Thames Tideway Project – Integrated Wastewater and Estuary modelling for Water Quality Compliance Assessment

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Introduction

Although the Thames Tideway now has a reputation of being a clean metropolitan river, it is still impacted by numerous storm sewage discharges during wet weather. These derive from a number of CSOs (combined sewer outfalls), pumping stations and wastewater treatment works. The discharges create amenity problems due to sewage-derived litter, potential health hazards due to pathogens in the sewage, and, from time to time, low dissolved oxygen levels which damage aquatic life.

In the light of these problems, it was agreed between Thames Water and its regulators (Environment Agency, Ofwat, DEFRA) that the Thames Tideway Strategic Study be carried out between 2000 and 2005 to investigate the issue of CSOs and identify possible solutions for implementation post 2005. A Steering Group was convened and included representatives from DEFRA, the Environment Agency, Thames Water and the Greater London Authority, with Ofwat represented in an observer status.

The strategic study is too extensive to cover in one paper. Instead, this paper concentrates on the technical issues involved in developing a modelling framework and a procedure to help understand the impact of wet weather discharges and to assess the effectiveness of potential solutions.

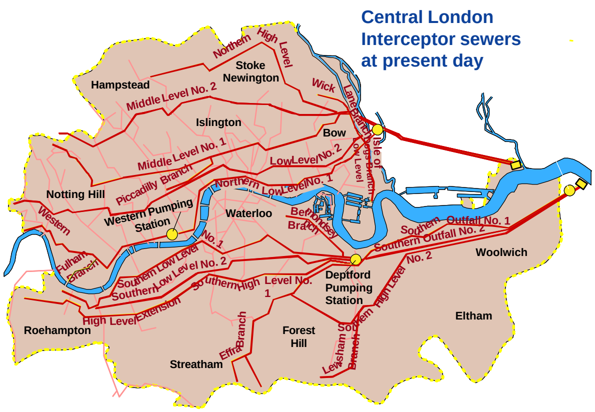
Like all CSO discharge problems, the measure is in the receiving water, but the solutions are in the management of the wastewater network. This requires an understanding of the performance of the estuary under present and possible future discharge conditions and also how the wastewater system can be modified to achieve the required improvements in water quality.

The catchment

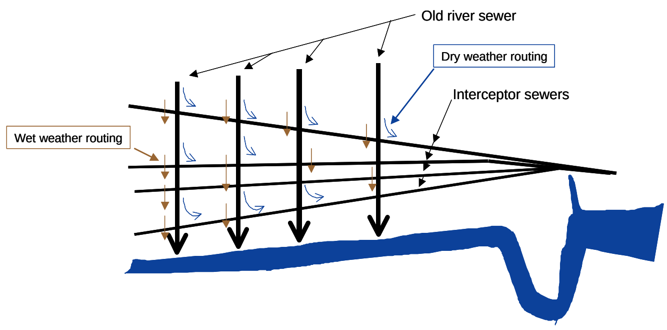
The Thames Estuary stretches from the tidal limit at Teddington to the North Sea beyond Southend, a distance of over 100 kms. The upper and middle reaches of the estuary between Teddington and Dartford are generally referred to as the Thames Tideway.

In the summer months the residual river flow that discharges to the estuary at Teddington is relatively low - normally less than 10 m^3/s - partly due to the high level of freshwater abstraction for water supply to London. The upper reaches of the estuary are particularly vulnerable to pollution because of the low dilution afforded by these freshwater flows.

Water quality in the Tideway is dominated by the discharges from 5 wastewater treatment works (WwTWs) operated by Thames Water, which include the largest works in the UK. Together these works serve a population of about 8 million. Under stable, dry weather flow conditions, the treatment works are capable of producing consistently high quality effluent. They are, however, limited in terms of maximum flow that they can treat satisfactorily and large quantities of storm sewage are discharged to the river during wet weather



The upper and middle reaches of the Tideway are also substantially influenced by CSO discharges from the Beckton and Crossness WwTWs catchments. These catchments cover an area from Acton to Barking and from Sutton to Walthamstow. The sewer network was mostly constructed in the mid 19th century with a number of interceptor sewers taking wastewater to the east of the then town boundary. These sewers intercepted many of the original watercourses, which had become heavily polluted with sewage. As a result the current system is fully combined.

