Thames Tideway Strategic Study

Objectives Working Group Report

February 2005

Thames Tideway

Volume 2

Modelling Study 2004

MAYOR OF LONDON
OFWAT
Environment Agency
Thames Water
RWE Group

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Objectives Working Group Report

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Thames Water
Gainsborough House
Manor Farm Road
Reading RG2 0JN

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1. Introduction

The modelling group was setup to assess the proposed solutions developed by the Solutions Group against the suggested interim objectives for dissolved oxygen (DO) in the Tideway. The Interim objectives produced a suggested list of interim dissolved oxygen (DO) standards, which should be met by any solution option for the CSO discharges (table 1). In order to assess the performance of the solutions against the interim DO standards, two estuary simulation models were selected and developed; WRc's one-dimensional Quests model and HR Wallingford's two-dimensional T2dv model. The models were used to simulate future scenarios for Tideway water quality, including the impact of the proposed solutions on Tideway DO.

Table 1: Interim Dissolved Oxygen Standards for the Tideway, derived by the Objectives Working Group.

Threshold	Dissolved Oxygen Concentration (mg/l)	Duration (tides)	Allowable Return Period (years)	Allowable Failures (over 14 years of event data)
1	4	29	1	14
2	3	3	3	5
3	2	1	5	3
4	1.5	1	10	1

Note: A tide is a single ebb or flood.

HR and WRc were commissioned to refine their models to produce a compliance test procedure (CTP) which would create a systematic method of assessing the improvements made in compliance against the interim DO standards. The studies were overseen by the Modelling Working Group consisting of members of both the EA and Thames Water. Over a period of a year the models were calibrated using inputs from the Thames Water sewerage model, EA automatic water quality monitoring stations (AQMS), rainfall data and various monitoring data.

The CTP comprised of a set of the 62 historically most significant rainfall events over a 14-year (1989-2002) period. The events were chosen via a sifting process, which looked at a combination of event intensity, duration, size and total CSO discharge load generated by the event. In selecting the 62 most significant events, a range of solution scenarios could be tested against the events to assess the number of DO standards breaches each scenario would generate. The inclusion of return periods for each standard meant that it was possible to determine the level of 'allowable failures' each solution scenario could generate in the 14-year assessment period before it would be considered as non-compliant (see table 1).

In order to determine the number of standard breaches each solution scenario would generate, the modelled DO profile in the river after each event was examined (see figure 1) as well as outputs from the models showing compliance plots for the full set of 62 events along the Tideway (see figure 2). The level of compliance achieved by each scenario allowed the Objectives Group to determine how compliant the proposed solutions would be against the interim standards.

Figure 1 – example 'half-tide' plot showing the impact of a single storm event on DO levels (mg/l) for 1 day along 1km sections of the Tideway.

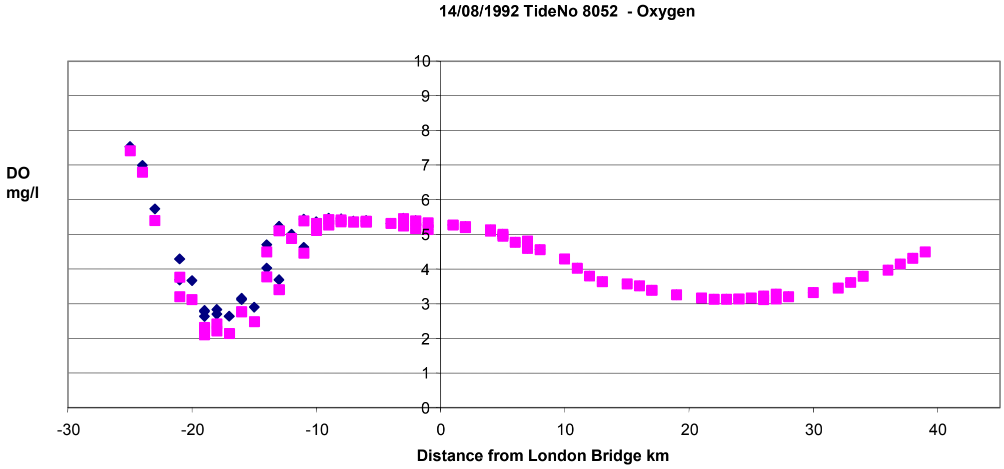
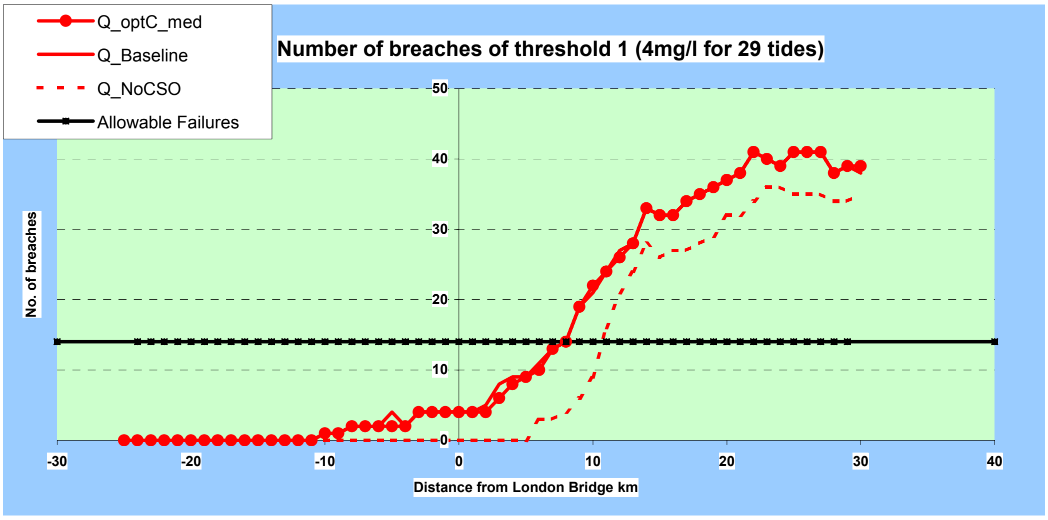


Figure 2 – compliance plot showing number of failures of the 4mg/l DO standard generated by solution option C (screening only) along 1km sections of the Tideway for all 62 events.



Details of how the models were chosen, calibrated and prepared for the CTP are detailed within a separate report: The preparation and application of the modelling Framework for the Compliance Testing of Options: Audit Report, Sept 2003.

2. Phase 1: Compliance Testing Results 2003

In order to provide assessment data for the various solutions for phase 1 reporting, the Modelling Group put a range of solution options through the CTP at the end of the calibration period in 2003.

At this stage in the overall study, the results were considered as interim as several areas of solution optimisation were identified which would assist in improving the performance of the models against compliance. In addition some areas of improvement work to the modelling process were identified and these were added to the scope of additional work to be carried out to the models and CTP during the 2004 continuation studies.

Model Limitation – 2003 Results.

As discussed, the two estuary models were put through an extensive calibration programme prior to the commencement of the compliance testing process in 2003. However, it was not possible to obtain perfect agreement between modelled and observed conditions due, in part, to a lack of good quality input data. It was also concluded that there were some processes occurring in the estuary, which were not sufficiently well understood to be able to accurately reproduce them in the models. The following were considered to be the main sources of error: -

- The presence of algae is a major factor in the oxygen balance in the Tideway. Although attempts were made to include the algal component in the models, it was not possible to simulate growth and decay with any degree of confidence and all compliance testing was carried out with the algal component in the models switched off;

- Observed DO levels in the Tideway show a correlation with the spring/neap cycle, particularly in the middle reaches. It has been hypothesised that this may be due to the resuspension of deposited material, creating an increased oxygen demand. Lack of available data and limitations in the modelling processes prevented this effect being modelled;

- The quality of the tributaries, including the freshwater Thames, varies diurnally and also changes rapidly under high flow conditions, particularly when rainfall occurs after hot, dry spells. This is due to the effects of urban run-off and variations in quality of the sewage effluent that is discharged to most of these rivers. Lack of comprehensive data for these tributaries resulted in the need to use mean quality conditions for these significant inputs;

- The performance of the STW's which discharge directly to the Tideway is one of the major factors affecting DO levels. Fairly comprehensive data sets exist for continuous loads discharged from the works but there are gaps in this data and very little information is available on the quality of intermittent discharges from the STW's and Mogden & Crossness storm tanks, which have a significant impact on DO levels during wet weather. The compliance testing process used fixed concentrations and flows from the STW's to establish pre-event conditions; these would have differed from the actual works performance;

- Investigations carried out as part of this project revealed that quantities of activated sludge are sometimes discharged from the Mogden STW at times of high flow. Further laboratory tests confirmed that this discharge could have a major effect on DO levels in the upper reaches. Despite efforts to recreate the effect of activated sludge in Mogden storm discharges, the lack of data on the load imposed by this discharge and lack of knowledge of which storm events trigger the release of activated sludge, precluded its inclusion in the models;

- Of the 57 CSO which discharge to the Tideway, indicative flow data only exists for around 9 of the pumped discharges and there is also some historical quality data. There is no flow data and virtually no quality data for the remainder. Obviously, comprehensive flow and quality data is essential for all these discharges if individual rainfall events are to be modelled precisely. It is likely that, depending on rainfall patterns, the quality of discharges from these outfalls will vary considerably throughout the event and each CSO will display a different pattern of discharge. It is also likely that antecedent conditions will influence the amount of solid matter flushed from the system. Under these conditions it is unlikely that it will ever be possible to acquire sufficiently comprehensive data. The sewer model was therefore used to generate flow and quality data for all the discharges from the CSOs and this data was fed into the estuary models. The sewer model has been refined over many years and represents the latest state of the art in hydraulic modelling. It is unlikely, however, that it can mirror the actual loads discharged to the river under all types of rainfall events, and it has no facility for generating data on resuspension of silt and consequent discharge to the river, which is thought to occur under some conditions of high velocity in the sewers.

