Thames Tideway Tunnel
Thames Water Utilities Limited

Application for Development Consent

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Needs Report

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Appendix F - Tideway Fisheries Review

APFP Regulations 2009: Regulation **5(2)(q)**

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Thames Tideway Tunnel
Creating a cleaner, healthier River Thames

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EXECUTIVE SUMMARY

Background, Aims and Scope

During its assessment of potential engineering solutions to the Thames Tideway CSO problem, the Thames Tideway Strategy Group (TTSG) recognised the need to improve understanding of fish responses to hypoxia (low dissolved oxygen –DO- levels). A two-year riverside and laboratory study set up for this purpose was undertaken by Fawley Aquatic Research Laboratories (FARL) and reported in 2004. This study provided a body of hypoxia response data which were then used to evaluate and underpin new environmental quality standards (EQSs) for DO on the Tideway. The final aim of the study was to ensure that the EQSs would protect the sustainability of the Tideway fish populations. This was evaluated through the Tideway Fish Risk Model, developed specially for the purpose.

Reviewing the validity of these outputs in 2009 in the context of the proposed Thames Tunnel Project, a number of new aspects need to be taken into account:

- The changing regulatory context, especially with regard to the Water Framework Directive (WFD), which is now more fully formed than before.
- External challenges to the TTSG outputs from bodies such as the Water Regulator, Ofwat, and the Consumer Council for Water (CCWater), who seek to ensure that value for money is achieved in any technical solution.
- Expected changes in Tideway background water quality that will result from AMP4 sewage treatment works upgrades and new information arising from associated studies.
- Any updated information on the status of fish populations in the Tideway.

It is also an opportune time to review the robustness of assumptions made in the Tideway Fish Risk Model (TFRM) with regard to the proper representation of Tideway fish species and the definition of sustainability used therein. The findings of an independent expert peer review of the fisheries work and the Model are also presented.

Validity of Fisheries Data and Modelling Approach

The TTSG fisheries study undertaken by FARL provided physiological sensitivity data to evaluate and underpin Tideway dissolved oxygen standards. This was based on the reasonable assumption that the fish community is a sensitive surrogate for the Tideway ecology as a whole. In reviewing the robustness of the scientific data, a number of points were questioned, viz.:

- Should the TFRM have included the effects on fish of ammonia toxicity?
- Was the set of seven common Tideway fish species tested representative of the full suite of fish found in the Tideway (>120 species recorded to date)?
- Were the fish mortality rate criteria used in the TFRM an appropriate measure of sustainability, or should this now be judged against WFD Ecological Status metrics?

The question of potential ammonia toxicity to fish in the tideway was examined by comparing levels of unionised ammonia recorded in the Tideway over a 33-year period (1976-2009) against the 200µg/L acute toxicity threshold for salmonids. 95th percentile values for this period were <10Ug/L and even the maximum recorded value (152 µg/L) was below the lethal threshold. The exclusion of ammonia toxicity from the TFRM therefore remains valid.

An independent expert review of the FARL fisheries study by Prof. Mike Elliott of Hull University provided strong support for the technical approaches adopted and interpretation of the results but suggested a need to take account of emerging WFD requirements. A detailed assessment in the present report takes account of new WFD water quality standards (see below) but concludes that WFD Ecological Status metrics for transitional water fish cannot readily be applied a priori to assess the outcome of improvements in water quality. The TFRM appears to remain the most suitable framework for this purpose.

Further Implications of the Water Framework Directive

At the time of reporting the fisheries study to TTSG in 2004, the implementation of the WFD was in its early stages and the implications were not fully known. Surface water quality standards have now been drawn up by UKTAG, the UK's WFD Technical Advisory Group. It has therefore been necessary to consider whether the proposed TTSS DO standards are sufficiently protective in light of WFD standards. A comparison of the WFD standards versus TTSS DO standards show that, while expressed in slightly different terms, the two sets of standards sit together harmoniously (Table E1). However, it is not possible to say that one set of standards is more protective than the other: it will vary from case to case, depending on the shape of the frequency distribution of DO.

Table E1 ***WFD Standards (pink shaded rows) and TTSS Dissolved Oxygen standards Compared***

Dissolved Oxygen (mgL^{-1})	Return Period (years)	Duration (no. of 6 h tides)
4[M]-5[FW]*	1	73 (as 5th %ile)
4	1	29
3	3	3
2	5	1
1.6[M]-2.0[FW] *	6	1
1.5	10	1

* WFD standards vary with salinity from marine [M] to freshwater [FW].

Using the QUEST model, WRc examined various improvement scenarios (AMP4 and tunnel solutions) and showed that the Tideway would fail WFD DO standards 5th percentile standards for 'good' status in the middle reaches, even with the solutions in place. Where the cost of achieving of Good Ecological Status or Potential is disproportionately greater than the benefit, according to EC rules the timescale may be extended into the 2020s (2027 at latest). The likelihood of not meeting WFD DO standards over this time period should not harm Tideway ecology, as outputs from the Tideway Fish Risk Model predicts that the full tunnel (Solution A) will result in lethality risk well within sustainable limits. In fact, since they have been forged empirically from Tideway water quality and fisheries data, whereas WFD standards are 'one-size-fits-all' for the whole of the UK, it may be concluded that the TTSS DO standards are a more reliable standard set for the Tideway than WFD.

Presently, the Tideway is classified by the Environment Agency under WFD terminology as a Heavily Modified water body having Moderate ecological potential. Artificial and Heavily Modified Waters (A/HMWs) are expected to achieve Good Ecological Potential (GEP) rather than Good Ecological Status. For an A/HMW, GEP is reached by having appropriate environmental mitigations in place.

External Challenges

Following publication of the Thames Tideway Strategic Study in 2004, Ofwat commissioned Jacobs Babtie to undertake an independent study to consider whether a cheaper engineering solution could be found that would deliver most of the benefits for a fraction of the cost. An area that the Jacobs Babtie report focused on was the large measure of improvement that the WRc's QUEST water quality model predicted would occur as a result of AMP4 sewage treatment work (STW) upgrades without a tunnel solution. It was also proposed that allowable water quality (dissolved oxygen) standards might be set at a less protective level if the ecological criterion were to be changed from "*no visible fishkills*" to "*maintaining sustainable fish populations*". This recognised that a degree of fishkill is sustainable (though not necessarily acceptable to the public).

CCWater, in their consultation paper, pursued this line and concluded that sustainability with or without the tunnel solution was "finely balanced" and therefore concluded that the tunnel solution might not deliver the required improvements identified by TTSG.

Subsequent reruns of the QUEST model for AMP4 STW upgrades carried out after the TTSG and Jacobs Babtie reports have produced markedly different outcomes. The revised assessments, which take account of refined water quality data updated fish survey data used within the Tideway Fish Risk Model, indicate relatively high numbers of 'not sustainable' cases and no longer suggest that the AMP4 STW upgrades alone would ensure sustainable fish populations in the Tideway. The benefits of the tunnel solutions versus AMP4 alone therefore now stand out much more clearly than before.

Conclusions

- The findings of the TTSG fisheries studies and the Tideway Fish Risk Model have been peer-reviewed and remain fit-for-purpose.
- Concentrations of unionised ammonia are well below acutely toxic levels for salmonids and present no risk of fishkill at levels recorded over the last 33 years.
- The TTSS DO standards are regarded by the EA as appropriate design standards for the Thames Tunnel. They have been empirically derived using lethal and sublethal response data from local fisheries and tested against historical and predicted water quality data. They are in reality likely to be more appropriate than 'one-size-fits-all' standards to address the issue of combined sewer overflows.
- WRc QUEST water quality modelling indicates that, even with the full tunnel (Solution A), middle sections of the Tideway will breach WFD DO standards. In spite of this, the TFRM runs using the latest available QUEST outputs indicate that implementation of Solution A would meet sustainability criteria for all fish species. Challenges from Ofwat (Jacobs Babtie) and CCWater implying marginal ecological benefits of Solution A would need to be reconsidered in the light of this newer information.
- As additional analysis was undertaken within the scope of the present report, no immediate need for further work was identified.

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1 Introduction

1.1 Background

The 'Thames Tideway' refers to the estuarine part of the River Thames, stretching from Teddington Lock in the west (the upstream tidal limit) to the open sea in the east. It is the most heavily urbanised waterway in Britain and has been the subject of numerous studies relating to its water quality and ecological status (e.g. Alabaster and Lloyd, 1982; Attrill, 1998; Attrill and Power, 2000a,b).

The Thames Tideway Strategy Group (TTSG) was established as a coalition of interests in the Tideway, including the Environment Agency (EA, Thames Region), Greater London Authority, Ofwat, DEFRA and Thames Water. Its main remit was to examine potential solutions to water pollution problems in the Tideway associated with combined sewer overflows (CSOs). Some 72 of these remain as a legacy of the Victorian sewerage system that serves London, providing relief at times when the trunk sewers become overloaded. Overloading occurs after periods of heavy rainfall, when surface drainage entering the trunk sewers mixes with raw sewage and excess is discharged to the Tideway. When this occurs during the warmer summer months, dissolved oxygen (DO) is rapidly stripped from the water column, occasionally resulting in mass fish mortalities; as the Tideway is subject to tidal excursions of ~13 km, resulting fish kills can cover very large areas, other aspects of Tideway ecology also being affected. Other non-ecological drivers considered by the TTSG included aesthetic impacts of visible sewage-derived solids entering via CSOs, and potential human-health effects, especially associated with water contact sports.

The TTSG Final Reports[1] considered a number of proposed engineering solutions to the CSO problem. Essentially these involve interception of the excess flows, and either temporary retention in storage vessels until sewer capacity becomes available, or transmission via one or more new pipelines for processing at Beckton sewage treatment works (STW), or combinations of these. The TTSG's final recommended solution is a single, long collector tunnel conveying all the waste to Becton STW, known as 'Solution A'.

Part of the process that informed the decision of the TTSG was an investigation of the water quality needs of fish populations in the Tideway, carried out by Fawley Aquatic Research Ltd between 2001 and 2003 (Turnpenny *et al.*, 2004). The Fawley study sought in particular to establish the DO requirements of several key 'indicator' species that are important to Tideway ecology. The work involved laboratory and riverbank 'ecotox' trials, the results of which were then entered into a new Tideway Fish Risk Model (TFRM), developed to assess the modelled water quality outcomes of various TTSG engineering solutions. The TFRM was designed to demonstrate whether Tideway fish populations would be sustainable under the various proposed solutions.

The present report was commissioned to review primarily two aspects of the fisheries work that need to be considered prior to the next stages of the project. First, the Tideway Tunnel is a major infrastructure project and, as such, is subject to public and political scrutiny. A key challenge is as to whether or not the full single

[1] http://www.thameswater.co.uk/cps/rde/xbcr/corp/ttss-background-supplementary-report-summary.pdf (accessed 23.10.09)

tunnel solution proposed is necessary to meet the three key objectives of ecological sustainability, aesthetic acceptability and public health and safety, or whether partial solutions might meet the required criteria at lower cost. This aspect has been considered by the Water Regulator, Ofwat (2006) and the Consumer Council for Water[2] (CCWater, 2009), both of which bodies represent consumer interests, and merits further examination.

Secondly, the period between the completion of the Fawley report in January 2004 and today, though relatively short, has seen major changes in environmental regulation of water bodies, mainly as a result of the European Water Framework Directive, which has for example led to the development of new draft dissolved oxygen standards. It is therefore now necessary to assess what effect, if any, regulatory changes may have had on TTSG's conclusions and recommendations with respect to fisheries.

It is also timely to consider whether any new information might influence conclusions, and whether all the assumption can still be considered valid. For example, assessments undertaken for the Tideway AMP4 STW upgrades after the 2004 Fawley report resulted in the TFRM being updated.

1.2 Terms of Reference

The following objectives were defined for the study:

- to identify the outputs from the fish studies that are most influential in determining/supporting the need for a tunnel solution of the scale and type currently being promoted
- to identify the underlying assumptions that have the most significant effect on the outputs from the study
- to make recommendations on additional work that could be carried out to defend the critical assumptions or investigate the sensitivity to weaknesses in these assumptions.

The agreed approach was as follows:

1. Review final reports from the work of the Thames Tideway Strategy Study and other reports relating to the final tunnel decision, and identify critical outputs.
2. Review reports and comments from other bodies (e.g. CCW) to identify where areas of potential challenge to the ecological standards may arise.
3. Review the detailed fish study reports to identify and clarify the key underlying assumptions.
4. Review work undertaken since 2006 to update the TTSS, and in particular the developments of Option 1c (single tunnel from Abbey Mills to Beckton STW) and updated sewage hydraulic modelling, in so far as their effect on the water quality standards.

[2] CCWater is a watchdog representing water and sewerage consumers in England and Wales.

2 Review of Reports Relating To Tunnel Decision

2.1 Fawley Fisheries Report: (1) Lethality Studies

2.1.1 Introduction

The Fawley study (Turnpenny *et al.*, 2004) was undertaken to acquire scientific data about the tolerances of estuarine fish species and life stages to low dissolved oxygen (DO) concentrations. Previous estuarine quality standards had been based on poor information, much of it relating to freshwater fish or to estuarine species not found in Britain. An initial literature review revealed very few data pertinent to Tideway fish and therefore TTSG commissioned an experimental study.

2.1.2 Scope of Studies

Following the initial literature review, the Project had three main strands of practical work:

- laboratory measurement of the acute lethality of low DO to various estuarine life-stages of selected fish ‘indicator’ species;
- continuous on-line field exposure of captive (tank-held) fish to Tideway water over the summer months, in the expectation of them experiencing one or more ‘live’ CSO-related hypoxia events;
- laboratory investigations of sublethal effects of hypoxia; particularly in relation to the potential avoidance of areas of hypoxic water, but also possible effects on fish growth.

The laboratory lethality work was carried out at two locations: Fawley Aquatic Research Laboratories (Fawley, Southampton), where lethality testing was carried out under controlled, constant temperature conditions using a mixture of bore-hole water and clean sea water. Parallel field studies were carried out at a temporary laboratory on the upper Tideway at Chiswick Pier, where tests were conducted in raw Thames water, but without the benefit of temperature control. Chiswick Pier was also intended as a location for monitoring the effects of live CSO events on fish. The experimental work was carried out over two successive summers; the majority of the experiments were completed in 2002, with supplementary laboratory testing and a continuation of live CSO testing in 2003.

The final stage of the Project was to review the findings of the experimental studies, within the context of the literature on hypoxia and fish, and to review them in relation to proposed DO standards for the Tideway. This included the development of a simple Tideway Fish Risk Model to calculate the likely exposure risk to hypoxia, given the seasonal and spatial distributions of different fish lifestages.

2.1.3 Objectives Met/Not Met

(a) Species and Lifestages Tested

Around 120 fish species have been recorded in the Thames Tideway. Although many of these are only occasional visitors, there are nonetheless are large number that are regularly found. Clearly, it would have been impracticable to measure the hypoxia tolerances of all these species and a subset of ‘indicator’ species had to be selected for the laboratory work. A number of species were therefore identified by the Project Board as being most important to study and as offering the most suitable indicator species. It was also important that they should be readily available. A further factor was that they should be typically present during the higher-risk summer months when CSO-related hypoxic events are most likely to occur. The ones selected for study were:

Brown trout (*Salmo trutta*) – as a surrogate for Atlantic salmon (*S. salar*)

Smelt (*Osmerus eperlanus*)

Sand smelt (*Atherina presbyter*)

Flounder (*Platichthys flesus*)

Common goby (*Pomatoschistus microps*)

Dace (*Leuciscus leuciscus*)

Apart from the salmon, all of these species are known to spawn within the Thames Tideway. Salmon, a seasonal migrant through the Tideway, would have been difficult to obtain and to handle in the adult form for the proposed testing methods and was replaced by the smaller brown trout (*Salmo trutta*), which acted as a surrogate.

A further species, the bass (*Dicentrarchus labrax*), was added to the project at a later stage when it became apparent that some life stages of the above species might not become available for the project. Bass spawn offshore but are present in large concentrations in the Tideway as juveniles (0-group especially) during the summer months (Colclough *et al*, 2000, 2002).

Of the species above, most relevant lifestages were tested; however, it was not possible to test the following lifestages during the period of the study, owing to supply and handling issues:

- large adult salmonids, comparable in size with returning adult salmon or sea trout (e.g. >50 cm);
- early life stages of smelt and flounder.

(b) Field Validation of Laboratory Data

The ‘real-time’ fish exposure work undertaken at Chiswick Pier failed to meet its objectives, due to the lack of appropriate rainfall and temperature conditions during the project. The weather pattern during 2002-3 appears to have been unusual when compared with the recent preceding years.