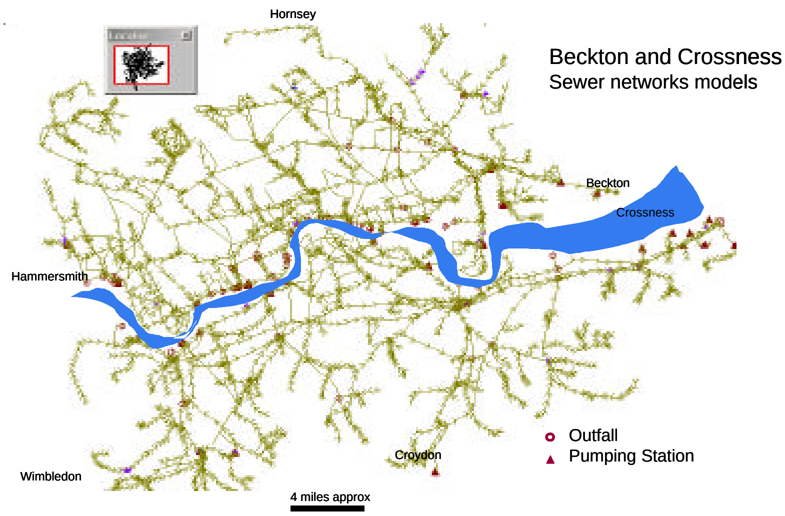


The operation of the system is illustrated in the diagram opposite. Wastewater and storm water gravitate to the old river sewers. These are large capacity sewers. At each interceptor, provided there is capacity, flow will be taken eastwards but kept as high as possible to minimise pumping. If there is no capacity available, then flow continues downhill and will eventually reach the Tideway at one of about 60 CSOs. Flow routing is fixed in dry weather, but in wet weather the route that the storm sewage can take is not defined.

Discharges from about 60 CSO's are made to the Tideway (or the tidal river Lee) between Hammersmith and Woolwich and have a major effect on water quality at times of wet weather. Even in moderate rainfall some CSOs can operate because of the limited sewer capacity to convey flows forward. The pumping stations that control many of the large discharges can pump the entire contents of their inlet sewers to the river. CSO discharges to the Tideway occur about 60 times per year with volumes in excess of 1 million cubic metres for large events. The other WwTW catchments are mainly separate systems.

Existing Sewer and Estuary Models

When the strategic study began in 2000 there were a number of existing sewer and estuary models available and a decision was taken to make maximum use of these models for the study. Two estuary models of the Tideway were available, both capable of simulating the hydrodynamics and water quality and using similar code for these processes. Thames Water had the 2DV model built by Hydraulics Research and the Environment Agency had the Quests1D model built by WRc. The Quests model is one dimensional throughout the whole length of the estuary and has the advantage of rapid simulation. The 2DV model is one dimensional upstream of Westminster but uses a multilayer structure downstream to provide a better representation of any depth variations in sediment and DO concentrations. Both models were built in the late 1980s/early 1990s and were calibrated with the best available data at that time.



Thames Water has InfoWorks network models covering the major sewerage catchments of London. The Beckton and Crossness catchment area (Martin, 1995) is modelled with all main sewers and diversion and bifurcation structures. This was completed in the mid 1990s and calibrated with the best available data at the time. The Mogden catchment is less complex and a more detailed model of this is available.

Water quality objectives

By reducing the load of storm sewage discharges to the Tideway, the Steering Group saw benefits for both the ecosystem and for the use and enjoyment of the river. This led to setting objectives covering three water quality areas:

- reduction in aesthetic pollution by sewage litter;

- maintaining dissolved oxygen (DO) levels to support a sustainable fishery, and;

- improved protection for water-based recreation.

The aesthetic and health related benefits were assessed, at this stage, largely on the basis of the reduction in the frequency of intermittent discharges – and this could be quantified by using the sewer models alone.

