Thames Tideway Strategic Study

Solutions Working Group Report

February 2005

Volume 1

Thames Tideway

MAYOR OF LONDON · OFWAT · Environment Agency · Thames Water · RWE Group

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Thames Water
Gainsborough House
Manor Farm Road
Reading RG2 0JN

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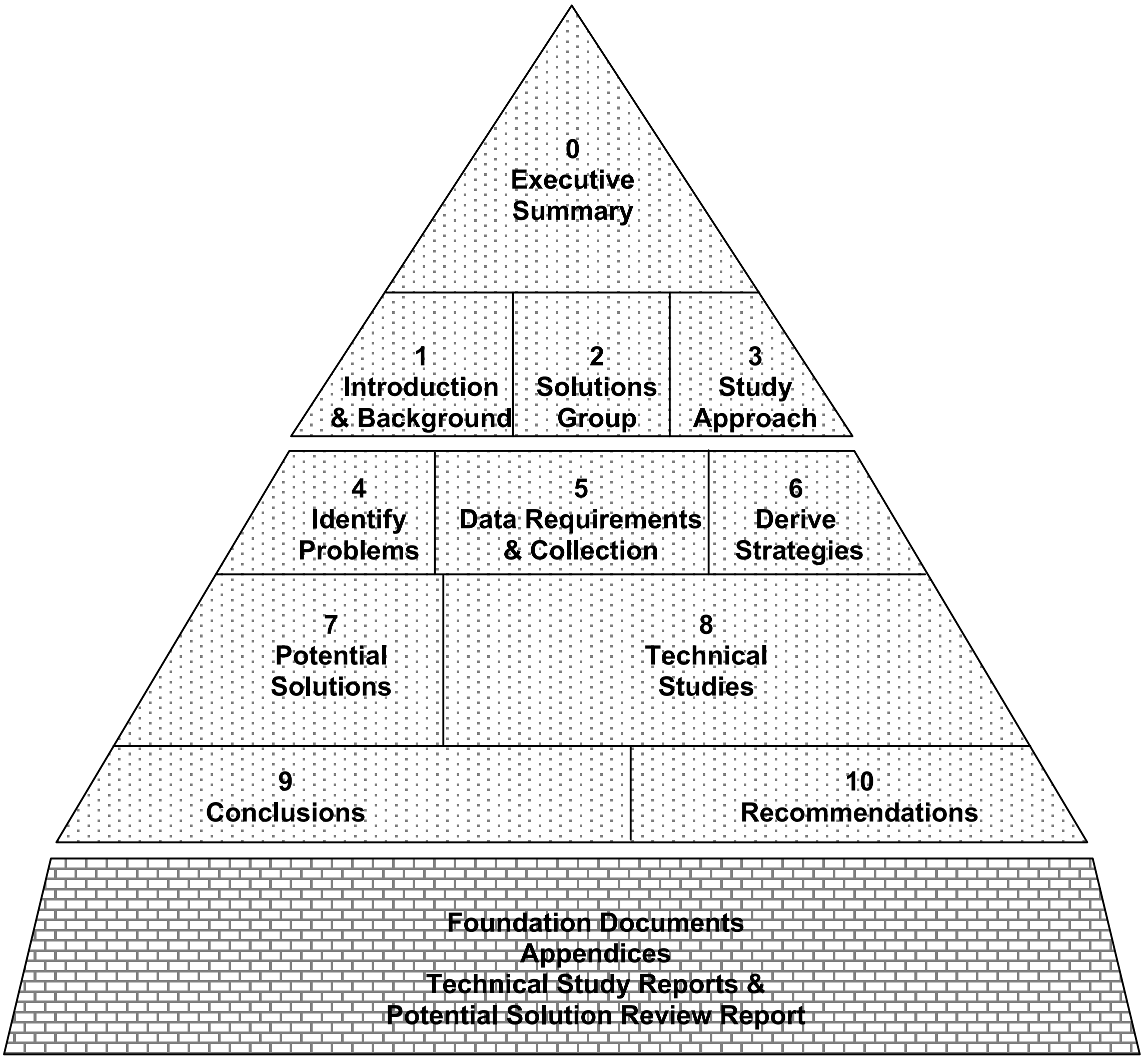
Structure and Use of Report

This report represents the contribution of the Solution Group to the strategic investigation of the Tideway Combined Sewer Overflow (CSO) discharges and is compiled in several related sections as indicated in ***Figure 1***. The content of each section and its context within the report is briefly described to enable the reader to select which section to address pertinent to his or her particular requirements.

Figure 1 - Solutions Group Report Structure



0 Executive Summary
The principal findings of the Solutions Group report are summarised within this section. The most viable solution concepts are identified and described. The basic problems associated with the Tideway CSO discharges are summarised in outline, together with derivation of strategies and the range of potential solutions considered. Budget capital and operational costs are also included.

1 Introduction & Background
The character of London's sewerage system in terms of historical development, public perspective and the particular challenges of CSO discharges in London are discussed.

2 Solutions Group
The relationship of the Solutions Group with the Steering Group and the other working groups is described.

3 Study Approach
The interpretation of the terms of reference for the Solutions Group is discussed in terms of primary and secondary objectives. The budget and programme for the study is described.

4 Identify Problems
The main problem areas are identified and discussed relating to reduction in dissolved oxygen, sewage litter and bacteriological contamination. Reference is made to the objectives and compliance testing of the potential solutions. These two subjects are covered in greater detail within the Objectives Group report.

5 Data Requirements & Collection
The basic data requirements for the study and assessment of derived strategies and potential solutions are identified. The methods used for collection are determined and described. The topics covered are rainfall, flow monitoring and pollutants. The specific analysis of the measurement of storm sewage constituents is covered in Section 8, Technical Studies, SCITTER (**S**torm sewage **C**onst**I**tuents **T**es**T** and **E**valuation **R**ig).

6 Derive Strategies
The four main strategies derived to address the problems associated with the Tideway CSO discharges are described and then assessed with respect to the findings of the Technical Studies and operational experience of London's sewerage system. The viable strategy is determined and the range of potential solutions for this strategy identified. These potential solutions are described and assessed in Section 7. The basic assumptions used to determine the outline parameters for each potential solution and level of intervention are described.

7 Potential Solutions
Each potential solution is described in outline. The viability of each is discussed individually with respect to the findings of the Technical Studies and by comparison of the main benefits and detriment. The overall comparison and ranking of the potential solutions is drawn together in Section 9, Conclusions. Other potential solutions that were identified during peer review and brainstorming exercises are also included for reference. These are briefly described and the reasons for discounting them discussed in outline.

8 Technical Studies
A précis of each Technical Study, carried out in support of this investigation by expert consultants, is included in this section. The full reports of these supporting studies are included in the Appendices. The principle conclusions and recommendations of each technical study are presented together with a discussion on how these impact upon the efficacy of the potential solutions. The findings of each study are discussed and expanded as appropriate. These principle conclusions and recommendations are used within Section 7 to assess each potential solution and are drawn together within Section 9 and 10 to formulate the overall conclusions and recommendations of this report.

9 Conclusions
Using the main conclusions identified by the technical studies and developed from operational experience of London's sewerage system the assessment of the four main strategies are summarised. Similarly the potential solutions of the most viable strategy are evaluated and the overall comparison and ranking is drawn together to identify the most feasible solution concepts. The budget capital and operational costs are presented. Comparison with other similar international and UK projects is also discussed.

10 Recommendations
The recommendations of the technical studies pertinent to option selection and development of the most viable are summarised. Recommendations for further study are described in outline.

Tideway Investigation - Solutions Group

0. Executive Summary

0.1 Introduction

The Solutions Group report outlines the strategies and options investigated to reduce the adverse effects on the tidal waters of the river Thames: **the Tideway**, caused by the discharge of storm sewage via Combined Sewer Overflows (CSOs) from the gravity sewers and pumping stations of central London. The range of strategies is described and the solutions that are likely to be successful are described in more detail. The main benefits and drawbacks of each potential solution are discussed. Indicative outline costs and comparisons are included leading to recommendation of the most cost effective conceptual solutions.

0.2 Storm Sewage Discharges to the River Thames

London's sewerage system is combined and, due to its history and development, is subject to significant land drainage flows. Whilst capacity is adequate for dry weather flows, rainfall events cause the sewerage system to surcharge quickly resulting in discharge of storm sewage to the river via the CSOs.

Discharges from the CSOs adversely affect the quality of the Tideway in three main ways:

1. By introducing large quantities of sewage derived litter, sanitary wastes including, needles and plastics and fats and grease, which create aesthetically offensive conditions in the river and on the foreshore.
2. By producing a rapid drop in dissolved oxygen (DO) concentrations, which can result in widespread fish mortality.
3. Storm sewage discharges also cause significant increases in the levels of pathogens, which can lead to a public health risk, especially for users of the river.

Water quality objectives to meet current and future legislative requirements have been formulated by the Objectives Group to address the above. In order to ensure compliance with these objectives substantial reductions need to be made in the pollution discharged from the CSOs. Interception of these discharges is a prerequisite to reduce the public health risk from increased pathogen levels.

Discharges from the Sewage Treatment Works (STW) during rainfall events can also degrade river water quality and combine with the CSO discharges to exacerbate the reduction in DO concentrations. It is now clear that STW effluent quality has a part to play in improvements to the Tideway and the CSO discharges cannot be considered in isolation.

Global warming is a challenge to scientists worldwide and is an issue considered within this report. Basically energy is being added to the atmosphere, causing changes to the current climatic patterns. The UKWIR CL10 project is currently considering how these changes will affect the climate affected design parameters currently used in sewerage design. The early indications are that summer period will be drier and winter periods will be wetter resulting in increased run-off and potential discharge to the river.

0.3 Strategic Objectives

The strategic objective is either to prevent storm water from flowing through the sewerage system into the river or allow the flow to continue but reduce the polluting load in the storm discharges to an acceptable level.

There are a number of strategies that might be employed to achieve the long-term objective of significant and permanent improvements in the water quality of the upper and middle tidal reaches of the river Thames.

These strategies may be grouped into four potential areas along the route of storm water from rainfall to flow in the river:

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

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

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

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

0.4 Evaluation of the Strategies

These strategies are considered in detail in Section 6. The main findings are summarised below.

0.4.1 Strategy 1

The catchment is very mature and serves a very densely urbanised environment. There is very limited opportunity to apply source control except at the upper reaches of the catchment, however the Tideway CSO spill flows are relatively insensitive to such changes. The widespread retrofitting of SUDS techniques is considered to be, at best, disruptive and costly and, at worst, not technically feasible. Alternative disposal routes for surface water flows are scarce or not available. Therefore, the strategy of preventing storm water from flowing through the sewerage system by source control or SUDS techniques is not considered to be viable.

0.4.2 Strategy 2

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

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

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

0.4.3 Strategy 3

It has been concluded that only solutions within this strategy could realise the objectives by providing appropriate solutions at the interface between the sewers and the river. It is worth noting that it is broadly this strategy that has been adopted to solve similar problems elsewhere in the world.

Potential solutions within this strategy have been investigated and costs estimated in outline. This exercise has revealed that there are only a few practical engineering solutions, which are likely to realise the desired levels of improvement at reasonable cost. Several of the potential solutions have been evaluated. It should also be appreciated that the ultimate solution to the Tideway water quality could involve a mixture of some of the appropriate techniques.

0.4.4 Strategy 4

This Strategy cannot be considered a real strategy in that once the sewage has reached the river the polluting effects can only be ameliorated and the aesthetic problems will not have been addressed at all.

0.5 Potential Solutions

General

At the commencement of this study the objectives were inadequately defined. Significant preliminary work was required to define the extent of the problem and to determine the appropriate limits. Whilst some clarity has developed it is likely that the objectives may be subject to further refinement.

It was therefore considered appropriate to explore the strategy 3 options by investigating the potential solutions at three levels of intervention: low, medium and maximum. Essentially the level of intervention determines the required capacity of the potential solution. In general terms the maximum level would only be exceeded once every 20years. The medium level capacity would be exceeded once every two years and the low level capacity exceeded three times per year.

The solutions considered were:

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

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

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

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

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

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

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

H. West London Scheme – initially formulated as the first phase of Option A, it was apparent that works at the western end of the Tideway would be more likely to achieve the greatest benefits from a given level of investment.

0.6 Comparison of Potential Solutions

Although these potential solutions are listed with apparent equal status it should be noted that some only address part of the overall long-term objective. Solutions B, C and F are essentially only screening and make virtually no contribution to improved water quality.

Solution H is effectively the western part of solution A. Alternatively additional partial solutions could be implemented to augment H such that it might be regarded as a more complete solution. Additional enhancement works at Modgen STW may also be required to facilitate implementation of this partial or phased approach.

Budget estimates are included as an initial indication of total cost for each solution. The estimated cost for potential solution F is inflated to represent the possibly extreme costs for compensation to third party asset owners. As these solutions are focussed to deal with the CSO discharges and treatment of the intercepted storm flows there is no allowance for any improvements to dry weather flow or storm flows at the STWs. These budget estimates include a general contingency of 30%, which is deemed appropriate at this stage of the investigation to represent the following:

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

The Overall Project Risk for each solution was assessed as described in 7.3. The main conclusion being that Solution A is the only feasible approach, as it does not involve any potentially insurmountable issues.

Tables 1-3 below compare the estimated benefits and drawbacks, costs and basic parameters for each potential solution at the three levels of intervention. For the purposes of comparison the level of benefit is estimated in terms of percentage reduction of the current perceived nuisance from litter (aesthetic) on a typical annual basis and DO compliance requirements for the upper and middle Tideway. It becomes clear that potential solution A offers the best compliance with the objectives at the most reasonable cost and therefore solutions based on storage must be considered to be the most favourable approach.

The main implication of climate change for the potential solutions is that additional capacity will be needed to accommodate the increased run-off. Within the industry there is still great uncertainty as to the impact of climate change effects. However for potential solutions based on storage (solutions A and H) there is an opportunity for the flexible approach of supplementing the storage capacity of the main tunnel with off-line tanks at some future date once trends are determined with greater confidence. This would avoid the potential risk of over-sizing the tunnel and incurring unnecessary expenditure.

0.6.1 Solutions Comparison Tables

Table 1 : Solutions Comparison: Construction and Impact Parameters

Solution /Intervention	Estimated Cost £M (@2002)	Estimated Operating Cost £M/yr	Land Take (ha)		
			Total (temp)	New (temp)	Ex TW (temp)
A Maximum Full Storage & Treatment	2,784	6.93	7.1 (3.5)	0.8 (1.5)	6.3 (2.0)
A Medium Substantial storage & treatment	1,776	3.50	5.1 (3.0)	0.8 (1.5)	4.3 (1.5)
A Low Moderate storage & treatment	1,287	1.93	3.3 (2.5)	0.8 (1.5)	2.5 (1.0)
B Maximum Full flow transfer with screening only	2,648	9.68	5.5 (3.0)	5.5 (3.0)	0 (0)
B Medium Substantial flow transfer with screening only	1,676	4.89	4.3 (2.0)	4.3 (2.0)	0 (0)
B Low Moderate flow transfer with screening only	1,164	2.29	3.1 (1.0)	3.1 (1.0)	0 (0)
C Maximum Full flow screened via 8 discharge points	4,149	10.33	6.3 (2.0)	6.3 (2.0)	0 (0)
C Medium Substantial flow screened via 8 discharge points	2,246	5.33	5.4 (1.8)	5.4 (1.8)	0 (0)
C Low Moderate flow screened via 8 discharge points	1,480	2.33	4.3 (1.3)	4.3 (1.3)	0 (0)
D Maximum Full flow screened via 8 discharge points with moderate storage	4,983	11.57	9.1 (3.5)	6.6 (2.5)	2.5 (1.0)
D Medium Substantial flow screened via 8 discharge points with some storage	3,153	5.98	7.4 (2.9)	5.7 (2.0)	1.7 (0.9)
D Low Moderate flow screened via 8 discharge points with minor storage	1,889	2.62	5.6 (2.3)	4.6 (1.5)	1.0 (0.8)
E Maximum Full screening with “forward” flow stored and returned to treatment	3,467	3.51	5.3 (61.4)	1.5 (60)	3.8 (1.4)
E Medium Substantial screening with “forward” flow stored and returned to treatment	2,213	2.13	3.6 (31.1)	1.0 (30)	2.6 (1.1)
E Low Moderate screening with “forward” flow stored and returned to treatment	1,518	1.23	2.5 (12.9)	0.8 (12)	1.7 (0.9)
F Full flow screened at each individual CSO	11,713	12.18	13.0 (8.0)	11.8 (5.5)	1.2 (2.5)
G Full transfer to constructed wetlands	2,714	5.64	400.9 (2.0)	400.9 (2.0)	0 (0)
H West London Option, 1st phase of A (Med)	650	1.24	1.9 (0.5)	1.9 (0.5)	0 (0)
H+ West London Option with additional partial solutions as “complete” scheme	1,265	2.24	3.5 (1.5)	2.5 (1.0)	1.0 (0.5)

Table 2 : Solutions Comparison: Quality and Compliance Parameters

Solution /Intervention	CBA Rank (Ave)	Red'n Gross Solids (%)	DO Compliance				Annual Discharge (Mm^3)		
			Upper		Middle		By pass	Scr'd only	Scr'd & treat'd
			CSOs only	+ AMP4	CSOs only	+ AMP4			
A Maximum	2	100	C	C	F	C	0	12.2	12.2
A Medium	1	97	C	C	F	C	0.38	11.82	11.82
A Low	3	81	C	C	F	F	2.28	9.92	9.92
B Maximum	11	100	C	C	F	F	0	12.2	0
B Medium	8	97	C	C	F	F	0.38	11.82	0
B Low	12	81	C	C	F	F	2.28	9.92	0
C Maximum	17	100	F	F	F	F	0	12.2	0
C Medium	13	97	F	F	F	F	0.38	11.82	0
C Low	16	81	F	F	F	F	2.28	9.92	0
D Maximum	10	100	C	C	F	F	0	12.2	10.13
D Medium	5	97	C	C	F	F	0.38	11.82	8.19
D Low	6	81	C	C	F	F	2.28	9.92	5.27
E Maximum	14	100	C	C	F	F	0	12.2	3.66
E Medium	9	97	C	C	F	F	0.38	11.82	3.55
E Low	15	81	C	C	F	F	2.28	9.92	2.98
F	18	100	F	F	F	F	0	12.2	0
G	4	97	C	C	F	F	0.38	11.82	11.82
H	7	48	F	C	F	F	6.28	5.92	5.92
H+	n/a	79	F	C	F	F	2.56	9.64	5.92

Key
C – achieves Dissolved Oxygen compliance
F – Fails to meet Dissolved Oxygen compliance

Table 3 : Solutions Comparison: Advantages & Disadvantages

Solution / Intervention	Advantages	Disadvantages
A Maximum	All stored flows screened & treated. All events in 20years covered Highest improvement in quality	Significant environmental impact. Disruption limited to interception structures and shafts
A Medium	All stored flows screened & treated. Bypass only once in 2 years* Very good improvement	Moderate environmental impact. Disruption limited to interception structures and shafts
A Low	All stored flows screened & treated. Bypass 3 times per year Good improvement	Moderate environmental impact. Disruption limited to interception structures and shafts
B Maximum	All flow screened and sensitive reach of river bypassed	First flush pass through likely Extremely high power requirements
B Medium	Significant flow screened, low bypass.	First flush pass through very likely Very high power requirements. High risk of tunnel choking
B Low	Moderate events screened, significant bypass	First flush pass through certain Significant power requirements. Very High risk of tunnel choking
C Maximum	All events screened, no bypass	Disruption at screening plant locations. No DO improvements
C Medium	Significant events screened, low bypass	Disruption at screening plant locations. No DO improvements
C Low	Moderate events screened, significant bypass	Disruption at screening plant locations. No DO improvements
D Maximum	Moderate events retained for treatment. Moderate DO improvements	Disruption at screening plant locations. Complex interception
D Medium	Small events retained for treatment. Some DO improvements	Disruption at screening plant locations. Complex interception
D Low	Minor events retained for treatment. Low DO improvements	Disruption at screening plant locations. Complex interception
E Maximum	All flow screened. Moderate DO improvements	Extreme impact on foreshore. Difficult operational access
E Medium	Significant flow screened. Some DO improvements	Very serious impact on foreshore. Difficult operational access
E Low	Vast majority of flow screened Limited DO improvements	Serious impact on foreshore. Difficult operational access
F	Screening only. Implement in stages	Intolerable construction disruption at most locations. Compensation / diversion costs are astronomic.
G	"Green" perception	Land take for constructed wetlands. Pump assist required. High energy
H	1st phase of A. 50% of flow treated and screened. Implementation in phases	Remaining CSOs discharge unscreened to river. Low DO compliance
H+	79% of flow screened. Implementation in phases	Remaining CSOs discharge unscreened to river. Low DO compliance

*** Note: bypass means the number of times the solution will be beaten and therefore still spill to the river.**

0.7 Technical Studies - Findings

Seven critical findings of the technical studies have a fundamental impact on the effectiveness of the potential solutions. These are listed as follows and discussed in more detail in Section 9, Conclusions:

1. The hydraulic capacity of the existing sewers to accept returned storage flow.
2. The minimum storage tunnel diameter required to prevent choking during filling.
3. Land acquisition, planning and environmental constraints and impact of implementation.
4. Characteristics of the London catchment, such as its extent and maturity.
5. Treatment limitations due to intermittent and variable flow and storm dilution.
6. Cost of capital investment and operation.
7. Effects of CSOs and STW discharges acting in combination on river itself.

0.7.1 Existing sewer capacity

Modelling analysis has shown that the capacity of the existing sewers constrain the ability to distribute the locations and volumes either of storm sewage discharges or to receive returned stored flows. No significant flows could be discharged in the western parts of central London because the sewers in this area are too small and would either cause flooding or simply spill immediately back into the river. This means that any solution based on storage or transfer of flows must of necessity discharge at the eastern end near to the major Tideway STWs.

0.7.2 Choking

Analysis shows that below a certain (large) diameter a storage tunnel would be at serious risk of choking, i.e. trapping large pockets of air within the tunnel, when receiving the significant flows from many of the connecting sewers. The application of the minimum tunnel diameter requirement to those potential solutions that are based on transfer or distribution tunnels (B, C and D) imbue these tunnels with an inherently large volume so that they become similar to that of potential solution A.

The process of tunnel filling has been modelled using Computational Fluid Dynamics (CFD). The results confirm that a main tunnel of 6m diameter is unlikely to choke during filling.

0.7.3 Land Issues

The severe land acquisition challenges and planning constraints that would confront potential solutions C, D and E, and in particular the extreme disruption associated with the implementation of F, weigh very heavily against the feasibility of these solutions.

0.7.4 Catchment Characteristics

As previously discussed the catchment is large and very mature and serves a very densely urbanised environment. Providing many separate storage elements has the major disadvantage that localised rainfall would only be able to utilise the tanks nearby and the majority of the storage would be unused.

Options to install storage ponds for rainwater at ground level are limited and the wholesale provision of new foul drains for almost every household in the Capital would involve immense cost and disruption on a very large scale. The strategy of preventing storm water from flowing through the sewerage system by source control, SUDS techniques or separation is considered to be not viable.

0.7.5 Treatment Limitations

A dedicated storm treatment facility would be required for treatment of the intercepted CSO flows, as full treatment at the STWs would not be practical. Rainfall events create intermittent and variable flow. This limits the application of secondary treatment, which is based on biological processes. Secondary Treatment of storm flow is only likely to be viable if supported by STW sites between rainfall events and for flow rates of up to about $10m^3/s$. Secondary treatment can only be applied to those potential solutions, which are based on storage of flows, which can be pumped out at a controlled rate.

The enhanced primary treatment process of Deep Bed Filtration, although relatively untried for storm treatment until recently, offers a physical process, which readily accommodates intermittent flow. Used in conjunction with Submerged Aerated Filters it could treat storm flows to a high quality and during dry weather periods could be used to enhance the secondary treatment and provide tertiary treatment to improve the effluent of the existing STW.

0.7.6 Costs

The estimated capital and operating costs for each potential solution at each level of intervention, as appropriate, are summarised in the table 1. Operation and maintenance of the interception structures, tunnels, treatment facilities, pumping station(s) and disposal of waste will be resource intensive and require significant additional manpower. The high rate treatment processes recommended are relatively expensive to operate due to their reliance on chemicals and compact nature.

0.7.7 CSO and STW Discharges

During the course of investigations into the affect of CSO discharges on DO concentrations in the river, it became apparent that discharges from the STWs during wet weather may be of more significance than was previously thought. This applies especially when storm conditions cause major CSO discharges to coincide with a significant wash through of activated sludge (AS) solids from the works into the river. In particular it was observed that on occasions Mogden STW, was responsible for a considerable proportion of the DO sags in the upper reaches of the river. Improvements to the STWs are being considered separately through the AMP4 process and will be an important contribution to meeting the proposed new objectives. This does not affect the need for dealing with the CSOs but will result in higher background DO levels in the river which will reduce, slightly, the degree of BOD removal required as part of the treatment for the CSOs.

0.8 Conclusions

0.8.1 The Viable Strategic Approach

As indicated, in section 0.4, of the four strategies investigated it was concluded that strategy 3, which is characterised by potential options constructed at the interface of the sewerage system and the river (i.e. at the CSO outfalls) represented the strategy that could be considered most viable and worthy of further investigation.

0.8.2 The Appropriate Potential Solution

The interception of storm flows to storage at or near the CSOs for transfer to treatment is seen to represent the most appropriate overall approach to meet the required objectives. This approach has the least technical challenge, the least impact in terms of land acquisition, planning and environmental constraints and the most flexibility to accommodate refinement of objectives.

The main conclusion of the Overall Project Risk assessment described in 7.3 was that this was the only approach that did not involve any potentially insurmountable issues. The most efficient provision of this storage, and least disruptive to implement, would be by large diameter tunnel, which would effectively perform the three functions of collection, storage and transfer to treatment of the intercepted CSO flow. The only issue to resolve is how much storage volume to construct and how much bypass to allow to the river during high rainfall events.

This approach is represented by potential solution A (low) which consists of a large storage tunnel (approximately 6m diameter, 34.5km long) constructed generally under the river, interception structures at the CSOs and a large pumping station to transfer flows to the storm treatment works. The treatment facility would be located adjacent to Crossness STW and would include screening and grit removal plant and deep bed filters. As it is proposed to increase the capacity of Crossness STW during AMP4 a significant portion of the flow could be pumped out to full treatment thus further improving the effluent quality.

The medium level of intervention represented by a larger tunnel further surpasses the river quality objectives. The additional volume of storage would allow for the interception of larger storm events and therefore less would bypass to the river. However this increase in benefit comes at greater capital and operating cost.

A partial version of the storage tunnel was also investigated called potential solution H. It consists of a storage tunnel for the western reach of the river, interception structures for the first 19 CSOs, a pumping station and treatment plant on the site of Heathwall PS. The treatment facility would comprise screening plant and deep bed filters. This plant could achieve a reasonable quality of storm effluent. However the compliance testing showed that it was insufficient to achieve river quality objectives. Implementation of additional partial solutions such as treatment plant at Abbey Mills, screening plant for Deptford, Charlton and Earl PS could augment H. However this would increase the total cost to that of A (low), but would not meet the objectives. These additional partial solutions are discussed in the addendum report “Variations for H”.

0.9 Recommendations

This study has concentrated on developing potential solutions to mitigate the adverse effects of the Tideway CSO storm discharges. The CSOs are, of course, not the only source of pollution to the Thames and it has become very apparent that this issue cannot be considered in isolation and that it is best to explore a holistic view of the Tideway.

To achieve a significant improvement to the river quality, at reasonable cost, it is essential to consider the relationships between all the polluting sources and to understand the response of the Tideway as a whole. For example, the significance of reducing the sewage litter from CSO discharges should be assessed in the light of total quantity of litter in the Tideway from all sources. This approach might also inform the intervention level chosen; for instance there seems little point in incurring the high cost of solution A (max) to secure a mere 3% improvement in capture of screenable solids over A (med) particularly if CSO discharges represent only a minor proportion of the total litter problem.

The existing STW effluent discharges and their response to rainfall events has significant effects on river water quality in the Tideway. Basic tests appear to show that oxygen depletion is exacerbated; most likely by a reaction between the remnants of activated sludge in the STW effluent and the CSO polluting load.

The most appropriate conceptual solution to resolve the adverse effects of the Tideway CSO storm discharges is to intercept the flows to a storage tunnel and transfer them to treatment later. This tunnel would represent a significant increase in capacity to the sewerage system as a whole. At present potential solution A (low) would appear to offer overall, the most cost-effective solution to the problem.

Further appropriate use of this additional capacity should have the potential to reduce the risk of sewer flooding, enable diversions for maintenance, disaster recovery and sewer cleansing. These potential synergies should be investigated and developed further to optimise investment and the realisation of benefits and improvements.

Current operation of the Thames Barrier to enhance flood response of the tributaries during prolonged heavy rainfall has a significant influence on Tideway river levels. There are likely to be potential effects on the operation of any implemented scheme, which should be identified and investigated.

As stated the strategic objectives were relatively poorly defined at the commencement of the study. Whilst some clarity has developed it is likely that the objectives will continue to be refined as a result of better understanding of the requirements of the Water Framework Directive and the cost benefit balance. It is essential that ultimately these key objectives are properly defined so that the most appropriate and cost effective potential solutions can be achieved.

0.9.1 Recommendations for Further Study

A number of scientific test regimes and sample analyses have been started under this study. Whilst a number of interesting and useful results have been obtained so far, it is clear that the range and quality of these tests should be greatly extended. The intermittent and unpredictable nature of rainfall events, together with the aggressiveness of the sewer environment continues to severely challenge effective measurement and monitoring.

This monitoring of CSO flows and pollution parameters is required to produce the data to improve the accuracy of the sewer catchment and river quality models. These models are essential tools to develop, test and optimise solutions.

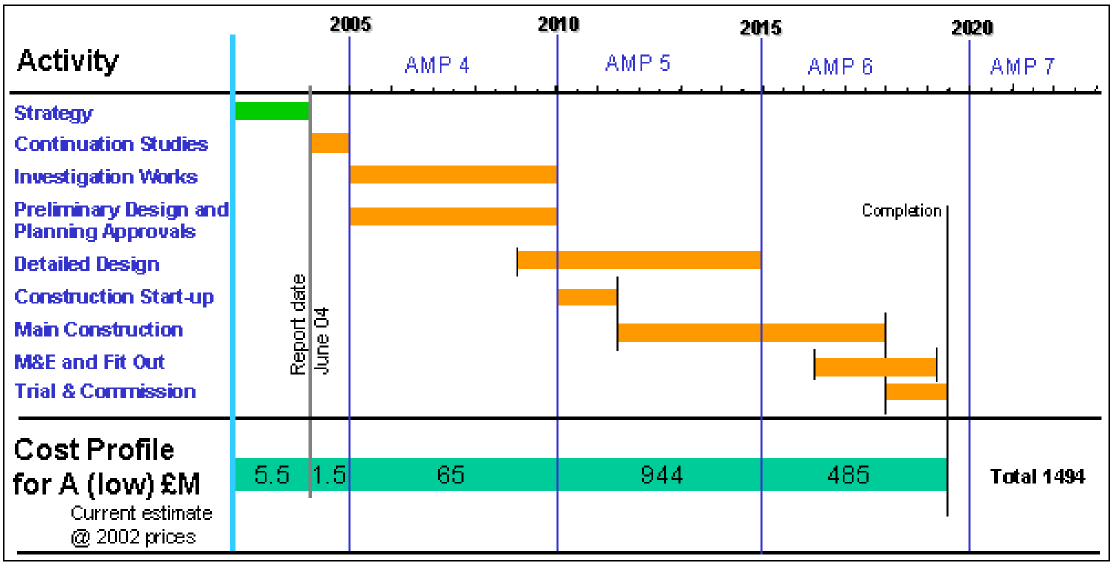
It is also vital to properly understand the pattern of flows in the system, the mechanisms for variation of pollutant concentration, the deposition and re-suspension of solids and the interaction of CSO and STW discharges for effective development of the models. The quality of this understanding and the models thus developed will support informed decision-making and enable the implementation of a cost effective solution.

Further investigation into the potential effects of climate change on the recommended solutions analysis has been carried out as part of the continuation study *(ref Modelling audit report)* and this work will continue as the results from the UKWIR studies become available.

The recommendation is for further development of the project in AMP4. Figure 2 shows the forecast programme for the favoured proposed solution - a storage tunnel between 6 – 9m diameter - Option A. This option was further assessed during the continuation study and Option A (low) chosen as the appropriate tunnel size to comply with BATNEEC (Best Technical Knowledge not Exceeding Excessive Cost). This is described in more detail in the refinement report.

For all solutions AMP4 will be used as the main design and planning phase with construction commencing at the start of AMP5.

Figure 2 – Outline Programme for Solution A (low)



1. Introduction and Background

1.1 Historical Background

The clean up of the Thames in the second half of the twentieth century is an internationally recognised success story. In the 1960s and 70s, biological sewage treatment was expanded to provide fully for the total continuous daily sewage flow from London and, in little more than ten years, the Thames was transformed from a lifeless, anaerobic river to one which could allow salmon to pass upstream. Further improvements in freshwater quality and operating agreements have improved the background quality to the extent that now 120 species of fish have been recorded in the Tideway. Several rare species now breed in the Thames, which has become an important spawning and nursery area for commercial fish types. This success has been achieved through the improvement of sewage effluent discharges to the river that occur under normal dry weather conditions. However when rain falls on London diluted sewage still flows into the Thames via CSOs (combined sewer overflows).

The foundation for the improvements in the Thames and the root of the current issue - was the construction of the London Main Drainage system in the 19th century by the great Victorian Civil Engineer Joseph Bazalgette.

The advent of a practical water supply and the mass production of water closets during the industrial revolution meant the previous system of foul water disposal based on cesspits began to break down. As London's population grew rapidly through the early 19th century the system was overwhelmed and eventually the land drainage system of local rivers and streams became the recipients of the rising tide of human waste. These had always been called 'sewers' but had until 1815 been exclusively for rainwater and land drainage. In that year the permitting of foul sewage to be drained into this system and the approval of its massive extension to keep pace with the housing boom was a catastrophe for the Thames. The new foul sewers discharged untreated and eventually overcame the ability of the river to purify itself, culminating in the 'Great Stink' of 1858, which caused Parliament to be evacuated.

The water supply was polluted causing over 100,000 deaths in the years 1830-55 and the government was forced, reluctantly, to take action. In 1855 Parliament created London's first central municipal authority, the Metropolitan Board of Works, which engaged Bazalgette to solve the drainage problem. From 1859-73 he built the system of intercepting sewers, which convey the dry weather flow from the old rivers and main sewers eastwards to new major outfall works on the north and south banks of the river, sited far enough downstream to stop the tide from bringing the sewage back into the city. These works at Beckton and Crossness had tanks adjacent to the outfalls that could store the sewage until the tide was just turning to the ebb when it could be safely discharged. Within a decade these storage works began to expand and provided ever-improving treatment processes for the sewage so that, by 1974, the effluent quality had risen to its current high standard.

London has a 'combined' drainage system: the sewers are the old rivers and carry all the rainwater as well as the foul sewage in a single pipe; there are no separate surface water sewers. Bazalgette was the first engineer to confront this problem of storm sewage and his new interceptors were only able to deal with a small amount of rainfall. Although a highly effective solution to the problem of continuous discharge, the intercepting sewers are necessarily of finite practical size and can only take about two to three times the normal dry weather flow. The excess, which in a severe storm may be up to 50 times the dry weather flow, overflows via the CSOs into the Thames together with the diluted foul sewage. This was an essential feature of the original design and should not be regarded as a failing. Had this decision not been made the system might never have been built as the technology, and the cost of a complete solution able to handle all the storm water, was beyond the Victorians. Even today the challenge this problem presents is daunting.

1.2 Why are CSOs a particular issue in London?

A combination of circumstances makes London unusual, if not unique; in the way main drainage affects the river on which it stands. At first sight the Thames appears to be a large river but this is because of the tide whose range in central London is very large and this is the key to the problem. Under summer conditions the incoming freshwater flows from upstream are in fact very low. Coupled with the length of the tideway and a very long retention time, there is very little dilution or flushing of any polluting load from the estuary. Add to this the very high population density and it is clear that even localised storms can cause a significant polluting load, potentially leading to river de-oxygenation and death to fish.

Until the 1970s this effect was masked by the generally poor background river water quality that kept the Thames virtually lifeless. After the general improvements to sewage treatment described above it was noticed that returning fish stocks would suddenly suffer after certain storm events when the CSOs discharged significantly. This was often localised and since then has been partially ameliorated by the injection of oxygen directly into the river from specially designed boats, which can be moved to the worst affected parts of the Tideway. This approach has further contributed to the establishment of a sizable and diverse fish population. There are concerns, however, that whilst adult fish are tolerant of periods of poor water quality, fish fry are not and the diversity or populations of fish may now be locally limited as a result of CSO discharges. The resilience of fry is one of the topics being investigated within this study.

CSOs are a normal feature of sewerage systems and, if operating infrequently, when the watercourse is in spate, cause manageable discharges that do little damage to the water environment. Moreover, in non-metropolitan areas discharge rates rarely exceed 0.5 cubic metres per second and are able to be screened or otherwise controlled by current technology. The London CSOs are different. In the last 150 years, to reduce the risk of sewage flooding to properties a large number of storm-relief sewers and pumping stations have been added to the system so that there are now some 60 points of discharge into the Tideway. Many are over two metres in diameter and individual discharges of over 10 cubic metres per second are commonplace. In a typical year the discharge can exceed 11 million cubic metres and the peak flow rate into the whole the Tideway could be over 450 cubic metres per second. These discharge figures are estimates based on hydraulic calculations and the data produced by the mathematical models of the Beckton and Crossness sewerage systems developed by Thames Water between 1990 and 1996 at a cost of over £10M. Accurate measurement of discharge in large sewers with a wide variation of flow rates is notoriously difficult. The impact of the tide and the many pumped outlets add to the degree of unreliability in the data. Nevertheless one part of this strategic study involves installing monitors to gauge these flows with greater accuracy (see section 5).

Current CSO technology is normally based on a combination of storage and some form of screening to remove suspended solids, which are carried forward in the foul sewer. The carry forward flow normally present in such CSOs is unfortunately not present in the Tideway outlets except in a few specific places. The huge increases of flow in storm conditions in fact overwhelm the intercepting system and the CSOs are just so many holes in an underground colander that remains full while the storm persists. The outlets normally receive actual reverse flows from points downstream and there is no retained forward flow of sewage to carry away any solid matter removed by screening. This means that the screenings removed must either be stored or removed during the progress of the storm. The option of returning screenings to the flow when the storm has passed has also been considered.

Not only are the rates of flow hard to measure. The relative quantities of organic and other matter in the sewage are not known very accurately and values based on the analysis of dry weather sewage samples are known to fluctuate wildly during storm events. To design installations to effect screening it is necessary to know both the anticipated discharges and the likely loading in the flow so that the plant is big enough but not too big and thus wasteful of investment. Establishing the constituents of storm sewage and how they vary during storm events is another object of the study.

The Tideway CSOs described above would require enormous plant installations each the size of significant sewage treatment works to treat the discharges locally. The solutions which may be successfully applied to the more modest CSOs in suburban or rural areas will not fit in central London on points of discharge where there is no land available and the necessary works would entail demolition of a number of famous noted landmarks and buildings, to say nothing of disruption to roads, rail and other significant utilities.

The construction of London sewerage system was the largest single civil engineering project in Britain in the 19th century. It is nearly 150 years since the work started and the central government had to create the first major Metropolitan authority in Britain to carry it out. A complete solution to the Thames Tideway storm discharges could be the biggest civil engineering project in Britain in the 21st Century. To 'retro-fit' such a solution to the London sewers now is a very special challenge indeed.

1.3 Public Perspectives

Until the early 19th century the river Thames was London's focal point and key transport artery. Samuel Pepys, in 1667, found it quicker to get from the Temple to Westminster by riverboat than by coach. Getting from place to place in London using the river rather than the roads did not start to decline until the advent of the railways after the middle of the 19th century. A large fishing industry, centred on Billingsgate market was also active until the 1820s, both downstream and upstream of the City. After the Middle Ages, Fulham, Chelsea and Battersea were counted amongst the many fishing villages located on the banks of the Thames from Teddington to Dartford.

London's river provided employment for tens of thousands of citizens in a wide range of occupations, especially in the docks. In fact, if ancillary trades are included, the Thames was until the end of the Victorian era, the source of employment for an actual majority of Londoners. It has also always been the main source of drinking water for the entire Greater London conurbation. Alternative supplies via the River Lee (which includes the New River aqueduct) in northeast London and the many boreholes in the west Kent area south east of the capital together supply barely 25% of the total. Despite the degradation of water quality in the 19th century and the disease due to pollution of the Tideway the main change to the water supply process has been to move the intakes upstream of Teddington weir. The private water companies continued to provide water until the end of the nineteenth century with the very minimum of 'treatment' that largely comprised sand filtration whose use was made compulsory by the Metropolis Water Act of 1852. The Metropolitan Water Board was formed in 1902 and the continuity and quality of the water supply has steadily improved since then.

Today no drinking water comes from the Tideway. In the 18th Century the river was fairly clean and the public would have regarded the Thames then as today residents of Cambridge regard the Cam or those of Oxford the Isis. In 1750 John Strype, a London gentlemen compared the taste of water samples from the Hertfordshire springs via the New River and from the Thames at London Bridge. It is hard now to regard the river through the eyes of a regency Londoner. The river had been since Roman times the main source of nourishment, business and movement to the people as well as providing a wealth of attractive vistas. To consider Wordsworth's poem inspired by the view from Westminster Bridge today one is likely to be a little bemused and to perhaps question his judgement. What one must realise is that he saw none of the buildings we see today, including the embankment, but beheld an altogether more elegant Georgian prospect. This scene, complete with a clean river Thames alive with fish and water birds and on which floated an abundance of small boats was clearly an inspiration to one of our greatest poets. We can presume that the view from the bridge up to then was truly wonderful but it was to last for barely twenty more years. The Industrial Revolution spelled disaster for the Thames. Iron pipes provided a better and more plentiful water supply that enabled the advent and spread of water closets. The explosion of the urban population caused by steam-powered factories in the centre of town meant that the primitive and ad hoc sanitation arrangements could no longer cope.

The expediency of the various steps taken by Parliament to begin with made things much worse. The degradation of the Thames following the permitting of foul drains to be connected to public sewers happened quite rapidly from about 1815 to 1850. The fishing industry was wiped out and not a single salmon was seen in the Thames for 150 years after 1824. Rich and poor alike risked death to drink water from either an indoor tap or the standpipes in the street. A cynical and pathetic revulsion for tap water descended on the populace as disease spread and the river became a stinking sewer. Londoners turned their backs on the Thames, which declined in status and importance as the nineteenth century progressed. The docks remained lively and active until the 1960s but from the 1880s the focus moved downstream away from the centre of London, first to the Isle of Dogs and later to the Royal Docks.

The many Parliamentary acts promised and from the point of view of Public Health, delivered, major improvements. But Bazalgette's great new sewerage system only briefly alleviated the state of the river, which declined further at the end of the nineteenth century and up to World War I. This was due mainly to the unforeseen continued increase in the urban population and the primitive methods of sewage treatment based on chemical additives. The river was free of disease because it was full of disinfectant as well as many polluting industrial wastes.

Although most people associate sewers with the water closet the worst pollution, then as now, comes from Industry. When imagining the industrial past of grim crowded cities and factory chimneys belching fumes everyone thinks of Birmingham, Manchester and "the north". In fact the largest centre of industrial production in Britain has always been London, which is what earned it the nickname "the Smoke". The wastewater from the metalworking and finishing trades, chemical and pharmaceutical production, papermaking, tanning leather, food processing and brewing and a number of other industries is what really killed the Thames.

Both the World Wars were periods when the quality of the Thames' aquatic environment was low on everyone's list of priorities. Ironically both contributed significantly to solving the problems in the longer term. In 1915 German blockades cut off the supply of the treatment chemicals, which were imported, causing this method to be abandoned in favour of biological purification. Emergency planning for World War II caused some major improvements in the way the system was managed so as to minimise the impact of bomb damage. Although this did little for the river whilst the war was being waged, peace brought major repairs and improvements to the sewerage system and by 1950 the political determination emerged to bring the Thames back to life. The river in that year was probably in its worst state ever with filthy stinking mud banks and no recorded aquatic life. The only way was up.

Since that date the quality of the Thames steadily improved as the sewage treatment works were massively extended and a number of anti-pollution measures have made it more costly and publicly unacceptable to pollute the water. Fish returned significantly in the 1980s and salmon are now fairly common. Today, except after storm discharges, the water quality has returned to a condition similar to the early nineteenth century. Anglers are seen all along the river at low tide. Eels are now being fished commercially in the Thames estuary and the further extension of fisheries is planned.

But few appreciate this success! Despite the widespread publicity the river has been so dead for so long that the results of these improvements have failed to penetrate people's minds. In 1986 a storm event caused a fish kill so that the floating bodies of half a dozen different species could be seen from the House of Commons. The MPs were astonished, not because the fish were dead but because they were actually there in the river at all. Some thought the fish were being delivered somewhere and fell into the river from the back of a lorry!

Modern methods of transportation mean that it is unlikely that the docks will return to inner London and the commercial Thames will not return. But the fishing and the boating could come back. Road traffic actually moves on average no faster now than in Samuel Pepys' time so riverboats could once more be a paying proposition. Over the next decade if the Tideway proposals move forward we can expect to see Londoners rediscover their long-dormant amenity. For the Cost and Benefits section of this report the public have been surveyed on their attitudes to this story. Their opinions have been clearly expressed – they want the Tideway cleaned up to the highest standard achievable and they are prepared to pay a price. The Tideway Solutions Group has demonstrated that this can be done and at a cost which falls within this price. It can be done, it should be done and it must be done.

2. Solutions Group

The project structure for the Tideway Strategy Team is described below and illustrated in Figure 3.

2.1 Steering Group

It was agreed between Thames Water and its regulators (Environment Agency, Ofwat, Defra) that a strategic study should be carried out between 2000 and 2005 to investigate the issue of CSOs and identify possible solutions for implementation post 2005. A steering group was convened, under the independent chairmanship of Professor Chris Binnie, to guide the project. This group includes representatives from Defra, the Environment Agency, Thames Water and the Greater London Authority, with Ofwat represented in an observer status. Reporting to the steering group are three working groups on Objectives, Solutions and Cost Benefits.

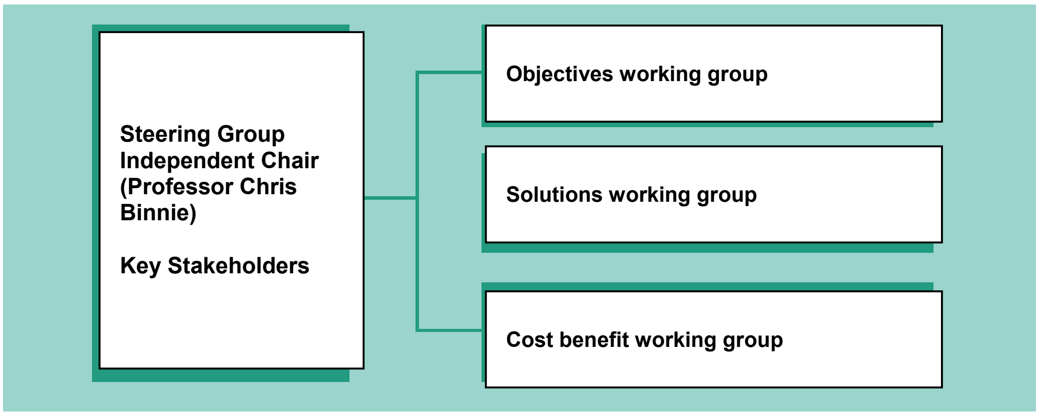
At the outset it was clear that the design life of any solutions could be very long — perhaps several decades. The approach then taken was to try to anticipate future requirements and conditions as far ahead as possible. This is proving particularly difficult as the requirements of a key piece of legislation — the recently adopted EU Water Framework Directive — are still under development. Equally hard is forecasting leisure activity on the river in say 20 years time, and predicting the consequences of climate change. The alleviation of sewer flooding is yet another variable in an already complex matrix.

An early output of the steering group was to derive an outline project timetable. It was critical that the range of options were developed in time for consideration at the next price review in 2004, which required completion of the study phase by late 2003. During the later part of 2003 it was decided to extend the study phase until the autumn of 2004 to allow for outline design and costing of Option A to be completed ready for consideration at the price review.

This is therefore a very ambitious project with much ground to cover and data to collect. It requires collaboration and liaison with numerous other interested parties, not least the Port of London Authority, the individual local councils and topic groups such as the Thames Estuary Partnership.

2.2 Working Groups

Figure 3 - Project Structure



2.2.1 Objectives working group

The role of the Objectives group is to predict, as far as possible, the potential statutory and non-statutory objectives which could be applied to the Tideway; for instance: what would be the practicality and consequence of the Tideway being declared recreational, or even bathing water? What might the Water Framework Directive require in terms of water quality and biodiversity? Initially the Objectives proved hard to define and the current status of the perceived objectives in terms of specific and itemized technical requirements has evolved from an iterative consideration of what the solutions could achieve.

2.2.2 Solutions working group

The role of the Solutions group is to develop and cost technical options to meet the objectives set — a difficult challenge on a scale not experienced elsewhere in the UK or perhaps the world. Linking the Objectives and Solutions groups are water quality models, which can be used to assist in setting objectives and testing technical options. The development of appropriate models has been an important early activity, as has been additional data collection.

The work carried out by the Solutions group represents the bulk of the entire activity both in terms of in-house and external resource commitment. As indicated above the solutions have fed into the potential objectives, which in turn have been adjusted to give a new starting point for reconsidering the solutions. This process has caused some abortive work and the omission until a late date of some other matters now seen as vital to be investigated.

However, this does at least mean that the working groups and by extension the Steering group now have a good grasp of those issues which have proved fruitful when investigated and those which turned out after all to be blind alleys. It is fairly clear what the right strategy will be and a number of difficult issues have been addressed and outline costs are now available for all the likely forward scenarios.

2.2.3 Cost Benefit working group

The role of the Cost Benefit Group is to consider the relative costs and benefits of the objectives and possible technical options. The work to date includes three main studies. Firstly an Environmental Costs study to estimate the impact of the various available solutions on the existing environment both during construction and then operationally in the longer term. Secondly a Market Valuation Study to estimate the value of the market effects associated with different sewerage solutions. The third study was a Stated Preference Survey whose objective is to establish the public’s opinion of the state of the river, the proposed potential improvements and the amount they might be prepared to pay to fund these improvements.

Specialist consultants under the guidance of the working group have undertaken these detailed studies and the final reports have produced a number of surprises that have greatly encouraged the working groups in the pursuit of the ultimate goal of significant improvements to the river.

3. Study Approach

3.1 Interpretation of the Terms of Reference

The Terms of Reference for the Solutions Group were determined at the Tideway Strategy Steering Group meeting on 25 January 2001 and were split into two complimentary objectives:

Primary Objective:

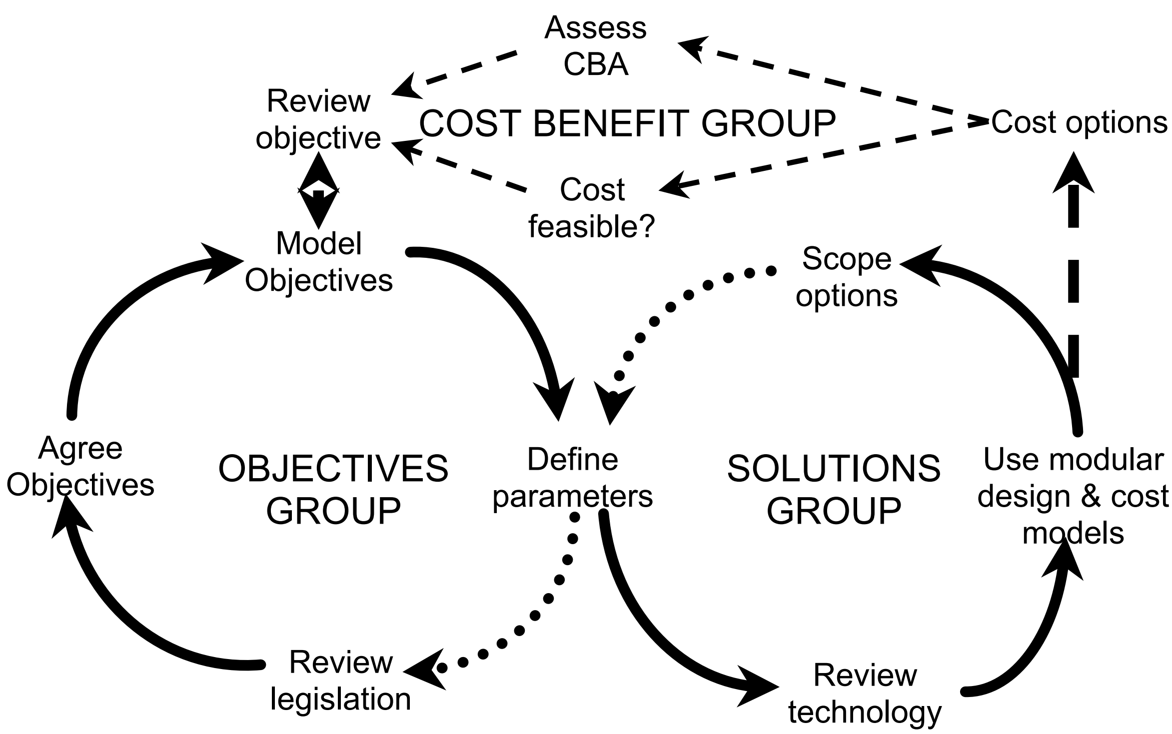
To conceive and evaluate technical solutions to achieve the requirements of the strategy set by the regulatory framework in general, and specifically, a range of technical solutions to achieve the objectives proposed by the Objectives Working Group and endorsed by the Steering Group.

Secondary Objective:

To consider the sewerage system and CSOs individually and in groups, the tideway as a whole and to plan the most economical way of delivering potential solutions ranging from one-off small scale projects to linking CSOs together for larger strategic solutions. To establish the characteristics of storm sewage and to assess existing treatment methods and equipment in terms of suitability for this use.

