Thames Tideway. Comparison of the models with field data.

Executive summary

The EU Urban Waste Water Treatment Directive (UWWTD) requires Combined Sewer Overflow (CSO) spills to occur only in unusual rainfall conditions. This note looks at the reliability of the Tideway sewer and water quality models and whether the Tideway meets the UWWTD criteria.

Whereas the European Court of Justice(ECJ) relied on the Thames Tideway Strategic Steering Group that there were about **60 spills** a year, following limited field work, even the model of the remaining CSOs shows that, after the completion of the Lee tunnel, the greatest number will drop to about **42**.

However Ofwat concludes the sewer modelling considerably overestimates flooding from the sewers. Ofwat states the **sewer modelling** output for the existing condition is "***unreliable and inaccurate***". The reasons for this include (a) the limited rainfall data and (b) that there is only spill data for 9 of the 57 CSOs. Even Thames Water (TW) state " *it is unlikely that it will ever be possible to acquire sufficiently comprehensive data*" to provide robust models.

TTSSG selected fish as representing the Tideway ecology. Whereas TTSSG reported an observed baseline of 8 fish kills per year, since 2003 only two have been reported due to Abbey Mills spills and two due Tideway CSOs (about 21 fish). Since fish can withstand at least 10% mortality each year, it would appear that the Tideway **ecology is already sustainable**.

The TW water quality model shows that, post the 5 Sewage Treatment Works (STW) upgrades, (cost about £1.2bn) there should be about 3 breaches of standard 1 and nearly 3 of standard 2 a year etc. Field data shows the upper Tideway between mid 2012 and mid 2015 had no breaches and, since mid September 2013, none in the lower Tideway. Thus the **water quality modelling is not robust.**

The **WFD good dissolved oxygen (DO) condition** was met in the upper Tideway from mid 2012 to mid 2015 and in the lower Tideway since September 2014. However the DO conditions in 2015 in the upper Tideway deteriorated. Thames Water state they "*make sure our sewers are as empty as possible whenever heavy rain is expected...*" Ofwat considered that it is " *unlikely that properties can be removed from the risk of flooding by operational improvements alone."* Thus TW new pumping regime has limited benefit whilst causing environmental harm and the DO to drop from WFD good to moderate. The ECJ Weser case finds that DO deterioration from good must be prevented. The WFD requires that "*all practical steps are taken to prevent deterioration*". TW should return to their previous pumping regime which provided good DO in the upper Tideway.

Thus, provided TW return to their previous pumping regime in the upper Tideway, there should be no failure of any dissolved oxygen standard. Thus would not the objective of the UWWTD to protect the environment against discharges be met?

The UWWTD requires systems which are "*in accordance with the **best technical knowledge not entailing excessive costs."*** The tunnel was compared in 2003 with full sewer separation and full SuDs. Since then Real Time Control has been developed and this has reduced the cost of flooding measures in Cardiff from £100m to £5m. No study has been done of a **combination of partial measures** using current best technical knowledge. Such a system could well save £3bn and time.

1 Introduction

The objective of the Urban Waste Water Treatment Directive is "*to protect the environment from the adverse effects of... water discharges.*" At the time of the selection of the tunnel the sewer model and the Tideway water quality model were used to assess whether the spill frequency and the Tideway water quality breached the particular dissolved oxygen standards set for it. Thus the solution selected to meet the UWWTD depended on the reliability of the models.

The Directive says in the footnote to annex 1A that spills should only be allowed under conditions such as "*unusually heavy rainfall*". Unusual is not defined in the UWWTD but the ECJ judgement October 2012, para 28, states that the European Commission (EC) "*does not propose a strict 20 spill rule but points out that the more an overflow spills.. the more likely it is that the overflow's operation is not in compliance with Directive 91/271."*

In his letter of 24th February 2014, the then Minister Lord de Mauley stated that "*after the Lee tunnel is operational, spills of between 50 and 60 times a year will spill from the CSOs into the tidal Thames."*

Thus it is clear that it is important to know the spill frequency of the CSOs and their impact sufficiently accurately. This note looks at the robustness of the models and whether they are sufficiently reliable to underpin expenditure of about £4bn and whether the Tideway meets the UWWTD requirements.

2 Basis of the European Court Judgement.

The evidence submitted to the European Court of Justice (ECJ) was the Thames Tideway Strategic Study Group (TTSSG) reports of 2005. *"The Commission, relying on a TTSS report of February 2005, observes that there were approximately 60 waste water discharges from storm water overflows in London per year..."* ECJ judgement para 85. The TTSSG in its cost benefit report, page 20, also states that the observed baseline is 8 fish kills per year. Thus the ECJ based its findings that the Tideway was non-compliant with the UWWTD on the original situation as found by the TTSSG in 2005, before the benefits to be achieved by the STW upgrades and Lee tunnel.

3 Ofwat assessment of the Thames Water hydraulic sewer model for London.

Thames Water has used its sewer model to assess CSO spill frequency and to assess the number of properties that are subject to flooding with a certain frequency.

Ofwat has issued a notice Thames Water: sewer flooding dated 22 July 2014. This says that, based largely on its sewer hydraulic model, Thames Water (TW) has misreported sewer flooding data. The text and para numbers below are taken from the Ofwat report.

"*there should be a good match between the properties the model predicts as flooding and those reported as flooding."* Para 47.

"*It is important to us*" Ofwat "*that the Reporter satisfies himself that the hydraulic models have been developed to an appropriate standard and quality."* Para 22. "*in a number of cases there were very limited numbers of actual reported flooding incidents to verify the modelled assessments. We*" the

Reporter " *are therefore concerned that a proportion of the Company's claimed outputs are not adequately supported."* Para 30.

"Ofwat carried out detailed analysis of 832 out of 867 properties reported as removed by company action. These properties were chosen because they were covered by 4 large scheme in London and represented 96% of the relevant properties" identified as flooding by the hydraulic model. Para 33.

" *The results of Ofwat's investigation indicates that about 73% of the properties reviewed should not have been removed by company action as they should not have been on the high risk register in the first place."* Para 80

" A discrepancy of such magnitude leads Ofwat to conclude that Thames Water's hydraulic models are not verified in the way that the reporting requirements describe and are therefore not verified hydraulic models for this purpose." para 47

"*Put simply, in light of the reporting requirements a hydraulic model cannot be used on a stand-alone basis to verify its own results.*" Para 43.

"Ofwat is satisfied that Thames Water submitted unreliable and inaccurate information", whereas va,

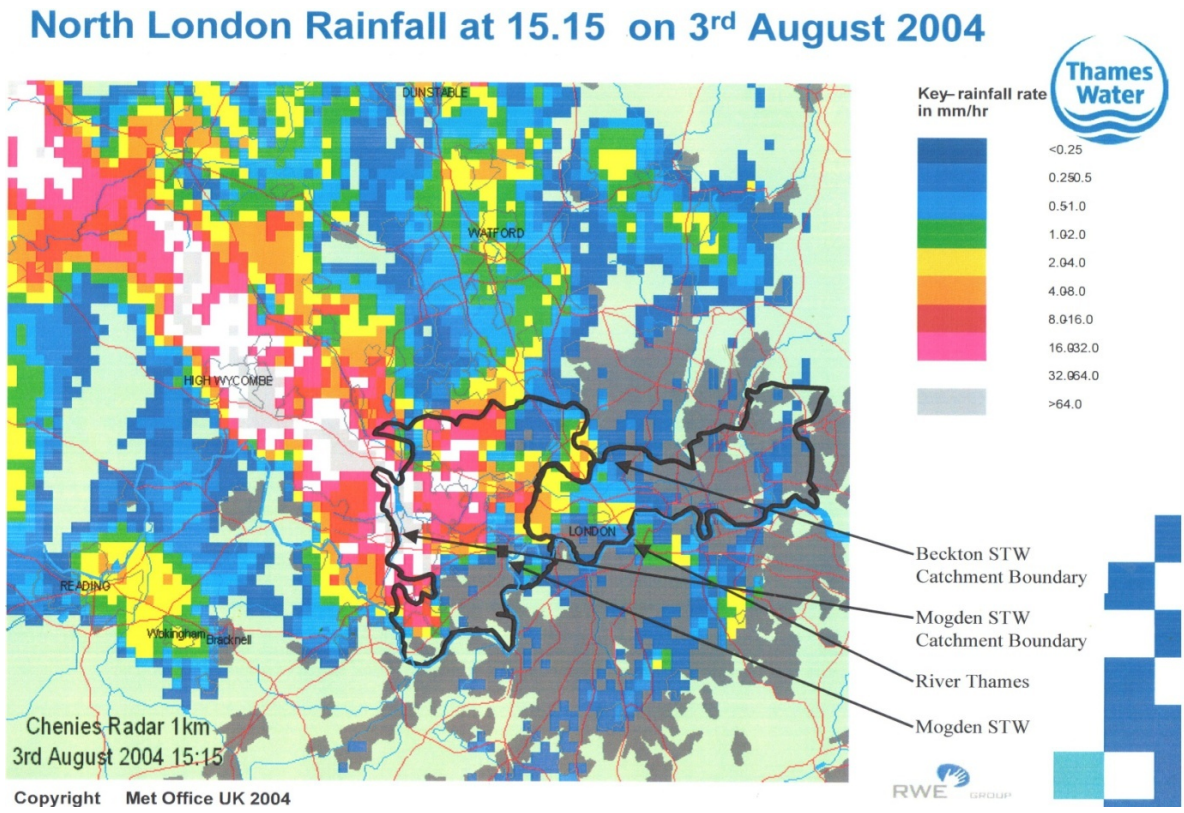
Conclusion.

Thus Ofwat consider the Thames Water sewer model is not to an appropriate standard, considerably over-predicts sewer flooding, and provides unreliable and inaccurate information. Further such a model cannot be used to verify its own results.