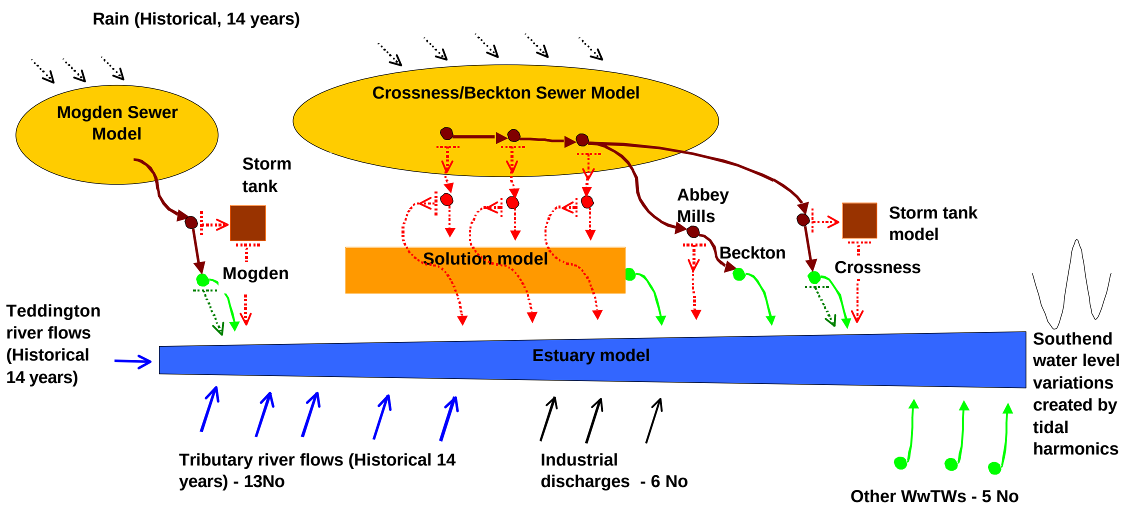
As there were no existing standards for fishery protection in this type of estuary, the Steering Group saw the need to develop standards based on the frequency and duration of low DO episodes in the Tideway. This approach is similar to that which underpins the use of the Fundamental Intermittent Standards (FIS) used for Urban Pollution Management (UPM) studies in freshwater rivers (FWR, 1998). The estuary standards that were developed (Table 1) include a 4 mg/l standard to protect fish from sub-lethal effects of hypoxia and a 1.5 mg/l standard to prevent large-scale fish mortality. These standards were corroborated by a fish study that investigated appropriate DO levels for local fish species.

Table 1 Interim Dissolved Oxygen (DO) standards

Dissolved Oxygen (mg/l)	Return Period (years)	Duration (tides)
4	1	29
3	3	3
2	5	1
1.5	10	-

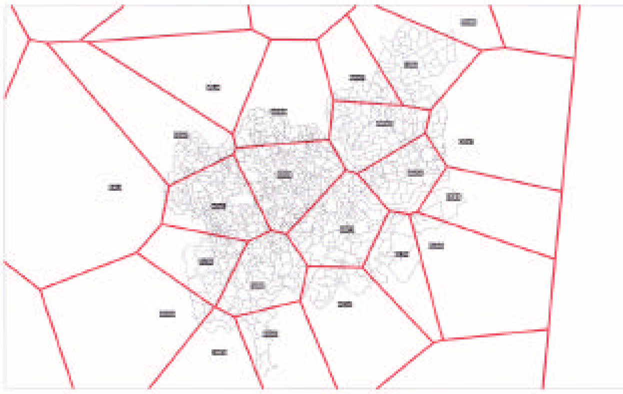
Establishing a Compliance Test Procedure

The DO standards required an integrated modelling approach using both the sewer and estuary models. For this purpose an overall modelling framework and test procedure were established. While the DO standards may change (for example, with the introduction of the Water Framework directive) the test procedure developed will be robust enough to allowing testing against other standards in the future.



Overall Modelling framework

It was decided that, for testing compliance with these standards, it would be necessary to use a set of events that were thoroughly representative of the rainfall and environmental conditions in the area. The use of historical events was agreed as this allowed the appropriate interaction of rainfall with other environment conditions such as river flows and temperature. A long historical record was required to give confidence in covering all the possible interactions. The main constraint on record length proved to be the rainfall data. The target was to have at least 15 years of data (to allow an adequate check on the 5 year Return Period standard) but the best that was available, with adequate spatial and temporal resolution, was 14 years. (This has since been increased to 30 years using a combination of historical data and a spatial/temporal rainfall model).



