-

Dissolved Oxygen (mg/l)	Return Period (years)	Duration (tides)
1.5	10	1
Note: The objective applies to any continuous length of river ≥ 3km. 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 would be assessed using the network of AQMS stations.		

Table 2.3 – DO Primary Standards for the Tideway as proposed by Jacobs Babtie

The importance placed on fish mortality issues by the public has been tested in the willingness to pay survey and it has been proven that respondents want to fund improvements in the Tideway which contribute to the prevention of significant fish kills. In fact, as noted earlier, Thames Water customers are already funding sewage treatment works improvements during AMP4/AMP5 that will meet this objective.

The second element of our revised objective is intended to reflect the importance of ecological sustainability issues and is as follows:-

JB Secondary Ecological Objective: To limit ecological stress by complying with appropriate DO standards.

We further propose the establishment of secondary set of DO standards as specified in Table 2.4 below:-

Dissolved Oxygen (mg/l)	Return Period (years)	Duration (tides)
Upstream of London Bridge		
4	1	29
All Tideway		
3	3	3
2	5	1
Note: The objectives apply to any continuous length of river ≥ 3km. 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 would be assessed using the network of AQMS stations.		

Table 2.4 – DO Secondary Standards for the Tideway as proposed by Jacobs Babtie

We contend that these secondary standards, which are slightly less onerous than the primary standard, but which do not compromise the need to prevent significant fish mortality better reflect the wider aims of the ecological objectives. We acknowledge that the set of DO standards proposed in Table 2.1 by the TTSS is also intended to target the levels of stress that might be imposed on the fish populations from depleted DO levels. We agree that this is a valid objective but are concerned that this issue was not tested in the willingness to pay survey.

Protect Health of Recreational Water Users

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

As stated earlier, the usage of the simple 'health risk day' criteria for assessing human health benefits is, we believe, too coarse, and paraphrasing the TTSS's comments in the Supplementary Report leads to an underestimation of the likely benefits of partial solutions even where they capture a significant proportion of those CSOs with a health risk impact.

A revised objective as stated below would facilitate the development of solutions that seek to substantially reduce the total bacterial load discharged in any spill set in similar flow proportional terms to that applied by the TTSS to the delivery of aesthetic improvements;

JB Proposed Health Objective: To reduce the level of risk to the health of river users by substantially reducing the disease burden in recreational areas in wet weather.

As noted previously, respondents to the TTSS ‘willingness to pay’ survey were led to understand that the CSO spills were the principal generator of health risk for recreational users of the Tideway. Revised TTSS figures show that the level of benefit derived from the reduction was overstated – a ‘Likely Health Risk’ classification will remain largely unchanged when compared to the WHO standards. As a result, this objective will need to be retested for ‘willingness to pay'. The survey question presentation should however reflect that a Tideway CSO improvement scheme can be expected to deliver significant reduction in the risk of exposure to bacteria during periods of wet weather.

For the purposes of this report we have used a simplification, approximating ‘disease burden’ to the volume of spill from those CSOs classified by the Environment Agency as causing or potentially causing a health hazard. Ultimately we believe the most appropriate approach should be to develop a model of the bacterial levels in the Tideway and to use it to make a quantitative assessment of the actual exposure to health risk of recreational users. This will enable TTSS to provide a relative assessment of solution effectiveness to a level of confidence similar to that achieved through the DO model analysis.

3.0 STRATEGIES REVIEW

3.1 Introduction

Section 6.1 of the TTSS Solutions Working Group Report Volume 1 identifies and assesses the suitability of four key strategies to deliver the long term objective of significant and permanent improvement in water quality in the Thames Tideway. The strategies are defined by the location at which the storm water management techniques would be applied and are as described below.

Strategy 1 **Before the rain water enters the sewerage system**
e.g. source control, SUDS

Strategy 2 **Within the sewerage system**
e.g. flow separation, local flow attenuation, on or off-line storage

Strategy 3 **At the interface between the sewers and the river (i.e. the CSO outfalls.)**
e.g. screening, storage and/or transfer flows to local or distant sites for treatment. It should be noted that the CSO outfall commonly picks up the discharge from a number of overflow or diversion structures some distance upstream.

Strategy 4 **In the river itself (i.e. treatment of the river water to mitigate the impact of storm water discharges)**
e.g. oxygenating the river water or collecting sewage-derived litter from the flow

The TTSS Solutions Working Group Report identifies potential storm water management options in relation to each strategy, discusses the pros and cons in relation to the sewerage catchment and concludes on the viability of these options to be developed into practical solutions. A brief summary of the arguments and issues arising is given below for each of the four strategies.

In addition to the above, we have added a fifth Strategy. Strategy 5 – Integrated Storm Water Management is a hybrid, using elements of Strategies 1-4. We believe this strategy, which is described below is worthy of due consideration.

3.2 TTSS Strategy 1 - Source Control

This element of the study was undertaken in collaboration with Professor Richard Ashley and his colleagues at Pennine Water Group. A summary of Richard's observations on the TTSS reports is included herein as Appendix 2.3.

The Executive Summary of the TTSS Solutions Working Group Report, Volume 1 concludes that: -

> "…the strategy of preventing storm water from flowing through the sewerage system by source control or SUDS techniques is not considered to be viable".

The TTSS report further states: -

> "…45% of the cityscape is impermeable which represents a very mature urban area with little scope for further infill. There is no prospect of impounding surface water without massive alterations to the system. The widespread retro- fitting of SUDS techniques are considered, at best, disruptive and costly and, at worst, not technically feasible."

These statements are based on the assumption of a single strategy and solution capable of fully resolving the problem of CSO discharges to the Tideway. In this context and when compared with the 'preferred' strategy and solution we would agree with the TTSS conclusion. However this approach fails to capture the benefits of source control techniques at a local level and in support of the other strategies.

Whilst concluding that Strategy 1 is not viable, the TTSS report notes that this strategy

> "could be used in a limited way because of the particular characteristics of the network".

The report goes on to consider where this might be applied but does not progress through to the solutions development stage.

The report also notes the existence of large green areas in north London and some in south London such as parks, (especially the Royal Parks), public heaths and larger public and private gardens all of which drain into the sewer system. Their contribution to storm sewer flows is noted to be a matter of conjecture; they may become nearly impermeable and contribute significantly to storm flows following protracted periods of light rain.

The report concludes that the chance of using such areas to provide source control is likely to be

> "now long-since past exploiting."

It is our view that such source control opportunities should be investigated, although it is the case that the application of such measures would be more appropriate as part of a medium to long term solution for the Tideway catchment rather than an as a short term measure to address the more pressing need to remediate key sections of the river systems ahead of the Olympic Games in 2012. In the first instance a review of sample areas to which SUDS might be applied, in say three types of catchment, could be followed by the identification and assessment of a number of potential schemes.

The TTSS confirms that 25% of land use has >90% permeability, and a further 31% has 55-65% permeability. These areas should afford an opportunity for serious consideration of SUDS retrofit.

The one example of source control noted in the TTSS Solutions Working Group Report is Hampstead Heath, where it was planned, in the 1980's, to intercept rainfall directly from the heath via ditches so as to attenuate flows to the High Level Interceptor. Unfortunately, whilst the associated North London Relief Sewer - Phase 2 was built, the proposed ditches were never constructed due to intractable planning issues. This idea to provide source control could be re-examined.

As noted above, whilst the SUDS approach can never stand alone and is suited to the resolution of problems arising from medium to long term stormwater discharges to the Tideway, it may nevertheless offset spending on larger capital works solutions and will contribute to the future rationalisation and enhancement of the sewerage networks in line with current thinking and practices. Appendix 2.3 refers.

As part of the TTSS SUDS Study, sensitivity analyses were undertaken by Thames Water modellers using the Info Works model for the Crossness catchment to ascertain the impact which SUDS schemes (and separation) might have on spill volumes to the CSO outfalls. This was achieved by the global application of reductions in the impermeability of selected connected areas based on land usage patterns. These reductions were found to have an appreciable impact on the spill volumes generated by the more modest storm events (42% reduction in 36 in 1 year event volume generated by just a 10% reduction in open commercial land), but were less marked on spills arising from the largest storm events (just 6% reduction of 3 in 1 year event). Nevertheless, compared with the modest reduction in area of what should be one of the easier land use types on which to instigate SUDS, the results are quite favourable.

The TTSS's Sustainable Urban Drainage Report, Model Sensitivity Testing states,

> "Overall the results suggest that, if it was feasible to apply SUDS and similar techniques on a widespread basis particularly in areas of Open and Medium Housing and Open Commercial land use, this would have the effect of significantly reducing the volume of many CSO discharges into the Tideway….if more modest performance criteria were adopted, the beneficial effects of SUDS and similar near to source control measures (if they could be implemented widely enough) could be significant"

One particular advantage that may be achieved through SUDS is in the Beckton catchment. We understand that constraints on the capacity of the Beckton works mean that hydraulically the flows from the upper and middle catchments uses the majority of the treatment capacity during storms. Consequently flows from the much more developed lower catchments that are pumped to the works through Abbey Mills are constrained and pumped instead to the Tideway. This results in one of the single most polluting discharges. Further modelling work may establish that an increased proportion of source control (and possibly separation/ storage) in the upper catchment might reduce the hydraulic load to Beckton and hence relieve this 'throttle' on the network at Abbey Mills.

There are techniques for the application of SUDS retrofit that will reduce the construction difficulties that the TTSS identifies. For example in a USEPA study a system of 'speed humps' retaining rainwater on the surface was used to attenuate storms in two towns in Illinois. 'Beany® block' type highway kerbs have a capacity that can be used for attenuating peak storm flows. Many new hard surfaced areas are now developed with shallow 'Storm-cell' type storage devices – a technology that can lend itself to retrofit storage at or near some of the commercial areas of the catchments at relatively low cost given its shallow depth and simple construction.

In reviewing this strategy, we accept that source control can provide only a partial and, most probably, medium to long term solution to the problem of CSO discharges. It is likely to be applicable in different parts of the catchment to differing extents and probably over differing timescales, utilising a range of technologies and management approaches. However a significant benefit of the use of source control will be to reduce hydraulic incapacity in the network overall and as such, it would be expected to have a significant impact on flood risks where it can be successfully applied.

Conclusion: Whilst the applicability of the relevant source control/SUDS techniques is likely to be severely restricted in the densely built up area of central London, TTSS confirms there are opportunities in the less densely occupied open commercial land use areas to achieve demonstrable benefits through modest separation. We believe these areas deserve more thorough investigation of what practical measures may be put in place. Sewerage network modelling may ultimately demonstrate that, in combination with other strategies, source control will provide medium to long term local flood relief and by relieving pressure on the low level interceptors, will reduce CSO spill frequencies. The Beckton catchment may prove suitable for the application of such an approach.

Recommendations: To ascertain the extent to which source control techniques may be applied practically and cost effectively in the Tideway area, we recommend that three types of catchment of varying land usage are assessed.

3.3 TTSS Strategy 2 – Within the Sewerage System

As with Strategy 1, TTSS's elimination of Strategy 2 is based on the concept of applying a single strategy to alleviate the Tideway problems. In this case, it would entail construction of an "entirely new" separate sewerage system, and the reasonable conclusion from this is that it would be a more costly and disruptive approach than the preferred Strategy 3.

The TTSS Solutions Working Group Report identifies the following contra indicators as regards in-sewer flow attenuation:

- Very little spare capacity to achieve in-line attenuation, the total volume available is trivial compared to the volume of storm water generated by even short duration rainfall events and the system very quickly becomes overloaded.

- The shallow depth of the sewers (presumably the local and interceptor sewers) means that artificial surcharge to fully utilise on-line storage would increase the risk of flooding the large number of basements.

- Off-line storage in discrete units is subject to severe challenge which renders its complete implementation very expensive, highly disruptive and severely difficult to operate and maintain.

- The large volume of additional storage can only be effectively provided via off-line tanks, which could either be shallow to allow for gravity return of flows or deep tanks with pumped return.

- To provide the storage equivalent to the spill at a medium level intervention, the indicative plan area of shallow tanks would be just over 85 ha., alternatively an estimated 175 deep tanks, each with a construction footprint of 0.3 ha. are indicated.

- To produce the greatest reduction in flow spilt to the river these storage tanks would have to be constructed immediately adjacent to the existing CSOs, close to the river with all the problems arising from such a location.

- Storage upstream of the CSOs would have much less of an impact and in effect, far larger volumes would have to be created to reduce the spill volumes. This was said to have been demonstrated by a technical study on SUDS analysis using the sewerage model.