It is important that these possible sources of error are considered when data from the models is analysed. It is noted that several of these sources of error are a consequence of the lack of availability of comprehensive and good quality input data. As a result, a range of data collection and model calibration studies were proposed as part of the 2004 continuation study in an attempt to minimise the uncertainties in the modelling process and create a greater degree of confidence in the CTP results.

Despite the limitations, at the end of the calibration phase the models were considered to provide a reasonable indication of the dynamic changes in DO that occur in the river following rainfall events, the models represent a very robust and sophisticated tool for testing solutions.

Phase 1: 2003 CTP Results Discussion

The requirement of the Modelling Group was to provide an assessment of the likely future performance of the solution options against the DO Standards, in turn providing fish mortality data to be assessed as part of the Cost Benefit Studies.

In the summer of 2003, the Modelling Group agreed on the models as 'fit for purpose'; defined as being suitable for use in the testing of solutions for compliance. The final list of solution options and intervention levels to run through the CTP were agreed by the Steering Group and used in the final assessment. The solution scenarios were assessed against a 'baseline' to represent the improvement made in DO levels against the theoretical 'existing situation'. In order to fully understand the impact of the solution options on the interim DO standards, an additional range of scenarios were also carried out. Descriptions of the scenarios put through the CTP are described below:

- ***Baseline** conditions;* the event with discharges from the CSOs and from the STW storm tanks included but without a solution option in place. This scenario was to provide a reasonable indication of existing conditions without improvements made to any discharges.

- ***No-CSO** conditions*; the event with no CSO discharges. Under these conditions there were no CSO discharges but the STW storm tank discharges remained, to enable an estimate to be made of the relative contributions from these two sources. In addition it would inform the objectives group as to the maximum possible improvement that could be achieved if a 'super solution' which intercepted all CSO spills from all rainfall events was theoretically possible.

- ***No-storm** conditions*; the event with no CSO or STW storm tank discharges This scenario has no wet weather discharges and provides an indication of conditions that would have prevailed had there been no rainfall induced discharges.

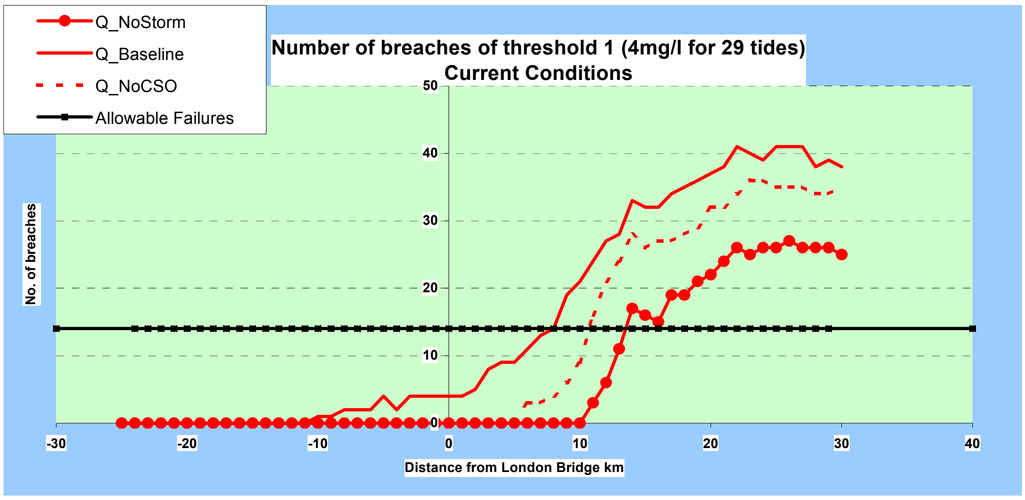
- ***Solutions Scenarios;*** baseline conditions for the event with individual **solutions** imposed on the sewerage system and the resulting changes to discharge loads and locations applied. These conditions attempt to predict the effects of introducing a particular CSO solution on the existing system and involved extensive use of the sewer model to simulate how the changes would affect the quality and quantity of discharges from the CSOs.

Initial Phase 1 CTP results – 2003.

The results from the CTP modelling were analysed by the Modelling and Objectives Group and the main conclusions were: -

- The DO standards in the middle reaches failed under "no-storm" conditions for many events, indicating that improvements were required to continuous STW performance in this part of the river during dry weather conditions (see figure 3)

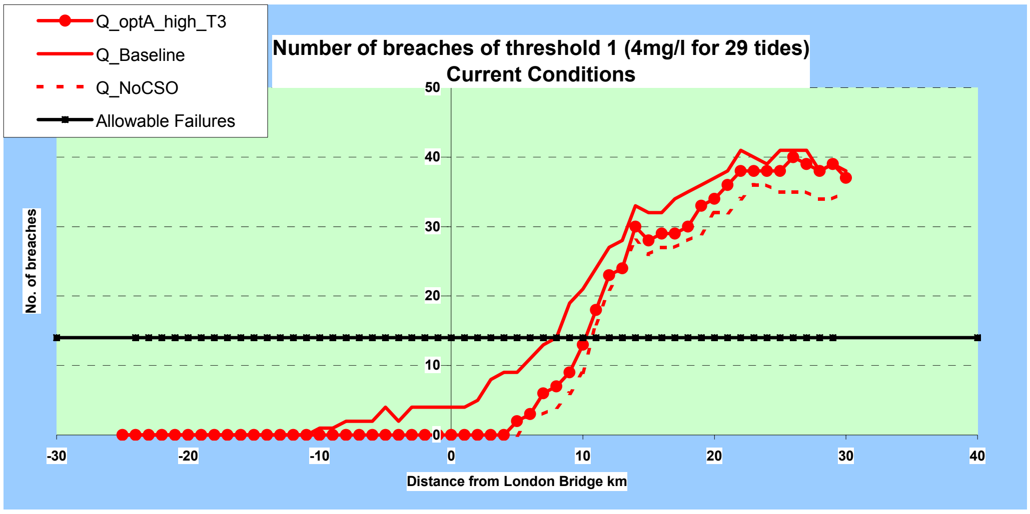
Figure 3 – compliance plot showing failures above the 'allowable' line even with 'no storm' inputs in the middle reaches; The quality of continuous inputs from the STWs is depressing the background DO in the middle/lower reaches.



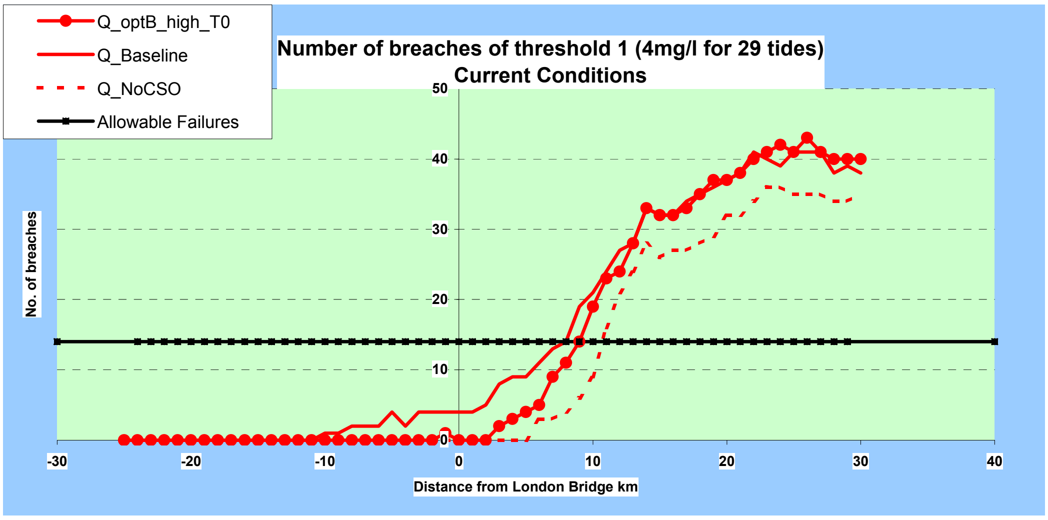
- Discharges from the storm tanks at Mogden and Crossness during wet weather, were very significant and, for some events, were sufficient to cause failure of the standards even in the absence of the CSO discharges (as demonstrated from the no-CSO runs). This again indicated that improvements to the STWs were essential to ensure compliance;

- Options A, B, D, and G, which all involve the interception of the discharges and conveyance to a new outfall in the middle reaches, all produce a similar pattern of compliance, with improved conditions in the upper reaches and little change in the middle reaches. (see figures 4 and 5);

Figure 4 – compliance of option A(high) against DO standard 1 (4mg/l).