From this period (1989-2002), fine resolution rainfall data were assembled from 23 land-based raingauges across London. The data were subjected to a screening process that was designed to identify confidently enough 'big' events to be sure of encompassing all those that could cause threshold breaches for an *upgraded* system. Only summer events were considered because DO problems in the Tideway only occur during the warmer summer months. An initial screening produced about 100 summer events that, after a spill load analysis based on sewer model results, were slimmed down to just 63 major events.

All the other environmental data that were needed for the estuary modelling were then assembled. These included freshwater river flows and quality, temperatures and solar radiation. These data covered a period of six weeks before the start of each storm and a following period of about 4 weeks. This allowed initialisation of the estuary models to the prevailing climatic conditions and also tracking of the recovery of the estuary after each event.

Finally, the major, continuous inputs to the estuary were defined and appropriate flows and quality assigned to each. These inputs included the five Thames Water WwTWs, three Southern water WwTWs and six industrial inputs (of which three were power station cooling water discharges).

Having gathered together all the necessary data, it was agreed that the overall Compliance Test Procedure, for any potential solution, would involve the following steps:

- representing the solution within the sewer models;
- running the sewer models for the 63 events to predict the intermittent discharges (CSOs, storm tanks and the extra flow through WwTWs during storms);

- running the estuary models for the same events, using the intermittent inputs from the sewer models, the appropriate environmental conditions and the continuous inputs;

- analysing the DO predictions from the estuary models to establish how often (times/year) the different DO thresholds (4mg/l for 29 tides etc) were breached at each location along the Tideway, and;

- comparing the predicted breach frequencies with those that were allowed by the water quality standards.

As detailed earlier, a major assumption in the procedure was that the 63 events would include all those in the 14 year period that could cause threshold breaches for an *upgraded* wastewater system. As such, there could be confidence in saying whether or not a solution was likely to be compliant with the DO standards. It is important to note that the 63 events did not include all those that could cause threshold breaches for the *existing* wastewater system. The procedure was not designed to quantify existing compliance or to fully quantify the *change* in performance that a solution would provide.

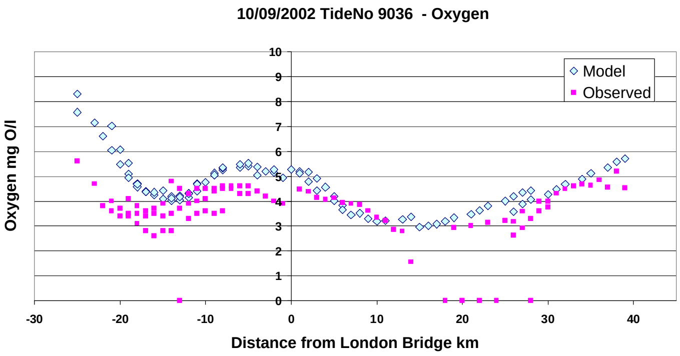
Refining the estuary models

Before using the models for compliance testing some time was spent in checking their performance and gaining a greater appreciation of their reliability and limitations.

The estuary models had, until recently, mostly been used for understanding the impact of continuous discharges. It was necessary to be confident that these models could predict reliably the DO response to storm events. To this end, a programme of recalibration and verification was carried out in 2001/02 based on using storm inputs predicted by the sewer models for historical events/periods and the corresponding DO responses as picked up by the routine Automatic Quality Monitoring Stations (AQMS) along the Thames. No new event monitoring was carried out.

The programme was iterative. Working closely with the Environment Agency, different historical periods/ storm events were selected and investigated to allow different processes to be explored. The models were first checked and recalibrated for a number of dry weather periods when there was little algal activity. The results showed that the hydrodynamic and salinity predictions were good and that the general pattern of DO levels was being represented although some features could not be explained. Then, a summer period, where there was substantial algal activity, was reviewed. The models had some success in representing the peak DO levels and the diurnal patterns created by the algal activity but had less success in predicting the trends over time. It seemed clear that the relatively simple algorithms used for the growth and decay of algae were not adequate for the complex processes in operation in the Tideway. Nonetheless, the next stage was to look at the model response over a full 6 month summer period that included a number of storm events. The most noticeable finding for this period was that the estuary models seemed to substantially underpredict the effects of storms. Further investigation indicated that this was due partly to problems with the radar data used to generate the rainfall inputs for the sewer models and partly due to the discharge of activated sludge from Mogden WwTW during storms.