4 Reasons of overestimate of modelled spill frequency

The data input to the models is described by Thames Water in the TTTT 2006 Vol 2 Modelling and Compliance page 10 which states "*Obviously, comprehensive flow and quality data is essential for all these discharges if individual rainfall events are to be modelled precisely.* " Many individual rainfall events were modelled. "*Of the 57 CSOs which discharge to the Tideway, indicative flow data only exists for around 9 of the pumped discharges and there is some historical data. There is no flow data and virtually no quality data for the remainder."*

As an illustration, the rainfall radar plots show substantial local rainfall variation across London, rainfall changing appreciably over just a few hundred metres.



Whilst the radar plots would have provided a good representation of the actual rainfall, they were found to be insufficiently reliable, so were not used.

Instead rainfall on about 80% of the area contributing to the combined sewers to be connected to

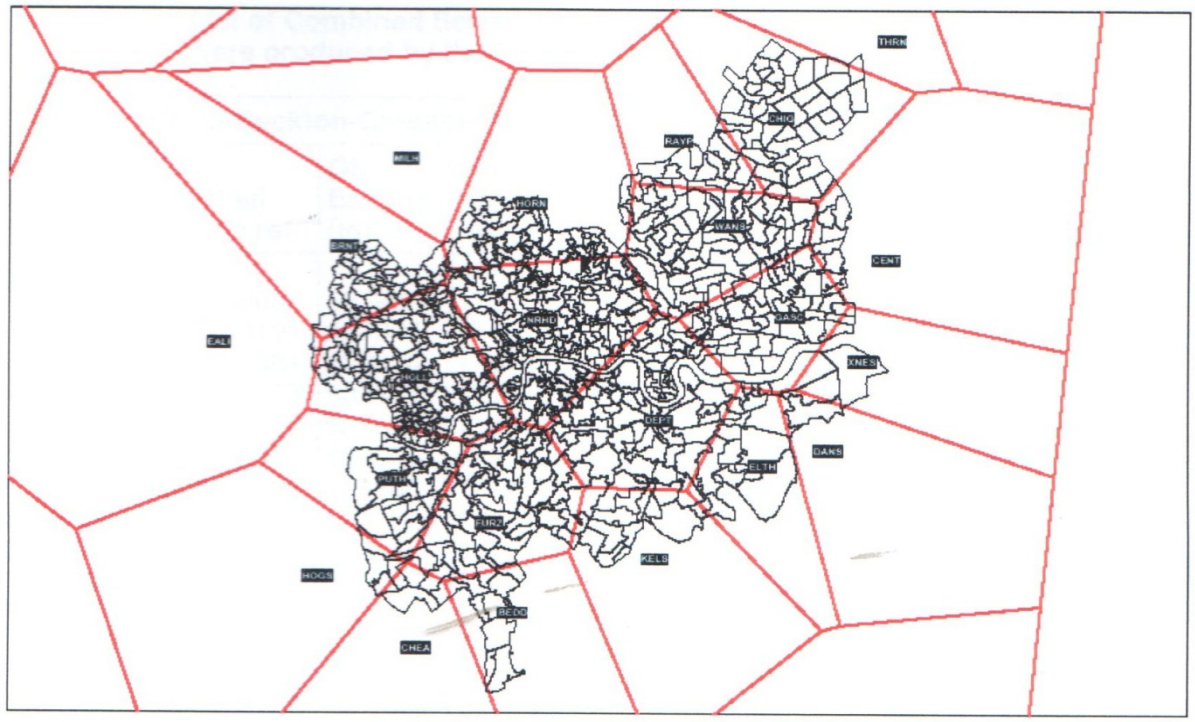


Figure 4.1 Allocation of rainfall gauges to sewer catchment areas

the Thames tunnel is based on just 4 single point raingauges spaced many kms apart, The preparation and application of the modelling framework for the compliance testing of options, Audit report 24th September 2003.

These 4 point raingauges cannot provide an accurate basis for modelling storms over a large urban area.

Further there is no record shown, or mention in the report, of runoff variation between virtually impermeable paved areas and parkland areas with terrace gravel subsoil, such as Hyde Park, where storm runoff would have been much lower.

The Audit report continued "*Under these conditions it is unlikely that it will ever be possible to acquire sufficiently comprehensive data.*" to model spill frequency sufficiently accurately.

Thus the rainfall and runoff model does appear to be based on insufficiently comprehensive data and to significantly over estimate spill frequency.

5 Reliability of modelled spill frequency for future years.

Population growth in London.

It has been said frequently by Thames Water that, because London's overall population is growing, then spill frequency will also grow. "*The population figure used in the model represents 2023 conditions"* Development Consent Order Application (DCO) 7.23 page 14.

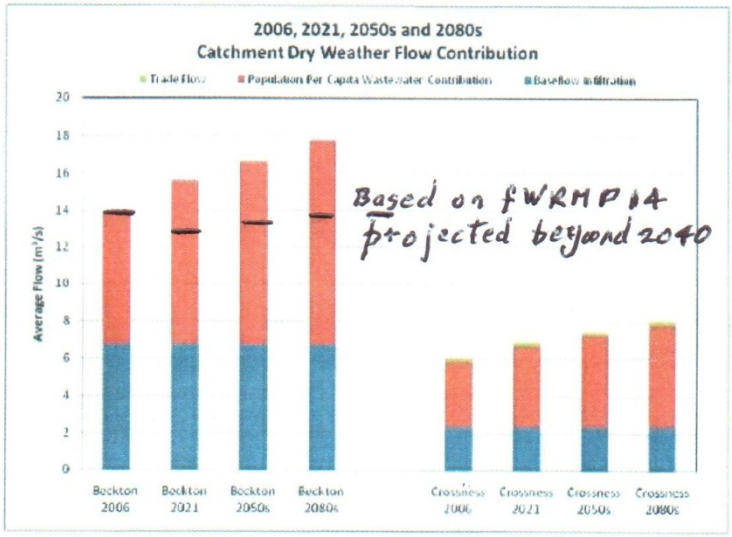
It is true that the population of Greater London is now growing. However, it is interesting to compare the population densities in 1939 with that in 2015, see plans on page 25 of the Economist of 7th February 2015. The total population of London is much the same, having gone down appreciably in the meantime and then risen in recent years. However the population in the inner boroughs has gone down and in the outer boroughs has, and is continuing, to go up.

For reasons of historical growth, London is split into the old central part that is predominantly combined sewers collected by the interceptors and with combined sewer over flows into the Tideway. The more modern suburbs are where the sewers are largely separated foul and storm water. Much of the more modern suburbs are taken to newer STW such as Mogden and Deephams rather than connected by the interceptors to Beckton and Crossness STW. Thus it is not the population of all of London that matters but the population contributing to the combined interceptor system in the old central part of London.

TW assumption of increase in sewer dry weather flow

The histogram below shows how Thames Water have projected the sewer flows in the Beckton and Crossness STW catchment. This assumes a sewer infiltration flow in blue and a flow in red based on flow from a growing population with a constant per capita water use. Thus, they assume that there are appreciable increases in sewer dry weather flow over future years, and hence in spill frequency from the 2006 base year to the design year, assumed at that time to be 2021.

Population and Wastewater Flows



Wastewater Profile	Per capita (L/head/day)	Catchment
Beckton Combined	200	Beckton
Beckton City	150	Beckton
Beckton Separated	150	Beckton
Crossness Combined	200	Crossness
Crossness Partially Separat	155	Crossness
Crossness Separated	155	Crossness
Fraser Rd (Separated)	145	Crossness

Assumptions:

1. Population change based on latest GLA projection to 2030 and ONS from 2030 to 2050
2. No change to per capita rating
3. No change in baseflow infiltration
4. No change in impervious connected area
5. Point 2, 3 and 4 subject to compliance to other TW work such as SOLAR values

Projection of water supplied

The areas served by the Tideway sewers are not exactly the same as the areas served by the Thames Water water supply system but they are not much different and one could assume a similar relationship.

In their water supply zones Thames Water are promoting water demand management and increasing smart metering of water supplied so, in reality, the water supplied, and hence reaching the sewers, will be affected by those measures and will be going down. The numbers in the Thames Water final Water Resources Management Plans WRMP 09 and 14 for water into supply are

2006 2180 Ml/d

2012/13 2028 Ml/d

2020/21 1948 Ml/d.

2039/40 1993 Ml/d

The effect of this on the flow in the sewers is shown by the black marks on the histogram above for the Beckton catchment. Crossness would be similar.

Since it is the excess flow above sewer capacity that leads to spills, the spill frequency and volume assumptions in the TW sewer model would be significantly greater than those based on flows projected by TW itself.

Comparison of assessments

Thus, from the quoted population projections, by 2020 the dry weather flow has been assumed by Thames Water to increase from 2006 by about 24%, see image above. The Development Consent

Order Application (DCO) document states that "*at peak times some sewers are running at 80% capacity*", page 13. Thus the flow in those sewers would, by 2023, reach about 99% capacity, hence spill very frequently.

Based on the Thames Water WRMPs numbers, by 2023, there would be a reduction of about 10% in water supplied and hence in sewer dry weather flow. Thus, for those sewers which were running at 80% capacity as quoted by TW in the DCO document, the capacity used at peak times in 2023 would actually be only about 72% of capacity. This reduction in dry weather flow from 99% of capacity to 72% of capacity, would make a significant difference in the frequency and volume of spill.

Conclusions

Thus the TW sewer model for the future further underestimates the spare sewer dry weather capacity, and thus further over estimates the CSO spill frequency.

6 Modelled spills .

Data availability

As far as I am aware there are few, if any, reliable flow measurements in the sewer network, so, if that is still so, it would be difficult to either assess the particular event conditions or to calibrate the sewer model with reliability.