While laboratory exposures provided objective testing, it was not possible to compare results against ‘real-time’ conditions to establish their validity in standards setting with respect to acute CSO episodes. The main implication of this is that laboratory exposures applied a constant DO level throughout the test period (in effect a square wave form), whereas in the river, the DO time-history would rise and fall in a more complex fashion. This creates a potential source of inaccuracy in the TFRM analysis, the significance of which is unknown. Given the problems encountered in attempting assess this effect ‘live’ on the Tideway, a more productive approach in any future studies would be to reproduce live events as monitored by the AQMS system under laboratory simulation.

2.1.4 Influence on Tideway EQS for DO

The purpose of the Fawley study was to provide scientific information on which to base future standards for the Tideway. Table 1 shows the Interim Standards that TTSG had developed prior to the Fawley study:

Table 2-1 Interim DO Standards of the Thames Tideway Strategy Group (Environment Agency)

Dissolved Oxygen (mgL^{-1})	Return Period (years)	Duration (no. of 6 h tides)
4	1	29
3	3	3
2	5	1
Minimum DO: 1.0 mg L^{-1}		
Note: the objectives apply to any continuous length of river ≥3 km. Duration means that the DO must not fall below the limit for the stated number of tides. A tide is a single ebb or flood. Compliance will be assessed using the network of AQMS stations.		

The basis of the Interim Standards was as follows:

- The one week standard (4 mg L^{-1}, 1 yr RP, >29 tides) was selected to ensure protection against chronic effects; these would include e.g. effects such as depression of growth and avoidance of hypoxic areas.
- The 24 h standard (3 mg L^{-1}, 3 yr RP, >3 tides) & 6 h standard (2 mg L^{-1}, 5 yr RP, >1 tide) were selected to provide protection to stocks by managing the scale and frequency of mortalities. It was accepted that greater mortality would occur with the more severe of the two standards, but intended that for both standards, fish loss would be fairly limited.
- The minimum (1 mg L^{-1}) was included to ensure protection from mass mortalities.

Standards that use allowable return periods in this way are termed Fundamental Intermittent Standards (FIS) (Best *et al*., 2007).

By applying the outputs from the laboratory in conjunction with the Tideway Fish Risk Model, which takes account of spatial and temporal distributions of exposure risk, it could be seen where shortcomings might exist in the Interim DO Standards. For most of the indicator species/lifestages, the Interim Standards appeared satisfactory, other than the 1 mg DO L^{-1} Minimum Standard, which was considered too low to be protective; raising this level to 1.5 mg l^{-1} was therefore recommended, applied with a return frequency of one tide in 10 years, rather than as the absolute standard originally proposed. The revised Tideway EQS for DO was therefore revised as follows Table 2-2:

Table 2-2 Revised DO standards on the Thames Tideway Strategy Group (Environment Agency)

Dissolved Oxygen (mgL^{-1})	Return Period (years)	Duration (no. of 6 h tides)
4	1	29
3	3	3
2	5	1
1.5	10	1
Note: the objectives apply to any continuous length of river ≥3 km. Duration means that the DO must not fall below the limit for the stated number of tides. A tide is a single ebb or flood. Compliance will be assessed using the network of AQMS stations.		

2.1.5 Effect of Altering FIS Frequencies and Return Periods

Selection of FIS frequencies and return periods is somewhat subjective and it is of interest to consider what the effect of changing these would be.

Frequencies are specified in these standards by establishing the maximum number of tides (6-h periods) when the DO level is allowed to fall below the nominated value within the set period of time (1, 3, 5 or 10 yrs for the 1.5, 2, 3 & 4 mgl^{-1} standards respectively).

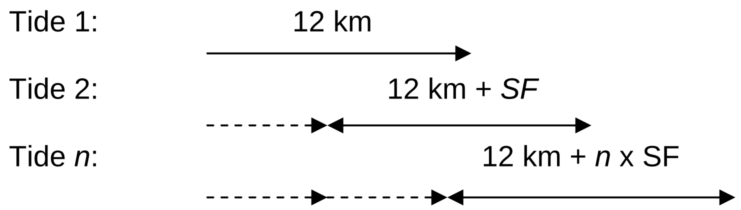
(a) Single Events

If we consider a single CSO event, increasing the duration of the event could have two main effects:

- increasing the hypoxic exposure duration of individual fish within the affected area;
- increasing the length of Tideway affected, and hence the proportion of the population.

The Fawley laboratory studies demonstrated that most fish are affected within the first 6-h and that after 24-h exposure, fish will either have died or will continue to survive indefinitely. Thus increasing the allowable duration of one event from 6-h to 24-h could increase risk of fish deaths but the risk would not increase further with longer exposure periods.

The length of Tideway affected will, however, be increased by extending the number of tides failing the standard. If we assume a nominal 12 km tidal excursion for the Tideway, a single breach event maintained for 6-h would be expected to affect a 12 km length of Tideway. With each subsequent tide, the area affected will be extended downstream according to the rate of residual seaward flow (*SF* -which will depend on fluvial input as well as other hydrographic factors), in this manner:



The area affected will thus depend on flow conditions at the time.

It could, of course, happen by chance that the whole of the population of a particular species/lifestage were present within the area swept by first tidal excursion, in which case, further spread would not make any difference.

(b) Multiple Events

If we assume that any additional tides allowed within an FIS standard occurred as separate events, the outcome could be quite different. Within a single event, it can be assumed that hypoxia would take out the most sensitive individual fish and that extending their exposure beyond 24-h would make no difference. Where lethal events are spaced out in time, e.g. by months or even years, the individuals making up the affected (sub-)population cannot be expected to be the same, owing to immigration-emigration, growth, etc, and in the worst case must be assumed to be statistically independent of those exposed in prior events. In this case, the impact on the population will increase proportionately with the number of breaches allowed.

(c) How this Applies to Tideway Standards

The effects can be considered for each of the standards in turn.

The one week standard (4 mg L^{-1}, 1 yr RP, >29 tides):

The laboratory data show no mortality at this level. Effects will be limited to sublethal ones, such as avoidance of affected areas and perhaps reduced growth and productivity or impaired disease resistance with protracted exposure.

Any increase in allowable frequency would be expected to have a pro-rata effect on these life functions.

24 h standard (3 mg L^{-1}, 3 yr RP, >3 tides):

Mortalities begin to become a risk at this level, affecting primarily the salmonids. As the suite of species tested are intended as surrogates for the full range of Tideway species, the possibility of other untested species being equally sensitive cannot be ruled out.

Assuming the worst case, of admitting separate, independent events by increasing allowable frequency, a pro-rata increase in mortality of salmonids and other sensitive species could be expected.

6 h standard (2 mg L^{-1}, 5 yr RP, >1 tide):

At this level, more species start to become at risk, exemplified by dace in the laboratory tests. Extending the allowable frequency could increase mortalities by extending exposure during a single or event, or more significantly where additional, independent events occurred. Assuming the latter, a pro-rata increase in mortality of salmonids and other sensitive species could be expected.

Lowest standard (1.5 mg L^{-1}, 10 yr RP, >1 tide):

This standard was devised to provide an effective minimum DO level; however, it was set as an FIS standard, recognising the need for a probabilistic approach. Any allowable increase in frequency at this level would be expected to incur increased mortality across most, if not all species and lifestages.

(d) Need for an Empirical Approach

It is seen from the preceding paragraphs that only broad generalisations can be about the likely effect of altering FIS standards on fish sustainability. A more robust approach is provided by the Tideway Fish Risk Model described below, which allows effects on sustainability to be examined for different FIS standards using complex water quality and fish population scenarios.

2.2 Fawley Fisheries Report: (2) Tideway Fish Risk Model

2.2.1 Purpose and Scope of Model

Hypoxia-related lethality rates estimated from experimental studies would not apply to the whole Tideway following a CSO event, as only certain areas are heavily affected. The Tideway Fish Risk Model (TFRM) is based on the premise that risk of hypoxic conditions within the Tideway is not randomly distributed with respect to either time or position along the Tideway. Hypoxia is predominantly a summer phenomenon, building up over the spring months and dying away in autumn. Differences along the length of the Tideway relate to the positions of the major inputs and Tideway hydraulics. Overlaid upon the temporal and spatial patterns of hypoxia are variations in the temporal and spatial distributions of fish lifestages. For example, some potentially sensitive fry stages might only be present in spring, before the risk of hypoxia occurs, or may be in a low-risk area of the river. Risk of fish exposure to hypoxia is calculated within the model by juxtaposing these spatial and temporal probability distributions to calculate the overall probability that fish of any given species and lifestage will experience exposure. It divides the Tideway into discrete 3km zones as used by the Environment Agency (EA) For the different water quality scenarios, the risk of fish mortalities by lifestage and zone is calculated, allowing the total annual mortality due to hypoxia (low DO) to be estimated.

2.2.2 Status of Data Sets

(a) Water Quality

Thames Water, in conjunction with the EA has used and developed a water quality model (WQM) which predicts effects on the Tideway of natural processes including climate change, CSO discharges and STW discharges. Based on automated quality monitoring system (AQMS) data collected over many years, it maps the frequency and degree of hypoxia events for each of the 3 km zones and identifies lapses in water quality as breaches of the TTSS DO standards (as indicated by thresholds shown in section 2.1.4. The WQM has been run for historical data sets to describe the baseline condition, for AMP4 STW improvement scenarios and for various Tunnel scenarios. The WQM data are fed into the TFRM to provide an objective basis for comparing baseline, 'with development' and 'without development' conditions for fish. The water quality database for WQM was updated subsequently for the Lee Tunnel and Beckton STW Extension project to include data for the River Lee (Scott-Wilson, 2008).

(b) Fish Distribution

Fish distribution data used by Turnpenny *et al*. (2004) for the TFRM were taken from EA multi-method seasonal (usually biannual) surveys conducted between 1994 - 2002 and provide the best available information for this purpose. The TFRM fish database was updated subsequently by Jacobs for the Lee Tunnel and Beckton STW Extension project (Scott-Wilson, 2008) to include data up to 2005.

2.2.3 Assumptions and their Validity

(a) Other Lethal Factors Associated with CSOs: Ammonia

Apart from hypoxic risk, other potentially toxic conditions left by CSO discharges merit consideration. CSO discharges invariably contain ammonia, the unionised form of which (known as 'free ammonia') is potentially toxic to fish. Ammonia toxicity was ignored in the TFRM as ammonia does not reach levels which are toxic to fish in the Tideway. The TFRM considered hypoxic effects acting alone.

It is also worth noting that the nitrification of ammonia consumes oxygen and that high ammonia levels will also therefore contribute to oxygen depletion. This aspect is however implicit in the Tideway water quality modelling and need not be considered further.

The question of ammonia toxicity was examined as part of a scoping report prepared by Fawley Aquatic Research prior to the experimental programme (Turnpenny, 2002). The report presented data for a number of storm events (Table 2) and stated:

Table 2 Recorded concentrations of unionised ammonia in CSOs and in the main river during storm events (source: EA, Crossness) (Turnpenny, 2002).

Site	Date	Unionised NH_3 μgl^{-1} Mean (min-max)
Ranelagh	5th July 2001	73 (60-90)
Acton Storm Tanks	7th October 2001	12 (5-10)
Hammersmith Pumping Station	7th October 2001	43 (10-110)
Western Pumping Station	17th July 2001 7th October 2001	51 (36-88) 41 (7-100)
River Thames, Zones 3-9	17th July 2001	20 (11-25)

"I*n defining ammonia criteria for freshwater, EIFAC report the lowest acutely lethal concentration of NH3 (unionised) for salmonids to be 200 μgl^{-1} (Alabaster and Lloyd, 1982). For coarse fish, lethal thresholds were rather higher than this. The recommended NH3 limit for salmonid waters is 25 μgl^{-1} but this is based on chronic exposure effects on growth and other sub-lethal responses and is therefore less relevant to consideration of acute CSO effects. The toxicity of ammonia can be increased by low DO, but this effect might be offset by any increase in free carbon dioxide concentration generated through aerobic metabolism. Salinity of around 10 ppt decreases NH3 toxicity compared with that in freshwater, the toxicity rising again towards full strength seawater*."

Concluding that:

"*while NH_3 concentrations in storm discharges may exceed the EIFAC 25 µgl^{-1} criterion, they did not reach acutely toxic levels, while in the river measurements for the event of 17th July 2001, they remained at or below the EIFAC criterion. There does not appear to be an ammonia toxicity issue per se with CSOs therefore, although its presence may be expected to have a slight effect on fish survival near to critical DO levels*."

Discussion with EA marine water quality technical specialist, Dr Andrew Wither, indicated that there are now more refined calculations for determining from total ammonia the unionised fraction, taking account of salinity, pH and water temperature. A copy of the EA's spreadsheet "NH3-sea.xls" was made available and calculations were performed for a Tideway data set supplied by EA Thames Region (Lars Akesson, pers. comm., email dated 16th June 2009). The data were for samples collected from the Tideway Northern Outfall at Beckton (NGR TQ45250812500) between January 1976 and April 2009, from which there were 1271 complete observations from spot samples analysed for total ammonia, pH and temperature. As there were no associated salinity values, calculations were made for fixed salinities of 1, 15 and 30 unit to bracket possible values at Beckton. The following table (Table 2-3) provides summary statistics:

Table 2-3 Statistics for unionised ammonia at Beckton, based on 1271 spot samples between January, 1976 and April 2009.

	Unionised Ammonia, ug/L		
Salinity	1	15	30
Mean	2.6	2.3	2.1
50%ile	1.3	1.1	1.0
95%ile	7.2	6.5	5.8
98%ile	11.3	10.4	9.5
Maximum	152	141	130

The TFRM is concerned with acute effects associated with short-term exposure to CSO events. It is seen from Table 2 that, using this calculation method for unionised ammonia, that even the 33-year maximum values fall well below the 200µg/L acute toxicity threshold for salmonids.

Conclusion: Ammonia

The exclusion of ammonia toxicity from the TFRM remains valid.

(b) Are Species & Lifestages Tested Suitable Indicators?

It became clear from the outcome of the Fawley trials that the species selected encompassed a wide range of hypoxia sensitivities (Figure 2-1), with the most sensitive (salmonid) species showing sensitivity at >3 mg DO L^{-1}, while others covered a progressive range down to <1 mg DO L^{-1}.

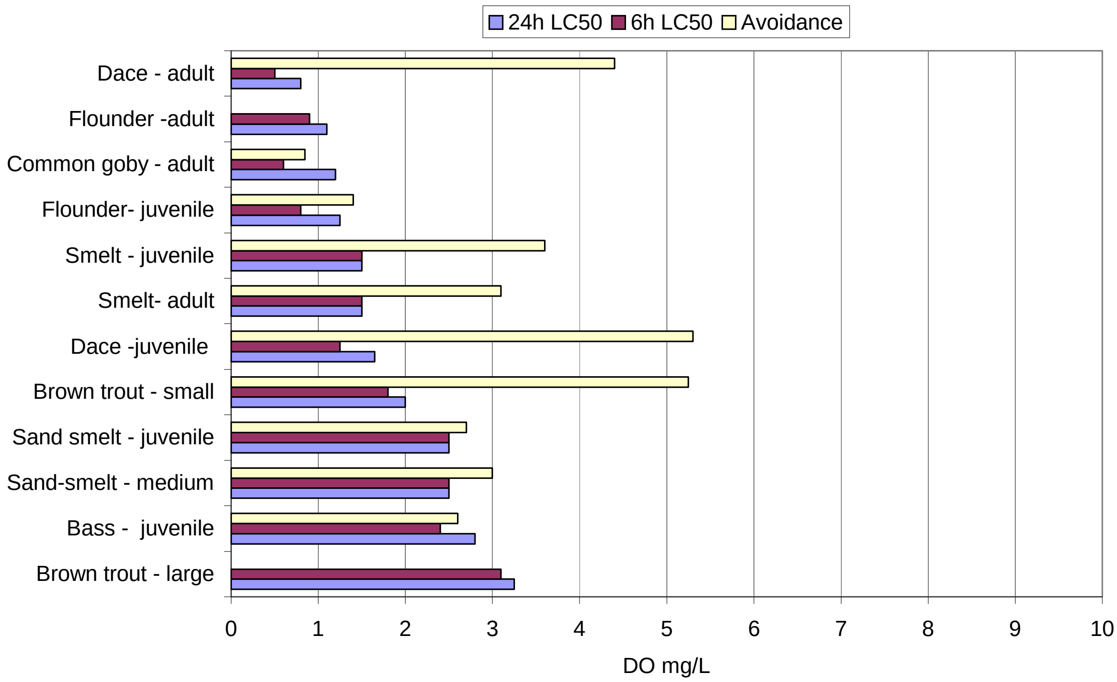


Figure 2-1 Median acute lethality and hypoxia avoidance thresholds for the seven test fish species and lifestages (Turnpenny **et al*****, 2004).***

At the end of the Fawley trials, Turnpenny *et al. (*2004) concluded the following in respect of species coverage:

"The seven species investigated in this study are still considered to provide suitable indicator species for standards setting. In future, it may be necessary to extend the list to include other species of conservation interest, including the river and sea lampreys and the Twaite and Allis shads.