Because the existing sewers become overloaded very quickly during rainfall events, attenuation within them is seen as impractical. Off-line storage is ruled out on the basis of the inherent problems associated with the location of the requisite tanks, the large storage volumes required and timely disposal of the storm water back into sewers that, in some areas, have little more than DWF capacity. However it is understood that the level of storm flow capacity within the sewerage system and the demand placed on it varies across the catchment with greater availability in the higher level interceptors.

As regards flow separation, the TTSS report states that this could only be achieved by construction of an entirely new foul sewerage system (length > 12,000 km), which would only be possible at extreme cost (approx. £12 bn) and disruption over a very long time period. It is also comments that complete separation could not be guaranteed and that foul cross connections made in error mean pollutants would still reach the river.

However, in Appendix 2.3, Professor Ashley and his colleagues have identified that the ‘quick-wins’ to be gained in a retrofit separation strategy often relate to the commercially developed areas, avoiding the technically relatively tortuous and expensive disconnection of individual properties, that TTSS identifies as a factor against this strategy. This principle has been proved for London in the model analysis carried out in the TTSS SUDS study.

Our experience in Boston (see Dennis Doherty’s report in Appendix 2.4 of this document) confirms the benefits of retrofit, where specially developed CSO regulator structures were used to control floatable materials at outfalls. If found suitable to install in the London sewer network, these could go some way towards reducing the litter problem. However, their application would depend on having a better understanding of and better control over the hydraulic operation of system, which implies a better model and real time control (RTC).

As a general comment, the work undertaken in Boston is of benefit at a strategic level in informing our approach to this study. However differences in the nature of the catchments in London and Boston mean that the specific solutions devised in Boston cannot be readily transplanted to the Tideway catchment.

We note that there is another water conduit, in the form of the Grand Union, Regent's and Hertford Union Canals, that forms a broadly continuous conduit (physically if not hydraulically) running from West Drayton in the west to Bow in the east. We would query whether there is the potential to re-engineer these canals to perform a useful 21st Century purpose as part of a storage system, conveying some returned surface water away from the city at a controlled flow rate.

The use of RTC is alluded to in the TTSS report but the idea is not developed as the technology is not seen as sufficiently advanced to be applied to the London catchment. Our understanding however is that RTC has advanced considerably in recent years and has been widely applied in such major cities as Paris, Vienna and Tokyo. We therefore see no reason why it should not have been considered seriously as part of the TTSS strategy, although its success might hinge on the adoption of other parts of a 'package'. For example separation of a proportion of the open commercial land-use as discussed in section 3.2 could be optimised to deliver still greater reductions in spill volumes if RTC techniques were applied to mobilise some of the sewer capacity so released. However, we recognise that RTC is dependent on the ability of the sewerage network model to accurately represent the operation of the system and appraise the impact of different strategies and operations, including our suggested Strategy 5.

The existing model for the Beckton and Crossness catchments is the result of many years development by Thames Water. However, the August 2005 draft of the TTSS Steering Group Supplementary Report in reference to off-line storage, acknowledges that, "to model such dispersed off-line storage would entail in practice re-designing the sewerage network model and this was not considered feasible within the time available". Furthermore, we understand that whilst the existing network model has been verified under dry weather conditions, this is not the case for storm conditions.

From discussions with Thames Water it would appear that there are sound technical reasons why the model has not been developed further. However the ability that such a model would provide to assess, in detail, the potential benefit of SUDS, separation and in catchment storage could be of great benefit in reducing the risks inherent in managing such a complex system.

We are therefore of the opinion that development of the network model to permit the proper assessment of the above options should be re- considered. This could be costly and time consuming in modelling terms, but the potential benefits in capital efficiency and operational flexibility in the longer term are likely to be far greater.

Conclusion: This strategy has been discounted in the TTSS report on the basis that it would be impractical in terms of time and cost to apply across the whole catchment. We believe there are likely to be opportunities to reduce the impact of the CSO discharges through the development of Strategy 2 based solutions. However, to do so requires a better network model capable of accurately representing the situation under storm conditions. We recommend the development of such a model with consideration of RTC to manage the system more effectively.

3.4 TTSS Strategy 3 – At the CSO Outfall

CSO Outfall Solutions

The TTSS report states;

> "It was recognised at an early stage in the study that this strategy represented the only solution that could be considered potentially viable and worthy of further investigation.... Potential solutions within this strategy have been investigated and cost estimated in outline."

The TTSS asserts that only solutions developed under this strategy can resolve the Tideway CSO problems.

The TTSS paper "An Assessment of the Frequency of Operation and Environmental Impact of the Tideway CSOs" presents a sound rationale for directing attention from all 57 Tideway CSOs to the 36 deemed to be causing adverse environmental impact. However it does not treat each CSO in its own right nor is it able to since the TTSS confirms that there is limited site specific data on the impact of individual CSOs (for example monitoring of flow is only available for 9 of the CSOs). Similarly no CSO specific aesthetic surveys have been carried out.

Each of the CSOs will have its own behaviour and history. The problem created by any individual CSO will be dependent on the characteristics of that CSO, i.e. its frequency of operation, the average and peak discharges recorded, the composition of the discharge in terms of litter, pathogens, DO, its location and physical surroundings, the upstream catchment and sewer configuration, its complaints history, etc. We believe that each outfall should be investigated individually in order to secure the best value solution to the Tideway CSO problem. In this way some CSOs might be found to have a proportionately lower impact, which would result in them being removed from the list to be attended to.

The TTSS report indicates that a number of the offending outfalls are suitable for the application of local screening. We would also expect to find others that might be interconnected or locally transferred to sites where screening or other separation is possible. Examination of these possibilities should be carried out in conjunction with consideration of the contributing areas and the situation with regard to the local receiving waters.

Conclusion: On the basis of the information that we have, we would not wish to dispute the TTSS core finding that, if a single stand-alone strategy is the requirement, Strategy 3 is likely to be the only practicable and economic means of fully meeting the three stated objectives.

We have, however, expressed our doubts over the validity of the defined objectives, and we similarly question the validity of a stand-alone strategy.

The Treatment Option

Treatment of flows at CSO outfalls as opposed to screening or storage is a variant of Strategy 3 that can best be addressed separately. However, this variant is concerned with improvements that could be achieved primarily through the provision of new storm water treatment plant located in or adjacent to the river, or by upgrading existing treatment works to raise the quality of treated effluent and thereby, the background river water quality. It is recognised that treatment is part of Option H (see section 4 for more detail), however in that case storage and transfer of the CSO discharge is the primary aim.

We have given some consideration to how treatment might be achieved on artificial islands constructed in the Tideway, at the bankside or on permanently moored barges.

Both of these options are likely to require significant bankside structures to manage flows, as flow attenuation and controlled pumping from the CSO will be required in order to manage the scale of installation that might practicably be installed in or adjacent to the Tideway.

The construction of artificial islands is likely to significantly disrupt the character of river flows and might result in difficult to predict effects to the river morphology and navigability. Given the tidal range of the Thames, a permanent piped connection to a barge is likely to present an impractical technical challenge.

The solids removed by any treatment facility located in the river would need to be stored and transported away so jetties would form part of the works – maintenance activities would also most likely require access by boat and this would require careful consideration as regards potential hazards for operational staff.

Given the scale of some of the structures required to achieve an appreciable level of treatment, even with some bankside storage, this option will not be reasonably practicable in the most sensitive upper reaches, where the Tideway is at its narrowest. For example an enhanced primary treatment plant at Heathwall for just eight of the relatively near CSOs would require a filter of some 40 x 400m in plan – likely to be significantly larger once all ancillary structures and accesses are included.

It might be most practicable in the middle reaches, where the flows are proportionally modest, and the Tideway reasonably wide.

An alternative approach would be to consider improvements at the existing sewage treatment works to improve the background river DO and bacteriological qualities permanently, such that the additional impact of the intermittent CSO discharges is less significant. To some extent it could be said that the effectiveness of this strategy is already proven in the fact that significant improvements to the DO profile will be made by the AMP4/AMP5 capital works programmed to increase the capacity and quality of discharges from Mogden, Beckton and Crossness.

We note from Table 2 in the TTSS Objectives Working Group Report Volume 2 that even after the AMP4/AMP5 improvements, the BOD consent for Mogden works discharging to the more sensitive upper reaches, will be less onerous than at Crossness and Beckton. Whilst appreciating this is a standard, not the actual performance, we assume this reflects the expected process capability at Mogden. Appendix D of the TTSS Cost Benefit Working Group Report supports this conclusion by indicating that tertiary treatment polishing filters are being introduced at Crossness and Beckton. Improving treatment standards at Mogden in line with the other works would result in reductions in pollutant load at the most sensitive stretch of the Tideway.

Furthermore the provision of disinfection at the point of discharge from the treatment works would be, in process terms, significantly more effective than at the CSO and this might be demonstrated by modelling to be a more effective way to target bacteriological quality in the Tideway.

Conclusion: The provision of treatment as the primary means of mitigating the impact of CSO discharges is likely to require significant bankside storage and transfer facilities. The development of suitably serviced treatment plant on artificial islands constructed in the Tideway, on the bankside or on permanently moored barges would involve a number of additional problems which make this an unattractive option.

The alternative of mitigating CSO impacts through upgrading existing treatment works discharges and thereby improving background river water quality appears very practical and should be considered.

3.5 TTSS Strategy 4 – In-river Treatment

As stated in the TTSS report, Strategy 4 cannot be considered to be a true strategy in terms of meeting the TTSS stated objectives, in that once the storm water is discharged to the river, the polluting effects can only be ameliorated. However schemes such as on-river litter collection and re-oxygenation of the Tideway may have a part to play in the overall solution.

The adoption of in-river treatment is dismissed by the TTSS, on the grounds that it is not a “preventative” strategy and that the Environment Agency are likely to consider in-river treatment unacceptable as a long term solution. It is further dismissed by the TTSS on the basis that it only addresses the DO objective and not the others, i.e. the aesthetic issue and health risk.

As stated above, we do not subscribe to the ‘all or nothing’ approach and we would be inclined to include in-river treatment as a realistic part of an integrated or hybrid solution to the overall problem. There are likely to be significant benefits to be gained from the application of such an approach as part of a ‘basket’ of measures that may be applied locally and over time in a manner which contributes to the overall delivery of the requisite improvements.

A number of in-river measures and technologies are currently being applied in the Tideway and show a considerable degree of effectiveness. In the short term

(AMP4) these will be augmented by additional hydrogen peroxide dosing points at a location currently being determined and the introduction of two additional 'fine' skimmer vessels.

It is believed that the deployment of coarse and fine skimmer vessels provides a viable and cost effective means of collecting a large quantity of the most visually offensive debris. In addition to the two existing coarse skimmers operated by the PLA, two fine ones are planned and others might usefully follow. This approach has been applied in a number of cities around the world including New York and Baltimore, which both have relatively large fleets (10-12 number) of such vessels. These have been shown to be effective with regards to the unsightly surface litter slicks that attract so much public concern.

In addition, oil skimmer devices are available – primarily designed to mitigate fuel oil spills at sea – these might be capable of adaptation to reasonable use to target the fat, oil and grease slicks that will not be easily captured by the fine skimmers. Fig 3.1 shows a typical oil skimmer.

Fig 3.1 – Typical Oil Skimmer

It is of particular note as regards the litter issue, that sewage-derived litter only represents around 10% of the total litter finding its way into the Tideway and a proportion of the sewage-derived solids sink to the bed of the river and are lost to public view. The expenditure of very large sums of money to collect and deal with sewage-derived litter before discharge to the Tideway, rather than skimming off a proportion of a much larger quantity originating from other sources should be challenged.

The TTSS team has eliminated the further application of in-river aeration as a long-term strategy. The existing aeration vessels are apparently constrained as to where they can access, in particular the more sensitive upper reaches, and in the quantity of oxygen they can discharge. With regard to the bankside installations, whilst accepting that hydrogen peroxide dosing is limited in its application, and carries its own environmental risks, a number of other techniques have been applied to improve the oxygen levels of water bodies worldwide.

Aeration has been adopted successfully at the rivers Tees and Tyne and the prestigious Salford Quays development and, along with local dredging to reduce the sediment oxygen demand (SOD), is being considered for the development of Preston Docks.

The Suzhou Creek Rehabilitation in Shanghai is also undertaking selective dredging and in-river aeration. This latter example followed completion of a sewerage interception programme that failed to achieve the expected improvements because of a lack of understanding of SOD.

Beijing employed surface aerators to improve river DO levels in advance of the 1990 Asian Games.

At the San Joaquin-river, California, a pilot fixed aeration system has been instigated drawing water from the river for bankside aeration prior to return to the river.

In a similar way to the skimmer vessels, additional aeration equipment could in fact target all instances of depleted DO rather than the tunnel that can only deal with the impacts of CSO spills.