In determining an outline plan to address these two objectives, the interaction of all three working groups was considered. This is summarised in *Figure 4.*

Figure 4 - Interaction of Working Groups



The interpretation of the terms of reference through the interaction of the Objectives and Solutions Groups are best described in the following order:

- The Objectives Group review present and future legislation to agree a set of objective standards, based on sewage-derived litter, dissolved oxygen concentrations and bacteriological standards.
- The objective standards are assessed either by empirical best estimate knowledge and understanding or through the computer modelling of the river's water quality.
- The Objectives Group then defines parameters for solutions to comply with, such as acceptable quantities of sewage-derived litter, minimum dissolved oxygen concentrations in the river and maximum bacteriological standards.
- The Solutions Group reviews the options available, by considering the implementation of current proven technology and innovative techniques, which are still in development but could be utilised in future years.
- The Solutions Group develops modular designs (i.e. transfer conduits and treatment systems), which can achieve the parameters stipulated.
- The Solutions Group scopes the possible modular designs and formulates strategies or potential solution, which could be implemented.
- The strategies and potential solutions are then assessed against the objective parameters to determine the level of compliance.

The Solutions Group proposed a number of strategies and options, the outputs of which fulfilled some or all of the objective parameters, and were periodically presented to the Steering Group for comment. This enabled the robustness and suitability of the proposals to be reviewed and challenged.

The costs for each option were calculated and passed through to the Cost Benefit Group to determine the viability.

3.2 Budget and Programme

At the final determination, a budget of £5m was set-aside for the Strategy Study for the duration of AMP3 (2000-05). By applying the Ofwat prescribed efficiency saving of 18%, this resulted in a study budget of £4.1m. Over the intervening years, the way in which Thames Water accounts for its corporate overhead, with respect to capital projects, has been modified. Therefore, the control costs of the study projects have been altered to allow for these changes, resulting in an actual study budget of £4.34m.

The intention of the study was to compete the outputs for the Steering Group to make recommendations for the inclusion in the AMP4 submission. The initial target was completion by December 2003. Following discussions at the Steering Group in February 2002, the decision was made to accelerate the study to complete by summer 2003, so that the output of the study could be included in the Strategic Business Plan and draft submission for AMP4. During the May 2003 steering group meeting it was decided to carryout additional work on the verify the willingness to pay survey and provide more detail to the chosen option – Option A.

The budget was allocated to five distinct phases via four discrete projects, which have been managed through the Thames Water Utilities capital projects (plan and acquire assets) process:

Table 4 : Tideway Project : Budget Allocation

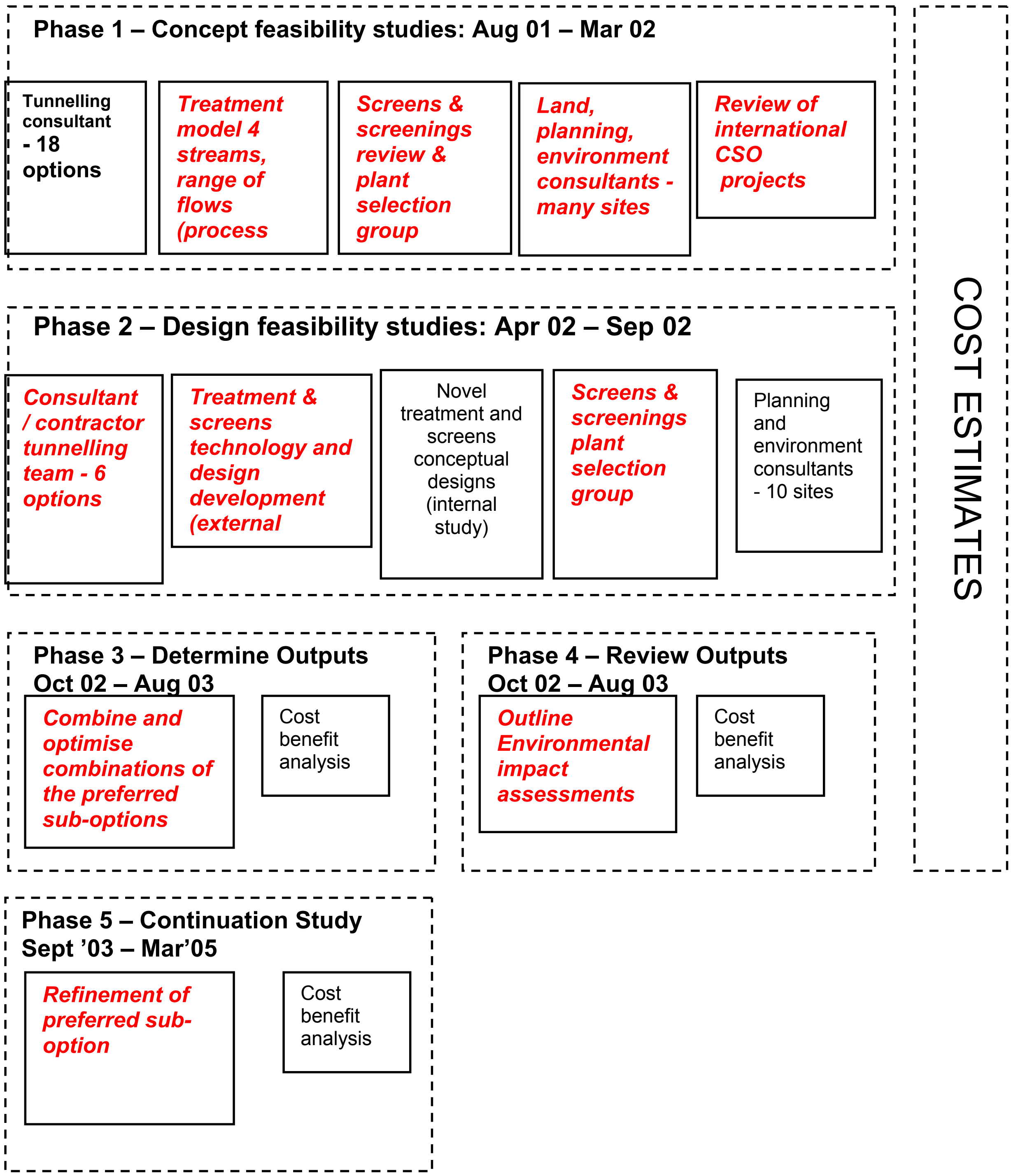
Phase:	**Ref:**	**Control Cost**	**Start Date**	**Finish Date**
1 – Data Collection	7CYC	£704k	Sep 2000	May 2001
2 – Modelling / Feasibility	5K5D	£1,276k	Jun 2001	Feb 2002
3&4 – Determine / Review Outputs	42VC	£2,356k	Mar 2002	Jun 2003
5 – Continuation Study	3TWD	£2,500k	Jul 2003	Mar 2005
	Total	**£6,836k**		

A programme was determined for the four phases of study and the activities that all three working groups had committed to undertake, within the confines of the overall budget.

3.3 Study Phasing

The overall programme for the Solution Group Study is summarised in figure 5:

Figure 5 - Solutions Group Programme



3.4 Working Group Interfaces

As explained in section 3.2, the very nature of the split of activities across three discrete working groups provided significant interaction between each. The interfaces were more easily managed by the appointment of the Study Project Manager and Chairs of each working group by a Thames Water representative. Also, the working groups did not have a discrete membership; for example:

- Chair of Objectives Group – also member of Solutions Group;
- Chair of Solutions Group – also member of Cost-Benefits Group;
- The EA's representative at the Steering Group was also a member of the Objectives and Solutions Group.
- The EA's other representative were members of the Objectives and Solutions Group;
- Some of Thames Water's technical experts were members of the Objectives and Solutions Group.

This cross-fertilisation of membership of the working groups ensured the close working relationships of the groups was maintained and the work activities spanning such interfaces were closely integrated.

4. Identify Problems

4.1 Introduction

The Thames Estuary, from its tidal limit at Teddington to the seaward boundary is approximately 100kms in length. The catchment area draining to the estuary is about 12,500 square kilometres and contains a population of 12 million.

Despite the size of this catchment area, the estuary is relatively small in terms of the freshwater flow that discharges to it. This is mainly due to the fact that large quantities of river water are abstracted in the lower reaches of the freshwater river, to be used as a potable supply for the population of London. In the summer months the residual flow that discharges to the estuary at Teddington is normally less than 10 cubic metres. This makes the upper reaches of the estuary particularly vulnerable to pollution because of the absence of sufficient water to provide dilution and protection.

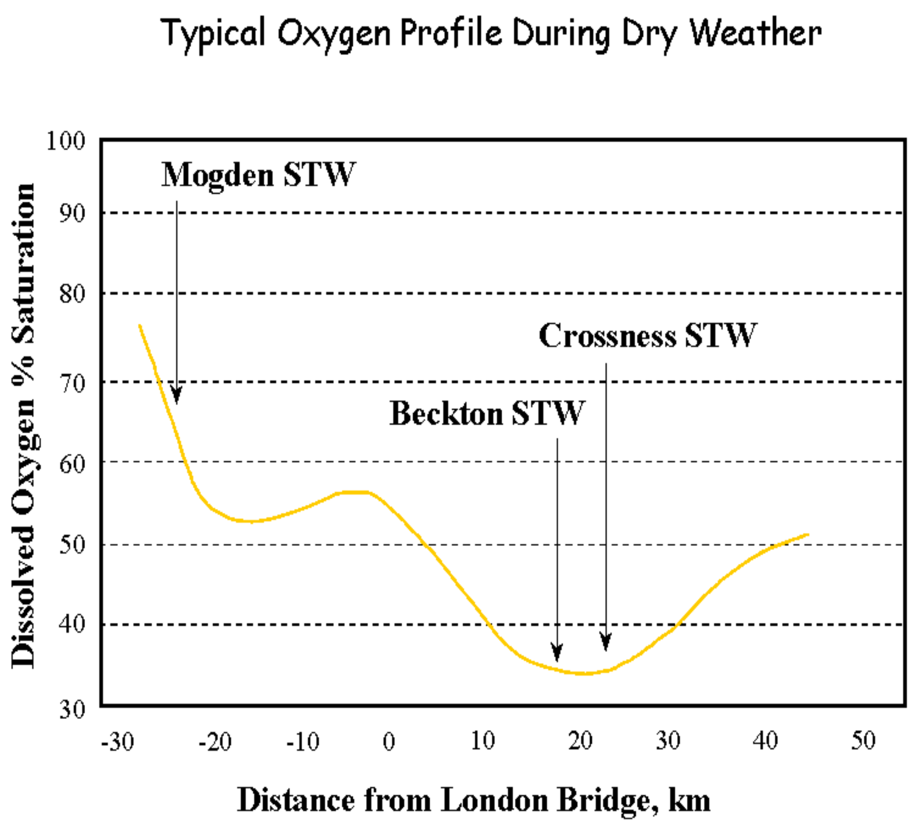
The low freshwater flows result in long retention times within the estuary and the net seaward movement is very slow. During the summer period it takes about 3 months for water to migrate from Teddington to Southend This means that any oxidisable matter that is discharged to the river will exert its total oxygen demand during its residence in the estuary. Clearly the management of a satisfactory oxygen balance is essential under these conditions. Historically, because of the location of London and its large population, the estuary has been badly polluted by discharges of sewage effluent and, although the situation has been dramatically improved, water quality in the estuary is still dominated by large discharges of sewage effluent from 14 treatment works between Isleworth and Southend, 5 of which are within the Thames Water region. Additional quantities of sewage effluent are also present in the freshwater Thames and most of the tributaries that discharge to the estuary. Effluent from the treatment works, which include some of the largest in the country, is normally of very good quality and is controlled by tight legal limits, which are imposed to ensure that the river meets its quality standards. Other discharges made to the river are mainly confined to uncontaminated run-off and cooling water, but there are a few discharges of trade effluent towards the seaward end of the estuary.

4.1.1 Monitoring

In order to provide the degree of management necessary to protect the highly vulnerable and fragile Eco-system contained within the estuary, it is essential to have in place a comprehensive system for monitoring the condition of the river on a day to day basis. The complexity and variability of the dynamic water quality processes that occur in the estuary require the use of instrumentation, which can provide a continuous record of water quality fluctuations in real time. The most appropriate means of meeting this requirement is to measure the dissolved oxygen (DO) profile along the length of the estuary. This profile is plotted against distance to give a "sag curve" (*Figure 6 - Typical Tideway Dissolved Oxygen Profile*
which shows where the DO levels drop in the vicinity of the effluent discharges.

Because of the tidal nature of the river, it is necessary to present data in a form, which allows for comparisons to be made between data obtained at different tidal states. For this reason all sag curves and DO profiles of the estuary are presented in a half-tide format, which shows the conditions prevailing at half-tide. Half-tide can best be understood as the point in the tidal cycle that is midway between high water and low water. The precise definition is, that for a given location, half-tide is the point in time when the volume of water between that point and Teddington is at its mean value.

Figure 6 - Typical Tideway Dissolved Oxygen Profile



Eight permanent automatic quality monitoring stations (AQMS) are installed along the river between Kew and Purfleet and generate data sets at 15-minute intervals for dissolved oxygen, temperature and conductivity. Data from these stations can be interrogated remotely in real time and can either be displayed as a simple time series or in half-tide format. It is normal practice to process the data from each site and produce a composite half-tide DO profile for each tide.

Samples are also taken from a specially equipped monitoring launch, the Thames Guardian, at weekly intervals during the summer months and fortnightly during the winter. These samples are taken at 26 points along the river and are analysed for 169 determinands. Samples are also taken of the effluent discharges to the river at predetermined intervals to assess the compliance of these discharges with consent standards.

4.1.2 Factors affecting water quality

Water quality is highly dependent on the quality of the sewage effluent discharges that can vary considerably over short periods of time. As well as the Biochemical Oxygen Demand (BOD) of the effluent, the load of unoxidised nitrogen (ammonia, nitrite and organic nitrogen) that is discharged is particularly important, since nitrification occurs very rapidly in the estuary and is one of the most critical processes affecting the oxygen balance. Physical and meteorological conditions also affect water quality very significantly. High fresh water flows provide extra dilution and increase the rate of seaward movement in the estuary, which lessen the impact of the discharges. Higher temperatures increase the impact by accelerating the rate of oxygen demand. Other variables, such as wind speed, sunshine hours and tidal range also influence the dissolved oxygen levels.

4.2 Storm overflows to the river

At times of heavy or prolonged rainfall, the delicate oxygen balance in the estuary is put under very severe threat. Additional polluting loads are discharged to the river from three main sources: - rivers, sewage treatment works and CSOs.

The loads from the tributaries to the Tideway are mainly derived from surface run-off, but there is also a sewage component in rivers, like the Wandle and Lee, which have STWs discharging to them.

Additional flows are received at the STWs during times of rainfall and these increased flows put the works under pressure and can lead to deterioration in performance. Depending on the amount of additional flow and the individual works, full treatment or settlement only is provided to the storm flow. In either case, the additional load imposed on the river is quite significant.

Discharges from the CSOs can be very large and very polluting. The discharges are essentially raw sewage, diluted to varying degrees by run-off (which can itself be very polluting). These discharges also include sediment and litter re-suspended by the increased flows, often referred to as the first foul flush. Total quantities discharged to the estuary are in excess of 1 million tonnes for the larger rainfall events and greater than 3 million tonnes for severe events. Clearly these additional polluting loads discharged to the river during wet weather conditions have the potential to cause very severe reductions in DO levels. Oxygen levels can be observed to fall rapidly following periods of heavy or prolonged rainfall and on frequent occasions in the past, have been reduced to the point where fish mortality has occurred.

Figures 7–9 illustrate a series of DO plots from the AQMS and these show the rapid decline that occurred in the Tideway following the heavy rainfall event on the 14th September 2000.

Figure 7 - Dissolved Oxygen Plot – 14th September 2000

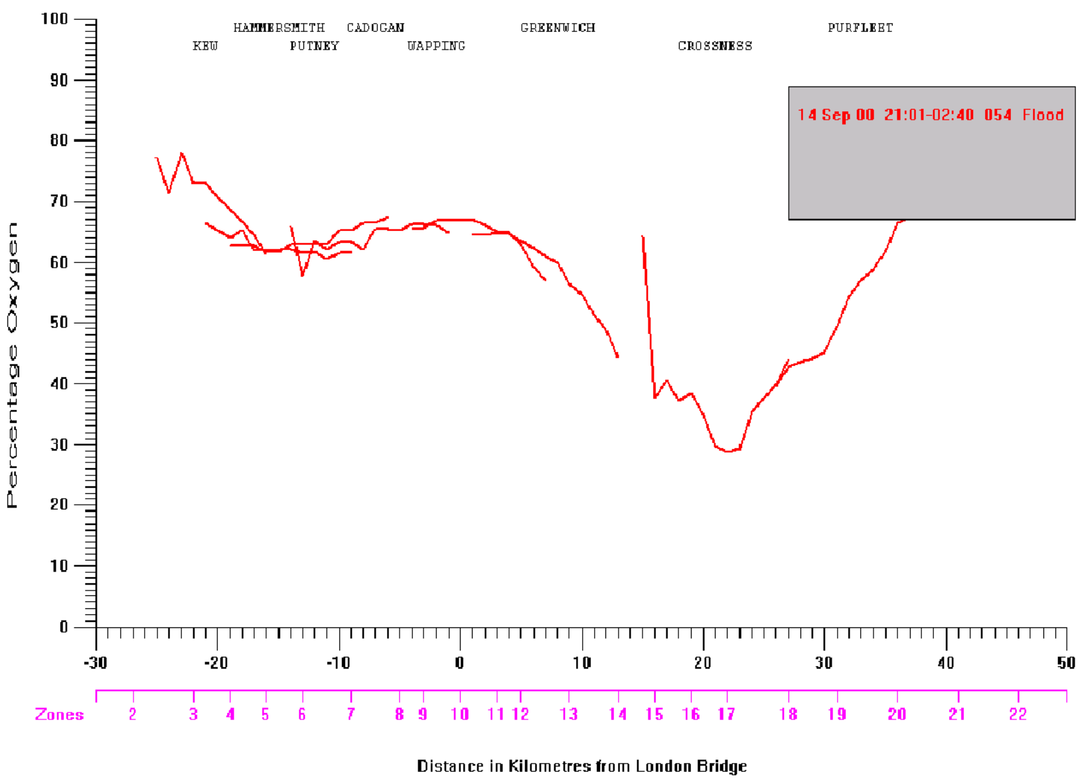


Figure 8 - Dissolved Oxygen Plot 14th - 15th September 2000

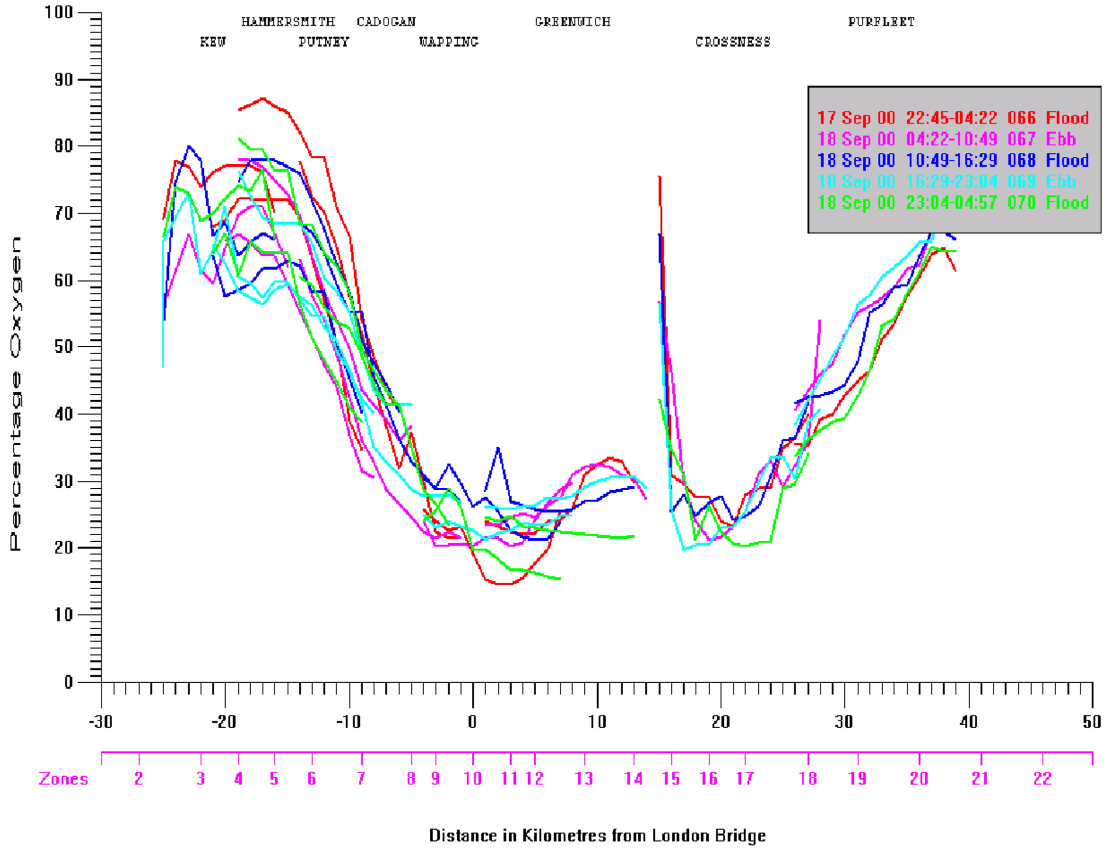
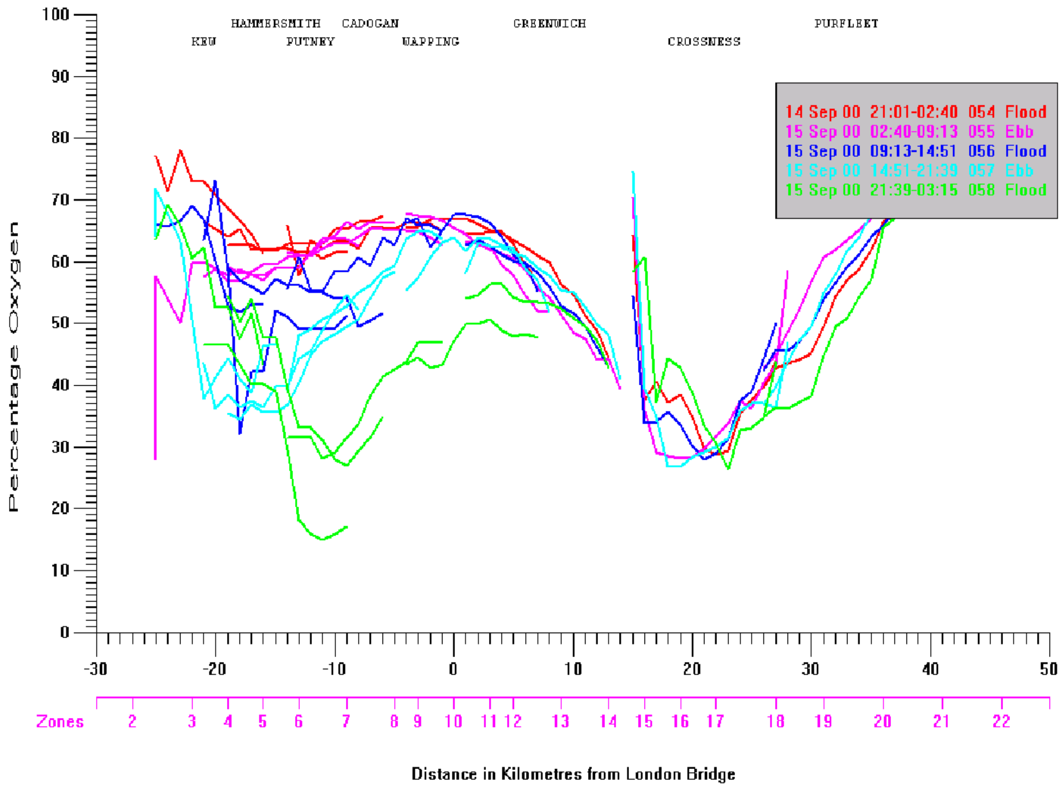


Figure 9 - Dissolved Oxygen Plot 17th - 18th September 2000



4.2.1 Aesthetics/litter

As well as the effect on DO concentrations, the CSOs create a very serious aesthetic problem, the river is covered with a greasy slick from the discharges and the presence of sewage is clearly visible in the water and on the foreshore. High bacterial counts are also associated with the CSO discharges, which can create a health hazard, particularly on those stretches of the river, which are used extensively for recreational activities, such as sailing and sculling.

4.2.2 Need for additional data

In order to assess the extent of the problem caused by the CSO discharges, and the best way of reducing the effect it was necessary to obtain a clearer understanding of the mechanisms responsible for the deterioration in water quality. It was also essential to identify if there were specific discharges, which were of greater significance due to quality, quantity or frequency of discharge.

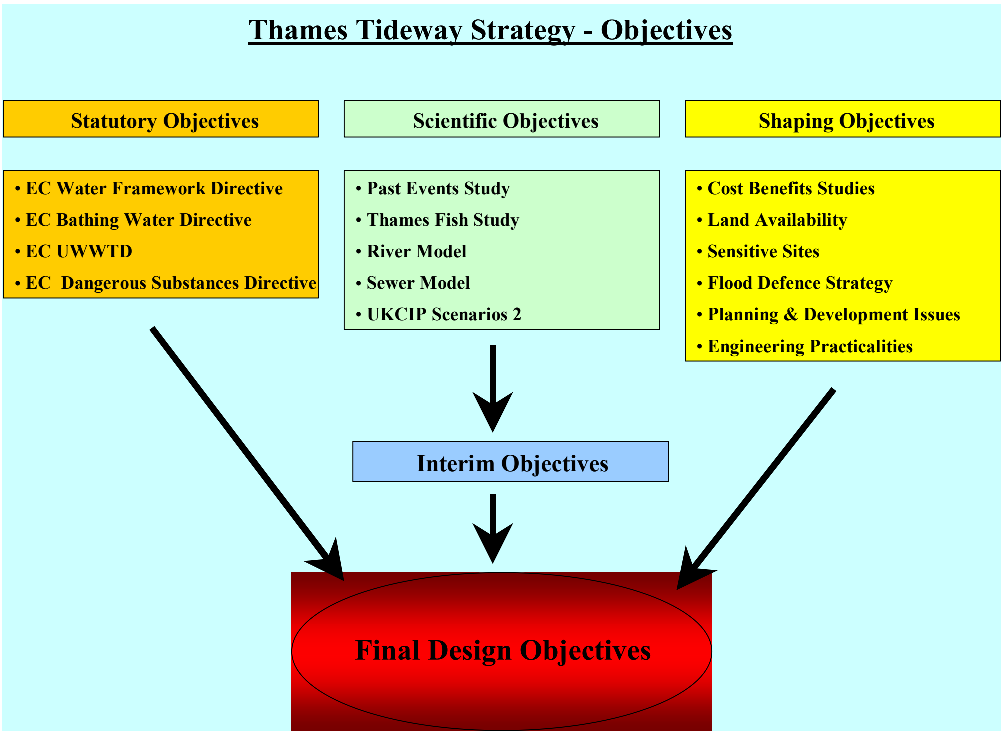
At times of rainfall extra polluting loads are also discharged to the river from the sewage treatment works (STW) and the tributaries. It was therefore necessary to obtain reliable data from all of these sources during wet weather conditions. In addition to monitoring all of the relevant discharges to the river, it was also essential to monitor the river itself to determine the reaction both temporally and spatially to the polluting loads that are discharged.

Three additional AQMS were installed and also temporary monitoring instrumentation was deployed prior to the occurrence of rainfall events. This information was supplemented by monitoring and sampling from the Thames Guardian launch, which was also utilised to observe the aesthetic effects of the discharges.

4.3 Objectives

The Objectives Group considered 3 broad categories of objectives as shown in figure 10.

Figure 10 - Tideway Strategy Objectives



The principal objective relates to dissolved oxygen concentrations and is summarised in *Table* 5.

Table 5 : Summary of Dissolved Oxygen Objectives

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

Comprehensive details of the objective setting process are supplied in the report of the Objectives Group

4.4 Formula A

Until the early 1970s standard sewerage practice for dealing with CSOs was to assume that an overflow would be set so as to retain 6DWF(six times dry weather flow) in the sewer to pass to treatment and spill the excess to the adjacent watercourse. This way of estimating the flow to treatment value had been regarded as unsatisfactory for many years and for many reasons. It is unreliable in assessing the increase in surface water flows that are independent of the population served, and makes no allowance for such factors as time of concentration, infiltration or industrial effluents.
In 1970 the wastewater technical committee of the Ministry of Housing and Local Government reviewed this issue and produced an improved, if still imperfect, way of assessing this flow to treatment value. This was “Formula A” and is as follows:

$$Q = DWF + 1.36P + 2E \quad \text{……………………………………………………(1)}$$

(where DWF = PG + I + E)

and P = population served

G = average domestic sewage produced per head of population (m^3/day)

I = Infiltration (m^3/day)

E = Average daily discharge of industrial effluent in the sewer (m^3/day)

[Note: rearranging (1) gives Q = P (G + 1.36) + I + 3E]
Q is the discharge in m^3/day (or divide by 86,400 to get m^3/sec), which should continue to the treatment works during a storm, the balance being spilled from the overflow. It should be noted that since typical values of G are 0.2 - 0.3 m^3/day, if flows I and E are ignored:

$$DWF \cong PG \cong 0.25P \text{ (say), and thus } Q > 1.61P > 6 \times DWF$$

It would thus be rare for the formula to produce a forward flow value of Q to be less than 6DWF. Few sewage treatment works even in ideal circumstances are routinely capable of dealing with 6DWF and it is therefore usual to provide storm tanks at works’ inlets to store sufficient flows to be returned later to treatment so as to come closer to this level of treatment coverage.

In this discussion note that, for any particular overflow, Q is the **forward flow to the works during storm events.** As has been frequently pointed out and made clear in the Solutions Group report investigations, it is quite normal for the majority of CSOs in London to have little or no forward flow to the treatment works at all during storms. In fact the total flows reaching the main London works during storms is less than 2DWF and comprises only flows originating in East London. In anything above moderate rainfall with a return period greater than 1: 5 years the entire flow from the sewerage networks west of a line drawn north - south approximately through the Isle of Dogs is discharged to the Thames. This includes 50 out of the 54 CSOs draining a combined total of some 500 overflow weirs within the catchments with no forward flow at all! It is clear therefore that if formula A is the design criterion which should be complied with, the central London catchments of Beckton and Crossness fail spectacularly to so do. For this reason it has always been regarded as pointless attempting to apply this formula to the London CSOs and it should also be noted that the EA has stated that the guidance for CSO design does not regard Formula A as a necessary approach.

However, in order to appreciate the impact of the proposed storage tunnel on compliance of the London systems in the context of Formula A, the following calculation has been produced to give an approximation of the flows in the Beckton and Crossness catchments.

Application of Formula A to Option A

In order to make some attempt at using the formula it is necessary to make a number of gross assumptions that effectively reduce the entire catchments to a single overflow. In this scenario Q is calculated from known (and estimated) parameters, the inlet flow equal to the available capacity of Beckton and Crossness is subtracted and the surplus is spilled into the proposed storage tunnel. Note the known available capacity at each works in the below table is the Flow to Treatment (FtoT). In the formula the Industrial effluent value E, estimated to be 10% of domestic flows, is added and an allowance for infiltration, I, of 5% is added on top.

Beckton and Crossness parameters

Basic parameters for London's two main catchments:

Parameter		Beckton	Crossness	Combined
Population (P)		2,710,000	2,100,000	4,810,000
G m^3/day		0.25	0.25	0.25
Domestic Flow = PG m^3/day		677,500	525,000	1,202,500
E = 0.1PG (say) m^3/day		67,750	52,500	120,250
I = 0.05(PG + E) (say) m^3/day		37,263	28,875	66,138
Thus Est DWF = PG + I + E		782,513	606,375	1,388,888
Q = DWF + 1.36P + 2E (formula A)		4,603,613	3,567,375	8,170,988
Max allowable FtoT (m^3/day)		1,009,000	600,000	1,609,000
Spill to Tunnel = Q - FtoT	m^3/day	3,594,613	2,967,375	6,561,988
	m^3/hr	149,776	123,641	273,416

From the above it can be seen that the flow to treatment calculated using formula A is about five times the total actual available capacity of Beckton and Crossness during rainfall. This underlines the gross inadequacy of the London systems and their failure to meet formula A.

Application to Option A

The intention of Formula A is that flows up to the value of Q are retained within the system and passed to the STW for treatment. The proposed storage tunnel will be part of the sewage system and therefore transfer of CSO flows up to the above spill values to the tunnel is effectively retaining this flow within the system. The intercepted flow is then pumped out to screening and treatment at Crossness STW. The tunnel options as proposed would have sufficient capacity to intercept spills for the following periods:

Option	A(max)	A(med)	A(low)
Storage Volume m^3	4,280,000	2,140,000	856,000
Discharge Rate m^3/hr	273,416	273,416	273,416
Storage time Hours	15.65	7.83	3.13

These storage rates are in line with modern wastewater practice with 2 or 3 hours being typical design values in sewerage and STW works design.

Once the spill flows exceed the available storage any excess would normally be subject to fine screening before discharge to the watercourse. For most typical CSOs this screening is provided by a mechanical screen installed in the chamber. However it has been shown by the Solutions Group investigations that at nearly all the CSO locations in London it is impractical or extremely disruptive and costly to install such screening plant. Therefore flows exceeding the above storage will flow untreated to the river. Fortunately only the more severe events will exceed the tunnel capacity and result in unscreened discharge to the river. This will occur approximately once or twice per year but will involve far smaller volumes and contain much lower polluting loads compared with current discharges.

Conclusions

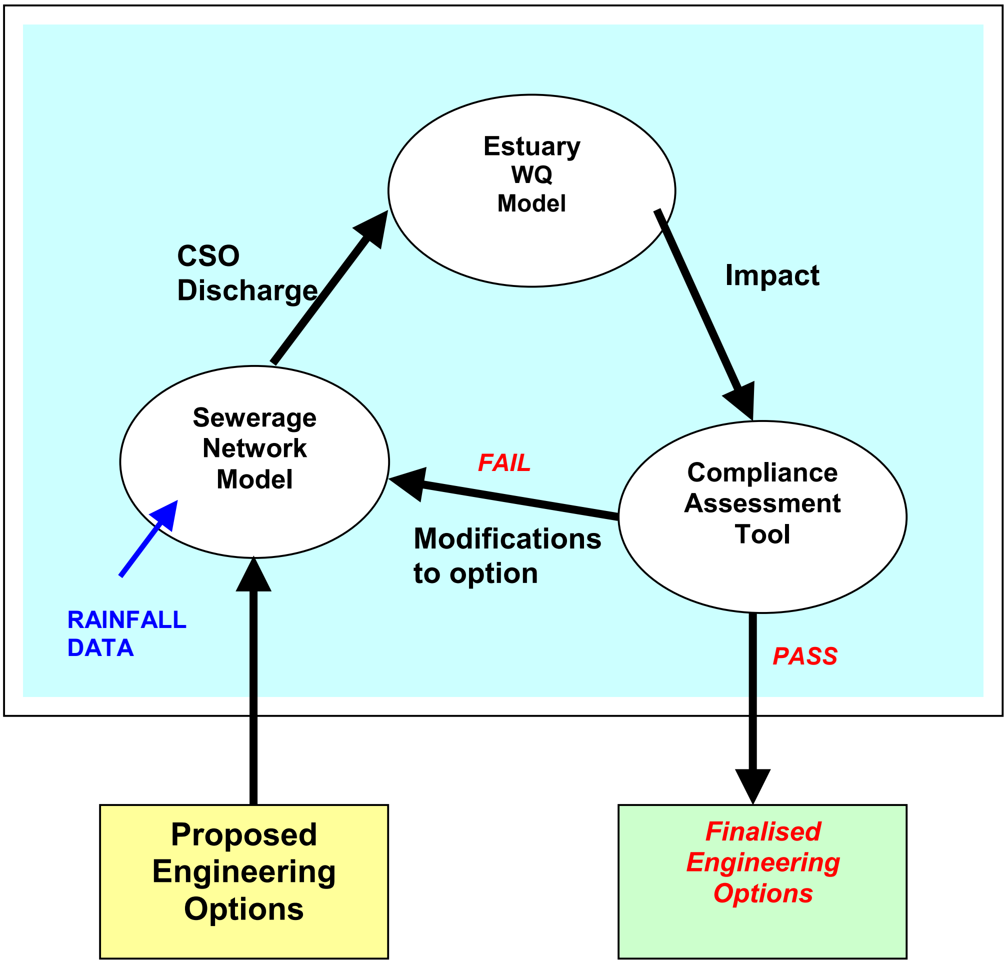
- The London sewerage system(s) currently fail spectacularly to comply with the requirements of Formula A as an hydraulic design principal.

The interception of CSO flows to the storage tunnel will enable London's sewerage system to comply with normal sewerage practice.

4.5 Compliance Testing

The compliance testing process that has been used to assess compliance of the potential solutions against the objectives is summarised in *Figure 11*. More detailed information is available in the Objectives Group report.

Figure 11 - Options Test Procedure



5. Data Requirements & Collection

5.1 Identifying Data Requirements

5.1.1 Introduction

Understanding the hydraulic performance of the sewerage system and the response of the river to polluting loads from the sewers and other sources and in river processes is critical to the effective development and evaluation of potential solutions.

The key areas of data requirement are as follows and are discussed below:

- Rainfall
- Existing sewerage system
- Storm sewage constituents
- River quality

5.2 Rainfall Data

Rainfall data is a fundamental input to Tideway modelling for option evaluation and compliance testing. River water quality in the Tideway is substantially affected by biological and aesthetic loads from sewage discharged from storm overflows. Understanding the performance and potential nuisance of each overflow is essential to long-term management of Tideway water quality.

The scale of storm water discharge from outfalls is dependent upon the volume and distribution of rainfall in the associated catchments.

Rainfall data is needed for four elements of the project:

- Identifying critical storms for use in design and compliance testing.
- Initial sizing for hydraulic load of any proposed works.
- Estimation of polluting loads entering the Tideway to simulate existing conditions. This will enable the Tideway water quality model to be calibrated for the entire river processes.
- Production of design polluting loads for assessing future compliance of options to meet water quality standards.

The area of the Beckton and Crossness catchments draining to Tideway CSOs is some 800km^2. Experience of rainfall patterns indicates that rain arrives in localised cells. In major events a number of cells may overlap to create a complex event. There will always be a wide variety of distribution of rain intensity both spatially and in time over an area of this size. Determining this variation for measured events, or predicting variation for design events is a particularly difficult task.

Sewerage catchments respond very quickly to rainfall. It is therefore desirable to collect data on rainfall intensities collected to a minimum of 5-minute intervals.

5.3 Rainfall Data sources

Rainfall is available from a number of sources:

- Daily reading rain gauges
- 15 minute reading rain gauges
- Weather radar at 5 minute intervals
- Design rainfall events developed as UK standard events
- Stochastically generated rainfall series to emulate full rainfall records.

Daily reading rain gauges

There are a number of daily reading rain gauges in the catchment. They provide data of depth of rain per day at each location. Their main benefit is that such comparative data has been collected for a very long time. Indeed several hundred years. Unfortunately they are of little direct value in sewerage network analysis but may be used for the following:

- Quality checks on other rain measurement site records.
- Checking whether climate statistics and hence rainfall patterns have changed.

15 minute reading rain gauges

A number of 15-minute reading rain gauge stations were set up in the late 1980s by Thames Water Authority to provide calibration stations for the new weather radar stations. These rain gauge stations use tipping bucket meters to record depth of rainfall in a 15-minute period. This is then computed to give rainfall intensity. The number of stations has been increased over the years such that there are now around 35 in the London area. The stations are telemetered for data collection. Over a number of years some stations have proved reliable, others less so. Each of the stations has an individual record of data integrity and availability. Data is extremely valuable in providing accurate, but smoothed, rainfall intensity records together with accurate volumetric measurement for that point. The disadvantage of these stations is that they can take no account of spatial distribution of events. In practice total depths of rain for cells, which pass either centrally or on the fringe average out over a long period, but for each event there is always uncertainty as to whether the exact peak intensity of a cell has been measured.

Weather radar at 5-minute intervals

In the late 1980's the Meteorological Office set up a number of weather radar stations to assist with rainfall measurement and forecasting. The weather radar has a beam resolution of 2km at a 76km radius. One station, at Chenies, near to Maple Lodge is therefore able to cover very nearly the whole of the Thames area. The radar works on a 5-minute cycle. During this period it searches the whole area and then uses return signal analysis to assess rainfall intensity for that 5-minute period for each 2x2km land square. The radar signals are subject to a lot of external variation. The signal is therefore calibrated against a number of local rain gauges.

Benefits of the radar data are:
- Readings every 5 minutes
- Good spatial distribution information
- Improved accuracy of total daily depth through calibration
- Data available from 1990 to present day

Difficulties with the radar are:
- Calibration process can be uncertain
- All data is smoothed to a maximum of 20mm/hr intensity
- Very large quantities of data to handle

A recent development of the Met Office (2001) is the advent of Nimrod data. This uses the same radars but more advanced processing allows:

- Topographically based calibration
- 1 km grid squares near radar (35 km which includes London)

Experience in using this data is limited because it has been available for such a short time, but has been shown to have characteristics similar to those of a rain gauge .

Design rainfall events developed as UK standard events

The Flood Studies Report of examined results from a large number of rain gauges over a number of decades. Data was used to identify the frequency of high rain depth wet days. A methodology was developed to determine design storm events based on these wet days by duration and return period based on depth of rainfall during that period and a theoretical rainfall distribution.

This data has been updated in the Flood Estimation handbook (2001). A similar methodology has been used, but analysis has been extended to be more regionalised. The reworking has indicated that design rain events in the Thames Valley may contain up to 20% more water than previously estimated. The effect of these predictions is still being evaluated by the water industry.

Stochastically generated rainfall series to emulate full rainfall records.

Many sewer design issues are best resolved by assessing a long time series of rainfall events. Rainfall intensity needs to be defined at a minimum of 5-minute intervals. This data is not available from rain gauge data. A software package, “Stormpac”, has been developed which will generate typical rainfall series that have the same statistical characteristics in daily terms as real rainfall. A Stormpac series will provide a range of representative rainfall events that can be used to evaluate ongoing performance of a network against typical rainfall.

5.4 Existing Sewerage System Data

Data on the existing sewerage system is available from three main sources:

- Eagle Geographical Information System
- Beckton and Crossness catchment hydraulic models
- CSO Database on Lotus Notes

The first is a Thames Water corporate asset data system, which comprises record information on a geographical basis. The hydraulic model of the catchments used in the Tideway was constructed as a one off project between 1991 and 94. Its construction is recorded separately. The CSO database was compiled specifically for this investigation and comprises survey reports (both recent and historical), photographs, location plans, record drawings etc pertaining to each CSO.

The hydraulic model of the catchment has not been validated for rainfall conditions because technology not being available at the time to carryout this task. It was essential, therefore, to embark on a flow monitoring exercise to record flows under a range of rainfall conditions to improve confidence in the model and if necessary enhance the accuracy of the model. This flow monitoring exercise concentrated on the west area of the Beckton catchment. More extensive monitoring will be required for the next stage of this potential project.

5.5 Storm Sewage Constituents

There is little published data concerning the constituents of storm sewage (other than those in CIRIA Report 177), and Industry knowledge of the mechanics of pollutants in the sewer system is not yet well developed. However, it is thought to be catchment specific and very variable, even within the same catchment and throughout the duration of any given rainfall event. The two main areas of data requirement concern pollutant profiles and screenable solids. The first is critical to development and validation of the river quality model to facilitate a rationale for interception of polluting flows. The second is critical to estimate the quantity and rate of generation of screenable solids to determine the appropriate capacity of plant, transportation and disposal.

CSO discharges represent a combination of legitimate foul dry weather flow (DWF), infiltration, stream inflow and direct storm runoff. The Storm Sewage constituents vary widely depending on a range of factors such as the nature of the catchment and the extent to which the system is combined, the amount of inflow, the intensity of the prevailing rainfall, intensity of and time lag since the last rainfall, time of day, etc. The two water quality aspects of particular concern to the Tideway project are sewage litter and water quality in terms of BOD & NH_3.

No regular measurements of pollutant profiles or screenable solids are currently recorded on the storm sewage network, other than those being undertaken by the Scitter sampling rig at Acton Storm Tanks to collect and evaluate storm sewage constituents as part of this investigation. The methodology and results for this are discussed in Section 8 - Technical Studies.

5.5.1 Modelling

The network models can simulate both flow volumes and pollutant concentrations. The Beckton and Crossness models have been partially verified for hydraulic performance using dry weather and minor rainfall events, and there is reasonable confidence in its hydraulic outputs. Some calibration assessment has also been undertaken to compare simulated pollutant loads with observed data. Initial calibration of the Tideway models suggested that 3 times multiplier of simulated CSO pollutant concentrations would be necessary, as derived using model default pollution parameters. But continuing work has shown this to be too high. A factor of 1.5 times simulated pollutant strength is now used and the value is being reviewed regularly.

The Urban Pollution Manual provides guidance on suggested water quality parameters and storm multipliers for use in storm simulation modelling. The proposed baseline pollution control levels appear generally in line with those obtained from the SCITTER trials. The storm multipliers are more difficult to assess, as the configuration does not allow full sampling of the entire storm range, which would be necessary to determine average concentrations. The suggested multipliers do not seem unreasonable given the results obtained so far. Quality results for peak storm periods at Acton show multipliers of 2 – 6 for low /med intensity events, and between 10 – 20 for higher intensity events.

5.5.2 Pollutants

Sands & silts enter the sewerage network through runoff from roads and other paved areas. These fine aggregates carry significant highway derived pollutant loads of oil, rubber and heavy metals. This denser fraction is transported as bed load, settling out under low velocity conditions, trapping and precipitating the lighter organic fraction and accumulating in larger diameter and flatter areas of the network. Upper layers of the sediment are remobilised on a daily basis and transported during peak diurnal flows. However the predominant load remains in-situ, breaking down under anaerobic conditions to be mobilised as the “First Flush” during next storm event. This first flush carries the heaviest concentrations of both pollutants and sewage litter, and the effect is clearly evident in many of the Scitter storm results.

The Pennine Water Group (ref.*[2]) have undertaken much research into sewer solids transport processes and have been consulted as part of this strategies development. However greater research is required to understand the processes and anticipated pollutant loads within the London catchment.

5.5.3 Fats, Oils & Grease (FOG)

Fats, Oils and Grease cause problems in many urban catchment areas due to the neglect of private grease traps, together with the profusion and concentration of restaurant trade in high street areas. Fats and greases are readily degradable under the controlled conditions of a sewage treatment plant, but are only slowly degradable in the cold anaerobic conditions of the sewer or river. They tend to solidify and build up on pipe walls, restricting sewer bore, or breaking off in chunks to cause sporadic blockages. This restriction in hydraulic capacity may cause CSOs to discharge more frequently than intended.

5.5.4 Biochemical Oxygen Demand (BOD)

BOD has two main constituents – carbonaceous organic matter and ammonical nitrogen. These two measures are the most important indicators as far as general health of the river are concerned. It is sometimes the case that ammonical nitrogen is the more important, as it not only exerts an oxygen demand itself, but is also toxic to aquatic life above certain concentrations, (particularly to the salmonoids).

The overwhelming majority of the BOD load is carried in solution and the micro particulates fraction, which is less than 6mm in size. The proportion of BOD that is associated with the particulate fraction and removable by sedimentation processes usually accounts for more than 50% of the total. However in practice chemical assistance is required to this level of BOD.

Crude sewage with little or no infiltration element has on average a BOD concentration of 300 - 400mg/l in dry weather conditions. (Ref.[*1])

Sewage flows arriving at Beckton STW commonly have BODs of around 150 - 200mg/l, demonstrating the significant levels of infiltration and direct surface water inflow within the network.

Data from Acton Scitter (ref[*4]), has shown BOD levels upwards from 130mg/l for DWF suggesting even higher levels of inflow. However values recorded during storm events can be as high as 1800mg/l, indicating a strong first flush. The BOD can reduce in concentration to around 35mg/l, indicating dilution of pollutants, which occurs typically towards the end of the event.

5.5.5 Ammonia (NH_3)

Nitrogen exists in sewage flows in four main forms, which in order of natural breakdown and oxidation are: organic, ammonia, nitrite & nitrate. Ammonia is produced at the first stage of decomposition of organic nitrogen, and is the most critical indicator of water quality due to its initially high oxygen demand and potentially toxic effects. It is mainly present in solution only, and hence relatively independent of the sewage litter or solids content of flows. STW discharge consents typically range from 2 – 10 mg/l, depending on the quality and dilution rates of the receiving water body.

Crude DWF sewage with little infiltration has average ammonical nitrogen readings of 40mg/l (ref.[*1]). Whereas data from SCITTER (ref.[*4]) has shown levels varying from 26mg/l for DWF and from 8mg/l – 30mg/l during storm conditions.

5.5.6 Suspended solids (SS)

This is the best quantitative measure of the particulate fraction of storm flows that is less than 6mm. The suspended fraction may be measured by conventional laboratory filter paper means, or indirectly assessed by optical means such as turbidity measurement. As BOD load is principally attached to the solids fraction, both Suspended Solids and Turbidity normally show close correlation with particulate BOD.

5.5.7 Total solids (TS)

Total Solids is the sum of Dissolved and Suspended Solids. However, Dissolved solids have little bearing on either BOD or Turbidity. For example, clean tap water in Thames region typically contains 500 mg/l of dissolved solids (calcium/magnesium etc and associated anions) with turbidity of 0.1 NTU. Hence while typically quoted in relation to water quality measures, TS shows no direct relationship with BOD.

Crude DWF sewage entering STWs normally has TS levels in the range of 500 – 1200mg/l (ref.[*3]). Dissolved solids (typically consisting of Ca, Mg, Cl & $S0_4$ salts) account for some 300 – 600mg/l of this figure, and Suspended Solids account for the remaining 200 – 500 mg/l).

Data from SCITTER shows levels of around 700mg/l for DWF, and anything from 125 to 5500mg/l for storm events. The lower readings suggesting generally high levels of inflow, and higher readings being indicative of a concentrated first flush effect. Note that the higher results will be due to increased SS, not TS.

As part of the Scitter investigations into Automated Solids Monitoring, samples have been analysed using Laser Diffraction Analysis to determine typical particle size ranges under DWF and Storm conditions.

5.5.8 Screenables

Sewage litter refers to screenable solids greater than 6mm in size. This may include a range of sanitary products, tissue paper, leaves, plastics, rubber, fat, litter, faecal, or other organic matter, and which, while visually disturbing, typically account for less than 5-10% of the overall BOD load (ref.[*3]).

Due to the practical difficulties of accurate sampling and handling, neither the TS nor SS sample tests include any significant screenable component. This is obtained by other means such as Skip loading rates in the case of STW inlet works, or “COPA” sack weightings in the case of SCITTER.

Research from Bradford University suggests the average DWF volume of screenables to be approximately 43g/head/day. This equates to 217 g/m3 for an assumed per capita consumption of 200 l/head/day, or 288 g/m3 based on 150 l/head/day, giving an average of some 250g/m3 (ref.[*5]).

Screening manufacturers such as Jones & Attwood commonly quote 1m3/hr of wet screenings from 1.0m3/s of flow as a rule of thumb. Assuming a wet screening density of 900kg/m3, this also equates to an average concentration of 250g/m3 of flow.

Others manufacturers quote design capacities of 400g/m^3 for typical peak diurnal screenables loading rates at STW inlets, while admitting that storm and first flush effects may produce several times this level.

Investigations by Sheffield Hallam University (ref.[*5]) based on smaller catchments, suggest that peak levels may be up to 30 times dry weather flow levels or even higher in extreme cases.

The SCITTER plant has so far identified peak screenings levels during even low to moderate storm events, of up to 3000g/m3 (i.e.; up to 12 times dry weather flow levels). This is thought to depend principally on prevailing storm intensity, and duration of intervening dry period since the previous storm event. However results for more severe storm events have yet to be captured.

5.6 River Quality Data

5.6.1 Data Collection

There have been many problems associated with the collection of data for water quality assessment purposes, not least being the unpredictability of the English climate and the near impossibility of being able to forecast the timing and magnitude of a rainfall event. This has resulted in many false alarms when people have been called out to obtain samples and also when opportunities to observe first flush effects from the CSOs have been missed. Much valuable data has been acquired however, and the use of automatic samplers and logging meters has proved to be extremely worthwhile.

5.6.2 River Monitoring

The existing AQMS network described in Section 4 provides comprehensive data on river quality, particularly in the upper reaches of the estuary. However there is a need to supplement this information during rainfall events. Additional temporary instrumentation has therefore been deployed and this has provided valuable data, which has been used to analyse some of the events that have occurred this year.

Use has also been made of the monitoring launch Thames Guardian for tracking the discharges from the CSOs, and to verify data from the AQMS. Samples from the river are analysed for DO using the "Winkler" chemical method, which allows for calibration of the AQMS. Samples are also taken for despatch to the Agency laboratory for more detailed analysis and for microbiological examination.

5.6.3 Sewage Treatment Works Discharges

In order to assess the effect of discharges from the Mogden STW on the river during times of rainfall, an automatic sampler was installed at the works. Results of the samples obtained are included in the Quality Monitoring report in the Appendix.

5.6.4 Tributaries

Samples were taken from the River Brent, Beverley Brook, and River Wandle during rainfall events, utilising automatic samplers and individual spot samples. Results are included in the Quality Monitoring report in the Appendix.

5.6.5 Pumping stations

Individual samples have been taken from the pumping stations at Western and Hammersmith, from the Acton storm tanks and the Ranelagh CSO. Results are included in the Quality Monitoring report in the ppendix.

5.7 Data Collection

5.7.1 Rainfall Studies

During the study period rainfall data has been used for the various tasks. Experience gained through the study has shown that the most robust representation of spatial distribution of rain is essential to enable accurate modelling of Tideway quality performance.

Because solution development has been undertaken in parallel with the Tideway analysis, early sewer modelling used easily accessible data. As the study has developed more focus has been put on rainfall data quality and robust procedures developed that make best use of all data available.

<u>Initial sizing for hydraulic load of any proposed works.</u>

For initial sizing of hydraulic loads for any works it is necessary to know the maximum flow rates and volumes that can discharge from the CSOs in any period. Since rainfall has no theoretical maximum intensity it is necessary to select a rainfall return period for design. Provision would then be made to bypass the new structures on the rare occasions that the maximum is exceeded. Different design standards can be achieved through varying return periods. In order to generate an initial option a guideline return period of 1:10 years was selected.