"Adult salmon have yet to be tested. To do this it would be necessary to agree a suitable source of stock and to establish larger test facilities. Another gap concerns early smelt fry. Although juvenile smelt were tested in the present study, it is hypothesized that the newly hatched fry may be the critical stage with respect to hypoxia…….. Similarly, further work on the earliest stages of flounder fry is merited."

These comments may require some qualification. First, while the Habitats Directive Annex 2 species such as shad and lampreys have been observed more frequently in recent years, and are of considerable conservation interest, they are insufficiently common at this time in the Tideway to have any effect on the outcome of the TFRM, were they to be included. Consideration of these species might, however, be appropriate in the context of WFD (see section 3.5.3 below).

Secondly, while adult salmon have not been tested, the virtual absence of a Thames adult salmon run in the last few years reduces the significance of this omission. With predicted continuing background temperature rises associated with climate change, it is not clear that there is any real chance of salmon runs improving in the future, although the STW upgrades may improve the situation. With regard to sea trout, the data for larger brown trout should be quite adequate as an indicator.

Smelt, which are known from elsewhere to be sensitive to hypoxia (Vinni *et al.*, 2004), were shown in laboratory trials to be only moderately sensitive: less sensitive, for example, than trout or sand-smelt (Figure 2-1). However, early lifestages from hatching to ~3 months were not available for testing and may be the “weak link” and testing of this stage remains an important priority.

Conclusion: Species and Lifestages

The species and lifestages thereof already tested are generally adequate for the purpose of the Tideway Fish Risk Model and its application to scenario testing, but there remains a need to test hypoxia tolerance of early lifestages of smelt..

(c) Are Sustainability Criteria Appropriate?

There are two questions to consider here:

i. Are the annual mortality rate criteria used likely to be a reliable indicator of sustainability?
ii. Is a mortality-based criterion appropriate under new WFD protocols or should status changes be described purely in terms of WFD classification (normative definitions) ?

(i) Mortality Rate Criteria

The Fawley report set 10% as the base figure for a sustainable annual mortality rate. ‘Base’ figure in this case means that any fish species not subject to fishing mortality should be sustainable at this level of annual mortality. It was argued that commercial fishery exploitation rates can be sustainable at >50%, depending on the population dynamics. Some longer-lived species, in which not all age-classes are present in the Tideway at any one time would, for example, be more likely to survive a major pollution event than a short-lived species that never leaves the Tideway.

How sound is this reasoning, and are the numbers right? The principles here are unlikely to be challenged but the numbers might be open to argument. The key weakness here is that it assumes that the populations are in a natural state and are not already subject to anthropogenic mortality.

The standard fisheries approach to population dynamics considers that a population is subject to an instantaneous **total mortality rate**, *Z*, which comprises **natural mortality**, *M*, and **fishing mortality**, *F*:

$$Z = M + F.$$

In a wider, industrialised context, fishing mortality, *F*, can be taken to include a variety of anthropogenic impacts, including e.g. losses due to pollution, entrainment into water intakes, as well as fishing. In fact, of the fish species considered in the TFRM, (salmon, smelt, sand smelt, flounder, common goby, dace and bass), only salmon and flounder (possibly bass, but mainly present as juveniles) are likely to be commercially caught in the Tideway and pollution and entrainment are likely to be the main components of *F*.

Conclusion: Mortality Rate Criteria

At present, mortality due to other forms of pollution and entrainment are not known. By far the most significant source is likely to be mortality due to hypoxia, which is the object of the TFRM, and therefore no correction needs to be made for this. Entrainment losses to power stations, desalination plant may be significant but it would be necessary to show that these, and any other pollutant-related mortality pushed the Value of *F* above 10%, or the higher figures adopted for some longer-lived species. The key weakness here is that existing mortality rates are not known.

(ii) WFD Classification

The Water Framework Directive classifies surface waters according to their ecological status or potential and for any future developments that might affect a water body, it will be necessary to assess possible changes in classification. This is discussed further in Section 3.5.

2.2.4 Fawley Fisheries Report: Peer Review

In September 2003, the draft Fawley report was peer reviewed by Prof. Mike Elliott of Hull University. The full review is attached as Appendix 1. The final report was issued in April 2004 and incorporated some of the suggestions that were considered to be within the scope of the initial brief. The review was strongly supportive of the approach, the experimental methods, and, in particular, the development of the Tideway Fish Risk Model as a tool for applying the experimental information, stating "*perhaps should be regarded as the best available approach based on presently available data*." It went on to say: " *The use of this is the most valuable part of the report in providing data on which to base the setting of water quality standards and, by extension, of discussing and provisionally giving those standards*."

Prof. Elliott felt that the report should have discussed the findings more in the context of emerging WFD requirements. This was considered to be outside the scope of the original brief but is addressed below in the present review, now that the implications have become more clear.

3 Material Produced Since 2006

3.1 Jacobs Babtie Report to Ofwat (2006)

Following the publication of the Thames Tideway Strategic Study (TTSS) in 2005, which recommended the full Tideway tunnel solution, the Office of the Director General of Water Services (Ofwat) commissioned a study by independent experts, Jacobs Babtie (2006) (now Jacobs Engineering), to review the assumptions and objectives of the TTSS. The study had the specific aim of considering whether a large part of the benefit of the TTSS could be achieved for a significantly reduced capital investment, thus reducing the impact on future water charges to pay for the scheme. The one relevant here is ecology. While the term 'ecology' embraces all aspects of biological life in the Tideway, in this context the term can be reduced to 'fish ecology', as fish were taken as indicators for general ecology. The key findings on fish are summarised in the following extract from the Executive Summary:

"Dissolved oxygen (DO) levels in the Tideway were modelled as part of the TTSS, for a representative range of storm events and solution options were assessed as compliant when the reference DO level was maintained through out the length of the Tideway. The view of our fisheries specialist [Andy Turnpenny] *is that the reference standards are designed to prevent fish kills and are set higher than those that might be required to maintain a 'sustainable' fish population. Furthermore it is likely that some larger fish will migrate away from areas where DO levels are too low and may seek 'refuge' in pockets of better quality water such as harbours, where some hydraulic separation can often be found.*

"Analysis of the TTSS data indicates that the majority of the required ecological improvements will derive from the planned AMP4/AMP5 works. Before committing large capital investment to CSO improvement works to achieve relatively incremental improvements in DO levels over those likely to result from the AMP4/AMP5 works, re-analysis of the criteria and the cost benefit study would be prudent."

This can distilled down to three questions:

- Are the DO standards too stringent?
- Should the ability of some fish, as demonstrated by the Fawley work, to avoid hypoxia, by e.g. migrating into better oxygenated areas be taken into account? This would require that they could also swim fast enough to outrun the strong tidal movements in the Tideway.
- Will the AMP4/5 improvements to sewage treatment works (STWs) reduce the risk to sustainability, thereby reducing the need to control CSO spills?

These points are considered briefly below. Some further clarification of the issues is given in written responses by the Thames Tideway Strategic Study (TTSS) Steering Group and Andy Turnpenny to queries raised by Defra and Ofwat, shown in full in Appendix B.

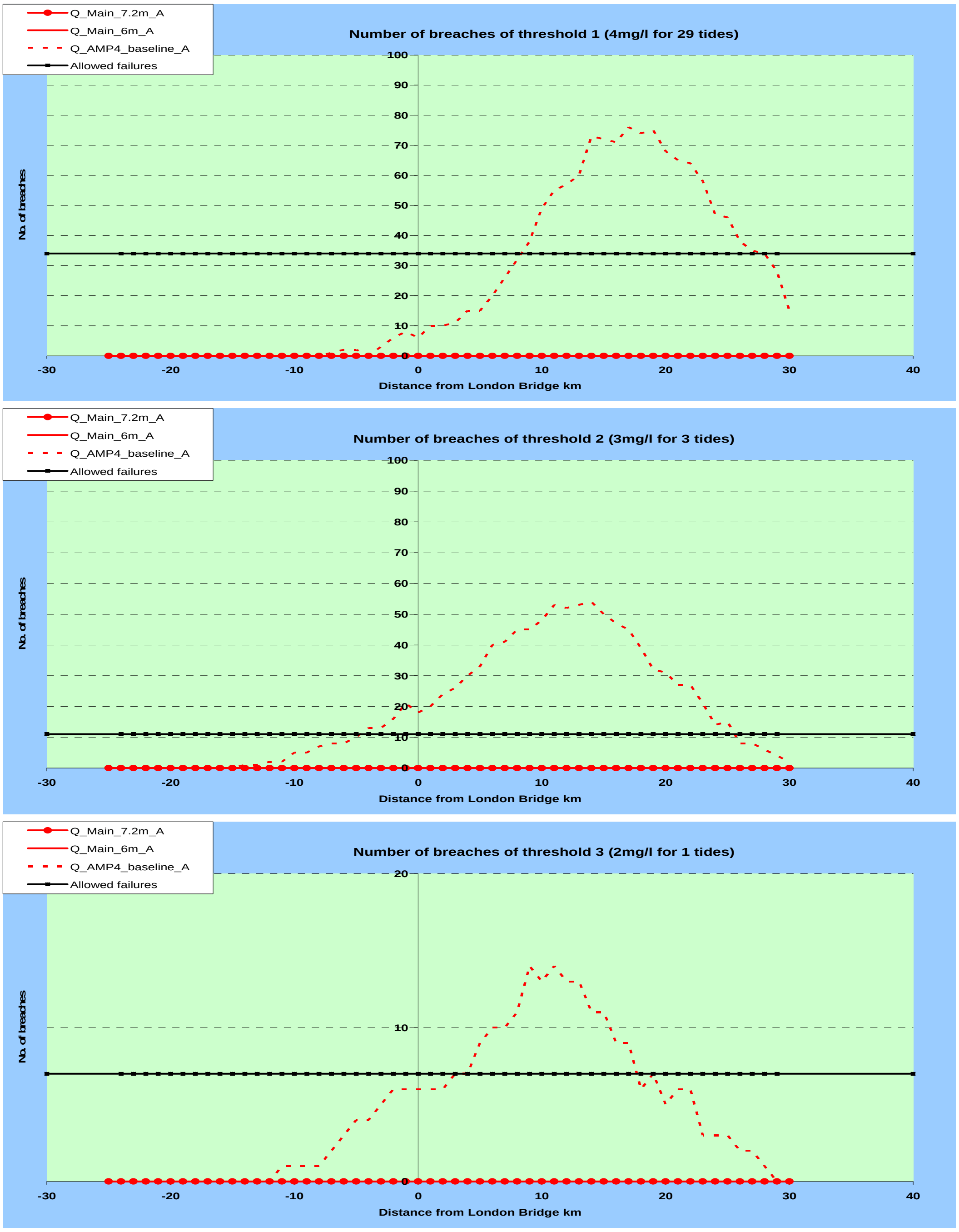
3.1.1 Are the DO Standards too Stringent?

This will be considered purely in relation to the TTSS objectives, rather than in the context of WFD standards, which are discussed in 3.5.4 below.

One of the questions considered by the Fawley study was "*Are the Interim Tideway standards for DO adequate?*" Bearing in mind that the Interim Standards were drawn up before the experimental study, it was appropriate to consider whether new ecotoxicological data revealed any shortcomings of the standards. After reviewing the laboratory data, it was concluded that the absolute minimum of 1 mg/l DO was insufficiently protective and that an FIS standard of 1.5 mg/l with an allowable breach of one tide in ten years was more suitable.

Figure 3-1 Compliance plot comparing 7.2m Main Tunnel A (Q_Main_7.2m_A) and 6.0m Main Tunnel A (Q_Main_6m_A) with AMP4 Baseline A (Q_AMP4 baseline_A)

Note: A refers to Crossness at 2.5 DWF (Dempsey* et al., *2007).



The question not considered by the Fawley study was "*Are the Interim Tideway standards for DO excessively stringent?*". The suggestion that the revised Tideway standards are *"set higher than those that might be required to maintain a 'sustainable' fish population*" stems from this. As the WRc's QUEST estuarine water quality model for the Tideway showed that the existing baseline conditions (referred to as 'Current Baseline') would generate a considerable number of breaches of the TTSS DO standards (Figure 3-1), one might be led to conclude that fish populations would not be sustainable. The purpose of the TFRM is, however, to put the significance of the QUEST predictions into a whole Tideway fisheries context. This showed (Table 3-1) that with the original Interim Standard values (including the 1 mg/l base standard), sustainability would not be achieved (as shown by the appearance of mortality values in red typeface). Using the revised 1.5 mg/l base standard, red figures were eliminated, indicating that the fish populations would be 'sustainable' (black typeface) or 'marginally sustainable' (blue typeface).The fact that this state is achieved with the large number of standards breaches associated with the Current Baseline can be taken to imply that Tideway fish populations should already be sustainable, which potentially undermines the case for improvements.

So, what would be the benefit to Tideway ecology of improving water quality so as to eliminate breaches of the TTSS DO standards? Under Current Baseline conditions, a number of limitations exist:

1. Populations of some species remain 'marginally sustainable'. This means that there is some scientific uncertainty about how much mortality these species could withstand.
2. Substantial periodic fishkills may occur without affecting sustainability, provided that they affect only a relatively small proportion of the Tideway habitat.
3. While fish mortalities may not be at unsustainable levels, fish are likely to be stressed by sub-optimal DO conditions, with possible adverse consequences for growth and reproduction (see Turnpenny *et al.*,2004, section 2, for review of sublethal effects of hypoxia).
4. Current predictions are that, without intervention, the frequency of CSO events is likely to increase in the future.

QUEST WQ model runs for the Tunnel project indicate that TTSS DO standards breaches can be eliminated with the full tunnel solution (Figure 3-1). This would remove issues associated with scientific uncertainty on sustainability and eliminate the kind of mass CSO-related fish kills that have occurred in recent years.

Table 3-1 Expected fish mortalities at the Interim Standard levels of 1.0 2.0, 3.0 and 4.0 mg DO l^{-1}, and 1.5 mg l^{-1} replacement standard based on Tideway Fish Risk Model (Turnpenny et al., *2004)*

Note:. Blue figures indicate >10% annual mortality due to hypoxia and possible marginal sustainability. Black figures indicate likely sustainability; red figures: not sustainable. PL Effect-=Population Level Effect.

CURRENT BASELINE															
Species	Lifestage	Effect of Proposed Standard on Predicted Fish Mortality													
		1.0 mg L^{-1}	1.5 mg L^{-1} (6h in 10y)	2.0 mg L^{-1} (6h in 5y)			3.0 mg L^{-1} (18h in 3y)			4.0 mg L^{-1} (1 wk per y)			No. of >10% PL Effect @1.0mgL^{-1}	No. of >10% PL Effect @1.5mgL^{-1}
				Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**		
Salmon	Smolt	**100%**	**100%**	100%	0.13	**13.1%**	10%	0.18	**1.8%**	10%	0.19	**1.9%**	5	5
	Adult	**100%**	**100%**	100%	0.29	**29.1%**	90%	0.52	**46.6%**	10%	0.40	**4.0%**		
Bass	Young Fry	**10%**	**10%**	10%	0.00	**0.0%**	10%	0.00	**0.0%**	10%	0.00	**0.0%**	0	0
	Juvenile	**10%**	**10%**	10%	0.25	**2.5%**	10%	0.41	**4.1%**	10%	0.30	**3.0%**		
Sand smelt	Egg/fry				0.05			0.07			0.00		2	0
	Juvenile	**50%**	**10%**	10%	0.29	**2.9%**	10%	0.52	**5.2%**	10%	0.57	**5.7%**		
	Adult	**75%**	**10%**	10%	0.33	**3.3%**	10%	0.58	**5.8%**	10%	0.85	**8.5%**		
Dace	Egg/fry	**100%**	**100%**	85%	0.01	**0.7%**	10%	0.03	**0.3%**	10%	0.07	**0.7%**	3	2
	Juvenile	**50%**	**30%**	10%	0.53	**5.3%**	10%	0.29	**2.9%**	10%	0.11	**1.1%**		
	Adult	**50%**	**10%**	10%	0.53	**5.3%**	10%	0.29	**2.9%**	10%	0.11	**1.1%**		
Smelt	Egg/fry				0.04			0.01			0.00		3	3
	Juvenile	**100%**	**40%**	40%	0.26	**10.3%**	10%	0.64	**6.4%**	10%	0.57	**5.7%**		
	Adult	**100%**	**40%**	40%	0.24	**9.7%**	10%	0.85	**8.5%**	10%	0.85	**8.5%**		
Flounder	Egg/fry				0.00			0.00			0.00		2	2
	Juvenile	**50%**	**50%**	15%	0.33	**5.0%**	10%	0.58	**5.8%**	10%	0.46	**4.6%**		
	Adult	**50%**	**40%**	15%	0.25	**3.8%**	10%	0.83	**8.3%**	10%	0.83	**8.3%**		
Common goby	Egg/fry			0%	0.00	**0.0%**	0%	0.00	**0.0%**	0%	0.00	**0.0%**	2	2
	Juvenile	**50%**	**40%**	10%	0.28	**2.8%**	10%	0.51	**5.1%**	10%	0.39	**3.9%**		
	Adult	**50%**	**40%**	10%	0.02	**0.2%**	10%	0.03	**0.3%**	10%	0.03	**0.3%**		
										Total PL Effects occurrences >10%			**17**	**14**
										Total PL Effects 'not sustainable'			**4**	**0**

3.1.2 Potential for Fish Avoidance of Hypoxia

The Fawley study was able to demonstrate the tendency of some fish species to avoid potentially lethal levels of hypoxia (Figure 2-1).It was also reported that, following the August 2004 fishkill/hypoxia event, unusually high densities of fish were found below Beckton, suggesting the possibility of mass downstream movements of fish to avoid hypoxia.