The TTSS reports do acknowledge that in-river treatment could be effective, albeit it is considered as an interim or short-term measure, to be applied only until the tunnel is complete. Its most obvious disadvantage is the continuing operation and maintenance cost.

Conclusion: It is apparent from the data presented in the TTSS that (i) sewage-derived litter is a minor issue in relation to the overall volume of litter on the Tideway (ii) the DO problem is more closely correlated with the quality of discharges from existing sewage treatment works than with CSO discharges and (iii) mitigation of the health risk may be more dependant on improving treated effluent quality than on reducing CSO discharges. In these circumstances, the benefits which can be achieved by in-river treatments such as the deployment of fine litter skimmers, bubblers and peroxide dosing plant can be significant and very visible to the public. We recommend that Strategy 4, ‘In-river Treatment’ be retained as part of a basket of measures to reduce the environmental impact of CSO discharges on the Tideway.

3.6 Strategy 5 – Integrated Stormwater Management

The TTSS report comments that Strategy 3 is ”the only solution that could be considered potentially viable and worthy of future consideration”. At the same time, it acknowledges that other strategies may have a part to play in some of the future global solution, though they cannot be considered as a complete answer in themselves.

In the context of identifying a single 'complete answer' to the storm water problem, the approach taken in the TTSS study may be reasonable. However, we would question whether such an approach provides the 'best value' solution to meet the objectives for such a large and varied catchment, in the longer term.

We believe that a hybrid strategy comprising an appropriate mix of Strategies 1 to 4 should be considered for the potential benefits it would bring at both the local and catchment wide levels. These views are supported by Ashley and Stovin's Overview of the TTSS Findings, which forms Appendix 2.3 of this review. Their discussions with leading experts in the field of urban drainage and review of approaches taken to similar problems elsewhere across the world highlighted the following issues:

- Current thinking is towards an integrated urban water management approach
- Storage is always going to be needed but the cost can be optimised by use of dynamic operational control
- Modern Real Time Control (RTC) systems are robust and have a proven record where there is full operator commitment
- Selective source control as opposed to a 'one size fits all' approach helps to control the problem over time
- There is strong evidence that the best solutions entail investment in extending waste water treatment works performance
- Separation and source control/retro-fit SUDS projects are underway at various locations in Europe, USA and Japan as a means of managing storm water problems and recent UK based examples are given in the report.

Strategy 5 encompasses a basket of potential measures including source control, attenuation, storage, end of pipe solutions, including storage and transfer, in-river treatment and upgrading of existing treatment facilities all playing their part in the final solution. We would anticipate all currently planned and future upgrades to the existing sewage treatment works and sewer network being co-ordinated with a view to obtaining a holistic solution to water quality problems in the Tideway. Such a holistic approach would not preclude early action being taken according to a hierarchy that might include environmental hot-spots and areas subject to persistent public complaint or political interest. One example where this will apply is the River Lee where the Olympic imperative will require the instigation of early remediation of the Abbey Mills facility ahead of the opening of the Games in 2012. For such an application, longer term measures such as source control would follow as later stages.

We would expect an integrated wastewater approach to be capable of providing earlier returns than the 'preferred solution' in terms of mitigating the most significant impacts of CSO discharges. The rapid deployment of fine skimmer vessels and oil skimming devices onto the Tideway is an example of measure which will bring quick returns. However, it may be necessary to accept that the full benefits identified for the 'preferred solution' would take longer to deliver, particularly if extensive retrofit solutions are instigated.

The capital cost of an integrated approach relative to the 'preferred solution', would depend on the balance of strategies. In support of this hybrid approach, we would cite our experience in Boston, where a single tunnel solution was replaced by an integrated solution that included infiltration and inflow reduction, hydraulic relief, sewer separation, new and upgraded treatment at some CSOs and CSO consolidation and storage schemes. The scheme costs were reduced from US$ 1.3bn for the tunnel solution to US$ 0.75bn for the integrated scheme. Our current review suggests that the circumstances at the Thames Tideway may make it suitable for the development of a hybrid approach, and in section 6 we have derived some broad cost estimates in support of this.

Conclusion: Recent international experience indicates that an integrated stormwater management approach can be effective and provide a potentially lower cost solution to the issues affecting the Tideway. Whilst the TTSS considers the only single 'complete answer' is provided by Strategy 3, it does acknowledge that other strategies could contribute to the long term solution. Our opinion is that the implementation of a mix of strategies (Strategy 5) creating a hybrid proposal might be more effective than predominantly relying on a single strategy, ie Strategy 3. Such an integrated strategy would, in our opinion, present the opportunity to reduce the scope of major capital works, and therefore cost and risk, through the increased application of locally focused solutions.

3.7 Overall Conclusion

In the context of a single stand-alone approach to resolve the storm water problems affecting the Tideway, the assumptions leading to the selection of Strategy 3 are reasonable, indeed the arguments are powerful.

However as part of an integrated storm-water management strategy we consider that major benefits could be achieved over a prolonged period of time by the wider selective and staged application of Strategies 1, 2, 3, and 4 both locally and as part of a holistic solution to address water quality issues in the Tideway. We consider that this approach should be given further, more detailed consideration.

4.0 SOLUTIONS REVIEW

4.1 Introduction

The TTSS initially considered 9 basic solutions identified as Options A to H+. A tenth option, a refinement of Option A, termed A (Ref.), was later developed and promoted as the preferred solution. Each of these 10 options was derived from Strategy 3, under which storm water is managed at the CSO outfall, and all the options were based on a combination of interception of the storm flow, storage and/or transfer and treatment. The TTSS also developed and reviewed variants to Options A to C based on high, medium and low levels of intervention.

In addition, the TTSS provided two supplementary reports primarily to advise DEFRA of potential interim and smaller scale measures, and to expand on some issues relating to Option A (Ref.). 'Appendix 3; Challenges and Responses' reviews these reports in more detail. As noted elsewhere in this review, one of these reports, the TTSS Supplementary Report to Government of November 2005, elected to revise the scope of Option H from that used in previous TTSS reports. In this report, we have continued to use the generic descriptor 'Option H'. However, where in detailed commentary we consider there is a need to distinguish between the two variants, we have adopted the terminology 'Option H (new)' and 'Option H(old)' for the November 2005 Supplementary Report and original versions respectively so as to avoid confusion.

Following our review of the TTSS Solutions Working Group Reports and our discussions with Thames Water and the Environment Agency we are broadly in agreement that the options have been pursued at a level commensurate with the process of identifying the preferred solution, using a given strategy to meet the TTSS stated set of objectives. However, we believe that other strategies, including those previously eliminated by the TTSS, may offer a viable toolkit of approaches with which to target solutions on a sub-catchment basis rather than the relatively coarse 'all or nothing' approach.

If the tunnel solution, A (Ref.) is to be accepted as the 'preferred solution', it is critical that it should first be evaluated against any variations in the objectives criteria, taking due cognisance of the impact on the Cost Benefit Analysis. Section 2 refers.

In the following sections we consider the potential risks and unproven assumptions related to Solution A / A (ref) that could have significant impact on costs should the scheme proceed. We have undertaken a high level review of Options B to G considering that they were not subject to the refinements incorporated in Option A (Ref.). However, some of the issues and risks identified in connection with Option A (Ref.) apply equally to the other options considered. Options H and H+ have been subject to a similar review but treated separately as they represent partial solutions, which we believe have a part to play in an integrated wastewater management solution

4.2 TTSS Solution A (Ref.)

Construction Issues

Working Space: The connection work at the 36 CSO outfall sites may present difficulties due to the lack of space. This same issue has been identified when considering the provision of screening plant at outfalls. As the project has not yet progressed to the detailed design stage the extent of these difficulties has not been fully established although we understand some preliminary work has been undertaken by consultants.

Groundwater Pressure: It is stated in the paragraph on tunnel boring machines (TBM) in section 2.3.1 of the TTSS Solutions Working Group Report Volume 2, that an earth pressure balance machine (EPBM) will be capable of operating in ground water pressures of up to 8 bar.

We have attempted to obtain references for high pressure EPBMs. The reference project quoted by TTSS at Westerschelde was 65m below sea level and operated at approx 7 bar. The machine was a mixshield slurry TBM not an EPBM and was designed for up to 8.5 bar pressure.

A further reference project we have is Hallandsås in Sweden, where boring commenced in September 2005 with a 13 bar mixshield slurry TBM. This is the third attempt since 1992 to drive this tunnel.

Having discussed the issue further with TBM specialists we are satisfied that the lower stretches of the tunnel will only be achieved by mixshield type devices, and that the tunnelling operation here will present a significant technical and health and safety challenge.

Unforeseen Obstructions: In the paragraphs on Obstructions in section 2.3.1, no mention was made of the presence of wells and other unexpected underground features. The Lavender Street incident during the construction of the CTRL caused major disruption to that project. Whilst the risk of such features under the Thames is obviously low there remains the risk where the tunnel is located away from the river or near to the bank, though we accept the TTSS comment that even here the risk is expected to be low given the depth of the tunnel.

Spoil Disposal: The estimated cost of Option A (Ref.) is compared with the cost of the CTRL construction. It is not clear whether proper account has been taken of the increased spoil disposal costs of Option A (Ref.) compared with the reduced costs on the CTRL. This difference is mentioned in the report but in the conclusions in Appendix A, the 7% increase in cost per km is explained as being chiefly due to the larger OD and the greater depth of tunnel.

Groundwater Ingress: The prediction of seepage of groundwater into the tunnel in section 2.3.7 of the TTSS report is based on the flow that would occur into a tunnel constructed to a specified standard. Achievement of this standard assumes that gaskets can maintain the required watertightness of the tunnel in the long term. We consider that the ability of gaskets to resist 8 bar external pressure is at the limit of currently available technology. Tunnels such as the Channel Tunnel are designed to leak and to deal with the ingress of water by means of pumping. The problems at tunnel connections are likely to be the most severe with control of groundwater being reliant on grouting, ground freezing or other similar measures.

Operation and Maintenance

Flushing and Ventilation: The flushing and cleaning activities necessary to prevent septicity, odour and the accumulation of methane or other explosive gases have not been thoroughly determined. The consequences of the problems and specifically the risk of rapidly expelling a large volume of noxious or explosive gas during tunnel filling are obviously potentially disastrous. Although the specifics are somewhat different, the Abbeystead Disaster provides evidence that such an occurrence is possible. TTSS believe that this can be managed by natural ventilation, though this appears to be untested. Furthermore, we note that TTSS has made provision for forced ventilation if required.

High Treatment Load: Assuming that the tunnel can be successfully flushed following use, this would entail a 'last flush' effect at Crossness treatment facility. The potential adverse impacts of a flush of high concentration effluent being passed forward to the treatment works should be examined. Whilst this might be within the capacity of Crossness the potential impact of shock loading of the process should be established and mitigated against if required.

Sediment deposition: It has been assumed that the difficulties of flushing and cleaning the tunnel can be solved at the detailed design stage. In view of the severity of the consequences of this risk it is possible that extensive modifications will be needed to the design with attendant increased costs, although we note work to mitigate this risk is ongoing and will continue into detailed design.

Solids loading data: The SCITTER investigation report recommends further monitoring to capture more data to provide a more reliable basis for the consideration of screening options. This work could indicate whether the preferred solution could be scaled down and implemented in combination with other measures that allow more of the flow to discharge untreated to the river.

Alternative Approaches

If the difficulties of construction and operation of Option A (Ref.) result in significantly increased costs, or if it is concluded that the safety aspects cannot be satisfactorily addressed, then an approach that either makes construction and operation more straightforward (perhaps by reducing the scale of the works) or achieves satisfactory objectives in a different way becomes more viable.

One such alternative is the use of a smaller diameter tunnel. The TTSS states that to prevent choking and air gulping problems a minimum diameter of 6m will be required. Whilst this is good practical advice, it should not preclude consideration being given to the use of smaller tunnel diameters as long as effective steps are taken to design out this problem by addressing 'air management' and 'transient flow regimes' through the use of appropriate venting mechanisms. The TTSS concludes that "any reduction in cost by employing a smaller diameter main tunnel would be more than offset by the high costs (and increased risks) associated with the construction of large underground connection chambers". The TTSS also states that "this matter is complex and would require detailed investigation and hydraulic modelling to resolve". We consider that it would be prudent to undertake such investigations before the option to use smaller diameter tunnels can be confidently eliminated.