Figures 5 – compliance of option B(high) against DO standard 1 (4mg/l), showing a similar pattern to option A (figure 4).



- Despite this similar pattern in DO failures, option A demonstrated the biggest improvement against the ‘no solution’ baseline DO condition;

- For each solution, the size of the intercepting tunnel (low, medium or high intervention) had very little effect on compliance, since there were few rainfall events that exceeded the capacity of the smallest tunnel and these were within the permissible return periods allowed by the standards (see figures 6 and 7);

Figure 6 – compliance plot for solution A(high) against DO standard 2 (3mg/l).

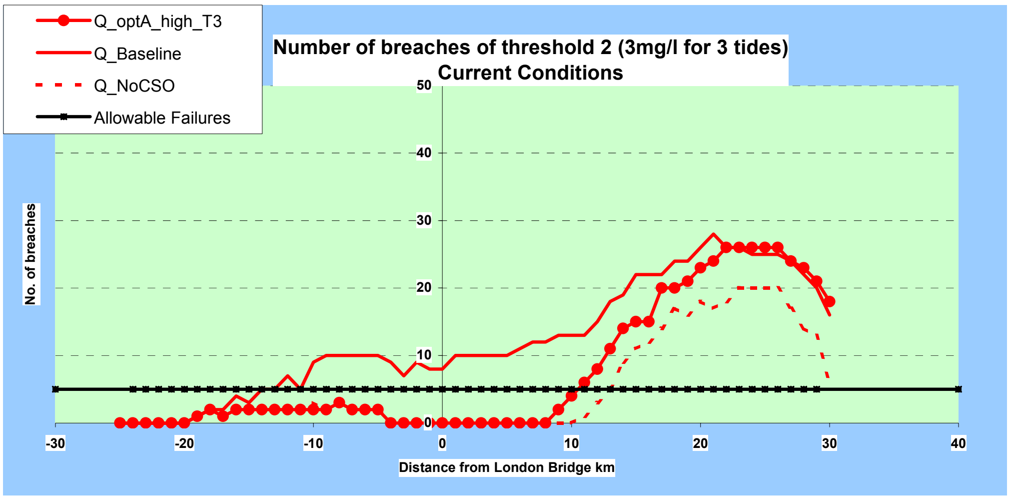
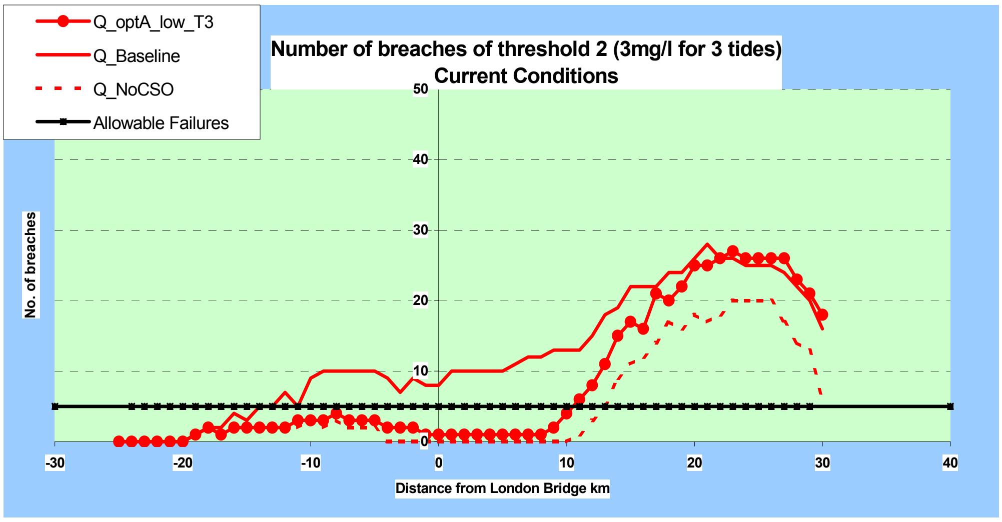
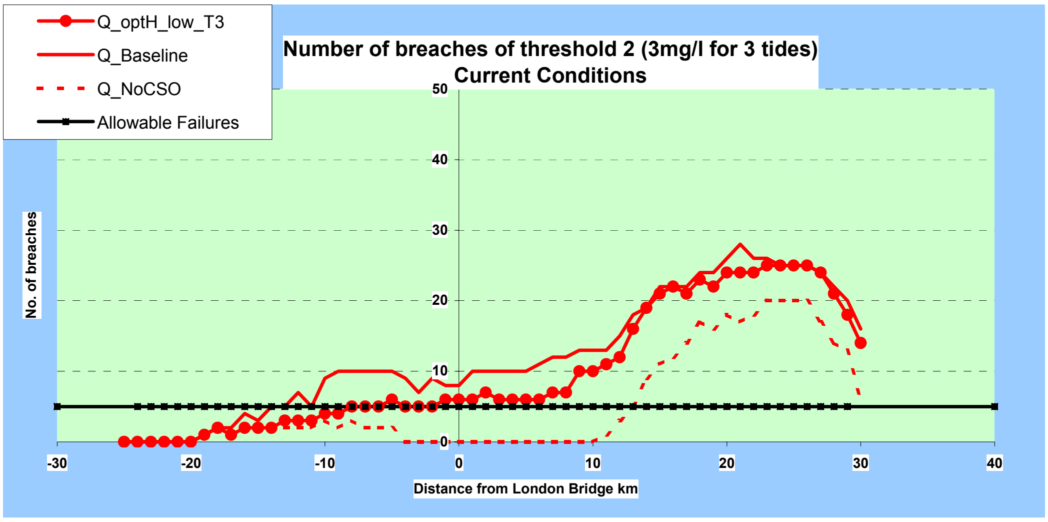


Figure 7 – compliance plot for solution A(low) against DO standard 2 (3mg/l) showing little difference to the higher intervention level (figure 6).



- Option H, a scaled-down version of option A constituting a 'half tunnel solution' option for the upper Tideway, produced much improved conditions in the upper reaches compared to Baseline conditions, but was not fully compliant for the middle/lower reaches and did not produce the same level of improvements as the full tunnel options in the upper Tideway.

Figure 8 – compliance plot showing the non compliance of option H compared to the baseline failures for standard 2 (3mg/l). Note marginal compliance in Upper Tideway, but poorer performance compared to option A (see figure 7).



AMP4 STW Improvements

The initial phase 1 compliance modelling indicated that improvements would be required to the STWs in order to achieve compliance with the standards and that dealing with the CSO problems in isolation would not be sufficient to ensure compliance. There were two areas of improvement required for the STWs.

- A reduction in continuous dry weather loads from the STWs discharging to the middle reaches (achieved by improved quality in continuous effluent discharge);

- A reduction in intermittent storm tank discharges during wet weather from the Mogden and Crossness works (achieved by increasing flow to full treatment [FFT] capacity of the Tideway works to prevent diversion to storm tanks or CSOs).

In order to achieve both of these requirements, the EA proposed a revised set of standards to be applied to the STWs in the model and which would be considered upgrades to the STW necessary as part of the AMP4 process. These revised 'AMP4' standards improved upon both the quality values applied in the initial model runs as well as the FFT capacity assumed (see table 2).

Table 2: Existing and Proposed STW Standards in 2003.