The study used two approaches. Flood studies rainfall was generated for a 1 in 5 year event with a 1-hour duration. The catchment is known to be sensitive to this duration of storm for peak flow rates. The Flood Studies Report (FSR) rainfall generates events with very high peak rainfall intensities. However the size of the catchment is such that the rainfall reduction as recommended by the FSR for large areas in sizing design events does not correctly apply in the modelling software. The volume of water generated by this event is likely to be higher than would occur on a 1:5 year basis.

In addition a 20-year Stormpac series, which generated 1208 rainfall events, was derived and run through the model. The results were then classified by maximum output rate and by maximum discharge volume. It is known that the synthetic rainfall series generates typical events, but is unlikely to produce realistic maximum intensities. It was therefore interesting to note that the maximum volume event in the 20-year Stormpac series was seen to equate to the volume of the FSR event for 1:5 years.

No firm conclusion could be reached, but it was considered reasonable to continue on sizing options based upon the volume of these maximum events that were estimated between 1:5 years and 1:20 years.

Tideway model calibration

A three month period for Tideway quality calibration was selected by the River modelling team. Initially the sewerage modelling team selected the weather radar data available for that period and the previous three month period was used for model set up. Detailed output files for CSO discharge volume and quality were obtained. The size of the data files was such that full data checking was not practical. Initial application of the CSO discharges to the Tideway model file seemed to provide representative results, although actual pollutant loads were low. However detailed review of the Tideway model indicated that there were major anomalies. These were investigated, and it was finally found that the Radar data had two major flaws:

- Random inclusion of wet periods giving large volumes of low intensity rainfall over the catchment.
- Smoothing of rainfall such that major storm cells were eliminated from the data set.

Finally it was concluded that although the radar data gives a generally representative view of precipitation in the catchment, the data set is not reliable enough for modelling use. It was found that the best data available for this was the calibration rain gauge data giving intensities at 15-minute intervals. These values were then distributed using a Thiessen polygon method to all parts of the Beckton catchment.

Development of Storms critical to the tideway

During the study it was decided that water quality compliance would be measured by assessing durations for which water quality fell below the levels set by the objectives. This would not preclude the discharge from CSOs to the tideway. Testing whether a scheme would comply would entail comparing the performance of the river against known rainfall events for the existing network with performance with new assets constructed. A representative series of rainfall would be needed to assess frequency of failure against design storms. To generate a series of representative storms a long record of daily rainfall was reviewed. Approximately 100 events were selected from a 20-year series based upon parameters of season and total daily rainfall depth. These events were checked to ensure that all Tideway failure events were included in the data sample.

Generation of Design Loads for Compliance Testing

Data for the critical events were then prioritised for use in compliance testing. Rain data was extracted from the 15-minute calibration rain gauges, or wherever data was available. Data was distributed across the catchment by a method of Thiessen polygons and then all events run through the model with catchments being allocated the appropriate rainfall. Event durations spanned from a few hours to several days.

5.7.2 Flow Monitoring Survey

Background to Survey

This flow monitoring survey was implemented to provide the necessary data to improve calibration of the Beckton and Crossness catchment models. This was of particular importance for storm flow conditions. It was determined that the new survey should include measurement of flows in both the trunk system and storm relief system.

Survey Method

The Survey was designed to verify the Beckton catchment model by measuring the sewer flows in the system north of the Thames in central west London i.e. the Hammersmith, Kensington, Chelsea area. The TW modelling group designated 18 sites as significant nodes on the sewer system. These sites are listed in the Flow Monitoring Report. A flowmeter was installed at each site and 11 of these had supplemental level instruments. A further three sites were selected to have rainfall gauge installations.

The survey period was selected to be twelve months during which the instruments would collect data continuously on:

Flow	m^3/s
Depth of Flow	metres AOD
Rainfall	mm/hr

Additional data were integrated into the survey reports from external bodies:

Rainfall (NIMROD)	Met Office
River Thames tide level	Environment Agency

During the continuation study phase a second flow survey was carried out to verify the Crossness catchment model. Nine flowmeters were installed all of which had supplemental level instruments. A further three sites were selected for rainfall gauge installations.

Survey Instruments
Calibration of the original Beckton Catchment Model TW used a newly developed Acoustic Doppler Flow Meter (ADFM) instrument manufactured by RD Instruments of San Diego, California. For this survey TW selected an improved version of the ADFM marketed by MGD Inc. also of San Diego, California. For instrument details see the Flow Monitoring Report.

The ADFM is a bi-directional flowmeter using ultrasonic sound waves to detect water flow and surface level. The head is equipped with 4 asymmetrical velocity beams and 1 vertically oriented surface height beam. Water movement and velocity is detected by Doppler frequency shift in the backscatter of the velocity beams and processed with the water depth data to calculate a directional flow output. By stratifying the cross section of water flow into measurement “bins” and calculating velocities in each “bin” the ADFM can achieve a highly accurate calculated flow by averaging the discrete values.

Supplementary level instruments of the hydrostatic pressure type were supplied by the survey contractor. The Rainfall Gauge used was of the tipping bucket type and supplied by the survey contractor. For instrument details see the Flow Monitoring Report.

Instrument Installation
The ADFM instruments were mounted into flow deflector “boots” which hold the instrument approximately 100mm above the invert of the sewer barrel. The assembly was secured to a stainless steel saddle plate, which was fixed by screws to the sewer floor. By use of the mounting “boot” the ADFM transducer head is clear of the bed load silt and larger objects rolling along the sewer floor. The head is cabled to the instrument processing unit that is housed in a pavement kiosk. At all sites the cable is taken via a man entryway, and below

pavement ducting to the kiosk. The kiosk houses the ADFM processor unit, mains power unit, and PSTN telephone connection for data telemetry.

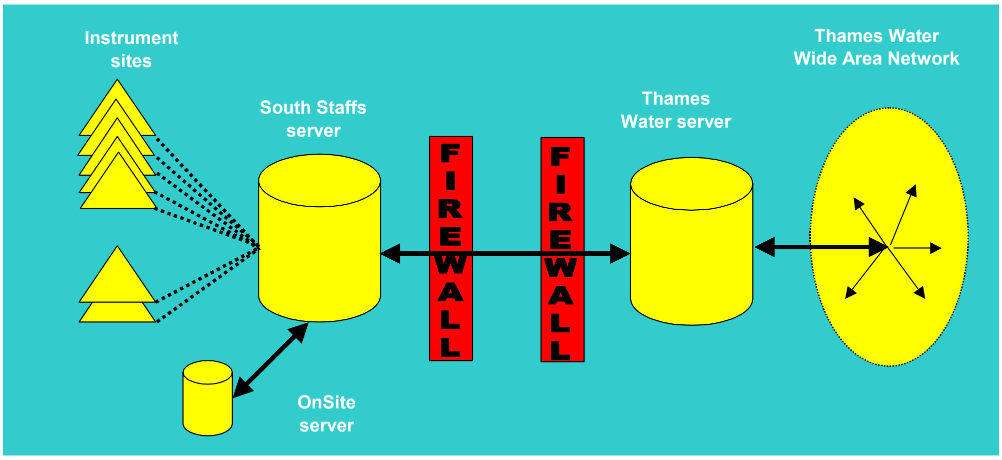
Figure 12 – ADFM Kiosk interior

Figure 13 - ADFM Kiosk

Where installed, a separate level instrument detects hydrostatic pressure, so it can measure surface level in surcharged sewers. The transducer head is fixed directly to the sewer invert beneath a stainless steel shield. The instrument is cabled separately back to the pavement kiosk, where the output is ported directly into the ADFM processor unit. The rainfall gauges are installed on roof top locations within the west London area.

<u>Data Recovery and Transmission</u>
For reasons of economy of resources and security of data, a data recovery system based on a telemetry network was selected for this survey. PSTN landlines from British Telecom were installed as the most cost effective medium for transmission. Automated data processing, including retrieval, was set up at the survey contractor's central data facility at Walsall, near Birmingham. The recovery system was set up to poll the measurement sites at 15-minute intervals, 24 hours a day. Each day of the working week the contractor's Data Manager accesses the data server at Walsall to verify the previous day's data and instigate data copy transfer to the TW data facility at Maple Lodge STW, near Rickmansworth, Herts. Nominated data users within TW were then able to access the full archive via the internal TW data network (figure 14).

Figure 14 - Data Transmission Process



The Survey Contractor developed a tailored suite of polling software for data retrieval and purchased the Hydrolog4 package of data processing software from Hydrologic Ltd, Bromyard, Worcester, to support data verification, tagging, storage and client access. See Figures 15 and 16 for typical flow/depth graphs from the SIMNET HYDROLOG Report.

Figure 15 - Simlog Hydrolog flow & depth graphs - 3th June 2002

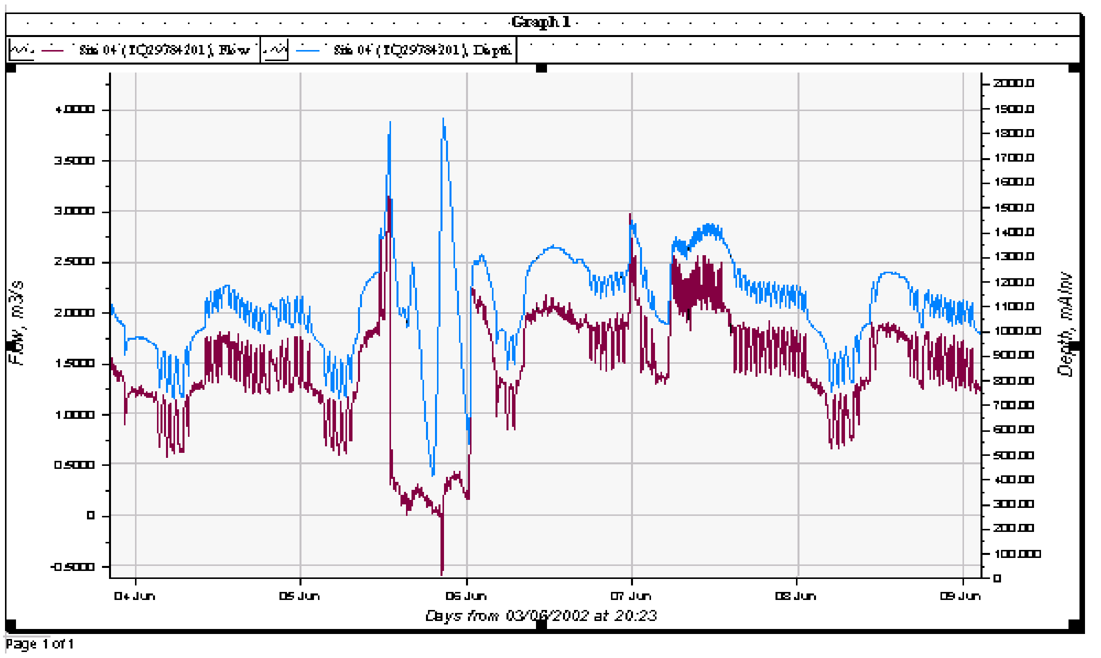
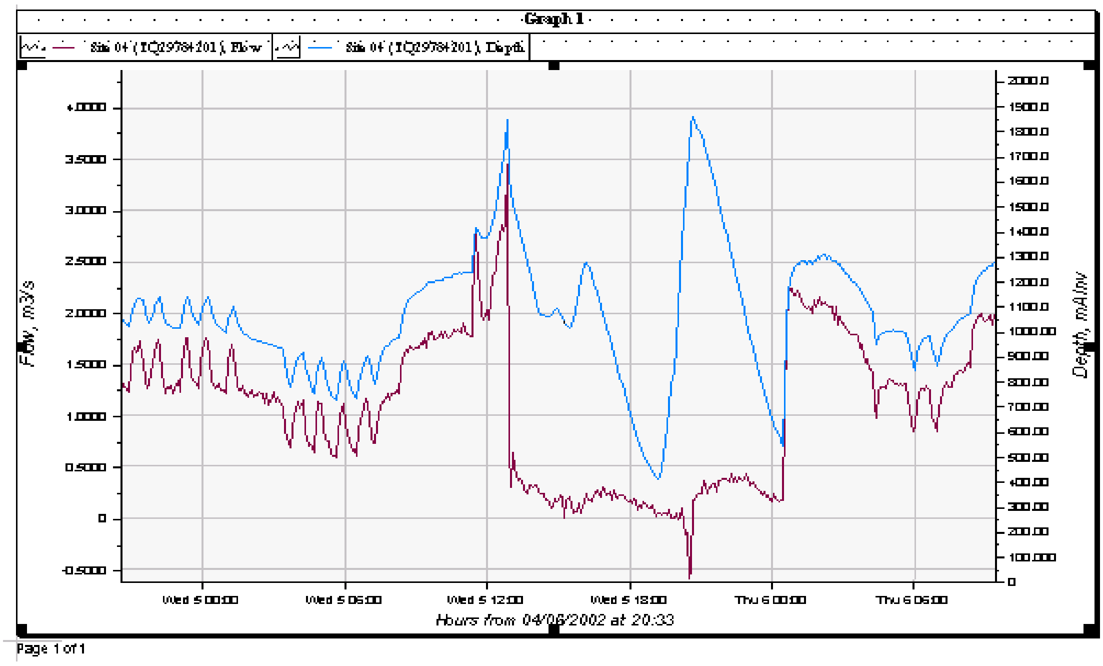


Figure 16 - SIMNET Hydrolog flow & depth graphs - 4th June 2002



5.7.3 Survey Outputs

Access to the Survey data is provided to the TW Tideway Team via their desktop PCs and the HYDROLOG4 interface. The interface provides a site navigation screen with associated data archives, a report-writing interface, and access to historical reports. Apart from the Monday updates from the weekend logs, the TW user can access data 24 hours a day in the working week that is no older than 24 hours.

The following items are covered in the Flow Monitoring report included in the Appendices:

- Qualitative Assessment of Data Stream
- Data Reports
- Catchment Model Calibration
- Acton SCITTER correlation
- Verification of System
- Certification
- Audits

5.7.4 SCITTER

The SCITTER plant was constructed at the Thames Water operational site of Acton Storm tanks. Its prime function was to measure the constituents of storm sewage and to facilitate calibration of the ADFM to read screenable solids.

A description of the plant, the methodology adopted and results obtained to date are discussed in summary in the précis in section 8 – Technical Studies and more completely in the SCITTER report in the Appendix.

6. Derive Strategies

6.1 Derivation of Strategies

Consideration of the character of the catchment area(s) of the London sewerage system(s) suggests there are a number of strategies that could be employed to achieve the long-term objective of significant and permanent improvements in the water quality of the tidal reaches of the river Thames. By considering the process of rainfall generating run-off, which becomes flow in the sewer system and then potentially a polluting overflow to the river, the objective is either to prevent storm water from flowing through the sewerage system into the river or allow the flow to continue but reduce the biological and chemical load in the discharges to an acceptable level. These strategies may be grouped into four potential areas of attack along the route of storm water from being rain to becoming flow in the river:

1. Before the rain water enters the sewerage system e.g. source control; SUDS

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

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

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

These strategies are discussed below:

6.1.1 Strategy 1: Before the sewerage system

The potential options for consideration under this strategy are based on the exclusion or control of rainwater run-off before it enters the sewerage system. These could include source control, detention ponds and other similar SUDS techniques.

Source Control

Since the 1870s a series of storm relief sewers have been constructed in inner London in response to flooding events. In general terms these floods have been caused by the gradual, but extensive, paving of the urban area to the extent that now some 45% of the cityscape is impermeable. This represents a very high rate of impermeability typical of very mature urban areas with little scope for further infill. Unfortunately sewerage practice in the 19th century did not allow for the separation of such rain flows from the foul flows that also enter the combined sewers. The storm relief sewers are arranged such that they receive overflows mostly from the intercepting sewers. There is no prospect of impounding surface water so as to prevent it reaching the main combined sewers unless massive alterations to the system are carried out. These would be comparable to those discussed below for wholesale separation. The widespread retrofitting of SUDS techniques are considered to be, at best, disruptive and costly and, at worst, not technically feasible. Exclusion of runoff from the sewerage system would require the construction of alternative disposal routes for surface water flows, which have now become scarce or lost due to the development of London.

There is simply not the space for surface watercourses or detention structures such as ponds and swales within the built up areas of London.

For these reasons options for SUDS or source control are not generally available in inner London. There are however a few locations, one such example is Hampstead Heath as discussed below, where source control could be used in a limited way because of the particular characteristics of the network.

Hampstead Heath

In the 1980s the North London Flood Relief Sewer – Phase 2 was constructed to relieve flooding in the Camden area south of the heath. One characteristic of the scheme was the provision of capacity in the storm relief to catch rainfall run-off directly from the heath via ditches so as to prevent heavy inflows to the High Level Interceptor. Although the sewer was built the ditches on the heath were never constructed due to intractable planning issues.

Although the North London Relief connects directly to the main system, the provision of extra capacity is apparently not used and rainfall, which could be stored and attenuated in this tank presumably, flows into the High Level as before. This idea could be reactivated and the south side of the heath could be used, in conjunction with the relief sewer for a single but sizeable source control scheme. It must be noted that implementation of this particular source control scheme would not significantly reduce CSO spill to the Tideway.

Although there are no other known options of this type which have been previously investigated it is worth observing that most of the large green areas in north London and some in south London such as the parks (especially the Royal parks) and the public Heaths and larger public and private gardens all drain into the sewer system when it rains. These are permeable areas and their contribution to storm sewer flows is a matter of conjecture. After dry spells the chances are that little run-off is experienced. However London experiences protracted periods of light rain where it may be assumed that once waterlogged these green areas become nearly impermeable and may contribute significantly to storm flows into the Thames.

It may be that the chances of providing source control in such venerable and prestigious recreational areas are now long-since past exploiting, but insofar as any option exists for future Source Control in inner London, these would be the locations to consider seriously.

6.1.2 Strategy 2: Within the sewerage system

The potential options within the sewerage system for consideration under this strategy include: attenuation within the system or by the provision of new on or off-line tanks and separation of the sewerage system.

The existing system, although sufficient for dry weather flows, very quickly becomes overloaded during rainfall events. Despite the huge size of some of the sewers in the centre of London the total volume available to achieve in-line attenuation is in fact trivial compared with the discharge volumes generated by a rainfall event of even short duration. The large sewers are mostly ancient culverted watercourses, which originally provided land drainage in the London area.

Although underground they are in fact very shallow and are associated with the significant risk of sewage flooding to large numbers of properties in the London area. This risk is mostly due to the very large number of basements, many of which are built at a lower level than the soffits of the large sewers to which they drain. This means that artificially surcharging these sewers to higher levels to utilise such storage would further increase this flooding risk, which would be counter-productive and unacceptable.

The construction of on or off-line storage in discrete units throughout the existing system has the appeal of implementation in stages, targeting the worst affected areas first, or taking pragmatic opportunities where redevelopment proposals allow. However, this approach is subject to severe challenges, which render its complete implementation very expensive, highly disruptive and severely difficult to operate and maintain.

There is very limited opportunity to implement on line storage, as this would involve significant enlargement of the existing sewers, which are typically quite shallow. The large volumes 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 a pumped return.

Ideally shallow storage tanks would be the preferred approach, however, because the existing sewers are typically quite shallow the effective depth for these tanks would be limited to 2 – 3m. In order to provide a storage volume of 2.14Mm^3, equivalent to the spill volume at the medium level of intervention, this would equate to a total area of storage of just over 85ha for an average depth of 2.5m.

The opportunity to acquire such a large area for the implementation of shallow storage, even on a piece-meal basis, would be very limited and it would be very unlikely that the total volume of storage required could be provided in its entirety. It would be reasonable to assume that only a small proportion of the volume required could be affected in such a manner.

Utilising deeper tanks, which would have to include for a pumped return, would reduce the total area required. Based on previous, similar examples a typical storage depth of 25m would not be unreasonable. However, this would still equate to a total storage area of 85,600m^2 or 175 tanks 25m in diameter. This excludes the footprint for construction, which is likely to be of the order of 3000 m^2 for each tank.

The cost of implementation of such a large number of discrete storage tanks will be much higher than a single large diameter tunnel of equivalent volume. This is largely due to the cost of site and equipment set-up for each unit. This increase in cost of storage implementation is demonstrated by considering potential solution E, which is described in Section 7. Although this option is based upon retention of only 30% of the intercepted flow in large diameter storage shafts it is just over 70% more expensive than a single storage tunnel. If one considers the implementation of the full storage volume in such shafts, then the cost is likely to be at least five times greater than that of a single large diameter tunnel.

To produce the greatest reduction of flow spilt to the river these storage tanks would have to be constructed immediately adjacent to the existing CSOs, that is very close to the river where land values and the style of development could reduce the opportunity for implementation. Diversion to discrete storage units upstream of the CSOs would have much less of an impact on reduction of spill volumes as the CSOs become relatively insensitive to changes further away from the river. This was demonstrated by the technical study on SUDS. Far larger volumes would therefore have to be created to reduce spill volumes thus further increasing the cost of implementation.

After the rainfall event, these tanks would have to be emptied. A twenty four hour period is considered reasonable to make the storage volume available for the next event and to reduce the onset of septicity, which would give rise to severe odour nuisance and possible treatment problems. This equates to a significant flow, which would overwhelm the existing sewer network. Additional capacity similar to that of the existing interceptor sewers would have to be implemented to prevent this flooding. This would be an expensive and disruptive construction.

The storage of such large volumes of storm sewage would create significant operational challenges. Large volumes of silt and debris would settle in the tanks. Mixers would be required to keep this material in suspension and all the tanks would have to be cleaned after each event. It is likely that the energy consumption for such operations would be very high.

The strategy of attenuation within the sewerage system is therefore not practicable and would be costly and inefficient.

Separation

As previously stated the sewerage system in London is combined and has evolved to be just large enough to cope with reasonably heavy rain without causing major flooding. In such conditions the system reverts to being a land drainage system, runs full and flows directly to the Thames. The disposal of sewage directly to treatment remains impossible unless an alternative system of dedicated foul sewers were to be provided. Thus separation could only be achieved by the construction of an entirely new foul sewerage system, which would only be possible at extreme cost and disruption over a very long time.

Interference with the existing sewers would be hard to avoid and would probably entail deeper construction with consequently major new pumping facilities, costly to provide and maintain. This new foul system would consist of over 12,000km of sewerage system installed in the already congested streets of London together with approximately 500 foul pumping stations. The drainage for approximately 3 million properties would also have to be entirely reconstructed. The overall cost is most unlikely to be less than £12B.

Even if such a proposal were to be seriously contemplated it would also fail to provide a complete solution to the storm pollution problems of the Tideway, as surface water run-off includes its own pollutants. Lengthy past experience also suggests that it cannot be guaranteed that the foul system would remain separate over an extended period due to redevelopment and misconnections.

6.1.3 Strategy 3: At the CSOs

The potential options at the interface of sewerage system and the river, that is at the CSO outfalls, include screening at the individual outfalls, interception to storage, transfer or distribution for screening or treatment elsewhere and storage adjacent to the outfalls.

It was recognised at an early stage in the study that this strategy represented the only solutions that could be considered potentially viable and worthy of further investigation. This has lead to the derivation of the potential solutions A to H, which are the main focus of this report.

Of all the potential solutions, those based on interception to storage and transfer to a purpose built treatment plant are the most feasible and suffer from the least technical challenges.

Essentially only strategy 3 is viable and could realise the objectives by the implementation of appropriate solutions at the interface between the sewers and the river. Potential solutions within this strategy have been investigated and costs estimated in outline. This exercise has revealed that there are only a few practical engineering solutions, which are likely to realise the desired levels of improvement at reasonable cost. It should also be appreciated that the ultimate solution to the Tideway water quality could involve a mixture of some of the appropriate techniques.

6.1.4 Strategy 4: Within the river

The potential options for within the river itself can only include reactive measures such as injected oxygen from river craft or riverside locations. In fact Strategy 4 really cannot be considered to be either a true strategy or an appropriate solution in that once in the river the polluting effects can only be ameliorated and the sewage litter problems will not have been addressed at all.

Dosing schemes of various types have already been implemented in a few locations along the river and although such methods may well have a part to play in some of the future main potential solutions, they cannot be considered as a complete answer in themselves.

6.2 Range of Potential Solutions

The strategy 3 options have been explored by investigating potential solutions at three levels of intervention: low – 20%, medium – 50% and high - 100%. This matter of intervention is discussed in more detail in Hydraulic Parameters below.

The solutions considered are:

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

Discussion on the development of each potential solution is included below with further description of each in Section 7 - Potential Solutions, detail consideration in Section 8 – Technical Studies and overall assessment in Section 9 - Conclusions

6.2.1 A: Storage

Interception of CSO flows to storage combined with controlled draindown to treatment is the basic approach of many similar projects throughout the world. It becomes a matter of adopting the most appropriate form of storage, which is dependant upon the catchment characteristics and the most appropriate form of treatment, which is dependant upon the required rate of drawdown and the treated effluent quality. The ability to empty the stored flows in a controlled manner enables one to optimise the treatment process to best effect and thus limit the capacity of the screening and treatment plant, pumping plant and peak power requirements.

Storage can be provided in typically one of three ways:

1. Surface storage ponds or lagoons
2. Underground storage tanks or shafts
3. Large diameter tunnel.

A storage tunnel is typically the key feature as it tends to perform two other complimentary functions as well as providing the required storage volume, namely transfer of the intercepted flows by interconnecting the CSO sites and transfer of the stored flow to treatment. By comparison discrete surface or underground storage tanks would require an array of conduits to collect and transfer the intercepted flows to storage and drainage conduits to transfer the stored flow to treatment.

Within an urban or heavily built up environment provision of storage by large diameter tunnel has the considerable additional advantage in that construction is much less disruptive. Open surface storage of storm sewage within an urban environment would be unacceptable even if the appropriate land area could be acquired.

Underground storage tanks or shafts incur high set up costs and although can be large in area they are ultimately limited in depth by ground pressures, the ability to pump from great depths and the exponential increase in cost of excavation and construction at great depth. In contrast although the initial set up costs for a large diameter-tunnelling machine are high the production thereafter becomes very cost effective and can proceed for several kilometres between construction shafts. The unit cost of storage volume constructed by large diameter tunnel is typically significantly less than by multiple large underground tanks or shafts.

Typically discrete storage tanks or shafts can offer a cost effective solution to localised pollution or flooding problems, but becomes very expensive as the basis for a strategic or catchment-wide scheme.

Potential solution A is therefore based upon a tunnel of diameter sufficient to provide the storage required for each level of intervention. The route typically follows the river to avoid passing under existing buildings and is between the CSO furthest to the west and the potential treatment site just to the east of Crossness STW. Interception structures and shafts would be required at each CSO, located to minimise disruption, with a short interconnecting tunnel between each shaft and the main tunnel.

6.2.2 B: Transfer

This potential transfer solution would work in much the same way as most storm relief sewers. The CSO flows would be intercepted and carried downstream to a very high capacity pumping station and screening plant for discharge to the lower reaches of the Thames. This approach is intended to prevent discharge of pollution load to the middle reaches of the river by transfer to the lower reaches where it is perceived it may cause less of an impact.

The peak transfer flow rates are likely to be very high, therefore only screening is proposed, as any form of enhanced primary treatment would not be practical.

Due to the built up urban nature of London the only possible means of construction would be by tunnel to minimise disruption as much as possible. The tunnel would vary in diameter, increasing in increments from west to east to accommodate the accumulated peak flow rates.

Although this approach is based upon transfer of flow, retention of storm flows for low volume events may be possible. It is therefore conceivable that these lower volume events could be pumped out slowly to treatment. This would effectively convert the operation to that of Option A. However for the larger events, which have a significant impact on the river, this low storage approach would not be possible, as the tunnel would have obviously insufficient storage and would revert to transfer.

The peak capacity of the pumping station and screening plant would have to be very high to cope with the largest events to prevent bypass of unscreened flow at the CSO interception structures, however this peak capacity is likely to be invoked infrequently.

6.2.3 C: Multiple Screened outlets

For this potential solution multiple purpose built pumping and screening stations would be connected via a collection and distribution tunnel, which intercepts flow from the CSOs. The discharged flows could only be screened, as any further treatment such as enhanced preliminary treatment to reduce BOD would be impractical. This approach would separate and spread out the high peak capacity required of a single outlet, as of B.

These stations need to be fairly evenly spaced between Hammersmith and Charlton, biased towards the high discharge outlets. At least eight high capacity stations would be required. The plan area of each would be of the order of 100x120m(1.2ha = 3 acres). The specific location for each could be somewhat more flexible than for the potential solution based on screening at the individual CSOs. However these would still have to be constructed in urban areas on potentially high value development land. They would represent a significant impact and a serious challenge to implement. It is likely that the environmental and planning requirements would be very restrictive and that compulsory purchase and the demolition of existing buildings may be the only possible course of action for some sites.

The collection and distribution conduit would need to be constructed in the tunnel to avoid disruption. It would also need to be of reasonable diameter to have sufficient hydraulic capacity to distribute the peak flows between the stations.

This potential solution realises less benefit for the river as flows are only screened. It would not be practical to allow for the construction of enhanced primary treatment facilities in central London locations. It would have a significant impact on the urban environment and therefore require considerable co-operation for implementation.

6.2.4 D: Multiple Screened outlets with storage

This potential solution was intended to be a hybrid of C and A, incorporating a second tunnel to store the first flush. For the logistical reasons previously discussed the storage and distribution conduits would need to be of tunnel construction. The first flush of the intercepted flows would be retained within the storage tunnel and passed to treatment, in much the same fashion as a lower capacity version of option A. The remaining flow would be distributed to the eight pump and screen outlet sites, as per option C.

This approach was proposed to explore the issues and potential costs to the addition of storage and treatment to improve option C.

However to prevent choking and consequent inability to capture the first flush this storage tunnel would need to be of a reasonable diameter, probably only a little smaller than that required for the potential solution based on tunnel storage alone.

In effect, the storage tunnel for this potential solution becomes so very similar to that required for A that the requirement for multiple pumping and screening outlets tends to become superfluous

6.2.5 E: Storage Shafts

In an effort to avoid the need of large diameter storage or transfer tunnels and potential disruptive screening plants this novel concept of static screens within a storage shaft was investigated.

Within options C, D and F the screening plant is based upon conventional inlet works arrangements, which necessitate the provision of screenings treatment, handling and transportation plant. It is all this ancillary plant, which makes up the greater proportion of the site area.

Typical CSO screening plant is based on the principle of excluding the screenable solids from the overflow and disposal by returning to the continuation flow to the sewage treatment works. This plant cannot be utilised for the Tideway CSOs, as there is generally no continuation flow to carry the return screenable solids away.

The novel approach of this potential solution is to employ static, self cleaning CSO type screens within the upper section of a large diameter shaft and to generate the required continuation flow to a storage volume in the lower section of the shaft. Of the total flow intercepted and passed to the shaft 70% is screened and passed immediately to the river and 30%, containing the returned screenable solids and representing the continuation flow, is retained for transfer to treatment.

The general location for these large screening/storage shafts would be in the foreshore, to avoid disruption to buildings, roads etc. However it is accepted that this construction approach would still be disruptive to river traffic and riparian owners. The impact on the foreshore itself will be considerable as it is ecologically sensitive. There would also be considerable impact on river frontage rights, which will be vigorously resisted.

Off-line storage shafts have been utilised for local flood relief schemes as shafts can represent good value for storage when compared with small diameter tunnels. This potential solution would require a complex array of collector tunnels (to transfer the flow to each individual shaft) and draindown tunnels for emptying would be needed to make operation effective. Each shaft would have to incorporate powered mixer units to keep sediment in suspension and a pumped draindown arrangement. So each shaft would require the provision of power, control systems and access for maintenance.

6.2.6 F: Screening at Individual CSOs

All previous potential solutions are based on substantial works for the interception, transfer or storage and treatment of the CSO flows. This approach is proposed to investigate the issues around providing screening plant for each individual CSO. There are three outline solutions for each site:

1. Screening plant constructed at the CSO outlet location immediately adjacent to the river.
2. Screening plant constructed upstream of the outlet but downstream of any major inflows
3. Construction of screening plant offline, with the appropriate diversion conduits.

The implementation of screening for an individual CSO is constrained by the following factors:

1. The actual location and arrangement of the CSO discharge.
2. Hydraulic effects on existing sewerage system and increased risk of flooding.
3. Size and capacity of plant required.
4. Planning and environmental restrictions at the given location.
5. Availability of extra land acquisition.
6. Impact on existing third party assets.

The installation of screening plant could be considered immediately adjacent to or upstream of the existing discharge (but downstream of any major inflows) or potentially diverted a short distance off-line. This would be dependent upon the above local factors for each individual CSO.

Hydraulic effects are critical, as the installation of screening plant would incur head loss which would increase surcharge levels in the existing sewerage system leading to increased risk of flooding upstream. Diversion of flows to off-line screening sites will incur even more head loss. The pumped CSOs could accommodate this increase in head by up rating of the pumping plant and remodelling of the existing stations. Gravity CSOs are far more sensitive to this effect; most would require the addition of low head/high flow pumping plant to compensate. This additional pumping would add to the overall space requirements.

The plant capacity required is dependent upon the peak discharge rate, which varies for each CSO. CSO type screens will not be appropriate as there is generally no continuation flow to carry the returned screenings away, therefore the plant will have to be based on typical inlet works arrangements. The overall site would have to accommodate the following plant; screens, screening handling and treatment, disposal skips, transport access, pumps, wash water storage and booster equipment, switchgear and control equipment. As this is equivalent to the inlet works treatment processes for a sewage treatment works it is worth noting that a significant number of the CSOs would require plant of a peak flow capacity much higher than the inlet works of Beckton STW itself.

The vast majority of these potential screening sites are in densely urbanised areas. It is anticipated that odour, access issues and overall appearance would be critical requiring the whole plant and loading areas to be covered by a suitable building. Most areas are fully developed so that land would not be freely available and it is also very likely that the construction of such plant will be contrary to the planning designations in most areas. Many of the CSOs are located adjacent to or under major transportation arteries or large buildings. The disruption caused by the construction of screening plant at these locations is likely to prove unacceptable. Compensation costs would far exceed the cost of construction.

The strategy of screening at individual CSOs cannot be considered as a complete solution because only a few sites could be accommodated without extreme disruption. It is estimated there are only 3 viable sites and another 10 that could, with considerable investment be made available.

6.2.7 G: Displacement

The strategy of displacement (G), based on a conduit normally left full, was developed in an attempt to overcome the high-energy cost associated with pumping out from great depth. It was hoped that it could represent a more sustainable and less energy demanding solution.

Another intended advantage of this option was the “green” character of the solution involving a managed wetland park in east London. A large low-lying area would be required to receive the intercepted and transferred flows to allow the displacement tunnel to operate under gravity as much as possible. This area would be converted to constructed wetlands to provide a reasonable treatment standard for the reduction of suspended solids and BOD.

Whereas this concept has been used successfully to intercept and transfer continuous foul sewage flows, for example the Harbour Area Treatment Scheme (HATS) in Hong Kong, the intermittent nature and the high peak transfer rates of storm flows associated with intercepting the Tideway CSOs leads to many hydraulic challenges. Ironically these challenges can probably be met only at the expense of an operating regime involving extensive pumping, which incur an even greater energy penalty.

The four essential elements of these hydraulic challenges are:

1. A daily flush would be required to turn over the body of flow in the tunnel to prevent septicity and to flush through the volume of intercepted storm flows. This could be achieved by gravity flow using a tidal flush of river water introduced at high tide to the western end of the system, provided that the discharge at the eastern end is very low-lying. However, velocities will not be high enough to re-suspend any accumulated sediment.
2. Regular pump assisted flushing to re-suspend sediment. This high flushing rate (approximately $150m^3/s$) would transfer very large volumes of flow (typically $2Mm^3$) with a high polluting load and as such could not be discharged direct to the river.
3. Pump assist for moderate events where the peak accumulated flows exceed the capacity under gravity flow.
4. Pre-emptive drawdown of the system to overcome the slow response due to the high inertia of the weight of the body of flow in the tunnel, which is in excess of 2M tonnes.

It has been calculated that the annual energy consumption for this potential solution would be over three times greater than for the potential solution based on storage. This is mainly due to the energy required for the pumping to assist flushing.

Conventional treatment cannot be considered viable for this potential solution because of the high flow rates and large volumes associated with pump assisted flushing. Hence the use of a large area (of at least $4km^2$) of constructed wetlands was considered to be the most appropriate. From the findings of the land use surveys it is most unlikely that enough land in a suitable east London location could ever be acquired.

This potential solution cannot be considered viable after all due to the complex hydraulic control, high-energy consumption and non-availability of such a large site for the constructed wetlands.

6.2.8 H. West London Scheme

As the study progressed it became apparent that works at the western end of the Tideway would be more likely to achieve the greatest benefits from a given level of investment. This 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 storm relief sewers enter the river.

Initially formulated as the first phase of Option A this solution offers a considerable advantage of lower cost with a shorter construction phase focussed on the most sensitive part of the Tideway. With the inclusion certain additional elements at Abbey Mills and Greenwich this solution could enhance water quality sufficiently to be regarded as a total package, at least until many years into the future.

6.3 Basic Assumptions

6.3.1 Hydraulic parameters

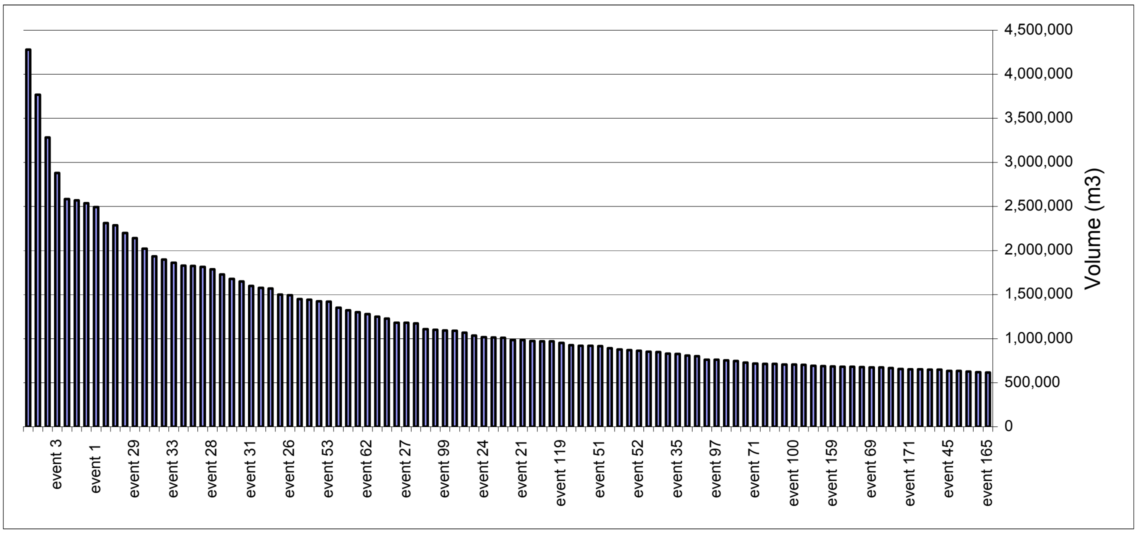
The required hydraulic capacities have been based upon the output of running 20 years of rainfall data (1208 historic events) through the Infoworks sewerage model and collating the spill volumes and peak flow rates of each tideway CSO.

The modelled spill volumes generated are considered to an over-estimate compared with actual events because of the following factors:

1. Each rainfall profile was applied simultaneously to the whole catchment area. Actual rainfall events vary with time and spatial distribution.
2. The Beckton and Crossness catchment areas are much larger than that intended to be computed by Infoworks. It is considered that this and other more detailed aspects of the model computations will tend to over-estimate generated volumes.

Much more study and investigation is required to determine actual spill volumes to the river and hence the volumes and flows that would be intercepted by any potential solution. *Figure 17* depicts the total spill volume for the top 100 events estimated by this method.

Figure 17 - Spill Volumes for top 100 events



For potential solutions based on storage the maximum level of intervention was determined by the maximum event, that is 4.28Mm^3. The medium and low levels of intervention were defined as 50% and 20% of this maximum volume respectively.

For this 20year period only 11 events would have exceeded the 50% volume (2.14Mm^3) and 62 events would have exceeded the 20% volume (0.86Mm^3). On a yearly basis that equates to less than 1 bypass event for the medium level of intervention and 3 bypass events for the low level. It is worth noting that overall 95% of the events would have been contained by the 20% volume option. It is also a reasonable assumption that the first flush of the larger events may also have been detained.

A similar pattern would be obtained if one considers peak flow discharges. But is more difficult to utilise to determine outline design parameters, as the accumulation of peak flow is dependant on the spatial variation of rainfall. At this stage it is impossible to accurately estimate accumulated peak flow in say a transfer or displacement tunnel option. However for comparison purposes it is considered appropriate to take the volumes above stretched over nominal event duration of 8hours with a peaking factor of 1.6 to estimate peak flow rates. This duration of approximately 8 hours has been estimated from inspection of the larger historic rainfall events and the application of a peaking factor of 1.6 to average flows has been estimated from general modelling experience of the London catchments.

It is accepted that this assessment is basic but it allows the adoption of the following peak flow rates for the three levels of intervention for transfer-based options:

Maximum	$240m^3/s$
Medium	$120m^3/s$
Low	$50m^3/s$

From the model runs of the larger events, peak flow values were also abstracted for each CSO, and recorded on the CSO Database, to assist with the concept design of the interception structures and interconnecting tunnels for most of the options. These values were also used to assess the screening plant capacities required for potential solution F.

6.3.2 Pollution Parameters

The main pollution parameters that have been considered within this report for the comparison of various options are screenable solids and Biological Oxygen Demand (BOD). Typical measured values have been used as simple indicators of relative performance.

For compliance testing a different approach was followed. The values for BOD along with other parameters, such as ammonia and suspended solids, were assessed using the default values generated in the Infoworks sewerage catchment model. This is discussed further in the Objectives report.

There is very limited published information on how these parameters vary throughout storm events. It is widely believed, and proven by measurement and experience, that the concentrations of BOD and solids increase dramatically in the early part of the storm flows. This is known as the first flush effect as accumulated debris is re-suspended or released by the flushing effect of faster flow.

Recent work by Sheffield University for the Pennine Water Group has shown that the peak concentrations of BOD and solids can be up to 20 times that of normal dry weather flow values before the diminishing to more diluted values in the second half of the storm event.

The results from SCITTER display a very prominent first flush effect, which concurs with the Sheffield University study and also shows that the response is very variable and dependent upon the severity of the event and the antecedent conditions. However it is expected that this will not be consistent throughout the catchment.

At this stage an effective cut-off point, that is where the concentration of the pollution load is sufficiently low for discharge direct to the river without causing adverse effects, cannot be determined. However there is a high level of confidence that the majority of the polluting load will be intercepted by the potential solutions even at a low level of intervention.

The main conclusion from SCITTER is that the response is very catchment and event specific. The measurements undertaken so far show that generally storm discharges display much higher concentrations of solids and BOD than normal dry weather flow, thus disputing the long held belief that storm flow pollution parameters are more diluted. It is likely that the flat nature of the sewerage system for London allows for a greater accumulation of debris in anticipation of being flushed out to the river in time of high rainfall.

With regard to screenable solids initially the value of $400g/m^3$ was adopted as an average value for the whole event. The results from SCITTER show that this is likely to be an under-estimate and that a value of $1200g/m^3$ is more appropriate. This value is not based upon the dry weight of screenable solids but is based on the weight of “wet screenings” extracted from a cubic metre of flow. This can be considered as the material that would be retained in a standard 6mm mesh sack, drained for approximately 30 minutes, but still containing a significant proportion of water. This simple but practical method of measuring wet screenings has been adopted as informal national standard at both Wigan and Chester-le-Street, where respectively CSO and inlet works screening devices have been tested.

This value of concentration of wet screenings is of key importance to enable an assessment of the capacity of the screenings treatment, handling and transportation plant required. This capacity is much higher than that typically associated with screening of normal dry weather flow.

A screenings treatment plant, such as a Liscep, would reduce the weight of wet screenable solids by approximately 80% by a washing and water removal process. This produces what may be considered a “dry” solid waste suitable for disposal to landfill. However this material is likely to consist of only 40% dry solids by weight.

These parameters for screenable solids have been used to assess the capital operational costs for the screening plant for each option and level of intervention based on an assessment of the intercepted flow on a typical annual basis.

Regarding BOD a typical average value of $70g/m^3$ has been assumed based upon measurements of CSO discharges taken by the Environment Agency. The work at SCITTER has shown that this may again be an under-estimate, however the results for BOD are much less representative and the test is notoriously difficult to carry out consistently. This area will be pursues in more detail in the Continuation study. The average value above was applied to the intercepted flows on a typical annual basis for each potential solution and level of intervention as a crude measure of prevention of release of BOD to the river as a basic comparator of performance.

6.4 Climate Change

6.4.1 Introduction

Global warming is a subject, which has been considered by scientists worldwide for many years. The reason behind this is highlighted by the fact that Bazalgette’s sewer scheme was built around 1865, 138 years ago with a lifespan of another century. It is predicted that the selected proposed solutions recommended within the solutions group report will have to last for a similar period, therefore highlighting the importance of climate change. Global warming basically adds energy to the atmosphere, which causes changes to the current climatic patterns. A number of models have been developed for a range of climate change scenarios and the general predictions are that continued warming in the UK region will cause a change to a more Mediterranean climate. The governments UKCIP02 project is looking at quantifying the potential change, the results from this study have recently been published. The UKWIR CL10 project is currently considering how these changes will affect the climate affected design parameters currently used in sewerage design. Initial results were published during early 2004.

Climate change has been considered within the Tideway project by Nick Martin, of Thames Water, who sits on the UKWIR steering group. It is anticipated that the principle factors of climate change likely to affect the Tideway are:

1. The total volume of rain – customers demand for water supply, flow over Teddington Weir.
2. Rainfall distribution – sewer response, event frequency
3. Temperature – river water temperature, dissolved oxygen, biological process rate.
4. Soil Moisture – rainfall runoff to sewers and watercourses.

As mentioned previously predicting rainfall changes due to Global Warming has been undertaken in the UKWIR CL10 project. This project has reviewed current design rainfall for all parts of the UK. It has then run the Global and regional climate models to develop new climate statistics including rainfall for the future (2080).

The current indications from UKWIR CL10 project for 2080 are:

1. Design storms for a given return period will have approximately 30% greater rainfall depth, which will lead to even greater volumes of run-off.
2. Summer rainfall will decrease by approximately 20%, however overall annual rainfall will not vary greatly. Therefore winter periods are predicted to be wetter.

Some initial simulations based on current climate change predictions have been carried out using the compliance test procedure; please refer to the Objectives Report (Volume 2). The early indications are that there would be a slight increase in the number and volume of bypass events. Further analysis will be carried out during the Continuation Study phase.

6.4.2 Impact on Potential Solutions

The main implication for the potential solutions is that additional capacity will be needed to accommodate the increase run-off due to climate change effects. The question is how much additional capacity will be required when there is still great uncertainty within the industry as the value of potential changes?

The risk of over-prediction is that excessive extra capacity would be included resulting in over-expenditure and a waste of resources. Conversely if too little extra capacity is included the new system will become inadequate. Augmentation of solutions based on transfer, for example, would be very expensive, as additional duplicate tunnels would need to be constructed.

However for potential solutions based on storage (solutions A and H) there is the opportunity for a more flexible approach. The decision on the size and capacity of the tunnel can be made at an early stage based on shorter term and therefore more confident prediction of climate change effects. Once the future trends are determined the storage capacity can be supplemented by the construction of off-line storage tanks if proven necessary. It must be ensured that the main tunnel has sufficient hydraulic capacity to transfer intercepted flows along parts of its length to potential locations of the off-line tanks. Provided that off-line tanks can be implemented relatively close to the main tunnel the hydraulic capacity should not limit the flexibility of this approach.

Although it has been shown in this report that off-line tanks are a marginally more expensive option than increasing the storage tunnel diameter, this approach will avoid the risk of implementing an unnecessarily large tunnel at increased initial cost.

6.5 Real Time Control

In the context of storm sewage disposal, Real Time Control or RTC is the facility to take action to manage parts of the sewerage system during rainfall events whilst they are actually occurring. This approach is an alternative to the normal method of managing storm events, which is to set the weirs, overflows and other operational control points in an optimum way based on experience so that when rain falls, the overloaded system behaves in a manner which achieves the desired performance and discharges in ways which minimise potential nuisance.

Usually the RTC is a set of automated penstocks or valves which either divert surplus flow to some storage tank or inhibit flow entering a part of the system which may be very sensitive to overloading. It may use attenuation to delay transfer of flow from one part of the network to the next or to route flows downstream through an optimum path.

There are a large number of such installations worldwide which attempt to control the flow of storm sewage so as to minimise pollution whilst avoiding any increased risk of flooding. This is quite difficult to do when retro-fitting such devices on existing systems and it is normal for the installation to include the provision of extra capacity for the RTC devices to utilise rather than attempt to modify the operation of an existing network where spare capacity is rarely to be found to be available.

Many RTC schemes have only limited scope and are usually confined to small separated catchments where a specific local issue is amenable to this method. It is understood that many of these have failed or fallen into disuse after a time.

Regrettably when retrofitting is attempted the performance historically of automated and intermittently operating mechanical and electrical plant within sewerage systems has a very poor track record and involves, almost universally, failure after a period of time. It is normal for the aggressive conditions within sewers to accelerate the decay of sensitive parts of such equipment so that either activation or control becomes firstly unreliable and the fails altogether. To prevent this it is usually necessary to carry out frequent maintenance on the equipment, which is sometimes so extensive that operational groups defer this until such time as an event of actual nuisance occurs due to the failure of the device. In many cases this can take years to occur and the subsequent renovation and reinstatement of such devices is rare.

London already has significant RTC in the form of storm sewage pumping stations. There are some 17 of these along the Tideway set to start pumping as the levels in the system rise when rain falls. A few of these are still operated manually although most are automated. Operations direct the lion's share of their maintenance capability at these stations so that reliability is generally good. However this RTC achieves only one result, which is to put more storm water into the river so as to avoid property flooding. It is also done to avoid operational difficulties at STWs where the unrestrained increase of storm water entering works can disrupt the treatment streams for long periods. This explains the high levels of discharge at Abbey Mills revealed by the study and caused by the need to manage the Beckton inlet flows.

With the advent of the UWWTD the objective now is to reverse this trend and try to minimise discharge to the river without increasing flood risk. Without the storage tunnel the amount of optimisation available within the existing system is fairly trivial and probably uneconomic to realise. However it is certainly true that without careful management the tunnel could be used inefficiently and fail to achieve the major benefits anticipated. When an event is of long duration and threatens to exceed the available storage, the tunnel should be used to capture the most polluted part of the storm discharge, which is assumed to be the "first flush". Obviously there is a need to provide a suitable level of control to achieve this.

One way would be to provide remotely operated or automatic penstocks at interception shafts to close off access to the tunnel at some point in the storm when the most polluting flow has been captured. This would entail measuring the polluting load in the sewage and triggering the control mechanism at the right moment. This is know to be very difficult to do and could lead to a situation where operational or maintenance failures cause the tunnel to overfill locally or silt up or cause flooding for which the water Company might then prove liable through negligence. There are non-mechanical ways in which the tunnel fill rate might be controlled such as control weirs and baffles in the tunnel and the use of these should be preferred for greater reliability.

In a major storm event in London the suddenness and the scale of the increase in flows is known to present serious potential hazards when intervention during the event is attempted. The inherent unreliability of automated mechanical devices indicates that if possible RTC should be avoided in favour of more reliable pre-set fixtures.

7. Potential Solutions

7.1 Potential Solutions - Description

7.1.1 A: Storage

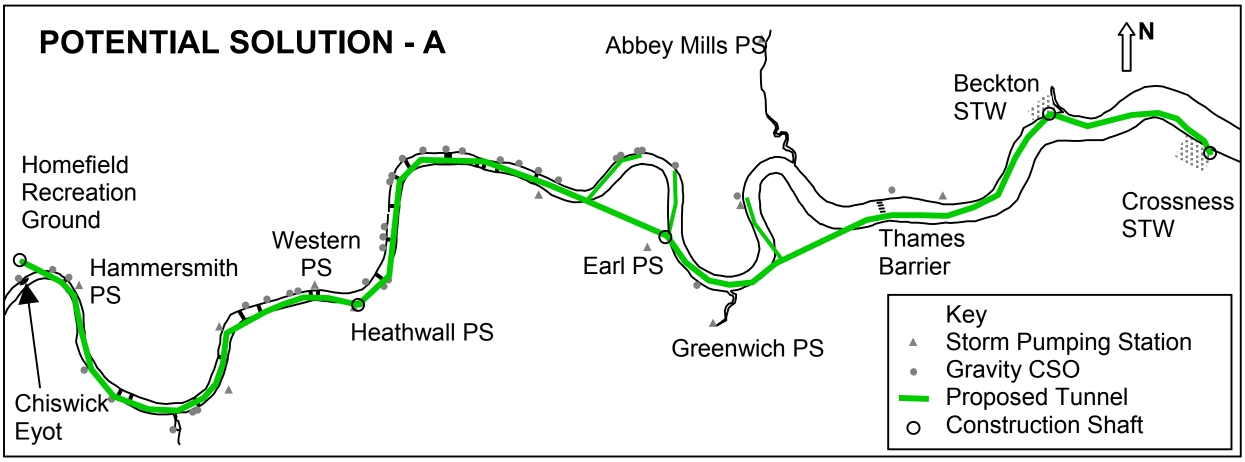
The potential solution investigated for this strategy is based on a tunnel of constant diameter between Homefield Recreation Ground in the west and Beckton and Crossness STWs in the east, which generally follows the river. CSO flows up to the maximum capacity of the tunnel are intercepted and stored. Intercepted flows are subsequently pumped out to a treatment plant located adjacent to Crossness STW. Excess flows would be bypassed at the interception structures direct to the river. The storage tunnel would be approximately 34.5km long (*Figure* 18) and the main parameters for each level of intervention are given in *Table* 6:

Table 6 : Potential Solution A Parameters

Intervention	Maximum	Medium	Low
Volume (Mm^3)	4.28	2.14	0.86
Diameter (m)	12.9	9.0	5.75
Ave pump rate (m^3/s)	50	25	10
Max Power rating (MW)	65	32	13

The average pump rate is given as an indication of the capacity of pumping station and treatment plant required. It is determined by the full volume emptied over a 24-hour period. Obviously lower rates can be employed for extended duration of emptying for smaller captured volumes to reduce pumping and treatment capacity and power supply.