Some of the risks described above could result in a very significant increase in the cost of the preferred option that might have the effect of making the choice less clear-cut and would make the further consideration of alternative approaches more attractive. If all effort is concentrated on the design of the preferred option and it then becomes evident that the cost of construction and operation of this option needs to rise to overcome certain technical issues, it will be difficult at that point in time to assess the benefits of alternative solutions. Continuing assessments of these alternative solutions, where necessary in parallel with the development of detailed designs, will enable their viability to be investigated and benchmarked against the preferred option

The assumptions relating to the objectives are addressed elsewhere in this report. However a major assumption imposed on all the options considered is that the entire flow from storms up to the target return period should be catered for. There does not appear to be any conclusive evidence of how the litter, DO and health risk issues relate to the pattern of discharge from the CSOs. It is possible that the bulk of the problem is caused in the first flush flow and may reduce as the discharge continues. The implications of this are that a smaller scale solution, perhaps involving real time control and insitu sampling, may achieve the objectives or a substantial part of the objectives.

A reduction in the scale of the proposed scheme will have benefits in terms of the practicality of construction, reduced construction cost, earlier deliver of the scheme and reduced operation and maintenance costs.

Alternative approaches include the reduction of flow discharged from the CSO outfalls, the removal of litter by screening or alternative means, capturing the first flush only or a combination of these measures.

Further Investigations

From the foregoing we believe, before Option A (Ref.) is progressed any further, that the following areas should be further investigated to reduce the financial and technical risks to the project.

The following should be confirmed;

- The tunnel itself can be successfully constructed,
- The connection works can be undertaken successfully and
- The tunnel can achieve long term watertightness

The space needed for the works at the CSO outfall locations should be established more clearly. This should be compared with the space needed for screening plant.

Work should be undertaken to establish in detail how the tunnel is to be operated and maintained to prevent the problems of septicity, odour, poisonous and inflammable gas occurring.

Further investigation should be undertaken to improve the understanding of where the major pollution load occurs throughout a CSO discharge event. In some cases this may necessitate capture of all the flow. In other events the first flush only may need to be captured and discharge of a large part of the flow into the river may be acceptable.

Further investigation of the viability of alternative measures should also be undertaken. In particular the opportunity to reduce the scale of the preferred option and hence save costs should be given further consideration.

4.3 TTSS Solutions B to G

For a variety of reasons, the TTSS has ruled out the potential solution Options B to G. We largely agree with the reasoning, however we note that the assessments were carried out on the basis that each solution considered must, in its own right, satisfy all of the project objectives; this need not be the case.

Some of the discounted solutions may therefore be able to be re-assessed on the basis that they could be implemented on a smaller scale, or over an extended timeframe to suit any revised ‘willingness to pay’ results arising from our queries targeted at the objectives.

We note that Options B to H+ were not revisited following preparation of the TTSS Solutions Working Group Vol. 2 Refinement Report. It is not therefore possible to comment fully on their comparative suitability against the revised design parameters implied by that report. This should be addressed in any future re-assessment.

A summary of our assessment of Options B to G is included in Table 4.1 below. Issues arising from this assessment, including further investigations and possible alternative approaches, are expanded upon below.

Issues to Investigate

There are a number of issues related to the Options B to G that might affect their viability when compared to Option A (Ref.). These are in addition to the issues that might reduce the viability of Option A (Ref.) discussed above.

Groundwater pressure: Any solution, or partial solution, that involves deep tunnelling should take cognisance of our comments under Option A (Ref.) above, with regard to construction and watertightness.

Power availability: In some solutions it has been assumed that it is necessary to provide major standby power facilities. However, the consequences of a power failure for a relatively short period of time may be tolerable as it could simply result in CSOs reverting to their current mode of operation.

Minimised capacity: The possibility of a ‘first flush only’ collector has been discussed above and this should be considered in any comparative re-assessment.

Siting of equipment: The possibility of constructing pumping and/or screening facilities in the river, in purpose built tanks, should be considered.

Testing of solutions: Where it is proposed to utilise untried technology or methods, or technology or methods pushed beyond their current limits of application, comparative assessment of the options involved should not be undertaken until what is proposed is proven beyond reasonable doubt.

Public engagement: The management of media and public perception will be vital to the success of any solution. No solution should therefore be dismissed on the grounds of its likely unpopularity until a campaign is initiated.

Alternative Approaches

Further technology that has been put forward with potential at the CSOs is (a) ‘vortex’ type solids separation and (b) possible disinfection. We have not at this stage reviewed this technology in detail, but would make the following initial comments:

- An installation to cope with the scale of flows discharged by the Tideway CSOs would require many multiples of these units, with associated potential difficulties in flow distribution.

- Whilst the units themselves are claimed to have a low head loss, the distribution system that might be necessary to control and distribute flows to a large number of separators might incur a significant head loss.

- The system does not overcome the difficulties observed by TTSS in developing Strategy 3, Option F – the difficulty of removing the solids extracted from the treatment system. Vortex separators assume a foul sewer in reasonable proximity to return the foul load to – this is not ordinarily the case in the Tideway. In fact if the supplier’s quoted performances are correct, the problem might in fact be exacerbated by the enhanced ability of the separator to remove organic matter.

Table 4.1 – Summary of Assessment of TTSS Strategy 3 Options B-G

Option Reference	Overview of Option	TTSS key points in discounting	JB verification of reasoning	Summary Any additional key points
B – Transfer	Intercept and transfer CSOs to screening plant downstream of Thames Barrier (i.e. shorter than A(Ref). Tunnel)	1. Minimum size constrained by need to oversize to avoid choking. 2. Screening only no impact on DO or health. 3. High pumping energy requirements. 4. First flush of BOD transferred straight to river in all but low volume events. 5. Risk to ecology/ navigation from occasional very high point discharges. 6. Health and safety issues of operating a deep tunnel.	1. Not accepted: Choking can be engineered out by the use of relatively short vents (c.f. in Chicago). We do not accept the tunnel needs to be oversized. 2. Qualified acceptance: there is some benefit to health derived from transfer away from the most sensitive upper reach. 3. Accepted. 4. Qualified acceptance: needs further evidence to prove. Some treatment could be provided. 5. Qualified acceptance: needs further evidence to prove. Should capable of being managed. 6. Not accepted: no different to Option A Ref.	On balance discounting this option appears to be sensible
C - Multiple screened outlets	Intercept and transfer CSOs to a series of 8 pump/screen/discharge locations between Chiswick Eyot and the Thames Barrier	1. Minimum size constrained by need to oversize to avoid choking. 2. Significant land availability and town planning issues. 3. Significant disruption during construction. 4. Screening only no impact on DO or health. 5. High pumping energy requirements. 6. Odour issues. 7. Transport issues. 8. Operational practicability of below ground plant. 9. Risk of pumps macerating solids reducing benefit of screens.	1. Not accepted: Choking can be engineered out by the use of vents (c.f. in Chicago). We do not accept the tunnel needs to be oversized. 2. Qualified acceptance - could practicable use be made of the foreshore as per Option E? 3. Accepted. 4. Qualified acceptance: there is some benefit to health derived from transfer away from the most sensitive upper reach. 5. Accepted. 6. Qualified acceptance: odour issues should not be insurmountable. 7. Qualified acceptance: screenings transport issues should not be insurmountable – use barges as domestic waste hauliers do in Central London? 8. Accepted. 9. Qualified acceptance: should be able to be engineered out with pump suppliers.	On balance discounting this option appears to be sensible

Table 4.1 – Summary of Assessment of TTSS Strategy 3 Options B-G (cont)

Option Reference	Overview of Option	TTSS key points in discounting	JB verification of reasoning	Summary Any additional key points
D - Storage and multiple screened outlets	As above plus additional storage tunnel from Chiswick Eyot to Crossness	1. Minimum size constrained by need to oversize to avoid choking. 2. Significant land availability and town planning issues. 3. Excess CAPEX and OPEX cost of twin tunnels.	1. Not accepted: Choking can be engineered out by the use of vents (c.f. in Chicago). We do not accept the tunnel needs to be oversized. 2. Accepted. 3. Qualified acceptance: query whether twin tunnels could be engineered into a single tunnel.	On balance discounting this option appears to be sensible
E - Storage Shafts	Up to 102 large diameter storage shafts incorporating static screens constructed in the foreshore, with a tunnel to treatment at Crossness	1. Significant land availability and town planning issues. 2. Significant disruption during construction. 3. Concern about large scale application of static screens and other novel elements of this option 4. Significant ecological impacts on foreshore.	1. Accepted. 2. Accepted. 3. Accepted. 4. Accepted.	On balance discounting this option appears to be sensible
F - Screen each CSO	Screen at each individual CSO	1. Significant land availability and town planning issues. Not reasonably practicable to screen at the majority of locations. 2. Extreme disruption during construction. 3. Screening only no impact on DO or health. 4. Risk of increase upstream flooding from screen head losses. 5. Operational practicability of below ground plant. 6. Odour issues. 7. Transport issues. 8. Very high CAPEX well in excess of other options.	1. Qualified acceptance: whilst the structures are accepted to be larger, could practicable use be made of the foreshore as per option E? 2. Accepted. 3. Qualified acceptance: there is some benefit to health derived from transfer away from the most sensitive upper reach. 4. Unproven, but concept accepted. 5. Accepted. 6. Qualified acceptance: odour issues should not be insurmountable. 7. Qualified acceptance: screenings transport issues should not be insurmountable – use barges as domestic waste hauliers do in Central London? 8. Accepted.	On balance discounting this option appears to be sensible
G – Displacement	Tunnel from Chiswick Eyot to Rainham and large scale wetland area.	1. Large land take – approx 4km2 2. Difficulties caused by need to maintain the tunnel normally full. 3. High pumping energy requirements 4. Most suitable available site requires removal of existing contaminated ground.	1. Accepted. 2. Accepted. 3. Accepted. 4. Accepted.	On balance discounting this option appears to be sensible

4.4 TTSS Solutions H and H+

Option H represents the 'Western' solution developed as a partial solution by TTSS to target the most sensitive sections of the Tideway that also contained some of the more polluting discharges.

The TTSS report 'Variations for H' TTSS Addendum report June 2003 states,

> "works at the western end of the Tideway would be more likely to deliver the greatest benefits from a given level of investment as these could be targeted to deal with the most vulnerable parts of the river and the most problematic discharges. This vulnerability is due to the greatly reduced volume of dry weather flows in the western end of the river compared with the eastern end and is particularly noticeable between Hammersmith and Heathwall where storm discharges from five major pumping stations and four major gravity relief sewers enter the river."….." this solution offers a considerable advantage of lower cost with a shorter construction phase focussed on the most sensitive part of the Tideway. However, with the inclusion of additional partial solutions, located at Abbey Mills and Greenwich for example, to augment potential Option H this amalgam of solutions could enhance water quality sufficiently to be regarded as a total package, at least until many years into the future."

Outline of Option H and variants

Option H is effectively the upstream third of the Option A tunnel, terminating at a screening and enhanced primary treatment plant situated at Heathwall. It is specifically targeted to address the most problematic discharges on the stretch of river between Chiswick and Heathwall Pumping Station. It targets some of the most sensitive areas of the Tideway from a human health perspective, and tackles some of the larger outfalls that will have a significant effect on DO and aesthetics. In the August 2005 draft of the Steering Group Supplementary Report, TTSS developed and reviewed two Option H solutions comprising 7.2m diameter and 9m diameter tunnel variants. In the TTSS Steering Group Supplementary Report to Government November 2005, Option H has been expanded to include two additional tunnel variants at 6m diameter and 10.6m diameter. Where necessary, to avoid confusion, we will refer hereinafter to the earlier options as Option H (old). The recent revisions to Option H have the effect of reducing the storage volume by removing the volume stored in the shafts, (apparently originally included in error), and shortening the length of full tunnel because of problems associated with locating the drive shaft at Homefield Recreation Ground. Thus, while the cost of each variant now revised is reduced significantly so is its efficacy in preventing pollution. The apparent benefits of Option H and its variants are therefore reduced. The changes in volume do not appear to have been applied to the assessment of Option A (Ref.) in the November 2005 Supplementary Report.

Option H+ comprises Option H extended to include enhanced primary treatment at Abbey Mills and screening plants for Deptford (transferred by small tunnel to Charlton), Charlton and Earl Pumping Station in the lower reaches. These extended works would enable Option H+ to intercept the majority of the flow depending on the tunnel diameter including eight of the nine worst single discharges quoted in the report ‘An Assessment of the Operation and Environmental Impact of the Tideway CSOs’. This has been subject to the same changes as Option H as discussed above.

The Steering Group Supplementary Report to Government November 2005 also considers options for dealing with the River Lee as a separate issue, recognising the need to precede the Olympics with a reduction in spills to the River Lee, flowing as it does in close vicinity to the site of the Olympic Village. Two principal options are reviewed for intercepting and transferring the most critical polluting CSOs in this area to Crossness for treatment. One of these ‘River Lee Option 2’ is then combined with Option H (new) to give the further variant Option H++.