" *Of the 57 CSO which discharge to the Tideway, indicative flow data only exists for around 9 of the pumped discharges and there is some historical 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.* " Thames Tideway Tunnel and Treatment-Option Development (TTTT) 2006 Vol 2 page 10

At the time of the TTSSG the only data about the volume of spills that was available was the pump run hours of the 8 pumping stations. The volume discharged by them was based on assumed pump discharge characteristics. Considering that these pumps are for sewage and are of variable age and the difficulty of calibrating them, then the accuracy of the assumed discharge characteristic may not be that reliable. Further, as flows from different contributing sewers arrive, it is possible that pumps start and stop several times during a single event. Thus the pumps may stop and start several times during a single storm, making it look like several different spills.

Let us look at the most frequent spilling CSOs. The base case should be once the STW upgrades have been completed and once the Lee tunnel is operational, due about the end of 2015.

Greenwich

The quoted modelled existing spill frequency at Greenwich in the Needs Report of 2010 is 51 spills/year. This is shown DCO Engineering Design Statement 7.18,Table 3.2 as being 28 in the base condition, 2020s. This drop is believed to be because the uprating of the Crossness STW has removed a bottle neck in the system, thus halving the spill volume at Greenwich and about halving the spill frequency. This improvement is believed to have already taken place.

Abbey Mills

Once the Lee tunnel is operational, about the end of 2015, then the about 50 modelled spills/year will drop to zero.

West Putney CSO

The original modelling of the West Putney CSO showed a modelled spill frequency of 59 spills/year. This CSO was monitored for about a year and it was found that the actual spill frequency was about 26 spills/year, TW Needs report 2010 Appendix E. Similar corrections reduced the modelled spills at Frogmore Buckhold Road from 29 spills/year to 19 spills/year.

Acton CSO

The provision of further detention tanks at Acton has reduced the modelled spill frequency for Acton CSO from 40 modelled spills/year to 17 spills/year.

Savoy Street CSO

Modelling in the DCO has shown that Savoy St CSO modelled spill frequency has dropped from 47 spills/year to 20 spills/year.

Mogden STW

The then Minister, Lord de Mauley, stated in Parliament that in its first formal year of operation, 2013/14, Mogden spilled on 54 days. The Mogden storm spill is from the storm tanks so does not receive secondary treatment so, under the UWWTD, it has also to be counted as an intermittent spill similar to CSO spills. The Environment Agency (EA) email to Chris Binnie of 24th July 2014, states "...*the overflow from Mogden STW storm tanks is regarded as satisfactory under the terms of the Urban Waste Water Treatment Directive*." On the assumption that significant spills on adjacent days are the same event then I assessed that there were 17 spill events. This is close to the frequency of 20 suggested by the EC and is presumably why the EA consider that the Mogden spill frequency is acceptable.

Hammersmith

The modelled spill frequency for Hammersmith was 50 spills/year. Thames Water provide discharge notifications to rowers and others on a web site whenever the Hammersmith Pumping Station spills. One assumption is that, like the Mogden assessment above, discharge notifications on consecutive days are the same storm event. This is reasonable as the contributing sewer network is long and storm flows from the same storm can arrive from different sewer catchments at different times. The discharge notifications show Hammersmith PS has discharged 61 times from July 2012 to February 2015. This is an average of 24 spills a year. This includes 2014 which the Centre for Ecology and Hydrology (CEH) describe as "*the 4th wettest year on record back to 1910*". Thus it is reasonable to assume that the modelled 50 spills/year is actually about 24 spills/year.

Overall.

Thus one can assume that, because the reduction in water into supply in TW WRMP14 means the sewer dry weather flow will be less in the 2020s than in the base case of 2006, then the worst condition is not the 2020s but the existing condition. The DCO 7.18 Table 3.2 shows the highest modelled spill frequency as 42 spills/year at Falconbridge PS and no others above 40 spills/year.

Thus it is clear that, without even considering whether the model over-estimates spill frequency, the modelled spill frequency post the Lee tunnel, due at the end of 2015, is not the stated 50 to 60 spills/year but no more than about 42 spills/year.

Clearly, as the note has demonstrated that the models overestimate spill frequency, the actual spill frequency is much closer to the 20 spills a year talked about by the EC than previously assumed.

7 Importance of spills

The European Commission Additional Reasoned Opinion dated 27/11/2008 states in para 21 *"an acceptable spill frequency ...taking place at times of heavy rainfall with a varied spill frequency depending on local situations and in particular the status of the receiving waters in each case*." Thus the EC consider particularly the status of the receiving waters.

The Advocate General's Opinion of the infraction proceedings, January 2012 para 48 states *"On several occasions, however, both in the pre-litigation stage and before the Court, the Commission did indicate that, as a rule, exceeding the limit of 20 overflows a year would be a cause for concern, suggesting a possible failure to fulfil obligations"* Clearly the EC do consider more than 20 spills a year as potentially acceptable providing the objective of the UWWTD of protecting the environment was not breached.

The Environment Agency have stated in the notes of the meeting on 25th September 2014 "*Spills alone is not regarded by the Environment Agency as an indicator of failure to comply with the UWWTD." "provided spills have not caused a significant adverse impact on the quality of the river...overflow is regarded as satisfactory."* This is after the issue of the ECJ Judgement so must have taken that, and the Directive footnote about unusual rainfall, into account, in affirming that it is meeting the objective of the UUTWD of protecting the environment that matters. In which case it would be the impact of CSO spills on the water quality of the Tideway that would matter.

8 Alternative measures to reduce spill frequency further.

The UWWTD directive states Annex 1 A "*The design, construction and maintenance of collecting systems shall be undertaken in accordance with the* ***best technical knowledge not entailing excessive costs.****"* My emboldening. The Defra River Basin Planning Guidance 2008 9.5 states "*The WFD requirement is to make judgements about the* ***most cost effective combination of measures****..."* My emboldening.

The current selection of a tunnel would reduce spill frequency to about 3 spills/year but the selection process has not taken account of current best technical knowledge, and at about £4bn might be described as excessive cost. How can this Directive requirement be met without considering a combination of the latest technical knowledge ?

Were it considered necessary to reduce the CSO spills further, then there are many ways this could be done. The alternatives considered at the time the tunnel was selected, 2003, included sewer separation of the entire CSO area and SuDs covering the whole area. No consideration was given to a combination of partial measures used where they could provide most benefit.

Since 2003 technology has advanced much. Real Time Control has been developed. When used in Cardiff the cost of reducing flooding was reduced from £100m for a conventional scheme to about £5m.

Partial SuDs at Llanelli has reduced the cost of a conventional scheme of £600m to about £145m. Whereas TW instructed its consultants to ignore infiltration as a means to reduce sewer flows, Bloomberg report Tunnel Vision p 19 states " *infiltration SuDs could be developed, subject to some technical adjustments, across 67% of London's surface area. This conclusion is in contradiction with Thames Water's argument that SuDs cannot be implemented in London because it was built on clay.*"

The storm water from new developments along the Tideway could be connected direct to the Tideway rather than the combined sewer system. This was done successfully in east London by the London Docklands Development Corporation. Detention tanks at Acton reduced the Acton CSO spill frequency from 40 spills a year to 17 spills a year.

Thus a study of how a combination of partial measures could reduce CSO spill frequency to whatever frequency was chosen might well reduce expenditure by about £3bn and shorten the time to achieve benefit.

Any action to reduce CSO spill frequency further, would, of course, further improve Tideway water quality.

9 Fish kills in the Tideway

The TTSSG in its cost benefit report, page 20, states that the "*observed baseline is 8 fish kills per year*". Thus the selection of the tunnel and its benefit assessment was based on this information. This would be the equivalent of 80 fish kills over ten years.

The Environment Agency Record of fish kills in the Tideway, sent to Chris Binnie on 13th January 2014 gives the recorded fish kills in the Tideway over the 10 years from 2003 to 2013. During almost all of this time there had been no upgrading of the STWs. This record shows 3 fish kills due to the Mogden STW spills of untreated sewage, 2 due to Abbey Mills spills, and one, of one fish, due to spills from the CSOs to be connected to the Thames tunnel. Whilst it is possible that other fish kills occurred during this period, because fish kills occur during the summer when the daylight hours are long and the river is tidal so any dead fish could be seen over a 15km tidal excursion, it is doubtful if many, or any, more would have occurred. Thus the TTSSG assessment and its cost benefit assessment would have been done on a false premise about fish kills.

During the summer of 2015 there was one further fish kill of some 20 fish related to CSO discharge in the Hammersmith/Cadogan area. However this period is considered as anomalous, as discussed later. Whatever, fishermen could fish this number every week and the numbers of fish in the Tideway still be classified as sustainable, see below.

Further, the objective of the Urban Waste Water Treatment Directive is "*to protect the environment from the adverse effects of... water discharges.*" The TTSSG selected fish as the representative species for the environment. TW Needs report Appendix F page 23 sets out the percentage mortality

Table 3-4 Values used for sustainable mortality. It is assumed that fish with more reproductive year classes are able to sustain a higher mortality in a single year.

Species	No. of Reproductive Age classes	Sustainable Mortality %
Salmon	3	30
Bass	10	30
Sand smelt	2	10
Dace	4	20
Smelt	2	10
Flounder	7	30
Common goby	2	10

which is sustainable. For instance a proportion of fish caught by fishermen can still mean the fish population is sustainable. For all species the sustainable mortality is 10% or more. There are many tens of thousands of fish in the Tideway. Thus, according to the EA record of fish kills, the number of fish, and hence the environment of the Tideway, would appear to have been sustainable for the last decade.