Figure 18 - Potential Solution A



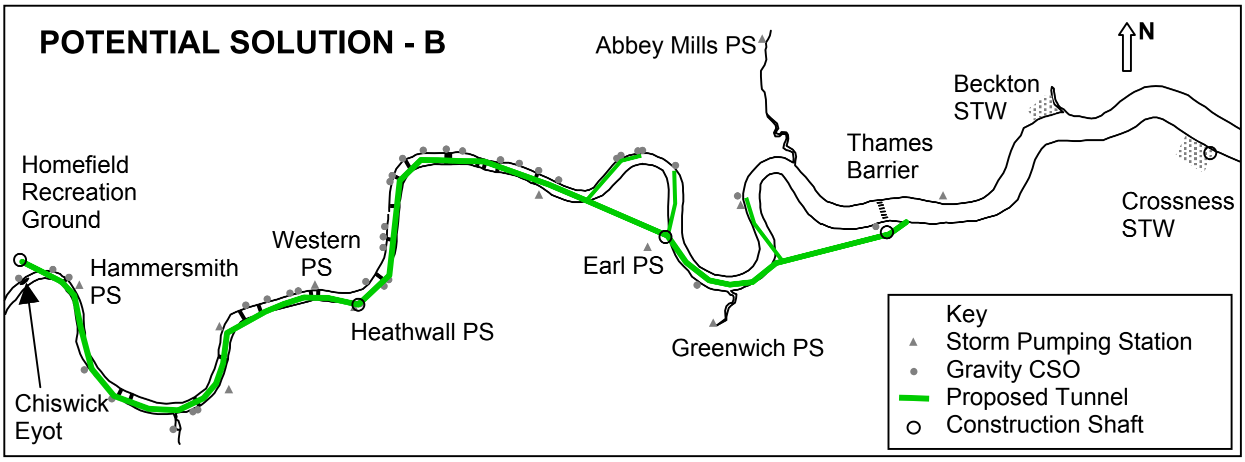
7.1.2 B: Transfer

The potential solution investigated for this approach is based on a tunnel between Homefield Recreation Ground in the west (*Figure* 19) and a high capacity pump and screen plant at Charlton in the east. CSO flows up to the maximum capacity of the tunnel are intercepted, transferred and pumped out for screening only before discharge at a single location back to the river. Excess flows would be bypassed at the interception structures direct to the river. The accumulated peak flows together with the main tunnel parameters for each level of intervention are given in *Table* 7.

Table 7: Potential Solution B Parameters

Intervention	Maximum	Medium	Low
Max capacity (m^3/s)	240	120	50
Max Power rating (MW)	350	175	75
Diameter range (m)	2.4-9.3	1.8-6.7	1.4-3.8
Volume (Mm^3)	1.38	0.69	0.23

Figure 19 - Potential Solution B



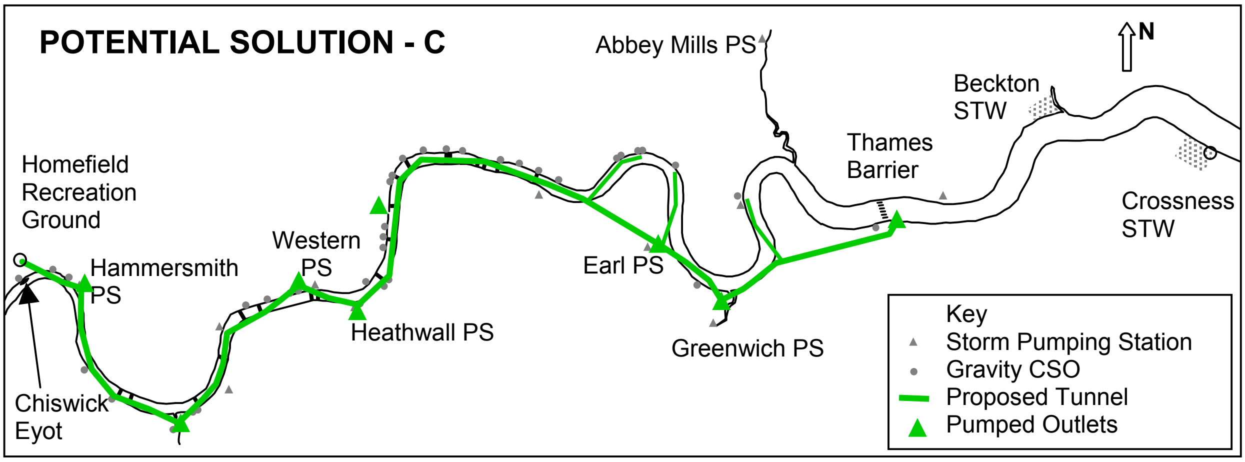
7.1.3 C: Multiple Screened outlets

This potential solution is based upon a collection and distribution tunnel between Chiswick Eyot and Charlton (*Figure 20*) and intercepts the CSO flows. These flows are distributed between eight high capacity pump, screen and discharge installations located approximately equidistant between Hammersmith and Charlton. Excess flows would be bypassed at the interception structure direct to the river. The average installation capacity together with the main tunnel diameter for each level of intervention are given in *Table* 8.

Table 8 : Potential Solution C Parameters

Intervention	Maximum	Medium	Low
Ave capacity (m^3/s)	40	20	8
Max Power rating (MW)	30	15	6
Diameter (m)	4.0	3.0	2.4

Figure 20 - Potential Solution C



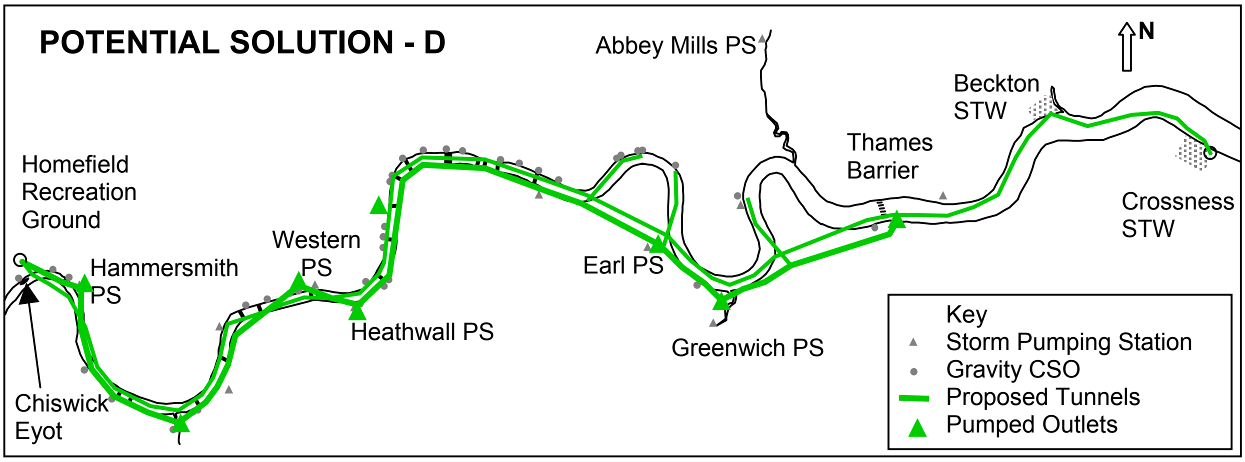
7.1.4 D: Multiple Screened outlets with storage

This approach is basically C with the addition of first flush storage (Figure 21). The potential solution considered for this application is as above plus a second tunnel for storage. The eight installations will have the same capacity as above. This second tunnel would pass from Chiswick Eyot to a pumping and treatment facility at Crossness STW. The main parameters for this tunnel are given in *Table* 9.

Table 9 : Potential Solution D Parameters

Intervention	Maximum	Medium	Low
Volume (Mm^3)	1.1	0.55	0.22
Diameter (m)	6.3	4.5	2.8
Ave pump rate (m^3/s)	12.7	6.4	2.5
Max Power rating (MW)	11	5.5	2.2

Figure 21 - Potential Solution D



7.1.5 E: Storage Shafts

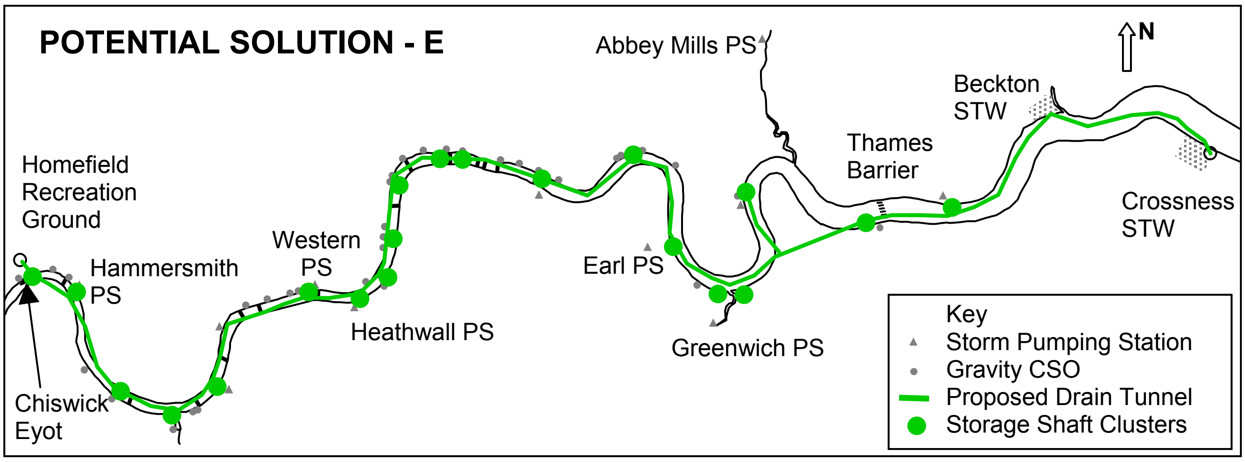
This potential solution is based on large diameter storage shafts constructed in the foreshore (*Figure 22*). The upper section of the shaft would house static self-cleaning screens and the lower section would provide a large volume of storage to generate a carry-forward flow. Intercepted flows would be split such that 70% would be screened and passed to the river and 30% would be detained, along with the screenable solids, in the lower storage section of the shaft. This section would be emptied by a network of small diameter draindown tunnels and pumping stations to treatment. It must be stressed that this approach is entirely novel and untested.

Incorporating this element of screening reduces the overall storage volume required for any given event. The introduction of these novel screens negates the requirement for screenings treatment, handling and transportation plant, as the detained screenable solids would be carried away for treatment. The level of intervention would be governed by the number of shafts installed, with several shafts being clustered for the larger CSOs. The main parameters for each level of intervention are given in *Table* 10.

Table 10 : Potential Solution E Parameters

Intervention	Maximum	Medium	Low
Volume (Mm^3)	1.3	0.65	0.26
Number of shafts	102	54	28

Figure 22 - Potential Solution E



7.1.6 F: Screening at Individual CSOs

This approach comprises the construction of screening plant, together with all the washing, handling and transfer plant, of the appropriate capacity at or adjacent to each existing CSO outlet. The screening plant capacity would be based on the peak spill flow for each CSO. Peak spill flows range from approximately 1m^3/s to over 40m^3/s and are dependant upon the hydraulics of the CSO structure and to some extent the severity of the rainfall event. However the tide level appears to exert the greatest influence on the peak spill flows for gravity CSOs. At this stage it is proposed that the capacity of the plant should be equal to the peak spill flow at low tide conditions in order to comply with the basic requirements of the Urban Pollution Manual and to ensure that the screening plant would not increase flood risk

The site footprints for each CSO are summarised in *Table 11*. Some adjacent CSOs are combined to reduce the number and areas of land take required:

Table 11: Potential Solution F Parameters

Peak Flow (m^3/s)	Footprint (m x m)	Number of Sites
3.5	35x65	20
7	35x70	6
10.5	40x70	7
17.5	40x75	3
28	50x75	5
42	80x75	3

This equates to a total land take of approximately 8.9ha for the CSO sites on the north bank and 4.1ha on the south bank.

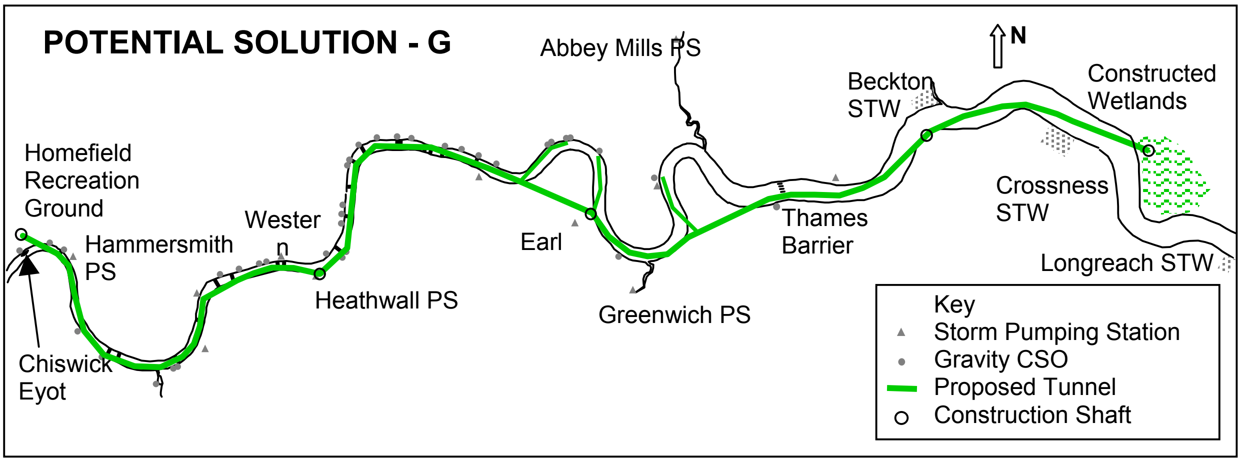
7.1.7 G: Displacement

This potential solution is based on a tunnel between Chiswick Eyot and a large, low-lying area of constructed wetlands, located in the Rainham area (*Figure* 23). The tunnel would be full and act as an inverted siphon. An intake structure constructed at Chiswick Eyot would be used to flush flow through the system to turnover the detained volume and to flush sediment through. Only the medium level of intervention, a 9m-diameter tunnel, has been investigated to determine the degree of pump assistance that would be required for peak transfer capacity and flushing. The basic parameters are detailed in *Table 12*.

Table 12 : Potential Solution G Parameters

Capacity	Flow (m3/s)	Power (MW)
Gravity Transfer (max. 6m head)	55	0
Pump assist transfer (20m head)	110	30
Pump assist transfer (40m head)	150	84
Pump assist flushing (2m/s)	130	55

Figure 23 - Potential Solution G



7.1.8 H: West London Option

This is based on a storage tunnel of constant diameter between Chiswick Eyot in the west and Heathwall PS in the east, which follows the river (*Figure* 24). It represents the first third of potential solution A. It is also specifically targeted to deal with the most vulnerable parts of the river and the most problematic discharges. CSO flows in this stretch of the river up to the maximum capacity of the tunnel are intercepted and stored. Intercepted flows are subsequently pumped out to a compact, high rate treatment facility located adjacent to Heathwall PS.

The volume of storage created is about 28% of the maximum spill volume generated by the CSOs of this reach of the river and therefore represents an intervention level higher than low, but less than medium. The tunnel would be approximately 10.4km long and its main parameters are detailed in *Table 13*.

Table 13 : Potential Solution H Parameters

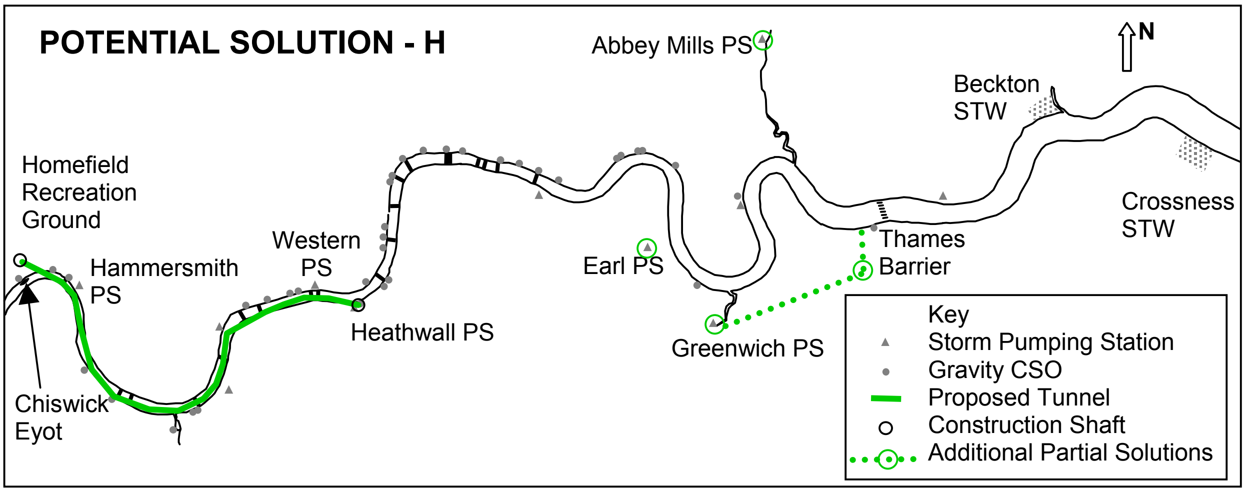
Intervention	Low+
Volume (Mm^3)	0.66
Diameter (m)	9.0
Ave pump rate (m^3/s)	5.5
Max Power rating (MW)	4.5

A reduced pumping and hence treatment rate have been considered appropriate for this option to minimise the space required for the treatment plant. The maximum draindown time would be approximately 34 hours for the full volume. The nineteen CSOs intercepted by this tunnel represent approximately half of the total spill volume to the river.

This potential solution could be considered as follows:

1. The first phase of potential solution A, completed at a later date, or
2. A complete solution augmented by other improvements such as screening plant for Earl PS, Greenwich and Charlton and treatment improvements at Abbey Mills.

Figure 24 - Potential Solution H



7.2 Reviews of Potential Solutions

The key conclusions of the Technical Studies have been used, extrapolated where appropriate, to review each potential solution. These reviews, which include a list of key features and summary discussion, are included below. A specific and detailed study of potential solution F, Screening at Individual CSOs, was carried out. The report for this study is included in the appendix and a summary of that report is included below.

7.2.1 A: Storage

7.2.1.1 Key Features:

- Consistent diameter continuous tunnel to provide storage of intercepted flows and transfer to treatment.
- For maximum and medium levels of intervention the main tunnel would be of sufficient diameter to avoid the choking effect upon filling. The tunnel diameter for the low level of intervention should be just sufficient to avoid this effect.
- Land acquisitions are limited to that required for shaft construction sites (retained in part for permanent operational access), treatment site and construction access for the interception structures.
- Treatment plant located adjacent to existing sewage treatment works to reduce environmental impact and to facilitate secondary treatment if required.
- Treatment stream would incorporate screening, enhanced primary treatment (Deep Bed Filters) and secondary treatment (Submerged Aerated Filters) to draindown flow rates of up to $10m^3/s$. Draindown rates in excess of $10m^3/s$ would receive screening and enhanced primary treatment only. However, an overall high BOD reduction can be expected.
- Controlled and relatively constant pump-out rates would reduce the power supply capacity to practical levels and reduce the treatment plant capacity required.
- The treated discharge to the river would be over an extended period of at least 24hours to further assist the capacity of the river to accept a low level of polluting flow.
- A flushing regime based upon plugs of river water would be required to remove accumulated sediment from the storage tunnel.
- Screenable solids removal and BOD reduction.
- The storage of intercepted flows for transfer to treatment is a typical strategy adopted for major schemes of this nature throughout the world.

7.2.1.2 Discussion of Potential Solution

Based upon the conclusions and recommendations of the technical studies it has become clear that the strategy of intercepting CSO flows to storage (A) represents the most appropriate approach to meet the required objectives as it consistently invokes the least technical challenge. It is also the strategy that is normally adopted for the interception and treatment of storm flows (combined or separate) for major schemes of this nature throughout the world.

The CSO flows would be intercepted, detained within the tunnel and pumped out at a controlled rate to treatment. This pump out rate can be optimised to reduce the capacity of the pumping plant, power supply and treatment plant conducive with making the tunnel available for the next rainfall event.

The single large diameter tunnel required for storage at the medium and maximum levels of intervention would have sufficient hydraulic capacity to absorb and distribute the flow without choking thus ensuring a stable filling process. However the diameter required for storage at the low level of intervention may suffer from choking during the more extreme events.

For the medium and maximum levels of intervention the main tunnel diameter has an important advantage for the construction of the interconnection tunnels. This enables the tunnelling machine to be launched from the main tunnel. This approach eliminates the requirement for construction shafts within the river and reduces the size of drop shaft at the interception structure.

For the low level of interception the main tunnel diameter would be too small to facilitate the launch of the tunnel machine. Therefore it would have to be launched from the interception structure. This would require larger drop shafts and increase the construction area required for the interception structures, most of which would have to be in difficult and confined locations. It may also not be possible to recover the tunnelling machine via the main tunnel for the larger interconnecting tunnels. Therefore reception shafts would be required to be constructed within the river. These factors add considerable cost to the low level of interception, which may make it a less favourable solution.

Flushing through accumulated sediment by a process based on pulses of river water seems feasible.

The economies associated with the construction of a single large diameter tunnel realise storage volume at a much lower overall rate of expenditure than other underground storage structures such as large diameter shafts or tanks. The only cheaper method of storage provision is the utilisation of open, earth-bunded reservoirs, which are not appropriate for densely urbanised environments.

The draindown pumping station and treatment plant could be located adjacent to the existing sewage treatment works at Crossness. This approach would minimise the impact on the urban environment. A treatment stream to level 3, screening and enhanced primary treatment would be appropriate for the pump-out flows for all levels of intervention. The reduced pump-out rate for the low level of intervention or extended duration of pump-out for higher levels could facilitate secondary treatment to improve BOD reduction.

Location of the storm flow treatment plant adjacent to the existing works is essential to maintain the secondary treatment processes between rainfall events. It is also much more likely to obtain planning permission and to facilitate optimisation of operating costs.

A summary of the main benefits of this potential solution, based on typical annual volumes is described in *Table 14*.

Table 14 : Summary of Solution A Cost Benefits

Intervention Level	Annual volume (Mm^3)		Screenable Solids (t)		Typical Annual BOD (t)			
	Intercepted	Bypass	Intercepted	Bypass	Intercepted	Return	Bypass	Total
Maximum	12.20	0	4880	0	854	165	0	165
Medium	11.82	0.38	4728	152	827	149	26	175
Low	9.92	2.28	3968	912	694	69	160	229

7.2.2 B: Transfer

7.2.2.1 Key features

- Up to 9.0m diameter collector transfer tunnel capturing all CSO outfalls between Chiswick and Woolwich.
- Pumped out for collective screening at a single downstream point of discharge.
- Cumulative peak flows could be 240m^3/s for maximum level of intervention.
- 100% option would have capacity to intercept all predicted flows up to a 20 year event.
- Overall tunnel size and annual energy consumption are similar to those for Option A.
- Massive standby power capability needed for peak flow pumping over brief and rare periods.
- Benefits are all aesthetic, no reductions achieved in BOD.
- Captured 1st flush would be returned straight back to river for moderate and larger events.
- Major single point discharge could create devastating impact on ecology, and a potentially serious navigational hazard to river craft.
- The application of the minimum tunnel diameter to prevent choking gives a tunnel volume, which nearly equates to that required for potential solution A, thus bringing into question the fundamental operating principle of transfer.
- Land acquisitions are limited to that required for shaft construction sites (retained in part for permanent operational access), screening plant site and construction access for the interception structures.

7.2.2.2 Discussion of Potential Solution

This transfer option would work on much the same principle as most storm relief sewers. The CSO flows would be intercepted and carried downstream to a very high capacity pumping station and screening plant in the Woolwich area, where collective discharge of screened flows would be returned to the lower reaches of the river. Hence while all levels of intervention would effectively address the screenable aesthetic element, they do not resolve the overall river quality / BOD problem to any significant degree.

The design originally envisaged a tunnel of varying diameters, increasing in increments downstream to cope with cumulative inputs en route. However, subsequent hydraulic studies have highlighted major risks relating to the issues of air entrapment, choking of flows and potentially explosive release of gas. The problem is particularly pertinent to this option due to the higher flow rates within the system.

Two recommendations have been made to avoid these problems:

- A secondary conduit with associated intermediate purge chambers is constructed above soffit, along the full length of the main transfer tunnel for the controlled escape of air. This additional feature has not been considered because of the cost and complexity of construction.
- That any such tunnel is a minimum of 6.0m - 9.0m in diameter. This would result in the tunnel for even the low and medium levels of intervention, becoming close in size to that needed for Option A. Hence what was originally conceived as a transfer tunnel could be considered and operated as a storage tunnel, thus negating the requirement for high capacity pumping and screening plant.

Even without the application of this minimum diameter requirement the transfer tunnel has an inherent volume. It could be possible to consider the retention of lower volume storm events and pump out slowly for treatment, thus marginally reducing pollution load to the river for these events. This additional function has not been included, as it only relates to low volume events, which do not typically cause a pollution problem for the river.

For moderate and larger storm events the transfer approach becomes increasingly flawed, as any first flush capture would be promptly returned to the river as a concentrated single point discharge of high BOD flow. This contradicts the logic of dispersing CSO discharges over a wider area to reduce their environmental impact. It would probably have devastating consequences for general ecology in the eastern end of the river, and pose a significant hazard to navigating river traffic during times of peak discharge. As a recent example a medium sized craft was struck broadside by the pumped discharge from an existing storm water pumping station and sunk. Obviously larger discharges could have greater effect.

The overall annual energy consumption for this option is similar to that required for Option A as this is a function of the total volume of storm flow intercepted and the pump lift. However the reduction in overall tunnel length, and small savings in tunnel diameter come at a high price. The need for rapid processing of flows to maintain optimum serviceable capacity in the system, carry massive requirements for peak pumping and screening plant capability.

Power requirements could vary between 75 - 350MW depending on the required level of intervention. This 1:5 power increase between minimum and maximum intervention, equates to predicted peak flows, (see Table 15 below). Provision of this peak power capacity will be expensive and challenging, particularly as it would equal that of some of the larger power stations in the country. A dedicated supply from the grid would prove virtually impossible to achieve or may only be provided at absurdly prohibitive cost, even if power supply companies were prepared to entertain such matters.

On the other hand, on site generation for this peak power capacity would entail the construction of a large power station. The infrequent or standby nature of the power requirement may suggest that generating capacity could be redirected and available to other customers when not called for on the Tideway. In reality, there are few customers whose business operation & production needs could be shut down sporadically at short notice or fluctuate inversely to weather conditions.

On the issue of the location of a single processing site at the eastern end of the tunnel this option may score better than the centrally located multiple site options such a C, D & F. Although available sites currently exist to accommodate the necessary power and screening plant in the Woolwich area, this would constitute the largest single inner London processing facility required for any option.

See *Table 15* for summary of solution B Cost Benefits.

Table 15 : Summary of Solution B Cost Benefits

Solution - Intervention Level	*Screenables reduction*	*BOD reduction*	*Energy pa. (MW)*	*Volume (Mm3)*		*Peak Q (m3/s)*
				Original	*6m min*	
Maximum	100	0	7600	1.38	1.54	240
Medium	97	0	7400	0.69	0.85	120
Low	81	0	6200	0.23	0.79	50

The first volume figure quoted for each level of intervention is based on the original diameters. The second set of volume figures are based on the smallest diameter, taken as 6m to avoid the risk of choking. These figures are included to show the storage volume that could be realised should the tunnel be operated as a storage conduit rather than one based on transfer.

Potential solution B, as with all the big tunnel options, carries major health and safety risks. As a consequence of the tunnel depth being in excess of 80m at the lower end, in soft ground and beneath the river, the risks would be focussed primarily around the construction and access for periodic maintenance needs.

In conclusion this option scores poorly from a Cost/Benefit point of view, particularly when contrasted with the likes of potential solution A. This can be summed principally under the following 3 issues: The ability to address the screenings objective only, its detrimental environmental effect on the eastern Tideway, and the massive operational costs of standby power and screenings processing.

7.2.3 C: Multiple Screened outlets

7.2.3.1 Key Features:

- A collection and distribution tunnel, intercepting all CSO outfalls between Chiswick Eyot and Charlton.
- Problems associated with tunnel choking mean the minimum distribution tunnel diameter will have to be at least 6m, irrespective of level of intervention, to facilitate interception of peak flows without choking. This is needed to avoid uncontrolled and un-screened bypass to the river.
- The large diameter distribution tunnel, which would be required to prevent choking, would have a large volume. This would tend to smooth the accumulated peak flows and make the utilisation of the maximum pump-out rates very rare.
- The distribution tunnel connects 8 high capacity pump, screen and discharge installations. These would be spaced between Hammersmith and Charlton, positioned more closely to the larger outfalls.
- All sites are in urban areas on high value land, planning constraints will make it very likely that plant will have to be located underground.
- The intercepted flows are screened, thus removing sewer litter, however BOD will not be reduced.
- For the maximum level of intervention each of the 8 installations may be required to cope with flows of 40 m3/s requiring 30MW of power, giving a total of 240MW. This maximum capacity would only be required for rare events. This maximum capacity would be reduced for the medium and low levels of intervention.
- Huge quantities of screenable solids will have to be removed from these sites in central London. The current estimate is 4880 tonnes per year.

The multiple screened outlet design acts as a distribution manifold for the intercepted CSO flows along the Tideway. Flows are carried to the nearest of 8 pumping stations where they are pumped through screening plant and then discharged to river.

Initially three levels of intervention were considered. However the potentially smaller tunnels for the lower levels of intervention have been found to be technically impractical due to the choking effect. A stable filling process is a critical factor for the design of a scheme, which is normally empty. The intercepted flows will displace air, which would be expelled through the shafts. If the hydraulic capacity of the tunnel is too small there is a risk of choking, rendering the system incapable of intercepting the CSO flows and thus bypassing them to river.

Modelling of the filling process is a very complex procedure to gauge the accumulated peak flow within the distribution tunnel. It is dependant on the spatial variation of rainfall, intensity and duration. These varying parameters provide so many flow possibilities that a relatively large diameter distribution tunnel, of about 6m, would be required as a minimum to accept the peak flows without choking and causing uncontrolled and unscreened bypass to the river.

This minimum 6m-diameter tunnel requirement has a significant volume, which would attenuate and reduce the accumulated peak flows in the tunnel itself. This would enable the pump-out rates to be reduced to such an extent that provision of highly intrusive and expensive pump and screening plant within central London become of dubious value. The distribution tunnel for this potential solution, at all levels of intervention, tends to become very similar in size to that required of the storage tunnel for potential solution A, which does not require such installations in central London.

Captured flows are pumped from 8 stations along the tunnel, each with a design capacity of 40 m3/s. Drum screens will be used along with the associated screening handling plant. The screenings handling plant will wash and dewater the screenings so as to minimise the cost of disposal to landfill. They will be collected and transferred by skips. The required footprint for the entire process will be approximately 100 x100m (1ha).

These 8 sites will be located in urban areas of high land value. As such large sites are required, open spaces have been targeted, but due to the restrictive environmental and planning requirements it is likely that most of these sites will have to be underground. This may allow the original land use or planning requirements to be reinstated.

Being underground presents a number of problems:

- Vast quantities of soil will have to be transported out of central areas of London, causing much disruption during construction.
- Large numbers of utility supplies will have to be relocated.
- Being so deep, each site will have to have 2 pumping stations, one to lift flows from the distribution tunnel, and a second to lift flows from the screening plant to discharge to the Thames.
- Balancing the pumped inflows and outflows, with only the screening plant as buffering volume, will be complex.
- Added costs of construction and operation.
- The screenings containers will require a sophisticated system to handle and raise them to ground level.
- Odour control in such sensitive locations will necessitate an air lock for the skip lorry and an effective odour control plant.

The annual power requirements of this option are 3800 MWh pa, similar to that of the partial solution A. It is likely that the attenuating effect of a larger diameter tunnel reduces peak flows thus reducing the required plant capacity. It is conceivable that this balance between attenuation and pump out rate could be optimised to reduce power costs.

Each site will require a supply of 30MW, which may not be possible at every site from the grid supply without huge costs. A standby power supply would also be required. It is unlikely that any onsite generation could be exported, as few customers would be prepared to have supply cuts at short notice, during times of rain, when demand from other parts of the network would be increased.

Option C with maximum intervention removes only screenable solids from the CSO flow. This equates to 4880 tonnes per annum. The option does not reduce the BOD load to the river, and in fact concentrates 50 spill points to 8. This has the effect of concentrating discharges, and potentially increasing local DO sags.

Table 16 summarises the main Cost Benefits of Solution C.

Table 16 : Summary of Option C Cost Benefits

Solution Intervention level	Reduction Screenable Solids %	BOD Reduction %	Energy Consumed (MWh pa)	Total Capacity m3/s
Maximum	100	0	3800	320
Medium	97	0	3700	160
Low	81	0	3100	64

In conclusion this solution realises less benefit to the river as only sewage litter removed. The required tunnel tends to become similar to that required for the storage tunnel of potential solution A. The solution is also based on the construction of high capacity screening plants in urban areas of high value land making the cost of acquisition and development too expensive. It is also likely that environmental and planning restrictions will prevent such installations being constructed.

7.2.4 D: Multiple Screened outlets with storage

7.2.4.1 Key features:

- This potential solution is essentially that of C with an additional tunnel to intercept and store the first foul flush.
- The twin tunnels intercept all CSO outfalls between Chiswick Eyot and Charlton.
- First foul flush captured in the storage tunnel and taken for treatment at dedicated works based at Crossness STW.
- When the storage tunnel reaches capacity, the distribution tunnel channels flows to 8 high-capacity pump, screen and discharge installations.
- Problems associated with choking in the storage tunnel mean the minimum diameter should be not less than 6m.
- This makes the first flush tunnel the same size as that required for the storage tunnel for A at the low level of intervention. The distribution tunnel and pump and screen outlets would therefore be of very dubious value.
- The 8 pump and screening sites are in urban areas on potentially high value land, with planning constraints making it likely that plant would have to be located underground.
- This option could be considered to remove all screenable solids and the BOD loading of the first flush.
- The implementation of twin tunnels would be very expensive.

This option is essentially option C with the addition of a storage tunnel to capture the first foul flush for treatment before being returned to river. Depending on quality, flows can be either put into the distribution tunnel or the storage tunnel, enabling optimisation of treatment.

The storage tunnel is designed to intercept the peak flows, where the highest BOD content is present. As with option C it is impossible, at this stage, to accurately estimate the accumulated peak flows. If the hydraulic capacity of the tunnel is too small then choking will occur and the first foul flush will not be caught. To ensure against this situation the minimum diameter of the tunnel should be 6m, making the storage tunnel alone comparable to Option A.

A dedicated treatment plant would be constructed at Crossness sewage works, capable of treating flows at 12.7m3/s. The process would be an enhanced primary treatment. Flows would then be discharged straight to the Thames. This process would remove approximately 40% of the BOD load from any flows captured in the storage tunnel.

In order to draindown the storage tunnel and supply the treatment works, a pumping station would be required of approximately 11MW for the maximum level of intervention. The pump rate would be approximately $10m^3/s$ and is based around the optimum design parameters of the treatment works. However at this draw down rate, solids will settle out within the tunnel. In order to remobilise these solids the tunnel will have to have to incorporate a flushing system, which would most probably be based on pulses of river water.

It is likely that the distribution tunnel would not have to intercept the peak flows, and therefore its diameter may be subject to the minimum required to prevent choking. This matter would have to be investigated in greater detail. However the pump and screening installations will remain the same, in order to cope with flows from the larger storms. Again flows caught in the distribution tunnel will only have screenable solids removed before being pumped to river.

All problems faced by option C will apply to the distribution element of this option. Eight similar sites are required between Hammersmith and Charlton. As with option C environmental and planning restrictions will be strict and sites will have to operate underground.

Operation and maintenance costs will be far greater than for many of the other options. This is mainly due to the upkeep of 2 deep tunnels, 9 major pumping stations, 8 screenings handling sites and a treatment works. On top of this, it has the third highest capital cost of all the options.

Table 17 summarises the main Cost Benefits of solution D

Table 17 : Summary of Solution D Cost Benefits

Solution Intervention level	Reduction Screenable Solids %	BOD Reduction %	Energy Consumed (MWh pa)	Distribution tunnel Capacity m3/s	Storage tunnel Volume (Mm3)
Maximum	100	33	6900	320	0.93
Medium	97	27	6200	160	0.48
Low	81	17	4800	64	0.19

In Conclusion this potential solution is basically option C with a second tunnel to store the first foul flush. This stored flow would be passed to treatment (based on enhanced primary treatment) and discharged to river. Although this solution will afford some reduction of polluting load it suffers from the same problems as option C with the added capital cost of a second tunnel and treatment works, and the associated operational and maintenance costs.

When taking into account the required minimum diameter of the storage tunnel to prevent choking, it in itself becomes very similar to the requirements of option A, rendering the need for multiple pumping and screening outlets superfluous.

7.2.5 E: Storage Shafts

7.2.5.1 Key features

- Localised screening and storage in shafts along the river foreshore between Hammersmith and Charlton.
- Static self-cleaning screens located at the top of each shaft. 70% of intercepted flow is screened and passed to river and the remaining 30% carries screenings to storage in lower section of shaft.
- The stored flow is pumped via draindown tunnels to treatment works east of London, adjacent to Crossness.
- Operational costs principally comprise of draindown pumping, mixing, treatment and access for maintenance.
- Shaft construction costs show poor economies of scale when compared with that of tunnels.
- Complex array of ancillary collector tunnels and draindown tunnels required.
- Each shaft would incorporate pumping plant and powered mixing units required for re-suspension of sediments. Access to this plant will be problematic.
- Short-term impacts on foreshore & river frontage could be significant, particularly for western areas.
- High level of aesthetic screening and capture of first flush BOD.
- Not viable as a total solution, but could form part of a wider combined package.
- The operation of such a potential solution is complex, hence the scope is difficult to determine in outline, without carrying out a more detailed appraisal.
- Capital costs are very high.

7.2.5.2 Discussion of Potential Solution

Screening and Shaft Storage Option E may be considered as a more refined version of the Multiple Screened Outlet Option C, without the difficulties of congested land based screening plant location. The concept would utilise static self cleaning screens located at the top of large diameter storage shafts positioned along the foreshore of the river to avoid land based disruption.

70% of the flow would be screened and discharged back to the river. The remaining 30% of flow would be used as forward flow to wash the screens and to convey the captured solids for temporary storage in the shaft below. Once the storage volume is full further flow would bypass untreated to the river. After a storm event, the stored flows and concentrated screenings would be pumped out to a collector tunnel for transfer and treatment at Beckton or other suitable downstream STW location. The maximum level of intervention for this option would remove all sewage litter and reduce the overall BOD load by 30%. This level of BOD capture is low when compared with the full treatment options, however in conjunction with the proposed AMP4 treatment standards an overall 30% capture level may well be an adequate objective for the majority of storm events.

The level of intervention is determined by the total provision of storage volume. To provide the maximum level of intervention for a 20-year storm, a total of 102 shafts would be needed at various locations along the river, giving a total storage volume of 1.28Mm^3. Requirements for lesser intervention levels are tabulated below. Storage needs have been based on the use of a 25m diameter / 25m deep shaft unit or multiples thereof. 20 sites have provisionally been identified for shaft locations on the basis of ranked CSO discharge volumes. The majority would be clustered around the larger CSO sites such as Hammersmith, Heathwall, Deptford etc, where multiple shafts systems would concentrated at key sites.

A complex array of collector and removal tunnels would be required to transfer flows to and from the individual shafts. A main transfer tunnel of minimum 6.0m diameter would then collect and convey captured flows for final treatment. Each shaft would require its own powered mixer unit to keep sediments in suspension and draindown pumps. Major pumping facilities to complete the draindown arrangement will also be required, plus a further array of tunnel linkages for maintenance access. These complexities are compounded by the considerable number of shafts needed to secure a reasonable level of benefit to the river.

Whilst novel this approach is considered technically feasible and would facilitate incremental implementation. However such a relatively complex system is as yet untried on this scale anywhere in the world. In view of this fact significant development work would be required before considering adoption on a wider scale.

The foreshore location for screening plant would clearly avoid many of the disruption and difficulties otherwise associated with shore based land acquisition. However, the foreshore itself is an area of considerable ecological sensitivity, and one for which detailed Environmental Impact Assessment would be a critical early step in defining the full effects of such works. The main impacts would be temporary in nature, as it is envisaged the finished shaft structures could be completely concealed beneath the riverbed.

Riverside frontage rights would remain an area of considerable conflict where prestige water front locations overlook the proposed sites. In the absence of any significant above ground structures, objections would probably be centred on the temporary construction phase and the permanent maintenance access structures.

Off line storage shafts have been widely used for local flood relief schemes where smaller volumes are concerned, as they can represent good value for storage when compared with small diameter tunnels. But the economies of scale for construction of larger diameter tunnels are considerably better than for shafts, which make this approach substantially more expensive than a tunnel storage option.

Operational costs are difficult to estimate for such a complex operation. Average annual energy consumption has been estimated to be lower than some other potential solutions; the actual full operating costs of maintaining such a diverse array of plant are likely to be much higher. This potential solution also ranks as the second most expensive in construction terms.

Table 18 summarises the main cost benefits of solution E

Table 18 : Summary of solution E Cost benefits

Solution - Intervention Level	Screenables reduction	% BOD reduction	Energy P.A. (MW)	Storage Volume (Mm3)	No. of Shafts
Max 100%	100	12	1300	1.28	102
Med 50%	97	11	1000	0.66	54
Min 20%	81	10	850	0.34	28

In conclusion this option has limited attraction for the following main reasons. It is not appropriate as a total solution, particularly at maximum or medium levels of intervention, due to the number of shafts and complexity of ancillary network required. It offers limited treatment of the BOD problem in only capturing 30% of total flows throughout any storm event. It is one of the most expensive options on capital grounds and could be complex and problematic to operate, again due principally to the number of shafts involved. However were the number of site to be considerably reduced, it could form part of a wider phased multi approach solution.

7.2.6 F: Screening at Individual CSOs

7.2.6.1 Key Features

- Approach based upon the provision of screening plant for each individual CSO
- Virtually all gravity CSOs would have to be pumped to compensate for the additional head loss associated with the screening plant.
- All existing storm pumping stations would have to be remodelled to maintain peak flows at the additional head.
- The location of screening plant relative to the CSO would be either at the point of outfall, upstream of the outfall or off-line.
- Only three sites are considered viable for this approach.
- Subject to land acquisition, planning and environmental constraints a further ten sites may be considered potentially viable.
- Provision of screening plant at the remaining 36 sites would cause extreme disruption at exorbitant cost and is therefore not considered viable.
- There are 6 CSO sites where the flows are either very low or zero, which may be considered for sealing off.
- Most CSOs are “end of pipe” outlets or there is no carry forward flow, therefore conventional CSO screening plant is not viable.
- Inlet works type screening plant arrangements must be adopted. These entail screenings treatment, handling and disposal plant.
- Screening plant sites will have a severe impact on the urban environment. Site footprints are quite large and most would have to be constructed underground for planning and environmental reasons.
- The cost of compensation, demolition, diversion, land acquisition etc for this potential solution will dwarf the actual construction costs of the plant required.
- It cannot be considered a complete solution as the provision of screening plant can be considered viable for only a very few sites.

7.2.6.2 Discussion of Potential Solution

The implementation of screening for an individual CSO is constrained by the following factors:

- The location and arrangement of the CSO discharge
- Hydraulic effects on existing sewerage system
- Capacity of plant required
- Planning and environmental restrictions
- Land availability
- Impact on existing third party assets

The installation of screening plant could be considered immediately adjacent to or upstream of the existing discharge (but downstream of any major inflows) or potentially diverted a short distance off-line. This would be dependent upon several local factors for each individual CSO.

Hydraulic effects are quite critical, as the installation of screening plant would incur head loss which would increase surcharge levels in the existing sewerage system leading to increased flooding. Diversion of flows to off-line screening sites would incur even more head loss. The pumped CSOs could accommodate this increase in head by up rating of the pumping plant and remodelling of the existing stations. Gravity CSOs are most sensitive to this effect; most if not all would require the addition of low head/high flow pumping plant to compensate. This additional pumping would add to the overall space requirements.

The plant capacity required is dependent upon the peak discharge rate, which varies for each CSO. The overall site would have to accommodate the following plant; screening, screenings treatment and handling, disposal skips, transport access, pumps, wash water storage and booster equipment, skip handling, odour control, switchgear and control equipment. In effect this comprises the inlet works treatment processes for a sewage treatment works. It is worth noting that a significant number of the CSOs would require plant of a capacity much higher than the inlet works of Beckton STW itself.

The vast majority of these potential screening sites would be in densely urbanised areas. It is anticipated that odour, access issues and overall appearance would be critical requiring the whole plant and loading areas to be covered by a suitable building. Most areas are fully developed so that land would not be freely available and it is also very likely that the construction of such plant will be contrary to the planning designations in most areas.

It is therefore considered that planning permission would not be forthcoming for the vast majority of screening plant sites. This conclusion is based upon the opinion confirmed by Queen's Counsel, who advised that the likelihood of gaining planning permission for such a plant at Western PS would be about 25%, even with the addition of prohibitively expensive mitigation measures.

Many of the CSOs are located adjacent to or under major transportation arteries or large buildings. The disruption caused by the construction of screening plant at these locations is likely to prove unacceptable. Compensation costs would dwarf the cost of construction.

Regarding this potential disruption, the viability of sites for implementation of screening plant for each individual CSO was assessed and summarised in Table 19.

Table 19 : Solution F - viability of sites

Category	Number of sites
NF - No Modelled Flow	6
0 - Extreme Disruption	19
1 - High Disruption	17
2 - Potentially Viable	10
3 - Viable	3

The 3 most viable sites are: Acton, Hammersmith and North Woolwich PS, which are all existing operational sites with available land.

The 10 potentially viable sites are: Stamford Brook, Isle of Dogs PS, North Woolwich PS, West Putney, Frogmore SR, Falcon Brook PS, SWSR, Heathwall PS, Earl Storm, Deptford Storm Discharge and Charlton Storm. With further investigation it should be possible to improve the viability of some of these sites, particularly Charlton Storm by development of an existing site owned by Thames Water, Heathwall PS by acquisition of adjacent land and Earl Storm PS by acquisition of nearby commercial land.

The strategy of screening at individual CSOs cannot be considered as a complete solution as only a few sites could be accommodated without extreme disruption. The capital cost for complete implementation of this option is over £11B, of which over £7B represents land acquisition, compensation, diversion and disruption costs.

The implementation screening of a select number of CSO sites has been considered as additional partial solutions to augment potential solution H, refer report Variations on H.

7.2.7 G: Displacement

7.2.7.1 Key Features

- The concept of a permanently full transfer tunnel was investigated in an attempt to reduce the energy penalty of pumping from great depth.
- This approach suffers from severe hydraulic challenges which perversely can only be overcome with high energy pumping.
- Transfer capacity of the displacement tunnel is limited by the hydraulic gradient, which can be made available. Pump assisted transfer would be required for moderate events to prevent untreated bypass to the river at the interception structure.
- The tunnel has an inherent large volume and will always be full. Therefore regular turnover of this volume would be required to prevent septicity. This could be achieved by using river water at high tide to flush the static volume through.
- The mass of static flow will have a slow response to any intercepted spill flows due to its massive inertia. Pre-emptive drawdown by pumping would be required.
- A large area of low-lying land would be required to receive flows. Constructed wetlands were considered ideal as treatment could also be provided.
- Conventional storage tanks would not be appropriate, as these would require pumping to empty.
- Such a large area of land at the appropriate level is not available.
- Construction of these wetlands would entail massive earthworks.

The strategy of displacement (G), based on a full conduit, was developed in an attempt to overcome the high-energy cost associated with pumping from depth. It was hoped that it could represent a more sustainable and less energy demanding solution.

Whereas this concept has been used successfully to intercept and transfer continuous foul sewage flows, for example the Harbour Area Treatment Scheme (HATS) in Hong Kong, the intermittent nature and the high peak transfer rates of storm flows associated with intercepting the Tideway CSOs leads to many hydraulic challenges. These challenges can probably be met, but only at the expense of extensive pumping regimes, which incur an even greater energy penalty.

The four essential elements of these hydraulic challenges are:

- Daily flush to turn over the body of flow in the tunnel to prevent septicity and to flush through the volume of intercepted storm flows. This could be achieved by gravity flow using a tidal flush of river water introduced at high tide to the western end of the system, provided that the discharge at the eastern end is very low-lying. However, velocities will not be high enough to re-suspend any accumulated sediment.
- Regular pump assisted flushing to re-suspend sediment. This high rate flushing (approximately $150m^3/s$) would represent very large volumes of flow (approximately $2Mm^3$) with a high polluting load and as such could not be discharged direct to the river.
- Pump assistance for moderate events where the peak accumulated flows exceed the capacity under gravity flow.
- Pre-emptive drawdown of the system to overcome the slow response due to the high inertia of the weight of the body of flow in the tunnel, which is in excess of 2M tonnes.

It has been calculated that the annual energy consumption for this potential solution would be over three times greater than for the potential solution based on storage. This is mainly due to the energy required for pump assisted flushing.

Conventional treatment cannot be considered viable for this potential solution because of the high flow rates and large volumes associated with pump assisted flushing. Hence the use of a large area (of at least $4km^2$) of constructed wetlands was considered to be the most appropriate. From the findings of the land use surveys it is most unlikely that a suitable location could ever be acquired.

This potential solution was only investigated for a 9m-diameter tunnel, which would equate to the medium level of intervention. Increasing or decreasing the pump assistance has been used to assess maximum and low levels of intervention respectively. The potential benefits are summarised in *Table 20*.

Table 20 : Summary of solution G Cost benefits

Intervention Level	Annual volume (Mm^3)		Screenable Solids (t)		BOD (t)			
	Intercepted	Bypass	Intercepted	Bypass	Intercepted	Return	Bypass	Total
Maximum	12.20	0	4880	0	854	342	0	342
Medium	11.82	0.38	4728	152	827	331	26	357
Low	9.92	2.28	3968	912	694	278	160	438

This potential solution cannot be considered viable due to the complex hydraulic control, high-energy consumption and non-availability of a site for the constructed wetlands.

7.2.8 H. West London Option

7.2.8.1 Key Features

- Storage tunnel based upon the first third of potential solution A
- Potential first phase of complete solution based on interception to tunnel storage.
- Intercepts 19 CSOs between Chiswick Eyot and Heathwall PS.
- These CSOs represent approximately half of the total spill flow to the river.
- Provides benefit to the most sensitive part of the river
- The remaining CSOs would discharge as existing arrangements
- Pumping, screening and treatment plant required on large site adjacent to Heathwall PS
- Land acquisition required. Current land use designation is commercial, but will have reasonably high value and compensation costs will be incurred to relocate existing commercial tenants.
- Potential planning and environmental restrictions would ensure all plant would have to be contained within buildings.
- Large site required for enhanced primary treatment.
- Secondary treatment is not appropriate as remote from existing sewage treatment works
- Screening removal and BOD reduction for western reach of the river, but no improvement to eastern section of the river unless combined with other works

7.2.8.2 Discussion of Potential Solution

As this storage option is basically a shortened version of A, it has similar advantages. The main tunnel will not choke during filling so that the peaks of the spill flows will be intercepted. This reach of the river is recognised to be the most sensitive so early implementation of this option would realise early delivery of benefit to the river. This first stage would intercept 19 CSOs, which represents over half of the total spill flow to the river.

The actual benefit to the river could be assessed to optimise any future extension. The rest of the storage tunnel could be constructed, if required, in later years thus deferring expenditure. Should the storage tunnel be extended the treatment process would be transferred to the eastern end, probably adjacent to Crossness STW. The treatment plant at Heathwall PS could then be abandoned and the land released for future development.

There are disadvantages to truncating the tunnel to finish adjacent to Heathwall PS, listed below:

1. Additional land is available adjacent to Heathwall PS, however this will be limited by the cost of acquisition and planning and environmental constraints. The pumping rate will have to be restricted thus extending the draindown time particularly for high volume interceptions. The treatment process will have to be of high intensity to minimise area required. These issues will add to the complexity and sensitivity of operation.

2. CSOs downstream of Heathwall PS would not be intercepted at all and would continue to discharge to the river as present.

The potential benefits are summarised in Table 21.

Table 21 : Summary of solution H Cost benefits

Tunnel Diameter	Annual volume (Mm^3)				Screenable Solids (t)		
	West			East	West		East
	Total	Intercepted	Bypass	Total	Intercepted	Bypass	Total
8m	6.71	5.60	1.11	5.49	2240	444	2196
9m.	6.71	5.91	0.80	5.49	2364	320	2196

Treated flows for BOD are shown in Table 22.

Table 22 : Solution H - Treated flow volumes for BOD

Intervention Level	BOD (t)				
	West				East
	Intercepted	Return	Bypass	Total	Total
8m dia.	392	235	78	313	384
9m dia.	414	248	56	304	384

Intercepted represents BOD load of flow captured in the west storage tunnel
Return represents the BOD load of treated flow returned to river in west
Bypass represents the BOD load of screened and bypassed flow to river in west
Total represents the total BOD load passed to the river in west
East Total represents the total BOD load passed to the river in east section.

Despite the difficulties listed above, implementation of this solution as the potential first phase of a complete scheme could represent the best compromise at a reasonable level of investment, particularly if additional improvements to the existing sewage treatment works could be implemented in parallel.

The implementation of screening of a selected few of the major outfalls to the east has been investigated as additional partial solutions to augment this solution, refer report Variation on H.

7.3 Risk Assessment & Contingency

The potential risks associated with the implementation of solutions were considered in two main parts, Technical Risks and Overall Project Risks. The methodologies adopted were based on qualitative assessments; these and the results are described below. The assessment of contingency value was made on the basis of a review of project risk registers compiled for recent projects involving substantial underground works undertaken by Thames Water.

7.3.1 Technical Risk Assessment Methodology

The technical risks associated were investigated at two stages by way of Technical Risk Registers. The first was carried out by as part of the Tunnelling Study by Halcrows and included the five potential options A to E at the three levels of intervention. Option G was not considered because it had not been identified at this stage. However the potential risks can be considered to be similar to that of A (Medium) as the tunnel diameter and depths are similar. Halcrows did not consider option F, as it does not involve significant underground works.

Faber Maunsell carried out the second as part of the Underground Works and Settlement study and was based on a more detailed consideration of option A (Medium). An individual risk assessment for option H was not carried out as the risks could be inferred from the exercise carried out for option A (Medium).