The TTSS team ultimately discounted Option H and its variants because they were considered to represent less value for money given the perceived benefits compared to Option A. It was also felt that Option H failed to comply with the objectives, and Option H+ only marginally met the objectives.

The key reasoning given in the TTSS for considering these solutions was their ability to at least partially achieve the objectives by focusing on a reduced scope of key CSOs on the most sensitive stretch of the river and, for Option H+ the benefits of enhancing this partial solution with other improvements.

The proposed scheme is essentially the first third (otherwise known as Phase 1) of potential Option A. This option has similar construction issues to Option A, albeit over a shorter length and at reduced depth.

Assumptions and Challenges

Options H and associated variants have been ruled out by TTSS mainly as Option H appears to achieve much less benefit, whilst the variants all approach the benefit level of Option A (Ref.) to some extent but at a less favourable unit rate (£M per % improvement). The TTSS also considered that the improvement to the quality of the Thames will be compromised by the CSOs that will continue to operate on the stretch between Heathwall Pumping Station and Crossness Sewage Treatment Works.

The CSOs that are not addressed by these options appear to be difficult to address by other means, such as screening facilities at the outfall location. This is due to their location in very densely developed areas of London. However many of the CSOs in this stretch are not classified as deficient in the comparative analysis carried out, but are included because of TTSS/ EA observations of aesthetic problems or receipt of public complaint. It may be that a number of the CSOs that are being addressed, whilst having a noticeable aesthetic impact locally, do not have a significant effect on the litter or health issues in the wider context of the Tideway.

Whilst Option A (Ref.) addresses 36 of the worst CSOs, the 14-17 of these not addressed by Options H or H+ do not have a significant impact on the most sensitive upper reach with respect to DO and health. For instance we note that the impact of those CSOs in the reach below Heathwall are referred to by the TTSS as follows

> "The required load reduction for the Vauxhall to West India Reach is only very small. No CSO loads have therefore been removed".

Similarly just four of the 19 CSOs in this reach are identified as having a health impact, the largest of which is a significant distance downstream of the upper reach and even given the tidal movement is unlikely to have much impact in the recreational areas. Option H+ improves on this still further by tackling Abbey Mills, the biggest single flow and load from a Tideway CSO. Thus, in capturing the flows from Abbey Mills, Option H+ will remove a significant element of the sewage-derived solids currently discharging to the Tideway. However we understand that no health benefit can be attributed to this improvement since TTSS in its assessment report on the impacts of the CSOs has concluded that flows from Abbey Mills have no adverse effect on health.

Thus by elimination, the above analysis points to litter as the principal water quality problem relating to discharges between Heathwall Pumping Station and Crossness. However it is important to note that with Option H+/H++ a very large proportion of the litter would already be being removed from the upper and lower reaches of the Tideway. If the remaining litter can be addressed by means other than a tunnel solution then it may be possible for this solution to meet the aesthetic objective.

The TTSS Steering Group Supplementary Report to Government November 2005 acknowledges that the method of analysis used by the TTSS leads to an understating of the public health benefits to be gained from the implementation of Option H and its variants. This has been discussed earlier in our report. In Table 4.2 below, we illustrate the disparities caused by the use, by TTSS, of different criteria in the analysis of aesthetic and health improvement, and show how the health benefit changes when these disparities are removed.

Option Storm event	Improvement criteria	% Improvement Event = 12 in 1 year	
		Aesthetics	Health
H (7.2m) New TTSS	Aesthetics = % flow captured Health = % Risk days reduced	24	14
H (7.2m) JB Assessment (% flow from target areas)	Aesthetics and health= % flow captured from those CSOs identified as deficient for that objective	23	69

Table 4.2 – Results of alternative analyses of performance criteria for Option H

By virtue of the smaller scale of this option and the fact that the western section will be mainly constructed in London Clay there will be less risk involved in the tunnelling works. This option therefore has the potential to avoid increased costs that could occur with Option A.

4.5 Alternative Approaches

Variations on the number of CSO connected in, the length and volume of tunnel storage and the type of treatment employed as part of Option H/H+ may permit a greater proportion of the benefits to be met. Conversely the review of the objectives discussed earlier in this report may conclude that these options are in any case compliant with a revised set of objectives.

One cost reducing alternative would be to reduce the length and diameter of the tunnel upstream of Heathwall, thereby reducing the number of CSO discharges that would be removed for treatment downstream. However, a reduction in the storage volume could result in a greater variation in treatment works load.

The argument presented in the TTSS reports about the difficulty of sustaining a biological process to treat very intermittent and widely varying storm flows and loads is accepted. Therefore we have quickly ruled out such processes as 'deep shaft' aeration. However, the deep bed sand filter technology selected for downstream stormwater treatment might also usefully be applied further upstream to give local health risk improvements without the need for the long tunnel if applied with disinfection. The sand filter alone would be expected to only marginally reduce the level of pathogens discharged compared to more sophisticated processes. TTSS quotes removals of the order of 95% for enhanced primary treatment facilities in the 'Impact of CSO Discharges on Microbial Water Quality of the Thames Tideway', though we would wish to investigate further whether this actually reflects figures for 'equivalent treatment' plants that include UV disinfection.

In consideration of this solution we have assumed that some of those sites that TTSS deemed suitable for screening plant could be utilised. Initial discussions with the treatment plant suppliers confirm that 'stacked' plants should be practicable, reducing the footprint area although undoubtedly at increased capex and opex costs. Treatment extending into the foreshore might also be practicable, but would still need to be relatively compact.

Elsewhere in the world equivalent or enhanced treatment of storm effluents is being applied. Enhanced primary settlement using lamellas, Actiflo, etc., followed by UV is achieving high effluent standards with simple small footprint plants. There are, however, consenting issues that currently stand in the way of such technology being applied in the UK. We understand United Utilities have trialled this system but that extensive EA monitoring requirements within the proposed consents have to date limited wider application.

Comment: There are assumptions made that technical problems with Option A (Ref.) can be overcome and that the estimate of the cost is robust. If this proves not to be the case then it will be highly beneficial if investigations into other approaches have been progressed to determine their potential to contribute to the achievement of the objectives. If these investigations are not progressed and the cost of Option A (Ref.) is found to rise significantly then either additional time will be required to carry out these investigations or there will be no alternative but to increase the budget for the scheme.

If the alternatives are not investigated in more detail then there will be a weakness in the planning case for the scheme.

Recommendations: We recommend that the use of a sand filtration plant (as proposed by TTSS for Option H and H+) as a means of providing primary treatment be investigated further, in particular the capability such a process has for removing bacteria.

5.0 COST BENEFIT ANALYSIS

5.1 Introduction

In view of concerns raised in connection with the objectives and strategies in sections 2 and 3 above, we are of the view that the Cost Benefit Analysis (CBA) may benefit from being repeated, possibly in a different format, once the key parameters of the TTSS have been revisited.

The CBA utilised three different methodologies to rank the Strategy 3 solutions options, which are discussed in sections 3 and 4 of this review. The methodologies are listed below and discussed in the following sub-sections;

- Stated Preference Survey – analysing respondents' willingness to pay (WTP).
- Market Evaluation Study – an assessment of the wider market benefits derived from meeting the chosen objectives.
- Environmental Costs Study – an assessment of the environmental costs of implementing and maintaining the solution.

5.2 Stated Preference Survey

The stated preference survey appears to have been carried out in a very robust and thorough way. However we believe there are flaws in the way in which the TTSS has framed its improvement scenarios to the respondents; as discussed elsewhere in this report, it presents the water quality in the Tideway and the improvements derived from the implementation of the TTSS in a way that tends to inflate the related benefits.

This calls into question the conclusions of the study. The key points at issue are:-

Ecological Objective WTP

'Fish kill' values presented to respondents are much higher than those derived from the modelling of CSO spills alone; the range '4-8' incidents per annum quoted derives from all events that lead to dissolved oxygen breaches, and therefore overstates the potential benefit of the CSO scheme. The analysis presented in the TTSS shows that the AMP4/AMP5 treatment works upgrades will generate by far the greatest benefit in terms of resolving critical DO levels resulting in mass fish mortality, when compared to the preferred CSO solution. Whilst accepting that CBA adjustments were made to account for greater benefits from Option A (Ref.) versus AMP4/AMP5 works, this is still built from the WTP for a reduction from eight to nil fish kills. We contend that the scale of the problem should therefore be presented to respondents afresh given the AMP/AMP5 works improvements and the emphasis placed on sustainability improvements rather than on fish kill reduction from the Tideway CSO works.

An extract from The Thames Tideway: Stated Preference Survey carried out by eftec/MORI states;

> "Fish kills: Currently 45 species of fish are present in the river at any one time. However, there is a risk that when severe overflow events occur, especially in the summer and autumn, large numbers of fish fry may be killed off from lack of oxygen. Experts estimate that currently there are about 8 overflows a year that are big enough to pose a risk to fish populations, potentially killing all the young of a particular species born in that year."

This was the information given to members of the public interviewed for the stated preference survey, which in turn was used to quantify the willingness to pay. Whilst this was the case at the time the survey was carried out, subsequent understanding of the impacts of the sewage works on DO leading to the AMP4/AMP5 works now planned will reduce this significantly to just 1.53 fish kills per year in total. We believe the revised scale of the problem means there is a need to carry out a new willingness to pay survey since the stated preference survey/ willingness to pay exercise, and the cost benefit analysis of solutions have been carried out on different baselines, with the former being inflated above what is now directly achieved by the TTSS.

Human Health WTP

We believe that health risk benefits that might be derived from TTSS solutions were described too optimistically during the willingness to pay survey. The background health risk, and the impact that the CSOs have had, have not been properly evaluated - either in the context of the WHO guidelines or a rigorous assessment of the hazard and exposure levels of Tideway users. Since our initial report, TTSS have provided revised figures that confirm – albeit on a limited data set – that even on dry days, the bacteriological quality is at or just worse than WHO guideline standards for 'Likely Health Risk'. This fact was not known to respondents taking part in the willingness to pay survey.

We disagree with the use of the health risk days as a means of gauging public health risk impacts and potential benefits. The use of health risk days as applied has the following weaknesses:-

- It takes little account of the volume of sewage discharged into the sensitive reaches
- Spill days are accounted in an overly simplified manner with 60 days allocated to each of three reaches. This does not appear to reflect actual spill events and whether or not the volume discharged falls below the adverse health effect criteria for a particular CSO
- Whilst the TTSS impact assessment classifies the reach below West India Dock as 'no adverse impact' for health, the CBA includes for example, 17 days of health risk days against Option H in this reach. This is not consistent.

The health risk day application tends to weight the CBA against partial solutions. For example the TTSS Supplementary Report November 2005 states that the variants of Option H (new) only provide a 15% improvement in health risk days whereas in reality this option captures nearly 100% of the spills in the reaches most sensitive to health risk. In addition, those spills not captured immediately downstream are, on the whole, small and infrequent. The small number of CSOs not captured which exhibit larger and more frequent spills occur so far downstream as to cause little additional risk. The impact of this method of analysis is acknowledged by TTSS which demonstrates in the sensitivity analysis of the CBA that removing the 'health risk WTP' elevates Option H+ and Option H to be the most beneficial options (in NPV terms).

In light of the points above, the extrapolation of a 'willingness to pay' value from the small number of respondents questioned, to provide a global figure as a notional publicly acceptable 'budget' is considered unsound, albeit the mechanics of the eftec work in this respect appear satisfactory.

It would be helpful to see the Present Value of Benefits and Present Value of Costs of the AMP4/AMP5 works alone presented for comparison with the Option A Cost Benefit Analysis summary in Table 8 of the TTSS Cost Benefit Working Group Report. Indicating this comparison to the survey respondents might have given them some way to gauge the level of 'return' in terms of environmental improvements.

The stated preference survey is open to challenge as outlined above; the results obtained being very sensitive to the questions asked. We have also challenged the objectives on which the preferred solution is based and we doubt the public's apparent commitment to the scheme would be as strong if they were aware of these areas of doubt.

Other issues we would highlight include:

- Are the public aware that significant fish kills will be much less likely to occur following the AMP4/AMP5 investment at the treatment works since this will significantly improve the prevailing DO profile in wet weather, mitigating the impact of CSO spills? We do however acknowledge that this will not altogether prevent fish kills caused by CSO spills, but the improvement derived from Option A(Ref) will be proportionately small.

- Whilst fish kills may continue to occur in consequence of CSO spills, do the public realise that the non-exceedance of the 10% per annum fish mortality rate in the Tideway is not a necessary prerequisite for a sustainable fish population? We note however the difficulty likely in explaining the concept of the 'sustainability' issues of the various levels of depressed DO.