10 Dissolved oxygen model outputs

At the time of the TTSSG studies there were no specific ecological requirements for the Tideway. The TTSSG concluded that fish were the best indicator species. Trials of the impact of dissolved oxygen conditions on a representative suite of fish species were carried out and four dissolved oxygen standards were set.

The water quality model was run to demonstrate dissolved oxygen conditions under various situations Eftec Update of the economic valuation of Thames Tideway Environmental Benefits 2015 . Table A2.3

Table A2.3: Simulated number of exceedances and scenario compliance against DO standards for the Tidal Thames

DO Standard	1	2	3	4
DO value and tidal duration threshold	4 mg/l for 29 tides[1]	3 mg/l for 3 tides	2 mg/l for 1 tide	1.5 mg/l for 1 tide
Allowable exceedances in 41 years (frequency)	41 (1:1 yr)	13 (1:3 yr)	8 (1:5 yr)	4 (1:10 yr)
Scenario	*Simulated maximum number of exceedances of DO thresholds*			
A. System as in 2006	211	193	99	60
	Fails	Fails	Fails	Fails
B. STW improvements	123	114	66	41
	Fails	Fails	Fails	Fails
C. STW improvements and Lee Tunnel	75	40	12	7
	Fails	Fails	Fails	Fails
D. STW improvements, Lee tunnel and Thames Tideway Tunnel	21	4	1	1
	Compliant	Compliant	Compliant	Compliant

Source: Adapted from Table 8-5 System Design Report (Scenarios A, C and D). Scenario B information provided by Thames Tideway Tunnels (October 2014).

This covers a 41 year period. Thus the current situation is of STW improvements, Mogden in early 2012, and Beckton/Crossness in early 2013, but no Lee tunnel. Thus the model shows there should be about 3 failures of the 4mg/l standard 1 each year, nearly 3 failures/year of 3mg/l standard 2 and one failure/year of 1.5mg/l standard 1.

11 Comparison of modelled and actual dissolved oxygen conditions.

General

The Environment Agency has established 9 Automatic Quality Monitoring Stations (AQMS) along the Tideway. These monitor a number of parameters including dissolved oxygen (DO) conditions and record these every 15 minutes. A research student at Exeter has plotted the dissolved oxygen for the various AQMS up to the end of 2014, see Annex A. Formal assessment of whether the Tideway breaches the standards is by half tide plots. I have those for the critical summer period of 2014 and 2015 but not for the earlier years. However, the annual plots of the worst AQMS stations do give a very good indication. This is because they show whether the DO drops below a particular threshold and if it does not then the Tideway cannot fail that particular standard. The critical period when DO breaches occur is between early July and the end of September, because water temperatures are higher and river flows lower during this period. Since some of the standards have return periods longer than one year, the Environment Agency considers that one needs the specific length of time before one can be sure that the DO standards are met. That aspect is considered in a later section, this section just considering if the standards were breached in a particular year.

Upper Tideway

The upper Tideway (Brentford to Chelsea) is impacted by the Hammersmith to Heathwall pumping stations. After analysing the half tide plots Putney appears as the representative of the worst DO conditions. Unfortunately the annual plot for 2012 is not correct so, for 2011 and 2012, the next downstream AQMS Cadogan (Chelsea) has been shown, see Annex A.

Looking at 2011, before Mogden STW was upgraded, one can see that dissolved oxygen conditions dropped below 3mg/l on a number of occasions, and clearly the Tideway failed to meet the standards.

Looking at 2012 there was only one occasion when DO dropped below 4mg/l and dipped below 3mg/l for only 5 hours compared with the 19 hours allowed in the standard. These appear to be for too short a period to breach the standards that year.

Looking at 2013 it would appear that the DO only dropped below 4mg/l for a few hours and not below 3mg/l at all.

In 2014, the Environment Agency state, Douglas/Binnie 27th March 2015 *"I have attached plots covering the period 14th July Flood to 15th Sept Ebb inclusive. You will see that this is a significant event in that there was no breach of the DO standards... "* Looking at the Annex A plot, one can see that breaches could not have occurred during the rest of the year.

Lower Tideway

For the stretch of the Tideway affected by Abbey Mills and Beckton STW spills, defined here as the lower Tideway, the most representative AQMS is Barrier Gardens. Before the Beckton and Crossness STW were upgraded, about the end of 2013, this stretch failed standard 1, 4mg/l, regularly. However, since September 2013, there has been no breach of the standards. Note this is before the Lee tunnel, which will about halve the volume of CSO discharges, becomes operational, due about the end of 2015

Comparison with the modelling

The 41 years of modelling for the STW upgrade condition shows that there should be about 3 failures of standard 1 and nearly 3 failures of standard 2 each year. Thus the modelling clearly considerably overestimates breaches of the standards.

Conclusion

In conclusion the water quality modelling cannot be considered robust and does not sufficiently reflect actual conditions to be used as a basis for expenditure of £4bn on the tunnel.

12 Water Framework Directive (WFD)

To achieve good ecological status under the WFD the dissolved oxygen has to be above 5mg/l for 95% of the time. The table below from the Exeter University analysis by Laurence Claxton shows the

dissolved oxygen content in mg/l at the 95% condition. Thus all numbers above 5mg/l would pass the WFD DO standard. Note the numbers for 2015 were for the first part of the year only so are not relevant. Please ignore all the colour coding as it is misleading.

5.5.10.2 – Results Table

Table 19 - Annual Breakdown 5th percentiles

		Year								
		2007	2008	2009	2010	2011	2012	2013	2014	2015
Upper Tideway	Brentford	-	*12.40*	4.49	5.16	2.37	4.65	6.35	7.41	*11.59*
	Kew	-	*12.50*	5.26	4.59	2.08	5.60	5.60	6.98	*11.47*
	Chiswick	*13.80*	*13.80*	3.71	5.17	3.44	6.79	5.53	6.57	*11.36*
	Hammersmith	*14.10*	*14.00*	1.60	5.04	2.69	6.05	5.45	6.49	*11.27*
	Putney	-	-	3.35	5.15	3.48	6.35	5.87	6.60	*11.18*
	Cadogan	*1.70*	*2.30*	3.80	5.24	3.86	6.32	5.51	6.26	*10.81*
Lower Tideway	Barrier Gardens	-	-	-	-	-	3.72	3.19	4.55	*9.88*
	Erith	-	*13.10*	3.89	3.76	3.65	3.35	3.22	4.69	*9.47*
	Purfleet	-	*3.43*	3.07	2.45	5.59	2.61	1.87	5.02	*9.26*

For 2013, and 2014 this shows that for the upper Tideway, Brentford to Cadogan Gardens, the dissolved oxygen was above 5mg/l for more than 95% of the time at each AQMS. Thus Good dissolved oxygen was achieved . Looking at the annual plot for Brentford in 2012 shows that all the readings below 5mg/l occurred before June bar one short dip in July. Thus, post mid 2012, Brentford also passed. Thus, from mid 2012 to mid 2015, the WFD conditions for good were achieved in the upper Tideway.

The lower Tideway, Barrier Gardens,etc, the 95% was generally just below 5mg/l, (albeit Purfleet in 2014 at 5.02 was very marginally above.) Thus during 2014 DO in the lower Tideway was moderate.

13 Anomaly of 2015 water quality

Change in water quality in the upper Tideway

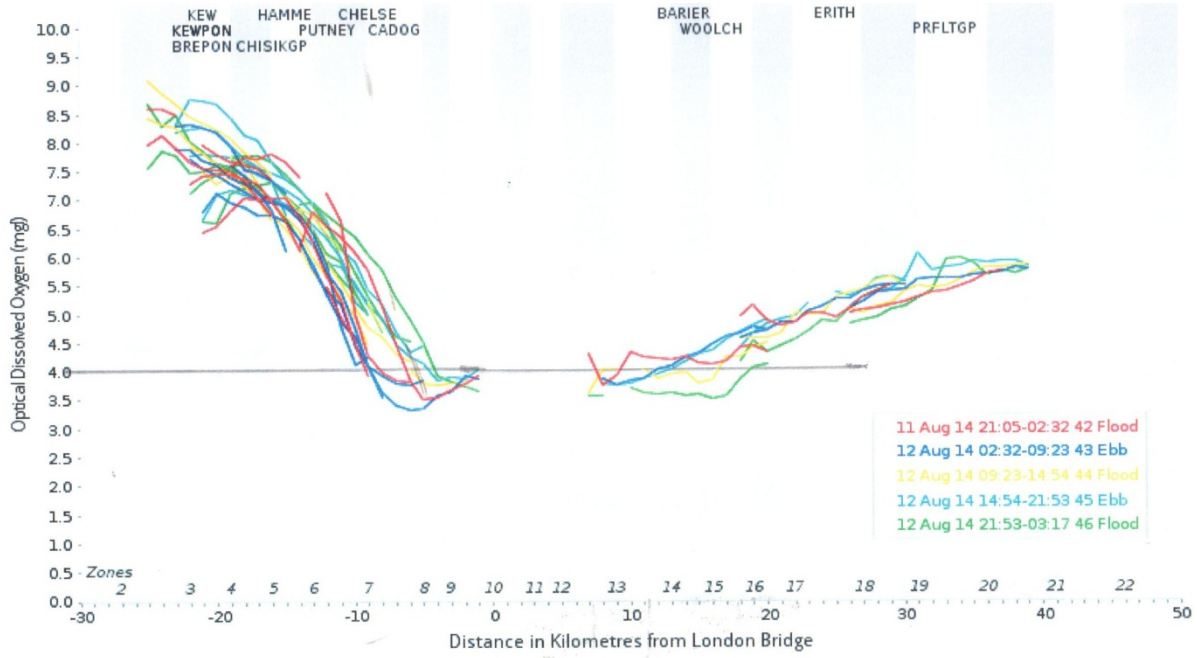
Thus thanks to the Mogden STW upgrade, the period from mid 2012 to mid 2015 does seem to have established a new and better norm in the upper Tideway with no breaches of the standards.