At present, the reality of avoidance behaviour as a protection against hypoxia remains speculative. There are a number of important considerations:

- The Fawley study showed that not all fish demonstrate this protective behaviour.
- Relatively few hydraulically isolated offline waters exist on the Tideway that might offer temporary refuges, leaving running upstream or downstream to unaffected areas the only options.
- Depending upon the scale of the event, fish may or may not be able to outrun the hypoxic front to find these areas.

With respect to the last of these points, adult fish are more likely to outrun an event, which may be one reason that juvenile fish are more commonly seen in fishkills[3].

There is also evidence from salmon tracking studies in estuaries (Clarke *et al.*, 2004; Solomon and Sambrook, 2004) that adverse combinations of low DO and high temperature, often associated with low summer flows will cause salmon to hold back in outer estuarine waters until conditions become more favourable. Solomon and Sambrook (2004) showed that this may result in fish missing their window of opportunity for entering freshwater.

Thus, while avoidance behaviour might reduce the risk to some fish, it would not help all species and its importance cannot presently be quantified without further scientific study at the field scale.

3.1.3 AMP4 STW Improvements

The effect of AMP4 Sewage Treatment Works (STW) improvements has been considered since 2006 as part of the Environmental Assessment for these schemes. This is considered further in Section 3.3.

3.2 Consumer Council for Water (CCWater) Response (2009)

The Consumer Council for Water (CCWater) (London and Southeast Committee) in August 2008 (CCWater, 2008) submitted a detailed response to the planning application for the Lee Tunnel and Beckton Sewage Treatment Works Extension scheme (Application Reference 08/01158/ODA), which incorporated discussion of wider issues relating to the Tunnel project. CCWater has a remit to protect consumer interests and, in this case, was considering whether the impact of the proposed Tunnel capital expenditure represented value-for-money. The scope of their comments covered the three key expected benefit areas (human health,

[3] Environment Agency R & D Project W2-026, 'Swimming Speeds in Fish' and the associated SWMIT v.3.3 MS Excel spreadsheet provide swimming speed data for a number of common Tideway fish species.

aesthetics and ecology) and only those relating to ecology will be dealt with here. The main body of comment relating to Ecological Damage is shown in Appendix C.

Figure 3-2 is the Map showing the proposed Thames Tunnel and Lee Tunnel options to deal with CSO spills. The main comment relating to fisheries was as follows:

- A comparison of FARL Tables 6.10 and 6.11, shown below as Table 3-2 and Table 3-3, showing the difference in expected fish mortalities with and without tunnels, illustrates a very finely balanced case for the investment in purely ecological terms.

These tables make comparisons for two alternative solutions, as follows:

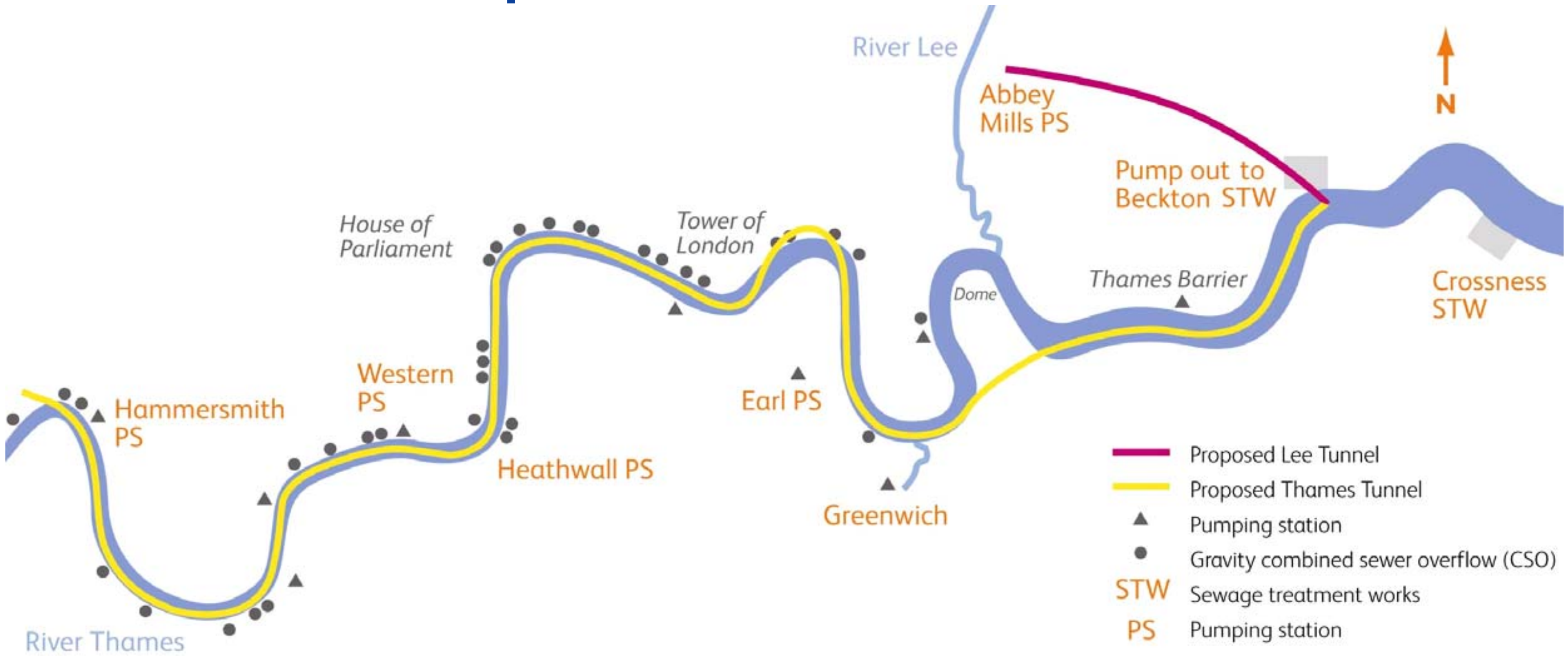
- Table 3-2 (AMP4): A scenario where improvements to the quality of discharge from the Tideway STW's are in place, but with no engineering solution for CSO spills.

- Table 3-3 (AMP4 + Tunnels): - AMP4 STW improvements in place as well as the Thames and Lee Tunnels (FARL Solution A) for CSO discharges. The Thames Tunnel comprises a collection and distribution tunnel, collecting discharge from CSO outfalls along the Thames Tideway and distributing the discharge to the lower Tideway to a treatment works operating to a secondary treatment level. The tunnel would start at Hammersmith in the west and end at Beckton STW (Figure 3-2).

The CCWater interpretation of these findings as ‘finely balanced’ is justifiable, as both tables show no cases that would be considered unsustainable under the criteria used. However, it will be seen in section 3.3 below that the analyses have been updated and revised, now yielding quite different outcomes.

Figure 3-2 Map showing Thames Tunnel and Lee Tunnel Options (Thames Tideway Strategic Study Option 1c, December 2006)

Tideway Tunnel
Full Tunnel Concept



- **Lee Tunnel** (Abbey Mills to Beckton STW)
  6.9km long, >7m diameter, up to 75m deep
  Construction 2009-2014
- **Thames Tunnel** (Hammersmith to Beckton STW)
  32.2km long, >7m diameter, up to 75m deep
  Construction 2012-2020
- **Beckton STW Extensions**
  Construction 2009-2014

Table 3-2 (Fawley Table 6.10) Expected fish mortalities with the proposed AMP 4 STW Schemes in place, at the proposed Interim Standard levels of 1.0 2.0, 3.0 and 4.0 mg DO L^{-1}, modified by the Fish Risk Model. The effect of a 1.5 mgL^{-1} Minimum Standard is also shown.

AMP 4														
Species	Lifestage	Effect of Proposed Standard on Predicted Fish Mortality												
		1.0 mg L^{-1}	1.5 mg L^{-1} (6h in 10y)	2.0 mg L^{-1} (6h in 5y)			3.0 mg L^{-1} (18h in 3y)			4.0 mg L^{-1} (1 wk per y)			No. of >10% PL Effect @1.0mgL^{-1}	No. of >10% PL Effect @1.5mgL^{-1}
				Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**		
Salmon	Smolt	**100%**	**100%**	100%	0.00	**0.0%**	10%	0.00	**0.0%**	10%	0.05	**0.5%**	4	4
	Adult	**100%**	**100%**	100%	0.35	**35.4%**	90%	0.63	**56.8%**	10%	0.53	**5.3%**		
Bass	Young Fry	**10%**	**10%**	10%	0.00	**0.0%**	10%	0.00	**0.0%**	10%	0.00	**0.0%**	0	0
	Juvenile	**10%**	**10%**	10%	0.35	**3.5%**	10%	0.63	**6.3%**	10%	0.53	**5.3%**		
Sand smelt	Egg/fry				0.00			0.11			0.00		2	0
	Juvenile	**50%**	**10%**	10%	0.35	**3.5%**	10%	0.63	**6.3%**	10%	0.59	**5.9%**		
	Adult	**75%**	**10%**	10%	0.35	**3.5%**	10%	0.63	**6.3%**	10%	0.87	**8.7%**		
Dace	Egg/fry	**100%**	**100%**	85%	0.00	**0.0%**	10%	0.00	**0.0%**	10%	0.00	**0.0%**	3	2
	Juvenile	**50%**	**30%**	10%	0.53	**5.3%**	10%	0.29	**2.9%**	10%	0.11	**1.1%**		
	Adult	**50%**	**10%**	10%	0.53	**5.3%**	10%	0.29	**2.9%**	10%	0.11	**1.1%**		
Smelt	Egg/fry				0.00			0.00			0.00		3	3
	Juvenile	**100%**	**40%**	40%	0.35	**14.2%**	10%	0.63	**6.3%**	10%	0.59	**5.9%**		
	Adult	**100%**	**40%**	40%	0.25	**10.0%**	10%	0.88	**8.8%**	10%	0.87	**8.7%**		
Flounder	Egg/fry				0.00			0.00			0.00	**0.0%**	2	2
	Juvenile	**50%**	**50%**	15%	0.35	**5.3%**	10%	0.63	**6.3%**	10%	0.56	**5.6%**		
	Adult	**50%**	**40%**	15%	0.25	**3.8%**	10%	0.83	**8.3%**	10%	0.83	**8.3%**		
Common goby	Egg/fry				0.00			0.00			0.00		2	2
	Juvenile	**50%**	**40%**	10%	0.35	**3.5%**	10%	0.63	**6.3%**	10%	0.53	**5.3%**		
	Adult	**50%**	**40%**	10%	0.00	**0.0%**	10%	0.00	**0.0%**	10%	0.00	**0.0%**		
										Total PL Effects occurrences >10%			**16**	**13**
										Total PL Effects 'not sustainable'			**4**	**0**

Table 3-3 ***(Fawley Table 6.11) Expected fish mortalities with Thames and Lee Tunnels (Solution A) (TTSS Feb 2005) in place, at the proposed Interim Standard levels of 1.0 2.0, 3.0 and 4.0 mg DO L^{-1}, modified by the Fish Risk Model. The effect of a 1.5 mgL^{-1} Minimum Standard is also shown.***

SOLUTION A														
Species	Lifestage	Effect of Proposed Standard on Predicted Fish Mortality												
		1.0 mg L^{-1}	1.5 mg L^{-1} (6h in 10y)	2.0 mg L^{-1} (6h in 5y)			3.0 mg L^{-1} (18h in 3y)			4.0 mg L^{-1} (1 wk per y)			No. of >10% PL Effect @1.0mgL^{-1}	No. of >10% PL Effect @1.5mgL^{-1}
				Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**		
Salmon	Smolt	**100%**	**100%**	100%	0.00	**0.0%**	10%	0.00	**0.0%**	10%	0.03	**0.3%**	3	3
	Adult	**100%**	**100%**	100%	0.00	**0.0%**	90%	0.63	**56.8%**	10%	0.56	**5.6%**		
Bass	Young Fry	**10%**	**10%**	10%	0.00	**0.0%**	10%	0.00	**0.0%**	10%	0.00	**0.0%**	0	0
	Juvenile	**10%**	**10%**	10%	0.00	**0.0%**	10%	0.63	**6.3%**	10%	0.56	**5.6%**		
Sand smelt	Egg/fry				0.00			0.00			0.00		2	0
	Juvenile	**50%**	**10%**	10%	0.00	**0.0%**	10%	0.63	**6.3%**	10%	0.57	**5.7%**		
	Adult	**75%**	**10%**	10%	0.00	**0.0%**	10%	0.63	**6.3%**	10%	0.87	**8.7%**		
Dace	Egg/fry	**100%**	**100%**	85%	0.00	**0.0%**	10%	0.00	**0.0%**	10%	0.00	**0.0%**	3	2
	Juvenile	**50%**	**30%**	10%	0.00	**0.0%**	10%	0.29	**2.9%**	10%	0.11	**1.1%**		
	Adult	**50%**	**10%**	10%	0.00	**0.0%**	10%	0.29	**2.9%**	10%	0.11	**1.1%**		
Smelt	Egg/fry				0.00			0.00			0.00		2	2
	Juvenile	**100%**	**40%**	40%	0.00	**0.0%**	10%	0.63	**6.3%**	10%	0.57	**5.7%**		
	Adult	**100%**	**40%**	40%	0.00	**0.0%**	10%	0.88	**8.8%**	10%	0.87	**8.7%**		
Flounder	Egg/fry				0.00			0.00			0.00		2	2
	Juvenile	**50%**	**50%**	15%	0.00	**0.0%**	10%	0.63	**6.3%**	10%	0.56	**5.6%**		
	Adult	**50%**	**40%**	15%	0.00	**0.0%**	10%	0.83	**8.3%**	10%	0.83	**8.3%**		
Common goby	Egg/fry				0.00			0.00			0.00		2	2
	Juvenile	**50%**	**40%**	10%	0.00	**0.0%**	10%	0.63	**6.3%**	10%	0.56	**5.6%**		
	Adult	**50%**	**40%**	10%	0.00	**0.0%**	10%	0.00	**0.0%**	10%	0.00	**0.0%**		
										Total PL Effects occurrences >10%			**14**	**11**
										Total PL Effects 'not sustainable'			**4**	**0**

3.3 AMP4 STW Upgrade Environmental Statements (2006)

In 2006, Scott Wilson (2006) prepared Environmental Statements for the proposed AMP4 STW upgrades at Mogden, Beckton and Crossness. The expected improvements in Tideway water quality, leading to fewer breaches of the TTSS DO standards, and consequent effect on fish sustainability, had previously been assessed by Turnpenny et al. (2004) using the TFRM as shown in the 'AMP4' scenario of Table 3-2. The Current Baseline (Table 3-1) was based on historical data prior to 2004.

As the analysis had been undertaken in 2003, the fishery data contained in the TFRM was updated with the latest available information up to and including 2005 EA fish survey data.

Further refinement was made to the sustainable mortality values for some species, as it was considered after discussion with EA fishery experts (S. Colclough, D. Clifton-Dey) that the 'marginally sustainable (blue typeface figures) had been overly generous in some cases in the original Turnpenny *et al*. (2004) analysis. Table 3-4 shows the revised figures used in more recent analyses.