- What would the public view be of the occasional use of parkland as a means of source control? The TTSS indicates an unacceptability to release public parks for this purpose but the opportunity has, to date, not been taken to test this. We would suggest that the survey should have been constructed to also test the public's opinions on the possible strategies rather than just the objectives.

We note that cognitive testing was undertaken to determine the respondents understanding of the stated preference survey questionnaire. We would, however, question the extent to which the designers of the cognitive test, understood the complexity of the essentially technical issues that were involved. This point was also made by Ofwat, as noted in the cost benefit report conclusions.

The public's aspirations with regard to significant bodies of water are fairly straightforward; as stated by MORI during the TTSS CBA, the priorities are the "maintenance of the quality of our river waters" and the "protection of important areas of wildlife and plants". We would suggest that the only clear outcome of the CBA is that the public are, indeed, willing to pay for environmental investment.

It is largely up to the environmental and economic professionals to ensure that these aspirations are met in a cost effective manner. Furthermore, when being consulted in such matters, the public should be aware of the costs and benefits of all proposed improvements in an area over a particular timeframe for which they are being asked to pay.

We agree with the contention that while the environmental costs and benefits cannot be easily quantified, they nevertheless should be taken into account in the decision making process. We are of the view that this should be the core aspect of any future CBA for the project.

5.3 Market Evaluation Study

The market evaluation survey largely found that there would be little market impact from meeting the TTSS objectives. However, if the associated strategies and solutions were included in the market sensitivity testing, the results might be different. For example the fact that other strategies might play a significant role in alleviating local flooding or providing new amenity areas could improve market conditions, albeit there might also be a negative impact from the proposed works close to residential / commercial areas.

5.4 Environmental Costs Study

The environmental costs study was presented in two reports. The first appears to have derived a reasonable estimate of the scale of environmental costs of the construction and operation of the Options A to G.

The second report into Option H seems less robust, having focused on the AMP4/AMP5 wastewater treatment works schemes and those elements of H relating to the pumping stations targeted in the lower reaches. The second report does not look at the impact of the short tunnel and treatment works at Heathwall, so cannot be used to compare Option H or H+ with the results of the earlier report.

Similarly if the study had been used to compare the strategies, it could have given a much stronger case - for example a system of source control and separation might be expected to require significantly less energy in its operation than the tunnel.

5.5 Conclusions and Recommendations

The technical quality of the cost benefit studies in support of Option A (Ref.) is of a high standard. However the direction taken and the information used has not resulted in the robust case that would be expected for a project of this scale.

Inevitably, in being carried out before a full understanding of the impact of improvements to the existing sewage treatment works on DO levels was made, and with the persisting lack of quantitative analysis of the human health impact of the CSOs, the stated preference survey, on which heavy reliance is placed, describes too optimistically the benefits of the implementation of the TTSS. Most notably, the survey fails to give the respondents the proper comparative environmental outcomes in relation to the actual and proposed upgrading works.

The WTP analysis has been carried out on an inflated impression of the importance and extent of fish kills since it was not able at that time to indicate the benefits that would be derived from the AMP4/AMP5 works. Respondent's WTP should be reassessed against the benefits that might be derived post the AMP4/AMP5 works, and with the concept of potential fish kills/sustainable fish populations more clearly explained.

Similarly with respect to the health objective, as the WTP findings are underpinned by the optimistic indication of the river water being largely free of health risk following implementation of the preferred solution, the validity of the Cost Benefit Analysis is likely to be undermined.

The Market Preference Survey on the other hand, which concludes there is little market benefit in particular in relation to litter, is given little prominence.

We therefore recommend that a full review of the CBA work is made once the objectives have been validated. In particular the stated preference survey should be given in proper context of the actual benefits that might be achieved solely through the implementation of TTSS, and there must be some means of respondents benchmarking the WTP cost bands against similar environmental enhancement projects. The study should be extended to canvas public opinion on strategies and solutions as well as the objectives.

6.0 ALTERNATIVE SCHEMES

6.1 Introduction

The overarching aim of the Study is to protect the Thames Tideway from the adverse effects of stormwater discharges from CSOs.

This Brief calls for a review of the work carried out originally to August 2005 and more latterly to November 2005 with a view to identifying possible strategies / schemes that may, in terms of costs and benefits, compare favourably with the option identified as the ‘preferred solution’ by the TTSS.

In the preceding sections, we have reviewed the objectives, strategies and the various schemes identified by the TTSS, including the ‘preferred option’. In so doing, we have drawn attention to a number of issues relating to the objectives, the strategies and the cost benefit analysis which lead us to believe there is a case for challenging the ‘preferred option’ by developing an alternative ‘partial’ scheme. Such an alternative scheme would be based on slightly less onerous objectives but would still be capable of delivering similar benefits but at less cost.

Taking cognisance of the new data presented in the TTSS November 2005 Supplementary Report, we have refined our proposals for alternative schemes, first presented as four alternative solutions in our December 2005 report to a single, costed, alternative partial scheme based on Alternative Solution 1 from that report. We have named this solution, Solution X so as to avoid confusion with Alternative Solution 1. We consider this alternative offers a significant proportion of the benefits of TTSS ‘preferred solution’ Option A (Ref.) but at much reduced cost. In addition to its principal storage and treatment elements, we envisage that Solution X, as part of a Strategy 5 approach, will also include initial quick wins already funded such as in-river treatment, but utilise them more effectively against the lesser, more localised pollution that might still occur. Further consideration could then be given in the longer term to generating in-catchment solutions based on Strategies 1 and 2 that will prove more sustainable.

6.2 Strategy

As noted in section 3, four strategies for dealing with stormwater discharges to the Tideway were considered by the TTSS and all but Strategy 3 was rejected on the basis that no single solution deriving from Strategies 1, 2 or 4 could fully meet all the objectives set out in the TTSS. To reiterate, these strategies are:-

- Strategy 1: Dealing with storm water before it enters the sewers
- Strategy 2: Dealing with the storm water within the sewerage system
- Strategy 3: Dealing with the storm water at the CSOs

- Strategy 4: Dealing with the storm water in the river

It is our view that greater benefit can, in the long term, be obtained from developing a hybrid integrated storm water management strategy (Strategy 5), across the Tideway area comprising a mix of solutions derived from Strategies 1 to 4 as appropriate. Such an approach could be used in conjunction with a programme of improvements to the quality of effluent discharged from upstream sewage treatment works where this can be shown to be cost effective.

Whilst the application of Strategy 5 is theoretically the most appropriate approach, particularly in the long term, we accept that delivering the Strategy 1 and 2 elements of the package, whilst simple in engineering terms, can be complicated by wider issues of adoption and maintenance. These are not insurmountable, and there is a significant argument for undertaking a more robust examination of the benefits derived from SUDS and separation in the catchment. TTSS found that a modest reduction in the connected areas of certain land uses could have a very significant impact on flow volumes from the most frequent storm events.

Taking cognisance of the issues raised above, we recognise the probability that storage and treatment will most likely comprise the key elements of any solution and it is on this basis that we have developed the alternative solution presented in the ensuing sections.

6.3 Solution Development

Initially, it was anticipated that alternative schemes developed in this review would be based on modifications to existing TTSS solution options to save costs. Whilst a number of technical issues, which may affect costs, have been raised in section 4 of this report, the key factors likely to drive down costs and increase benefits are the amendments to the objectives and strategies proposed in sections 2 and 3 of this review. Thus, with such fundamental changes mooted, options previously rejected by the TTSS may become worthy of further consideration though this is outwith the scope of this review. In addition, the development of new solutions based on revised objectives yet to be developed will involve a substantial amount of work and must likewise be considered outwith the scope of this report. We recommend that this additional work should be carried out since it offers the opportunity to make substantial savings.

In our initial review of TTSS's various options, we were able to rapidly discount Options B to G. See further discussions in section 4. As a result, we have developed our solution drawing principally from the remaining Options A and Option H and its variants.

Following the arguments developed in earlier sections, we initially sought to develop an alternative solution, Solution X, based on a broadly applied integrated stormwater management strategy (Strategy 5) approach. However, recognising the many short term difficulties of incorporating Strategy 1 and 2 elements into our proposal (see 6.2 above), we have elected instead to focus on a solution comprising a combination of Strategy 3 and 4 measures. In taking this approach, we recognise, that for reasons of practicality, Strategy 3, treatment and storage methods must form the principal element of any solution if both the revised objectives and the Olympic imperative are to be met. The use of skimmer craft, a Strategy 4 measure, provides a quick resolution to the current global issue of litter slicks, whilst in the medium to long term offers a flexible solution to litter in the middle reaches of the Tideway where more conventional solutions are unlikely to prove cost effective.

We consider that Solution X offers the best balance between; achieving substantial improvements in water quality; rapid potential for delivery in two parallel schemes; and better value for money for the customer.

Solution X (see Fig 6.1 below) comprises four key improvement elements which are defined and commented on below:-

Element 1 : Enhanced Primary Treatment at Abbey Mills

The need for expedience in providing an improved river environment in time for the 2012 Olympic Games means that aesthetic improvement measures required at Abbey Mills take an elevated priority. Some improvements here, such as those which would result from constructing weirs or locks on the channels upstream of Abbey Mills, could be delivered relatively quickly (but would not address water quality issues in the lower Lee). Alternatively as well as providing an enhanced environment in the River Lee near to the Olympic Village, the provision of treatment at Abbey Mills will contribute to improvements in the levels of litter and DO impact on the Tideway itself. The latter is illustrated in figure 2 of Appendix C of the TTSS Supplementary Report November 2005.

Element 2: 9km long, 7.2m dia. Tunnel from Hammersmith to Heathwall and associated Screening Plant

General - We have chosen the 7.2m diameter tunnel because the TTSS states that the intercepted volume can be returned to the network without the need for a large enhanced primary treatment facility so close to central London. This also avoids the need for excess land purchase.

Health Benefits - By targeting the majority of those CSOs classed as causing a health risk impact in the upper reaches of the Tideway, this storage tunnel, which is broadly based on TTSS Option H (new), offers significant health benefits. Analysed for compliance against our revised objective, this option gives a more positive, and in our view, a more accurate demonstration of the benefits of the Western Tunnel than the 'health risk day' approach adopted by TTSS.

Aesthetic Improvements -This element also targets all the aesthetic pollution discharged directly into the upper reaches. Excess flows from larger storms will be pumped to the screening plant at Heathwall rather than returned to the sewer. Whilst proportionally, this represents only 23% of the sewage-derived solids entering the Tideway, without this intervention, much of these solids would have migrated to the middle reaches of the Tideway. When combined with the Abbey Mills treatment plant this element enable some 75% of the total sewage-derived solids by volume to be targeted at just over 50% of the cost of Option A (Ref.).

Ecological Benefits - TTSS states that Option H (old) 7.2m achieves the same small increment fish kill improvement as Option A (Ref.). The figure for Option H (new) 7.2m is not given but is assumed to be similar. As far as our proposed secondary ecological sustainability standard is concerned the level of compliance is indicated in the TTSS Compliance testing analysis results in Appendix C of the Supplementary Report November 2005. This shows that this element is compliant for the 2mg/l DO standard and our revised 4mg/l DO standard, but not the 3mg/l standard. However in combination with Element 1, full compliance with our three revised standards is achieved and with the original TTSS 2 and 3mg/l standards.

Element 3 : Deployment of AMP4/AMP5 skimmer vessels

The TTSS impact assessment identifies specific 'aesthetic hotspots' which exhibit excessive levels of sewage-derived solids. These hotspots include the upper reaches of the Tideway and the area in the vicinity of Westminster, Greenwich and the Thames Barrier. Element 2 above largely addresses the solids issues in the upper reaches. We propose that the aesthetic problems in the remaining areas should be resolved by the deployment of the skimmer vessels, already funded in AMP4. With the other improvements delivered as part of Solution X, we expect the skimmers to be much more effective at dealing with the reduced volume of sewage-derived solids that might still occur occasionally in the Westminster, Greenwich and Thames Barrier areas.