Mogden WwTW, serving a population of 2,000,000, discharges into the upper reaches of the Tideway. During wet weather periods, considerable quantities of activated sludge are discharged to the river. On a falling tide the Mogden effluent can interact with CSO discharges further downstream and create a significant biochemical reaction resulting in a rapid loss of dissolved oxygen. Some effort was made to quantify the problem and represent it in the estuary models, but this has not been fully successfully. However, the work has identified a biochemical process that will need to be addressed separately from the CSO discharges.



In the final calibration stage, events were selected that were largely free of the Mogden effect and for which more reliable ground-based rainfall data were available. The observed DO sags for these events suggested a more rapid decay process for CSO material. The model decay rates were adjusted for these discharges so as to better represent the shape and recovery periods for the DO sags. However, it was still clear that total CSO loads were being under-represented by the sewer models and a decision was taken to factor these loads, as discussed in the next section.

Refining the sewer models

Sewage quantity

When the sewer models were first built in 1994 they were verified for dry weather and minor events. However, at that time the available monitors and rainfall data were not adequate for verification against major events.

As part of this Tideway strategic study, Acoustic Doppler Flow Monitors (ADFM) were installed in targeted locations and some larger events were captured and used to check the model. The results provided reassurance that no significant changes were needed to the model.

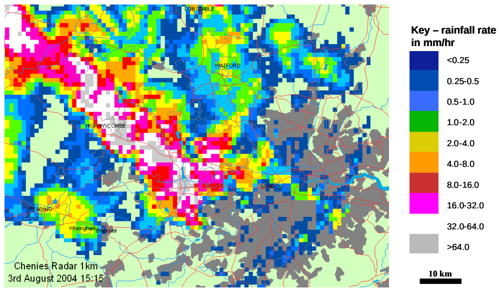
For running the calibration events for the estuary models a good spatial representation of the rainfall was required so that CSO discharges along the whole length of the Tideway were accurately estimated. Weather radar data in 2 km squares was available for the test periods. These data had been calibrated using the IOH HYRAD methodology (Moore et al, 1991) but the volume of the data made it very hard to check completely. When used for the calibration events the spill output was much lower than anticipated. Going back over the radar data in detail established 2 points:

- that the radar calibration had smoothed out peaks and troughs more than was realised, with a general reduction in volume for major events, and;

- from time to time the data included a widespread indication of long duration low intensity rainfall that was not really there. This did not create enough wetness to upset the statistics for a single location, but was enough to seriously overestimate flow volumes in a dry period.

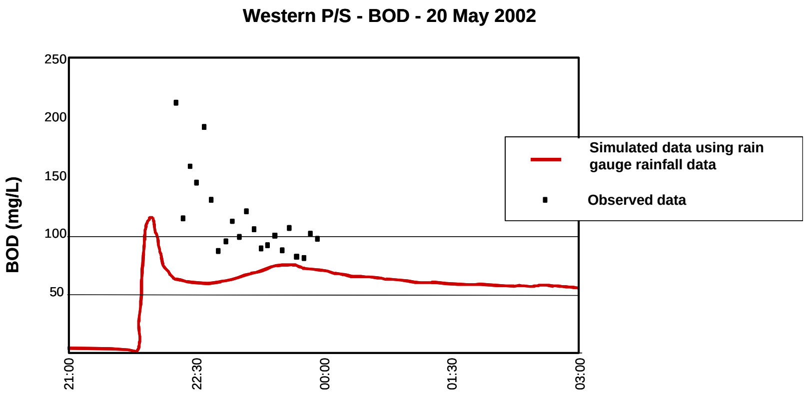
The radar data was again reviewed and compared with local raingauge data. The conclusion was that the radar data gave a reasonable representation of daily rainfall but was too inconsistent for sewer modelling. Subsequent sewer modelling used the land-based raingauge data described earlier.

The review of the radar data also included a review of the new Nimrod data (Kitchen and Blackall, 1992) from the Met office (see picture). This gives rainfall at 1km resolution and will clearly be extremely valuable for future sewer modelling.