	Phase 1: Existing Standards 2003			AMP4 Standards Proposed in 2003		
	FFT*	**BOD**	**NH3**	**FFT***	**BOD**	**NH3**
Units	*Ml/d*	*mg/l*	*mg/l*	*Ml/d*	*mg/l*	*mg/l*
Mogden	690	11	1	1075	11	1
Beckton	1420	6	1	1420	5	1
Crossness	982	10	7	1485	5	1
Longreach	298	20	25	298	15	15
Riverside	177	15	20	177	7	7

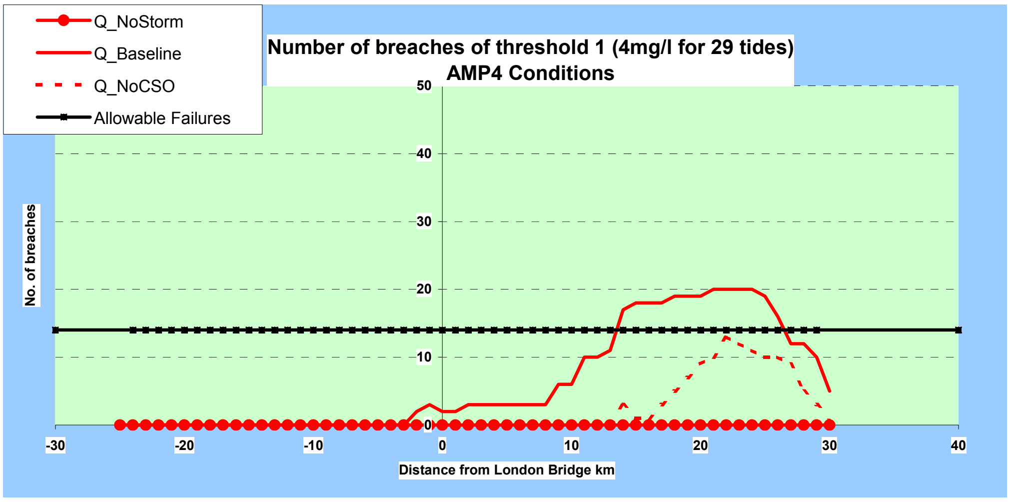
* FFT = Flow to Full Treatment (M^3 X 10^6)

Phase 1 Compliance Testing with AMP 4 Standards

The proposed AMP 4 standards (see table 2) were used in a further batch of CTP modelling runs and the outputs tested for compliance with the DO standards. By this stage of the option evaluation process, options E, F and G had been rejected as impracticable due to hydraulic, operational and land acquisition problems and were not therefore included in any further modelling. The main points arising from the modelled results with AMP 4 conditions were: -

- The entire Tideway complied under "no-storm" and "no CSO" conditions (see figure 9), proving the STW as vital to ensuring compliance;

Figure 9 – Compliance during 'No storm' and 'No CSO' conditions using the AMP4 STW improved assumptions.



- The impact of the load from Mogden storm tanks, in the upper reaches, was greatly reduced, to the extent that even without improvements to the CSOs, the upper reaches complied (see figure 9 – baseline is compliant above London Bridge);

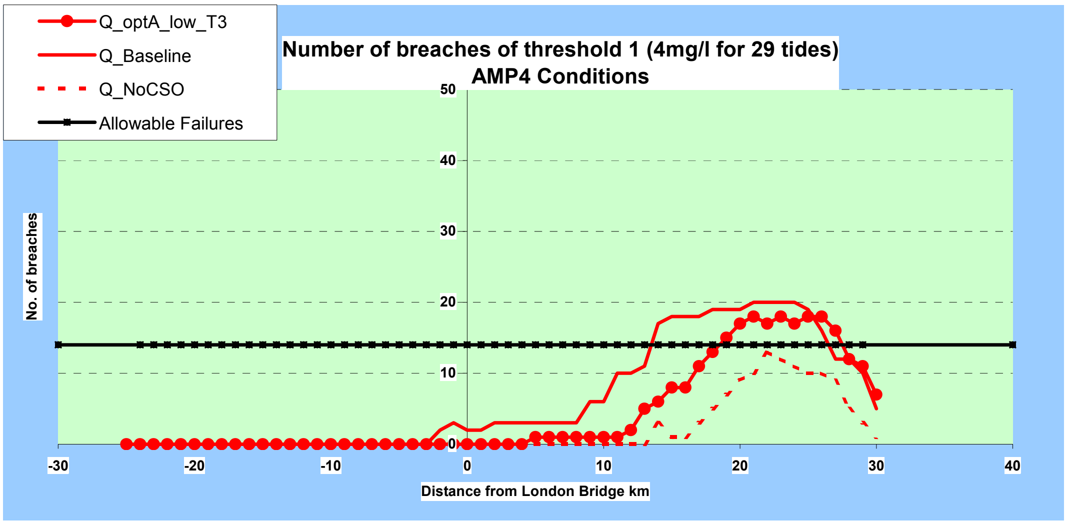
- The reduced wet weather load from Crossness storm tanks decreased the number of event failures 9 – baseline still fails in middle reaches);

- Option C, which is a screening-only option has little effect on DO levels and therefore did not produce compliance (see figure 2);

- Options B and H gave compliance in the upper reaches but failed in the middle reaches at all tunnel sizes;

- Despite a similar pattern to options B and H, option A was the closest solution to achieving compliance with only a very marginal failure of standard 1 (4mg/l) – see figure 10.

Figure 10 – Marginal compliance of Option A under AMP4 conditions.



Compliance Testing with Additional Treatment

In light of the very marginal failure of option A, a decision was taken to investigate the various additional treatment options, which might facilitate achievement of compliance for option A. The modelling group derived a range of additional sensitivity runs which would assist in determining the extent of additional treatment required to produce compliance in the middle reaches; these were:

a) ***Enhanced primary treatment of the Abbey Mills CSO discharge***. The initial design of option A by the solutions group did not include capacity to capture Abbey Mills discharges. As a significant input to the Tideway during storms, it was thought that a reduction in BOD and Ammonia loading via enhanced primary treatment could reduce the number of DO failures for the solution scenario in the middle reaches.

b) ***Enhanced primary treatment of the discharge from the Crossness storm tanks***. During large storm events, discharges from Crossness storm tanks were thought to have a big impact upon DO levels in the middle reaches

c) ***Doubling of the Crossness storm tank capacity***. For similar reasons to above, an increase in Crossness storm tank capacity would reduce the frequency of untreated discharges reaching the Tideway

d) ***Secondary treatment of the tunnel discharge from option A.*** This option was a sensitivity test to assess the impact of the discharge of the CSO discharges stored within the tunnel option A after an event. Initial design of the solution suggested only a primary level of treatment was suitable for the option discharge point (30% reduction in BOD and Org N). The modelling results had shown that the inclusion of the solution slightly raised the number of failures in the middle reaches, over and above the baseline, because the discharge was applying a point source pollution load to this area of the Tideway

e) ***Improved dry weather effluent quality from Long Reach STW***. This scenario was to raise background DO levels in the Tideway which might be affected by continuous discharges from Long Reach STW. Improved quality of Long Reach discharges might improve background DO and hence reduce the impact of the treatment tunnel discharges.

The results of scenarios a, b and c showed little change and no significant improvement in compliance. Options d and e however, both produced compliance for option A at all levels of interception (see figures 11and 12). A decision was thus taken to investigate these options further in the continuation study in 2004. Using the output from the continuation study, these additional 'package' investigations would have the added benefit of being carried out on better-calibrated models from a proposed suite of monitoring and analysis work on various CSO and STW discharges allowing more accurate verification data for the models.

Figure 11 – showing compliance for solution A when secondary treatment is applied to the Tunnel discharge.