Element 4 : Medium to Long Term Strategy

In the longer term, SUDS and in-sewer storm water control solutions, including Real Time Control (RTC), could potentially supplement elements 1 to 3. This might provide flexibility to meet more stringent quality requirements or to future proof against changes in the catchment. This could reduce both the total volume of wastewater reaching the CSOs and the rate of flow within the sewerage system. This approach may allow a better flow balance to be achieved between the upper and lower interceptor sewers with the following benefits:

- Improved storm water flow regime at the Abbey Mills CSO
- Greater capacity in the low level sewers to accept flow pumped out of the proposed storage tunnel forming Option H(new)
- Reduced storm water discharge from the CSOs in the middle reaches of the Tideway, in particular for frequent events
- Reduced local flood risk
- Free up capacity for the use of RTC in the network

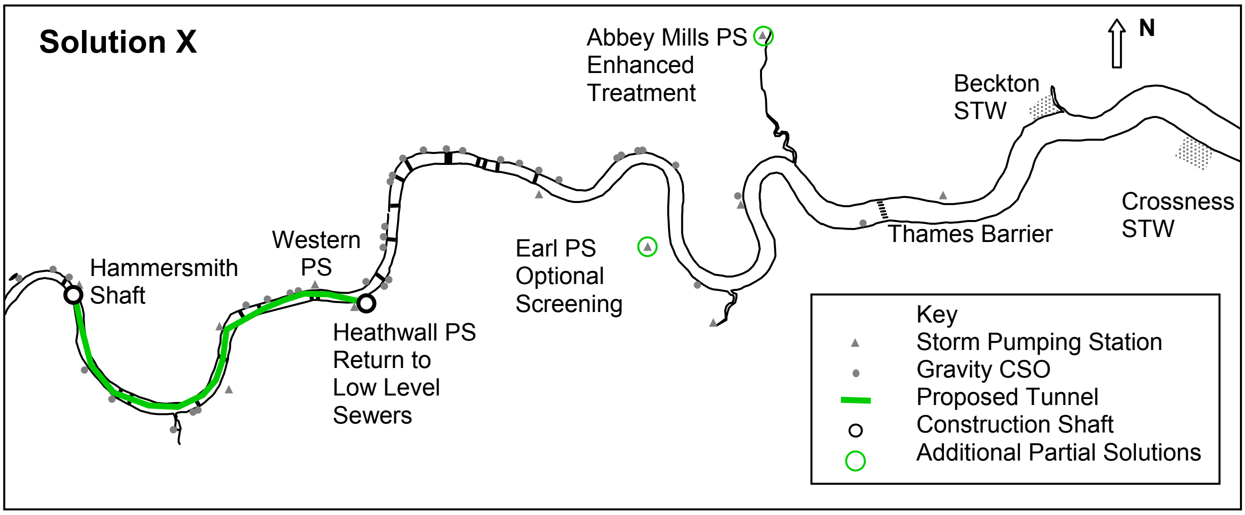

Fig 6.1 Showing outline of Solution X

6.4 Outline Costs for Solution X

Table 6.4 provides details of costs for a range of potential solutions to resolve water quality issues arising from the discharge of stormwater to the Tideway. These costs are based exclusively on those presented in the TTSS reports and reflect a 2004 cost base date. Cost information relating to the elements comprising Solution X has been drawn from Table 6.4 and is presented as Table 6.1.

Solution X

Element	Components of Solution	Capex £M
1	Abbey Mills Enhanced Primary Treatment	399
2	H (new), West London Scheme (7.2 m dia tunnel and screening plant)	496
3	Fine Skimmers	Already funded
4	Strategies 1 and 2	See below
	Estimated total capital cost	**£895 Million**

Table 6.1 Capital Cost of Solution X Elements as based on TTSS

Whilst Solution X element 4, Strategies 1 and 2 have for completeness been included in the above costings table, the cost for this element has been omitted since expenditure on this item is difficult to predict with an equivalent level of accuracy, and it in any case presents a medium to long term prospect which would most likely be applied whatever solution is ultimately implemented. Our initial rough order of costs estimates that 10% of the suburban area might be controlled in this way at a capital cost of the order of £375 Million.

Table 6.2 below compares the compliance of Option A (Ref.) and our Solution X with the revised objectives proposed. 'Target spill' as given in the table is a spill from a CSO identified in the TTSS as having a negative impact against the given parameter i.e. 35 aesthetic impact CSOs, 19 health impact CSOs and 10 DO impact CSOs. We have included CSOs classified by TTSS as 'borderline' in the set. Removing these enhances Solution X further, particularly for health. DO is included for consistency, although both Option A (Ref.) and Solution X are 100% compliant with our revised ecological objective (DO). For the purposes of this comparison, Option A (Ref.) is indicated in the tables below to achieve 100% removal although a small number of spills will continue to occur.

The proportion of Tideway spill intercepted by Solution X varies, improving with increasing storm frequency. This is because, as discussed in our argument against the use of health risk days, many of the central CSOs do not spill or spill very low volumes during the most frequent storm events. Only during the larger storm events do many of those CSO not intercepted by the western tunnel start to spill.

However in all cases it can be seen that Solution X offers a significant degree of improvement against our revised objectives at a much reduced cost and lower cost per proportion of objective achieved when compared with Option A(Ref.). The exception to this is DO, for which Solution X is slightly less cost effective. As stated earlier, our interpretation of the TTSS reports is that the ecological objectives will become very much a secondary consideration once the AMP4/AMP5 works have substantially resolved the fish kills issue.

Option	Capex £Bn	Storm event	36 in 1 year			12 in 1 year			2 in 1 year		
			Aest	Health	DO	Aest	Health	DO	Aest	Health	DO
A (Ref.)	1.698	% target spill	100	100	100	100	100	100	100	100	100
		£M per % target spill	17	17	17	17	17	17	17	17	17
Solution X	0.895	% target spill	75.29	74.49	52.08	71.72	68.75	51.78	68.51	65.12	52.32
		£M per % target spill	11.9	12	17.2	12.5	13	17.3	13.1	13.7	17.1

Table 6.2 Comparison of the performance of A(Ref.) and Solution X in terms of total percentage improvement and £M spent per % improvement

The percentage removals of litter shown in Table 6.2 are broadly in agreement with the TTSS Supplementary Report November 2005 when reviewing solutions for the Western end plus the River Lee. However we note that the Steering Group report Table 0.4 states that the treatment plant at Abbey Mills only captures 10% of litter, whilst piping Abbey Mills for treatment at Crossness captures 49% of the litter. To be consistent with the approach adopted elsewhere in the TTSS, we have assumed that the percentage of litter captured equates to the percentage of flow captured and have therefore adopted this approach in developing the performance figures in Table 6.2. These improved performances should be practically achievable especially since the revised cost for the works at Abbey Mills includes for storage and new screening plant which will give the opportunity to design out the existing problems arising from high pumping rates direct to the screens. Notwithstanding this, we have also derived costs for a variant on Solution X, Solution X+, (Table 6.3) which includes primary treatment in place of screens at Heathwall to show the 'worst case scenario' should screens not prove effective.

In the longer term, nothing in Solution X precludes the installation, at a later date, of measures to deal with some of the larger overflows in the lower middle reaches such as Earl, Deptford and Charlton. In fact, a discrete screening plant at Earl could be added whilst maintaining a favourable comparison with Option A (Ref.). This has also been included in our Table 6.3 worst case scenario for Solution X+. It illustrates that the capital cost and cost per percentage of objective achieved still remain better than Option A (Ref.), except for DO as discussed previously. We do not believe that Solution X+ offers any appreciable benefit over Solution X and therefore our recommendation is that only Solution X is considered further.

It may be possible to optimise Solution X further considering the wider implications of revised objective criteria. We believe that greater cost savings are achievable if objectives are set that are more appropriate taking into account the conclusions we have drawn on the actual impact of the CSOs.

Option	Capex £Bn	Storm event	36 in 1 year			12 in 1 year			2 in 1 year		
			Aest	Health	DO	Aest	Health	DO	Aest	Health	DO
A (Ref.)	1.698	% target spill	100	100	100	100	100	100	100	100	100
		£M per % target spill	17	17	17	17	17	17	17	17	17
Solution X + (9.0m dia. variant) + Earl screens	1.120	% target spill	77.37	74.49	52.08	74.55	68.75	51.78	71.37	65.12	52.32
		£M per % target spill	14.5	15.0	21.5	15.0	16.3	21.6	15.7	17.2	21.4

Table 6.3 Comparison of the performance of Option A (Ref.) and Solution X+ (9.0m dia. variant)+ Earl screens in terms of total percentage improvement and £M spent per % improvement

6.5 Conclusions and Recommendations

An outline cost estimate has been presented for our preferred alternative solution, based largely on information extracted from the TTSS Final Supplementary Steering Group Report, and is identified as potentially offering an economic (partial) solution compared with the TTSS's 'preferred solution'. This Solution X intercepts broadly 70% of the unsatisfactory CSO spills at circa 50% of the cost of Option A (Ref.).

In addition, an alternative integrated water management strategy (Strategy 5) has been developed based on a slightly revised set of TTSS objectives and on strategies which require further development before the solutions and cost estimates can be developed in detail. The alternative strategy has potentially significant advantages both in terms of overall cost and the time to achieve initial benefits.

It is recommended that Phase 2 of this review be implemented in order to:

- refine the objective criteria;
- develop Solution X further;
- re-assess the contribution to a solution which may derive from improvements to sewage treatment works discharges, in particular wet weather discharges;
- consider the part which Strategies 1 and 2 solutions could play in the overall solution in the medium to long term.

TABLE 6.4 - BASIS FOR COSTING ALTERNATIVE SOLUTIONS AND SOME OTHER TTSS COST AND PERFORMANCE COMPARISONS

Strategy	Ref.	Solution Description[1]	% improvement[2 3]			Comment	Capex £M[3]	Opex £M/yr[3]
			DO	Litter	Health			
1. Pre-Sewer	-	Sustainable Urban Drainage - SUDS	75	75	75	Incremental implementation. Reduces peak storm flow rate & volume. Major disruption to business & long implementation period. Impractical as a total solution. Could form part of an integrated or hybrid solution.	16,000	No data given
2. In Sewer	-	On or Off Line storage	100	100	100	Incremental implementation, reduces peak storm flow rates - relies on spare capacity after the storm has passed. Unlikely to provide total solution. Major disruption to business & long implementation period.	16,000	No data given
	-	Separation of Storm & Foul Flow	90	95	90	Major disruption to business & long implementation period. Impractical as a total solution. May contribute to a hybrid solution.	20,000	No data given
3. At CSO	A (ref)	Storage & Transfer Tunnel (7.2 m dia)	100	100	100	Complies fully with the original objective criteria, which are now open to question. Opex increased threefold.	1,698	6.45
	A (low)	Storage & Transfer Tunnel (6.0 m dia)	60	81	50	Largely complies with the original objective criteria, which are now open to question.	1,431	1.9
	H	West London Scheme (9.0 m dia)	26[4]	26	15	Deals with approx. 25% of storm flow and the most sensitive stretch of the river. Intercepted flows pumped returned to Low Level Sewer. Excess flows screened, treated, peroxide dosed & discharged at Heathwall	603	No data given
	H	West London Scheme (7.2 m dia)	22[4]	22	13	Deals with approx. 25% of storm flow and most sensitive stretch of the river. Intercepted flows returned to Low Level Sewer. Excess flows screened, peroxide dosed & discharged at Heathwall	496	No data given
	-	Abbey Mill Enhanced Primary Treatment	5	10	1	Deals with approx. 48% of storm flow. Expanded to include storage and revised treatment plant design	399	No data given
	-	River Lee Option 2 (9.7m dia) Abbey Mills Tunnel Transfer to Treatment at Crossness	49	49	0	Tunnel from Abbey Mills to Crossness STW + PS + treatment link tunnel to Beckton STW from main tunnel.	781	No data given
	-	River Lee Option 1 (8.5m dia) Eastern Section of A(ref), Abbey Mills/Charlton to Treatment at Crossness	49	49	0	Tunnel from Abbey Mills PS to Charlton, then to Crossness STW + PS + treatment link tunnel to Beckton STW from main tunnel	888[5]	No data given

1 For full details, see Solutions Working Group Report, Volumes 1 & 2, , and Steering Group Supplementary Report November 2005.
2 Percentage improvements are related to the objective criteria and assessments discussed in the TTSS Report, February 2005.
3 Costs and Compliance data is derived from draft TTSS Steering Group Supplementary Report, November 2005 esp. Table 0.4. CTP2004 results giving a better indication of DO compliance are on pages Figs 1 to 6 on pages 63 to 70.
4 Table 2 of the Solutions Working Group Report Volume 1 indicates compliance upstream of London Bridge following implementation of the AMP4 treatment works improvements
5 Costing from Steering Group Supplementary Report, August 2005, Appendix D- figure of £554M at 2002 prices increased by 6% to bring it up to 2004 prices

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary of Findings

A global summary of our findings is given below followed by a brief discussion of our conclusions relative to each Working Group Report.