The risk assessments were prepared based on consideration of the following generic risks:

- Tunnel Construction
- Shaft Construction
- TBM Operation
- Tunnel Operation
- Tunnel maintenance
- CSO Connections (construction)
- Ground Conditions

For each of these basic activities the associated hazards were identified together with a numerical estimate of likelihood and consequence as indicated in the table below:

Likelihood		**Consequence**	
Title	**Scale**	**Title**	**Scale**
Frequent	5	Catastrophic	5
Probable	4	Critical	4
Occasional	3	Serious	3
Remote	2	Marginal	2
Improbable	1	Negligible	1

The compound of these two numbers gives the risk rating for each hazard, which is summarised in the following table:

Score	**Actions**
17-25	**Very High Risk** – Not acceptable. Apply mitigation measures to eliminate or reduce risk
10-16	**High Risk** – Apply mitigation measures to eliminate or reduce risk
1-9	**Low Risk** – May be acceptable if all reasonably practical control measures are in place

The risk rating for each hazard was also re-assessed based upon the mitigation measures that could be employed to determine the residual risk rating.

These risk-rating scores enable a qualitative assessment to be made for each potential hazard item by highlighting the critical (high scoring) item. These critical items and the average risk rating score can also infer a general comparison of overall risk for each option. No attempt was made to determine a monetary value for individual potential hazards as it was deemed inappropriate at such an early stage in the risk assessment process.

7.3.2 Preliminary Technical Assessment

The results of this preliminary technical risk assessment were used as a qualitative means to consider the overall level of risk for each options, which was represented by the average risk rating. This was calculated from the sum of all the individual risk ratings and then divided by the number of risks considered for each option.

The average residual risk rating varied from 4.7 to 6.4, which implies an overall low level of risk for all the options. However certain individual high-risk issues for each option were also identified. In particular the high number of large diameter shafts required for option E was identified as a high-risk item that counts against this option.

On a more general basis the risk rating score was increased by factors such as main tunnel diameter and depth. Therefore option A tended to score marginally the highest technical risk, however no account had been taken at this stage of the overall project risks associated with disruption, planning and environmental constraints. It must also be noted that the hydraulic constraint of tunnel choking during filling had not been appreciated at this early stage. It is a reasonable assumption that this constraint would have had a significant impact on the results of this preliminary risk assessment for options B, C and D that were initially based on smaller tunnel diameters.

Correspondingly option A tended to score marginally the highest technical risk, however no account had been taken at this stage of the overall project risks associated with disruption, planning and environmental constraints. It must also be noted that the hydraulic constraint of tunnel choking during filling had not been appreciated at this early stage. It is a reasonable assumption that this constraint would have had a significant impact on the results of this preliminary risk assessment, particularly those options which were initially based on smaller tunnel diameters.

A comparison of the average residual risk ranking for options A to E at the medium level of intervention showed that at this early stage there was little to differentiate between them.

Option	**A**	**B**	**C**	**D**	**E**
Average Risk Rating	6.157	5.308	4.923	5.500	6.082

7.3.3 Option A (Medium) Technical Risk Assessment

A more detailed risk register was determined for Option A (Medium) based upon the preliminary technical assessment, but was adjusted to reflect the suggested construction methods and to include some potential issues that may impact on the project as a whole. This risk assessment highlighted several high-risk items and a few very high-risk items. Those items that scored 15 and above, before mitigation are listed below, together with their respective residual risk score following mitigation:

Risk Item	**Score**	
	Initial	Residual
Difficulties in obtaining insurance	20	9
Groundwater encountered during shaft construction	20	15
Removal of sediment from tunnel following storm event	20	16
Difficulties experienced steering the TBM	16	4
Disruption and impact of spoil disposal	16	6
Leakage of storm water from tunnel	16	3
High water pressure in aquifer	16	8
Unforeseen ground conditions	16	9
Construction site availability	15	6
HSE limit drive lengths	15	6
Inadequate power supplies	15	8

7.3.4 Overall Project Risk Methodology

The overall project risks for all the options, except H, were considered as part of a Technical Review Workshop held in October 2002. This review followed the substantial completion of the Technical Studies, carried out by the specialist consultants. Option H was under development at this stage. Although no individual risk assessment was carried out for this option the technical risks and overall project risks can be considered to be very similar to that of option A.

The workshop attendees included the members of the Solutions Group, Thames Water Operations representatives, several Senior Engineers specialising in the relevant disciplines and three senior peer reviewers from Thames Water Engineering. As the main areas of risk were already perceived to be associated with geology, land availability, planning and environmental constraints representatives of GCG and Cascade also attended.

Each option was considered against each of the specialist technical study areas, land, modelling and river quality. The qualitative scores were allocated on the following basis:

Rating	Description
0	No significant issues
1	Minor or moderate issue
2	Significant issue, difficult to resolve
3	Major issue or risk
4	Potential Show Stopper

7.3.5 Overall Project Risk Results

The scores were judgements based on an understanding of the principle conclusions and recommendations of the Technical Studies (as described in Section 8). With particular reference to the scores for river quality it is worth noting that this judgement was made prior to the river quality modelling work having been carried out and therefore represents an experienced view of the potential impact on river quality. The results of this qualitative assessment are summarised below and represent the collective view of the Technical Review Workshop attendees:

Opt	Specialist Area											
	Hyd	O&M	H&S	UGW	Smt	Tmt	Scr	Ppg	Pwr	Land	Mod	RQ
A	1	2	2	2	2	1	1	2	3	3	0	2
B	3	2	2	2	2	4	2	2	4	3	0	4
C	3	2	3	2	2	N/a	1	2	2	4	0	4
D	3	2	3	3	2	1	1	2	2	4	0	3
E	3	3	3	3	3	1	3	2	2	4	0	3
F	N/a	3	3	N/a	N/a	N/a	1	2	2	4	3	4
G	4	3	3	2	2	1	2	2	3	4	0	2

The key to the specialist areas is as follows:
Hyd Hydraulic Operation
O&M Operational and Maintenance issues
H&S Health and Safety issues
UGW Underground Works, construct ability
Smt Settlement and potential effects on sensitive structures
Tmt Treatment, viability of processes
Scr Screening, viability of process
Ppg Pumping, availability of appropriate plant
Pwr Power requirements, availability of supply
Land Land availability, Planning and Environmental constraints
Mod Modelling of flow and availability of data
RQ River Quality, perceived level of benefit to Tideway.

In this instance the allocation of score 4 is more relevant that the total score for each option in as much that Option A is the only option which does not include a potential show stopper, that is an issue that is so difficult or impossible to resolve as to make the option infeasible.

7.3.6 Determination of Contingency

As previously mentioned the risk registers were based on qualitative assessment and no monetary value was therefore ascribed. In order to determine an appropriate level of contingency at this stage previous risk registers for large projects involving underground works undertaken by Thames Water were reviewed. These risk registers had been compiled between the outline design and pre-construction stages of their respective projects. The methodology for these risk registers is based on a compilation of hazards together with an assessment of the likelihood including an estimate of the potential cost. A statistical analysis of this leads to an overall estimate of the potential extra cost that a project may be subject to.

Typically this value was found to be in the range of 25% to just over 30% of the budget cost (excluding any contingency values) for the project. It was therefore considered appropriate to adopt an overall contingency value of 30% for all the options considered in this investigation. EC Harris carried out an audit of the derivation of budget estimates and also considered that this level of overall contingency was appropriate at this stage.

This contingency value should be considered to represent the following items:

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

8. Technical Studies

8.1 Introduction

An investigation into such a complex study requires expert advice from a wide range of technical and other complementary areas. This section reports on the key conclusions and recommendations of these expert studies by way of a précis of each, based upon the full reports, which are included in the appendices.

Each précis also includes, the application of the principal conclusions and conclusions, or extrapolation where appropriate, to the potential solutions and a brief discussion of the study.

Many of the technical studies concentrated on a selected few potential solutions in order to focus on particular challenges and issues. This approach assisted the development of a more detailed understanding that may have otherwise been overlooked by broader study.

8.2 Précis of Technical Studies

The following technical studies were commissioned for this investigation. They are listed as follows and are summarised in the précis below:

Technical Study	Source
Tideway Investigation	Halcrow
Hydraulic, O&M and H&S Study	WS Atkins
Underground Works Study	Faber Maunsell
Settlement & Ground Movement Study	GCG
Treatment Study	Black & Veatch
Pumping Study	KSB
Power	McLellan
Screening	Thomson RPM
Trash Disposal	Thames Water Engineering
Control System	Thames Water Engineering
River Quality Study	Environment Agency
SUDS	Black & Veatch
Land, Environment and Planning	LUC and Cascade
Construction Cost Estimates	EC Harris
Derivation of Budget Capital Costs	Thames Water Engineering
Derivation of Budget Operational Costs	Thames Water Engineering

The following complementary studies were also commissioned for this investigation. They are listed as follows and are summarised in the précis below:

Complementary Study	Source
Fish Trial	Environment Agency
SCITTER	Thames Water Engineering and R&T
Flow Monitoring	Thames Water Engineering
Catchment Modelling	Thames Water Engineering
Literature Search	Thames Water R&T
Legislation	Thames Water Legal Department

8.2.1 Précis of Tideway Investigation – Halcrow

8.2.1.1 Principal Conclusions and Recommendations

This pre-feasibility study was carried out by Halcrow as an initial assessment of the following five potential solutions:

1. Potential solution A: A tunnel to intercept flow from all the CSOs, sufficiently large to store the flow and convey it to Beckton and Crossness Sewage Treatment Works (STW) for treatment before discharge to the river.
2. Potential solution B: A transfer tunnel to intercept flow and convey it to a point near Woolwich for screening and discharge to the river.
3. Potential solution C: A collection and distribution tunnel somewhat similar to Option B, except that multiple outfalls to the river are incorporated.
4. Potential solution D. Two tunnels, one storing and conveying part of the flow to the two STWs for treatment, and the other providing multiple screened discharges to the river as in Option C.
5. Potential solution E. Multiple large diameter shafts along the length of the river foreshore, which house fixed screens. Part of the flow is screened and passed to the river; the remainder is stored and conveyed by tunnel to the STWs for treatment.

These options were each identified with three different levels of intervention – maximum, medium and low. These were respectively equivalent to 100%, 50% or 20% of the maximum design flow. The options therefore cover a significant difference in size and scope of work, and potential benefit to the river.

Recommendations were made with regard to the direction of further studies. Main points include the following:

1. Detailed tunnel assessment studies should commence on preferred options .
2. More detailed analysis of alignments, risks and cost estimates.
3. Inviting an appropriate TBM manufacturer and Contractor to contribute to the studies to explore risks and opportunities in more detail.
4. Undertaking further geological and hydrogeological studies and adding this data to the tunnel model to refine the risk assessments.
5. Undertaking further assessment of bypass arrangements and the effect of the proposals upon the existing sewerage system, to establish how asset management of existing outfalls and pumping stations may be impacted, and to assess any change in level of service.
6. More detailed analysis of tunnelling spoil disposal during construction.
7. Mathematical modelling of the sewer system should be developed to predict the numbers, locations and volumes of storm spills for the various options and levels of intervention,
8. The impact of these discharges on the receiving water in the river should be modelled to establish and optimise the benefits to the river.
9. Pumping and screening requirements should be developed to ensure achievability and compatibility with tunnel options.

8.2.1.2 Discussion of Study

This study was requested before firm objectives had been set for the quality improvements required for the river, and consequently before the requirements determining how the CSO discharges need to be limited. The purpose of this brief study is therefore an initial assessment to identify geological boundaries influencing tunnelling horizons and viability, identify major engineering obstructions affecting tunnel alignments, assess the feasibility of the options, and identify tunnel alignments and outline costs for the above options and others that arose through the study – all with a view to aiding the narrowing of the options to be considered in subsequent analysis at a more detailed level of study.

Tunnelling routes were established and the merits of single tunnel / twin tunnel provision explored. Ordnance survey, geological and existing asset information was gathered to generate a three-dimensional computer model of the area. Information has also been gathered on bridges over the River Thames. Outline pumping requirements were assessed. An outline assessment of technical risks and environmental/socio-political (ESP) risks was also undertaken, along with a preliminary estimate of costs. Preliminary estimates of the cost of the construction works were made as an indicative comparison between the various potential solutions and levels of intervention.

The main recommendations reached are listed above and the overall conclusions are summarised as follows:

- All the options are technically feasible
- Each realise a different levels of risk
- Budget costs for each are quite diverse
- Each would deliver differing benefit to the river.

8.2.1.3 Application to Potential Solutions

The outline scope of each of the potential solutions A to E, at the three levels of intervention is included in the full report. It is considered inappropriate to attempt to extrapolate these early findings as they have largely been superseded by later developments.

8.2.2 Précis of Hydraulic, O&M and H&S Study – Atkins

8.2.2.1 Principle Conclusions and Recommendations

1. Minimum hydraulic capacity of main tunnel to prevent choking. For effective interception of flow the main tunnel is required to be able to transfer peak inflows when part full. This translates to a minimum diameter requirement of at least 6m for all potential solutions and levels of intervention.
2. Storage tunnels will incur deposition, which will require some form of flushing regime to keep the tunnel clear. The concept of flushing the tunnel with plugs of river water introduced at high tide should work well in principle.
3. The hydraulic capacities for potential solutions A and H are sufficient to ensure stable filling, venting, emptying rates for reasonable treatment capacity and flushing requirements
4. Potential solution G, displacement tunnel, suffers from several hydraulic drawbacks, which require high-energy consumption to resolve.
5. Tideway scheme operation will require additional permanent manpower
6. There are no O&M or H&S issues, which imply major differentiation between the potential solutions.

The requirement of a minimum tunnel diameter, at least 6m, has a profound impact on the potential solutions based on transfer and distribution tunnels, in particular at the medium and low levels of intervention. In effect the main tunnels for potential solutions B, C and D at all levels of intervention become 6m in diameter, which makes the inherent storage volume included in all these potential solutions remarkably similar. There becomes little to differentiate between the main tunnel of B, C or D and that of potential solution A, at the low level of intervention. The massive requirement for pumping and screening capacity for B, C and D is therefore seriously in question. The hydraulic effects and impact on the potential solutions of this issue of hydraulic choking is discussed in more detail below.

8.2.2.2 Application to Potential Solutions

The principle findings of the study have been extrapolated for each potential solution and level of intervention as appropriate. These are summarised in Table 23.

Table 23 : Atkins - Summary of principle findings for Potential Solutions.

Solution /Intervention	Minimum Diameter	Flushing Process	Comments
A Maximum	12.9	River	Diameter based on storage
A Medium	9.0	River	Diameter based on storage
A Low	6.0	River	Diameter based on storage/transfer capacity
B Maximum	6.0 (*1)	River	Max diameter is 9m
B Medium	6.0 (*1)	River	Transfer tunnel becomes constant diameter
B Low	6.0 (*1)	River	Tunnel diameter same as medium intervention
C Maximum	6.0 (*1)	River	Distribution tunnel becomes constant diameter
C Medium	6.0 (*1)	River	Tunnel diameter same as maximum intervention
C Low	6.0 (*1)	River	Tunnel diameter same as maximum intervention
D Maximum	6.0 (*1)	River	Applies to both storage and distribution tunnel
D Medium	6.0 (*1)	River	Tunnel diameters same as maximum intervention
D Low	6.0 (*1)	River	Tunnel diameters same as maximum intervention
E Maximum	N/a	N/a	(*2)
E Medium	N/a	N/a	(*2)
E Low	N/a	N/a	(*2)
F	N/a	N/a	Based on individual screening
G	9.0	Pumped	High flow pump flush to re-suspend sediment
H	9.0	River	Diameter based on storage

Key
*1: Diameter based on hydraulic capacity to avoid choking
*2: Potential solution E requires a network of separate interception tunnels and draindown tunnels, the hydraulic capacity of which can be based on the individual maximum flow rates.

8.2.2.3 Discussion of Study

Scope
This study concentrated on investigating the hydraulic, O&M and H&S issues associated with the potential solutions of a storage tunnel and displacement tunnel. The study was carried out in two sections. The scope of the first was:

- Hydraulics of the main tunnel for A and G, principally 9m, but 6m also considered
- Interception of flow from existing CSOs
- Sedimentation issues
- O&M and H&S issues

The second section extended the study to include a review of potential solution H.

Tunnel Diameters – Hydraulic Effects

The issue of a stable filling process, and the implication of a minimum tunnel diameter of at least 6m, has a profound impact on the potential solutions based on transfer and distribution. Therefore no apology is made for including a detailed discussion of this issue below.

Introduction
The operating strategies for all of the Tideway options, except Option G, include the intention to empty the system following a storm event. This is held to be necessary to avoid odour and septicity problems (Option G planned for tidal or pump assisted flushing). In any solution, therefore, a new storm event must involve an initial phase where the system is filling.

One of the main conclusions made in the WS Atkins Hydraulics Study was that this filling phase must take place in a controlled manner, with a stable free surface flow profile and a suitable area above to allow for the unobstructed passage of displaced air to venting locations. It was argued that preventing choking, the occurrence of 'gulping' flow and the potential to trap large volumes of air within the tunnel was key to providing a safe and predictable system performance. Trapped air would not only risk reducing significantly the amount of storm water that the system could accept (and so lead to excessive bypass to the river), but could also result in uncontrolled and potentially explosive 'blowbacks' up the drop-shafts.

For a given filling flow rate, the parameters, which directly affect the stability of the free surface flow profile, are the tunnel diameter and gradient. The theoretical stability limit requires the flow to reach no more than 80% depth. Current practical guidelines for, admittedly smaller, gravity flow systems suggest that, to avoid choking, free surface depths should be restricted to between 50% -66% of the tunnel diameter.

Since the gradients of the tunnels proposed for all of the Tideway options are fairly similar, the critical parameter for safe operation becomes the diameter. The selection of diameter is, itself, dependent on the storm water flow rate the tunnel is required to convey during filling.

It is possible that the issue of choking could be sidestepped by providing displaced air venting all along the length of the tunnel, rather than just at the main shafts. This approach has been considered but would suffer from the following challenges:

1. Each interception point would require two conduits or tunnelled connections. The first to carry the intercepted flow and the second to carry the displaced air back to the drop shaft.
2. This second conduit would have to be installed to connect above the crown of the main tunnel to effect air release. This would entail the construction of an expensive underground chamber at each connection point

3. High flows discharging into a small diameter tunnel would create localised high water levels, which would still obstruct the displacement of air, unless the underground connection chamber was large enough to ameliorate such effects.
4. Overall this matter is complex and would require detailed investigation and hydraulic modelling to resolve. It is considered most likely, however, 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 these large underground connection chambers.

In their report, WS Atkins focussed on the filling characteristics of tunnels of 9m and 6m diameter. They also investigated factors, which may affect the total flow that could occur at any point in the tunnel with respect to the inflow rates that may arise at each CSO. This latter issue, which is eventually seen to be of paramount importance, defines the required tunnel filling 'capacity' and is discussed in more detail below.

Tunnel Filling Flows

Any rainfall event of sufficient intensity will generate a volume of spill to the river and hence a polluting load of sewage litter and BOD. The quantity of polluting load will depend on many and various factors, but probably of highest significance will be the flushing effect on the sewerage system. It is likely that concentrations of polluting load will increase in proportion to the flow in the sewerage system; at least until peak flows are reached.

The volume of spill and the rate it is generated will depend on the spatial and temporal variations of each rainfall event - that is where, when and how much it rains. These three factors are highly variable and, although there will be trends, the exact outcome will be difficult to predict. From the study of serious polluting events it is reasonably clear that a spill of at least moderate to high volume over a relatively short duration is required to produce a serious impact on the river. These events will produce high peak flow rates of spill to the river, which would need to be intercepted effectively by any potential solution to ensure a reasonable improvement.

The most straightforward categorisation of storm events can be made on the basis of spill volume. Unfortunately, spatial and temporal rainfall variations mean that there is often no direct relationship between total spill volume and peak spill rate. A given spill volume could be generated either by short-lived, high flows or by much lower, longer duration, spill rates.

It is quite feasible for a pattern of rainfall to cause peak overflows from adjacent sub-catchments to occur at the same time and produce a greater instantaneous filling flow rate than otherwise might be expected.

Important points can be made on the basis of these observations:

1. The polluting load from a storm may ultimately only occupy a modest volume but it could require a high filling 'capacity'.

2. In simplistic terms, a low intervention level storage concept solution will, under large storms, fill to capacity and be overwhelmed causing bypass of excess volume to the river. In reality, however, if a solution is provided which does not have the filling capacity for a large storm, then when one occurs (as it inevitably will) it will choke before filling to capacity, causing premature bypass of the first foul flush to the river.

WS Atkins argued that the modelling that had been performed on a range of storm events could not provide definitive information on likely instantaneous flow rates, as it did not include spatial and temporal effects. They noted, however, that a peak spill rate of 250 m^3/s had been assumed to represent a high intervention level for transfer solutions. This figure was estimated by taking a notional 60% of the sum of the maximum peak flow of each individual CSO. Taking this figure as a filling capacity requirement led to the conclusion that stable filling and venting could just be achieved in a 9m diameter tunnel. Any smaller diameter would have a reduced capacity, with the 6m tunnel limit calculated at just under 100 m^3/s. However this flow rate would equal the sum of the peak flow rate from several adjacent CSOs.

The instantaneous peak flow rate is obviously critical to the selection of the main tunnel diameter. This can only be estimated by more accurate and detailed modelling of the sewerage system under a wide range of rainfall events. At present the conclusion to be drawn is that there is a limit on how small the main storage or transfer tunnel can be and that it must almost certainly be bigger than 6m and is unlikely to be less than 9m.

Impact on Potential Solutions

The general impact of hydraulic capacity and interception of peak flow rates is that potential solutions, which incorporate small diameter main tunnels, that are less than 6m in diameter, are unlikely to work effectively.

Halcrows did not consider this potential choking effect in the initial study, as the scope was to consider a very wide range of issues associated with several potential solutions and levels of intervention in much broader outline. The subsequent more detailed appraisal of the hydraulic issues by WS Atkins, by concentrating on the potential solutions A and G at medium level of intervention only, uncovered this problem. The impact of this issue, particularly on the medium and low levels of intervention for the transfer-based options, has a fundamental effect.

In essence for potential solutions B, C and D at the medium and low levels of intervention the transfer or distribution tunnels at the diameters initially quoted in the Halcrow report will not work effectively. Tunnel sizes were initially quoted as small as 2.1m in diameter. These would choke. Similarly the storage tunnel for potential solution D will not fill effectively and be unable to capture the assumed first foul flush, unless it is at least 6m in diameter.

For potential solution D, at all levels of intervention, the diameter of the storage tunnel would have to be 6m. This is equivalent to the storage tunnel for potential solution A at the low level of intervention. This minimum requirement for the storage tunnel of D means that all but three events per year would be completely retained in this tunnel. As the capacity of the storage tunnel would only be exceeded three times a year, it questions the need for a transfer/distribution tunnel and the eight pumped/screened outlets.

For potential solution C, the transfer/distribution tunnel would need to be a minimum 6m in diameter for all levels of intervention. In effect this is the same size as the storage tunnel for potential solution A at the low level of intervention. This transfer/distribution tunnel for C is shorter than for A, but would still afford a considerable volume (approximately $0.72Mm^3$), which would be only be exceeded 5 times per year. Extending this transfer/distribution tunnel for C questions the need for the pumped/screened outlets.

Considering potential solution B in a similar vein would make the transfer tunnel for both the medium and low levels of intervention 6m in diameter throughout their length. Once again the vast majority of rainfall events would be completely retained by this volume. The high capacity pumping/screening plant and the associated extremely high power supply would only be required infrequently.

In conclusion this minimum requirement for the hydraulic capacity, that is diameter, of all storage or transfer tunnels gives each potential solution a significant volume, which would only be exceeded a few times per year. The investment in the high capacity pumping and screening plant for potential solutions B, C and D is therefore of doubtful benefit as they would be utilised infrequently.

Other Hydraulic Effects

The other hydraulic findings associated with a storage tunnel for both potential solutions A and H were around that of draindown and flushing.

The velocity generated in the main body of the stored flow by the draindown process will be approximately 0.3m/s and therefore too low to re-suspend sediment. Deposition along the entire tunnel length will result and hence a flushing process will be required. The concept of utilising a plug of river water introduced at the western end of the tunnel was investigated in outline. It was shown that this process would generate sufficiently high velocities, at approximately 2.5m/s, to re-suspend sediment. Flushing regimes for both A and H were developed in outline and described in the main report. There is scope to optimise the pump-out rates and flushing flow rate.

Hydraulic Limitations of Potential Solution G

Investigation of the normally full displacement tunnel, potential solution G, produced serious drawbacks as listed below:

- Limited capacity under gravity, therefore high capacity pumping required to transfer peak flows for moderate events
- Pre-emptive drawdown of system required to overcome inertia effects
- The tidal flush process is insufficient to re-suspend sediment, therefore regular high flow pumping required to remove deposition
- Floating debris retained in shafts
- Regular tunnel and shaft flushing would be required to prevent septicity, requiring complex control.

O&M and H&S Issues

The following operation and maintenance and health and safety issues, as appropriate to all potential solutions based on interception to a main tunnel, were reported:

- The operation of the Tideway scheme will require additional manpower
- Planned maintenance during dry periods will be critical for satisfactory performance
- Safe working methods can be developed from existing procedures
- Quality and quantity of sediment is critical for development of O&M strategy
- Single deep sediment removal process may be more beneficial than traditional surface approach
- Floating debris could adversely affect the operation of option G

Potential Solution H

This partial concept is no less an ambitious scheme in terms of deep tunnelling, interception shafts, access etc, than the complete solution considered previously. This assessment, however, would appear to show that the proposed configuration for this partial solution has the potential to overcome some of the hydraulic drawbacks identified for the full solution in the main report. However, O&M and H&S concerns remain similar to those reported before.

Stable filling, venting, emptying rate (treatment capacity) and flushing requirements would all appear to be more likely to be achievable with the current Partial Solution proposals than previously anticipated. This is due to the fact that the main section of the tunnel can be significantly steeper than that considered for the full-length system. Also the proposed main tunnel diameter is 9m and the instantaneous flow rates are likely to be lower as fewer CSOs are intercepted.

This study investigated further the concept of flushing the tunnel with plugs of river water introduced at high tide. The hydraulic calculations demonstrated that this concept should work well in principle. Operation and Maintenance, Health and Safety Conclusions are:

- In principle, the proposals for the Partial Solution adhere to current standard H&S practice and experience, however, a more detailed review of planned ingress and unplanned egress will be required as the detail of the design emerges.
- A purpose built vehicle for transport in the tunnel between the main shafts will be necessary to facilitate the inspection and maintenance duties
- An additional access shaft midway between Acton and Heathwall is necessary to provide safe egress facilities

8.2.3 Précis of Underground Works Study– Faber Maunsell

8.2.3.1 Principal Conclusions and Recommendations

1. The ground conditions, depth and groundwater pressures will be serious technical challenges to the successful implementation of the main tunnel of any potential solution. However, TBM development has and continues to progress, which should be of benefit to this project.
2. CSO interception structures are all in difficult locations and are in danger of becoming even more difficult as development along the river frontage proceeds rapidly. Alternatives should be considered wherever possible.
3. Spoil disposal will present major difficulties. Identification of alternative uses is critical.
4. Storage provision by Off-line tanks is more expensive than a single large diameter tunnel.
5. Construction site availability is a critical issue for effective implementation. Each site must have adequate access, working and storage space. Timely provision of an adequate power supply for these sites is essential.
6. Tunnelling activities are considered as high risk by the insurance market. It is possible that the cost of construction insurance could be prohibitive.

The ability to construct the interception tunnels by launching the TBM from the main tunnel is key to minimising the diameter of the shaft at the interception structure. Should smaller diameter main tunnels be adopted this approach will not be possible. The TBM for the interception tunnel would have to be launched from a larger shaft at the interception structure. This requirement for a larger shaft would have greater impact on what would already be a difficult location. To avoid the costly approach of either the non-recovery of the TBM or the construction of reception shafts in the river, there would also be a lower limit main tunnel diameter to effect recovery of the TBM.

8.2.3.2 Application to Potential Solutions

This study was based upon the three potential solutions of A (medium), G and H. A table listing the main construction features, such as maximum depth/diameter and geological strata encountered, for the remaining potential solutions / levels of intervention is included below for comparison (Table 24).

Table 24 : Faber Maunsell - Main construction features for Solutions Amed, G and H

Solution /Intervention	Maximum		Geology				Comments
	Depth	Dia.	LC	W	Th	Ch	
A Maximum	100	12.9	Y	Y	Y	Y	Tunnel for A (Max) passes under tunnels to west, therefore deeper throughout
A Medium	85	9.0	Y	Y	Y	Y	
A Low	85	6.0	Y	Y	Y	Y	
B Maximum	100	9.0	Y	Y	Y	Y	Steeper gradient required for drawdown, therefore just as deep although shorter
B Medium	85	6.0	Y	Y	Y	Y	
B Low	85	6.0	Y	Y	Y	Y	
C Maximum	45	6.0	Y	Y	Y	N	Distribution tunnel will be very close to existing tunnels
C Medium	45	6.0	Y	Y	Y	N	
C Low	45	6.0	Y	Y	Y	N	
D Maximum	85	6.0	Y	Y	Y	Y	First flush storage tunnel will be similar profile to A (Low)
D Medium	85	6.0	Y	Y	Y	Y	
D Low	85	6.0	Y	Y	Y	Y	
E Maximum	35	25.0	Y	Y	Y	Y	Construction difficulties for large diameter shafts within river
E Medium	35	25.0	Y	Y	Y	Y	
E Low	35	25.0	Y	Y	Y	Y	
F	10	N/a	Y	N	N	N	
G	75	9.0	Y	Y	Y	Y	
H	50	9.0	Y	Y	N	N	London Clay predominates

Key: LC=London Clay; W=Woolwich & Reading; Th=Thanet Sands; Ch=Chalk
Note: For transfer and distribution tunnels, a minimum diameter of 6m has been adopted to avoid the choking effect.

8.2.3.3 Discussion of Study

This study was carried out in two parts.

First Stage
The first concentrated on the issues associated with construction of the main tunnels, intercepting structures and interconnecting tunnels. It was lead by Faber Maunsell and assisted by Amec in the area of construction activities and Lovatt for tunnelling machine issues. The scope was generally as follows:

- Based on main tunnel for A and G, principally 9m, but 6m also considered
- Construction of interception structures
- Connections to main tunnel
- Predicted settlement

Preliminary plans and sections were produced for the tunnel routes, the interconnecting tunnels and the intercepting structures. Five existing CSOs were selected for this preliminary development of the intercepting structures as typical examples for the whole. Detailed consideration was also given to construction compound requirements, tunnel machine requirements and construction logistics.

The main findings of this study were as listed above and are discussed below:
Construction logistics were thoroughly investigated, including construction shaft sites, interception structures, interconnecting tunnels, tunnelling machines and the main tunnel itself.

Concerning the interconnecting tunnels it was considered practical to launch the TBM from within the main tunnel itself, 9m in diameter sized for the medium level of intervention. This approach negates any possible requirement for construction shafts within the river and reduces the size of drop shaft at the interception structure. Detail drawings of the TBM launch are included in the main report.

This approach may not be possible for the smaller tunnel, which is 6m in diameter for the low level of intervention. Larger drop shafts at the interception structures to facilitate launch of the tunnelling machine would be required. This would increase the impact of construction of the interception structures, most of which would have to be in difficult and confined locations. For the larger interconnecting tunnels it may also not be possible to recover the tunnelling machine via the main tunnel itself, thus prompting the requirement for shafts within the river. These factors would add considerable cost to the low level of interception, which may make it less attractive.

Off-line storage tanks were also considered to supplement provision of storage. Whilst a practical alternative these tanks were more expensive to construct than the equivalent storage afforded by a large diameter tunnelling operation. The example used was a tunnel 6m in diameter (A low) supplemented by 12 large underground tanks to realise a total storage volume equivalent to a single tunnel 9m in diameter (A medium). The increase in cost was approximately £600M, which is mainly due to the construction logistics. Once a relatively large tunnelling machine is launched the operation is quite efficient. However the repeated site establishment costs associated with the construction of underground storage tanks adds considerable cost to this operation. Additional land acquisition costs would also be incurred in conjunction with this approach, which are likely to be very high in the London area.

Second Stage
The second stage of the study concentrated on developing an outline proposal for potential solution H, based on a storage tunnel from Homefield Recreation Ground in the west to draindown pumping station and treatment plant based at Heathwall PS in the east. A revised

plan and long section for this tunnel route together with site plans for the pumping station and treatment works and access shaft were prepared.

The proposed relocation of the access shaft in the east was made following advice from the Land and Planning study to avoid the local conservation area.

This study was also co-ordinated with the extensions to the Hydraulics, Pumping and Treatment Studies.

The main findings of this section part of the study, in addition to the issues identified previously, were as follows:

- A large site is required for the construction of the pumping station, treatment works and interception structures adjacent to Heathwall PS.
- The tunnel route is largely within the London Clay strata and should present minimal risk.
- Diaphragm wall is an appropriate construction technique for both the main shaft and the caisson for the treatment plant.
- The drive shaft, located at Heathwall PS, would need to be approximately 25m in diameter. However, to accommodate the pumping plant recommended in the Pumping Study a shaft of 31m in diameter is required.
- The reception shaft, located at Homefield recreation ground, would need to be approximately 17m in diameter. However, to accommodate the necessary flushing volumes as recommended in the Hydraulic, O&M, H&S Study a shaft of approximately 25m in diameter is required.

8.2.4 Précis of Settlement & Ground Movement Study – GCG

8.2.4.1 Principle Conclusions and Recommendations

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

Tunnelling conditions are likely to be particularly difficult in the water bearing Thanet sands and particular problems are to be expected at the interface of this material with the overlying Lambeth Group and the Chalk beneath.

8.2.4.2 Application to Potential Solutions

The principle findings of the study have been extrapolated for each potential solution and level of intervention as appropriate. These are summarised in *Table 25*.

Table 25 : GCG - Summary of principal findings

Solution /Intervention	Comments
A Maximum	Construction of the larger diameter tunnel for A (Max) would increase impact on existing structures, whereas the impact would be reduced for A (Low)
A Medium	
A Low	
B Maximum	Impact on existing structures would be similar to A (Med)
B Medium	
B Low	
C Maximum	As the distribution tunnel is shallower it would have a more pronounced impact on existing tunnels. It may be possible to lessen the impact on bridges by careful selection of route.
C Medium	
C Low	
D Maximum	Impact of distribution tunnel as for C. Impact of storage tunnel on existing structures would be similar to A (Low)
D Medium	
D Low	
E Maximum	Construction of these large diameter shafts in the foreshore would have severe impact on long stretches of the river wall. High risk associated with accidentally detonated ordnance
E Medium	
E Low	
F	Potential extreme impact on river wall, but localised
G	Impact on existing structures would be similar to A (Med)
H	Tunnel almost entirely within London Clay strata, risk reduced.

8.2.4.3 Discussion of Study

The potential route of the main tunnel principally follows the river to intercept the CSOs in the most effective manner. This also has the added advantage of avoiding the densely built up areas and minimising impact on buildings. However the route would therefore pass under many sensitive structures such as the bridges, existing tunnels and the river walls. Hence, based on 9m ID tunnel for options A and G, the scope of this study was as follows:

- Identify and collate details of the bridges, tunnels and river walls.
- Develop a methodology for the assessment of impacts on bridges, tunnels and river walls.
- Carry out a detailed prediction of 3D ground movements and preliminary assessment of each bridge and tunnel.

The methodology and risk categorisation for the bridge and tunnel structures was developed as the following categories:

1. Likely to be significantly affected, may prevent tunnel construction. Full individual structural survey and analysis required. Protective/mitigation works almost certain.
2. Unlikely to present an intractable obstruction. Full individual structural survey and analysis required. Protective/mitigation works likely
3. Not likely to be affected.

For the bridges structures limiting values for the three categories of differential settlement, differential rotation and longitudinal strain in span are proposed. Similarly for the tunnel structures limiting values of diametral strain and longitudinal radius of curvature are proposed for each category. Based upon the proposed tunnel sections a full prediction of the 3D ground movements was carried out for each bridge and tunnel structure. Using the categories detailed above no bridge was assessed to be in highest risk category. The assessment is summarised below:

Category	1	2	3
Bridges	0	14	8
Tunnels	5	19	6

Of the five tunnels in Category 1, the highest risk, four are Thames Water tunnels. They include the LWRM (twice) and the Hammersmith to Barnes Old and New Siphons. The risk to these assets is considered manage-able due to common ownership. The principle advantage of aligning the tunnel close to these tunnels is a reduction in overall depth of the whole tunnel route by over 15m. The fifth tunnel in category 1 is the Beverley Brook Gas Tunnel. Initial discussions have been held with Transco regarding this crossing. At this stage potential duplication of this strategic gas supply may be considered an appropriate mitigation to ensure gas supply.

8.2.4.4 Conclusions

- River walls unlikely to be affected except at Battersea Park
- No bridges assessed to be in highest risk category
- Most of the principal structures will require impact assessments and a significant number may require protective/mitigation works
- Tower Bridge and Hungerford Bridge require further analysis due to their unusual nature
- Tunnel gas crossings carry very serious consequences especially that at Beverley Brook
- The GPO tunnels require special attention and the LUL tunnels will be of great sensitivity
- Thames tunnels at west end of route are at high risk but manageable through common ownership
- Tunnelling conditions are likely to be particularly difficult in the water bearing Thanet Sands and particular problems are to be expected at the interface of this material with the overlying Lambeth Group (lower strata of the Woolwich and Reading Beds) and the Chalk beneath.

8.2.4.5 Recommendations

- Determine precise line/level for Thames Water Tunnels
- Determine line/level and construction for GPO Tunnels
- Discuss Gas crossings, particularly Beverley Brook
- Carry out detail assessment of Tower Bridge and Hungerford Bridge due to their unusual nature
- Carry out detail analysis of five span bridges
- Confirm tunnel alignment affecting Chelsea and Grosvenor Bridges and re-assess
- Determine service pipes carried on bridges
- Carry out plans/licence survey along foreshore
- Review/risk assess proposed locations for shafts with respect to structures vulnerable to inundation either by construction induced movements or accidentally detonated ordnance.

8.2.5 Précis of Treatment Study – BBV

8.2.5.1 Principle Conclusions and Recommendations

The initial driver for consideration of storm overflow management was the aspiration to remove/reduce visible litter in the Tideway. In addition the Environment Agency (EA) has concerns that excessive dissolved oxygen (DO) depletion is occurring in the River Thames and that increased treatment may be required to correct this deficiency. The extent and causes of oxygen depletion are not fully understood as water quality modelling is incomplete.

The scope of this study was to develop a range of modular processes that would be appropriate for the treatment of intermittent storm flows derived from the various potential solutions, but focussed mainly on A and H.

The main findings of this Treatment Study are:

1. Purpose built storm treatment facility is required to treat intercepted flows
2. Secondary Treatment is only likely to be viable up to about $10m^3/s$ flow rate
3. Secondary Treatment could only be supported adjacent to STW sites
4. Deep Bed Filters are the preferred Enhanced Primary Treatment
5. Submerged Aerated Filters are the preferred Secondary Treatment
6. Flow rates for the Transfer Tunnel Option B are considered too high to be practical

The existing treatment works cannot be used to treat the intercepted flows, as they will also be subject to high in flow. In any event, even the lowest pump out rate would overwhelm the existing treatment streams. A purpose built treatment facility is therefore required.

Submerged Aerated Filters (SAF) is considered to be the most appropriate secondary treatment process for this application as they will tolerate low concentrations and changes in flow more readily than other processes. However, as it is a biological process it must still be sustained between rainfall events. It is envisaged that a proportion of the Crossness STW flow could be fed through this process stream, but the overall capacity of storm treatment that can be sustained is still limited. Providing a greater capacity would be counter-productive, as it would further dilute the flow and tend to starve the biological process making it ineffective.

Deep Bed Filters are relatively untried for this application. However as this is a physical process it can be used to treat a wide range of flows by controlling the number of units on stream. It can also offer the flexibility of being used as a polishing treatment process for normal flows between rainfall events. Location adjacent to an existing site is also important for support of the operating infrastructure and use of existing sludge treatment facilities.

Locating this storm treatment facility adjacent to an existing high capacity treatment site is essential to enable the secondary treatment process to be sustained, however it also offers the considerable potential benefits of improvement to the secondary treatment and polishing of the final effluent of the existing works during the considerable time periods when storm water filtration is not required.

The instantaneous peak flows that can be generated by the potential solutions based on transfer or distribution can be very high and limited in duration. Although enhanced primary treatment facilities of sufficient capacity could be constructed for these peaks at enormous cost, it is understood that the full peak capacity would only be required infrequently. It is also not be appropriate to implement secondary treatment for these peak flow rates as it would not be possible to sustain the biological process between peak events. The interception of storm flows to storage enables the pump-out rates to be controlled and consistent, which facilitates use of enhanced primary treatment and secondary treatment processes. It also facilitates optimisation of treatment capacities.

Sludge treatment was only included as far as thickening sludges and storage tanks. It has been assumed that the Incinerators would process the additional sludge produced. If this is not the case additional cost will be incurred for sludge disposal.

The treatment process for potential solution H can only be based on the physical process of Deep Bed Filters or "Actiflo" because the proposed site is remote from any existing treatment works so that Secondary Treatment could not be sustained between rainfall events. There are also severe limitations on the potential site area available.

8.2.5.2 Application to Potential Solutions

The Rainfall and Tunnelling studies produced a number for possible options for storing and/or transferring the storm flow. Each solution could be applied at 3 different levels of intervention. This produced a matrix (Table 26) of possible flow rates that would require treatment.

Table 26 : BBV Summary of Rainfall and Tunnelling principle findings

Option	Intervention Level		
	Maximum m^3/s	Medium m^3/s	Low m^3/s
A - Storage Tunnel	50	25	10
B – Transfer Tunnel	240	120	50
C – Multiple Screened Outlets	40	20	8
D – Screened Outlets with Storage	10	5	2
E – Storage Shafts	15	7.5	3
F – Screened CSOs	N/A	N/A	N/A
G – Displacement		120	
H – Western Area only Storage	5.5		

Four levels of treatment were investigated as follows:

1. Preliminary Treatment
2. Primary Sedimentation
3. Enhanced Primary Treatment
4. Secondary Treatment

Various options were also explored for each of the four levels of treatment, which are detailed in "Discussion of Study". The principle findings of the study have been extrapolated for each potential solution and level of intervention as appropriate. The applicability of each solution is summarised in Table 27.

Table 27 : BBV Treatment Study principle findings

Solution /Intervention	Level 1 Screens	Level 2 PST	Level 3 Enhanced Primary	Level 4 Secondary Treatment	Comments
A Maximum	**Y**	**Y**	**Y**	**Partial**	Up to $10m^3/s$ for Level 4
A Medium	**Y**	**Y**	**Y**	**Partial**	Up to $10m^3/s$ for Level 4
A Low	**Y**	**Y**	**Y**	**Y**	All Levels applicable
B Maximum	**Y**	**X**	**X**	**X**	High flow, screening only
B Medium	**Y**	**X**	**X**	**X**	High flow, screening only
B Low	**Y**	**X**	**X**	**X**	High flow, screening only
C Maximum	**Y**	**X**	**X**	**X**	Limited site, screening only
C Medium	**Y**	**X**	**X**	**X**	Limited site, screening only
C Low	**Y**	**X**	**X**	**X**	Limited site, screening only
D Maximum	**Y**	**Y**	**Y**	**Y**	Stored flows only treated
D Medium	**Y**	**Y**	**Y**	**Y**	Stored flows only treated
D Low	**Y**	**Y**	**Y**	**Y**	Stored flows only treated
E Maximum	**Y**	**Y**	**Y**	**Partial**	Stored flows only treated
E Medium	**Y**	**Y**	**Y**	**Y**	Stored flows only treated
E Low	**Y**	**Y**	**Y**	**Y**	Stored flows only treated
F	**Y**	**X**	**X**	**X**	See Screens Study

G	**Y**	**X**	**X**	**X**	Reed Bed Treatment
H	**Y**	**Y**	**Y**	**X**	No secondary treatment

The preferred treatment stream for each potential solution/level of intervention is summarised in the tables (28 – 34) below, together with budget estimates of capital and operational costs. An allowance for contingency and other project costs is included in the capital costs below, however this has been deleted from the total cost summary.

Potential Solution A

Table 28 : BBV-Treatment study -Summary of preferred treatment stream for Solution A

A	Level 1 Screen & degrit			Level 3 Deep Bed Filters			Level 4 SAF		
	Rate (m^3/s)	Capex £M	Opex £M/yr	Rate (m^3/s)	Capex £M	Opex £M/yr	Rate (m^3/s)	Capex £M	Opex £M/yr
Max	50	95.0	0.936	50	61.7	3.730	10	55.3	0.887
Med	25	60.2	0.582	25	32.9	1.776	10	55.3	0.887
Low	10	32.0	0.319	10	24.8	0.648	10	55.3	0.887

Flows up to 10m3/s will receive all levels of treatment, for flows in excess of 10m3/s level 4 will be bypassed.

Potential Solution B

Table 29 : BBV-Treatment Study – Summary of preferred treatment stream for option B

B	Level 1 Screen & degrit		
	Rate (m^3/s)	Capex £M	Opex £M/yr
Max	240	450.0	4.560
Med	120	225.0	2.228
Low	50	95.0	0.935

Flows considered too high and too intermittent for any treatment other than screening and grit removal. Capital and operational costs are extrapolated by capacity.

Potential Solution C

The screening plant sites would be located in built up areas of London and will have to be completely enclosed in large underground bunkers. Construction costs for these screening plant site are included elsewhere. The operational costs are included below; these are based upon screening and grit removal only for the eight sites. Other operational costs such as pumping and odour control are included elsewhere.

Table 30 : BBV-Treatment Study – Summary of preferred treatment stream for option C

C	Level 1 Screen & degrit		
	Rate (m^3/s)	Opex Each £M/yr	Opex Total £M/yr
Max	40	0.750	6.00
Med	20	0.375	3.00
Low	8	0.150	1.20

Potential Solution D

This potential solution is based on C with a storage tunnel for the first foul flush. Once again the capital costs for the screening plant are included elsewhere. The operational costs relate to the treatment plant for the storage tunnel only. Operational costs as for potential solution C should be added to these below:

Table 31 : BBV-Treatment Study – Summary of preferred treatment stream for option D

D	Level 1 Screen & degrit			Level 3 Deep Bed Filters			Level 4 SAF		
	Rate (m^3/s)	Capex £M	Opex £M/yr	Rate (m^3/s)	Capex £M	Opex £M/yr	Rate (m^3/s)	Capex £M	Opex £M/yr
Max	10	32.0	0.319	10	24.8	0.648	10	55.3	0.887
Med	5	16.0	0.160	5	12.4	0.324	5	27.7	0.444
Low	2	32.0	0.064	2	5	0.130	2	25	0.177

Potential Solution E

The capital and operational costs relate to the treatment plant for the stored flows only. Operational costs for the individual storage and screening shafts have not been included:

Table 32 : BBV-Treatment Study – Summary of preferred treatment stream for option E

E	Level 1 Screen & degrit			Level 3 Deep Bed Filters			Level 4 SAF		
	Rate (m^3/s)	Capex £M	Opex £M/yr	Rate (m^3/s)	Capex £M	Opex £M/yr	Rate (m^3/s)	Capex £M	Opex £M/yr
Max	15	48.0	0.480	15	37.2	0.972	10	55.3	0.887
Med	7.5	24.0	0.240	7.5	18.6	0.486	7.5	41.5	0.665
Low	3	9.6	0.096	3	7.4	0.194	3	36.2	0.266

Flows up to 10m3/s will receive all levels of treatment, for flows in excess of 10m3/s level 4 will be bypassed.

Potential Solution F

The capital costs for the implementation of this potential are estimated elsewhere. The estimated operational costs are £9M per year. This is based on a total screening and grit removal plant capacity of approximately 480m3/s. This excludes the energy costs associated with the additional pumping required.

Potential Solution G

The capital costs for the implementation of screening and grit removal plant for this potential solution are included below. The costs for the implementation of the constructed wetlands are estimated elsewhere.

Table 33 : BBV-Treatment Study – Summary of preferred treatment stream for option G

G	Level 1 Screen & degrit		
	Rate (m^3/s)	Capex £M	Opex £M/yr
Med	120	225.0	2.250

Potential Solution H

The Level 1 treatment for this potential solution is based on screening only, as there is likely to be insufficient space for grit removal plant. Level 3 treatment is based on Deep Bed Filters.

Table 34 : BBV-Treatment Study – Summary of preferred treatment stream for option H

H	Level 1 Screen & degrit			Level 3 Deep Bed Filters		
	Rate (m^3/s)	Capex £M	Opex £M/yr	Rate (m^3/s)	Capex £M	Opex £M/yr
Med	5.5	9.2	0.13	5.5	13.6	0.356

Potential solution H captures approximately 50% of the total spill to the river at the low level of intervention, similar to A(Low). The construction costs for the facilitating works for the treatment plant are included elsewhere.

8.2.5.3 Discussion of Study

The output for the Treatment study has been constructed on a modular basis to allow a wide range of flow rates and degrees of treatment combinations to be evaluated. Four levels of storm treatment were considered:

1. Preliminary Treatment (for all flows)
2. Primary Sedimentation
3. Enhanced Primary Sedimentation
4. Secondary Treatment

A range of processes were considered for each Level of Treatment and these have different applicability's depending on the level of treatment required and the total flow to be treated. These are summarised in Table 35.

Table 35 : BBV - Summary of processes for each Treatment level.

Preliminary	Applicable Flow Range	Advantages	Disadvantages
6mm Screening & Degritting	Low – Maximum	Meets litter removal requirement. Removes some BOD. Known technology.	Large amount of waste generated for disposal over a short period. Small impact on Oxygen Demand discharged.

Primary Sedimentation	Applicable Flow Range	Advantages	Disadvantages
Conventional Primary Sedimentation	Low – Maximum	Will remove significant BOD. Known Technology. Low Opex.	No Ammonia removal. Will generate a sludge stream for disposal. Large footprint.
Lamella Sedimentation	Low – Maximum	Will remove significant BOD. Low Opex. Smaller Footprint.	Technology not used on this scale in TWUL. No Ammonia removal. Will generate a sludge stream for disposal.

Enhanced Primary Sedimentation	Applicable Flow Range	Advantages	Disadvantages
Chemically Assisted Primary Sedimentation	Low – Maximum	Will remove more BOD. Known Technology. Higher Opex.	No Ammonia removal. Will generate more sludge for disposal. Large footprint.

Chemically Assisted Lamella Sedimentation	Low – Maximum	Will remove more BOD. Higher Opex. Smaller Footprint.	Technology not used on this scale in TWUL. No Ammonia removal. Will generate more sludge for disposal.
Actiflo	Low – Maximum	Very Small Footprint. Good BOD Removal	Produces large volume of thin sludge High Opex No Ammonia Removal. New Technology to TWUL.
Deep Bed Filters	Low – Maximum	High BOD Removal. Some Ammonia removal Could be used to polish normal flows. Small footprint	High Opex.

Secondary Treatment	Applicable Flow Range	Advantages	Disadvantages
Conventional Activated Sludge	Low – Medium	Good Ammonia Removal.	Only applicable to low flows, cannot treat high volumes of weak sewage. Needs to be run permanently not just in storm. Very High Opex. Produces Waste Activated Sludge. Can only be used at an existing STW site. Large Footprint. Sedimentation Tanks required.
Sequencing Batch Reactor	Low – Medium	Good Ammonia Removal. Final Sedimentation integral in tanks. Smaller footprint than conventional A/S.	Only applicable to low flows, cannot treat high volumes of weak sewage. Needs to be run permanently not just in storm. Very High Opex. Produces Waste Activated Sludge. Can only be used at an existing STW site.
Submerged Aerated Filter	Low – Medium	Good Ammonia Removal. Can run only in storms. Smallest Secondary Treatment Footprint. Lowest Secondary Treatment Opex.	Only applicable to low flows, cannot treat high volumes of weak sewage. High Opex. Only applicable to low flows, cannot treat high volumes of weak sewage.

Several general assumptions had to be made to allow treatment options to be developed.

1. The effluent quality requirements from the storm treatment plants were not defined at this stage, but are based on standards typically required elsewhere. The quality parameters are therefore only indicative. The process models predict generic effluent quality from each process considered to provide inputs to any catchment quality model that is developed.

2. Each process was sized to give an indication of footprint against flow treated. This will allow the process units to be assessed against possible sites for treatment plants. The footprints were illustrated by superimposing the plant layouts on the Crossness site.

3. The treatment study made assumptions about the strength of storm sewage a since little or no measured data was available. This estimated included and allowance for first flush sewage strength and subsequent dilution by additional flows.

4. The treatment study assumed the storage tunnel is pumped out and wastewater is treated in a 24 hour period. The 24 hour pump-out/treatment period was chosen for two reasons:

   - Large flow 'back to back' storms occur only very rarely within this period.
   - Storm sewage should not become septic in this period so significant malodours and problems treating septic wastewater should not occur.

5. Pump-out flow will vary because the characteristics of the pumping system will inevitably result in higher than average pump flows (say +30%) at high sewer level and lower than average pump flows (say –30%) at low sewer level. Therefore all hydraulic features are sized and costed for a maximum instantaneous flow of 1.3 x average flow, which is reasonable assumption at this stage.

6. This 24 hour pumpout/ treatment period was considered to be sustainable for the large majority of occasions because the average pump-out rates have been based on the assumption that emptying the sewer only occurs once the high level has been reached when in fact emptying will frequently begin at some suitable partially full point.

It may be possible to increase the pumpout/treatment period above 24 hours. This would allow a proportional reduction in hydraulic and biological treatment capacity, though sludge treatment capacity should not be decreased. Treatment process footprint, capital and operational costs may be relatively easily recalculated for an increased pumpout/treatment period above 24 hours. It may be possible to increase the pumpout period to 36 hours in which case required hydraulic and biological treatment capacity would be reduced by 1/3. However, the stored flows may become septic leading to treatment and odour issues. This would require further investigation.

Inter-stage pumping has not been included in this study as this operation is very dependent upon the detail site layout. It has been assumed that the lift from the main pumps will be sufficient to facilitate gravity flow through the treatment processes thus requiring minimal inter-stage pumping. The cost of land acquisition is assumed to be included elsewhere. Membrane Bioreactor options have not been considered appropriate as the current examples are for low treatment only. The capability to increase size and capacity is unproven and operational costs are very high.

Within most of the levels of treatment several different process options were sized and costed. This will allow different levels of treatment to be applied from this matrix as total flow increases. A possible approach would be to give preliminary treatment to all flows up to the treatment limit, primary treatment up to a point where the polluting load from colloidal BOD/COD became relatively insignificant and secondary treatment to the smallest portion of flow until the polluting load from Ammonia-N became relatively insignificant.