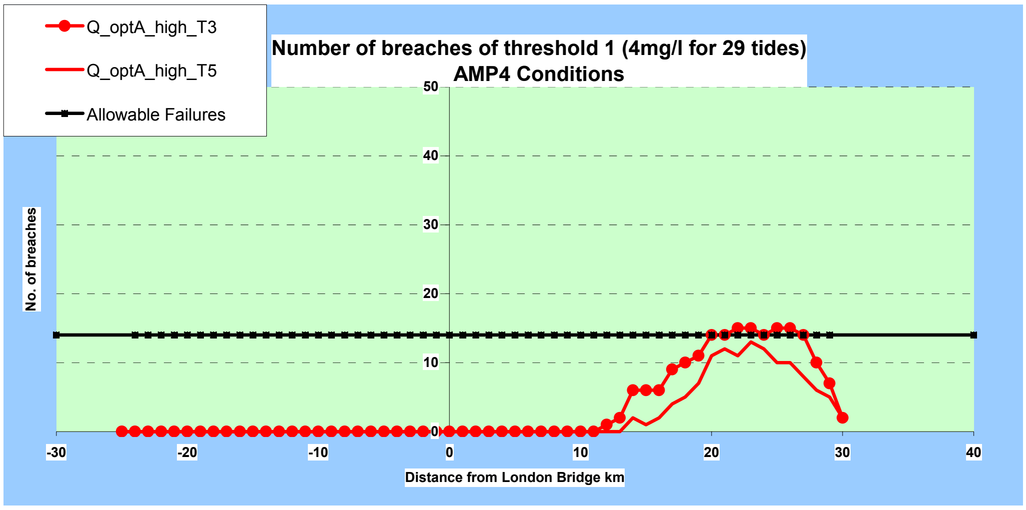
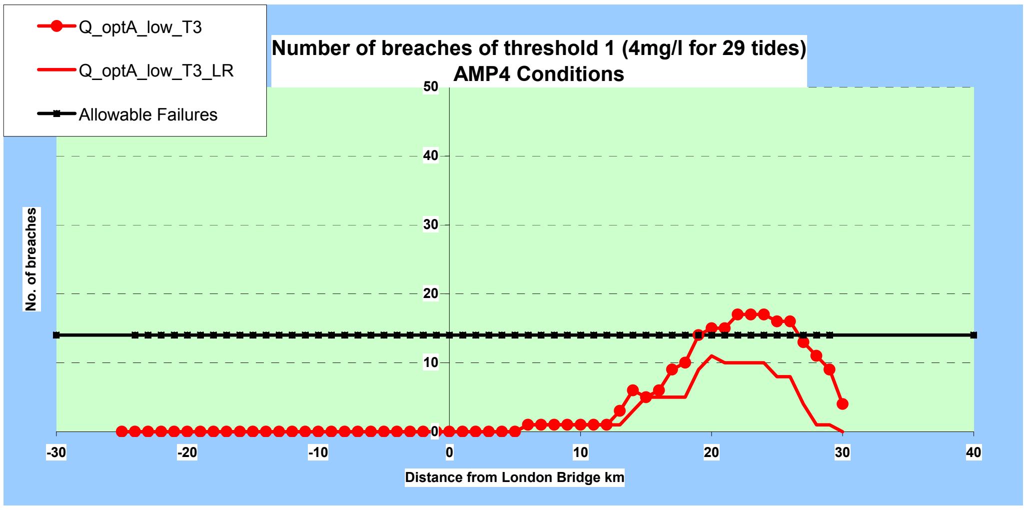


Figure 12 – showing compliance when improvements to Long Reach continuous discharge quality are modelled.



Overall Conclusions from 2003 Phase 1 Compliance Testing

The CTP covered only the chemical parameters (principally dissolved oxygen) of water quality. Remembering that aesthetic and bacteriological assessments also need to be considered, then the following overall conclusions can be drawn from the 2003 phase 1 compliance testing process: -

a) It was possible to obtain compliance with the DO objectives for option A by selecting an appropriate "treatment package" which would include improvements to the STWs and treatment of the CSO discharge from the tunnel.

b) No other solutions showed compliance with the objectives, although B and H were very close, with a few more failures in the middle reaches than allowed for in the return period.

c) There was no worthwhile improvement obtained in increasing the tunnel size beyond the low level of intervention.

d) Option H, although only a short tunnel that does not intercept all the CSO discharges, gave a very similar level of compliance, in terms of dissolved oxygen, to the longer tunnel options under AMP4 conditions but was less effective under existing conditions. Marginal failures still persist for both current and AMP4 conditions in the middle/lower reaches.

e) Consideration was given to the effects of climate change on the frequency and intensity of future rainfall events, which might impact on compliance. It was initially concluded that the impact would be relatively insignificant however an agreed detailed assessment was scoped out for consideration in the Continuation Study and is reported in section 4 of this report.

3. Phase 2: Continuation Study

3.1 Final Compliance Test results

Aim of the Continuation Study

The principal aim of the Modelling Continuation Study was to improve the reliability and confidence in the performance of the models in assessing the effectiveness of the solution options. Several areas of work were identified which would improve:

- The CTP itself – obtaining a more comprehensive rainfall data set from which to select the worst storm events for the CTP; thereby giving greater confidence that the solutions would comply with a more comprehensive set of historical rainfall events.

- Knowledge of the quality of various input parameters to the Estuary models, which had previously relied upon a combination of sparse recorded data and estimates from best available knowledge. This would include verification of the Thames Water Sewerage Network Model to provide more reliable and representative input data from the CSOs and sewer system.

- The performance of the chosen solution, such that optimisation of the preferred solution could be achieved from the previous generic design for assessment purposes. This work would build on the 'package' of treatment options identified in the interim CTP results to make solution A compliant.

At the end of the model calibration and improvement period, the models would then be used in the revised CTP to give final assessment of the performance of the chosen solution proposal.

Upgrades during continuation study – CTP changes

During the initial calibration period, concerns had been raised as to both the temporal and spatial representation of the historical rainfall data set. The data set was used to run the sewerage models but also to identify the 62 most significant events to create the CTP. For the interim CTP set up, EA rain gauge data for 1987 – 2001 was used. However, there were gaps in the data in terms of recorded time periods for some gauges as well as geographical areas where gauged data was not available. In order to rectify this, a proposed rainfall desegregation exercise was undertaken. A stochastic model was used to generate and infill missing spatial and temporal data based on the historical data set available. Statistical analysis confirmed that the method was robust and hence a revised data set was generated for a more comprehensive area cover as well as time period. The new data set consisted of data from 1979 – 2004 (25 years), from which an additional 90 significant events were selected for use on the compliance testing to create a total of 152 events for the 2004 CTP. The additional events raised the number of 'allowable failures' for each modelled scenario as the events were selected from a 25 year period as opposed to 14 (see table 3).

Table 3: Interim Dissolved Oxygen Standards with revised allowable failures for the 2004 CTP work (blue).

Threshold	Dissolved Oxygen Concentration	Duration	Allowable Return Period (years)	Allowable Failures (over 25 years of event data)
UNITS	mg/l	Tides	Years	Failures
1	4	29	1	25
2	3	3	3	9
3	2	1	5	5
4	1	0	-	0

Note: A tide is a single ebb or flood.

The revised rainfall data set was also used to drive the sewerage model, so that the flow and load results from the sewerage model used as input to the Estuary models produced a greater confidence that full effect of storm events was included in the assessment procedure.

Upgrades during continuation Study – Model Calibration changes

Data was collected over the course of 2004, from storm events at selected CSO and STW sites in the Tideway as well as some flow monitoring data from several strategic points within the sewer network. Previous lack of available field data for calibration and verification had resulted in the requirement to make assumptions about flow and quality inputs to the 2003 CTP.

The sampling and analysis data facilitated a better calibration in the Crossness catchment of the sewerage network model giving greater confidence in the flow calibration. In addition, the representation of the split between Beckton treated flows and Abbey Mills CSO was improved such that the flows modelled by the sewerage network model were more representative of the pump records for Abbey Mills discharges during storm events. These improvements increased the accuracy of the storm flows which were inputted into the Estuary models for the compliance testing.

Several large storm events were captured by the monitoring programme, such that some useful quality and flow data was recorded for the three major STWs. The recorded data was used to verify the assumptions applied to the Estuary models and sensitivity testing was carried out to test the change in sewerage model inputs as well as revised quality assumptions in the model.

The changes to the modelling process had the impact of increasing the frequency of storm flow inputs to the Estuary model thereby increasing the confidence in the performance of a solution to capture all major rainfall events.

Upgrades during continuation Study – Solution changes

As a consequence of the Phase 1 CTP results, the Solution Group and hence Modelling Group concentrated solution optimisation on the tunnel option A(low). It was evident that to achieve compliance with the three interim DO standards, only option A would be capable of delivering the objectives. In addition, it was agreed that from the Phase 1 modelling results that the level of intervention of the tunnel solution did not have a major impact on compliance hence the low intervention level (lower costs) was chosen.

Several areas of solution scenario modification were highlighted in the Phase 1 reporting which would create a ‘package’ of deliverables to create a compliant solution. These scenario modifications were taken further in the Continuation Study to create the final solution, which would be assessed for compliance.

Solution Optimisation: Abbey Mills Discharges

Following calibration of the Sewerage Network model, the additional flows generated from Abbey Mills emphasised the importance to including discharges from this CSO within the final solution design. In order to capture the discharges, a link tunnel was added to the solution design, which would capture a large percentage of the discharges from the CSO and convey them to link with the main tunnel at Greenwich. At the confluence of the two tunnels, the main solution tunnel had to be widened to prevent choking of the system.

Solution Optimisation: Tunnel Treatment

In order to reduce the impact of the polluting load of the tunnel outfall point, a review was carried out of the likely improvement in quality that could be achieved through treatment of the tunnel discharge. Following the review it was agreed that a 60% reduction in BOD and organic nitrogen loads from the tunnel output could be achieved with advanced primary treatment.