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

It was also considered more realistic for the assessments to consider a baseline for the year 2020 (earliest date of Tunnel project completion), taking into account forecasts of STW loading based on predicted 2020 London population size (expanded) and any effects of climate change on water quality. WRc provided Quests modelling on this basis and the TFRM was run for a 2020 baseline, which is now considered the most appropriate baseline for Tunnel assessment.

The resulting updated analyses for baseline and AMP4 conditions for 2020 are shown Table 3-5 in as "No Improvements 2020', and Table 3-6 for the AMP4 Baseline, 2020. Note that these tables use only the 1.5 mgl^{-1} TTSS DO standard. The revised assessments indicate relatively high numbers of 'not sustainable' cases (13 for baseline 2020 and 11 for AMP4 2020) and no longer suggest that the AMP4 STW upgrades alone would ensure sustainable fish populations in the Tideway.

Two further TFRM runs were carried out at this stage, one for the full main Tunnel solution as recommended in the TTSS Report (February 2005) (Table 3-7) and the second for the 2-Part East-West Tunnel solution (Jacobs-Babtie proposal) both using the 2020 AMP4 baseline.

Table 3-5 TFRM Outputs for No Improvements Scenario, based on the projected conditions for the year 2020

No Improvements - 2020																
Species	Lifestage	Standard 4 1.5 mg L^{-1} (6h in 10y)			Standard 3 2.0 mg L^{-1} (6h in 5y)			Standard 2 3.0 mg L^{-1} (18h in 3y)			Standard 1 4.0 mg L^{-1} (1 wk per y)			No. of >10% PL Effect @1.5mgL^{-1}	No. of Reproductive Age classes	Sustainable Mortality %*
		Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**			
Salmon	Smolt	100%	0.21	**21.1%**	100.0%	0.23	**22.8%**	<10%	0.24	**<10%**	<10%	0.16	**<10%**	5	3	30
	Adult	100%	1.00	**100.0%**	100.0%	1.00	**100.0%**	90.0%	1.00	**90.0%**	<10%	1.00	**<10%**			
Bass	Young Fry	10%	0.61	**<10%**	<10%	0.74	**<10%**	<10%	0.86	**<10%**	<10%	0.67	**<10%**	0	10	30
	Juvenile	10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
Sand smelt	Egg/fry		0.48	**<10%**		0.60			0.70			0.47		0	2	10
	Juvenile	10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
	Adult	10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
Dace	Egg/fry	100%	0.44	**44.2%**	85.0%	0.55	**46.5%**	<10%	0.63	**<10%**	<10%	0.45	**<10%**	3	4	20
	Juvenile	30%	1.00	**30.0%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
	Adult	10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
Smelt	Egg/fry		0.47	**<10%**		0.54			0.65			0.47		4	7	10
	Juvenile	40%	1.00	**40.0%**	40.0%	1.00	**40.0%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
	Adult	40%	1.00	**40.0%**	40.0%	1.00	**40.0%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
Flounder	Egg/fry		0.00	**<10%**		0.00			0.00			0.00		4	2	30
	Juvenile	50%	1.00	**50.0%**	15.0%	1.00	**15.0%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
	Adult	40%	1.00	**40.0%**	15.0%	1.00	**15.0%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
Common goby	Egg/fry	0%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	1	2	10
	Juvenile	40%	1.00	**40.0%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
	Adult	40%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**			
											Total PL Effects occurrences >10%			**17**		
											Total PL Effects 'not sustainable'			**13**		

Table 3-6 TFRM Outputs for AMP4 STW Improvements Scenario, based on the projected conditions for the year 2020

AMP4 Baseline A 2020 PE																
Species	Lifestage	Standard 4 1.5 mg L^{-1} (6h in 10y)			Standard 3 2.0 mg L^{-1} (6h in 5y)			Standard 2 3.0 mg L^{-1} (18h in 3y)			Standard 1 4.0 mg L^{-1} (1 wk per y)			No. of >10% PL Effect @1.5mgL^{-1}	No. of Reproductive Age classes	Sustainable Mortality %*
		Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**			
Salmon	Smolt	100%	0.07	**<10%**	100.0%	0.09	**<10%**	<10%	0.18	**<10%**	<10%	0.13	**<10%**	3	3	30
	Adult	100%	0.65	**64.7%**	100.0%	1.00	**100.0%**	90.0%	1.00	**90.0%**	<10%	1.00	**<10%**			
Bass	Young Fry	10%	0.24	**<10%**	<10%	0.32	**<10%**	<10%	0.55	**<10%**	<10%	0.45	**<10%**	0	10	30
	Juvenile	10%	0.62	**<10%**	<10%	0.96	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
Sand smelt	Egg/fry		0.18	**<10%**		0.31			0.59			0.30		0	2	10
	Juvenile	10%	0.67	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
	Adult	10%	0.66	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
Dace	Egg/fry	100%	0.19	**19.0%**	85.0%	0.24	**20.4%**	<10%	0.41	**<10%**	<10%	0.29	**<10%**	3	4	20
	Juvenile	30%	0.47	**14.2%**	<10%	0.71	**<10%**	<10%	1.00	**<10%**	<10%	0.99	**<10%**			
	Adult	10%	0.44	**<10%**	<10%	0.67	**<10%**	<10%	1.00	**<10%**	<10%	0.91	**<10%**			
Smelt	Egg/fry		0.18	**<10%**		0.24			0.42			0.30		4	7	10
	Juvenile	40%	0.68	**27.3%**	40.0%	1.00	**40.0%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
	Adult	40%	0.76	**30.3%**	40.0%	1.00	**40.0%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
Flounder	Egg/fry		0.00	**<10%**		0.00			0.00			0.00		4	2	30
	Juvenile	50%	0.66	**33.2%**	15.0%	1.00	**15.0%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
	Adult	40%	0.79	**31.6%**	15.0%	1.00	**15.0%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
Common goby	Egg/fry	0%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	1	2	10
	Juvenile	40%	0.67	**26.8%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
	Adult	40%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**			
											Total PL Effects occurrences >10%			**15**		
											Total PL Effects 'not sustainable'			**11**		

Table 3-7 Revised TFRM output for Thames and Lee Tunnels Solution (TTSS Report, Feb 2005) with 2020 AMP4 Baseline

Main Tunnel 7.2 A 2020 PE														
Species	Lifestage	Standard 4 1.5 mg L^{-1} (6h in 10y)			Standard 3 2.0 mg L^{-1} (6h in 5y)			Standard 2 3.0 mg L^{-1} (18h in 3y)			Standard 1 4.0 mg L^{-1} (1 wk per y)			No. of >10% PL Effect @1.5mgL^{-1}
		Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	
Salmon	Smolt	100%	0.00	**<10%**	100.0%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	0
	Adult	100%	0.00	**<10%**	100.0%	0.00	**<10%**	90.0%	0.03	**<10%**	<10%	0.09	**<10%**	
Bass	Young Fry	10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	0
	Juvenile	10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.03	**<10%**	<10%	0.09	**<10%**	
Sand smelt	Egg/fry		0.00	**<10%**		0.00			0.00			0.00		0
	Juvenile	10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.03	**<10%**	<10%	0.09	**<10%**	
	Adult	10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.03	**<10%**	<10%	0.16	**<10%**	
Dace	Egg/fry	100%	0.00	**<10%**	85.0%	0.00	**<10%**	<10%	0.01	**<10%**	<10%	0.00	**<10%**	0
	Juvenile	30%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.08	**<10%**	<10%	0.00	**<10%**	
	Adult	10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.08	**<10%**	<10%	0.00	**<10%**	
Smelt	Egg/fry					0.00			0.00			0.00		0
	Juvenile	40%	0.00	**<10%**	40.0%	0.00	**<10%**	<10%	0.03	**<10%**	<10%	0.09	**<10%**	
	Adult	40%	0.00	**<10%**	40.0%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.16	**<10%**	
Flounder	Egg/fry		0.00			0.00			0.00			0.00		0
	Juvenile	50%	0.00	**<10%**	15.0%	0.00	**<10%**	<10%	0.03	**<10%**	<10%	0.09	**<10%**	
	Adult	40%	0.00	**<10%**	15.0%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.15	**<10%**	
Common goby	Egg/fry	0%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	0
	Juvenile	40%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.03	**<10%**	<10%	0.09	**<10%**	
	Adult	40%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	
											Total PL Effects occurrences >10%			**0**
											Total PL Effects 'not sustainable'			0

Table 3-8 TFRM output for 2-part Tunnel Solution (Jacobs-Babtie proposal)

2 Part E-W Tunnel A 2020 PE														
Species	Lifestage	Standard 4 1.5 mg L^{-1} (6h in 10y)			Standard 3 2.0 mg L^{-1} (6h in 5y)			Standard 2 3.0 mg L^{-1} (18h in 3y)			Standard 1 4.0 mg L^{-1} (1 wk per y)			No. of >10% PL Effect @1.5mgL^{-1}
		Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	
Salmon	Smolt	100%	0.00	**<10%**	100.0%	0.00	**<10%**	<10%	0.01	**<10%**	<10%	0.06	**<10%**	1
	Adult	100%	0.02	**<10%**	100.0%	0.04	**<10%**	90.0%	0.16	**14.6%**	<10%	0.66	**<10%**	
Bass	Young Fry	10%	0.02	**<10%**	<10%	0.04	**<10%**	<10%	0.04	**<10%**	<10%	0.07	**<10%**	0
	Juvenile	10%	0.02	**<10%**	<10%	0.04	**<10%**	<10%	0.16	**<10%**	<10%	0.66	**<10%**	
Sand smelt	Egg/fry		0.00	**<10%**		0.00			0.06			0.08		0
	Juvenile	10%	0.02	**<10%**	<10%	0.04	**<10%**	<10%	0.16	**<10%**	<10%	0.70	**<10%**	
	Adult	10%	0.02	**<10%**	<10%	0.04	**<10%**	<10%	0.16	**<10%**	<10%	1.00	**<10%**	
Dace	Egg/fry	100%	0.01	**<10%**	85.0%	0.02	**<10%**	<10%	0.02	**<10%**	<10%	0.02	**<10%**	0
	Juvenile	30%	0.01	**<10%**	<10%	0.02	**<10%**	<10%	0.08	**<10%**	<10%	0.12	**<10%**	
	Adult	10%	0.01	**<10%**	<10%	0.02	**<10%**	<10%	0.07	**<10%**	<10%	0.11	**<10%**	
Smelt	Egg/fry		0.02	**<10%**		0.03			0.04			0.08		0
	Juvenile	40%	0.02	**<10%**	40.0%	0.04	**<10%**	<10%	0.16	**<10%**	<10%	0.70	**<10%**	
	Adult	40%	0.03	**<10%**	40.0%	0.05	**<10%**	<10%	0.21	**<10%**	<10%	1.00	**<10%**	
Flounder	Egg/fry		0.00	**<10%**		0.00			0.00			0.00		0
	Juvenile	50%	0.02	**<10%**	15.0%	0.04	**<10%**	<10%	0.16	**<10%**	<10%	0.68	**<10%**	
	Adult	40%	0.03	**<10%**	15.0%	0.05	**<10%**	<10%	0.21	**<10%**	<10%	1.00	**<10%**	
Common goby	Egg/fry	0%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	0
	Juvenile	40%	0.02	**<10%**	<10%	0.04	**<10%**	<10%	0.16	**<10%**	<10%	0.68	**<10%**	
	Adult	40%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	
											Total PL Effects occurrences >10%			**1**
											Total PL Effects 'not sustainable'			**1**

3.4 Lee Tunnel Environmental Statement (2008): Option 1c

An Environmental Statement prepared by Scott Wilson (2008) on behalf of TWU examined the environmental effects on the River Lee and Thames Tideway of a proposed Lee Tunnel, connecting the Abbey Mills and Beckton STWs. The tunnel would collect discharges from all the CSOs currently entering the R. Lee, which presently account for around 50% of the total CSO discharges into the Tideway.

As part of this study, Jacobs were commissioned to run the TFRM to assess the potential benefits to Tideway fish. The model runs used the updated (2006) fisheries data and 2020 AMP4 baseline (see section 3.3 above). Outputs from the model are shown in Table 3-9. Known as 'Option 1c', this includes Thames Tunnel and the Lee Tunnel (Option 1c, TTSS and Thames Tideway Tunnel and Treatment (TTTT), Summary Report, December 2006) and the AMP4 2020 Baseline.

It is seen from Table 3-4 that only a single 'not sustainable' case results, and two 'marginally sustainable'.

Table 3-9 ***Expected fish mortalities with Thames Tunnel (Solution 1c) and the Lee Tunnel (TTSS and TTTT Summary Report, December 2006) in place, at the proposed Interim Standard levels of 1.5, 2.0, 3.0 and 4.0 mg DO L^{-1}, from the Tideway Fish Risk Model. Solution 1c includes AMP4 STW upgrades.***

Solution 1c with AMP4 + Lee Tunnel Solution - 2020

Species	Lifestage	Standard 4 1.5 mg L^{-1} (6h in 10y)			Standard 3 2.0 mg L^{-1} (6h in 5y)			Standard 2 3.0 mg L^{-1} (18h in 3y)			Standard 1 4.0 mg L^{-1} (1 wk per y)			No. of >10% PL Effect @1.5mgL^{-1}	No. of Reproductive Age classes	Sustainable Mortality %*
		Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**			
Salmon	Smolt	100%	0.01	**<10%**	100.0%	0.02	**<10%**	<10%	0.07	**<10%**	<10%	0.09	**<10%**	3	3	30
	Adult	100%	0.10	**10.3%**	100.0%	0.21	**20.7%**	90.0%	0.69	**61.7%**	<10%	1.00	**<10%**			
Bass	Young Fry	10%	0.05	**<10%**	<10%	0.08	**<10%**	<10%	0.16	**<10%**	<10%	0.15	**<10%**	0	10	30
	Juvenile	10%	0.10	**<10%**	<10%	0.20	**<10%**	<10%	0.67	**<10%**	<10%	1.00	**<10%**			
Sand smelt	Egg/fry		0.03	**<10%**		0.08			0.24			0.12		0	2	10
	Juvenile	10%	0.10	**<10%**	<10%	0.21	**<10%**	<10%	0.71	**<10%**	<10%	1.00	**<10%**			
	Adult	10%	0.10	**<10%**	<10%	0.21	**<10%**	<10%	0.70	**<10%**	<10%	1.00	**<10%**			
Dace	Egg/fry	100%	0.04	**<10%**	85.0%	0.05	**<10%**	<10%	0.12	**<10%**	<10%	0.10	**<10%**	0	4	20
	Juvenile	30%	0.14	**<10%**	<10%	0.25	**<10%**	<10%	0.67	**<10%**	<10%	0.35	**<10%**			
	Adult	10%	0.13	**<10%**	<10%	0.24	**<10%**	<10%	0.67	**<10%**	<10%	0.33	**<10%**			
Smelt	Egg/fry		0.04	**<10%**		0.09			0.15			0.12		0	7	10
	Juvenile	40%	0.10	**<10%**	40.0%	0.21	**<10%**	<10%	0.71	**<10%**	<10%	1.00	**<10%**			
	Adult	40%	0.07	**<10%**	40.0%	0.17	**<10%**	<10%	0.68	**<10%**	<10%	1.00	**<10%**			
Flounder	Egg/fry		0.00	**<10%**		0.00			0.00			0.00		0	0	30
	Juvenile	50%	0.10	**<10%**	15.0%	0.21	**<10%**	<10%	0.70	**<10%**	<10%	1.00	**<10%**			
	Adult	40%	0.08	**<10%**	15.0%	0.19	**<10%**	<10%	0.72	**<10%**	<10%	1.00	**<10%**			
Common goby	Egg/fry	0%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	0	2	10
	Juvenile	40%	0.10	**<10%**	<10%	0.21	**<10%**	<10%	0.71	**<10%**	<10%	1.00	**<10%**			
	Adult	40%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**			
											Total PL Effects occurrences >10%			**3**		
											Total PL Effects 'not sustainable'			**1**		

3.5 Water Framework Directive

3.5.1 Water Body Classifications

The Water Framework Directive (WFD) aims to achieve Good Ecological Status in water bodies by a target date of 2015. Ecological Status is measured on a scale with respect to agreed reference conditions, from Bad to High, using a number of physico-chemical, hydromorphological and biological quality elements. For Transitional or Coastal (TraC) waters, the biological quality elements used include:

(i) Benthic invertebrates
(ii) Fish
(iii) Phytoplankton
(iv) Macroalgae; and
(v) Angiosperms

The UK Technical Advisory Group on the WFD (UKTAG, 2007) explains the classification process as follows:

"The degree of disturbance to each quality element is assessed against a "reference value or set of values" for that element. A reference value for a biological quality element is a value identified from the range of values the quality element may have when subject to no or only very minor alteration as a result of human disturbance (i.e. when it is in a reference, or high status, condition). UKTAG recommends that reference conditions should reflect 'a state in the present or in the past corresponding to very low pressure, without the effects of major industrialisation, urbanisation and intensification of agriculture, and with only very minor modification of physico-chemistry, hydromorphology and biology'".