Our key finding is that, with only a slight reassessment of the existing objectives, a solution is available that delivers a significant proportion of the benefits in capturing some 70% of the unsatisfactory storm spills at 52% of the cost of Option A (Ref.). We have entitled this Solution X.

Having reviewed and assessed the TTSS main and subsidiary reports, we find that there are a number of areas which warrant further investigation before promotion of a preferred solution should proceed. These include:-

- The objectives, which are open to challenge and should therefore be re-examined;
- The selection of an appropriate strategy to meet the objectives. Whilst the TTSS acknowledges that the 'preferred' Strategy 3 based solution might be supplemented through the application of in-river treatment and SUDS, we believe that greater emphasis should be placed on the application of an integrated strategy in preference to the addition of other strategies as 'bolt-ons'. We consider this will generate more efficient local solutions and ultimately a more cost-effective overall solution;
- There are a number of risks associated with the preferred solution that remain unresolved and which could present fundamental difficulties at a later stage;
- Conclusions based on the 'willingness to pay' survey are open to challenge and in consequence, the cost benefit analysis is also open to question:
- The current sewerage model is not verified for significant storm events – thus the impact of partial solutions cannot be fully assessed and;
- A model of the bacteria levels in the Tideway, similar to the DO river quality model developed for the TTSS should be commissioned and used as a basis to quantify heath risk issues and develop solutions.

7.2 Conclusions

Objectives Working Group Report

Aesthetics: Sewage-derived litter appears to form a small part of the total mass of litter polluting the Tideway. Our review of the arguments regarding aesthetic pollution indicates that further analysis of the quantitative and qualitative impacts of sewage-derived material is needed before potential benefit from this objective can be considered as 'proven'.

Ecology/Dissolved Oxygen: The data concerning the impact of oxygen depleting discharges from CSO spills suggests that much of the work required to achieve the high key environmental objective of reducing fish kills already forms part of the planned AMP4/AMP5 works. The 'willingness to pay' for the remaining sustainability benefits has not been tested.

Human Health: The direct impacts of the CSOs, and consequently the benefits to be derived should the 'preferred solution' be implemented are uncertain. The cost benefit analysis appears to have been carried out on an inflated impact by suggesting that the prevailing bacteriological water quality is good and only the CSO spills cause it to fail. This is not correct.

Solutions Working Group Report

Derivation of Strategies:

Our conclusions are set out in terms of the four strategies defined in the TTSS report and listed below, plus one additional strategy developed in the course of our review; Strategy 5 - Integrated Stormwater Management.

- Strategy 1, Before the rain enters the sewerage system
- Strategy 2, Within the sewerage system
- Strategy 3, At the CSO outfalls
- Strategy 4, In the river itself

Strategy 1: Whilst the applicability of source control/SUDS techniques is likely to be severely restricted in the densely built-up area of central London, there are likely to be opportunities, which should be explored in the larger and less densely developed sub-urban fringes. Sewerage network modelling may ultimately demonstrate that, in combination with other strategies, source control will provide local flood relief and by relieving pressure on the middle and low level interceptors, will reduce CSO spill frequencies. The application of SUDS techniques is considered to be a medium to long term measure which would be best applied as part of a holistic 'basket' of measures. Whilst it is correct that limited benefit will be derived for larger storms, TTSS have established that the frequent small storms that generate spills could be tackled by a relatively modest source control scheme targeted at non-residential land uses.

Strategy 2: This strategy has been discounted in the TTSS report on the basis that it would be impractical in terms of time and cost to apply across the whole catchment. We believe there are likely to be opportunities to reduce the impact of the CSO discharges through the development of Strategy 2 based solutions. However, to do so requires a network model capable of accurately representing the situation under storm conditions.

Strategy 3 – CSO Outfall Solutions: On the basis of the information that we have, we would not dispute the TTSS core finding that, if a single stand-alone strategy is the requirement, Strategy 3 is likely to be the only practicable and economic means of fully meeting the three stated objectives. However, we have expressed our doubts over the validity of the defined objectives and we similarly question the validity of a stand-alone strategy.

Strategy 3 – Treatment Option: The provision of treatment as the primary means of mitigating the impact of CSO discharges (the ‘Ofwat Option’) is likely to require significant bankside storage and transfer facilities. The development of suitably serviced treatment plant on artificial islands constructed in the Tideway, on the bankside or on permanently moored barges would involve a number of challenges, additional to those impacting on the TTSS solutions, which make this an unattractive option.

Strategy 4: It is apparent from the data presented in the TTSS that (i) sewage-derived litter and solids has not been fully quantified in respect of its impact (ii) the worst of the DO problem is resolved by the already funded AMP4/AMP5 works at the sewage treatment works and (iii) the direct impacts of the CSOs in terms of health risk remain to be robustly proven. In these circumstances, the benefits which can be achieved by in-river treatments such as the deployment of fine litter skimmers, bubblers and peroxide dosing plant can be significant and very visible to the public, initially as short-term ameliorating measures whilst data is gathered and optimised solutions are developed and implemented. Following this, the in-river treatment can be used to supplement the improvement works in areas where local benefits can only be achieved at high cost.

Strategy 5: Recent international experience indicates that an integrated storm water management approach can be effective and provide a potentially lower cost solution to the issues affecting the Tideway, particularly if preceded by a reappraisal of the objective criteria that the strategy is aiming to achieve.

Whilst the TTSS considers the only single ‘complete answer’ is provided by Strategy 3, it acknowledges that other strategies could contribute to the long term solution. Implementation of a hybrid strategy has the advantage over Strategy 3 of benefit streams that commence earlier, a resolution to local flooding issues, and potentially lower operation and maintenance costs.

In the context of a single stand-alone approach to resolve the storm water problems affecting the Tideway, the assumptions leading to the selection of Strategy 3 appear reasonable, indeed the arguments are powerful. However we consider that major benefits could be achieved by the selective application of Strategies 1, 2, 3, and 4 i.e. Strategy 5, both locally and as part of a holistic solution and consider this should be given further, more detailed consideration.

Development of Solutions

Solutions A, H and H+: This encompasses storage tunnel Options A, A (Ref.), H, H+ and H++ which are all variations on the same theme and in the same location, albeit, H and variants only cover part of the 'A' route. Some revision has been made to the capacity of H in the November 2005 Supplementary Report that has affected the efficacy of the option and its variants. This is primarily as a result of a reduction in the tunnel storage length which it is now proposed will start at Hammersmith rather than at Homefield Recreation Ground, and the loss of storage volume within the shafts. We do note, however, that these same issues would appear to apply equally to Option A (Ref.) but that the efficacy of this is unchanged.

The operation and maintenance issues listed below, which are common to all of these solutions, were identified as being inadequately quantified and representing a potential risk to the successful implementation of the works:

Construction Issues:

- Working space
- Groundwater pressure and availability of high pressure TBM
- Unforeseen obstructions
- Disposal of spoil
- Groundwater ingress

Operation and Maintenance

- Flushing and ventilation
- High treatment load
- Sediment deposition
- Solids loading

Solutions B to G: A number of points of detail were identified in connection with these options in addition to the points noted above in connection with tunnelling elements of Options A and H. These are listed in section 4.2 of this report.

Alternative approaches were considered in terms of the most appropriate solutions to comply with the existing or partially revised objectives only.

Cost Benefit Working Group Report

The technical quality of the TTSS cost benefit studies in support of Option A (Ref.) is very impressive. However, the direction they have taken and the information they have used has not resulted in the robust case that we would expect for a project of this scale.

In particular the stated preference survey, on which heavy reliance is placed, overstates the benefits of the implementation of the TTSS through failing to give the respondents the proper comparative environmental outcomes in relation to the actual and proposed upgrading works.

The WTP analysis has been carried out on an inflated impression of the importance and extent of fish kills caused by CSO spills. Respondents' WTP needs to be reassessed against the benefits that might be derived post the AMP4/AMP5 works, and with the concept of potential fish kills/sustainable fish populations more clearly explained.

Similarly with respect to the health objective, as the WTP findings are underpinned by the promise of the river water being largely free of health risk following implementation of the preferred solution, the validity of the cost benefit analysis is likely to be undermined.

On the other hand, the Market Preference Survey, which concludes there is little market benefit, is given little prominence.

7.3 Recommendations

Objectives

Aesthetics: We recommend that a more detailed analysis of the quantitative and qualitative impact on the Tideway of sewage-derived material be carried out. The potential benefits and value of any reduction in CSO discharges should be re-assessed in the context of aesthetic pollution. If there is no clear case for inclusion of this objective then it should be dropped as far as evaluation of options is concerned.

Ecology/Dissolved Oxygen: We recommend that the DO standards and mode of assessing DO compliance levels in the Tideway be re-visited to take account of fish behaviour and the mortality levels required to ensure a sustainable fish population. Any revision to the approach should then be used to re-assess possible solutions.

Before committing to a large capital investment to achieve a relatively incremental improvement over the DO improvements achieved through the AMP4 / AMP5 capital works programmes, re-analysis of the criteria and cost benefit study should be undertaken.

Human Health: We recommend that if health risk reduction is to remain a key objective of the TTSS, then further sampling and analysis work be carried out to define the wet day and dry day water quality in comparison with the WHO Guidelines. This would require sufficient samples to underpin a credible 95 percentile calculation for any reach of interest. This should be presented in terms of the projected reduction of the disease burden in preference to health risk days, since this term is misleading in the context of the prevailing bacteriological quality of the Thames. A model of the bacteria levels in the Tideway, similar to the DO model developed for the TTSS should be commissioned and used as a basis for the analysis of the problem and the development of solutions.

The alternative of mitigating CSO human health impacts through upgrading existing treatment works discharges and thereby improving background river water quality appears very practical and we recommend it be seriously considered.

At the same time, we believe that the Integrated Stormwater Management Strategy, (Strategy 5) should be thoroughly assessed and developed to the point that it can be shown to meet a new set of agreed objectives. These may comprise those previously discussed, although the 'health' objective could focus on variable standards for certain designated recreational areas, and the DO objective would seek to foster a sustainable fish population in the Tideway.

Strategies

In the context of a single stand-alone approach to resolve the stormwater problems affecting the Tideway, the assumptions leading to the selection of Strategy 3 appear reasonable, indeed the arguments are powerful. However we consider that major benefits could be achieved by the selective application of Strategies 1, 2, 3, and 4 i.e Strategy 5, both locally and as part of a holistic solution and we recommend this be given further, more detailed consideration.

We recommend that this is seriously reconsidered along with the possibility of using RTC to manage the system more effectively. However, to do so would require a network model capable of accurately representing the situation under storm conditions and such a capability should be developed as an integral part of solution development.

We recommend that Strategy 4, 'In-river treatment' be retained as part of a basket of measures to reduce the environmental impact of CSO discharges on the Tideway. This offers both the opportunity to achieve early intervention in the campaign to reduce the impacts of stormwater discharges on the water quality of the Tideway and an option for the provision of localised improvements where capital works cannot be cost effective.

To ascertain the extent to which source control techniques may be practically and cost effectively applied in the Tideway area, we recommend that three types of catchment of varying land usage are assessed. We envisage the use of source control techniques as a medium to long term proposition.

Solutions

Storage tunnels: Before the storage tunnel Options 'A' or 'H' proceed any further, we recommend that investigations to identify and manage the financial and technical risks be undertaken to confirm that:

- The tunnel itself can be successfully constructed;
- The connection works can be undertaken successfully;
- The tunnel can achieve long term watertightness;
- The tunnel can be operated safely.

Alternative Solution: Solution X, which is based on a Strategy 5 approach, has been developed and outline cost estimates prepared for a staged implementation. Whilst it is a partial scheme, Solution X provides substantial compliance with the original objectives. To reflect the fact that the works comprising Solution X do not intercept all of the key CSOs, the solution makes provision to utilise and add to the current level of in-river treatment with the aim of reducing the impact of litter from all sources and improving DO levels in the Tideway under all conditions. Solution X offers advantages when compared with TTSS's 'preferred solution' both in terms of overall cost and the time to achieve initial benefits.

We recommend that Alternative Solution X should be progressed and that further review be implemented in order to:

- refine the objective criteria and apply these to the development of this solution;
- re-assess the contribution to the solution which may derive from improvements to sewage treatment works discharges;
- consider in detail the part which Strategies 1 and 2 solutions could play in the overall solution and;
- assess the impact and optimum shape of the proposed alternative solution.

Cost Benefit Analysis

We recommend that a full review of the CBA work is made once the objectives have been validated. In particular the stated preference survey should be repeated in proper context of the actual benefits that might be achieved solely through the implementation of TTSS, and there must be some means of respondents benchmarking the WTP cost bands against similar environmental enhancement projects. The study should be extended to canvas public opinion on strategies and solutions as well as the objectives.