Solution Optimisation: Use of additional Capacity at Crossness and Beckton STW

To further reduce the impact of the polluting load of the tunnel outfall point, simple code was added to the models to make use of spare treatment capacity at both Crossness and Beckton STW. The revised model process allowed discharge stored in the tunnel to be returned to Crossness (directly) or Beckton (via a restricted link tunnel) whenever either works had spare capacity below its Flow to Full Treatment capacity. Dependent on the size of the storm, this allowed a certain percentage of the intercepted discharges to be treated to a full treatment level thus lowering the amount of failures in the middle reaches of the Tideway.

The benefits of this solution optimisation were further increased by the inclusion of a pump out time of 48 hours for the tunnel storage, allowing more time for additional treatment capacity at Beckton and Crossness to be utilised.

Phase 2: Final CTP Results, 2004

Phase 2 Interim L1 driver improvement results

Prior to final reporting to DEFRA, an interim Cost Benefit report was submitted in July 2004, which formally assessed the relative benefits of introducing the STW improvements in achieving the Tideway objectives. The 2003 CTP runs had shown that without including proposed AMP4 improvements, the estuary was failing the DO standards even under no storm conditions. This suggested that proposals to improve the quality of continuous treated discharges as well as reducing the quantity of intermittent untreated STW discharges to the Tideway were essential. A cost benefit analysis of this part of the treatment ‘package’ was required and hence additional runs of the different STW improvements were carried out.

To complete a Cost Benefit Analysis (CBA) of the solution and the STW improvements it was necessary to establish the baseline by which all improvement scenarios could be assessed. It was agreed by the Objectives group that the assessment baseline for the solution scenario and the STW improvements would be the UID driven ‘statutory improvements’. The UID drivers encompassed the increases in Flows to Full Treatment (FFT), which would be required at the three major Tideway STW (Crossness, Mogden and Beckton) in order to comply with the Urban Waste Water Treatment Directive.

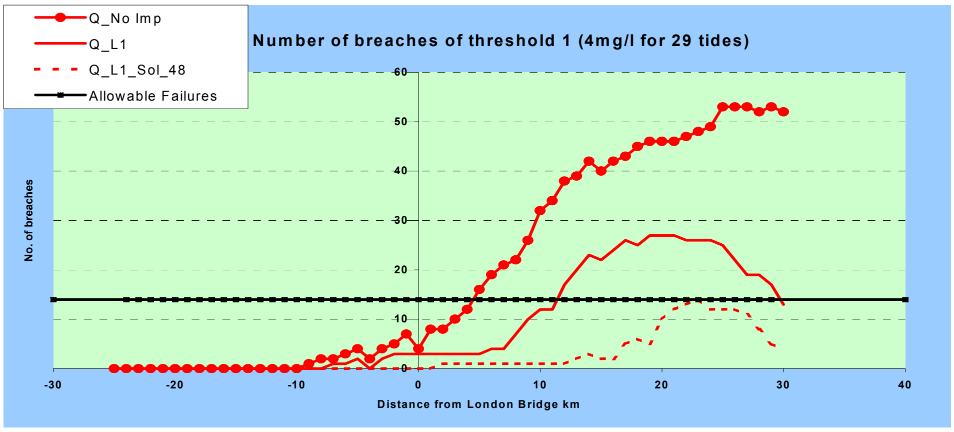
The interim CBA then assessed the DO improvements, which could be achieved by a series of L1 (local driver) improvements, which encompassed improvements in the treated quality of discharge from the five Tideway STWs as detailed in table 4.

Table 4 – summary of L1 and UID driver changes to the modelling.

STW Name	Current Consent Std (mg/l)					EA Driver	Proposed Consent Standards		
	BOD	NH4	BOD (Summer)	NH4 (Summer)	Current FFT (m3/d)		BOD Summer (mg/l)	NH4 Summer (mg/l)	Increased FFT (m3/d)
Beckton	22	6	6	1	-	L1	5	1	-
					1,400,000	UID11	-	-	1,800,000
Crossness	25	16	10	7	-	L1	5	1	-
					982,000	UID11	-	-	1,485,000
Mogden	23	7	11	1	810,000	UID11	-	-	1,075,000
Long Reach	50	53	20	25	-	L1	15	15	-
Riverside	20	10	15	20	-	L1	7	7	-

The L1 driver model runs were completed with all continuation study model improvements with the exception of the revised calibrated models and the new rainfall data for the CTP. The results showed that only by including the full range of L1 driver improvements, alongside the statutory driver and the fully optimised tunnel option A(low) could marginal compliance be achieved (see figure 13). The fully optimised solution included: 48 hour tunnel pump out, secondary treatment of tunnel outfall, Abbey Mills link tunnel and utilisation of additional FFT capacity at Crossness and Beckton STW.

Figure 13 – interim L1 results. The dashed line shows the fully optimised solution A(low) + L1 improvements at all STW + statutory improvements.

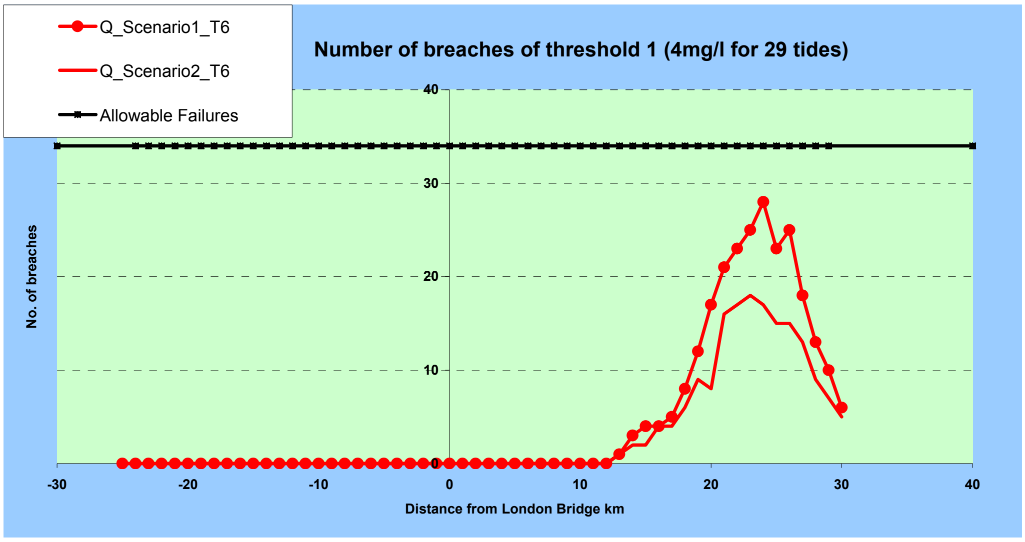


Final 2004 CTP runs

The final CTP runs were completed for the optimised solution, but now using the fully calibrated models. As discussed previously, the use of the new calibrated models and the inclusion of the more comprehensive rainfall data was creating more baseline failures. The combination of changes was increasing the amount of discharge from the storm events assessed.; this increase would improve confidence in the solution performance.

Final modelling results showed that despite the increase in baseline failures, the optimised solution A was able to achieve full compliance with all standards assuming all L1 and statutory driven improvements went ahead. See figure 14.

Figure 14 – Final CTP results 2004 showing full compliance of the optimised solution A(low) with all L1 and statutory STW improvements included.



NB – scenarios 1 &2 denote slight changes in the FFT capacity for the UID Crossness driver to test sensitivity – both scenarios produce compliance.

The final results of the Phase 2 modelling were used to assess the performance of the optimised solution A(low) for the final Cost Benefit Analysis.

<u>Other areas of work ongoing in the continuation study</u>

It was not possible to complete all areas of modelling investigations within the timeframe of the continuation study; hence there are several areas of ongoing work, which will be reported, in early 2005.

1) Back to Back Storm sensitivity

Currently, the CTP assesses each of the 153 storm events in isolation; hence the solution option is always empty before any event storm spill is assessed. Investigations are taking place into the potential to simplify the outputs of the Sewerage Network model by using a version of the SIMPOL catchment model, which simplifies the Beckton and Crossness components of the Sewerage Network model. If successful, this model can be used to assess the impact of back-to-back storms and assess how effective the performance of the tunnel option would be if it was unable to empty in time before the next rainfall event occurs

2) 2D modelling

Observed DO levels in the Tideway show a correlation with the spring/neap cycle, particularly in the middle reaches. It has been hypothesised that this may be due to the resuspension of deposited material, creating an increased oxygen demand. Lack of available data and limitations in the modelling processes prevented this effect being modelled for the Phase 1 and Phase 2 CTP runs. A comprehensive survey of the vertical variation in a range of water quality parameters and determinands during the spring/neap tide cycle has been undertaken. The data from this survey will be used to calibrate the 2D component of the Tideway-2DV model used throughout the modelling assessment. It is hoped that a better representation of the hypothesised vertical variation in DO demand will help to improve the model performance in the middle lower reaches of the Tideway

4. Climate Change Scenario

The Modelling Group devised a method by which UKCIP predictions for climate change could be used to assess the performance of the solution under future climate change conditions. It was originally suggested that the stochastic rainfall model used in the phase 2 CTP could be applied in generating a future rainfall data set which would drive the sewerage Network model and produce revised storm spill data to run the Estuary models. However, future UKCIP rainfall series are based on a single gauge at Greenwich only, and it was concluded that interpolating the entire catchment from a single gauge would not give the confidence required from the results.