Any combination of processes could be proposed and costed hence there are a very large number of possible outputs from this study. The full range of capital and operational costs are included in the treatment study report. The cost of incremental treatment can be illustrated by the ratio of costs incurred for moving from one stage of treatment to the next.

To move from Level 1 to Level 2 the capital cost increases by a factor of 4.3
To move from Level 2 to Level 3 the capital cost increases by a factor of 1.3
To move from Level 3 to Level 4 the capital cost increases by a factor of 1.7

Level 1 (screening and de-grit) to Level 2 (primary sedimentation) requires the largest incremental increase, but achieves 25% BOD removal and 50% TSS removal.

Moving from Level 2 (primary sedimentation) to Level 3 (enhanced primary sedimentation) increases the relative removal of BOD and TSS by x 1.6. The increase in capital cost is modest, though the increase in operational cost is high. This suggests that Level 3 offers cost advantages over Level 2 as significant improvement in BOD and TSS removal should be obtained for modest additional capital cost.

Moving from Level 3 (enhanced primary sedimentation) to Level 4 (secondary treatment) increases the relative removal of BOD by 2.3 and TSS by 1.16. The capital and operational costs are higher.

Additional work needs to be done to confirm the capacity of the Incinerators to process the sludge produced by any combination of processes. The cost of additional sludge facilities has only been included for thickening to 5%DS and holding tanks. If the sludge needs to be treated at both Incinerator sites at Beckton and Crossness, this will require a sludge transport mechanism between the two.

8.2.6 Précis of Pumping Study – KSB

8.2.6.1 Discussion of Study

The proposed solutions for screening the Thames Tideway Combined Storm Outfalls generally involve collecting the individual flows into deep, large diameter tunnels several kilometres or more in length. The flows from each outfall will drop into such tunnels by gravity, but pumps will be required to lift the combined storm water back up to ground level for screening, treatment and discharge back to the river.

The flows and heads of these pumping stations will be larger than those of any existing storm sewage installations, and the differential head required of the pumps will be variable for most of the options considered, due to surcharging of the tunnel by water in the drop shafts and the tunnel's own flow characteristics. The combined storm sewage from Central London is known to be difficult to deal with, because of its high grit content and the large quantities of screenings it carries. The pumps must therefore be resistant to abrasive wear and blockage.

A further problem will lie in the testing and commissioning of the pumping plant. In general, when very large mechanical plant is first put to work in novel situations, a certain amount of trial running and troubleshooting is necessary before reliable operation is achieved. The unpredictable nature of rainfall will make such exercises very difficult to carry out with the Tideway pumping plant. Trial pumping with river water would be possible, but it would lack the grit and screenings content, and it might be difficult to avoid entraining and killing fish.

Thames Water commissioned KSB to carry out a study of the feasibility of pumping storm sewage under these conditions and of the technical factors, which would be important. Their report runs to 99 pages: the main points are summarised hereunder.

The hydraulic design of the pumps will have to be a compromise between the desire for efficiency in pumping the large flows involved and the need to minimise abrasion and blocking. An impeller design of high efficiency can be used if the leading and trailing edges of the impeller vanes are modified to limit local flow velocities and hence reduce the force of impact of grit particles, and if relatively slow rotational speeds and large impeller passages are used to eliminate blockages. In order to provide resistance to abrasion and cavitation, particular grades of stainless iron are recommended for the impeller and wear rings. Low rotational speeds will also reduce the pump's tendency to cavitate. Cavitation is still inevitable because of the range of flow and head required, and so resistant materials are essential. There are also important secondary erosion mechanisms related to the tendency of grit particles to stratify in the flow through the impeller, and also the occurrence of vortices at the leading and trailing edges of the impeller vanes. The effects of these can again be minimised by particular hydraulic design features, and by the resistance of the stainless iron. Optimal grades of stainless iron and steel have been identified for all major pump components.

Pumps capable of the range of flow and head we need are already manufactured for use with slurry in the mining industry. The idea of using these existing designs incorporating the appropriate materials seems promising. Mining slurries are much more abrasive than combined storm sewage, and so the casing and impeller contours needed to minimise abrasion are already available. The impellers of these pumps are not specifically designed to resist blocking by screenings, but with a through let of typically 360mm they would be expected to perform well in this respect. A test facility is available where one of these pumps could be test run either with storm sewage tankered in, or with mains water laced with rags and other material. It is very encouraging that proven designs exist which seem to be able to meet our requirements with minimal modification.

It is suggested that the pumps should be fitted with condition based monitoring to record vibration levels, thrust bearing deflection, and bearing temperatures. This would help to protect these very large and expensive machines from component failures and consequent serious damage.

Based on German practice for large diameter sewers, it is suggested that butterfly valves be used in the pump discharge pipework. Each pump would have two such valves: one as a simple isolating valve, the other a hydraulically operated unit that would function as a reflux and anti-surge valve.

The suggested maximum flow velocities are 2 m/s for the suction pipework and 2.5 m/sec for the delivery. This is to minimise abrasive wear. Equally, velocities should not drop too far below these figures in order to keep the grit entrained in the flow.

The KSB study included the modelling of a pumping system drawing from an early design for a maximum intervention storage tunnel. The model demonstrated that currently available mining pumps could deal with typical and severe storm events. Variable speed control was essential to match the pump performance to the changing conditions in the tunnel: the big variations of head as well as of flow prevent control being achieved simply by using multiple units and switching individual pumps on and off. Various options for implementing variable speed control have been examined: the best seems to be variable frequency inverter drive to electric motors. Engines are not practical at the bottom of a deep shaft and neither would a drive shaft arrangement 80 or100m long from the engines at ground level. Hydraulic transmissions in the MW range were previously made for rail traction, but have long fallen out of use due to the better reliability and practicality of electric drives. However the need for variable frequency drives complicates the power arrangements.

An approach to the transfer options was also modelled, this being the situation which would arise if two severe events appeared in immediate succession, so the second would strike the tunnel when it was already full, and so require the terminal pumping station effectively to take the full arriving flow with little attenuation. Again, it was possible to deal with the situation using mining pumps under variable speed control, however the numbers of pumps (30) and the power consumption (nearly 150MW) were high.

The initial KSB study has shown us that even quite extreme solutions can be accommodated by development of existing pump technology, although the scale of the numbers is very large by water industry standards. Further work is being carried out by KSB on three of the less extreme solutions, particularly the Western Partial Solution, Option H. Using the work already done, it has been possible to produce broad estimates of the pumping power required for all the options currently under consideration. These estimates have been made without any detailed modelling of the operation of the respective systems. Therefore the numbers and ratings of pumps in the tables are a good indication, but may well be subject to detail change in the event of a particular option being pursued.

Points to note from the table are the extremely high power requirements for Options B, C, and D. Option G and the maximum intervention version of Option A are little better. The medium and low intervention versions of Option A and the allied Option H are more realistic in terms of achievability. Options E presents quite a modest power requirements in comparison and Option F is just about realistic, but both require multiple pumping stations (102 for E and 43 for F) to be constructed on the river bank or in the foreshore in Central London.

Option H would be a pumping station located adjacent to the existing Heathwall PS. There would be two large pumps (duty and standby) operating at variable speed to pump storm flows to treatment and thence to the Thames. Smaller fixed speed units would pass flows through the existing Cross Thames Link Sewer to Western PS and ultimate treatment at Beckton, and separately to the adjacent LL1 (South) sewer to treatment at Crossness. This is currently being studied by KSB as the most realistic option.

8.2.6.2 Application to Potential Solutions

The pumping requirements for each potential solution are summarised in Table 36.

Table 36 : KSB – Summary of Potential Solutions pumping requirements

Potential Solution	Intervention Level	No of Pumps Running at Max Output	Total No of Pumps	Total Maximum Running Power MW	Capital Cost of Pumpsets £k	Total Capital Cost inc.Pump Installation £k
A	Maximum	11	14	65	7,000	15,000
	Medium	6	7	15	3,500	8,000
	Low	3	5	6.5	2,500	6,250
B	Maximum	48	53	280	26,500	57,000
	Medium	24	27	130	13,500	29,000
	Low	10	12	60	6,000	13,000
C	Maximum	64	80	220	32,000	65,000
	Medium	32	40	110	16,000	32,000
	Low	8	16	44	6,400	15,500
D	Maximum	67	84	230	35,000	70,000
	Medium	34	43	115	18,000	36,000
	Low	9	18	46	7,500	17,500
E	Maximum	106	211	17	5,700	11,500
	Medium	55	110	8.5	3,200	6,500
	Low	29	58	4	2,100	4,500
F	Maximum	43	86	56	50,000	100,000
G	Medium	20	25	84	12,500	27,000
H	Medium	1	6	4	1,000	3,000

These costs exclude power supply, standby generation, switchgear and control, ventilation, odour control and other mechanical/electrical plant, which are included elsewhere.

8.2.7 Précis of Power - McLellan

8.2.7.1 General

Electrical Power requirements for the Tideway Strategy Options are wide ranging.

A transfer tunnel option has the highest power demand at a single connection and a fully distributed outfall solution will have the lowest (individual) power demand at a single connection. The project range of power required is likely to be from around 350MW to 1MW (and below), at any individual site.

These extremes (and options between) will have very differing solutions and widely variant cost. High power requirements will involve connection to the National Grid or be achieved in provision of a stand-alone generating power station. Lower power may be available from the existing network of distribution, with or without network reinforcement. Where connection is impractical or costly, local generation is the only solution.

To quantify recognised options, McLellan and Partners were commissioned to study and report on the various methods of connection to grid or network and the requirements for independent generating plant. Their findings are presented in their Report.

In essence, McLellan's findings are that it is not practical to determine a solution or the estimated cost of a power supply connection to grid or network until the power demand is known, the location agreed and a programme date established. This arises since grid and network distribution are dynamic. Power becomes available in reinforcement and is taken up in committed development. Availability cannot be forward projected. There is, therefore an element of uncertainty, both in the viability of a power supply solution and in its method of implementation

Viability of an alternative of generation will be determined by non-availability of power from grid/network or in whole life cost and environmental assessment showing generation to be advantageous.

The McLellan report uses a unit cost, building block, approach that allows for interpolation to suit a wide range of strategy solutions.

8.2.7.2 Maintenance of plant

Connection to grid or network will not impose any specific maintenance issues in respect of the power supply. The power supplier will be expected to maintain primary switchgear and transformers.

Generation requires fuel storage/delivery and implies exhaust pollution, noise and vibration in operation and maintenance. For a generation alternative long periods without operation will be onerous for mechanical plant maintenance.

8.2.7.3 Ground Area

A consideration for all installations is ground area. A 350MW installation will require in the order of 11000m^2.

It is probably that power can be made available at any location under consideration. Final cost will depend on the degree of network reinforcement required for the secure connection needed.

There will be a significant impact of space availability at individual outfalls, especially where the addition of screening adds a head loss that will need to be managed by the addition of a pumping installation.

Even the smallest of the distributed outfalls where screening is planned will require space for control gear as a minimum and may additionally need switchgear and transformers. The alternative of local generation will require space for the generator, fuel storage and consideration of environmental impacts such as noise and pollution. In many locations the cost may be prohibitive.

Guidance to space requirement is given in the McLellan report.

8.2.7.4 Costs

Costs included in the McLellan report are based on data given by National Grid and by the REC network supplier, 24seven.

National Grid connection will only be required (and will only be practical) for an installation in proximity to a National Grid substation. This would be for major installation at e.g. Beckton and will not be appropriate for distributed solutions.

Indicators for network connections via the REC are based on an assumption that the network will need reinforcement at each location.

An apparent anomaly in costs for 50MVA installations under Case 1D and Case 2A arises since Case 1D is costed for a higher voltage connection to the National Grid and Case 2A is costed for a lower voltage connection at the REC network.

The final cost of any connection will depend on the capacity of the network at each location, what level of reinforcement is required, by what strategy reinforcement is carried out and over what distance. All major reinforcement schemes have extended lead-time. This will be particularly so if National Grid reinforcement is required for the larger power demands of e.g. the transfer tunnel.

8.2.7.5 Electrical Operational Issues.

For any electrical connection to the network there is a standing charge for the capacity required. For a network connection at high voltage this is approximately £1,200/MW/month. This figure is payable irrespective of demand usage. For infrequent operation of a large capacity connection this figure may be significant, especially where the maximum capacity is not often required.

Similarly, there are cost and maintenance issues of installing a large generating plant for infrequent operation, again especially where the maximum capacity is not often required.

Network power will be available on demand. Any generation installation will require a finite time for start-up. Reliable generator start will necessitate regular maintenance.

Any solution that offers a steady load over extended periods will optimise the cost of electrical power. This would seem to favour a bulk storage scheme with steady pump-out.

The overall power requirements are summarised below.

Table 37 : McLellan – Summary of power requirements

Potential Solution	Int' Level	No of Pumps		Total Maximum Running Power MW	No of sites	Av'b'y Charge £k p.a.	Network Connection		On-site Generation	
		No at Max Output	Total No				Capital Cost £k	Total Annual OPEX £k	Capital cost £k	Total Annual OPEX £k
A	Max	5	7	65	1	936	24,104	1089	39,000	782
	Med	3	4	15	1	216	16,653	356	25,600	564
	Low	1	2	6.5	1	94	16,653	211	14,000	361
B	Max	48	53	280	1	4,032	54,255	4,174	112,000	1,863
	Med	24	27	130	1	1,872	48,965	2,000	58,500	1,043
	Low	10	12	60	1	864	24,104	980	36,000	689
C	Max	64	80	220	8	3,168	137,080	3,251	165,000	2,582
	Med	32	40	110	8	1,584	133,220	1,665	66,000	1,094
	Low	8	16	44	8	634	133,221	702	44,000	747
D	Max	67	81	230	9	3,312	154,215	3,446	172,500	2,760
	Med	34	41	115	9	1,656	149,873	1,777	69,000	1,191
	Low	9	17	46	9	662	149,873	761	46,000	817
E	Max	106	211	17	103	245	50,856	300	17,000	326
	Med	55	110	8.5	55	122	27,156	175	8,500	196
	Low	29	58	4	29	58	14,319	103	4,000	118
F	Max	43	86	56	43	806	21,231	823	56,000	862
G	Med	20	25	84	1	1,210	22,950	1,729	46,200	1,362
H	Med	1	6	4	1	58	888	107	2,000	93

8.2.8 Précis of Screening – Thomson RPM

8.2.8.1 Principle Conclusions and Recommendations

- Ensure screens are adequately sized – assume 250l/s per m^2 effective screen area for types of screens used for Tideway Projects
- Consider use of drum screens where flows are greater than 20 m^3/s
- Wash Water supply is critical. Sufficient supply for cleaning is required
- Use maceration/grinding to achieve volume reduction
- Skips need to be covered to prevent rewetting.

8.2.8.2 Application to Potential Solutions

The principle findings of the study have been extrapolated for each potential solution and level of intervention as appropriate. These are summarised in Table 38.

Table 38 : Thompson RPM – Summary of Principle findings

Solution	Intervention	Flow (m^3/s)	No. Screens	Screen Type	Screenings Quantity (tonne/hr)	No. Liseps @12m3/hr	Wash Water Flow (l/s)	No. skips
A	Maximum	50	4	Drum	72.0	7	160	32
	Medium	25	3	Drum	36.0	4	120	16
	Low	10	3	Band	14.4	2	60	6
B	Maximum	240	10	Drum	345.6	30	800	160
	Medium	120	5	Drum	172.8	16	400	72
	Low	50	4	Drum	72.0	7	160	32
C	Maximum	40	3	Drum	57.6	6	120	28
	Medium	20	2	Drum	28.8	3	80	14
	Low	8	3	Band	11.5	2	60	6
D	Maximum	12.7	3	Band	18.3	3	60	10
	Medium	6.4	3	Band	9.2	2	60	6
	Low	2.5	2	Fine	3.6	2	40	3
E	Maximum	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Medium	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Low	n/a	n/a	n/a	n/a	n/a	n/a	n/a
F		n/a	n/a	n/a	n/a	n/a	n/a	n/a
G	Gravity	55	4	Drum	79.2	8	160	36
	Pump assist 20m	110	5	Drum	158.4	15	400	66
	Pump assist 40m	150	6	Drum	216.0	20	480	90
	Pump flushing	130	6	Drum	187.2	16	480	80
H		5.5	3	Fine	7.9	2	60	6

8.2.8.3 Discussion of Study

Introduction
There are 55 Combined Storm Overflows (CSOs) located along the tidal section of the River Thames through London. Of these 49 will need to be intercepted. The combined potential maximum flow from these sites is approximately $420m^3/s$ and the sewage litter load (aesthetic pollution) to the Thames from them is potentially high. There is no current data for sewage litter loads, however from the investigative work using the SCITTER plant at Acton average concentration values of $1500g/m^3$ have been recorded with peak values in excess of $3000g/m^3$. This may not be representative of the whole Tideway as the generation of sewage litter during a storm event is thought to be very catchment specific. The Environment Agency has stated the minimum objective of capturing this litter and removing it from the flow.

Screening Treatment Type Review by Thompson RPM

Thompson RPM was commissioned by Thames Water to carry out a survey of available screening technology and to come up with criteria for screen selection. The report was jointly funded by the Tideway Strategy and the Waste Water Treatment Programme, and therefore looked at all sizes of screen, screenings treatment and grit treatment, rather than just those that might apply to the Tideway Strategy.

The primary output from the report was a flow chart to select types of screen according to different criteria. These charts are included in the full report by Thompson RPM.

Selection Criteria and Drawing Requirements

It is noted that there is no one glove fits all category of screen. Each individual site will have its own peculiar requirements, and the variety of ways that the equipment can be installed is now shown in the guides with the leading dimensions. Another factor in the selection of the screen will be the downstream process. It may be a requirement that there is no carry over, i.e. no particle larger than the screen hole diameter or screen bar width bypassing the screen capture.

There are no hard and fast rules for screen layout, and some of the screens have a variety of ways of being installed. They will all have similar restraints as follows:

- Limiting approach velocity in the flow approaching the screen, typically 1 m/s
- Headloss across the screen due to the constriction in the flow. This will usually be in the order of 200-300mm
- In general, the screen should be sized on the basis of 250l/s per effective square metre of screen for moving screens and 100l/s per effective square metre of screen for static screens
- For the Tideway projects, for flows greater than 10 m3/s, where space permits, it is suggested that a drum screen would be preferable. They have less moving parts, and would require less maintenance. At lower flows, however, the cost of the civil works required for a drum screen may be more prohibitive.

The major criteria for selecting a screen may well be the space available and the juxtaposition of other facilities and structures. There may limitations imposed by the screen structure such as minimum and maximum widths and depths and therefore channel design will have to accommodate these. Space will also have to be allowed for maintenance around the screen and withdrawal of components without dismantling adjacent equipment or structures. Finally, overhead access and some form of lifting facility will be required in order to maintain major components.

Grit and Stones

Most screening and screenings treatment machinery is susceptible to damage and wear due to grit and stones. As launder channels are used for the type of screens that will be required for the Tideway projects, it is necessary to incorporate a stone trap in the launder channel and grit traps and pumps in the conditioning tanks of macipumps, or chopper pumps.

Other Services

An important consideration in the sizing and selection of any screening process is the availability of ancillary service.

An adequate electricity supply must be made available, not only for the screens, which will be relatively small, but for all the required accompanying services: stone trap, screenings treatment, skip loaders, wash water pumps, grit treatment, grit pumps, liquor/drainage pumps, site lighting.

For the types of screen required for the Tideway Projects, a supply of washwater for cleaning the screens will be required. This water may also be used for transporting the screenings and in the screenings treatment process. In a normal sewage treatment works, this water would be supplied by final effluent, but in the case of the majority of CSOs, there are no downstream processes and therefore consideration needs to be given to using strained screened effluent, potable water, groundwater from boreholes or river water. All of these options cause operational problems or raise licensing issues.

Screenings Handling

Where CSO screens are mounted on overflows, and there is a carry-on flow to a works, there is no need to keep the screenings for treatment. The vast majority of the Tideway CSO will be terminal CSOs with no carry on flow to take the screenings away and the screenings are removed from the flow. Therefore screenings handling equipment is required to wash and dewater the screenings

The quantity of screenings expected from the installation of screens at any location cannot be accurately determined as this is a characteristic of the catchment. Based on data measured in other urban environments, it has been estimated that the average quantity of screenings collected could be in the order of 400 g/m^3 to 2000 g/m^3 of storm flow with peaks up to 4000g/m^3 (before dewatering).

Screenings Treatment

The design guide reviews suitable equipment along with leading dimensions. The main points to remember when selecting equipment is the power and water required, the frequency and duration of operation, the volume/weight reduction of the process (and subsequent disposal costs) and any limitations on the disposal route. A requirement that has emerged more recently is the quantity to be disposed of, and it has been shown that macerated or ground screenings offer an improved volume reduction; therefore treatments that macerate the screenings are preferred. These systems also offer the benefit that the screenings are less identifiable as having come from a sewer, and, in some cases, this makes it easier to take to landfill.

Skips

A common issue on most sites is that of open skips, which allow dewatered product to be re-watered by rainfall. This could lead to the skip being rejected by landfill operators as it is deemed to be liquid waste and needs to be disposed as such. Therefore all skips need to be covered.

8.2.9 Précis of Screenings and Grit Disposal – Engineering

8.2.9.1 Principle Conclusions and Recommendations

- A company wide strategy is required for screenings and grit disposal
- New study required to review potential use of gasification
- It is necessary to know the characteristic of the catchment before determining a solution.

8.2.9.2 Application to Potential Solutions

The principle findings of the study have been extrapolated for each potential solution and level of intervention as appropriate. These are summarised in Table 39.

Table 39 : Screenings and Grit Disposal - Summary of principle findings

Potential Solution	Level of Intervention	Flow Intercepted per year Q(m3)	Weight of treated screenings per year W(tonnes)	Number of skips per year	Cost of disposal per year (£k)
A, B, C, D & E	Max	12,200,000	2,928	293	278.2
	Med	11,820,000	2,837	284	269.5
	Low	9,920,000	2,381	238	226.2
F	-	12,200,000	2,928	293	278.2
G	-	11,820,000	2,837	284	269.5
H	-	6,383,000	1,532	153	145.5

The figures in the table above are arrived at considering an average screenings load of 1200g/m^3. Although potential solutions A to E and G are based on very different concepts of operation, they will capture sewage litter in proportion to the level of intervention. Potential solution F would capture the same as the maximum level of intervention and H only intercepts half of the total flow to the river.

8.2.9.3 Discussion of Study

Introduction

The purpose of this report is to review the issues surrounding the disposal of screenings and grit that will be collected from fine screens on flows some of the 54 CSOs in the tidal section of the River Thames.

The Screenings and Grit to be disposed of

The screenings and grit, in the case of the 54 outfalls that form the Tideway Project is assumed to be screenings larger than 6mm in 2 directions, grit that may have been collected separately in a grit trap and extracted by a separate system and stones that may have been collected separately and extracted by a separate system.

Sewage litter, often referred to as screenings, largely consist of items that could easily be disposed of by alternative means and include sanitary towels, condoms, disposable nappies, plastics of various forms, fat, clothing and miscellaneous items.

Grit is generally road gravel that is washed in by storms. This needs to be separated out in order to prevent damage to the screenings conditioning equipment.

Stones are items collected in stone traps. These items may include stones, but are noted to include (from observations at Mogden and Maple Lodge) golf balls, tennis balls, fat balls, wood, plastic bottles full of water, etc.

Quantities

For the main east London Treatment Works:

Table 40 : Screenings and Grit disposal volumes

Site	**Tonnes per year**
Crossness	4,022
Riverside	1,000
Long Reach	3,008
Beckton	5,800
Expected from Abbey Mills CSO	3,200
Total	**17,030**

As can be seen from the above figures (Table 40*Table 40*), the amount generated by the storm screens at Abbey Mills is expected to be only 18% of that from all the East London sites put together and therefore does not justify a solution in itself, especially as the production rate is going to be so erratic. The cost of disposal of screenings as a whole, however, is an issue that is going to be company wide and needs to be reviewed alongside the issues of sewage sludge disposal.

8.2.9.4 Current Disposal Issues

The current method of disposing of screening is to put them in a skip and call the contracted operator to take it away, typically to landfill, as this is currently the cheapest option for road transported skips. There has been little incentive for contractor's to develop alternative disposal strategies, although Thames Water is considering alternatives.

The disposal costs estimated for the AMP3 Tideway CSO Fine Screening project at Abbey Mills SPS are:

- £120 per journey at weekdays and regardless of weight
- £180 per journey – weekends and bank holidays regardless of weight
- Landfill costs of £23 per tonne
- Landfill tax of £12 per tonne this year rising £1.00 per year for the next two years after which it is expected to then rise rapidly to meet European levels of taxation.

Whilst the £23 per tonne sounds quite reasonable, the actual cost is more like £60 per tonne once transport and skip rental is taken into account.

It is also noted that the quantities of screenings collected can be 20-30 greater than that collected in dry weather flow at an inlet works. The average loading could be 400 g/m^3 to 2000 g/m^3 of storm flow. Based on this and figures of flow duration and quantities from Abbey Mills PS, it has been calculated that the fine screening plant being installed there could have filled 35 container skips in one storm on the 29 June 1999.

For Abbey Mills, this means that up to 16 Liseps / washpactors may be needed, feeding at least 40 skips plus associated controls and services, costing about £7.5 million, plus the operation and maintenance costs, and a 3000 kW electricity supply.

10 tonne Limit

It has become apparent that some landfill sites impose a 10 tonne daily limit for screenings disposal. This limit seems to based on the practical issue of having to cover the tipped screenings with inert material in order to allow subsequent deliveries to the landfill to be safely tipped, to allow traction of tipping vehicles, and to prevent the spread of contaminated material to other parts of the site or the public highway.

There problem is also exacerbated because the screenings being identifiable as having just been hauled from the sewer and were, in some cases, very wet. Further discussions with tip operators indicate that if the quality were improved (cleaner, drier, macerated) then this limit would not be necessary. Investigating the differences between the output of various screenings conditioning equipment, it is noted that the volume reduction achieved by a J+A Washpactor is about 52%, whereas a JWCe Screenings Washer Monster and the Haigh Lisep achieve 80 – 90% volume reduction. This has a dramatic affect on the amount of screening handling required and the operational costs in terms of waste disposal; however, there is an increased maintenance requirement for this plant.

Regulations

Landfill sites are currently being re-licensed under the IPPC regulations, and as part of this, all sewage screenings need to undergo some form of pre-treatment. This must include washing, as compaction and dewatering are not classified as pre-treatment, although clarification is required from the EA as to the amount of treatment required.

There are now requirements from the new landfill directive on the quality and the amount of liquid in the waste. This means more capital is required for treatment equipment and correspondingly more power, water, maintenance and manpower.

A new regulation effective from 16 July 2002 is the classification of waste in a skip as liquid waste. The ruling states that a skip load is classified a liquid waste if it meets the <u>lesser</u> of the following categories:

- There is 250 litres of free liquid in the skip
- 10% of the load is liquid (the lesser of weight or volume)
- A small depression made in the load quickly fills with liquid

Under the latest revisions to the European Landfill Directive, waste, which fails the above tests, is a liquid waste and cannot go to landfill. This will have most effect on grit, but will also affect screenings where the treatment equipment is in poor condition.

It is noted that current screenings treatment machinery, where maintained, meets these requirements where the skips are covered.

Alternative Disposal Routes being investigated.

(i) Incineration – Municipal Waste Incinerators

Continental Europe has long ago decided that incineration is the most practical method of disposal of screenings and deals with about 85% of its screenings in this manner. The UK, however, has been slow in this area with less than 4% being disposed of by incineration and there is now a very strong opposition lobby to any further incineration being developed, especially by Greenpeace, Friends of the Earth and local residents.

There are two municipal waste incinerators in London, one in Edmonton and one in South London. Thames Water has previously pursued incineration of screenings at Edmonton before privatisation. It is not known why this was not developed further. Efforts to discuss this with London Waste Ltd, the operators at Edmonton have not proved fruitful to date. The UKWIR Report on Screenings: Quantity and Quality, Report Ref. No. 00/WW/06/3 notes that incineration becomes a viable option when gate fees for landfill exceed £30 per tonne. Once considered one the possible disposal routes, however public opinion and pressure groups have caused 36 recent applications for new incinerators to be abandoned.

(ii) Incineration – Cement Kilns

One side effect from investigating incineration has been the discovery that the cement industry is on the search for alternative fuels for their cement kilns. Blue Circle currently operate a kiln in Northfleet and are developing its replacement in Medway. Both sites are on the river and a similar distance as Rainham landfill is from TW sites in London.

Blue Circle has been approached with a view to accepting screenings as fuel for their incinerators. However more information on the variability of the screenings is required. It is therefore necessary to carry out some more tests on East London screenings. These analyses will not only be useful to determine the possibility of burning our screenings by Blue Circle, but could provide data to enable other incinerators to determine the acceptability of sewage treatment wastes.

(iii) Gasification

The possibility of gasification has been researched extensively within Thames, especially for use at Mogden STW, with a pilot plant having been built to prove the principle at Maple Lodge. The scheme at that stage was originally conceived for the generation of electricity, and it was looked at using waste from Mogden and also for waste from surrounding sites to see whether the cost of such a plant was cost effective. For the generation of electricity, successive reviews have shown that the plant would not be cost effective for the foreseeable future.

However, along with RWE, there has been growing interest in the development of engines and power sources that use pure hydrogen. One such user would be the London bus operators who would be interested in a viable source of hydrogen to run their busses. Hydrogen as a vehicle fuel commands a higher premium than electricity and this could make gasification a viable option. This is an area that needs further investigation.

(iv) Education

In researching possible disposal issues, along with the contents of the UKWIR Report on Screenings: Quantity and Quality, Report Ref. No. 00/WW/06/3, there is a reasonable quantity of material caught by screens that could be reduced by an appropriate education campaign. Discussions with some London local authorities revealed that they currently have education campaigns running in local schools to educate children on the needs and benefits of recycling, bagging and binning, etc. They were receptive to the idea that Thames Water could get involved in these campaigns so that the campaigns included education about what should be disposed of down the sewer system, and could also include water use education. The feedback that they have measured from their current campaigns show that they are effective and that by educating the children, they force the parents to recycle and dispose of waste with more care. Aiming the education at adults proved to have little effect.

(v) Alternative Transportation

In trying to develop solutions to screening handling problems for the central London sites for Tideway, the option of trying to make use of the barges that carry municipal waste was investigated. There are two operators currently moving waste by barge out of London, they are Cleanaway and Cory. Cleanaway has been the more forthcoming with information. Their preferred method would be to make use of 9 of the 18 ISO containers usually fitted to each barge. However, they also have the facility for handling loose filled barges or containers, although the equipment at Rainham will need to be recommissioned and reinsured for our use. Assuming that the mooring of barges can be achieved local to our CSOs, the use of these barges may well solve the problems of providing skip storage and transport of skips.

If barge transport proves economically viable, it might provide an alternative for the East London works at Beckton, Crossness, Longreach and Riverside as well as the Tideway site on the main river.

It is noted that river transport is a preferred method of transport to road transport and that London Boroughs, through the GLA, are actively promoting river transport ahead of road transport options.

(vi) Use of Existing Infrastructure

It is noted that the storm screening at Abbey Mills requires a lot of equipment to be provided at Abbey Mills for treatment, dewatering, packing of screenings that will spend 95% of the time (400 hours of storm out of 8760 hours per year) standing idle. Manning the site will be necessary to ensure that the equipment is available when a storm occurs for many unproductive hours.

The alternative to having the treatment equipment located at Abbey Mills is to consider the transfer of the extracted screenings to a site where they already have the infrastructure and manpower for looking after the skips and treatment equipment. This could be done by either returning the screenings to the Northern outfall sewer or by direct pipeline to Beckton STW. For this second approach the screenings could be chopped or macerated, stored in storm tanks, and pumped at a lower rate. The tanks would be fitted with mixers and tank washing to keep them clean. A similar system, though based on a much shorter pipeline, is in operation at Mogden STW. However reliability has not been good as grease and rags form solid mats in the storage tanks. Operational and maintenance of this system has been very challenging.

Screenings from the storm screens at Abbey Mills are only 18% of the total east London screenings production. Screenings from other Tideway solutions would not significantly add to this total, and therefore the Tideway Storm Screening, in itself, does not constitute enough of problem to justify developing a standalone disposal strategy. It does need, however, to be considered as part of a company wide strategy for dealing with screenings and sludge in light of changes to the landfill regulations and pricing. It is therefore recommended that there is a revised study into gasification of screenings and sludge for east London sites, including tideway storm screenings, to review the economics and practicality of such a disposal route.

More work needs to be done on reviewing the installation of screenings treatment plant at unmanned sites, and the wisdom of such an investment which will be idle for the majority of it's life. For Abbey Mills, this work will be done as part of the Phase 2 design review, but also needs to be considered when developing the strategy for screening at other standalone sites on the Tideway (Greenwich).

8.2.10 Précis of Control System – Thames water Engineering

8.2.10.1 Introduction

Primary control of the selected option for the Thames Tideway Strategy will reside in small control kiosks local to the penstocks, pumping stations, and other associated plant installations. This local control will provide automatic response to local conditions, a Human Machine Interface (HMI), and a means of gathering operational data and transmitting these data to a central 24-hour manned facility.

Due to the nature of the operational decisions to be made for system management,

- Duration of present and immediate forecast rainfall events
- Available capacity in the system
- Available treatment capacity
- Power demand consideration

There will be a need for expert decision making, supervised by human operators.

Thames Water will require high operational security, and system analysis, for such critical and large-scale plant. Within the Operations Management Structure of Thames Water a number of area level control rooms exist which could provide the environment for the strategic control of the Tideway System.

8.2.10.2 Architecture

To provide the visibility and control to the Control Room Operators, a SCADA system built to handle between 500 to 1000 I/O points would be appropriate. The SCADA package would allow for display of operational data and command intervention in real time, and an archive of strategic data for operational analysis in tabular and graphical formats.
Within the timescale of this project it is also likely that the SCADA system would provide operational decision support displays.

The SCADA system would be based on a number of desktop clients accessing a central dual redundant file server computer. The desktop workstations may or may not be within the same building as the host server. The SCADA server would be linked to the satellite local control stations for data gathering and control.

In addition to the SCADA system of control a remote Alarm management system based on the Wastewater Operations Serck Telemetry would be required, to provide the Maple Lodge Management Support Centre visibility of plant alarms, etc.

8.2.10.3 Location

The most appropriate location for the remote control centre would provide the following features:

- Existing 24 hour operation
- Access to final treatment capacity status
- Secure communications and power supply
- Physically close to the Area Operations Management Team
- Good computer system support environment

The Central Control Room in the Beckton SPG (Sludge Powered Generator) would be an ideal facility.

8.2.10.4 Communications

The practical media that would support the SCADA communications are:

- BT Leased Line
- BT Public Switched Telephone Network (PSTN)
- BT Integrated Switched Digital Network (ISDN)
- Corporate landline
- Radio
- Mobile Phone (GSM)
- Microwave transmission

Because the plant installations are largely within the London area and therefore served by a comprehensive BT network, the first three options are the most cost effective.

The Thames Water Alarm Telemetry system is supported by the BT PSTN communications.

8.2.10.5 Costs

Indicative costs for such a system break down as follows,

Installation

• SCADA Servers and workstations (2) supplied and programmed	£75k
• Local Outstations (included in overall budget costs)	
• Telemetry Outstations supplied and programmed	£10k / site
• BT Leased Line	£5k / site
• BT PSTN / ISDN	£500/ site

Rental

• BT Leased Line	£3k/ site/ yr
• BT PSTN / ISDN	£1k/ site/ yr

These budget costs are relatively low and are deemed to be generally included within the overall budget estimates.

8.2.11 Précis of River Quality Study – Environment Agency

8.2.11.1 Analysis of historic events

Historic rainfall events that have been associated with a significant reduction in DO levels, have been analysed using data generated from the AQMS. This data is available in half-tide and time series format and forms a comprehensive data base to study and identify the conditions under which the formation of oxygen sags occur in the river

The main difficulty associated with this study was the complexity of tidal movement in the river and there was a need to devise a simple method of displaying the four main variables of time, distance, DO concentration and tidal state, in a clear format in order to observe the changes that occur during the dynamic conditions when CSOs are operating.

The method eventually selected was to utilise a physical three-dimensional data model (normally referred to as the "TOTEM" model) displaying time, distance along river and DO concentration, superimposed on a baseboard showing tidal movement. Experience gained with this model enabled a more simplified two-dimensional derivative to be used at a later stage in the investigation

This allowed an evaluation to be made of how the DO in a particular zone of water varied with time and provided an indication of where and when a discharge occurred that may have impacted on DO levels. Using the prevailing tidal movement at this time and place, it was possible to determine the approximate origin of the sag and relate this to the position of known CSO outfalls.

The results of this detailed data analysis indicated, that for many of the rainfall events, the initial reduction in DO was first registered by the Kew AQMS on the ebb tide. This indicated that the origin of this effect must be a discharge to the river upstream of the Kew AQMS, the most likely source being from the Mogden STW that discharges to the river 3km above Kew.

There were also events where it appeared that the discharges from the CSOs in the Hammersmith area were moving upriver on the flood tide and merging with storm tank discharges from Mogden to form a zone of water with a severe oxygen sag, which then moved slowly seaward, expanding in length and dropping in dissolved oxygen concentration for a few days before recovery took place. Sampling and inspections at the Mogden STW revealed that at peak flows, following rainfall events, large amounts of activated sludge were lost from the final tanks and discharged to the river. It is thought likely that the presence of activated sludge in the river, when combined with the organic loads discharged from the CSOs and from Mogden storm tanks is likely to accelerate the oxidation rate of BOD and ammonia, and result in rapid uptake of oxygen, thereby causing the deep sags that have been observed. . A series of laboratory tests carried out by both the Environment Agency and Thames Water confirmed that, under laboratory conditions, this does occur. The results of these tests are included in the Activated Sludge Trials report in the appendix.

In addition to the oxygen sags that appear to originate in the Kew area, most large rainfall events cause a general deterioration in the river between London Bridge and Putney and the results of analyses of the available data suggest that the large pumping stations at Lots Road, Western, Heathwall and Falcon Brook are probably responsible for this

The effect of the CSO discharges in the middle reaches is less clear. Due to the larger volumes of water in this part of the estuary the river is slower to react. Four large treatment works are situated in these reaches, as is the River Lee, which is the largest tributary and contains a high proportion of sewage effluent. Variations in quality from these sources can create difficulty in differentiating between the effect of the CSOs and the sewage effluent. There is also a correlation between the spring/neap tidal cycle and DO concentration, which is thought to be due to the resuspension of previously deposited organic matter. It is likely, although at present there is insufficient data to support the theory that the main effect of the CSOs is to introduce large amounts of particulate BOD to the river. This solid matter is deposited on the bed of the river and has, over time, formed a large source of organic material that, not only exerts a high benthic demand, but under conditions of increased tidal velocity becomes re-suspended in the water column and causes an overall deterioration in DO levels.

8.2.11.2 Aesthetic Quality

Upon cursory inspection the river normally appears brown and silty, which is due to be its tidal nature. Interception of the CSOs will not change this generally turgid appearance. However the offensive conditions caused by sewage litter will be prevented or mitigated.

The river has been inspected during and after a number of rainfall events and the effect of the CSO discharges on aesthetic quality has been assessed. Large greasy, grey/black slicks with associated floating sewage-derived material was observed in all of the reaches to which the CSOs discharge. On the ebb tide, sewage solids are deposited on the foreshore and are clearly visible. The most badly affected parts of the river are in the Putney to Vauxhall area but depending on tidal conditions and the operation of the CSOs, other locations can be very badly affected.

8.2.12 Précis of SUDS – Black & Veatch

8.2.12.1 Principle Conclusions and Recommendations

1. The application of SUDS techniques is not a solution in its own right.
2. The widespread retro-fitting of SUDS would be, at best, disruptive and costly and, at worst, not technically feasible
3. CSOs are relatively insensitive to any changes to the upper reaches of the catchment
4. Alternative disposal routes are scarce or not available.

Therefore the findings of the SUDS study are not appropriate to the range of potential solutions.

8.2.12.2 Discussion of Study

A study was carried out for the Tideway project by Black and Veatch to identify whether the application of Sustainable Urban Drainage Systems (SUDS) and similar "near-to-source" flow control measures could play a significant role in managing polluting loads discharged into the Thames Tideway from CSOs of the Beckton and Crossness sewer systems.

The available SUDS and other flow reduction/prevention measures suitable for application at, or near, to source were identified. Their potential benefits were described, initially in general terms and then in the context of the London situation. The major alternative disposal routes for flows removed from the combined sewer system, i.e. groundwater and natural watercourses, were identified and their potential use examined. In another strand of the study, pre-existing hydraulic simulation models were used to test the sensitivity of CSO spills to changes in inflow in the upper catchment. A limited review was made of experience elsewhere in the world (principally the United States) of large scale SUDS application to overcome CSO problems in major urban areas.

The primary conclusion is that the potential to significantly reduce the frequency and volume of CSO spills into the Thames Tideway by the application of SUDS is limited. The main reasons for this are:

- The densely urbanised nature of the catchment
- The paucity of alternative disposal routes for diverted surface water runoff.
- The relative insensitivity of CSO performance for larger rainfall events to changes in inputs in the upper reaches of the catchment.

These issues are further discussed below.

8.2.12.3 The densely urbanised nature of the catchment

The catchments are completely mature with very little space available for new construction. This makes widespread retro-fitting of SUDS, at best, disruptive and costly and, at worst, not technically feasible. For installations to be made on private sewers and on above ground controls there would be legal issues associated with working Ultra Vires.

The complete separation of the sewerage network was considered briefly. This would entail a completely new foul sewerage network in central London with connections to all buildings. The cost of this work is in excess of £12 billion and would be extremely disruptive to all Londoners over a long period. Similar work carried out for other Utility services cannot be compared with sewerage because of the size of pipes and excavation depths needed to maintain straight pipe runs.

8.2.12.4 The paucity of alternative disposal routes

There are few opportunities to dispose of substantial extra flow volumes to either groundwater or natural streams.

The sewerage networks incorporated many major streams during development in the 19th century. In North London there are no streams between the River Brent and the River Lea. In the south the Wandle, Beverley Brook and Ravensbourne still exist. But they are now a major part of the local land drainage arrangements and are themselves subject to over-topping and flooding in major storms.

London is situated on a clay stratum overlaid by river gravels and underlain by Thanet Beds and chalk. The lower strata are a major potable water source. Discharge of surface water runoff, which contains many types of pollutants, is not acceptable. The overlaying gravels are largely saturated and their capacity to accept additional flows questionable. Increasing water level in these strata would increase the risk of polluted water leaking to the potable aquifer.

8.2.12.5 Relative insensitivity of CSOs to changes in upper reaches of the catchment.

There is greater potential for SUDS solutions to be undertaken at the edges of the catchments. In these areas the development is more suburban with parks and larger garden spaces. However in these areas there is some partial separation of the networks already, and lower connectivity of impervious areas to the combined sewers means that sewers are generally smaller.

A sensitivity analysis was undertaken using the network model in which possible inflows to the sewers in the suburban areas were reduced by 10%. Discharges to the Tideway were reduced by less than a third of this reduction.

A further sensitivity check on run off flows for Crossness catchment was made. Reduction of flows by 10% caused a similar reduction in discharge volume, but since the catchments would still overflow at the CSOs in 2mm of rain in 2 days it was not considered that this change would significantly affect frequency of discharge and associated capital works.

Notwithstanding the above principal conclusions, actions were identified by which a degree of sustainability could potentially be introduced to the overall solution to the Tideway CSO problem and by which some improvement could be secured. The recommended actions include

- Developing a policy of encouraging the use of SUDS for all new developments in the catchments;
- Investigating opportunities to achieve reductions in base flows through public awareness to reduce water consumption, and the location and elimination of significant point inflows;
- Model testing to identify the requirements for additional in-sewer detention tanks in the upper reaches of the sewer systems; and
- Investigating the feasibility of an improvement scheme(s) based on the principles of partial sewer separation, inlet control and overland flow.

8.2.13 Précis of Land, Environment and Planning – LUC and Cascade

8.2.13.1 Principle Conclusions and Recommendations

The objective of the study was to identify sites along the Thames Tideway that are suitable for collecting, collating, conveying and screening or treating discharges from combined sewer overflows.

1. Initial study identified sites covering 18 London Boroughs and the Boroughs of Dartford and Thurrock.

2. Site identification criteria used - minimum footprint 2500m^2; situated within 1000m of River Thames, between Barnes Bridge and Dartford Crossing or 1000m from Stamford Brook halting at Acton P.S.

3. 112 sites identified but after further investigation this number was reduced to 46.

4. Study identified lack of potential sites in West London therefore open spaces were investigated, 172 were identified.

5. Availability of London sites changes rapidly, therefore dynamic nature of land required for future strategies needs to be recognised.

6. Identification and securing of potential sites is a key element.

7. Planning constraints are greatest around Central London but ecological restraints are common throughout the whole study area

8. Homefield Recreation Ground site is common for all schemes around West London

8.2.13.2 Application to Potential Solutions

The principal sites being considered for each option are indicated in *Table 35*.

Table 35 : LUC & Cascade – Summary of principle sites

Sol'n	**Homefield** (1)	**Chiswick Eyot** (1)	**Battersea** (2)	**Heathwall** (2)	**Earl P.S**	**Beckton**	**Thames mead**	**Crossness**	**Dartford**
A	✓	✓	✓	✓	✓	✓		✓	
B	✓	✓	✓	✓	✓				
C	✓	✓	✓	✓	✓				
D	✓	✓	✓	✓	✓				
G	✓	✓	✓	✓	✓		✓		✓
H	✓	✓	✓	✓					

<u>Notes</u>

1. Chiswick Eyot is an extremely sensitive site and unlikely planning permission will be granted, therefore Homefield more favourable drop shaft location.
2. Battersea very sensitive site development and would be opposed by local council and local pressure groups. Therefore Heathwall more favourable main construction site location.
3. Options E/F not included in above table as both are unviable due to lack of sufficient land being available within central London for either option.

8.2.13.3 Discussion of Study

An important issue for the Tideway strategy was to assess the availability of land for the implementation of any potential solutions. The outcome of this study was that the land availability situation is a constantly changing picture.

As part of the Tideway Strategic study a Land, Planning and Environmental review was carried out by consultants Cascade and LUC. The aim of this study was to carry out a desktop review of available land, which would be suitable for the collection, conveying and screening or treating of discharges from combined sewer outfalls (CSOs).

This work was split into two phases:

The first phase completed February 2002 concentrated on the site identification aspect. The scope of the site search comprised sites exceeding 2500m^2, located within 1000m of the River Thames between Barnes Bridge and the Dartford Crossing. Also considered were sites within a 1000m radius of the Stamford Brook as far as Thames Water's Acton pumping station. Sites were identified using various sources such as Development plans, Aerial photographs, 1:25000 Ordnance Survey Explore sheet maps, Greater London Street Atlas and the National Land Use Database. All sites were explored as regards to potential residential development, employment use, and initially public parks were excluded. The report identified 112 potential sites within 18 London Boroughs and the Borough of Dartford and Thurrock. It should be noted that public parks were excluded from the search.

Site Valuation

For each site a desktop appraisal was undertaken by Chartered Surveyors based on site location, area and identified planning issues. It was assumed that all titles to the sites were free from defects and were freehold. Valuations were undertaken within the following bands:

Less than <£0.5M	£0.5-1M	£1-5M	£5-10M	£10-20M	Greater than 20M

BPEO Assessment

Following on from each site being valued it was assessed using the Best Practicable Environmental Option methodology (BPEO) developed for Thames Water's Water Resources Planning Strategy. Eight key criteria and three indicatives values for each criterion were established. The BPEO was used to select possible sites for each proposed option. Site indicative values were banded into the following ranges £<1M, £1-10M and >£10M. These values were based on the following assumptions (Table 41):-

1. Minimum land area required for pumping station or screening a small CSO with flows up to 10m^3/s – 2500m^2
2. Screening a major CSO with flows up to 20m^3/s – 4000m^2
3. Screening and primary treatment of a CSO – 8000m^2

Table 41 : LUC & Cascade – Summary of Banding criteria

Criterion	**Indicative Value**		
	Red	**Yellow**	**Green**
Site value	>£10M	£1 -10M	<£1M
Site size	2,500-4,000m^3	4,000-8,000 m^2	>8,000m^3
Planning Constraints	National	Local	None or positive
Ecological designations	Designated	Adjacent designated	None
Distance to nearest sensitive receptor $_{(1)}$	0 -100m	100 -200m	>200m
Distance to nearest CSO/STW $_{(2)}$	>2km	1-2km	<1km
Distance to River Thames	>100m	<100m	Adjacent
Road Access	Minor residential	Minor non residential	Major.

(1) Residential property, school, hospital, recreational area

(2) CSO, STW.

The values used for distances to the nearest receptor were based on typical impact distances for individual CSO sites in Central and East London.

The second phase (July 2002) investigated these potential sites further by means of (a) establishing their planning history and current status and (b) visual inspection to check their suitability and availability. A number of additional potential sites were identified from visual inspection. Also Thames Water Engineering proposed a number of sites as possible tunnel shaft locations, which were assessed. A total of 46 available sites were identified, predominantly located in East London.

In view of the lack of potential available sites in West London, a review was also undertaken of open spaces within an area from Mogden Sewage Treatment Works (STW), near Twickenham, to the downstream boundary of the London Borough of Newham. A total of 172 open space sites in 14 Local Authority districts were identified from development plans within the area of search. These comprised mainly park and sports grounds that might offer potential for construction of structures below ground.

A number of potentially viable sites were investigated in more detail; sites were inspected either from the road or from the River Thames. The size, accessibility, suitability and planning history of each site were ascertained and adjacent land issues noted.

Preliminary consultations were undertaken with the relevant local planning authorities and an environmental appraisal was carried out to determine the sites' suitability for development of screening infrastructure.

Analysis of Proposed Options

The following sections analyse the sites associated with each engineering option identified by the Solutions Group.

Option A
Option A is a west-east storage tunnel with storm flows pumped out at Crossness STW for treatment. Possible sites associated with this option are as follows:

Foreshore drop shaft	Chiswick Eyot
Drive shaft/main construction site	Battersea Park
	Beckton STW
Reception shaft	Earl PS
Drive shaft/local treatment site	Heathwall PS
Drive shaft/local treatment/underground storage site	Feathers Wharf
Reception shaft/main treatment site	Crossness STW

The planning status and potential availability of these sites was assessed and is summarised briefly as follows:

- Chiswick Eyot is designated as a Local Nature Reserve, a Site of Metropolitan Importance, Metropolitan Open Land and is within the Thames Policy Area, a Conservation Area and the setting of listed buildings and designated Historic Parks and Gardens. Chiswick Eyot is an extremely sensitive site, with very articulate residents living in the Old Chiswick Conservation Area overlooking the site. From consultation with Hounslow Borough Council, it would be very unlikely that permission for development would be granted.

- Battersea Park is designated as Metropolitan Open Land, a Conservation Area and a Local Nature Reserve. It is within the Thames Policy Area and an Archaeological Priority Area. The site is very sensitive and any development would be likely to be opposed by local pressure groups such as the Friends of Battersea Park. Wandsworth Borough Council would be likely to resist any permanent loss of car parking area since this would cause operational difficulties within the Park.

- Beckton STW is located within Metropolitan Open Land. The proposed site is in an area of old sludge beds which are likely to be contaminated and would need remediation prior to development. Ongoing mixed use development of the British Gas site to the west and the Barking Creek area to the east of Beckton STW is likely to introduce residential receptors to within approximately 400-500m of the site, but this is not considered by Newham Borough Council to be a barrier to development.

- Earl PS is a Site of Nature Conservation Importance and is within an Archaeological Priority Area. The site is close to residential receptors and is constrained in terms of the available area for development.

- Heathwall PS is within a Riverside Employment Area; development of sites within these areas should generally provide a significant level of employment. The adjacent RMC site includes a protected wharf, and the Thames Path crosses the site. The site also is situated in an outer protection zone (Zone II) of a groundwater abstraction borehole on the north bank of the Thames. Housing development and residential barges are located 50-100m to the east and west respectively, and may be subject to noise nuisance during construction (eg piling for cofferdam formation). Despite this, the site is considered to have potential for development.

- Feathers Wharf is within the Thames Policy Area and an Archaeological Priority Area. The site is also in the Wandle Delta Area, which is subject to regeneration funding. Wandsworth Borough Council would be looking for mixed use development including public amenity space, public access along the rivers Thames (Thames Path) and Wandle, and ecological enhancement of the riverside. Above ground development would be likely to be resisted but a sub-surface storage option with provision for open space above may be possible. The site was previously a waste transfer station and would be likely to require remediation work prior to any development.

- Crossness STW is adjacent to an Area of Metropolitan Importance for Nature Conservation. The nearest sensitive receptors are approximately 200m to the west of the STW boundary at Thamesmead development. There may be potential noise impacts from operation of the large pumps proposed at the site. Bexley Borough Council has current concerns over odour at this site, which may make promotion of a major development difficult.

In view of the sensitivity of Chiswick Eyot and the constraints at Earl PS, two alternative sites were identified as follows:

- An open space site at Homefield Recreation Ground, north of Chiswick Eyot. This site is designated as Local Open Space. The proposed site would be located in that part of the ground lying north of the A4, since the southern part of the site is within the Thames Policy Area, Conservation Area and Thames floodplain. There is residential development within 100m of the site and traffic impacts at peak hours would be an issue. Tunnelling from Chiswick Eyot to Homefield Recreation Ground may cause potential vibration impacts on housing in the Old Chiswick Conservation Area. Hounslow Borough Council would consider development on this site, if improvement works to the open space were provided.

- A marina car park at St George's Wharf in Southwark. This site has no planning designations but is immediately adjacent to housing and the Thames Path. Impacts resulting from construction noise and potential odour during operation may be significant due to the proximity of sensitive receptors.

Furthermore, since the site in Battersea Park would be difficult to promote, an alternative would be to utilise the Heathwall PS site as a drive shaft. Due to the length of tunnel, this would necessitate smaller interim shafts for emergency access/egress, which could be sited off line from the main tunnel. These could potentially be located at Thames Water owned land at Lots Road PS, or at available sites in Wandsworth (Feathers Wharf, Brewhouse Street and Causeway Island) or Hammersmith (two sites on Carnwath Road).

Option B
Option B comprises a tunnel which intercepts the first flush storm flows and transfers these to a site near the Thames Barrier for screening and discharge. Option B would utilise the same sites as Option A but east of St George's Wharf, the tunnel would terminate at a site in Newham or Greenwich. The site would need to be large (over 5ha) to accommodate the pumps required to lift the first flush flows from the tunnel for screening prior to discharge.