In contrast for 2015, by my analysis, the upper Tideway drops back to moderate WFD dissolved oxygen and breaches standards 2 and 3.

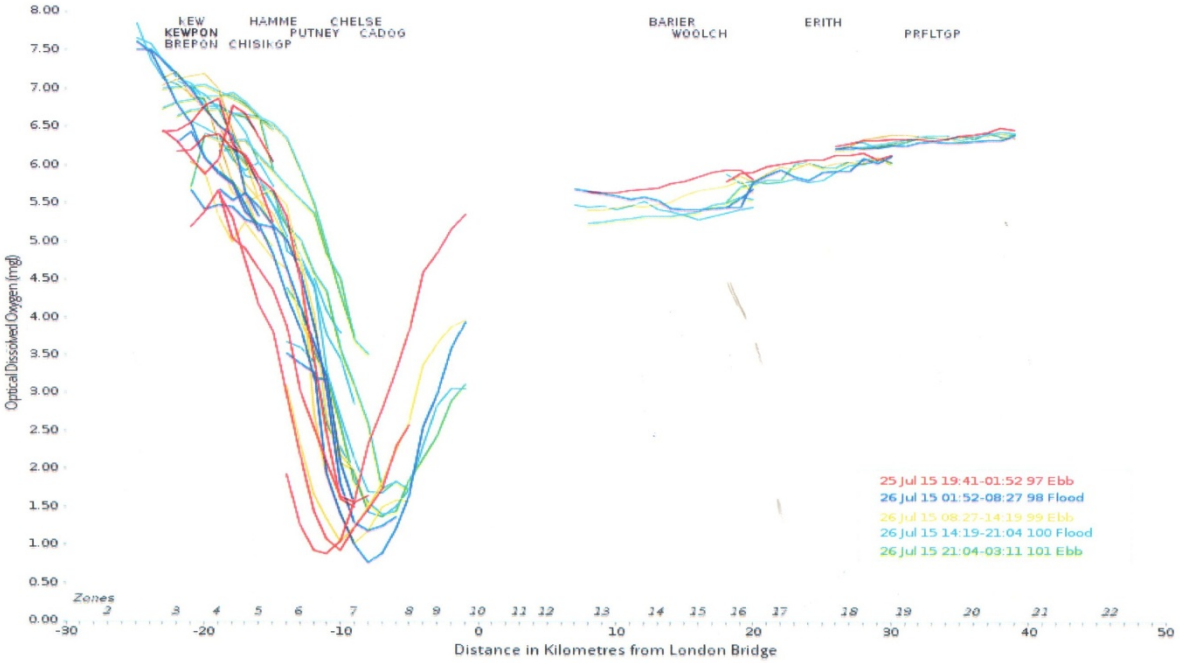
Based on the plots I have received from the EA for the critical 2015 summer period, the lower Tideway has almost no AQMS readings which are below 5mg/l, thus its DO becomes good.

Thus for almost adjacent stretches in the same river, and hence subject to the same river conditions, the upstream which was good has become moderate and the downstream that was moderate has

become good ! Thus the upper Tideway DO readings for 2015 appear to be an unexplained anomaly. It would appear that this could only be caused by a change of operational regime of the upper Tideway pumping stations. As an illustration below is the half-tide plot of what is probably the worst condition in 2014 and 2015.



In 2014 the dissolved oxygen in the upper Tideway and the lower Tideway are similar. The upper Tideway condition was similar in 2013. However in 2015, for a similar event, the dissolved oxygen is considerably different between the upper Tideway and the lower Tideway, as shown by the half tide plot below. This shows considerable deterioration in the upper Tideway.



Reason for the deterioration in the upper Tideway

Could the difference be because of a change in the rainfall? I have been unable to obtain relevant daily rainfall figures. However I have obtained monthly rainfall totals for Heathrow. For the relevant two months in the plots above, the August 2014 amount was 97.6mm and the July 2015 amount was 71.8mm. This would indicate that the substantial deterioration in water quality in the upper Tideway is unlikely to be because of change in rainfall.

In a recent press release, Builder & Engineer 3rd November 2015, Richard Aylard of TW states. "*We work really hard to make sure our sewers are as empty as possible whenever heavy rain is expected...*"

This can only be done by Thames Water pumping sewage from the combined sewers. If this were along the sewer system, then there would be less storm discharge to the upper Tideway, hence conditions in the upper Tideway would improve. However they deteriorate. Thus, to provide extra sewer capacity and hence potentially reduce on- land storm flooding, the sewer contents would have to be pumped to the Tideway. However the sewage being pumped from the combined sewers would be raw sewage or the first flush. This is much more concentrated than the mixture of storm water and sewage pumped previously to the Tideway and hence the revised pumping system is more polluting of the Tideway. That would explain why the 2015 dissolved oxygen in the Hammersmith/Chelsea section of the Tideway is appreciably lower during storm events than that in 2014. Hence the worse DO conditions in the upper Tideway in the summer of 2015.

Did Thames Water need to pump to alleviate household flooding? The numbers of properties are set out for 2008-9 and 2009-10, Ofwat Thames Water: sewer flooding page 13. There were a total of 5.77 million domestic properties connected to the sewer system in the whole Thames Water sewered area in 2009-10 of which the CSO area to be connected to the Thames tunnel might be of the order of about a third. Flooding can occur for a number of reasons including, equipment failure, blockages such as fat balls, sewer collapses, and severe weather. As an illustration, the table, Ofwat sewer flooding notice page 13, shows that in 2008-9 there were 19 properties in the whole TW sewer area flooded due to severe weather. This number would vary from year to year depending on actual weather conditions. There is no breakdown of this number to show the number in the Tideway CSO area, but, considering that the upper sewers and high and medium level interceptors have fixed level interconnecting weirs, then the area of the London CSO that could benefit from pumping action must be small, maybe a tenth of the whole Thames Water sewer area, hence the number of properties affected by flooding in the London CSO area that could benefit, ie not flood because of operation of the CSO pumping stations, must be very small.

Ofwat Thames Water: Sewer flooding states para 15 "*It is unlikely that properties can be removed from the risk of flooding by operational improvements alone.*"

Thus, there does not seem to be sufficient reason for Thames Water to have changed its CSO pumping regime and thus cause deterioration of the dissolved oxygen and harm to the ecology and the environment.

ECJ ruling on deterioration in the recent Weser case.

On 1st July 2015 the European Court ruled in the Weser case C-461/13.

"*Member States shall implement the necessary measures to prevent deterioration of the status of all bodies of surface water (obligation to prevent deterioration).*"

"*The concept of "deterioration of the status" of a body of surface water in Article 4(1)(a)(i) of Directive 2000/60 must be interpreted as meaning that there is deterioration as soon as the status of at least one of the quality elements, within the meaning of Annex V to the directive*" Annex V includes "oxygenation conditions" " *falls by one class, even if that fall does not result in a drop of the classification of the body of surface water as a whole.*"

Indeed, as shown above, the dissolved oxygen in the upper Tideway water body, Brentford to Chelsea, has deteriorated from good in mid 2012 to mid 2015 to moderate in 2015.

"It follows that, unless a derogation is granted" which I understand has not happened *"any deterioration of the status of a body of water must be prevented, irrespective of the longer term planning provided by management plans and programmes of measures. The obligation to prevent deterioration of the status of bodies of surface water remains binding at each stage of implementation of Directive 2000/60."* Thus the future benefit of the tunnel, or other measures, cannot remove the obligation to maintain good dissolved oxygen conditions now.

There is an allowance for temporary deterioration under certain circumstances. "*Article 4 section 6 Temporary deterioration in the status of bodies of water shall not be in breach of the requirements of this Directive if this is the result of circumstances of natural cause or force majeur which are exceptional or could not reasonably have been foreseen, in particular extreme floods and prolonged droughts, or the result of circumstances due to accidents which could not reasonably have been foreseen, when all the following conditions have been met.*

However the unusually low dissolved oxygen happened on 24/25th July 2015 and again on 27th August 2015, so the rainfall events were not exceptional.

Since the deterioration appears to be the result of predetermined direct action by Thames Water, then the circumstances were not due to accidents which could not have been foreseen. According to Richard Aylard they were due to deliberate acts by Thames Water "*We work really hard to make sure our sewers are as empty as possible whenever heavy rain is expected...*"

WFD Article 4 section 6 continues "*All practical steps are taken to prevent further deterioration in status...*" Thus Thames Water must be instructed to return to the operational regime which took place between mid 2012 and mid 2015 and resulted in good dissolved oxygen in the upper Tideway.

It might be argued that either the length of time, 3 years, or the extent of the water body, Brentford to Chelsea, was not sufficient. However it is clear that, as the section from Barrier Gardens to Purfleet also meets the good dissolved oxygen, then , without the action which resulted in the 2015 anomaly , the whole Tideway, with the Lee tunnel but without the need for the Thames tunnel, would in future be classified as good dissolved oxygen at some time in the future, thus would be deteriorated by the continuing action which caused the 2015 anomaly.

Conclusion

Thus, in conclusion, should not 2015 dissolved oxygen conditions in the upper Tideway be considered an anomaly, and Thames Water be required to return to the CSO pumping regime which it has operated in the previous 3 years which resulted in WFD good dissolved oxygen conditions in the upper Tideway ?

14 Tideway water quality

This would mean that the Tideway would revert to the previous condition. Since there appear to have been no DO breaches in the upper Tideway between mid 2012 and mid 2015 it seems most unlikely that there would sufficient breaches of the dissolved oxygen standards to cause failure of the TTSSG standards.