An analysis was therefore carried out between two UKCIP rainfall series at Greenwich for now (2000) and predicted in 2080 (both based on the medium high scenario). The storm events in both the 2000 and 2080 sets were grouped into 'event size' categories according to their depth. A comparison was then made between the depth categories of the two rainfall sets such that a ratio was determined of all the depth categories between the 2 years. The ratios were then used to calculate how the generated storm events from the current compliance testing procedure (CTP) would change in 2080. For the summer, the ratios showed that there would be an increase in bigger depth (greater intensity) rainfall events but a decrease in the frequency of lower depth events. Using the figures for the ratios, the current rainfall events used in the CTP were adjusted accordingly to create a set of 2080 storm events to run through the CTP and these where then put through the model to create a 2080 scenario. (See tables 5-7)

In addition to this, the environmental conditions were altered to reflect the climatic and environmental input conditions expected in 2080. This included temperature predictions, changes in solar radiation and dew point temperature all used to calculate changes in river temperature and air temperature within the model. All changes were based on historical data using UKCIP predictions for climatic changes. Sea level changes, which affect tidal levels in the estuary, were included in the modelling.

Hydrology changes

It was originally envisaged that the freshwater flows into the estuary could be adjusted in line with predicted changes in hydrology as a result of climate change, however the decision was taken to not include these changes at this stage for the following reasons:

a) Comprehensive research carried out to date has only been based on predictions as far ahead as 2020 for the South East region. This research predicts that average river flows could reduce in the critical summer months by as much as 35%. The limited research for 2080 predictions however, has shown that dependant on the method chosen for applying climate change scenarios (statistical downscaling or applying change factors to historic data sets) different predictions are generated for the change in hydrology with different rainfall and potential evapotranspiration estimates. Despite this, the 2080 research carried out does indicate that reductions in flows are expected to increase between 2020 and 2080; some macro-scale models have predicted by as much as 65%.

b) Due to regulation for abstraction and navigation and because the Thames abstraction agreement could change between now and 2080, it is not possible to predict actual flows over Teddington weir sufficiently accurately to warrant using the predictions in analysis. Should there be no change in the Teddington agreement then the flow to the Tideway for dilution would almost certainly decrease appreciably, thus increasing the risk of an event causing pollution. However, were the Teddington agreement to be altered to reflect the change in flows then the effect would be dependent on the new agreement.

Despite these limitations, it is acknowledged that by 2080, the natural freshwater flow component of summer flows in the Thames could be appreciably reduced which in turn could have an impact on DO levels in the Tidal reaches. It is also acknowledged that the operating agreement for freshwater flows over Teddington could be altered as a direct consequence of climate change. As a result, a sensitivity analysis will be undertaken on a range of freshwater flow reductions as a separate report to the work carried out for the continuation study climate change analysis. This will be reported in 2005.

Tables 5-7 showing the difference in intensity of rainfall events between the 2000 and 2080 rainfall series for Greenwich.

Table 5: Present Data (Greenwich 2000) after manual grouping. 10 years

No events/month in depth category

Month	**6-10**	**10-15**	**15-20**	**20-25**	**25-30**	**30-35**	**35-40**	**>40**
Apr	0	0	0	0	0	1	0	0
May	0	0	0	0	1	0	0	0
Jun	0	0	0	3	0	0	0	0
Jul	3	3	1	2	0	0	0	0
Aug	6	11	6	0	2	1	0	1
Sep	3	3	4	4	0	0	1	0
Oct	0	0	0	2	1	0	1	2
Grand Total	12	17	11	11	4	2	2	3

Table 6: Future Data (Greenwich 2080) after manual grouping. 10 years

No events/month in depth category

Month	**6-10**	**10-15**	**15-20**	**20-25**	**25-30**	**30-35**	**35-40**	**>40**
Apr	0	0	0	0	0	0	2	2
May	0	0	0	1	1	0	0	0
Jun	0	0	0	2	0	0	1	0
Jul	1	3	3	1	0	1	0	0
Aug	5	2	4	2	1	1	2	3
Sep	0	2	5	3	1	0	0	0
Oct	0	0	1	0	0	0	0	3
Grand Total	6	7	13	9	3	2	5	8

Table 7: Difference in event numbers (2080-2000) 10 years

Month	**6-10**	**10-15**	**15-20**	**20-25**	**25-30**	**30-35**	**35-40**	**>40**
Apr	0	0	0	0	0	-1	2	2
May	0	0	0	1	0	0	0	0
Jun	0	0	0	-1	0	0	1	0
Jul	-2	0	2	-1	0	1	0	0
Aug	-1	-9	-2	2	-1	0	2	2
Sep	-3	-1	1	-1	1	0	-1	0
Oct	0	0	1	-2	-1	0	-1	1
Grand Total	-6	-10	2	-2	-1	0	3	5
Pro rata to 34 years	-20.4	-34	6.8	-6.8	-3.4	0	10.2	17
	Less events		No change			More events		

In summary, the same assumptions and methods were used for the climate change runs as were for the final 2004 CTP runs, except for the following:

1. ***Environmental conditions.*** Temperatures and solar radiation are predicted to increase under climate change scenarios. HR Wallingford provided daily estimates for the future dew point temperatures, solar radiation, river temperatures at Teddington and sea boundary temperatures.

2. ***Sea level.*** Sea levels are predicted to increase under climate change scenarios. HR Wallingford suggested a future mean sea level increase of 0.45m.

3. ***Rainfall.*** Rainfall patterns are predicted to be different under climate change conditions with fewer small summer events and more large summer events. This has been factored into the storm input files as described above.

CSO quality and sewer retention periods

An additional component which was considered for inclusion in the runs, was the impact of increased sewer sediment and subsequent 'flush out' following extended dry periods expected during the summer with climate change. This effect is referred to as 'first flush' and represents a higher pollutant loading from CSOs during a large rainfall event, which re-erodes the sediment accumulated during drier spells. As mentioned in the model limitation section of this report, the CTP design and the lack of comprehensive observed CSO quality data for calibration makes it extremely difficult to apply varying CSO quality loads with different events and antecedent conditions. Although it is acknowledged that possible longer drier spells in the summer months would increase polluting loads for climate change scenarios, it is not possible to include this in the current compliance testing framework without substantial improvements to the sewerage network model's functionality and a very comprehensive monitoring programme to analyse CSO discharge quality under different rainfall patterns.

Climate Change Modelling Results

Figure 15 shows the results for runs where the environmental conditions and sea level are changed while keeping the rainfall at the current, historical pattern (Rainfall2000). By first changing the environmental conditions temperatures and solar radiation only [Q_CC_rainfall2000 in figure 15], there is a significant increase in the failures against standards 1 (4mg/l). The rise in river temperature increases decay rates and reduces oxygen saturation concentrations – both effects combine to increase the risk of DO failures for the 4mg/l standard only – all other standards are compliant.

The effect of also increasing the mean sea level (Figure 15; Q_CC_SL_rainfall2000) is a marginal increase in the numbers of Threshold 1 failures, but without changing the maximum number of failures. The net effect upon DO failures appears to be insignificant.

Figure 15 difference made by environmental condition changes; 2000 – 2080 as well as sea level rise.