One possible site identified was a 2ha vacant area abutting Prospect Park, adjacent to the Thames Barrier on the north bank. Above ground works on this vacant site combined with below-ground works in Prospect Park was considered. However, the vacant site has since commenced development for housing and is thus unavailable.

An alternative area may be available on the south bank near New Charlton on the Anchorage Point Industrial Estate & Meridian Trading Estate. This 40ha site is situated to the south of the Thames Barrier and is within the London Borough of Greenwich. The site is an industrial area and has an aggregates zone to the west with safeguarded wharves for river freight (which might be considered for purchase similarly to the RMC plant adjacent to Heathwall PS). Other parts of the site have recently been developed for a retail/business park and for industrial use. Further investigation would be required to determine the potential within this area for siting screening plant for Option B.

Option C
Option C comprises a tunnel intercepting the majority of storm flows and transferring them to a site at Charlton in Greenwich for screening and discharge. Option C would involve eight sites from Homefield Recreation Ground upstream and terminating at Thames Water owned site immediately south of Charlton Athletic Football Ground. Potential intermediate sites include those identified for Option A (Feathers Wharf; Heathwall PS; St George's Wharf) plus three additional open space sites near the river in Westminster or Lambeth, Southwark and Greenwich. Securing permission to use open space sites, particularly within the City, is likely to be difficult and reduces the feasibility of this option.

The area required for the treatment plant at Charlton would be 6000m^2. It is understood that the stands at Charlton Athletic Football Ground are shortly to be rebuilt; any implications of this with regard to the proposed screening plant would need to be assessed.

Option D
Option D comprises Option C with an additional tunnel to collect the first flush storm flows and divert them to the foul sewer. The remaining storm flows would be collected and screened prior to discharge to the Tideway. Similar constraints apply to Option D as to Option C.

Option E
Option E involves a series of foreshore dropshafts near each CSO. The 25m diameter shafts would be sited on the inter tidal area; an adjacent bankside area of approximately 600m^2 would be required for siting electrical plant. Since they would be sited within the river channel, the shafts would have potentially significant impacts in terms of flow impedance and restriction of the channel cross sectional area; obstruction to navigation; landscape and visual impact (particularly at low tide); and possible ecological and archaeological effects from landtake on the foreshore and banks.

Option F
Option F comprises the provision of individual screening plants at each CSO. A preliminary engineering investigation into the design and site requirements indicates that this solution would be feasible at 13 of the 55 CSOs, but that construction works at the remaining CSOs would involve extensive disruption, road rail and bridge closures, demolition of important buildings, and potentially significant environmental impacts. The close proximity of many of the sites to sensitive receptors would also be likely to result in odour, noise and traffic impacts during operation.

The lack of suitable sites in Central London for on-site screening, particularly in the City, generally weighs against this approach and favours solutions utilising sites in west and or east London.

Option G
Option G is a gravity tunnel, utilising the same upstream sites as Option A, but east of St George's Wharf connecting a possible drive shaft site at Thamesmead to an extensive reedbed treatment site (approximately 4km^2) at Havering or Dartford Marshes. Potential sites are as follows:

- The Thamesmead site lies within the Thamesmead Masterplan Area, adjacent to the River Thames Site of Metropolitan Importance for Nature Conservation. Consultation with Greenwich Borough Council identified a potentially suitable area of land immediately to the north of the ongoing Gallions Reach development, within a zone that has been allocated for a future road bridge crossing of the Thames. Access to the Thames Path would need to be maintained but otherwise the site has no significant constraints.

- Havering Marshes is largely designated as SSSI grazing marsh and much of the area is owned or managed by the RSPB. Part of the marshes is used by the Port of London Authority as a dredgings lagoon but this is likely to be required for the next 10-15 years. An area currently used for waste management is to be developed into a country park. No available sites of sufficient size for reedbed treatment were identified in consultation with Havering Borough Council.

- Dartford Marshes could provide a potentially large reedbed site. This use would be compatible with its proposed designation as a Local Nature Reserve but some public access would need to be retained. The site is located within the Thames and Darent floodplains and potential overtopping of contaminated water was raised as a concern by Dartford Borough Council. Mixed use development of the Joyce Green Hospital and Littlebrook Power Station sites could result in potential traffic and odour impacts.

Thamesmead and Dartford Marshes could be potentially suitable sites for this option.

Option H
Option H would provide a partial solution based on a tunnel connection from Homefield Recreation Ground to a screening plant at Heathwall PS. This would necessitate land purchase at Heathwall to provide a large enough site area. The estimated cost of the FedEx site to the west of Heathwall PS is £1-5M with its current use as a freight depot and £5-10M for redevelopment for residential use. The estimated cost of the RMC site to the east is £0.5-1M with its current use as a concrete batching plant and £1-5M for redevelopment for residential use. Both sites are prime river frontage and residential development would be likely to be a major aspiration.

8.2.13.4 Conclusions
The status of sites in London, particularly on the riverfront, changes rapidly and in setting out a future strategy, the dynamic nature of land availability on the Tideway has to be recognised. Identification and securing of potential sites is on the critical path. In this respect, the purchase of sites adjacent to Heathwall PS to facilitate a partial solution (Option H) or a longer-term two-phase solution could be considered.

Although many sites were initially identified, very few of these were suitable to be incorporated within the potential solutions. The lack of suitable sites and difficulty in obtaining sufficient land area within central London precludes options with individual CSO screening plants (Option F), and the planning and environmental constraints associated with installing dropshafts in the Thames foreshore is also considered to preclude Option E. While potential open space sites could be pursued to facilitate Options C and D, the chances of securing permission on these sites will be less than for currently available sites, thus less certainty can be ascribed to these options. Possible sites have been identified for Option G, although the potential for obtaining permission for a 4km^2 reedbed site is probably not high. Further work would be needed to identify a specific site for Option B.

Environmental appraisal of the sites proposed for Option A has identified a number of constraints, some of which (such as vibration from tunnelling) would also be common to other options. The impacts of pumping and treating the major stormwater flows at Crossness STW would also be significant.

On balance, Options A and H are considered the most viable in land, planning and environmental terms.

8.2.14 Précis of Construction Cost Estimates – EC Harris

8.2.14.1 Principle Conclusions and Recommendations

1. The upper value of the original budget estimates for construction costs prepared by Halcrow are recommended as appropriate for potential solutions A to E
2. Budget estimates for A(medium) and A(low) prepared by EC Harris are very similar to those prepared by Halcrow
3. The cost of providing storage using large underground tanks is more expensive than a single large tunnel
4. The budget estimates include for transport of surplus excavated spoil and construction materials by barge. However it is considered that road transportation would prove more economic despite the obvious environmental benefits
5. The method of calculation of these budget estimates of construction costs is made on a detailed element-by-element resource approach based on the construction programmes produced by Faber Maunsell.
6. The budget costs prepared by EC Harris include an allowance of 10% for risk and contingency. This allowance is removed upon transfer to the overall budget cost table to avoid double counting of risk and contingency.

8.2.14.2 Application to Potential Solutions

The budget estimates for the construction of potential solutions A (med), A (low), G and H are as summarised in Table 42.

Table 42 : EC Harris – construction budget estimates – options A, G and H

Potential Solution	£M @ 2002 prices	£M @ 2003 prices
A (Med)	1,085	1,230
A (Low)	919	1,043
A (Low) + Tanks	1,553	1,766
G	1,136	1,289
H	n/a	384

The item A (Low) + Tanks includes for 12 number off-line tanks to supplement the difference in storage capacity between a main tunnel of 6m diameter and 9m diameter. This exercise clearly shows that the provision of storage via large tanks is much more expensive than via a large diameter tunnel.

8.2.14.3 Discussion of Study

The study was carried out in several parts as follows:
1. Audit of cost estimates for potential solutions A to E, in the Tideway Investigation report by Halcrows
2. Budget estimate for potential solution A (med) and G, based on drawings provided by Faber Maunsell.
3. Supplementary budget estimate for A (low) and off-line tanks, based on drawings provided by Faber Maunsell.
4. Budget estimate for potential solution H, the West London Solution, again based on drawings provided by Faber Maunsell.

The general exclusions are:

- Design
- Strengthening of third party assets
- Mechanical and electrical fit-out
- Treatment plant
- Land acquisition and planning fees
- Environmental requirements

- Thames water, Environment Agency and Consultant Fees
- Inflation for start later than 2003

The budget estimates have been used as the civil construction costs and incorporated in a spreadsheet to assess the overall cost of each potential solution at each level of intervention. The summary table for these overall budget estimates is included in Section 9 – Conclusions.

The method of calculation has been on a detailed element-by-element basis by consideration of the resources and materials required and the programmed duration of activities. The exception being specialist subcontract work where quantities have been priced from experience of other recent similar work. The advantages of detailing the price down to individual elements of each structure is as follows:

- It provides a more accurate estimate
- It allows cost optioneering exercises to be undertaken quickly and accurately
- The project costs can easily be sub-divided into multiple contracts id required.

8.2.15 Précis of Derivation of Budget Capital Costs – Thames Water Engineering

8.2.15.1 Discussion of Study

The budget costs for the each potential solution at each level of intervention have been derived from the following elements:

1. Tunnel & Civil construction
2. Screening plant and structures
3. Treatment plant and structures
4. Pump and power plant and installation
5. Risk and contingency
6. Resource costs
7. Land costs
8. Update from 2002 to 2010 prices

Tunnel & Structures Construction
These budget costs are based on the upper values originally prepared by Halcrow for potential solutions A to E. These have been verified and supplemented by EC Harris where appropriate.

EC Harris also prepared more detailed budget estimates for potential solutions A(med), A(low), G and H. The detailed breakdown of these were used to build up budget estimates for the various additional partial solutions to supplement potential solution H as described in the addendum report Variations on H.

Screens
In general these have been obtained from the budget estimates produced by Black and Veatch in the Treatment Study.

The budget costs for the screening plant in underground chambers for potential solutions C, D and F have been developed pro-rata from estimates built up by Network North Alliance of Thames Water for AMP3 fine-screening options and supplemented with the budget costs built up by EC Harris for underground tanks.

Treatment
These have been derived from the budget estimates produced in Treatment Study by Black and Veatch and are based on enhanced primary treatment only. The allowance for contingency and risk has been removed in favour of the overall contingency and risk allowance. The additional costs for secondary treatment, based on submerged aerated filters, are included below, following the summary table.

Pump & Power
Pumping plant costs have been extrapolated from budget estimates produced in Pumping Study by KSB. The power costs extrapolated from budget estimates produced in Power Study by McLellan. Estimates were produced for both network supply and on-site generation. Generally there was little difference between the capital cost for network supply and on-site generation. The highest cost of either has been included in the overall budget costs.

Contingency and Risk
This has been based on 30% of sum of Tunnel Costs, Screens, Treatment and Pump & Power.

Resource Costs
This has based on 12% of sum of Tunnel Costs, Screens, Treatment and Pump & Power. This sum is intended to cover planning, design, project management by Thames Water, specialist consultancy and similar.

Land Costs
This has been based on outline costs of land acquisition from Land, Environment and Planning Study by LUC.
Preliminary estimates for compensation costs for suspension/diversion of railways and roads, relocation of businesses, loss of amenity and similar also been included under this item. These preliminary estimates for compensation are, unavoidably, very approximate and are intended to demonstrate the likely scale of disruption.

Update from 2002 to 2010 prices
This allowance was estimated by EC Harris to indicate the likely increase in cost due to general inflation to the year 2010. This allowance is excluded from the summary table below for clarity, but is included in the summary table in Section 9 – Conclusions.

8.2.15.2 Application to Potential Solutions

All the above budget costs are included on Thames Water Engineering spreadsheet, filename "Tideway Capex June03.xls". The summary table (Table 43) is included below for reference.

Table 43 : Summary June03 Capex budget costs

Potential Solution /Intervention	Estimated Cost (£M)							
	Tunnels & Structures	Screens	Treatment	Pump & Power	Contingency & Risk 30%	Resource Costs	Land Costs	Total Costs
A Maximum	1,673	95	49	77	568	227	94	2,784
A Medium	1,058	60	26	40	355	142	94	1,776
A Low	763	32	20	25	252	101	94	1,287
B Maximum	1,062	450	0	241	526	210	159	2,648
B Medium	718	225	0	125	320	128	159	1,676
B Low	400	95	0	72	212	85	159	1,164
C Maximum	812	1,167	0	331	836	334	194	4,149
C Medium	515	714	0	144	434	173	194	2,246
C Low	348	448	0	93	272	109	194	1,480
D Maximum	1,550	1,199	20	353	1,012	405	194	4,983
D Medium	981	732	10	155	625	250	194	3,153
D Low	633	456	4	100	358	143	194	1,889
E Maximum	2,112	99	30	59	690	276	202	3,467
E Medium	1,320	51	15	31	425	170	202	2,213
E Low	881	24	6	17	278	111	202	1,518
F	0	3,045	0	192	971	389	7,115	11,713
G	1,033	225	480	98	551	220	106	2,714
H	388	9	14	8	126	50	55	650

The total capital costs are included in the summary table Section 9 – Conclusions and Section 0 – Executive Summary.

The additional capital costs for the implementation of secondary treatment for each potential solution, as appropriate, is illustrated in Table 44.

Table 44 : Secondary treatment costs

Potential Solution /Intervention	**Additional Cost for Secondary Treatment (£M)**			
	Treatment	**Contingency & Risk 30%**	**Resource Costs**	**Total Costs @ 2002**
A Maximum	44	13	5	63
A Medium	44	13	5	63
A Low	44	13	5	63
D Maximum	44	13	5	63
D Medium	22	7	3	31
D Low	20	6	2	28
E Maximum	44	13	5	63
E Medium	33	10	4	47
E Low	29	9	3	41

The maximum capacity of the secondary treatment plant is 10m3/s, capital costs are therefore capped to plant of this capacity.

8.2.16 Précis of Derivation of Budget Operational Costs – TW Engineering

8.2.16.1 Discussion of Study

A preliminary assessment of operational costs for each potential solution and level of intervention has been made for comparison purposes. Many of the features of the potential solutions, such as scale, depth and flow rate, are unique. As such this assessment is based on extrapolation of operational costs for existing works and estimation from basic principles where operational data is not available. Further work will be required to develop the estimate of operational costs for the preferred solutions. There are four main areas of operational activity considered for resource and funding:

1. Tunnel & Sites
2. Pump & Power
3. Treatment
4. Screening Disposal

A detailed breakdown of the cost assessment is included in spreadsheet "Operating Costs June03.xls". Description of how the costs were estimated is included below:

Tunnel & Sites

For potential solutions A to E, G and H this section includes activities relating to operation, routine maintenance and inspection of the interception structures, main tunnel, shafts and main shaft sites including the control system, buildings and ventilation. For Potential solution F the activities relate to inspection of the bunker installations and the flow control structures, which will be similar to the interception structures required for the other options and ventilation plant.

The interception structures will be subject to approximately 60 spill events per year. Each structure will include flow, depth and pollution monitors and large activated penstocks to control the flow. Due to the aggressive nature of sewage and the debris it contains it would be reasonable to assume that several of these interception structures will require attention after each spill event. The anticipated activities could include cleaning and removal of rags from monitors, replacement of broken or displaced monitors, removal of large debris from penstocks, removal of deposited silt etc. Confine space entry will be required to carry out these functions. A team including Manager, Supervisor, Technicians and an Inspection Gang (five members) would be required for these duties on a regular basis.

It is anticipated at this stage that the main tunnel itself would require an annual inspection. This will have to be a carefully planned operation and would involve a team similar to that described above. For potential solution E, the large storage shafts will require regular internal inspection for access to the pumping and mixing plant. This will prove to be a much more resource intensive due to the large number of shafts to be inspected.

The interception structures, main shafts and buildings shafts will require routine and regular inspection by a Roundsman to as a security check. This is likely to be a full time job. The ventilation and odour control plant at each of the main shaft sites will also require routine inspection and maintenance.

Using potential solutions A(medium) and H as examples the assessment of resources required, in terms of Full Time Equivalents (FTE), would be as follows (Table 45):

Table 45 : Typical resource requirements for options A(med) & H

A(Medium)		H	
Resource	FTE	Resource	FTE
Ops Manager	0.2	Ops Manager	0.1
Team Leader (Supervisor)	0.4	Team Leader (Supervisor)	0.2
Technician	0.4	Technician	0.2
Sewer Gang	5x0.4	Sewer Gang	5x0.2
Roundsman	1	Roundsman	0.5

Pump & Power

Each potential solution will include large pumping plant. The costs of energy consumption and the provision of electrical power will be significant. It is worth noting that for most potential solutions the difference in cost between grid supply or by on site generation is not very significant. Security of supply is therefore likely to be the main driver.

The operational costs for pump and power have been assessed as follows:

1. Energy costs based on estimates of flow intercepted annually.
2. Grid supply including availability charges.
3. On site generation includes routine maintenance estimated as 1.5% of the capital cost of the generation plant required.
4. Pump maintenance based on 2% of capital cost of pump sets

Treatment

The operational costs for treatment are derived from budget estimates produced by Black and Veatch for the Treatment Study. Using the treatment plant for potential solution A (Medium) as an example the assessment of resources required, in terms of Full Time Equivalents (FTE), would be as follows (Table 42):

Table 42 : Typical Treatment operational costs – option A

Screening Plant		Deep bed Filters		Secondary Treatment (SAF)	
Resource	FTE	Resource	FTE	Resource	FTE
Operator	1	Operator	1	Operator	2
Technician (Mech)	0.5	Technician (Mech)	1	Technician (Mech)	1
Technical (Elec)	0.5	Technical (Elec)	1	Technical (Elec)	1
		Technician (ICA)	1	Technician (ICA)	1
		Admin	0.5	Admin	0.5
		Ops Manager	1	Ops Manager	1
		Team Leader	1	Team Leader	1

In addition, allowances are also made for plant maintenance, energy, disposal and chemicals.

The deep bed filtration plant for potential solution H, although of lower capacity, will require a similar level of resource. This is due to the complexity of operation of the plant and the requirement to keep such plant fully functional in such a sensitive location.

Screening disposal

The generation of screenable solids for disposal has been assessed from the estimates of flow intercepted annually for each potential solution. The costs include transport and disposal to landfill. Landfill costs are predicted to rise to £80 per tonne.

Total Costs

Total operating costs for each potential solution is derived from the sum of the above. It is worth noting that no contingency allowance has been included for the operating costs.

The total operating costs are included in the summary table Section 9 – Conclusions and Section 0 – Executive Summary.

8.2.16.2 Application to Potential solutions

The operating costs are summarised in Table 47. Treatment costs are based on screening, de-grit and enhanced primary treatment only.

Table 47 : Operating Costs for all potential solutions

Potential Solution /Intervention	**Estimated Cost (£k)**							
	Tunnels & Sites	**Power**		**Pump**	**Treatment**	**Disposal**	**Total Costs**	
		Grid	**On-Site**				**Grid**	**On-Site**
A Maximum	298.7	1,088.6	781.5	175.0	5,087.0	278.2	6,927.5	6,620.4
A Medium	298.7	355.7	359.8	87.5	2,779.0	269.5	3,491.6	3,495.8
A Low	298.7	211.2	248.4	62.5	1,388.0	226.2	1,887.9	1,925.1
B Maximum	298.7	4,174.4	1,863.4	662.5	4,560.0	278.2	9,675.1	7,364.1
B Medium	298.7	2,000.2	1,042.5	337.5	2,280.0	269.5	4,887.1	3,929.5
B Low	298.7	979.8	689.2	150.0	935.0	226.2	2,291.0	2,000.3
C Maximum	298.7	3251	2,582.0	800.0	6,000.0	278.2	10,329.3	9,660.2
C Medium	298.7	1665	1,093.7	400.0	3,000.0	269.5	5,334.0	4,763.2
C Low	298.7	702	747.0	160.0	1,200.0	226.2	2,287.7	2,333.2
D Maximum	298.7	3,445.8	2,759.8	875.0	6,967.0	278.2	11,565.9	10,879.9
D Medium	298.7	1,777.5	1,191.4	450.0	3,484.0	269.5	5,981.0	5,394.9
D Low	298.7	760.7	817.1	187.5	1,393.4	226.2	2,567.7	2,624.1
E Maximum	1,342.2	300.1	326.0	142.5	1,452.0	278.2	3,514.9	3,540.8
E Medium	858.6	175.4	196.3	80.0	726.0	269.5	2,109.4	2,130.3
E Low	542.8	102.8	117.7	52.5	290.0	226.2	1,214.3	1,229.2
F	786.3	823.0	861.8	1,250.0	9,000.0	278.2	12,137.4	12,176.2
G	298.7	1,728.9	1,362.4	312.5	3,030.0	269.5	5,639.6	5,273.1
H	242.2	107.3	93.5	25.0	718.0	145.5	1,238.0	1,224.2

The additional operating costs of secondary treatment for the appropriate potential solutions is shown in Table 48.

Table 48 : Secondary treatment operating costs

Potential Solution /Intervention	Secondary Treatment (£k/yr)
A Maximum	887
A Medium	887
A Low	887
D Maximum	887

D Medium	444
D Low	177
E Maximum	887
E Medium	665
E Low	266

The maximum capacity of the secondary treatment plant is $10m^3/s$; operational costs are therefore capped to plant of this capacity.

Précis of Other Studies

The following complementary studies were also commissioned for this investigation. They are listed as follows and are summarised in the précis below:

Other Studies	**Source**
Fish Trial	Environment Agency
SCITTER	Thames Water Engineering and R&T
Flow Monitoring	Thames Water Engineering
Catchment Modelling	Thames Water Engineering
Literature Search	Thames Water R&T
Legislation	Thames Water Legal Department

8.2.17 Précis of Fish Trials – Environment Agency

8.2.17.1 Fisheries Study

In their report, Fawley Aquatic Research Ltd, have recommended DO standard levels based on analysis of the experimental work carried out. However as part of the study, they have identified several additional work areas, which are recommended to add significant value to the results gained from the studies thus far.

The additional work constitutes a desk study into the impact of CSO events along the entire length of the Tideway. The aim of this study is to assess the percentage of any fish species population, which is directly affected by a single CSO event. Current experiments reveal the percentage mortality expected for any given fish species population present in the entire Tideway. In reality a single CSO event will only affect a small percentage of the population at the specific CSO location. This area of work is crucial to understanding the effects of CSO events on population dynamics of all fish species and therefore standards levels set for the Tideway.

At present the Chiswick Pier facility remains in place to allow work to commence should funding be made available.

8.2.17.2 Risk Study Report

Fawley Aquatic Research Ltd has undertaken a risk study to ascertain the impact of differing spatial and temporal characteristics of the fish species studied in the fisheries investigations. The main area of study concentrated on laboratory and field based experiments, which provide data on the impact of CSO discharges on an entire tideway population of a fish species. The risk study aims to show how the distribution of CSO events and presence of different fish species along the tideway varies as does the seasonal presence of the fish species.

The analysis, which has been undertaken in the risk study, has therefore assessed the spatial and temporal implications of the outputs of the lethality testing. The procedure applied suggests that the impact on population lethality will be much less than anticipated by direct application of the fish studies results. Indications so far suggest that the interim standards thus far applied, would be adequately protective enough to ensure sustainable fish populations. However, consensus within the fisheries team on what this analysis means in terms of welfare of fish species in the tideway has yet to be reached. How the risk analysis will be applied to formulation of standards and therefore objectives still needs to be concluded by the fisheries team. It is very likely that although the outputs of this study hang greater reality on the lethality results, the analysis can only produce indicative outputs.

8.2.18 Précis of SCITTER Investigation – Thames Water Engineering & R&T

8.2.18.1 Principle Conclusions

This paper summarises the objectives and the findings of early results from the SCITTER storm screenings rig. The acronym SCITTER is derived from:

Storm sewage Constituents Test and Evaluation Rig

Reliable results have been recently obtained for lower intensity winter storm profiles, which show typical screenable solids loading rates of up to 3000 g/m3. Loadings for earlier spring and summer results, based on less reliable data, are suspected of being well in excess of this level. It is apparent that there are significant seasonal differences in screenable solids loading rates.

The results display a prominent first flush effect. A reasonable correlation is developing between the size of the first flush load and the duration of the preceding dry periods for a given event. Further trials are needed to establish a fuller appreciation of seasonal variations and to capture more extreme events. It is expected that the first flush effect will vary according to the location and nature of the catchment upstream of each individual CSO.

Initial difficulties experienced with ADFM flow monitoring during heavy storm conditions is better understood and measures have been put in place to resolve the issues of incomplete data. Useful water quality & Raw ADFM data has also been obtained in support of automated solids monitoring for development of Real Time Control. It is anticipated that the DWF results currently under analysis, will give stronger confidence for the prospects of this development work.

8.2.18.2 Discussion of Study

Introduction

A significant element of the Thames Tideway Strategy Investigation is the potential obligation to remove sewage litter from all intermittent discharges to the tidal section of the River Thames. Sewage litter is defined as solids greater than 6mm, but in particular Persistent Synthetic Substances. A better knowledge of both the quality and quantity of such substances, and their variation during storm events, is essential to more accurately determine the likely scale of screenings requirements involved.

The Beckton & Crossness sewer models provide quantitative information for most CSO discharges along the tideway. However information on quality and knowledge of pollutant transport mechanisms within the catchment is poor.

Aims

The SCITTER project has 2 main objectives:

1. To investigate the characteristics of storm discharge in terms of screenable solids.
2. To assist the development of a solids monitoring system using conventional ADFM flow monitors. This development may enable Real Time Control (RTC) of the catchment, allowing selective retention of the most polluting material and corresponding discharge of less polluting volumes, thus optimising the cost / benefits of any storage or treatment element of a given solution.

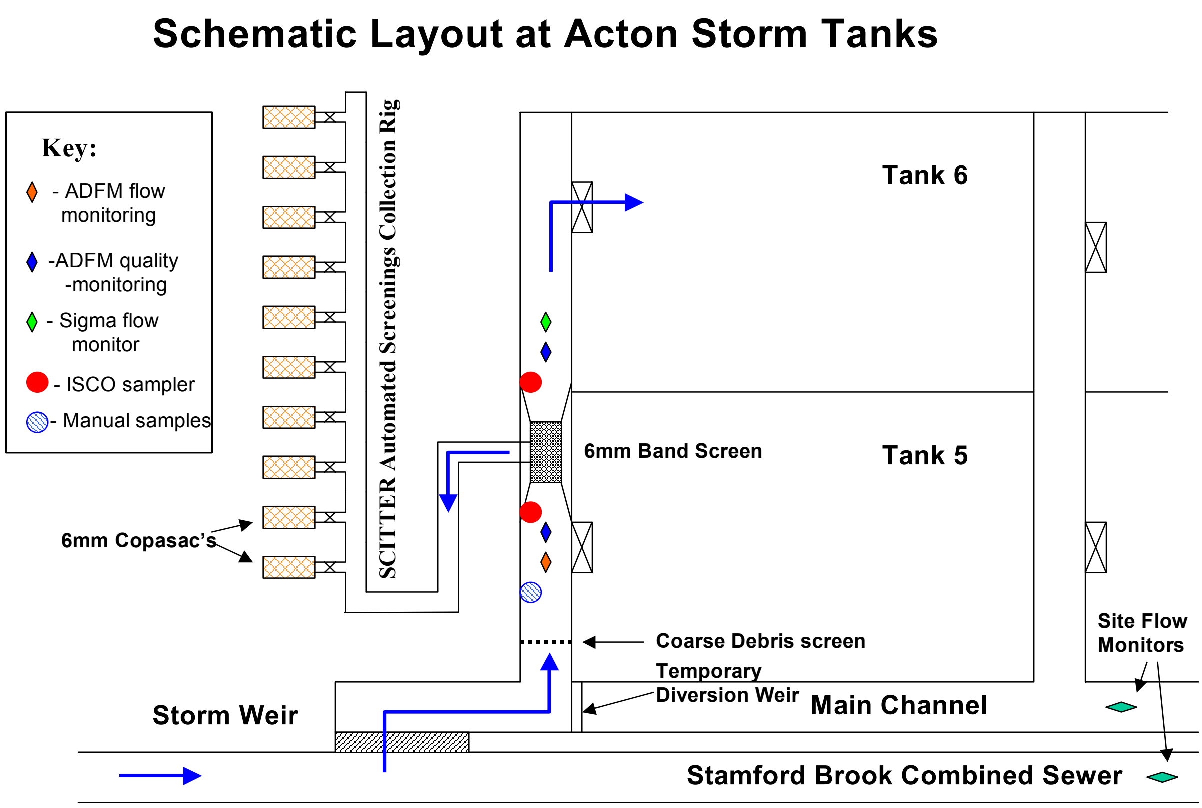
Description of the SCITTER plant

The SCITTER plant is situated at Acton storm tanks (Figure 25). The tanks receive flow from the Stamford Brook trunk sewer. In storm conditions, the sewer weirs over into the storm channels, which lead to the six storage tanks on site. A temporary weir was installed across the inlet channel to divert preferential storm flows into the SCITTER rig.

A 1200mm diameter GRP pipe has been placed in the channel upstream of the rig, and the channel modified downstream, so as to create a steady flow regime for accurate measurement of velocities and depth.

The rig itself consists of a Jones & Attwood high flow vertical band screen. The screenings are washed from the 6mm screen and directed in turn to each of the 15 Copa-sacks throughout the course of a storm event by an automated pneumatic valve system. This can be set to variable catch & spill times, allowing a custom sampling sequence to be built up for an anticipated storm profile. The current sampling sequence is set to a maximum of 60 minutes duration.

Figure 25 - Scitter layout schematic



Operation - Phase 1

Construction of the SCITTER rig was undertaken during Feb to March 2002, with automated operation thereafter.

Several significant storm results were captured during the April / May period. After a few initial teething troubles the automated sack collection system worked well. Unfortunately many storm results suffered from intermittent failure of the ADFM flow monitor. Consequently, the early estimates of screenable solids loading rates were derived from incomplete flow data. While this may have lead to some initial over prediction, the results clearly showed a First flush effect, with screenable solids loading rates significantly higher than rates initially assumed for general screen design purposes.

The failures in flow data capture were initially thought to be due to ragging of the instrument, and the generally unfavourable hydraulic conditions. Modifications were proposed to overcome these problems and a package of minor improvements was undertaken during June / July, during which, the rig was removed from operation.

Operation - Phase 2 (Post Modification)

Despite the works carried out to improve the monitor location, the initial results from autumn storms showed similar failures of the ADFM flow monitor. Until such time as the difficulties with the ADFMs have been fully resolved, a non-intrusive radar type flow monitor has been installed as an alternative method to record flow. Meanwhile, the manufacturers of the ADFM flow monitor are making attempts to re-analyse the incomplete Phase 1 flow data.

Screenable Solids Loading Rates

Recent results have provided useful data on the variable screenings content for lower intensity storm events, with screenable solids loadings of up to 3000 g/m3. However, the loadings from earlier spring and summer results, despite the necessary interpretation of incomplete data, still showed significantly greater solids loadings.

The recent set of autumn data has been supplemented with water quality samples from some selected events. These samples have been submitted for Biological Oxygen Demand (BOD) & Total Solids (TS) testing.

Recent Storm events showed the following trends (Table 49):

Table 49 : Typical Storm screenable loading rates

Storm Date	* No. of preceding dry days	Average Screenable Load mg/l	Peak Screenable Load mg/l	TS mg/l	BOD mg/l
17/09/02	DWF	275	650	730	130
12/10/02	32	1400	3000	5500	>1854
15/10/02	0.5	700	1600		
08/11/02	0	130	200		
10/11/02	1	70	150		
12/11/02	0.5	200	440	122	35
29/01/03 *DWF*	6	20	28.9	360	140
01/02/03	8	622	3400	1320	353
01/05/03	60	1500	2892		777

Results for two example storm events are shown below (figures 26 – 29), which depict the variation of flow and screenable solids loading throughout the events.

Figure 26 – Scitter results - Event 12th November 2002 – Sack weights and Flow

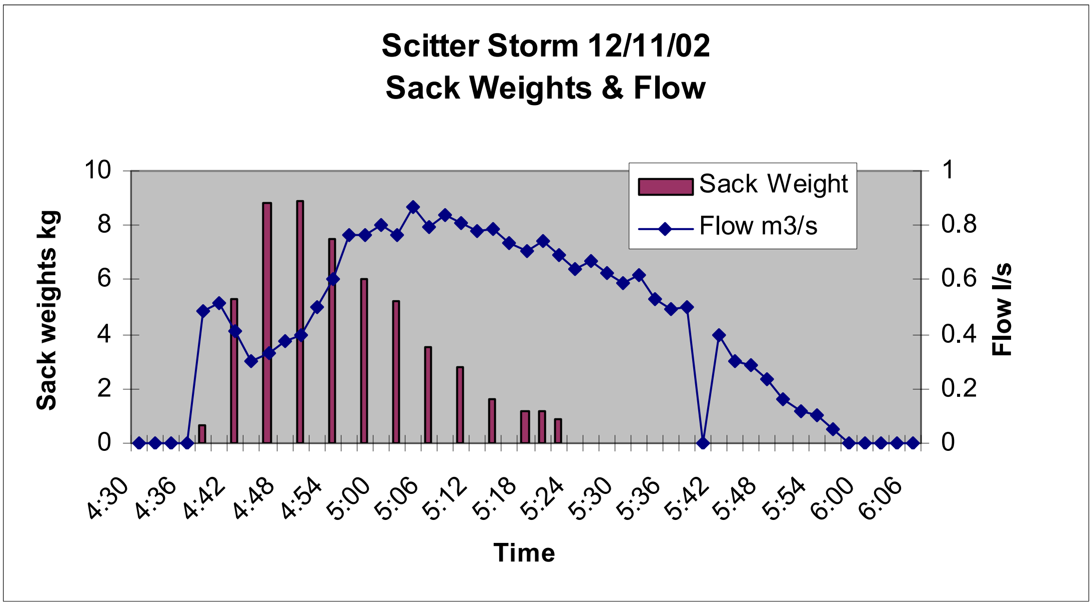


Figure 27 – Scitter screenings loadings – event 12th November 2002

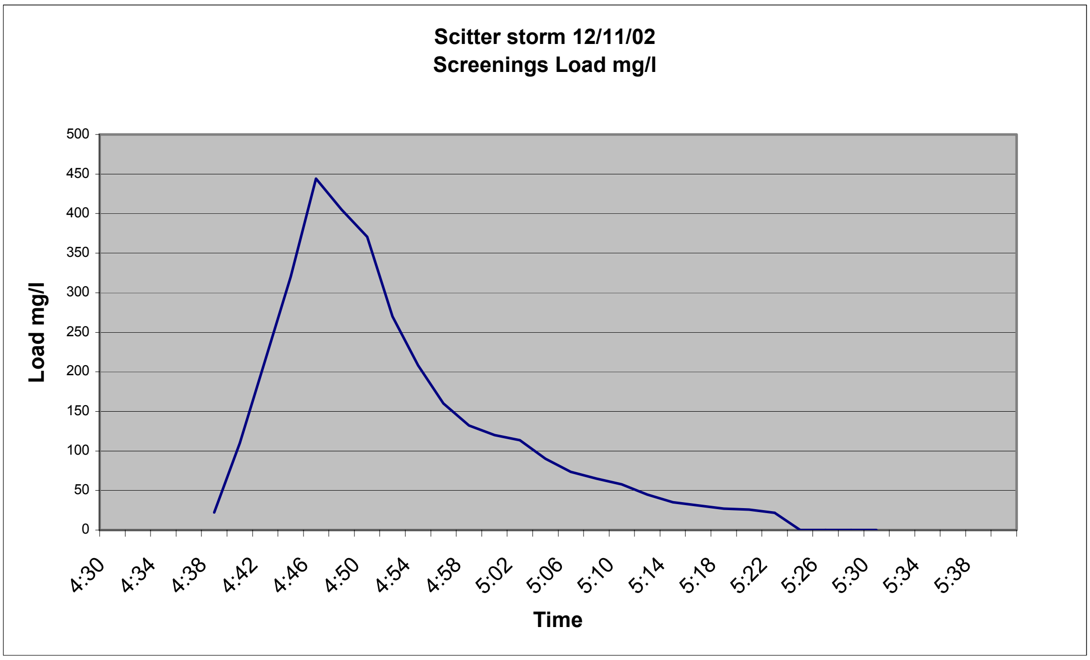


Figure 28 - Scitter results - Event 12th October 2002 – Sack weights and Flows

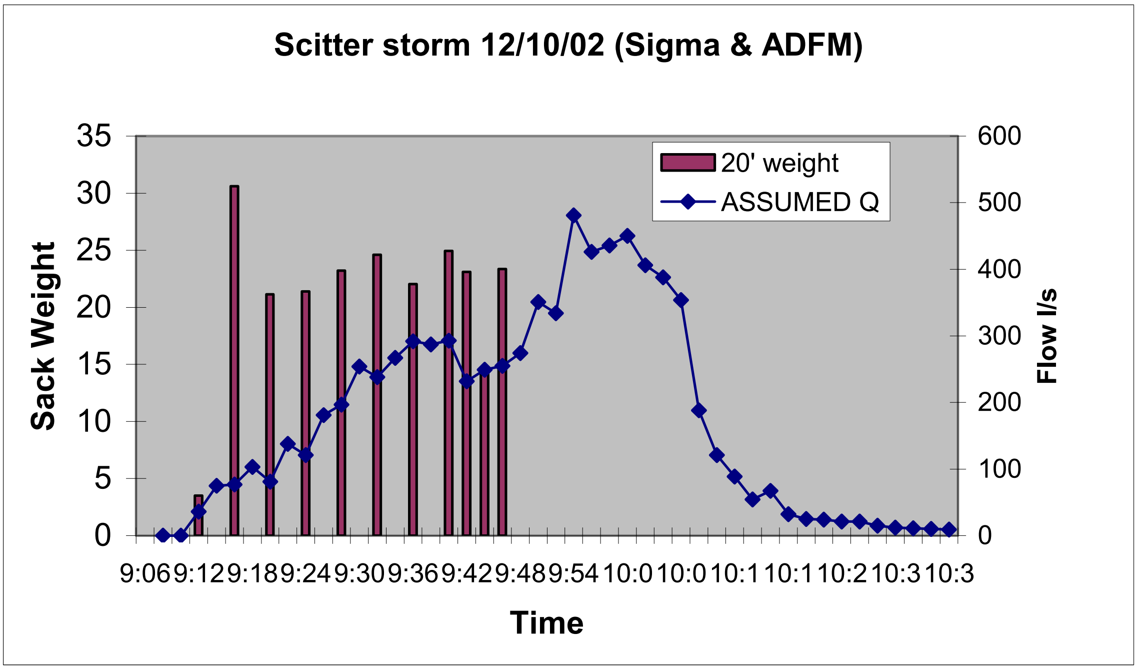
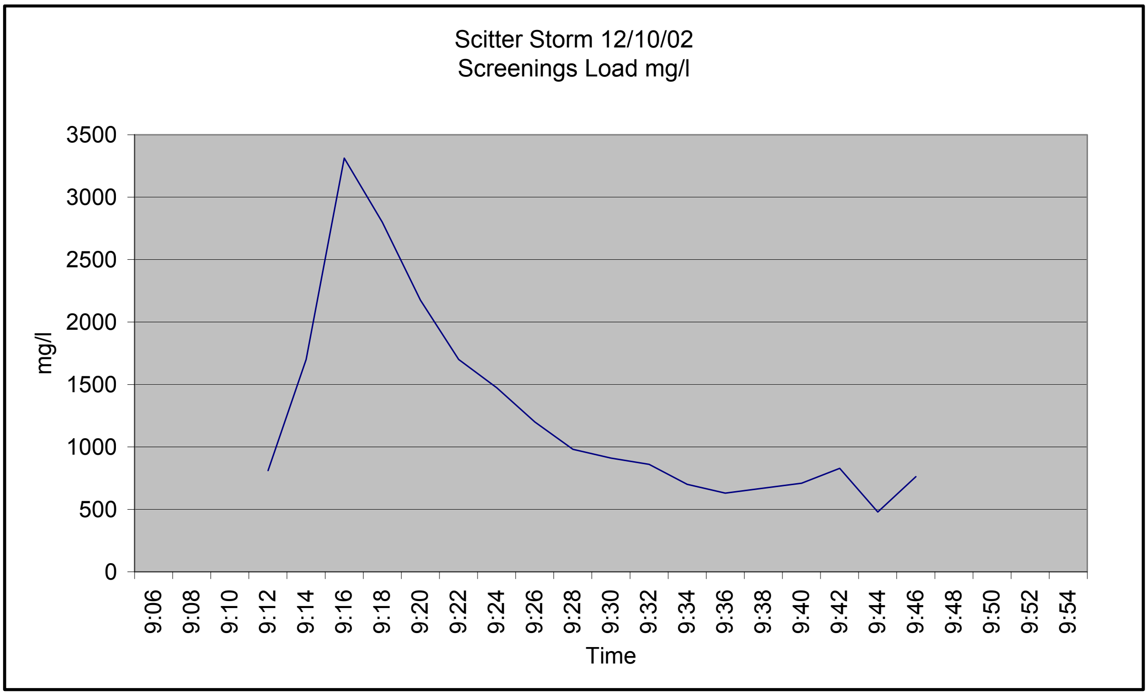


Figure 29 - Scitter screenings loadings – event 12th October 2002



Solids Monitoring Development

Development of the ADFM flow meter for Automated real time solids monitoring, relies upon complex analysis of raw data reflectance from particulate matter within the flows. Two ADFM monitors have been located upstream of the SCITTER rig, one set to record flows and the other to record the necessary raw data.

To understand the significance of the raw signals requires detailed monitoring of the water quality content. To this end, automated ISCO water quality samplers have been located up and downstream of the screen. These are programmed to sample simultaneously with the screen and COPA sack filling sequences. The samples obtained are tested for chemical & biological quality, as well as particle size distribution of solids.

Comprehensive tests were undertaken on 17th September to establish a record of baseflow characteristics during typical Dry Weather Flow (DWF) conditions. Captured data included standard lab tests such as BOD, COD, NH3, SS, TS, COPA Sack weights for screened materials, Laser Diffraction Analysis and “Raw ping” ADFM data both Up and down stream of the rig.

Summary of Operational issues

Due to the variable and difficult nature of sewage, some difficulties with measurements and monitoring had been anticipated. The learning curve has been steep, particularly with regard to the automatic collection of data. These problems have been largely overcome and the operation of the SCITTER rig is now quite robust. These operational experiences have highlighted the need for robust monitoring and control mechanisms, as well as a regular and rigorous maintenance regime.

Further Monitoring Required:

- There currently appears to be little research available on the screenable solids content of storm flows, with the exception of the UPM Manual, so more reliable data is essential for screening plant design purposes, in particular the screenings washing, handling and disposal units.

- A wider range of data is necessary for confident development of the ADFM real time solids monitor.

- A wider capture of storm types, particularly for heavy convective storms following long dry periods, is required to allow better prediction of likely maximum screenings handling requirements. Current results indicate a distinct correlation between the number of dry days (recess), preceding a given storm event and the resulting total screenings load. Reliable results to date have mainly captured short recess/back to back winter storms, or intermediate spring events.

8.2.19 Précis of Catchment Model – Engineering

8.2.19.1 Summary

This report reviews work that has been undertaken on and with the Beckton and Crossness Sewerage network models.

Existing sewerage network models have been used to:

- Estimate the size and scope of options that may be needed to improve Tideway water quality;
- Provide Combined Storm Overflow (CSO) data that enabled calibration of the Tideway water quality model;
- Help identify rainfall events that cause pollution of the Tideway and should therefore be used for model compliance testing;
- Test solution options so their performance in improving Tideway quality can be assessed.

During these processes a number of technical issues have had to be resolved. In addition the performance of the models has been assessed and work is in hand on extending model calibration and working with specialist suppliers to improve input data and site monitoring for performance calibration.

8.2.19.2 Introduction

The Tideway study is set up to examine the effect of storm sewerage discharge in the tidal Thames in the reaches from Hammersmith to the sea limit. The study has been initiated because of the statutory requirement to manage solids discharges from CSOs in the region, and to ensure that the water quality in the Tideway is managed to maintain an appropriate biological habitat. The study is now possible because of the current availability of Tideway water quality models and sewerage network models of the Beckton and Crossness catchments.

The Beckton and Crossness catchments cover some 450 sq miles distributed both sides of the Thames from Hammersmith in the west to Dagenham and Erith in the east. The sewerage system was developed predominantly in 19th century and is a mainly combined system. As a result there are some 55 storm-discharge points to the Tideway, which form an integral part of the sewer network. The network is very complex with a large number of interconnecting trunk and storm relief sewers.

The sewer networks were modelled during 1991-1994, using the best available techniques and developing new methods as appropriate. The model building was looking forward to a “tideway” type study and included all the elements that would be needed to complete the study. However at the time, because some parts of the methodology were new, such as sewage quality modelling, there were some limitations to the development of the model, which may have needed to be upgraded to meet current best practice. The models now run using the InfoWorks^{tm} software.

The project files, including all reporting and background information are archived in the Thames Water Engineering Archiving system with all box names and contents listed in the document record system under project 1748.

8.2.19.3 Initial Modelling

An early requirement of the Tideway study was to estimate the range of volumes of flow and flow rates of sewage that would need to be handled by new works. To study this a time series of rainfall events, which could be applied to the model, was developed using the Storm Pac software. A 20-year series of events included some 1200 events. (The derivation of this series has been discussed in the rainfall data availability section of the report). Each of these events was simulated using the sewerage models and maximum flow rates and total discharge volumes were recorded.

From this data it was possible to derive maximum volumes and flow rates to be dealt with, together with an assessment of the possible performance of assets designed to retain 50% and 20% of the flow by volume.

Analysis of the outputs showed that maximum flow rates from the CSOs for major storm events were not very sensitive to the nature of the event. This indicates that hydraulic routing; flow diversions and levels are reasonably reliable. However for volume of discharge, this is very sensitive to the specification and calibration of the hydrologic models. It was therefore proposed that this aspect of model performance of the models was rechecked.

All output from the storm series modelling is archived on the Sewerage modelling group area on Server Eng03 (\\Eng03_gh\SEWERAGE\sewerage modelling\# Current Projects\SCUM-Part 3 including the Infoworks database SCUM-Part-3-modelling)

8.2.19.4 Model recalibration

Model building and calibration is discussed in the final reports of the model building project and is not repeated in detail here. All reporting and background information is archived in the Engineering Archiving system with all box names and contents listed in the document record system.

The models were built with a great deal of care with regard to input data for sewers and catchments. However due to the extent of the catchments some generalisation of surface hydrology and catchment connectivity was necessary. In summary the reports conclude that the model building is reasonably verified for dry weather flows and for minor rainfall events, but that calibration was not possible for major rainfall events. The models have been left such that in general flooding is predicted at all the correct locations for significant events, but that there are many other areas where flooding is predicted but not observed. This would leave the model conservative in that it is likely to over predict flows.

The limitation to the model was generally due to:

1. Difficulties with obtaining adequate flow measurement in major events.
2. Difficulty in obtaining realistic estimates of spatially distributed rainfall for calibration.

In the long term it will be necessary to recalibrate the whole model, but in the short term it was agreed that the team would review the effectiveness of the methods used in modelling by addressing a small area of the catchment in detail.

Accurate ADFM monitors were installed in the northwest part of the catchment. Flow data has been accumulated for a number of dry and wet days together with Nimrod radar data and rain gauge data. This has provided data to run accurate catchment simulations.

The areas of the model covered by the measurement have been reviewed in detail:

- Subcatchment areas have been included as map boundaries and their relevance checked.
- Demographic data contained in the model has been reviewed and updated.
- Hydrologic parameters within each boundary have been checked.
- Simplifications and additions (such as replacement storage volumes in pipes) to the network have been checked.
- A search has been made for anomalies occurring through either changing modelling software over the years, or through improvements to practice, and these removed as necessary.
- Base flows have been reviewed to take account of changes in time. It is essential that these are correct to accurately undertake simulation of sewage water quality.

- A review of the model performance in relation to the current flooding history database has also been performed.
- An assessment of the verification criteria was made against which the performance of the models was to be measured.

Model simulations have been run using the collected data and the model checked for timings, profiles and volumes. The overall results have indicated a good fit between simulated and measured results. The changes that have been needed have generally been small giving confidence in the results obtained so far. However in the long term it will be necessary to apply all changes to the methodology identified by the pilot study to the whole of the models in order to expedite full recalibration.

Installation and management of the ADFM flow survey is reported separately in this study. All work associated with review and recalibration of the models is archived on the Sewerage modelling group area on Server Eng03 (\\Eng03_gh\SEWERAGE\sewerage modelling\# Current Projects \ Beckton & Crossness Model reverification - May 2002 including the Infoworks Database).

8.2.19.5 Tideway Model Calibration

The existing models were used to provide storm sewage loads for calibration of the tideway model. Initially it was planned that calibration would include for 3 month dry weather periods with no algal and high algal activity in the river, and for some storm events. Major difficulties were found in providing suitable data for the tideway model, and results were produced for a long dry weather period and for 3 major rainfall events.

8.2.19.5.1 Sewerage modelling constraints

- The dry weather period included some rainfall so CSO modelling was required of this period
- The model was run implementing the water quality module. This substantially slowed the process such that processing of one month of data would take 4-5 days
- The dry weather simulation was for a three months period. In addition an initialisation period of 1 month was simulated to ensure reasonable representation making 4 months simulation.
- To get adequate spatial distribution of storm discharges, spatially varied rainfall was needed.

8.2.19.5.2 Resolution of difficulties

Initially spatially distributed rainfall was input using radar data. Although the radar substantially underestimates rainfall peaks but total daily rainfall is realistic. It was considered that matching of rain depths would be suitable for this type of modelling. However there were found to be anomalies in the data where some days had random but long duration (many hours) of unrealistic low intensity rainfall information. Numeric data checking could not isolate these anomalies. Finally it was decided to abandon use of this data and simulations were completed using data obtained from a number of rain gauges. This has been distributed across the catchment to give a spatial representation.

The model was found to create some spurious and very high pollution levels at some outfalls and some ancillaries. The results from these were abnormal, and easy to identify. They were also localised. To begin with these results were ignored. After several months of effort the software supplier was able to understand the problem and provide a fix to resolve the problem.

The problem of run time could not be addressed. However by running simulations for part of a month, and using output of one simulation to initialise the next it was possible to identify faults and problems without wasting too many days and rerun only those time elements that were affected.

Pollution loads produced by the model seemed to be low. The response measured in the Tideway was more significant than modelling processes predicted using the load. There are known to be elements in the pollutant model, particularly the functionality to model long term solid deposits within the sewer that may lead to underestimates. A comparison was made between some data sampled by the Environment Agency at pumping stations and storm simulations and storm simulations for those days. An increase in the pollutant load factor for the discharge of 3 seemed appropriate.

All work sewer model work associated with calibration of the Tideway models is archived on the Sewerage modelling group area on Server Eng03 (\\Eng03_gh\SEWERAGE\sewerage modelling\Tideway Quality 1997\Tideway Quality including 3 off Infoworks databases).

8.2.19.6 Compliance test simulations

Development of test rainfall events.

During the development of the Tideway study it has been seen necessary to develop a time series of real rainfall events against which the performance of the potential solutions can be tested to see if they improve river water quality. The test procedure is working with a measure of dissolved oxygen in the river and it is considered that rainfall events, which cause the worst loss of dissolved oxygen, should be used. Real rainfall events are used to get a spatial distribution and realistic timing of events. The model was therefore set up to take rainfall from a number of different rain gauges and distribute these inputs around the catchments.

The compliance procedure identified some 100 rainfall events for review. All were run through the model incorporating the default sewer quality parameters and outputs of both CSO volumes and strengths were provided to the tideway modellers. From this information a selection of the 61 most demanding events has been made.

The problem of run time for the simulations was resolved by processing rainfall events on five PCs in parallel.

Option testing.

There are two elements to option testing:

- Getting base flows for each event used in testing
- Running each event though all of the options to reduce storm discharges to the Tideway

Base flows - The base simulations for all test storms were already run, to provide storm outfall data. Additional data was needed to get full representation of pollution events along the whole distance from Teddington to the Sea Reach. To achieve total data collection additional processing of the output files was undertaken providing estimates of flows above the normal dry weather flows for the Crossness and Beckton process streams and an estimate of storm tank discharges at Crossness. Further work was required to provide similar data for Mogden STW. For this the Mogden model was grossly simplified, tested for performance against the original model, then run for all the events listed. Only the extra over flow and storm outputs were recorded.

Testing options - For each option to be tested the flows in the network and treatment works would remain constant. Therefore a simple model has been built of each option. Input hydrographs have been formed from the CSO discharge hydrographs for each event. Each event has been run for each option providing a family of sewage outputs/inputs for the Tideway model for testing.

All sewer model work associated with calibration of the Tideway models is archived on the Sewerage modelling group area on Server Eng03 (\\Eng03_gh\SEWERAGE\sewerage modelling\Tideway Quality 1997\Tideway Quality).

All sewer model work associated with providing base case sewage pollution loads and the equivalent loads for each possible solution is archived on the Sewerage modelling group area on Server Eng03 (\\Eng03_gh\SEWERAGE\sewerage modelling\Tideway Quality 1997\Tideway Quality\Solution testing. The individual options are in the Infoworks database in this folder as a separate catchment group).

8.2.19.7 Conclusions

The Beckton and Crossness sewerage models have proved to be extremely valuable tools to help understand the performance of the sewerage network and its effect on water quality in the Tideway.

Several limitations in existing data and technology have had to be resolved.

The quality of output of the models has been adequate to enable the study to progress. However at the same time a better understanding is being gained of where there is potential for improvement, and these areas are being progressed through model recalibration and working with specialist suppliers to improve input data and process monitoring.

8.2.20 Précis of Literature Search – R&T

8.2.20.1 Principal Conclusions and Recommendations

A literature search was conducted to investigate the water quality improvement solutions adopted by other urban cities. In general the solutions adopted were additional stormwater storage by either tunnel or storage tanks. These solutions were also commonly complemented with one or many of the following; rehabilitation of existing infrastructure, separation of stormwater from the foul/combined network, stormwater treatment and Real Time Control (RTC). The following are the main findings from the literature search: -

1. Many projects address both flooding and river quality issues.
2. An integrated catchment assessment and approach is promoted.
3. Long term (10 year +) planning and studies are invested for similar scale schemes.
4. Virtually all solutions required increased storage capacity, which was achieved by a tunnel or reservoir/tank.
5. RTC can be used to optimise the effectiveness of a solution.
6. Satellite treatment of CSO discharges is an option. However an important consideration to any solution is the upgrade required to the wastewater treatment works.