For the lower Tideway, since the upgrading of the Beckton and Crossness STW there was no breach of the standards in 2014 or in the summer of 2015, thus one would expect that situation to continue. In any case the Lee tunnel is due to become operational at the end of 2015 thus reducing the total spill into the Tideway by about half, so there would be negligible risk of the lower Tideway failing the standards in future.

Looked at another way, standard 1 allows 1 breach every year but there were no breaches in 2014 or 2015. The provision of the Lee tunnel, due at the end of 2015, will much reduce the risk of breaches occurring.

For standard 3 the model, see table A 2.3 in section 10, shows that, without the Lee tunnel, modelled breach frequency would be 66 breaches in 41 years. However there were no breaches in the upper Tideway from mid 2012 to mid 2015 and none in the lower Tideway in 2014 and 2015. The Lee tunnel would reduce modelled breaches from 66 to 12 breaches. Thus it is clear that the addition of the Lee tunnel will much decrease breach frequency. In any case the modelled 12 breaches with the Lee tunnel is not much in excess of the 8 breaches allowed. Thus it appears almost certain that the addition of the Lee tunnel, due by the end of 2015, will ensure that Standard 3 will be met then.

Similarly, for standard 4 where the modelled spill frequency without the Lee tunnel was 41 breaches in 41 years. In actual fact there were none in the upper Tideway from mid 2012 to mid 2015 and none in the lower Tideway since late 2013 and the upgrading of the Beckton and Crossness STWs. The addition of the lee tunnel is modelled to reduce breach from 41 breaches in 41 years to 7 breaches, a dramatic drop. Even the model shows this almost reaching the requirement of 4 allowable breaches. Thus there seems little doubt that with the Lee tunnel the standard 4 would be met.

Thus, providing TW reverts to the previous sewer operating regime, there seems negligible risk of the Tideway not meeting all the standards.

In addition, should any action be taken to reduce CSO spill frequency, then the Tideway water quality would improve further.

15 Period required to demonstrate compliance with UWWTD standards.

The TTSSG DO standards refer to once in a year for standard 1 up to once in 10 years for standard 4.

The Environment Agency has suggested that a period of 10 years would be required to demonstrate compliance. The implication of this is that one would have spent the £4bn constructing the tunnel before one would be able to demonstrate that one did not need it ! Is this sense?

As a comparison, flood defence schemes may be constructed with a design flood of 1 in 100 year. No one waits 100 years to find out if they conform. Similarly the Thames Barrier is designed against a 1 in 1,000 year event but is considered compliant by the Environment Agency without waiting 1,000 years.

Thus, one method of assessment would be to adapt the models so they replicated the current situation and then check whether all the standards were met.

In contrast the Environment Agency, email Simon Hughes/Chris Binnie 24th July 2014 regarding spills from Mogden STW after about one years operation, stated "*The Environment Agency is not aware of any instances when storm discharges from Mogden STW have caused a significant adverse impact on the quality of the river since the upgrade of the works. On this basis, the overflow from the Mogden STW storm tanks is regarded as satisfactory under the terms of the Urban Waste Water Treatment Directive."* Mogden spills from the storm tanks are not fully treated so need to be considered in accordance with the TTSSG dissolved oxygen criteria.

Thus it would seem appropriate to follow this Environment Agency approach of using one years data in the assessment.

16 Conclusion of the water quality assessment of the Tideway.

The conclusion is that, as about two years data for the lower Tideway and about three years for the upper Tideway show it not breaching the standards, then subject to Thames Water returning to its previous operational regime and continuing monitoring, the Tideway would continue to meet the TTSSG and WFD dissolved oxygen criteria.

If there is any doubt about longer term events, then the sewer and water quality models should be corrected to reflect the response to actual rainstorms, and then run for the full suite.

17 Cost of the tunnel

The contract for the construction of the tunnel includes payment for the tunnel, the construction of which is estimated at about £4bn. In addition the cost to be paid includes the financing costs during the period from the construction until the total cost has been written off many years hence. This will significantly increase the cost of the tunnel. Whilst this is funded by the Infrastructure Provider, Bazalgette, most of the cost has to be repaid by the Thames Water sewerage bill payers. The contract is a target cost contract. Thus, if the construction hits problems, then the cost to be repaid could escalate appreciably. Whilst all reasonable precautions have been taken, tunnels are risky ventures and tunnels under water even more so. The London Water Ring Main tunnel was stopped

on two occasions. One of these was when it hit a water bearing fault. This required the fault to be frozen which took many months. In that case it was under an open common so had easy access. In this case the tunnel is under the Tideway, potentially a much more onerous and expensive situation. Thus the Tideway tunnel, despite all the efforts to reduce the risk, is a significantly risky project. A proportion of the cost overrun is born by the general taxpayer.

Does not the government owe a duty to the Thames Water sewage customers and the general taxpayers, to discuss with the European Commission whether the current water quality, and hence the environment, meets the UWWTD or at least identify the minimum alternative measure scenario needed to do so? Tony Berkeley has reported that his discussions with the EC a few months ago indicated that, at that time, such a discussion had not happened.

18 European Commission fines

On the basis of the situation reported by the TTSSG in 2005 of 60 spills/year and 8 fish kills/year, the European Court of Justice in 2012 found the UK in breach of the UWWTD for the Thames Tideway.

The UK government could be fined for the breach. The basis of the fine is a country factor, an environmental impact factor, and a length of occurrence factor. Based on the reported condition in 2005, and the period from when UK was supposed to conform with the UWWTD of 2000 to when the Thames tunnel is expected to be operational, currently programmed for 2023, the fine could be large, maybe up to a billion euros.

Were it possible to agree a programme of alternative measures such as Real Time Control to reduce spill frequency, then these could be implemented much sooner than the tunnel thus reducing the time factor.

Were it possible to convince the EC that, after spending £1.2bn on the STW upgrades and the Lee tunnel, the objective of protecting the environment, ie achieving the dissolved oxygen standards, had been met, then the fines would be reduced considerably.

This fine would have to be paid by the British taxpayer. Should not such discussion with the EC be undertaken?

19 Conclusions

UWWTD requires CSO spill only to occur "*in conditions such as unusual rainfall* ". The TW sewer modelling showed that, even with the Lee tunnel, the spill frequency was too high and thus reduction of spill frequency was required, hence the tunnel recommendation.

Whereas the ECJ relied on the TTSSG that there were about **60 spills** a year, following limited field work, even the model of the remaining CSOs shows that, post the Lee tunnel, the greatest number will drop to about **42 spills**/year.

However Ofwat shows the sewer modelling considerably overestimates flooding from the sewers. 73% of properties investigated by Ofwat as predicted by the model to flood,were found to have no evidence of flooding. Ofwat concludes the **sewer modelling** output for the existing condition is "***unreliable and inaccurate***". Reasons for this include the limited rainfall data and that there is only

spill data for 9 of the 57 CSOs. Even TW state " *it is unlikely that it will ever be possible to acquire sufficiently comprehensive data*" to provide robust models.

The model further **over-predicts future spill frequency** because it assumes no change in per capita water use, and hence increasing sewer dry weather flow. However TW WRMPs show water into supply lower in 2020 and 2040 than in the base year of 2006.

The UWWTD requires systems which are "*in accordance with the* ***best technical knowledge not entailing excessive costs."*** The tunnel was compared in 2003 with full sewer separation and full SuDs. Since then Real Time Control has been developed and this has reduced the capital cost of flooding measures in Cardiff from £100m to £5m. Other partial measures such as some sewer separation to discharge direct to the Tideway, would also be cost effective. No study has been done of a **combination of partial measures** using current best technical knowledge and how such a system could meet the required spill frequency. Such a system could well save £3bn and time.

TTSSG selected fish as representing the Tideway ecology. TTSSG reported an observed baseline of 8 fish kills per year, and this was part of the evidence on which the ECJ found the system failed the UWWTD. Since 2003 only two fish kills have been reported due to Abbey Mills spills and two due to Tideway CSOs (about 21 fish). Further Abbey Mills related fish kills will be dealt with once the Lee tunnel is operational about the end of 2015. Since fish can withstand at least 10% mortality each year, it would appear that the Tideway **ecology is already sustainable**.

The water quality model shows that, post the STW upgrades, there should on average be about 3 breachs of standard 1 and nearly 3 of standard 2 a year. Actually in the upper Tideway between mid 2012 and mid 2015 there were none and since mid September 2013 none in the lower Tideway. Thus the TW **water quality modelling is not robust and is not sufficient to support the expenditure of £4bn on the tunnel.**

The AQMS data and analysis shows that the **WFD good dissolved oxygen condition** was met in the upper Tideway, Brentford to Chelsea, from mid 2012 to mid 2015 and in the lower Tideway, Barrier Gardens to Purfleet, since September 2014.

The dissolved oxygen conditions in summer 2015 in the upper Tideway deteriorated from those in mid 2012 to mid 2015, see half-tide plots above. Thames Water state they adopted an **operational regime** to "*make sure our sewers are as empty as possible whenever heavy rain is expected...*" This appears to be by pumping from the sewers to the Tideway. In 2008-9 only 19 properties were flooded in their entire sewer area due to severe weather. Because of the fixed level of the sewer/high and medium level collectors interconnections, it would appear that very few properties would benefit from the altered regime. Ofwat considered that it is " *unlikely that properties can be removed from the risk of flooding by operational improvements alone."* Thus it is concluded that TW revised operational regime has very limited benefit in reducing household flooding whilst causing **deterioration from good** dissolved oxygen condition and **ecological and environmental harm.**

The result of the recent ECJ Weser case judgement is that **dissolved oxygen conditions must not deteriorate from good** to moderate and that **all practical steps** are to be taken to prevent this. This would require TW to revert to the previous sewer operational regime which gave good dissolved oxygen conditions in the upper Tideway.