UKTAG goes on to define the classification levels, known as 'normative definitions':

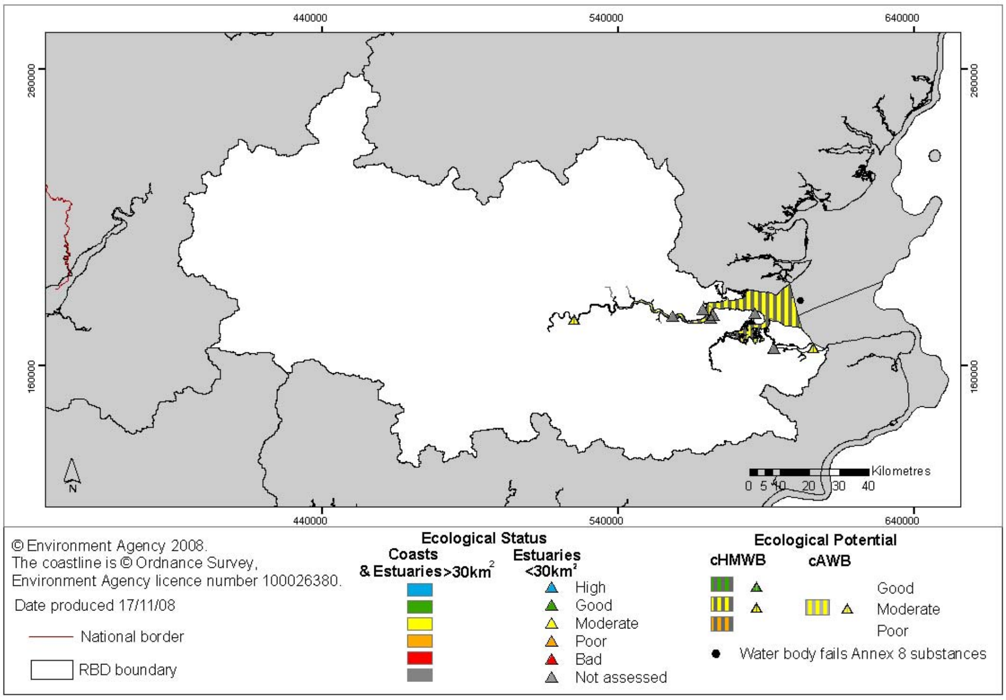
- **High** – at reference condition
- **Good** – no biological quality element more than slightly altered from reference condition
- **Moderate** - one or more of the biological elements may be moderately altered
- **Poor** - alterations to one or more biological quality elements are major
- **Bad** – severe alterations such that a large proportion of the reference biological community is absent.

The WFD allows certain types of water body to be designated as Artificial and Heavily Modified Waters (A/HMWs), in which case, the measure is Ecological Potential rather than Status. UKTAG have adopted the 'mitigation measures approach' for classifying A/HMWs. This approach assesses whether mitigation is in place to the extent that could reasonably be expected. If this mitigation is in place, then the water body is classified as achieving at least Good Ecological Potential. If this level of mitigation is not in place, then the water body will be classed as Moderate or worse Ecological Potential.

3.5.2 Present Status of the Thames Tideway

Within WFD terminology, the Thames Tideway is classified as a transitional water, falling within the Thames Upper and Thames Middle waterbodies. These are A/HMWs, classified as achieving Moderate Ecological Potential.

Figure 3-3 Thames Tideway WFD Classification



3.5.3 Assessment of Ecological Status

Through UKTAG, a number of biological quality element "tools" have been developed and tested. The fish tool, or Transitional Fish Classification Index (TFCI) is a multi-metric index which uses the ten metrics listed in Table 3-10: Deviation from the reference condition is measured on a 1-5 scale for each metric. The total score of metrics is compared against the maximum possible score that would apply under reference conditions to give a Relative Score (RS) (Coates *et al.*, 2007):

$$\mathrm{RS} = \frac{\text{Total score of the 10 metrics}}{\text{Maximum score possible}}$$

Table 3-10 Metrics Used in the Transitional Fish Classification Index

Metric Type	No.	Metric
Species diversity and composition	1	'Species composition'
	2	Presence of 'Indicator Species'
Species abundance	3	Species relative 'abundance'
	4	Number of taxa that make up 90% of the 'abundance'
Nursery function	5	Number of estuarine resident taxa
	6	Number of estuarine-dependent marine taxa
Trophic integrity	7	Functional Guild Composition
	8	Number of benthic invertebrate feeding taxa
	9	Number of piscivorous taxa
	10	Feeding Guild Composition

Table 3-11 shows the Ecological Quality Ratio (EQR) values required to achieve ecological status levels ('normative definitions'). These are similar but not directly equivalent to the RS values used by Coates *et al.* (2007). These authors suggested that "*The criteria for ecological potential require a water body to not deteriorate and will most probably will be compared to the same reference conditions as those that are not heavily modified, but the boundary criteria may be different*."

Table 3-11 EQR scores required to achieve different status levels (UKTAG, 2007).

Boundary	EQR
High – Good	High ≥0.8
Good - Moderate	Good ≥0.6
Moderate – Poor	Mod ≥0.4
Poor – Bad	Poor ≥0.2
	Bad 0 – 0.2

The Environment Agency have systematically sampled the Thames Tideway since 1992, using a variety of survey methods, and Coates *et al*. (2007) have used these data to investigate the TFCI tool. An example of their findings for the 1992-2004 data series is shown in Figure 3-4 Relative Score values for the upper Thames Tideway reported by Coates *et al.* (2007) based on a combination of beam trawling and beach seining methods, and an average score for both methods.

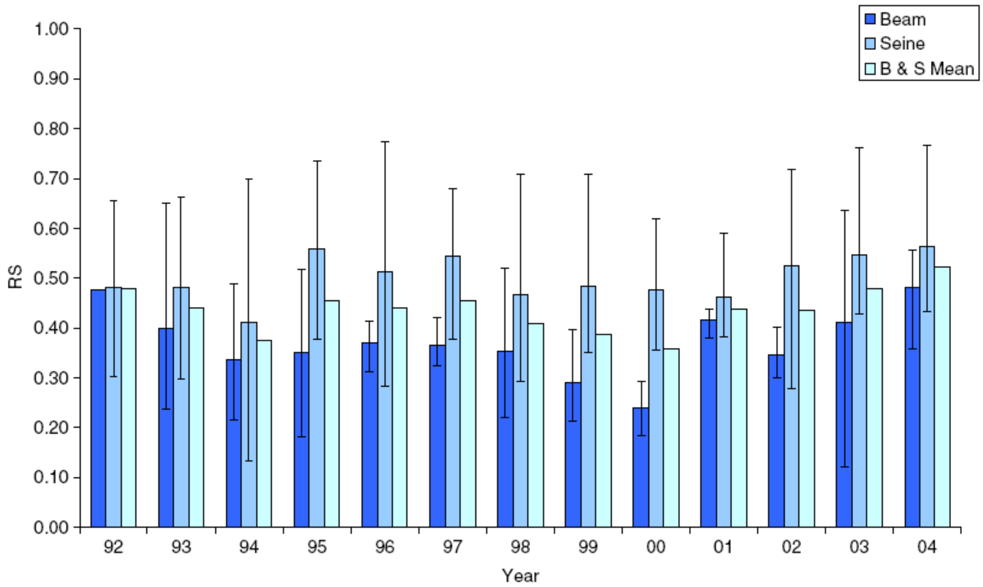


Figure 3-4 Relative Score values for the upper Thames Tideway reported by Coates* et al. *(2007) based on a combination of beam trawling and beach seining methods, and an average score for both methods.

Table 3-12 shows the ranges of scores by this method for the three sections, Upper (Teddington to Battersea), Middle (Vauxhall to Crossness) and Lower (Greenhithe to Southend)indicating that the Upper Tideway is most highly stressed, with some improvement towards the outer estuary. As the RS values were not referenced to a true pristine reference condition as required by WFD, the RS values may generate higher score relative to true EQRs, therefore the WFD status of the Tideway remains unclear.

Table 3-12 Summary of fish population Relative Scores estimated by Coates* et al. *(2007) for Upper, Middle and Lower Tideway and implied status based on boundary values in Table 3-11

Area	Range of RS Values
Upper Tideway	0.37 – 0.51
Middle Tideway	0.30 – 0.68
Lower Tideway	0.40 – 0.67

Conclusion: WFD Metrics

The above explanation shows the high degree of complexity involved in generating EQR values needed to classify Ecological Status or Ecological Potential with respect to the fish element. It is not appropriate to translate the available water quality and ecotoxicology predictions for various tunnel and STW improvement scenarios into changes in EQR values for the various parts of the Tideway. EQR values are a longer term assessment within the WFD reporting timeframe.

3.5.4 WFD Draft Surface Water Quality Standards (2008)

(a) Introduction

For transitional and coastal waters the Water Framework Directive identifies five ‘‘General chemical and physiochemical elements supporting the biological elements''. These are transparency, thermal conditions, oxygenation conditions, salinity and nutrient conditions. From 2004, UKTAG has led the development of new surface water standards applicable to UK water bodies. The purpose of the standards is to support the objectives of the WFD, in other words to provide water quality that will support the required ecological status or potential. Three reports summarising proposed new standards have been published. Phase 1 (UKTAG, 2008b) deals, amongst other matters, with DO requirements for TraC waters, while UKTAG (2008a) includes ammonia in TraC waters. The third, (UKTAG, 2007), covers temperature, nitrogen and suspended solids for TraC waters.

(b) WFD DO Standards

WFD requires that: "t*emperature, oxygenation conditions and transparency do not reach levels outside the ranges established so as to ensure the functioning of the ecosystem and the achievement of the values specified above for the biological quality elements*". Best *et al.* (2007) describe the considerations in reaching new WFD DO standards for TraC waters.

The standards are set in two tiers: a primary table of values set as annual 5-percentiles – the concentrations that should be bettered for 95% of the time (Table 3-13); for water bodies where there is an expectation of intermittent hypoxia events (such as in estuaries subject to CSO discharges) a second table of Fundamental Intermittent Standards with permissible return frequencies may be applied Table 3-14. This requires that DO should not fall below 2 mg/l at the freshwater end or 1.6 mg/l in marine conditions for more than one 6 hour tidal cycle over a 6 year period. Table 3-13 covers freshwater and fully marine situations. For transitional waters, intermediate values can be determined from Figure 3-5. The FIS values are allowable only on waters of Good or Moderate status.

Table 3-13 UKTAG Dissolved Oxygen Standards for Freshwater and Transitional and Coastal Water Bodies

	Freshwater	Marine	Description
	5-percentile (mg/l)		
High	7	5.7	Protects all life-stages of salmonid fish
Good	5 - 7	4.0 – 5.7	Resident salmonid fish
Moderate	3 - 5	2.4 – 4.0	Protects most life-stages of Non-salmonid adults
Poor	2 - 3	1.6 – 2.4	Resident non-salmonid fish, poor survival of salmonid fish
Bad	2	1.6	No salmonid fish. Marginal survival of resident species

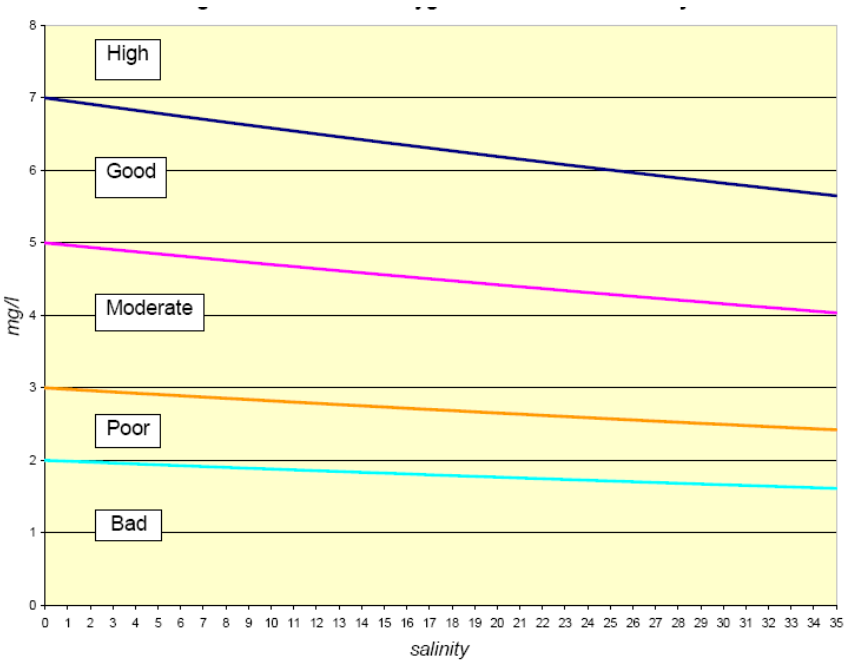


Figure 3-5 Adjustments of class boundaries to take account of salinity

Table 3-14 Second-tier DO Fundamental Intermittent Standards for waters subject to intermittent hypoxia. The levels shown may not be exceeded for more a single six-hour period with the return frequency shown.

Status	Minimum DO, freshwater-marine (mg/l)	Return Period (years)
Good	2 (freshwater)- 1.6 (marine)	1 in 6
Moderate		1 in 3

In preparing the WFD standards, UKTAG took account of a wide variety of existing standards and of the ecotoxicology data generated in the Fawley study (Best *et al.*, 2007). In Figure 3-6, the 5th-percentile WFD standards corresponding to class boundaries in freshwater have been overlaid onto the lethality data. Note that the vertical bars indicate the marine criteria and that for less saline conditions, the bars will move further towards the right of the chart. This shows that the WFD criteria are highly protective for 95% of the time, with the risk of lethality being negligible in waters down to Moderate classification, with the possible exception of salmonids in near-freshwater conditions. However, these first-tier standards on their own would permit potentially lethal values to any for up to 18.25 days of the year (5%) in waters where CSO spills can occur. Applying the second-tier values from Table 3-14 (equivalent to the Poor boundary in Figure 3-6) would be protective of some species leaving more sensitive ones such as salmonids, sand-smelt and bass at risk. While only three species are shown here, it must be remembered that these may be representative of a wider range of species in the Tideway at large.

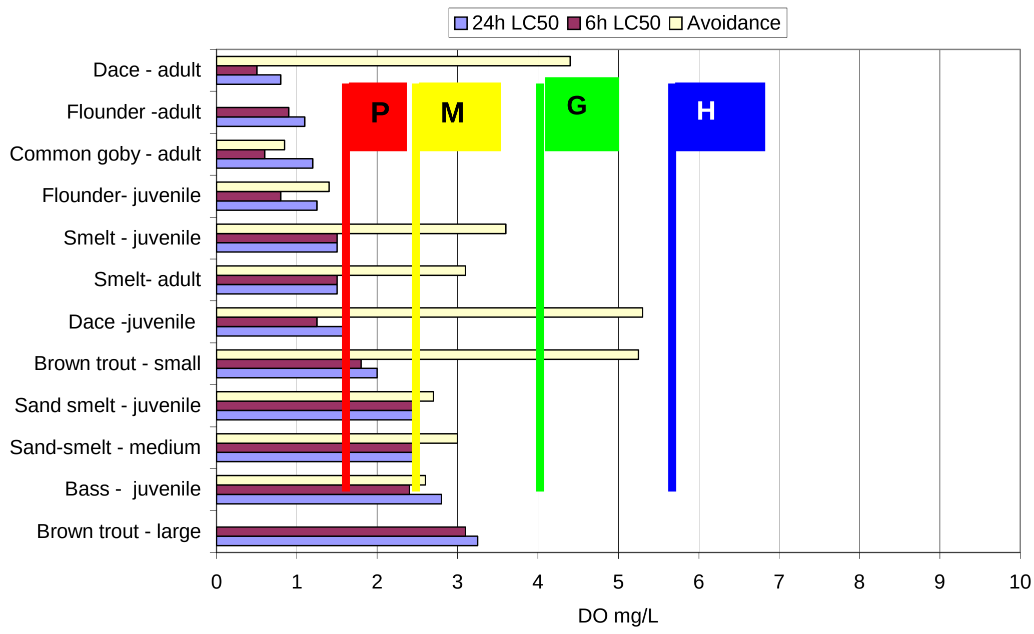


Figure 3-6 ***WFD marine class boundaries (Bad, Poor, Moderate, High) overlaid on the Fawley lethality data from Figure 2-1. Note that for transitional water, class boundaries will shift to the right to take account of lower salinity.***

(c) Are WFD DO Standards More Protective than TTSS DO standards?