This strategic Tideway study has considered the main findings above, however these should be carried through to the detailed study and may envisage a long-term study to ensure a successful solution.

The information collected is restricted to that published and available in the public domain. There is little published information on performance achieved, operational experience or problems and difficulties. This aspect can only be resolved by more detailed investigation, which may include technical visits and the interviews with operators.

8.2.20.2 Methodology and Results

A literature search was conducted using the Cambridge Scientific Abstracts database, ‘Google’ Internet search engine and previously collected information within Thames R&T. Key words were chosen through discussion with Thames Water employee’s involved in the Tideway solutions group and experts in this field including Prof. Adrian Saul (University of Sheffield) and Richard Field (US Environmental Protection Agency).

To limit the number of references that were generated from the search, focus was made on papers published in the last ten years and websites updated within the last year. Each paper was evaluated for its objective for improvement, scale of the project and issues encountered.

The results are presented in as a reference table highlighting the solution investigated and/or employed within each city. As concluded above virtually all solutions required increased storage capacity, which was achieved by a tunnel or reservoir/tank and complemented by additional treatment, RTC, or separation.

Key for table overleaf:

CSOs – Combined Sewer Overflows	FFF = First Foul Flush	SW = Stormwater
DO = Dissolved Oxygen	BOD = Biological Oxygen Demand	SS =Suspended Solids
Dia. = Diameter	WWTW = Wastewater Treatment Works	USEPA = United States, Environment Protection agency
RTC = Real Time Control	I&I = Inflow and Infiltration	EPA = Environment Protection Agency

Table 49 : Literature Survey Review Summary

Location	Solution					Driver	Who	Employed	Cost	Comments
	Tunnel	Tank	Treatment	RTC	Separation					
Chicago, Illinois	Storage 210km 11m dia.	136 acres open air storage				500 CSOs & Flooding		1960 - 2004	$3bn	Capture 85% FFF SW detention at inlets
Milwaukee Wisconsin	Storage 91.5m deep					Pollution Control	District Council	Yes	$2.2bn	CSOs intercepted. Coliforms, BOD & Zinc reduced. SS same.
New York, New York	57,000m^3 in-line storage	108,000m^3 12m deep	Vortex separators, max to WWTW			Low DO, Coliforms, Aesthetics & Odour		1993 – 2001 (Not complete yet!)	$240m	Dredged bay, 1 in 1 month containment, 1 CSO = 60% pollution, chemical disinfection proposed
Rochester, New York	Storage 21.4km, 3-5m diameter, 5km siphon		30 WWTW's to 1 lake Ontario WWTW	3 scenario's, weather monitoring, forecasting & sewer monitoring		Rivers & bay septic	USEPA 75%, Dept. Env & Cons 12.5% & Council	1970's – 1992	$550m	CSO excellence award. Flushing from river, odour control, de-aeration chambers at drop shafts, transient pressures overcome.
Nashville, Tennessee	5km, 2.7m diameter	Detention replaced by separation.	WWTW upgraded		I&I removed 9.8Mm^3	Low DO, Toxic, Coliforms, Nutrients.	Dept. Health & Env.	1990 - 2006	$726m	70 spills PA before solution, aim to contain 70.8Mm^3 PA. Rates increase to pay for work, >177km rehabilitation,
Seattle, Washington	Existing interceptor with capacity			Upgraded local RTC to predictive				1990-92 upgrade only	$2.9M	Pumps down the interceptor as a storm approaches. Checks system in DWF for blockages/collapse.
Fort Worth, Texas			Ballasted sedimentation.		Separate network: I&I study			8 yr		Separate Network therefore solution was I&I study & additional treatment. 70% capex saving

Location	Solution					**Driver**	**Who**	**Employed**	**Cost**	**Comments**
	Tunnel	**Tank**	**Treatment**	**RTC**	**Separation**					
Montreal, Quebec	2 interceptors, $13,000 m^3$ in-line storage			Global RTC. Radar, controlled weir's gates etc		Long term CSO plan		Completed 1999	$4M	2hr predictions using radar rainfall data. Only implemented May-Sept. Different management modes. High Opex
Toronto, Ontario	Storage/ Transfer, 9.4km & 6m dia, 7km & 8m dia.	$8,000 m^3$ tank	Primary treatment for discharge, maximise quantity to WWTW			Long term CSO plan. Part of master plan (includes surface water)		20 – 25yr Unknown if completed		90% CSO reduction aim 1 per season. 30% BOD removal and 50% SS removal at treatment.
Niagara Falls, Canada			Satellite Treatment			EPA Area of Concern.	EPA/ Councils	1998-2000 Unknown if adopted		1st cities to employ satellite treatment in Canada after clean up fund study
Windsor, Canada						EPA Area of Concern.	EPA/ Councils	1998-2000 Unknown if adopted		
Hamilton/ Wentworth Canada				Demonstration project		EPA Area of Concern.	EPA/ Councils (Clean up fund)	Doesn't appear to have been adopted		Clean up fund demonstration project.
City of Elizabeth, New Jersey	Large diameter sewers with capacity			12 remotely controlled flushers				1990		
Whitten, Germany	Storage 770m long x 2m diameter									Automatic river flushing of storage tunnel after use.

Location	Solution					Driver	Who	Employed	Cost	Comments
	Tunnel	**Tank**	**Treatment**	**RTC**	**Separation**					
Paris, France	Interceptor : (Ivry-sur-seine catchment)	Open air 120,000m^3 underground 50,000m^3 (upstream of Paris)	Screen, de-grit and de/sludge underground storage	Mouse on line (Boulogne Billancourt) Condensed CSOs & control by RTC (Ivry-sur-seine)		CSO control		Yes (Boulogne Billancourt RTC 1998 - 2001)		Several catchment projects detailed under Paris.
Michigan area		20 tank storage schemes						Yes		Using flushing systems for over 5 years now
Hong Kong	70km deep transfer tunnel.		Chemically enhanced treatment			Sewage strategy 1989 to combat pollution.	Government funded	1989 - 2008	$13bn HK	Overpopulation requiring new infrastructure. 16 catchments requiring upgrade. Construction problems encountered. Primary treatment being improved to chemically enhanced.
Osaka, Japan	Storage trunk sewer, 6m diameter, 15m deep	Under WWTW may construct CSO tanks	WWTW extended. Multi-storey system	Considering using rainfall radar for pumping station optimisation		Flooding & eutrophication in Osaka bay	Osaka municipal government	1979 Flood review → 1986 - 2008		Network required doubling in capacity. CSO lamella plate settler developed, however unknown if employed. 20 yr experience of multi-storey WWTW's

Location	Solution					Driver	Who	Employed	Cost	Comments
	Tunnel	Tank	Treatment	RTC	Separation					
Tokyo, Japan	Storage, 8m diameter, 2.4km long, plus 5.3km lateral connections		2 day settlement in sewer		Separate storm systems under construction	Flooding. Strategically aim to contain 70yr RP event			312 M yen ($2.5 M US)	Due to cost starting with 17yr RP containment, previously only 3yr RP. Aim to improve 10% by infiltration & detention projects & 90% by sewer and river. 37 overflows intercepted by the Wada Yayoi trunk sewer.
Bangkok, Thailand	300km 0.6-3.2m diameter					Clean up of R.Phraya and Bangkok canals				Infrastructure development project
Barcelona, Spain				Mouse model		CSO improvement		1992 integrated plan.		
Bilbao, Spain				RTC to optimise interceptor use		Population growth 1995 – 2000 (to 960,000) & CSO improvement		1983 study, unknown if employed	£200,000	Studies still ongoing. Not known how much, if any, RTC has been implemented 21 CSOs aim to recude from 15 – 7 PA
Nancy, France		$12,000m^3$				Flooding & CSO improvement	EU LIFE funded project	Study 1996 – 2000 unknown if employed		Hydroworks model used. Unknown if tank actually constructed.

Location	Solution					Driver	Who	Employed	Cost	Comments
	Tunnel	**Tank**	**Treatment**	**RTC**	**Separation**					
Brussels, Belgium		Yes however no details				Water Quality improvement		unknown if employed		Considered CSO and WWTW's impact on river
R.Rhur (whole catchment		447 detention basins	Upgrade WWTW to deal with peaks	Being considered		Stormwater management	Ruhrver band			Aim to balance stormwater across catchment. Experience in the use of automatic cleaning of tanks.
Odenthal, Germany			Forward most polluted to treatment	Yes		Improve water quality of R.Dhuenn		No		Study to integrate the sewer network and treatment to obtain overall River improvement.
Munich, Germany		Storage of 90,000m^3 over 2 storeys						Suggests it is.		Design and installations described.
Aachen, Germany		10 storage tanks, 28,579m^3		Yes, Static → global.		Optimisation of CSOs		unknown if employed		Optimise storage and route textile input to treatment as priority.
Essen, Germany				Yes		Pollution containment		unknown if employed		River and CSO interactions highlighted need for investigation.
Halmstad, Sweden		3,500m^3 storage	Full upgrade for N&P removal	RTC to maximise 10,500m^3 storage across network	Separate impervious areas from combined	N&P removal, CSOs and flooding		1996/7 tank designed Rest unknown if employed	3M ECU (tank only)	Aim for <5 CSOs PA i.e. 90% reduction. 1 in 10 year flood protection. 2.5% annual wastewater volume discharged by CSOs. 5-year rehabilitation programme of network & treatment.

Location	Solution					**Driver**	**Who**	**Employed**	**Cost**	**Comments**
	Tunnel	**Tank**	**Treatment**	**RTC**	**Separation**					
Helsingborg Sweden			Maximise even flow rate to treatment	Planned RTC simulation		N&P removal		1994-99 CSO/flood plan	5M ECU (not WW TW)	EU funded integrated model project. Sediment modelling also included.
Malmo, Sweden				Maximise on-line storage in trunk sewers		Reduce storm peaks to WWTW to improve treatment		unknown if employed		Modelling study
Copenhagen Denmark				Yes		DO problems in River		1994 + partial		Several RTC studies completed and some implemented
Hastings, UK	Transfer tunnel. 52,000m^3					Bathing water quality			£450 m	
Bolton, UK				Global predictive RTC						

8.2.21 Précis of Legislation

8.2.21.1 Parliamentary and Statutory Requirements

Introduction
Bircham Dyson Bell, a Westminster based law firm was instructed to provide a briefing on the Parliamentary, statutory, planning and environmental law requirements for implementing options A and G. Although only two options were looked at the information is generic for all the other tunnel schemes.

Options A and G both require the construction of a tunnel underneath the River Thames running from Chiswick to East London, with option A ending at Crossness STW and option G at Rainham on newly constructed reed beds. These tunnels will accept storm water from combined sewer overflows (CSO) and transport the water to East London for treatment. The majority of the tunnel routes are along the tidal section of the River Thames which commences downstream of Teddington Lock. Five to six access shafts will also be required to be constructed at equidistance along the tunnels route. As well as the access shafts, jetties will also be constructed to assist with the construction of the tunnel and then used to remove the operational waste from the site, if appropriate, rather than using the local road network.

The outcome of the legal review is summarised below: -

1. Tunnels, shafts and any accessories can be classified as 'sewers' and so will fall within the 'relevant pipe' as defined in the Water Industry Act 1991 (WIA). The jetties fall outside this definition so have to be dealt with separately.

2. Thames Water can use its powers under section 159 of WIA to carry out the Tideway scheme (and under section 158 for parts of the scheme under roads) without having to negotiate for and purchase rights from affected landowners. Landowners must however be given notice and have a right to be compensated. Thames Water can apply for a compulsory purchase order under section 155 WIA but the jetties cannot be constructed under section 159 WIA.

3. The scheme cannot be authorised as a whole under the Transport and Works Act 1992 or the Harbours Act 1964.

4. A licence is required from: -
   - the Secretary of State to carry out all the works under the river (which includes the tunnel and the jetties)
   - the Crown Estate or government departments for works under their land and
   - the Port of London Authority for works in the river affecting jetties, structures and navigation.

   To the extent that the jetties and construction work constitute a material interference with navigation, a licence from the Port of London Authority would provide sufficient protection against any claims.

5. The proposed scheme is classified as development under the Town and Country Planning Act 1990. The parts of the scheme that are situated underneath the ground have permitted development rights unless an environmental assessment is required. Planning consent can be applied for from local authorities or planning direction can be sought from the Secretary of State for the remainder of the scheme. Planning direction can be granted in consultation with consent being issued by the Secretary of State for work in or under the river.

6. It has been highlighted that the Tideway project will probably require an environmental impact assessment to be carried out. This environmental assessment process would only be triggered following the application for planning permission and not by the application for planning direction from the Secretary of State. It has been advised that an environmental impact assessment should be carried out.

7. Along the proposed route of both schemes there are no sites, which are protected under European conservation legislation, which the works would affect. Thames Water has specific duties as set out in the Wildlife and Countryside Act 1981. Local designations will be taken into account at the planning permission stage.

8.2.22 Precis of Town Planning Process

8.2.22.1 Principle Conclusion

An important issue for the Tideway Strategy is to assess the possible planning routes and their requirements for the implementation of any potential solution. The outcome of the study was that a final decision on the most appropriate planning route cannot be made at this stage and is unlikely to be decided until the detailed design phase has commenced.

8.2.22.2 Discussion of Study

The objective of the study was to investigate and identify the planning requirements for the Tideway project and to recommend the most appropriate route for planning submission of the final scheme.

A number of potential options for promoting the Tideway scheme through the planning process were considered.

These were:

1. Deemed planning permission under the General Permitted Development Order (GPDO).
2. Separate planning applications for each individual scheme component to be determined by each LPA.
3. Separate planning applications to each LPA but with agreement for 1 LPA to take a 'lead role' in considering the applications comprehensively.
4. A Special Development Order under section 59 of the Town and Country Planning Act 1990.
5. Planning Direction given by the Secretary of State in accordance with Section 90 of the Town and Country Planning Act.
6. Private Parliamentary Bill.

It is unlikely that the whole scheme as it stands could be built using permitted development rights. Screening of the individual scheme components highlighted a number of elements that would require planning permission (for instance where there would be a building associated with an access shaft), and some where EIA may be required given the scale of the works and the potential environmental effects (for instance the necessary upgrading works at Crossness STW). The scheme may also be regarded by the planning authorities as either a "long distance aqueduct" or an "urban development project" of a scale which would require EIA under Schedule 2 (10) of the EIA Regulations. Where EIA is required, permitted development rights are withdrawn and a planning application is necessary.

Separate planning permissions could be submitted for each scheme component, most logically on a site-by-site basis to the relevant borough (eg that for the tunnel shaft at Homefield Recreation Ground to LB Hounslow, etc). Some of these may be subject to individual EIAs. This would make it possible to negotiate each separate permission, although would leave open the possibility of one or more Boroughs effectively holding the entire scheme to ransom or otherwise standing in the way of its progress. Works at any of the 55 CSOs may also require planning permission, involving applications to up to 13 different boroughs (including Richmond; Hounslow; Wandsworth; Kensington and Chelsea; Westminster; Lambeth; Southwark; Lewisham; City; Greenwich; Newham; Tower Hamlets and Bexley). It would also leave open the question of how to deal with the tunnel (defined as a sewer in the note on planning prepared by Thames Water's lawyers, Bircham Dyson Bell, entitled "*Thames Tideway Parliamentary and Statutory Requirements*" 14 Feb 2003). This could be promoted as Permitted Development, but due to the potential environmental effects an EIA may be required and hence PD rights would be withdrawn.

Alternatively, if agreement could be reached, I LPA could take responsibility for considering all the planning applications comprehensively. This is not an uncommon circumstance when a proposed development scheme straddles local authority boundaries. It would be for the authorities affected to make arrangements so that the scheme could be dealt with in this way and they are under no compulsion to do so. It is usually the authority with the majority of the scheme within its jurisdiction that takes the lead.

A Special Development Order could be sought under Section 59 of the Town and Country Planning Act 1990 pursuant to which the Secretary of State grants permission for the scheme by way of statutory instrument. This can be a time-consuming and somewhat inflexible process. Nonetheless it would allow for the scheme to be consented by means of a single process rather than numerous separate applications.

Section 90 of the Town and Country Planning Act 1990 allows normal development control procedures to be circumvented where the authorisation of a Government Department is otherwise required to carry out development, as it allows for the Secretary of State to grant planning permission for the scheme at the same time by way of a direction. Bircham Dyson Bell note that for Tideway, Government authorisation could be sought for works below the high tide mark under section 187 of the Water Industries Act. There is no guarantee, however, that the Secretary of State would be prepared to make a planning direction as part of that process.

Whether EIA would be required before the Secretary of State could lawfully make a direction in this case is not entirely clear, but in view of the scale of works and impacts identified through the preliminary screening reports, it would be advisable to submit an ES voluntarily to put the matter beyond doubt.

The option of a Private Bill was considered untenable, as it would have to be shown that there was no alternative method of achieving consent for the scheme.

8.2.22.3 Preliminary Consultations

A number of consultation meetings were held to obtain preliminary views on the Tideway scheme and discuss the possible planning routes for implementation. The Consultees and salient points raised by each are listed below.

Government Office for London

GOL took the view that the option of submitting conventional planning applications to all the boroughs involved without any specific effort to co-ordinate consideration of the applications was administratively unattractive, with so many boroughs involved. Submission of conventional planning applications with co-ordination of the process, perhaps through a lead authority, was considered to be preferable. GOL were willing to facilitate this approach, through liaison with the Association of London Government.

GOL was not aware of any insuperable obstacles to the use of a planning direction under Section 90 of the Town and Country Planning Act 1990, but could not confirm that its use would be regarded as appropriate for the Tideway scheme. Consultation with the Department for Food, the Environment and Rural Affairs (Defra) was recommended. GOL noted that Special Development Orders have been very little used in recent years; experience had indicated that they are inflexible and tend to be administratively cumbersome.

If a conventional planning application route were adopted, GOL would advise the Secretary of State upon the appropriateness of a call-in (for example, where an application is for a proposal that would be a departure from the relevant local authority's development plan, then the Secretary of State must be notified). GOL was willing to discuss this option prior to submission and to complete any consideration of call-in quickly, in line with Government targets, so that the implications for the project as a whole could be taken into account. This route would be similar to that taken with T5, where the application was submitted to the local authority then immediately called in and the planning process managed by GOL.

Department for Food, Environment and Rural Affairs (Defra)

The Water Quality Division of Defra was consulted regarding the potential for seeking a Planning Direction in association with a consent for works below the high tide mark under section 187 of the Water Industries Act. Defra provided a list of information required to support such an application, but were unable to advise on procedures for obtaining a Planning Direction. Consultation with the Office of the Deputy Prime Minister (ODPM) was recommended.

Office of the Deputy Prime Minister (ODPM)
Preliminary consultation with ODPM resulted in a recommendation to consult GOL. Further consultations are in progress.

Greater London Authority (GLA)
The GLA was consulted as the Mayor is a statutory consultee for planning applications of potential strategic importance for London. Accordingly he may comment upon and indeed support these applications, or, if he considers it necessary on strategic planning grounds, direct the London Borough concerned to refuse planning permission. The Mayor cannot direct approval of applications or himself grant permissions. His powers, including the definition of an "application of potential strategic importance", are set out in the Town and Country Planning (Mayor of London) Order 2000.

Because of the unusual nature of the Tideway scheme, it does not fall specifically within any of the categories of application of potential strategic importance set out in the above mentioned order. Notwithstanding this, the application may well be of interest to the GLA as the scheme transcends borough boundaries and has a significant footprint, much of which is adjacent to the Thames.

The GLA suggested that the Mayor could take a co-ordinating role if the lead authority route was chosen, co-ordinating the Boroughs' responses to the application. However, it would still be up to the relevant local planning authority to issue consent as the GLA has no powers to do so. If the route involving a lead borough was chosen, GLA suggested that LB Wandsworth be considered. (NB: LB Wandsworth provided the most positive response in the preliminary round of consultations held on the Tideway Strategy with the key riverside Boroughs.)

Association of London Government (ALG)
ALG acts in an advisory role to the London Boroughs but would be willing to act as a focal point for dissemination of information, probably through one of their liaison groups, viz Chief Planning Officers Group; Development Control Group or Policy Group. ALG noted that once the Tideway programme was set out, they could assist in making representations at the appropriate time in respect of the GLA London Plan revision (2005/6) and the Borough Local Development Strategies (December 2004 – planning frameworks to be in force by 2007).

Additional Consultations
Consultations have been held with Boroughs where major tunnel shafts would be located. Consultation meetings have also been arranged with the Thames Estuary Partnership and Port of London Authority.

8.2.22.4 Preliminary Conclusions on Planning Route

Preliminary conclusions are as follows:

- No particularly strong steer on a suitable planning route has been forthcoming from the various authorities who may be involved – it is Thames Water's decision.
- The planning authorities are unfamiliar with the Planning Direction and Special Development Order routes and would not appear to encourage their use.
- The option of separate applications to multiple London Boroughs (with or without ESs depending on the scope of works) would be administratively complex, likely to lack cohesion, and thus probably undesirable.
- If a lead authority route were to be adopted, it would be preferable to approach LB Wandsworth to discuss the possibility of their taking the lead, as from experience to date they are more proactive and might be more receptive to this than other Boroughs. Alternatively, discussions could be held with the GLA regarding acting as the lead authority.

- If it appears likely that the project will need to be considered at a Public Inquiry, an immediate call-in and determination by the Secretary of State would appear to be preferable.

8.2.23 Précis of CFD Study

8.2.23.1 Principal Conclusions and Recommendations

1. A main tunnel 6m in diameter is most unlikely to choke during filling when subjected to the predicted inflows.
2. Choking would result from higher inflows at increased velocity.
3. Smaller diameter connections, though desirable for construction, would increase inlet velocity and therefore increase the likelihood of choking with the main tunnel.
4. Computational Fluid Dynamics (CFD) is an appropriate modelling tool to predict the potential effects of choking.

8.2.23.2 Application to Potential Solutions

The results of this study confirm that choking is very likely to be a problem for tunnels smaller than 6m diameter and thus supports the impact on potential solutions as detailed in 8.2.

With particular regard to potential solution A, the main tunnel diameter of 6m can be considered as sufficient for the predicted inflow rates.

Discussion of Study

The requirement of a minimum hydraulic capacity of the main tunnel to prevent choking has a significant impact on the viability of various potential solutions. As displaced air can only be vented at the main shafts, it is essential that there is continuous free space above the surface of the flow during filling in the main tunnel to allow for the passage of air to these shafts. High rates of inflow to the main tunnel can create localised increases in flow level, due to turbulence, which may hinder the passage of displaced air. Under certain circumstances this localised increase in flow level can create a plug of water, thus effectively preventing the release of displaced air and choking the tunnel. Should air become trapped, the tunnel will not properly fill leading to a reduction in the interception of the polluting flows. Air trapped by high inflows can also become pressurised which can result in uncontrolled and explosive release.

A state of the art Computational Fluid Dynamics (CFD) package was used in this study to model the inflow to the main tunnel to predict the likely flow patterns and levels under filling conditions to determine whether choking is likely to be a significant issue for the storage tunnel options.

This study consisted of three parts

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

Three CFD model runs based on the Fleet Main line CSO were carried out for the modelling of a single high inflow to the main tunnel, these included:

Inflow (m^3/s)	Main tunnel diameter	Connecting tunnel diameter
37	9	4
37	6	4
73	6	2.5

All three model runs continued at the constant inflow rate until the main tunnel completely filled. The first two runs showed that the flow into the main tunnel was relatively smooth. Although there was a localised increase in flow level around the connection no plug developed within the main tunnel to hinder displacement of air until the main tunnels were very nearly full.

For the third model run the inflow rate was virtually doubled and the diameter of the interconnecting tunnel reduced to further increase the velocity. Under these inflow conditions a plug of swirling flow developed almost immediately. Such inflow conditions would undoubtedly prevent release of displaced air and cause the main tunnel to choke.

The second part of the study included CFD modelling of a section of tunnel to determine the combined effect of multiple inflows. The section of storage tunnel for A(low) between the main shafts at Heathwall and St Georges Wharf was used. This section of the tunnel would be approximately 10km in length and would receive flow from several CSOs, some with high peak inflow rates. The model was based on constant inflow from each CSO based on the predicted maximum.

CFD model runs of this nature are based millions of calculations within each iteration. Consequently fast and powerful computers are required to carry out these computations. As an indication this model run took 5 days to complete.

The results showed that despite the combined effects of several CSOs the main tunnel filled relatively smoothly. There were localised increases in depth at the connections, but no plug formed until the tunnel was virtually full.

The small scale physical model was based on a single connection and was carried out to validate the CFD model to increase confidence in the predictions.

9. Conclusions

9.1 Introduction

At the commencement of this study the objectives were relatively poorly defined, as significant preliminary work was required to determine the appropriate limits. Whilst some clarity has developed it is felt likely that the objectives may well be subject to further refinement. It is a significant challenge to develop appropriate and robust solutions without well-defined objectives.

This study has concentrated on the investigation of strategies and the development of potential solutions to mitigate the adverse effects deriving from the Tideway CSO storm discharges. During development of the solutions, it has become very apparent that this issue cannot be considered in isolation and that a holistic view of the Tideway must be explored which encompasses sewage treatment works discharges, the risk of sewage flooding and flood prevention measures.

9.2 Assessment of Strategies

9.2.1 Strategy 1 – Before the system

The potential options for consideration under this strategy are based on the exclusion or control of rainwater run-off before it enters the sewerage system. These could include source control, detention ponds and other similar SUDS techniques.

The catchment is very mature and serves a very densely urbanised environment. There is limited opportunity to apply source control at the upper reaches of the catchment. Modelling shows however that the CSO spill volumes are relatively insensitive to such changes. The widespread retrofitting of SUDS techniques is considered to be, disruptive and costly at best and probably not technically feasible.

Exclusion of runoff from the sewerage system is not feasible as alternative disposal routes for surface water flows are scarce or not available. There is simply not the space for surface watercourses or detention structures such as ponds and swales within the built up areas of London.

The strategy of preventing storm water from flowing through the sewerage system by source control or SUDS techniques is not viable.

9.2.2 Strategy 2 – in the system

The potential options within the sewerage system considered under this strategy include: attenuation within the system or by the provision of new on or off-line tanks and separation of the sewerage system.

The existing system, although sufficient for dry weather flow, very quickly becomes overloaded during rainfall events. Despite the huge size of some of the sewers in the centre of London the total volume available to achieve in-line attenuation is small compared with the discharge volumes generated by a rainfall event of even short duration. The large sewers are mostly ancient culverted watercourses, which originally provided land drainage in the London area.

Although below ground they are in fact very shallow and are associated with the significant numbers of properties at risk of sewage flooding in the London area. This risk is mostly due to the very large number of basement properties, many of which are formed at a lower level than the soffits of the large sewers to which they drain. This means that artificially surcharging these sewers to higher levels to utilise such storage would further increase this flooding risk, which would be counter-productive and unacceptable.

The construction of on or off-line storage in discrete units throughout the existing system would be very disruptive. A far larger volume would have to be created as the CSO flows become relatively insensitive to changes further away from the river. Emptying of these additional storage volumes would be problematic for a number of reasons. As described above the land drainage river sewers and the collectors, which intercept them, are shallow. Implementation of the required volume would require large, shallow tanks spread over large areas to achieve gravity draindown or deeper tanks with the inevitable requirement for pumping plant to empty them. To achieve quick emptying to reinstate the storage volume for the next event, draindown flows would need to be large and would overload the existing system causing CSO spills. Hence dedicated additional sewer capacity would have to be implemented to accommodate these draindown flows. The strategy of attenuation within the sewerage system is therefore not viable as it would be very costly and disruptive.

Separation would entail the construction of an entirely new separate sewerage system, which would only be possible at very high cost and disruption over a long period. It is also unlikely to solve the storm pollution problems of the Tideway, as surface water runoff generally includes its own pollutants. It also cannot be guaranteed that the systems would remain separate over the long term due to redevelopment and misconnections.

This approach of separation has been investigated in outline by considering converting the existing combined sewers to the surface water system and implementing an entirely new foul system. This new foul system would consist of approximately 20,000km of sewerage system installed in the already congested streets of London together with approximately two thousand foul pumping stations. The drainage for approximately 3 million properties would also have to be entirely reconstructed. The overall cost is most unlikely to be less than £12B.

9.2.3 Strategy 3 – At the interface

The potential options at the interface of the sewerage system and the river, that is at the CSO outfalls, include screening at the individual outfalls, interception to storage, transfer or distribution for screening or treatment elsewhere and storage adjacent to the outfalls.

It was recognised at an early stage in the study that this strategy probably represented the type of solutions that could be considered potentially viable and worthy of further investigation. This led to the development of solutions A to H, which are the main focus of this report.

Of the potential solutions, those based on interception to storage and transfer to a purpose built storm sewage treatment plant are the most feasible and suffer from the least technical challenges.
Potential solutions within this strategy have been investigated and costs estimated in outline. This exercise has revealed that only a few of the possible engineering solutions are likely to realise the desired levels of improvement at reasonable cost. It should also be appreciated that the ultimate solution to the Tideway water quality is likely to involve a combination of various techniques.

9.2.4 Strategy 4 – in the river

Options within the river itself can only include reactive measures such as injecting oxygen from river craft or bankside installations. In fact this strategy 4 cannot be considered to provide an appropriate solution in that the polluting effects can only be ameliorated and the sewage litter problem will be entirely unaffected on DO.

9.3 Conclusions of Technical Studies

There are six critical conclusions of the technical studies, which have fundamental impact on the efficiency of the strategy or potential solutions. These are listed as follows and discussed in more detail below:

1. Minimum main tunnel diameter to prevent choking during filling and for constructability.
2. Land acquisition, planning and environmental constraints and impact of implementation.
3. Catchment characteristics, such as its maturity.
4. Treatment limitations due to intermittent and variable flow.
5. Cost of capital investment and operation.
6. Effects of CSOs on river.

9.3.1 Minimum Tunnel Diameter

The requirement of a minimum tunnel diameter, of at least 6m, to enable stable filling without choking has a profound impact on the potential solutions based on transfer and distribution tunnels, in particular at the medium and low level of intervention. In effect the main tunnels for potential solutions B, C and D at all levels of intervention has to become 6m in diameter, which makes the inherent storage volume included in each all these potential solutions remarkably similar. There becomes little to differentiate between the main tunnel of B, C or D and that of potential solution A, at the low level of intervention. The massive requirement for pumping and screening capacity for B, C and D is therefore seriously in question.

Main tunnel diameter is also a fundamentally important factor to facilitate driving of the interconnecting tunnels from the main tunnel itself. This facility would enable land take and disruption at the interception structures to be minimised by reducing the size of drop shaft required. This shaft would only have to be large enough to enable recovery of the tunnel-boring machine. Alternatively, should the main tunnel diameter be selected to be too small to accommodate this approach, the interconnecting tunnels would have to be driven from larger shafts at the interception structures and there may even be the requirement for a reception shaft adjacent to the main tunnel in the river. This approach would lead to significant additional disruption and cost.

9.3.2 Land Acquisition, Planning, Environment & Impact

The availability of London sites changes rapidly, the market for land is very dynamic in nature. Identification and securing of potential sites is a key element to successful implementation of any potential solution. Planning constraints are greatest around Central London but ecological restraints are common throughout the Tideway.

The acquisition of large areas of land for use as storm sewage treatment sites in central London will be very challenging and would come only at high cost. These issues will severely impact on the viability of potential solutions, which rely on such sites in Central London. That is C, D and in particular F.

Although there may be some flexibility with the actual locations for the pumping and screening sites for potential solutions C and D they must, for hydraulic reasons be located relatively close to the major CSOs. It is very likely that these would have to be constructed entirely underground, which would impose engineering and operation challenges and increase cost dramatically.

For potential solution F, the implementation of screening plant for each individual CSO, is very limited flexibility as to the location of such plant. Even if all these sites were constructed entirely underground it is considered that the vast majority of such installations would impose either extreme or intolerable disruption.

Potential solution E imposes a very high impact on the foreshore, which is an increasingly valued amenity.

The remaining potential solutions, based on storage or transfer tunnels, would have a lesser impact on Central London and requires the least acquisition of land. However there are two areas of significant challenge, which must not be overlooked.

- Sites for the construction shafts, which will be retained in part for operational access, are required.
- Securing access for construction and maintenance of the interception structures will be very difficult in most locations.

9.3.3 Catchment Characteristics

The catchment is very mature and serves a very densely urbanised environment. There is very limited opportunity to apply source control except at the upper reaches of the catchment, however the CSO spill flows are relatively insensitive to such changes.

The widespread retrofitting of SUDS techniques is considered to be, at best, disruptive and costly and, at worst, not technically feasible. Alternative disposal routes for surface water flows are scarce or not available. Construction of an entirely new separate sewerage system would only be possible at extreme cost, approximately £12B, and disruption over a very long time. The strategy of preventing storm water from flowing through the sewerage system by source control, SUDS techniques or separation is not viable.

The existing system, although very adequate for dry weather flow, very quickly becomes overloaded during rainfall events. Therefore there is very limited opportunity to utilise attenuation within the sewerage system. The construction of on or off-line storage in discrete units throughout the existing system would be very disruptive. A far larger volume would have to be created as the CSO flows become relatively insensitive to changes further away from the river. Emptying of these additional storage volumes would be problematic as the draindown flows would accumulate and overload the existing system. Hence dedicated additional sewer capacity would have to be implemented to accommodate these draindown flows. The strategy of attenuation within the sewerage system is not viable.

Essentially the only strategy, which is viable and could realise the objectives is the implementation of appropriate solutions at the interface between the sewers and the river.

9.3.4 Treatment of Intermittent Flow

Rainfall events create a large intermittent and variable flow. Because the times of concentration are very short this limits the application of secondary treatment, which is based on biological processes. Secondary treatment is only likely to be viable if supported by STW sites and for flow rates of up to about $10m^3/s$ maximum. Secondary treatment can only be applied to those potential solutions, which are based on storage so that the flows can be pumped out at a controlled rate. That is A, D and E.

The upper limit of secondary treatment flow rate means that for the medium and maximum levels of intervention for solution A, not all the flow from the large events can receive this full treatment unless the tunnel empties.

The physical processes of screening and enhanced primary treatment are more tolerant of such intermittence and variability as units can be switched on or off to accommodate the flow rate. However for the very high flow rates associated with potential solutions B and C, only screening would be possible.

Secondary treatment for potential solution H will not be possible as the treatment site is remote from existing treatment works and the biological process could not be supported between rainfall events. Enhanced primary treatment based on deep bed filters is considered appropriate for this application. However, this part of the river is also heavily affected by the storm tank discharges from Mogden STW. It would be necessary, therefore, to enhance the treatment process at Mogden STW to improve effluent quality to enable the river to accept the treated effluent of the storm treatment plant at Heathwall. It could also be possible to provide a more enhanced treatment at Mogden in order to compensate for a lower degree of treatment at the Heathwall site.

9.3.5 Cost of Capital Investment & Operation

Obviously the cost of implementation and operation are key factors. The capital costs (at 2002 figures and updated to 2010 figures) and operational costs are summarised in Table 50.

Table 50 : Potential solution 2002 and 2010 Capex and Opex costs

Potential Solution / Intervention	**Estimated Cost (£M)**		
	Capital Investment		Operating Costs
	@2002	**@2010**	**Per year @2002**
A Maximum	2,784	3,527	6.9
A Medium	1,776	2,250	3.5
A Low	1,287	1,630	1.9
B Maximum	2,648	3,354	9.7
B Medium	1,676	2,123	4.9
B Low	1,164	1,474	2.3
C Maximum	4,149	5,256	10.3
C Medium	2,246	2,846	5.3
C Low	1,480	1,875	2.3
D Maximum	4,983	6,313	11.6
D Medium	3,153	3,994	6.0
D Low	1,889	2,393	2.6
E Maximum	3,467	4,392	3.5
E Medium	2,213	2,804	2.1
E Low	1,518	1,924	1.2
F	11,713	14,837	12.2
G	2,714	3,438	5.6
H	650	823	1.2
H+	1,265	1,602	2.2

The operating costs are generally based on the figures, which include for grid supply of electricity.

9.3.6 Effects on River Quality

The River Quality Study showed that the CSO discharges affect the river in different ways depending on their size and location. It is therefore possible to allocate priorities according to the river needs and have regard to compliance with the future objectives. Potential solution H has evolved in response to these priorities, since it focuses on the upper reaches of the river which have, historically, suffered the most severe DO losses and where major fish mortalities have occurred. It is also an area where a high degree of importance is placed on aesthetic quality due to recreational activities.

It has been established that improvements at some of the STWs are essential if the full benefits of tackling the CSOs are to be realised. This cannot be regarded as a completely separate issue since additional treatment of storm flows at a treatment works may offset the need to treat CSO effluent to a higher standard. If it becomes necessary, due to financial constraints, to consider partial solutions the above priorities may need to be considered.

9.3.7 Other Main Conclusions

There are many other conclusions, which have important influences on the selection or scope of potential solutions. These are listed in the précis for each study in Section 8 – Technical Studies and are summarised below:

1. Tunnels will suffer from deposition, therefore a robust flushing regime will be required
2. Displacement tunnel will have insufficient capacity unless assisted by high flow pumping
3. All potential solutions will require additional manpower to operate and maintain
4. Spoil disposal and potential re-use is a key factor
5. Off-line tanks are more expensive than large diameter tunnel for storage
6. Construction insurance risk is perceived to be very high
7. Peak flows for transfer/distribution solutions are too high for treatment other than screening
8. Peak power requirements for transfer solutions are too high to be practical/economic
9. Inlet type screening plant is required as there is no carry-forward flow to accommodate CSO type screening plant
10. The results from SCITTER at Acton display very prominent first flush effects
11. Company wide strategy is required to tackle the screening and grit disposal problems.

9.3.8 Impact on Potential Solutions

The impact of the critical conclusions and the other main conclusions is summarised in Table 51.

Table 51 : Impact of Potential Solutions

Potential Solution	Principle Factors
A	Interception to storage facilitates treatment of storm water to highest quality. Storm water treatment plant can be used to improve treatment at existing STW. Disruption/land take limited to interception structures and construction shaft sites. Viable with existing construction technologies. Very flexible in storage/transfer capacity.
B	High transfer flows require high pumping and screening capacity and inordinately high peak power capacity. Appropriate treatment is screening only. Application of minimum tunnel diameter to prevent choking changes character of main tunnel from transfer to storage.
C	Construction of large pump and screening sites in central locations will be disruptive. Appropriate treatment is screening only. Application of minimum tunnel diameter to prevent choking changes character of main tunnel from distribution to storage.
D	Application of minimum tunnel diameter to prevent choking of storage tunnel implies first flush tunnel for all levels of intervention will be as big as that required for A (low).
E	Large storage shafts in foreshore will be disruptive to construct and difficult to operate Additional draindown tunnels required. Becomes very costly
F	Construction of screening plant at individual CSO locations will be unacceptable at most locations. Compensation and diversion costs are potentially astronomic.
G	Transfer capacity under gravity is too limited, requires pump assisted transfer. Regular high flow pump flushing consumes excessive energy. Appropriate location for Constructed Wetlands impossible to acquire
H	Potential first phase of A. Treatment plant at Heathwall based on screening and enhanced primary treatment. Requires improvement in treatment at Mogden STW. Implementation of additional partial solutions could augment this solution.

9.4 Comparison with other Similar Projects

Most other major projects of this nature are based on the approach of interception to storage followed by treatment before discharge back to the watercourse. There are three main examples from the USA, that is Chicago, Milwaukee and Rochester NY.

Summary details for these projects are included in the Literature Search Précis in Section 8, however outline details are included in Table 52 for reference:

Table 52 : Summary of comparisons with other major US project

Name	Cost	Description	Objective
Chicago	£1.9 billion	210km of deep tunnel to 10.8m, 85% first foul flush capture. 73 Million m^3 of surface storage. Population of 3 million and a greater urban area of 9 million	Intercept 500 CSOs and reduce flooding
Milwaukee	£1.4 billion	Pollution abatement, interception of CSOs to 90m deep storage tunnel. Population of 600,000 and a greater urban area of 1.7 million	Intercept CSOs to reduce coliform levels and BOD discharges to lake Michigan
Rochester New York State	£350 million	21km tunnel, 30-drop structures, 5 major control structures. Two phases over 15 years. Population of 220,000 and a greater urban area of 1 million	Reduce CSO discharges in to the Irondequoit bay, which suffered from septicity in the summer.

There are only a limited number of UK examples. As part of Southern Water's Operation Seaclean, a coastal pollution abatement programme of £450 million overall cost, the following two examples are based on interception of CSO flows to a storage tunnel (table 53):

Table 53 : Summary of comparisons with other major UK projects

Name	Cost	Description	Objective
Hastings	£40 million	6.5m diameter on-line storage tunnel, pumping station and treatment works.	To improve bathing water quality driven by the UWWTD and reduction in flooding.
Brighton	£36 million	5.5km of 6m diameter storage tunnel to intercept four major outfalls. Serves a population of 156,000.	To improve bathing water quality driven by the UWWTD.

These examples clearly show that the adoption of storage of intercepted flows, generally to a large diameter tunnel is the typical approach adopted to reduce the pollution from CSOs and to reduce the risk of flooding.

9.5 Overall Conclusions

9.5.1 The Viable Strategic Approach

Of the four strategies investigated it was concluded that strategy 3, which included potential options at the interface of sewerage system and the river (that is at the CSO outfalls) represented the only solutions that could be considered potentially viable and worthy of further investigation. These strategic conclusions are further discussed in Assessment of Strategies below.

9.5.2 The Appropriate Potential Solution

Of all the potential solutions investigated the approach of intercepting flows to storage at or near the CSOs for transfer to treatment is seen to represent the most appropriate overall approach to meet the required objectives. This approach has the least technical challenge, the least impact in terms of land acquisition, planning and environmental constraints and the most flexibility to accommodate refinement of objectives. The main conclusion of the Overall Project Risk assessment described in 7.3 was that this was the only feasible approach, which did not involve any potentially insurmountable issues. The challenge is to quantify storage volume requirement and how much bypass to allow to the river during high rainfall events. As there is inadequate space for surface storage in London, the most efficient provision of this storage, and least disruptive in implementation, would be by large diameter tunnel. This solution provides a single facility to collect; store and transport the CSO spill flows to the treatment plant downriver.

This approach is represented by potential solutions A and H, a complete and partial solution respectively, which are summarised briefly below:

1. Potential solution A consists of a storage tunnel constructed generally under the river, interception structures for all CSOs and a large pumping station to lift flows to the storm treatment works. The treatment facility would be located adjacent to Crossness STW and would consist of screening and grit removal plant; deep bed filters and submerged aerated filters. This plant could achieve a high quality of storm effluent. It would also offer the potential benefit of enhancing the secondary treatment and tertiary treatment of effluent for the existing works.

2. Potential solution H consists of a storage tunnel for the west reach of the river, interception structures for the first 19 CSOs, pumping station and treatment plant at Heathwall. The treatment facility would consist of screening plant and deep bed filters. This plant could achieve a reasonable quality of storm effluent. However, improvements to Modgen STW treatment processes would be required to enable the river to accept the treated storm discharge at Heathwall without detriment. This potential solution basically represents the first phase of implementation of potential solution A.

Further consideration has also been given to augment potential solution H by the implementation of further partial solutions, in order to make it a more complete concept. This is referred to as potential solution H+. Various additional partial solutions were investigated. The conclusions and recommendations are included in the addendum report Variation on H. The recommended additional partial solutions include:

1. Enhanced Primary Treatment at Abbey Mills
2. Screening plant for Deptford and Charlton
3. Screening plant for Earl PS

The first should assist reduction in BOD load to the middle reach of the Tideway. The two screening solutions would increase the interception of sewage litter to just less than 80%. However the estimated capital costs are not insignificant. The total cost for implementation of H+ is only nominally a little less than that for potential solution A (low). The principle advantage of phased implementation is appealing; however there is little reduction in capital cost and the overall improvement to the Tideway is compromised by significant untreated CSO discharge.

For solutions A and H there is the opportunity for a more flexible approach for the requirements of climate change. The size and capacity of the tunnel can be decided at an early stage based on current climate conditions and more confident short-term prediction of climate change effects. Once the future trends are determined the storage capacity can be supplemented by the construction of off-line storage tanks if proven necessary. It must be ensured that the main tunnel has sufficient hydraulic capacity to transfer intercepted flows along parts of its length to potential locations of the off-line tanks.

The implementation of a complete solution based on a large diameter storage tunnel must still be considered as the most effective option in terms of cost and improvement in river quality

10. Recommendations

10.1 Strategy Recommendations

This study has concentrated on developing potential solutions to prevent or mitigate the adverse effects of the Tideway CSO storm discharges. It is now evident that this issue should not be considered in isolation and that a holistic view of the Tideway should be taken so as to produce an optimised solution. This approach will also assist in development of objectives.

The existing STW effluent discharges and their mode of response to rainfall events has significant effects on the river water quality in the Tideway. It seems most likely that severe oxygen depletion is caused by a reaction between the remnants of activated sludge in the STW effluent and the CSO polluting load.

To achieve a significant improvement to the marine environment, at reasonable cost, it is essential to consider the relationships between all polluting sources and to understand the response of the Tideway as a whole.

The most appropriate solution to prevent or mitigate the adverse effects of the Tideway CSO storm discharges is to intercept the flows to a storage tunnel and transfer these to treatment. This storage tunnel would represent a significant increase in capacity to the sewerage system as a whole. Appropriate use of this additional capacity should have the potential to reduce the risk of sewer flooding. This potential synergy should be investigated and developed further to ensure optimal investment and to maximise realisation of benefits and improvements.

Current operation of the Thames Barrier to enhance flood response of the tributaries during prolonged heavy rainfall has significant influence on the Tideway river levels. This is likely to affect the operation of any implemented scheme. These potential effects must be identified and investigated.

At the commencement of this study the objectives were relatively poorly defined, as significant preliminary work was required to determine realistic appropriate limits. Whilst some clarity and sense of perspective has emerged it is likely that the objectives may be subject to further refinement. It is essential that these key objectives are identified and robustly defined so that the most appropriate and cost effective potential solutions can be realised.

10.2 Recommendations of Technical Studies

There's a very wide range of detailed recommendations within each of the technical studies. The principal recommendations are listed below:

10.2.1 Hydraulic

1. The hydraulic capacities of all potential solutions are based on hydraulic model output. For overflow conditions the model has been subject to relatively little validation, hence the predictions of the flow and pollution parameters cannot be considered highly accurate. It is essential therefore to implement a significant programme of flow and pollution parameter monitoring to facilitate enhanced validation of the model.

2. The potential choking effect and hence the application of a minimum tunnel diameter has a fundamental impact on the efficacy of the potential solutions. This effect should be investigated further by mathematical and physical modelling to determine limits and to develop a better understanding of the system flow characteristics.

10.2.2 Construction

1. Whilst current construction methods are capable of carrying out the required works further development and improvement of tunnel-boring machines (TBMs) is desirable to ensure successful and cost effective implementation of a tunnelled based solution. This is of particular importance when tunnelling at depth and under high groundwater pressures. A structured assessment of recent experience of the whole tunnelling process, considering problems and successes, experience with relevant geologies, predicted costs and out-turns and project insurance would facilitate this development and benefit the implementation of this project. It is desirable that the knowledge gained from current tunnelling works e.g. the Channel Tunnel Rail Link (CTRL) is captured.

2. Most of the interception structures are likely to be in very difficult locations and this is likely to get even worse as developments along the river frontage proceeds. Consideration of alternative locations is essential. The development of alternative arrangements for the interception of flow and the construction of the interconnecting tunnels to minimize land take and disruption is of significant importance.

3. All solutions will produce large quantities of excavated spoil for disposal. Much of the spoil will be suitable for re-use such as increasing the height of embankments for improved flood defence, capping over contaminated land, land remediation and landscaping. Development of alternatives for disposal and appropriate re-use will depend largely on the location and programming of other projects. This issue is one of the most costly of any other project and is worthy of significant further investigation

4. All potential solutions will involve significant underground works. A structured programme of geotechnical investigations is therefore essential for the safe, effective and efficient implementation of this project. Further investigation in respect of third party assets impacted by the works will reduce risks from unexpected constraints.

10.2.3 Treatment

1. Deep Bed Filters are recommended as the most appropriate enhanced primary treatment for storm flows due to their inherent flexibility of operation.

2. Submerged Aerated Filters are recommended as the most appropriate secondary treatment for storm flows, used in conjunction with Deep Bed Filters.

3. It is essential to locate any new storm treatment plant adjacent to existing STWs to enable the biological processes to be sustained between rainfall events. This offers the additional benefits of improvement to the secondary treatment and tertiary treatment of the final effluent of the existing works.

10.2.4 Facilitation

1. Timely availability of the appropriate construction sites and treatment sites will be critical to the successful and efficient implementation of this project. It is essential therefore to develop early on a programme to secure and acquire the required sites and to develop the necessary planning and environmental approvals.

10.3 Further Investigation and Study

Development and implementation of the most appropriate and cost effective scheme to realise the necessary improvements to the Tideway will be an iterative process and require further investigation and development of the project during AMP4 as indicated below.

10.3.1 Further Technical Matters

The Technical Studies identified many recommendations for further study to assist the development and implementation of this project during AMP4. These are listed in the précis in Section 8 and in the full study reports in the Appendix.
The main elements are listed below:

1. Mathematical and physical modelling to further develop the understanding of hydraulic effects of fast tunnel filling
2. Structured assessment of entire tunnelling process to facilitate TBM development, in particular implementation of earth pressure balance machine (EPBM) technologies.
3. Develop alternative locations for the interception structures
4. Implement a programme of geotechnical investigation
5. Treatment – develop process models for storm flow treatment and potential to improve treatment of normal flows.
6. Treatment – review sludge stream
7. Develop capital and operating cost models for “preferred” solution
8. Investigate alternatives for spoil disposal and re-use
9. Determine legislative framework, consultation procedures and programmes for potential implementation
10. Principle structures and existing tunnels to be further assessed and analysed
11. Carry out detailed investigation of similar, previously implemented projects to capture construction, operation experience and cost.

10.3.3 Cost Breakdown

Table 55 shows the cost breakdown for the first five years of programme. During AMP4 it is envisaged that outline and detailed design work will be progressed to a level required for the environmental impact assessment to be submitted in partnership with the necessary planning application. Site investigation work will commence along the proposed tunnel route this will entail sinking various boreholes. At the end of AMP4 the first tunnel boring machine will be purchased ready for construction to start at the beginning of AMP 5. It is envisaged that further parcels of land will be purchased at locations assigned for the tunnel shafts.

Table 55 : AMP4 cost breakdown

Number	**Description**	**Cost (£k)**
1	Land Acquisitions	25,000
2	Planning and EIA	2,150
3	TBM Development	500
4	Outline Design	1,000
5	Detailed Design	11,000
6	Site Investigation	7,050
7	Flow and Quality Monitoring	5813
8	Model Development	1,000
9	Resources Thames Environment Agency Steering Group and working group consultants Consultants (Technical)	 2000 500 500 1000
10	Overheads	1,000
11	Contingency	6,000
12	**Total**	**62,500**

References

*1 CIRIA Report 177 - Dry weather flow in sewers.
*2 Pennine Water Group – Sewer sediments & processes research.
*3 (Ref : P.Pearce Thames Water, Research & Technology 2003).
*4 Thames Water Research &Technology - SCITTER DWF Trials Report & Methodology
*5 A Saul - Sheffield Hallam University.

Appendices

Appendices

Appendix No.	Technical Study	Source
1	Thames Tideway Strategy; Phase 2 Stage A; Tunnelling Study; March 2002	Halcrow Group Ltd
2	Tideway Strategy Study Phase 3 – Final; Hydraulics, Operations, Maintenance, Health & Safety, Systems Control	WS Atkins
2	Tideway Strategy Study An addendum Report; The Partial Solution (West Catchment Solution); Hydraulics, Operations, Maintenance, Health & Safety	WS Atkins
3	Tideway Strategy Phase 3; Underground Works and Settlement; September 2002; Volume 1 - Narrative	Faber Maunsell
4	Tideway Strategy Phase 3; Underground Works and Settlement; September 2002; Volume 2 - Drawings	Faber Maunsell
3	Tideway Potential Solution H; West London Option; March 2003	Faber Maunsell
5	Tideway Phase 3; Construction Induced Ground Movements and their Anticipated Effects on Structures; September 2002	Geotechnical Consulting Group
6	Tideway Strategy; Assessment of Storm Sewage Treatment; Version 1.0; August 2002	Binnie, Black & Veatch
7	Tideway Report (Pumping Study)	KSB Fluid Systems
8	Thames Tideway Project; Power Supply Study; Revision A; April 2003	McLellan
9	Thames Tideway Strategy; Sustainable Urban Drainage Systems (SUDS) Study; November 2002	Binnie, Black & Veatch
10	Thames Tideway Strategy; Land, Planning and Environment Strategic Review; Final Report; February 2002	Cascade Consulting & Land Use Consultants
11	Thames Tideway Strategy; Land, Planning and Environment Strategic Review; Report 2; July 2002	Cascade Consulting & Land Use Consultants
11	Thames Tideway Strategy; Land, Planning and Environment Strategic Review; Screening Reports; May 2003	Cascade Consulting & Land Use Consultants
11	Thames Tideway Strategy; Land, Planning and Environment Strategic Review; Site Valuations; Report 4; June 2003	Cascade Consulting, Land Use Consultants & Mann Smith
12	Tideway Strategy Phase 3; Underground Works and Settlement: Budget Estimate; October 2002	EC Harris
12	Tideway Strategy Phase 3; Supplement to Budget Estimate; Option A(Low) & Option A(Low) Plus Tanks; November 2002	EC Harris

12	Tideway Strategy Phase 4; Option H – Partial Solution; Budget Estimate; March 2003	EC Harris
13	Litter disposal Paper	Thames Water Utilities
13	Screening Selection Paper	Thames Water Utilites
14	River Quality Study	Environment Agency
	Other Supporting Documents	**Source**
15	Tideway Investigation; Solutions Group; Variations for H; Addendum Report; June 2003	Thames Water Engineering
15	The Impact of Activated Sludge Biomass and CSO Effluent on River Water Quality; June 2003	Thames Water Research & Technology
15	International Solutions to CSO Pollution in Urban Cities; April 2003	Thames Water Research & Technology
15	SCITTER - Storm Sampling Report; July 2003	Thames Water Engineering and R&T
15	SCITTER – Dry Weather Flow Trial Report and Methodology; July 2003	Thames Water Engineering and R&T

	Other Studies	**Source**
16	Thames Tideway: Parliamentary and Statutory Requirements	BDB