Sewage quality

Obtaining storm sewage quality data in London sewers and outfalls is difficult and very few data were available. Simulated model output was compared with some data collected by the Environment Agency. Patterns of concentrations were found to be similar but in general the simulated values were lower than those measured – see plot opposite. It was concluded that the underprediction was largely due to the fact that the sewer models did not include the *long-term* build-up of sediments and subsequent resuspension during large events.



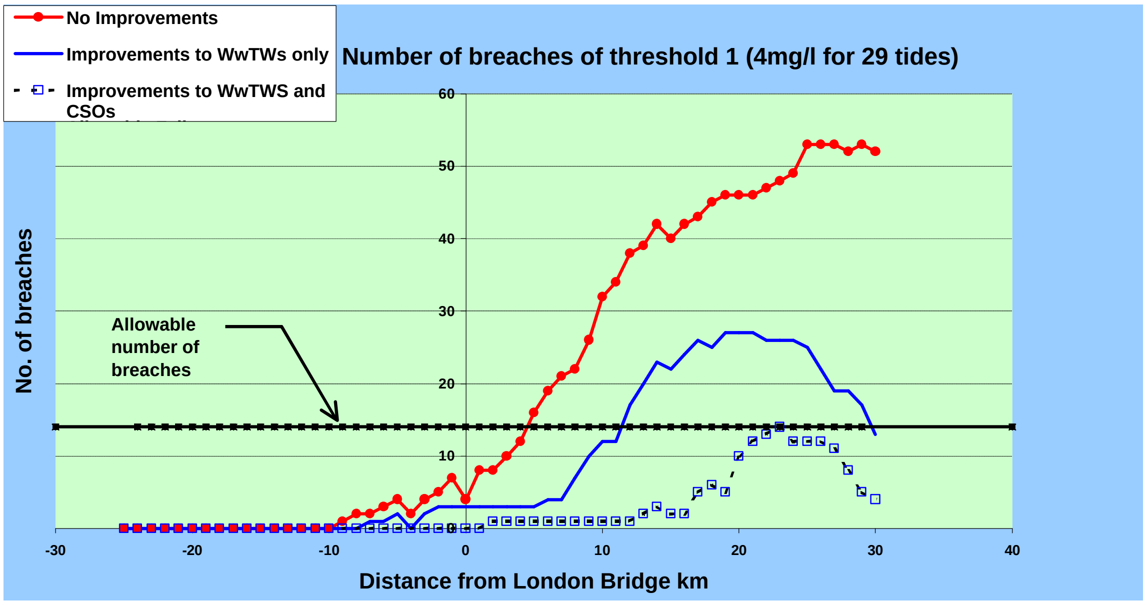
Comparison of Measured and simulated concentrations at CSO

As indicated earlier, a decision was taken to factor the spill loads predicted by the sewer models. This was justified by the underprediction in spill concentrations and the need for greater loads to explain the DO sags produced in the estuary. It was found that a multiplier of 1.5 on simulated load, to cover the unmodelled elements, gave the best compromise for predicting DO sags over a range of events. This is an area for further investigation where a lot more data will be needed

Solution testing

With the models checked and calibrated as far as possible with the available data, the Compliance Test Procedure was applied, as described earlier. The procedure was executed for the existing system and for a wide range of solution options involving both WwTWs and CSO improvements. Each application of the procedure resulted in an estimated number of breaches of the DO thresholds within the estuary – and these numbers could be compared with the DO standards.

The results were presented in graphical form so that the Steering Group could easily see where there were problems in the estuary and the relative effectiveness of different options. The illustrative plot below shows how improvements to both the WwTWs and to the CSOs are needed to achieve compliance.



Conclusions

1. The study started from a position where there was little knowledge and less confidence about the importance of CSO discharges on the Tideway quality.

2. It has been possible to make highly effective use of existing data and models and to gauge the reliability of their use.

3. The study has highlighted a number of important issues affecting the Tideway and identified where further data collection and model refinement are needed

4. The Compliance Test Procedure has proved effective and robust and has given confidence in quantifying improvements for different options.

5. The study started from the premise that the modelling would only be used for a comparative performance assessment. It was recognised that it would not be perfect. This is still true, but as the study progresses there can be a more realistic evaluation of the results in absolute terms.

References

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Acknowledgements

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