A comparison of relevant WFD and TTSS DO standards is shown in Table 3-15. Although WFD standards may appear at first to be more stringent than the TTSS DO standards, being based on the 5 mg/l limit in freshwater, viewed in full for TraC waters, this expands to a 4-5 mg/l limit, depending on the associated salinity value. Use of the 5th percentile, which allows breaches for time amounting to 18.25 days per year implies that the standard values can be breached for up to 73 x 6h tides per year. Thus, under fully marine conditions (4 mg/l DO), the WFD standards are more lenient than the TTSS DO standards, since the latter would allow breaches on only 29 tides, versus 73. Under freshwater conditions, the TTSS DO standards may or may not be more lenient, depending on the frequency distribution of values (i.e. are breaches of 4 mg/l on 29 tides more lenient than breaches of 5 mg/l on 73 tides?).

Table 3-15 WFD Standards (pink shaded rows) and Tideway EQSs for Dissolved Oxygen Compared

Dissolved Oxygen (mgL^{-1})	Return Period (years)	Duration (no. of 6 h tides)
4[M]-5[FW]*	1	73 (as 5th %ile)
4	1	29
3	3	3
2	5	1
1.6[M]-2.0[FW] *	6	1
1.5	10	1

* WFD standards vary with salinity from marine [M] to freshwater [FW].

With respect to the WFD FIS standard that allows breaches of the 1.6-2 mg/l for 1 tide in 6 years, this also straddles the TTSS 1.5 and 2 mg/l DO standards (Table 3-15).

Conclusion: DO standards. The main conclusion that can be drawn from viewing both sets of standards together in Table 3-15 is that they sit harmoniously together but are expressed slightly differently. It is not possible to say that one set of standards is more protective than the other: it will vary from case to case, depending on the shape of the frequency distribution of DO.

An important distinction that can be made, however, is that whereas the WFD standards have been developed as a 'one-size-fits-all' solution for the whole of the UK, the TTSS DO standards have been developed specifically for that situation, the validity of which has been tested via the bespoke Tideway Fish Risk Model.

It should be noted that within the WFD water body classification system, DO is not reported separately. An EQR is derived from the combination of biology, physicochemical status and levels of specific pollutants. The EQR is determined by the lowest denominator in what is termed a 'one out, all out' approach.

(d) Legal Status of WFD Standards

The WFD standards have been subject to external consultation and those dealing with DO are now designated 'Final'. At present, however, they remain proposals and are subject to approval by the European Commission before they can be fully adopted in UK law. It is not expected that the proposed standards values will change at this stage.

Once adopted, surface water standards arising from other EC directives will be overridden by the WFD standards. Thus, any ad hoc 'standards' that have for example been based on the Freshwater Fish Directive or Shellfish Waters Directive will be superceded by WFD standards. These would include, for example, interim measures proposed under UKTAG guidance (WQTAG160[4]) for the protection of marine Natura 2000 sites.

The requirement to meet WFD standards by 2015 will not be absolute. WRc water quality modelling undertaken by Dempsey *et al* (2009) has shown that WFD 5th percentile standards for 'good' status will not be met in the middle reaches, even with the solutions in place. Where the cost of achieving of Good Ecological Status or Potential is disproportionately greater than the benefit (according EC rules)[5], the timescale may be extended into the 2020s (2027 at latest). It is anticipated that this will happen in the case of the Thames Tideway.

[4] Guidance on assessing the impact of thermal discharges on European Marine site WQTAG 160
[5] http://www.eeb.org/activities/water/documents/DisproportionateCostsAnalysis.pdf (accessed 31.07.09)

4 Conclusions

- The findings of the TTSG fisheries studies and the Tideway Fish Risk Model have been peer-reviewed and remain fit-for-purpose.

- The concentrations of unionised ammonia are well below acutely toxic levels for salmonids and present no risk of fishkill at levels recorded over the last 33 years.

- The TTSS DO standards are regarded by the EA as appropriate design standards for the Thames Tunnel. They have been empirically derived using lethal and sublethal response data from local fisheries and tested against historical and predicted water quality data. They are in reality likely to be more appropriate than 'one-size-fits-all' standards to address the issue of combined sewer overflows.

- WRc QUEST water quality modelling indicates that, even with the full tunnel (Solution A), middle sections of the Tideway will breach WFD DO standards. In spite of this, the TFRM runs using the latest available QUEST outputs indicate that implementation of Solution A would meet sustainability criteria for all fish species. Challenges from Ofwat (/Jacobs Babtie) and CCWater implying marginal ecological benefits of Solution A would need to be reconsidered in the light of this newer information.

- As additional analysis was undertaken within the scope of the present report, no immediate need for further work was identified.

5 References

Alabaster, J.S. & Lloyd, R. (1982). Water Quality Criteria for Freshwater Fish. (2nd edition). Butterworths, London, 361p.

Attrill, M.J. (1998) *A rehabilitated estuarine ecosystem, the environment and ecology of the Thames Estuary*. Kluwer Academic Publishers, The Netherlands.

Attrill, M.J. and Power, M. (2000a). Modelling the effect of drought on estuarine quality. *Water Research*., **34 (5),** 1584-1594.

Attrill, M.J. and Power, M. (2000b). Effects on invertebrate populations of drought-induced changes in estuarine quality. Marine Ecology Progress Series 203, 133-143.

Best, M.A., Wither, A.W. & Coates, S (2007). Dissolved Oxygen as a physico-chemical supporting element in the Water Framework Directive. *Mar. Poll. Bull*., **55**, 53-64.

Borja, A. and Elliott, M. (2007). What does 'good ecological potential' mean, within the European Water Framework Directive? *Mar. Poll. Bull*. **54**, 1559-1564.

Clarke, D.R.K., Evans, D.M., Ellery, D.S. and Purvis, W.K. (1994). Migration of Atlantic salmon (*Salmo salar* L.) in the River Tywi estuary during 1988, 1989 and 1990. National Rivers Authority Report No RT/WQ/RCEU/94/7

Coates, S., Waugh, A., Anwar, A. and Robson, M. (2007). Efficacy of a multi-metric fish index as an analysis tool for the transitional fish component of the Water Framework Directive. *Mar. Poll. Bull*., **55**, 225–240.

Colclough, S., Dutton, C., Cousins, T. & Martin, A. (2000). A fish population survey of the tidal Thames, 1994-1996. Environment Agency, Thames Region, internal publication, 62pp.

Colclough, S.R., Gray, G., Bark, A., Knight, B. (2002) Fish and fisheries of the tidal Thames: management of the modern resource, research aims and future pressures. *Journal of Fish Biology*. **61. (A):** 64-73Consumer Council for Water (2008).

Dempsey, P., Ellison, S., Murray, D. and Song, J. (2007). Thames Tideway Project Quests Modelling Results Report – Draft. Report No.:UC7304 v3.

Jacobs Babtie (2006). Independent Review to Assess whether there are Economic Partial Solutions to Problems caused by Intermittent Storm Discharges to the Thames Tideway – Phase1 Final Report. Office of the Director General of Water Services, Ofwat Ref: PROC/01/0021.

Lee Tunnel and Beckton Sewage Treatment Works Extension scheme, ODA Consultation. Application Reference 08/01158/ODA. Comments by CC Water London and South East Committee, 13 August 2008.

Scott Wilson (2006).

Scott Wilson (2007).

Solomon, D.J., and Sambrook, H.T. (2004) Effects of hot dry summers on the loass of Atlantic Salmon, Salmo salar, from estuaries in South West England. *Fisheries Management and Ecology*, **11**, 353-363

Turnpenny, A.W.H. (2002). Thames Tideway Strategy Phase 2: Fishery Scoping Study. Consultancy Report no.FCR358/02 to Thames Water Utilities, Ltd. Fawley Aquatic Research, Fawley Southampton, January 2002.

Turnpenny, A.W.H., Clough, S.C., Holden, S.D.J., Bridges, M., Bird, H., O'Keeffe, N.J., Johnson, D., Edmonds, M., Hinks, C. (2004). Thames Tideway Strategy: Experimental Studies on the Dissolved Oxygen Requirements of Fish Consultancy Report no.FCR374/04 to Thames Water Utilities, Ltd. Fawley Aquatic Research, Fawley Southampton, April, 2004. http://www.wfduk.org/LibraryPublicDocs/ThamesTidewayStrategyExperimentalStudiesontheDissolvedOxygenRequirementsofFish [accessed 03.08.09]

UKTAG (2007). UK Environmental Standards and Conditions (Phase 2), June 2007. UK Technical Advisory Group on the Water Framework Directive.

UKTAG (2008a). Proposals for Environmental Quality Standards for Annex VIII Substances, Final Report, January 2008 (Revised June 2008). UK Technical Advisory Group on the Water Framework Directive.

UKTAG (2008b) UK Environmental Standards and Conditions (Phase 1) Final report. UK Technical Advisory Group on the Water Framework Directive.

Vinni, M., Lappalainen, J., Malinen, T. & Peltonen, H. (2004). Seasonal bottlenecks in diet shifts and growth of smelt in a large eutrophic lake. *J. Fish Biol*., **64**, 567-579.

Appendix A Peer Review of Fawley Report

THAMES TIDEWAY STRATEGY: EXPERIMENTAL STUDIES ON THE DISSOLVED OXYGEN REQUIREMENTS OF FISH
Report for Thames water utilities by Dr. A. W. H .Turnpenny et al., Fawley Aquatic Research

Review of the Report by Dr M Elliott, Institute of Estuarine & Coastal Studies, University of Hull (DRAFT)

General Comments

The project was very well structured with good internal and external project management and peer review and it had a good set of aims and objectives and implicit testable hypotheses. There was a very good experimental design and equipment set up and the experiments appear to have worked well. The report has a good coverage of the available literature, especially with the (unseen) earlier review although there are a few other papers with relevant information.

There was a good and appropriate set of numerical and statistical methods although other objective testing (e.g ANOVA and post hoc testing) could have been used to give greater confidence in the differences observed. There was a good set of methods of data presentation although some of the aspects (see below and on the annotated report) require to be further explained for a wider audience, depending on the use to which the report is put.

The discussion sections cover a wide field although they are often too brief and would benefit from being taken further. For example, the development of strategies by fishes to avoid hypoxia and to be tolerant of it is an interesting idea and worthy of further study for a wide range of species. There is a good set of recommendations for further work but there is the need to further collate and expand the suggestions and proposals to cover several of the aspects mentioned briefly in the final discussion, e.g. the impact of the work in meeting Directives, the use in classification schemes, the life history aspects of the fishes and the greater knowledge of the physical processes operating in the estuary. In particular, there is the need to summarise the development, spatial and temporal extent of water quality barriers and the behaviour of the different types of fishes in relation to these.

The Fish Risk Model is an especially interesting, valid and valuable idea and shows a good, logical approach. It makes a good use of the available data and perhaps should be regarded as the best available approach based on presently available data. The use of this is the most valuable part of the report in providing data on which to base the setting of water quality standards and, by extension, of discussing and provisionally giving those standards. While the method of deriving those standards is scientifically robust, the suggest of any standard as low as 1mg l^{-1} will be open to criticism as not being sufficiently in line with the precautionary approach. (It is also at odds with all other attempts to set WQ standards.) Hence the recommendations by the authors to use the higher standards will be more favoured by the environmental protection and nature conservation bodies. In particular, the responses by the rare, fragile and endangered species together with those by the dominant, and occasionally large, populations is important. Similarly, the authors should discuss the sensitivity of the species together with the vulnerability of the species (see below).

Specific Comments

Some changes of style and scientific reporting are needed but on the whole the report is very well written. However, some parts need rewording in order to clarify the text for the non-specialist and the summary needs further explanation (e.g. of how risk factors were calculated, for those who will not see/read the appendices).

The experimental set up using temperatures, etc as expected for the area is valid but there is the need to consider further the stressed state of the fishes prior to use (handling and starving). There is a good representative set of species, indicative for the estuary although, as emphasised by the authors, other species could be used. Furthermore, the authors have to consider further how these species can be combined.
The practical work had the major problem that CSO events did not occur in the frequency expected, based on previous years, but this could not be avoided. Hence it would be of benefit to repeat the experiment under CSO event conditions.
There is the need further to consider the stressors in combination (not just salinity), and there is the need to consider further the synergistic (and perhaps antagonistic) stressors, especially salinity, temperature, ammonia, turbidity and current stress. The importance of temperature and salinity in relation to time of migration needs rto be constantly mentioned and tested and the fishes' responses should be linked to the seasonal and spatial natural and anthropogenically-mediated DO sags in the upper (freshwater-seawater interface, FSI, turbidity maximum zone, TMZ) parts of estuaries. Because of this there is the need for more information on the tidal currents influencing the patterns and the fish behaviour, especially the effort required by fishes to overcome tidal stressors. Finally, although indicated briefly here, there is the need to further understand the physical processes, for example, by superimposing of the tidal patterns over the DO patterns.
Despite the slight reticence by the authors, it is considered here that avoidance is as important as mortality. Hence there is the need to consider the behaviour by fish in migrating through the area, the water column strata chosen during migration, and the possibility/actuality of an oxygen debt after migrating in relation to a DO minimum of given lengths. There is the need to consider further the fishes' behaviour in relation to water quality barriers and to consider further the carrying capacity of a water body both for oxygen and for given sizes of fish populations.
The fish chosen are a good, representative selection of the species present but there is the need to extend the list, especially for other Annex II species. This should then be accompanied, as indicated in various parts of the report, by further information on the lifestyle interactions of the fish, i.e. link the behaviour and avoidance to the times when they use the estuary and their osmoregulatory changes. These aspects are brought into the final discussion of the Risk Model but could be developed further.
The toxicity approach, using LC_{50} (and LC_{10}, LC_{90}) is valid and, in some places, there is an approach of range-finding tests followed by definitive tests (even though these terms are not used). However, as a further development and to make greater use of the data obtained, ET_{50} (effective time) and EC_{50} (effective concentration) indices could be calculated (based on behavioural data) and similarly LT_{50} could be calculated from the data as well as LC_{50}. In addition, the calculations for the toxicity parameters have been done graphically and it would have been better to have used probit analysis for calculating the toxicity summary data (LC_{50} etc) as this would give confidence limits (e.g. as on SPSS).
The findings have been complicated by using both Fawley and Chiswick experiments but perhaps this could not have been avoided. The differences between the two data sets are interesting but the importance and validity of the differences between the two are not known – hence it is always better to use the local conditions and local fishes, i.e. the Thames set-up and with Thames fishes.
It is a good idea to use the 10% mortality criterion but the authors should check that this represents sustainability. The latter will be related to population size irrespective of the proportion of fishes lost. There is also, as indicated on occasion, the need to incorporate the size of the fishes killed as pre-spawning mortality may be more important than post-spawning ones.

The authors acknowledge the problem of using trout as a surrogate for salmon, hence the need for further work especially to assess further the effects of salmon physiologically adapting prior to migration. The assumption that trout are considered as 'small salmon' needs to be checked as much rests on this conclusion. Similarly, there is the need to put both the conclusions and the suggestions for further work in the context of the times of passage of smolts, grilse and kelts in order to define the times and stages likely to encounter WQ problems.

The report mentions the other biological features of the estuary but the effects of low DO on prey species need to be expanded. In particular to discuss the effects on the abundances of prey not just presence of species. Similarly, other biological attributes, such as the genetic basis and differences within the fishes are mentioned but there is the need for more discussion on the genetic and phenotypic adaptations to hypoxia.

The report touches on many aspects but there is the need for more discussion on some especially to put the report in a management context. For example, the physiological responses, the energetics of adapting to the conditions, and the effects on the basal metabolic rate. There is the need for more information on interactions between the fishes, and it is necessary to consider the responses when there is a large number of fish migrating (as there is a BOD exerted by the fishes). Finally, here, there is the need to cover the problems of large associations rather than just the few fish in the tanks. It is especially acknowledged that the report does mention many of these aspects in passing but that further discussion and interpretation is required.

The data giving the ranking of the sensitive nature of different stages and different fishes is interesting and fits in with other literature. It is what one would expect for different estuarine fishes, sizes and stages, and for different ecological groupings (freshwater species, estuarine migrants and estuarine residents). In providing further experimental evidence of these features, the project is doing a great service. It would be possible, as a further development and refinement, to incorporate for these and other fishes, the ecological trait information.