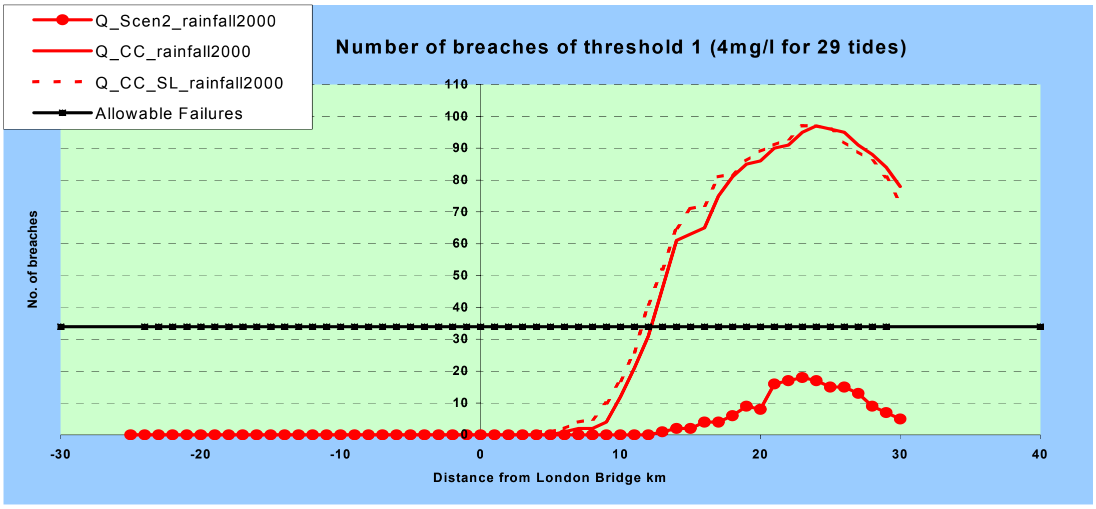
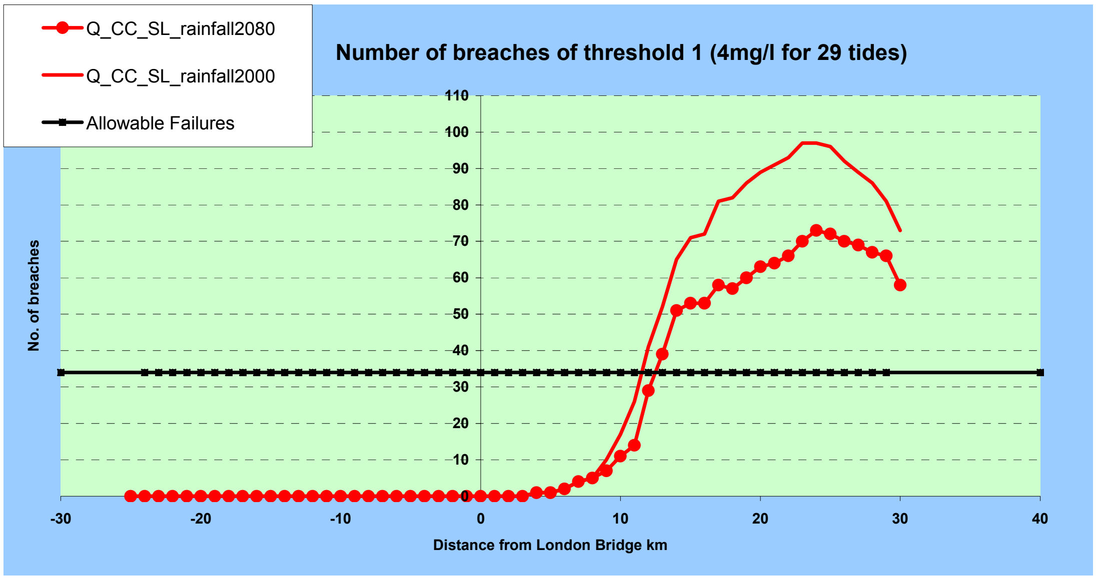


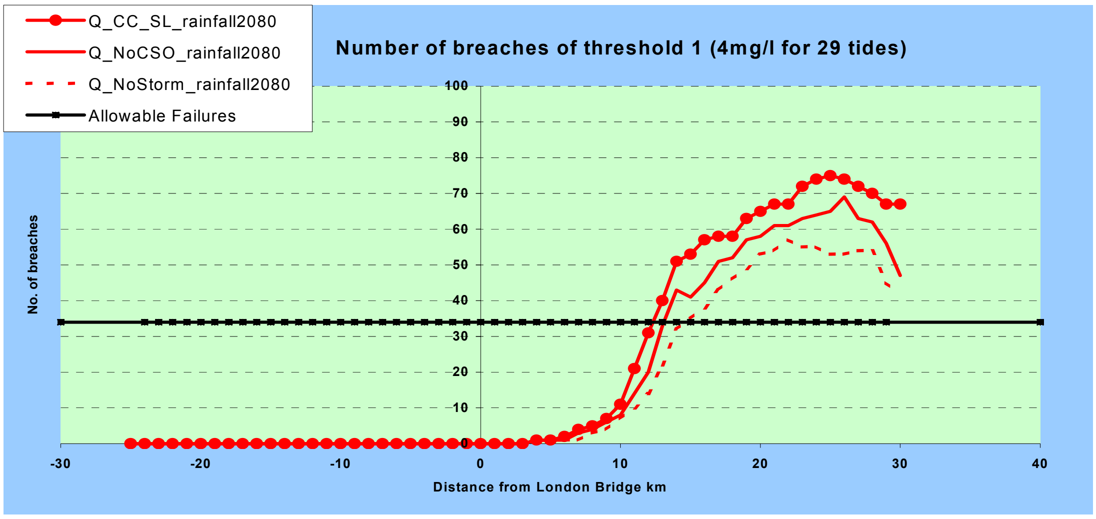
Figure 16 shows the effect of changing the environmental conditions but altering the rainfall series used between 2000 and 2080. The effect shows that the actual number of failures decreases with the 2080 scenario.

Figure 16 – Difference between rainfall sets only for 2000 and 2080 scenarios



From these results, it is evident that the temperature/solar radiation impact is the most significant climate change effect. Figure 17 shows that even by removing all CSO discharges and 'wet weather' discharges (effectively a super solution capturing all rainfall events) the Tideway will be non-compliant with the 4mg/l standard under the 2080 scenario.

Figure 17 – effect of a 'super solution' – Q_NoStorm_rainfall2080 – on failures of the 4mg/l standard – the Tideway is still non compliant with the standard.

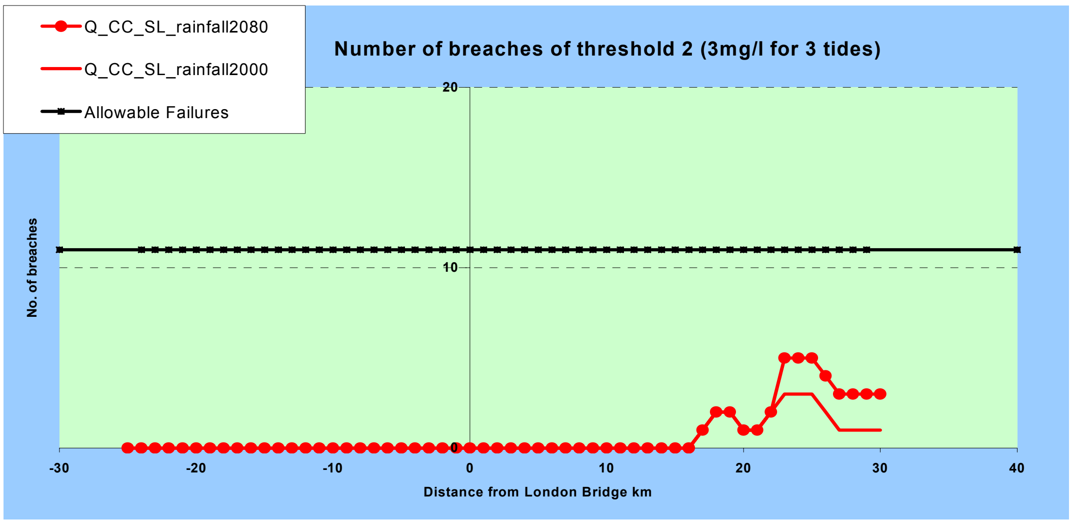


It can be deduced that the environmental conditions predicted for 2080 have the greatest impact on performance of the solution by affecting the 4mg/l standard only and that changing rainfall patterns are likely to have a positive impact on the performance of solution A(low).

The remaining standards (3mg/l and 2mg/l) are clearly compliant regardless of the rainfall predictions or changes in environmental conditions modelled, although the 2080 rainfall series appears to slightly raise the number of 3mg/l standard failures but remaining within compliance (see figure 18). The numbers of failures of the 2mg/l standard are not affected.

The results show that the tunnel size as designed is adequate to capture the rainfall events as predicted for 2080 but that environmental conditions are likely to affect compliance of any solution applied to the CSO discharges.

Figure 18 – Climate Change effects on the 3mg/l standard (without changes in freshwater flow or CSO quality parameters.)



5. Conclusion

Over the course of 2 years, a comprehensive analysis has been undertaken of the various solutions.

The final results have shown the optimised solution A(low) is the only solution which is complaint with all DO objectives following a comprehensive and improved compliance testing procedure. The solution can achieve compliance in combination with a suite of L1 and UID driven improvements as well as a ‘package of treatment’ options to optimise the solution performance.

Climate change is only likely to affect the performance of the solution with regards to the 4mg/l standard due in the main to the change in environmental conditions raising the water temperature of the river which alters the biological dynamics of the river in a way which would be difficult to mitigate with an engineering solution. Solution A(low) would still remain compliant with the critical fish mortality standard of 3mg/l even with climate change considerations factored in.