Thus, provided TW return to their previous operational regime in the upper Tideway, there should be no failure of the dissolved oxygen standards, thus it would appear that, with the addition of the Lee tunnel due by the end of 2015, the **objective of the UWWTD to protect the environment against waste water discharges will be met.**

Should **reductions in spill frequency** also be required, then there are **several measures** which could be used in a combination of partial measures to achieve the required spill frequency at a **substantially lower cost** than the Tideway tunnel. Such a system has **not yet been studied**.

Prof Chris Binnie MA, DIC, Hon DEng, FREng, FICE, FCIWEM

TTT modelling spill frequency 22.11.2015

Annex A Plots of the annual dissolved oxygen from An Investigation into the need for the Thames Tideway tunnel by Laurence Claxton University of Exeter, September 2015.

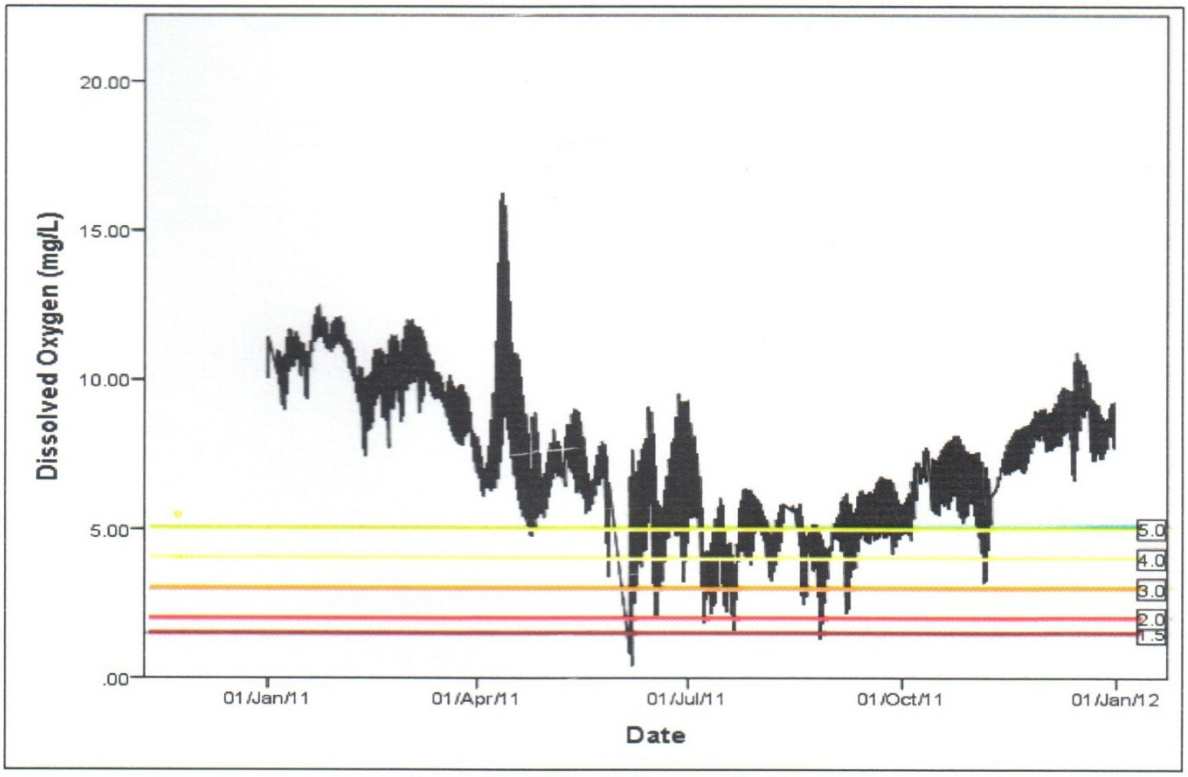


Figure 73 - SA4 TSG: Cadogan 2011

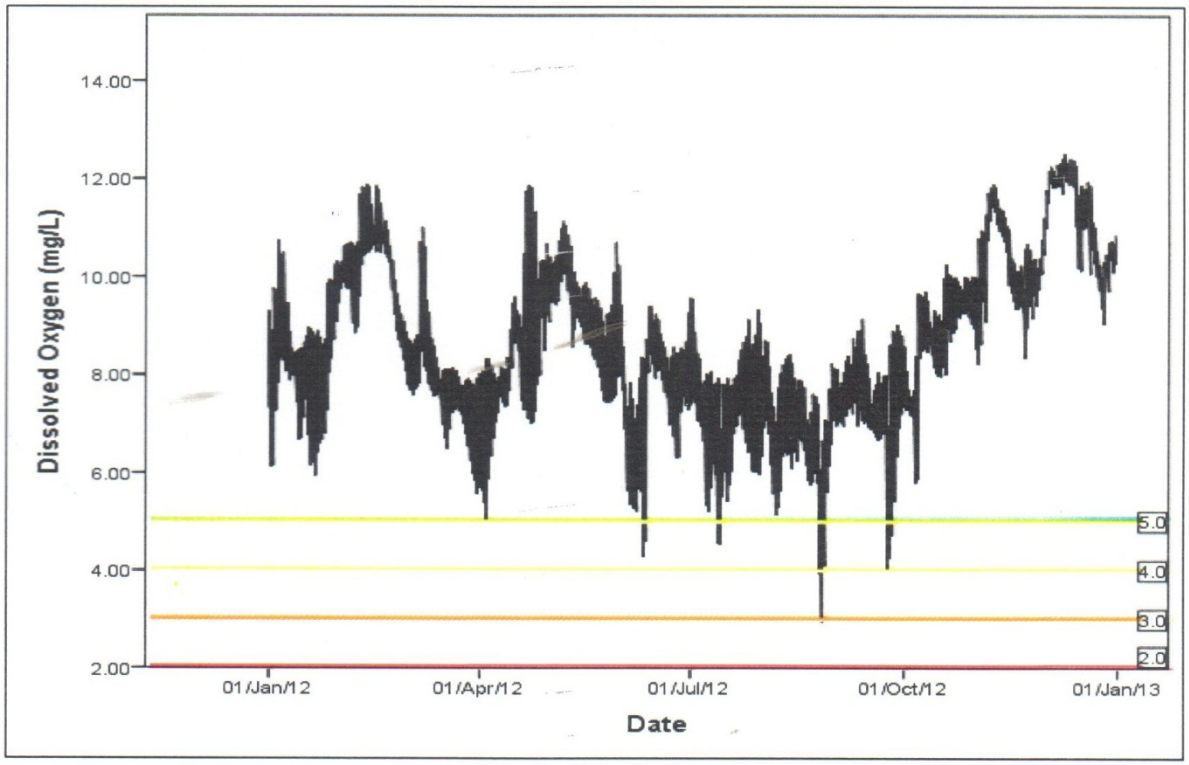


Figure 74 - SA4 TSG: Cadogan 2012

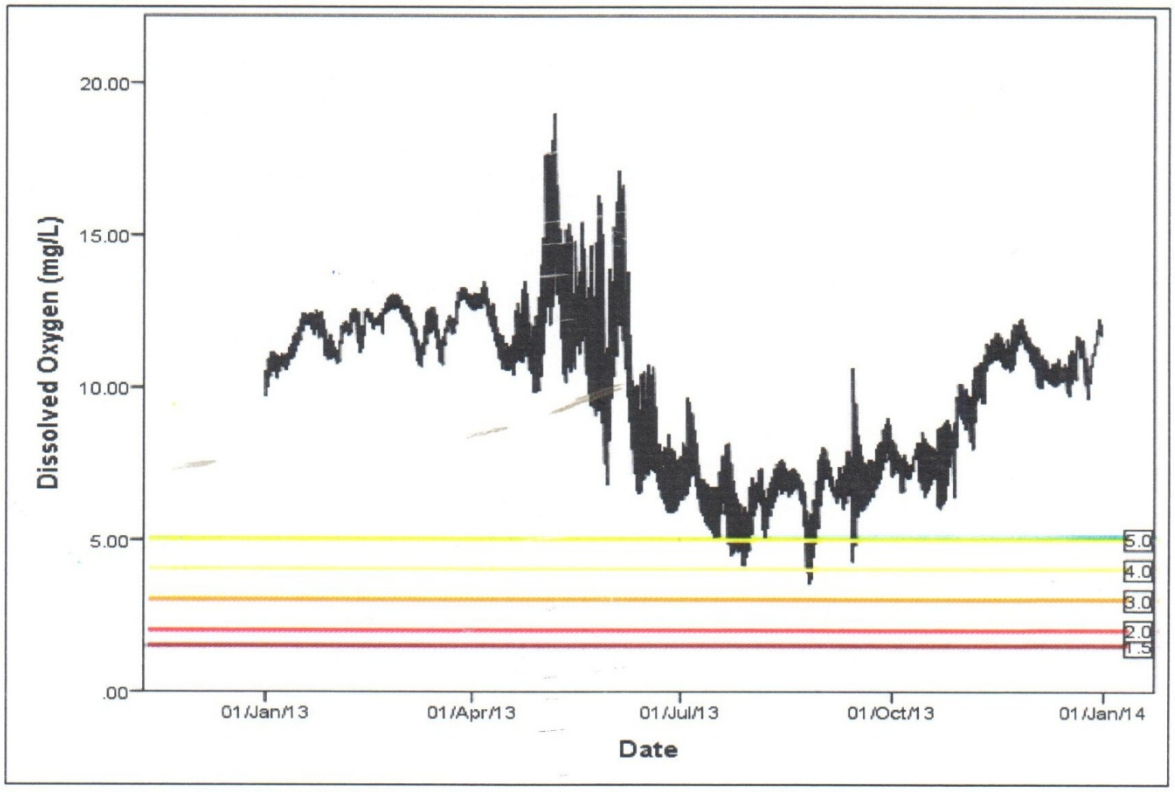


Figure 68 - SA4 TSG: Putney 2013

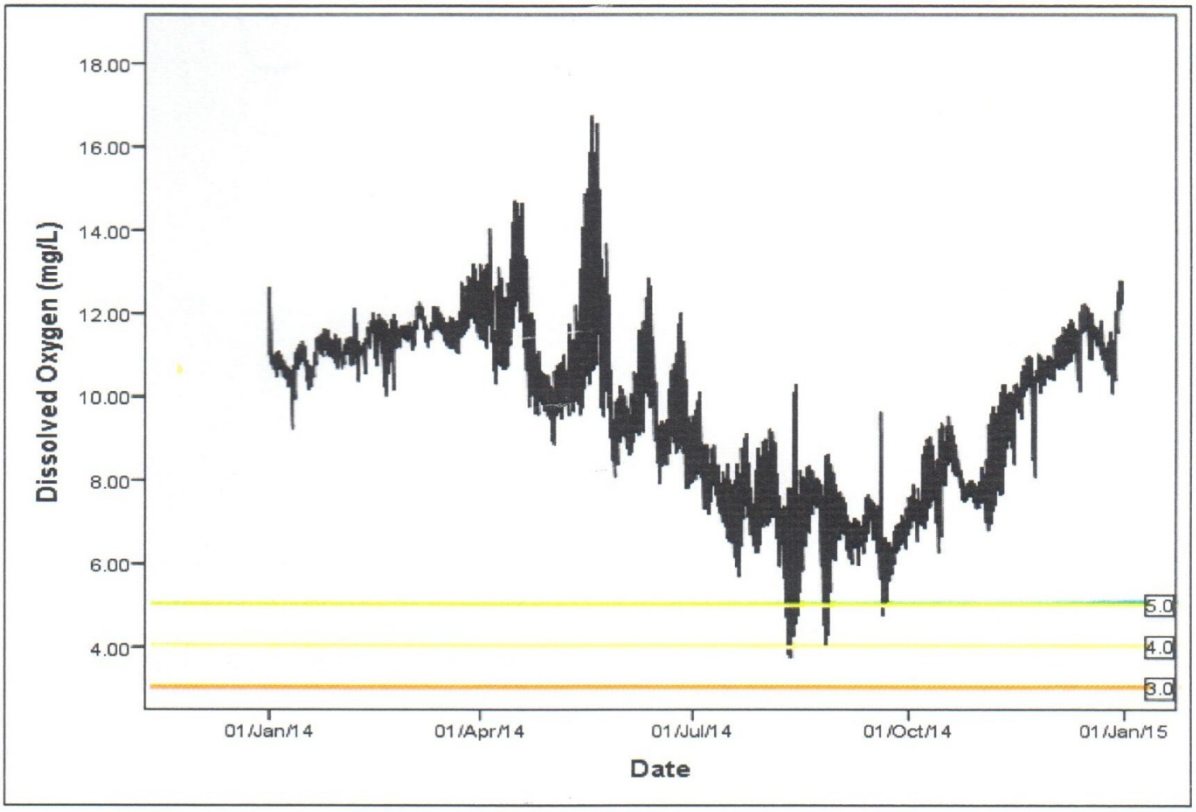


Figure 69 - SA4 TSG: Putney 2014

A2.7 – Barrier Gardens

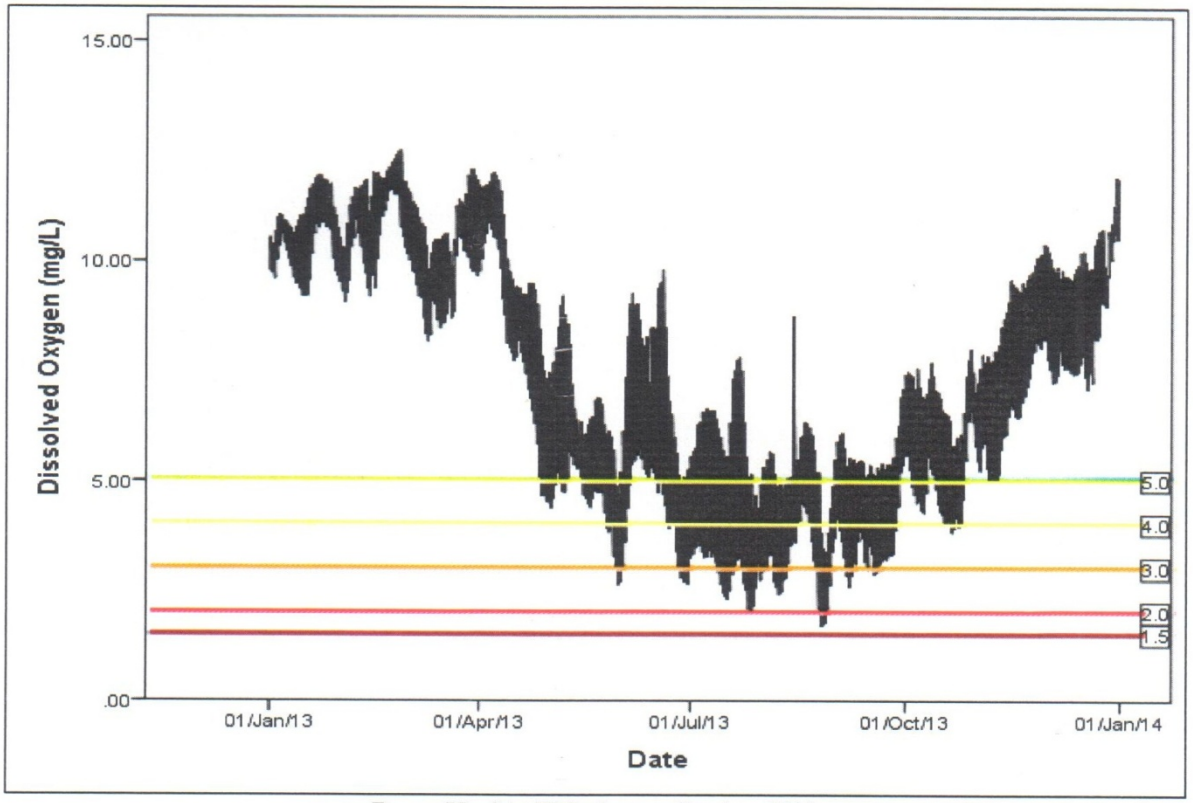


Figure 77 - SA4 TSG: Barrier Gardens 2013

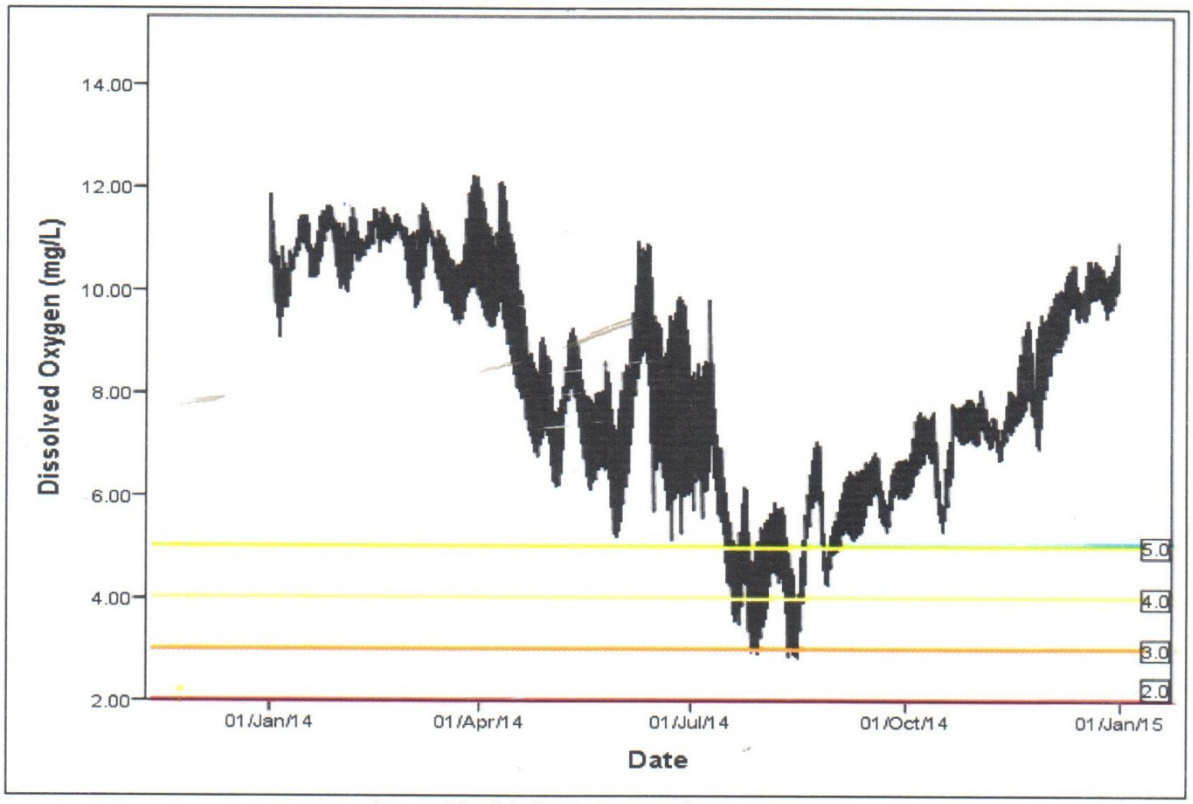


Figure 78 - SA4 TSG: Barrier Gardens 2014