The report mentions the effects of exposure to low DO events and it touches on the effects of time period of exposure. It provides a case-study of the DO minima in relation to tidal patterns. However, there is the further need to assess the recovery time for any fish from exposure to low DO events in relation to tidal patterns superimposed on the low DO (and hence the effects of repeated exposure to low DO events). Furthermore, given the energetic requirements (and thus oxygen requirements) of osmoregulation and the energetic requirements or moving with and against currents, it is better to assess the patterns at different salinities in relation to the euryhaline/stenohaline/freshwater preferences coupled with the migration patterns and behaviour of the fishes.

The discussion on the implications of the implementation of the EU Directives needs to be expanded or removed as at present it is too brief to be of value. In particular, it omits the recent discussions regarding classification schemes, the development of reference conditions, and the elements of the fish community in transitional waters to be monitored. Furthermore, it needs to mention the possible designation of the Thames as a Heavily Modified Water Body which will affect the use of the results. The implementation of the Water Framework Directive depends on the creation of reference conditions and the nature of reference estuaries. As the WFD concentrates on community structure rather than the presence of individual species then it is possible that changes to susceptible species may be masked. However, perhaps more emphasis should be placed on the implementation of the Habitats Directive and the maintenance of favourable conservation status for the Annex II species.

The discussion on the standards setting is very worthwhile although it also needs to be expanded. This discussion should be framed in terms of sensitivity and

vulnerability – a species or habitat could be sensitive but if there is not much of the habitat or species in a particular habitat then it will not be vulnerable. The main aim is to determine whether the fish use the available habitat, even if that is upstream of the water quality barrier, irrespective of whether the estuary is in/designated in a pristine state. Hence the main aspect will also be to determine the maintenance of favourable conservation status of the designated species. This will require an assessment of what is meant by Favourable Conservation Status of these fishes using estuaries and thus how to protect the species of conservation concern (see Elliott & Hemingway 2002 - Fishes in Estuaries, Blackwells Publ.).
The discussion of the use of standards and classification schemes again is valuable and valid although one questions whether it sufficiently incorporates a default category in line with the precautionary principle and thus recent thinking (see also the SEPA/EHS(NI) classification scheme and its default approach). For example, it will be necessary to include the most sensitive values/species (even if this means using sand smelt) but also the changes expected throughout the whole community. However, it is agreed that the first aim is to protect community structure although the conservation lobby and legislation puts emphasis on the rare, fragile and endangered species.
The Fish Risk Model is perhaps the greatest value of the report and is worthy of wider publication. It would be of benefit if it could be developed further with more data and for further species, especially all of those species listed as Annex II of the Habitats Directive. In particular, there is the need for the relative use by different population sizes in different parts of the estuary. It is arguable that the physics of DO sags in the estuary are not sufficiently understood (in relation to all environmental factors) in order to superimpose the behaviour of fish populations and different life traits over them and so further understanding is required for this. Finally, here, future work should be considered to incorporate this approach into a model and decision support system to aid managers.
The report and the findings indicate the importance of testing young and thus susceptible stages, again leading to the further checking of the worst-case scenario. In addition to this, there is the need to look at other water quality parameters in tandem, eg NH_3 and thus further create the scenario(s) giving the combination of conditions likely to produce the greatest effect. As an addition to this, it would be necessary to incorporate a (semi)quantitative element indicating the size of the fish populations at risk, e.g. Table 6.7 could have relative abundances added as a refinement.
Now that it has been developed, there is the need to consider the Fish Risk Model in more detail and to test against future scenarios and to consider hypotheses for future change. By necessity, the Fish Risk Model contains some educated guesses/assumptions which need further testing, for example the combination of events required to produce DO sags. The final comments regarding the applicability and the applying of the standards are valid although the use of the most lax, 1mg l^{-1}, despite being based on best available science, would be counter to all other approaches adopted for estuaries and may be regarded as being not-precautionary. Conversely, the use of 4mg l^{-1} is approaching the values used most often (5 mg l^{-1}) and intuitively as what is needed for protecting all species. The latter would this fit with a duty of care approach and the precautionary principle.
The use of the LC_{10} approach is considered robust and sufficient to satisfy the concerns of the nature conservation and environmental protection agencies. Because it builds in an element of a precautionary approach, although not totally, then it will be acceptable. Similarly, the use of a shorter exposure period (6 hr vs 24 hr) for the toxicity testing but coupled with an analysis of the periodicity of DO sags in relation to storm and tidal events, recovery times by the different fish species and the effects of repeated exposure to low DO periods will be useful and defendable.

Finally, there is a good set of recommendations but there should be even greater emphasise on further work on linking the life stages (especially the more susceptible juvenile stages), migrations patterns (especially of salmonids but also of flounder), synergistic effects and DO cycles.

/estfish/Thames Tideway/Review of Turnpenny Report 324.doc 30th September 2003

Appendix B TTSS Steering Group Responses to the Jacobs Babtie (2006) Ofwat Report, and Andy Turnpenny's Comments on TTSS Responses (given at the time).

Query based on JB report/ Ofwat or Defra question in relation to TTSS	TTSS Steering Group response	Andy Turnpenny Response to TTSS Steering Group Response
1. JB believe the storm of August 2004 resulted in tighter DO standards. Page 20 " *The high profile given to visible fish kills* " in the August 2004 event *"appears to have driven the setting of standards that are higher than would have been required on a purely ecological basis"* Were the standards set before August 2004?	The standards were set before the August 2004 event.	I am not sure where this JB comment came from. The standards were set before August 04.
	The standards were set as a result of laboratory studies on lethal dissolved oxygen concentrations for several species as well as 'avoidance' behaviour as a result of exposure to low dissolved oxygen levels.	Agreed.
2. Page 20 *"Allied with the avoidance noted above there is anecdotal evidence of the phenomenon of fish seeking refuge in harbours and of-line waters where some hydraulic separation can often be found*".	Although the fish studies identified that some species could take avoidance action, the speed and intensity of the onset of lethal conditions is likely to preclude this. There are no harbours. In the upper reaches there are a few small tributaries but these are not accessible, either because of weirs/barriers or because they dry out at low water. In any case they would probably be affected by polluted water during the next flood tide. All the docks have physical barriers. The best refuge is the open estuary but that means all the fish species would have to be able to travel there and back and to be able to tolerate the much higher salinity.	I agree with this in respect of juvenile fish but not necessarily adults. I agree that off-line opportunities in the Upper Tideway are presently limited.

	The August 2004 event happened within a few hours and it would have been impossible for fish to outrun the oygen"sag".	I don't believe this is necessarily the case. Again it will probably be true for the smallest fish. Evidence from JB trawling surveys carried out in September '04, following the extended period of hypoxia (which lasted throughout August) showed that fish were five times more abundant than when surveyed by identical means at the same time of year in 2002. One possible explanation is that fish moved down the Tideway in response to deteriorating conditions. There could be other explanations, e.g. 2004 was a 'better year' for fish but there seems to be no other evidence for this. The main point I am trying to make about avoidance is that we know from lab studies that certain fish have the ability to avoid hypoxia under suitable conditions and that there is circumstantial evidence that that fish do try to avoid hypoxia in the Tideway. I believe that gaining a better scientific understanding of this would help us to fully evaluate the significance of this potentially protective effect and possibly to work with it in developing solutions.
3. Would it be all species?	No it would not be all fish species. Different fish species behave differently. Flounder, one of the main species in the Tideway, did not exhibit migration away from poor quality water.	Agreed.
4. Would this effect the levels of DO allowed?	No. There are no refuges available to maintain sustainable fish populations.	See comments above. Movement within the Tideway but outside the hypoxic plume may protect some fish and would therefore contribute to sustainability.
5. JB suggest *"The DO criteria are fixed to achieve an aesthetic objective of preventing fish kills and not the true ecological aim of maintaining a sustainable fish population*" that the DO levels were set to prevent fish kills. Is this correct?	The DO standards derived for the Tideway are composite. They cover a range of concentrations, durations and return periods. This is to ensure that fish kills are avoided (1.5mg/l MIN) and sustainability achieved (2, 3, 4 mg/l). The durations and return periods were derived from literature and commissioned laboratory experiments which acknowledged that dissolved oxygen levels could be breached within a given time period without affecting the long term sustainability of overall populations. The standards were set to achieve sustainability, whilst accepting that there would be a certain amount of mortality. The overall conclusion of the fish study was that with the AMP4 STW improvements and a CSO solution in place, fish sustainability would be marginal.	

6. If so could the DO levels be relaxed and still maintain a sustainable fish population?	The interim standards had the three current standards for certain time frames and frequencies with a minimum dissolved oxygen standard of 1.0mg/l. Extensive fish studies were carried out both in the river and in the laboratory. This used a Fish Risk Model to help set standards. The report " Experimental Studies on the Dissolved Oxygen Requirements of Fish" state in *"7.6 Setting Standards .For most of the indicator species/lifestages, the Interim Standards appear satisfactory, other than the 1 mg DO/l Minimum Standard, which is possibly too low to be protective; raising this level to 1.5 mg/l would provide appropriate protection for the fish stocks.*" The 1.5mg.l minimum standard was adopted. The suggestion that standards should be relaxed for certain sections of the river, to allow grossly polluting discharges to cause frequent fish mortality, is without precedent in this country, and is in direct contravention of the UWWTD requirement to limit pollution from CSOs.	I agree that the standards set are appropriate to the STSS objectives. The point of the JB approach is that we were asked for the purposes of this project to suggest possible partial solutions that might deliver a large part of the benefit for a small part of the cost. My own approach to this has been strongly influenced by analysis undertaken by JB following the August 2004 event. Applying ecotoxicological response data to to the EA water quality observations predicted that for several of the species considered, mortality levels would be sustainable, and that for the remainder, marginally sustainable, based on a return period for this magnitude of event of no more than 10 years. That is with no solution; I am therefore suggesting that with AMP4 improvements and a partial CSO solution, it may be possible to push the fish into sustainability, though accepting the possiblity that some fish kills might still happen. See box below also. I wouldn't advocate different standards for different sections of the river, although the spatial discontinuities are important in this debate. Fish in the Tideway are generally scattered through a number of Tideway 'zones' and therefore while suffering high mortalities in the grossly polluted reaches, the bulk of the population may survive. This can mean that there will be heavy fishkills but that mortalities over the Tideway as a whole would still be sustainable. 'Sustainability' in this context I have previously proposed as meaning 10% or less mortality per annum for short-lived species such as gobies or smelt, and possibly 20% or more for multi-spawning-class species such as salmon, flounder or bass.
7. If so to what level?	Comparison of the TTSG standards with other widely used standards shows the TTSG to be less stringent.	

	The draft standards for the Water Framework Directive specify the achievement of a 95 percentile of 5mg/l for "good status", with 3ml/L DO for moderate status. Habitats Directive requires a 95 percentile of 6mg/l for low saline water (such as the upper Tideway). The UPM has set 4mg/l for 1hour in a year. (The TTSSG allows this for 29 tides before conditions are presumed to breach the standard). Although the TTSS standards do not incorporate 95 percentiles, it has been calculated that to comply with the whole suite of standards would mean that the proposed scheme would be required to meet a 95 percentile of less than 3mg/l. This is less onerous than any of the standards above. In the context of DO standards, it should be noted that national policy requires schemes for improving unsatisfactory CSOs to use the UPM standard, and that large numbers of schemes utilising this procedure have been approved, funded and implemented.	
8. The JB report suggests that the STW improvements will be sufficient. *"The data presented to us in the TTSS study appears to suggest that the majority of the work required to achieve this objective already forms part of the planned AMP4/AMP5 works."*	Whilst the STW improvements are vital to resolve the chronic low DO in the middle reaches, and to achieve the 4mg/l standard and do reduce the number of fish kills assessed, they are not sufficient to meet the remaining criteria and to provide a sustainable fish population, in particular the acute fish kill affects of storm events such as that seen in August 2004.	See comments above. From a sustainability point of view, the AMP4 improvements might have pushed the present sustainable/marginally sustainable status into fully sustainable, while not preventing acute fish kills. For example, improving conditions in the middle reaches might increase the likelihood of fish outrunning hypoxic fronts. This may not be sufficient by itself to ensure sustainability - a partial solution for the upper reaches might still be required.
9. "Recommendation …reanalysis of the criteria and cost benefit analysis would appear to be necessary."	The Steering Group has reconsidered the criteria and considered them appropriate. The cost benefit analysis already takes account of the reduction in fish kills from the STW improvements and is therefore appropriate. The benefits to accrue from the STW improvements on their own and with the tunnel were fully assessed in the cost	See my response to item 6 above.

	benefit analysis.	

Appendix C Extract from Consumer Council for Water (2008) Comments on Tunnel Scheme, regarding Ecological Damage

Taken from pages 9-11:

Ecological considerations

1. The considerations are as follows:

i. **Cost benefit**. Whether the full scheme is cost beneficial depends on the final balance between any revised estimates of costs and cost risks on the one hand, and benefits or possible damage from overflows on the other. We have no further information about costs than those given in the Thames Tideway Regulatory Impact Assessment in January 2007. There is however some uncertainty about benefits (see Para 53 below.)

ii. **Significant risk of actual ecological damage**. The planning note gives an assessment of ecological risk. It does not address the environmental downside of the substantial carbon footprint of such a large concrete and steel structure as the full Thames Tideway tunnel, estimated at 590,000 tonnes of C02 in embedded energy, plus another 181,000 tonnes in energy for tunnel boring (see table 15, Thames Tideway RIA.)

Nor does it address the possibility that the ecological impact of the tunnel may be overtaken well within the life of the asset by further adverse changes in the ecology of the river due to rising temperatures. The study by Fawley Aquatics for the Thames Tideway Strategic Study Group remains the most comprehensive study of the difference a Tideway tunnel might make to the sustainability of various fish species in the Tideway[i]. A comparison of tables 6.10 and 6.11, showing the difference in expected fish mortalities with and without a tunnel, illustrates a very finely balanced case for the investment in purely ecological terms. It is not clear whether the further modelling reported in Chapter 8 of the Environmental Impact assessment overtakes this. There has been some discussion of the progressive development of standards taking account of water framework directive technical advisory group work. This moves the focus on from acute events, i.e. fish kills (the aspect offered to respondents in willingness to pay (wtp) valuation work) towards chronic influences on sustainability and the EA's wider objectives for protecting the river. These may involve a degree of future-proofing against global warming. Improved summer levels of dissolved oxygen may allow salmon to migrate at higher temperatures. If such considerations are in play, they should be made explicit – especially where they carry a significant carbon cost.

iii. **Reasonable certainty between risks and potential causes.** One of the drivers of the EA's concerns about storm overflows in the Tideway has been the suspected impact of present conditions on salmon, and in particular the possible role in the poor or intermittent return of introduced salmon from migration. It seems to be accepted that some 40 of the 120 species sighted in the Tideway exist in sustainable populations, and that they are sustainable whether or not the full Tideway tunnel scheme is built. The absence of sustained returns of salmon from salmon migration may be a function of water quality in the Tideway, water temperature (both in the Tideway and in the Southern North Sea), water flow, and the ability of reintroduced fish to follow the olfactory clues that guide return to their natal river. Although CSO overflows can be a factor in deterring migration of adult salmon, it is unclear whether it is thought that dealing with overflows is a sufficient measure to ensure return of salmon for an extended period, despite projected temperature increases which are already near the physiological ceiling of the species in hot summers. We note also that there has been considerable difficulty in establishing contributions to the causality of fish kills, including the relative contributions from storm overflows from the collecting system and those from sewage treatment works. It is clear, however, that the most often cited event of 3 August 2004 had little to do with overflows from the Tideway collecting system. This fish kill followed a severe storm that caused release of untreated effluent from storm tanks and activated sludge from Mogden sewage treatment works, which is outside the catchment. Overflows from Mogden have played a part in many oxygen depleting events, and will be addressed by agreed investment outside the scope of the Tideway tunnel.

iv. **Reasonable certainty that the remedial measure will give its predicted positive effect**. The RIA suggests that the tunnel will not meet its ecological objectives by some point before 2080. There is a possibility that it may not meet them by 2050. If this is likely, it reduces the value for money of investment in a full Tideway tunnel.

v. **Infraction proceedings:** given the lack of information about the European Commission's case, it is difficult to say more than that the ECJ ruling in the Bromley case is a relevant new fact. It is also notable that the only cost benefit information available to the Commission in April 2006 was net present value (npv) calculations of the Thames Tideway Strategic Study Group, based on the overtaken wtp survey of 2002. In so far as any justification for the investment is based on the requirements of the WFD, as well as the UWWTD, it is too soon to say what bearing the Directive has. As indicated above, the Directive recognises the concept of disproportionate costs. DEFRA has yet to issue guidance on how this should be interpreted.

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