Integrated Urban Catchment Management in the Upper River Tame catchment

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ABSTRACT
Historically the river quality in the Upper River Tame in the Birmingham conurbation has been affected by wet weather discharges from the urban wastewater system. This paper investigates the polluting load and its impact, using the Integrated Catchment Model (ICM) SIMPOL3. The ICM helped to quantify the combined sewer overflow (CSO) contribution to river flow, and demonstrated that this contribution could be 50% of the total flow for short periods. The modelling allowed the contribution of the CSO and storm tanks discharges to be quantified in terms of their effect on DO, and demonstrated that their entire removal would only improve the resultant dissolved oxygen sag by 1mg/l.

Real Time Control (RTC) functionality was incorporated into SIMPOL3, to identify the potential for storage savings, and the enhanced model was used to demonstrate, for a continuous 3 year rainfall record, that RTC could provide the same level of environmental protection for a 10% volume saving at the downstream treatment works storm tank and reduce the spill volume by 16%. CSO spill volume was reduced by 9%. RTC did not result in significant improvement in river quality, due to the dominating effect of effluent load from upstream. Consequently, RTC for this catchment, for the conditions modelled, would not be economically viable given the Capex and Opex costs of an RTC scheme.

INTRODUCTION
Historically the water quality in the River Tame has been poor, suffering from the legacy of the industrial revolution. There have been fish kills that were associated with summer high flow events following extended dry weather periods, notably in July 1995. But steady improvements have been made in the last two decades resulting in an improvement in river quality. At the beginning of the AMP3 period there were approximately 400 operational CSOs in the catchment. The Environment Agency had identified over 90 as unsatisfactory intermittent discharges (UIDs), some of which contributed large volumes of diluted sewage into the river during rainfall events, and instructed Severn Trent Water to upgrade these overflows and reduce the polluting load in the river.

In order to derive effective upgrading solutions it was necessary to understand how these primarily summer rainfall events caused the observed DO sags and pollution problems. As the Birmingham catchment is so large and complex, understanding how the catchment responds as a whole to rainfall and identifying sources of sewage derived pollution has been very difficult to date. Although a previous study had attempted to determine the wet weather pollution problem (WRc 1998b) it was constrained by the use of the limited EA routine sampling data, which is unlikely to provide a comprehensive view on the wet weather situation. Indeed this previous study had shown that the routine data did not identify an ammonia problem associated with wet weather in the catchment. What was required was a tool that would help understand this response by representing the various catchment components and modelling observed effects and then help to identify suitable upgrading options.

This paper presents part of a PhD study undertaken at the University of Birmingham (Murrell, 2008) to investigate the transfer of pollutant load from sewer to river and its fate using an integrated catchment model capable of simulating many years of continuous rainfall. An additional aim was to understand the influence of storage in the sewerage system on that transport. This paper will focus on an investigation of Real Time Control (RTC) and whether it can offer any benefit in terms of maintaining, or enhancing, river water quality for reduced in-sewer storage.

INTEGRATED CATCHMENT MODELLING

River Tame UPM Study

In 2000, WRc proposed the use of their SIMPOL3 model, which was in development and had not yet been used on a large urban catchment. They proposed that SIMPOL3 would help identify the volume of storm sewage entering the river and its subsequent impact. This was unique because although it had previously been possible to identify the volume of storm sewage, through the use of sewer hydraulic models, it had not been possible to predict the impact of these spills on a river network that was responding to the same rainfall and could also account for the effects of upstream pollution from the same event. Once the sources of pollution had been identified and represented and their impact understood, the SIMPOL3 model could then be used to identify upgrading solutions to those UIDs which would enable the river to achieve the Environmental Quality Standards (EQS) set by the Environment Agency.

This SIMPOL3 model was specifically designed and built to fulfil the requirements of the Tame UPM Study (WRc, 2003a, 2003b, Dempsey *et al.*, 2003 and Smith *et al.*, 2003).

The completed model has the following characteristics:

It is a fully integrated representation of all the wastewater systems in the catchment. As such, any interactions between elements of the systems (e.g. the effect of storage in one part of the system upon spills further downstream) are represented.

The hydraulic performance of the combined sewer system has been calibrated against that of the InfoWorks models provided by Severn Trent Water. The hourly SIMPOL3 results were compared with the InfoWorks 5 minute results that had been aggregated up to hourly values. In doing so some loss of precision was inevitable, which would be more apparent in smaller subcatchments where response times to rainfall events would be in the order of minutes rather than hours. This limitation could be resolved by using a smaller timestep, to provide a better representation in possible cases where the sewer catchment spills before the river catchment has responded at all and, therefore, the dilution offered would be little more than DWF levels. This was not done for this study as this capability in SIMPOL3 had not been fully tested at that time.

The SIMPOL3 model generally predicts the overall flows to within 1% of those in the InfoWorks model and spills to within 5%. The model includes backing-up effects caused by surcharging on the Black Country Trunk Sewer (BCTS).

The sewer base flow and quality have been set based on load per head of population and trade flow, plus infiltration. The modelled results are broadly in line with those observed at different locations, although there is wide variation when compared with observed data, with BOD varying between -80% to +50% of the observed data. A similar variation is observed for ammonia.

The sewer sediments and storm quality response has been estimated based on observed data. Again the variation in load mobilised during storm events is large with BOD ranging from 0 – 52g per head of population.

The river flow response has been calibrated against observed flows over three years at four gauging stations in the catchment. The general level of agreement is reasonable in terms of baseflows and storm response, such that the model is likely to predict a sensible river flow at the time of CSO spills where both processes are driven by the same rainfall events.

Default process rates have been used for the river water quality parameters in the model. These default rates are considered to be conservative. The background river quality has been calibrated, where possible, against the results from routine GQA sampling. Good agreement has been possible at some sites. However, at other sites the GQA data indicates very poor quality that cannot be explained by the model. At these locations there are likely to be other significant inputs which are not explicitly modelled and which cannot be adequately represented by the method used in the model for background quality. The model predictions for river ammonia and DO concentrations have been compared with the continuous monitor data at Water Orton and show a similar response to storm events. To some degree this helps to confirm that the river process rates used are reasonable.

The model predictions have been compared against a strategic dataset collected during the 2002 summer. These comparisons provide confidence in the overall validity of the SIMPOL3 model.

Catchment Response

The SIMPOL3 model was then used to investigate the transport mechanisms of flow and load within the catchment, particularly under wet weather conditions. For this analysis individual rainfall events were studied in detail. The event of 30th July 2002 was notable for its large size and variability, as shown in Figure 1. The SIMPOL3 model was run for a continuous two year period and the results for this event were examined in more detail to determine the CSO spill contribution to the river flow and its subsequent impact.

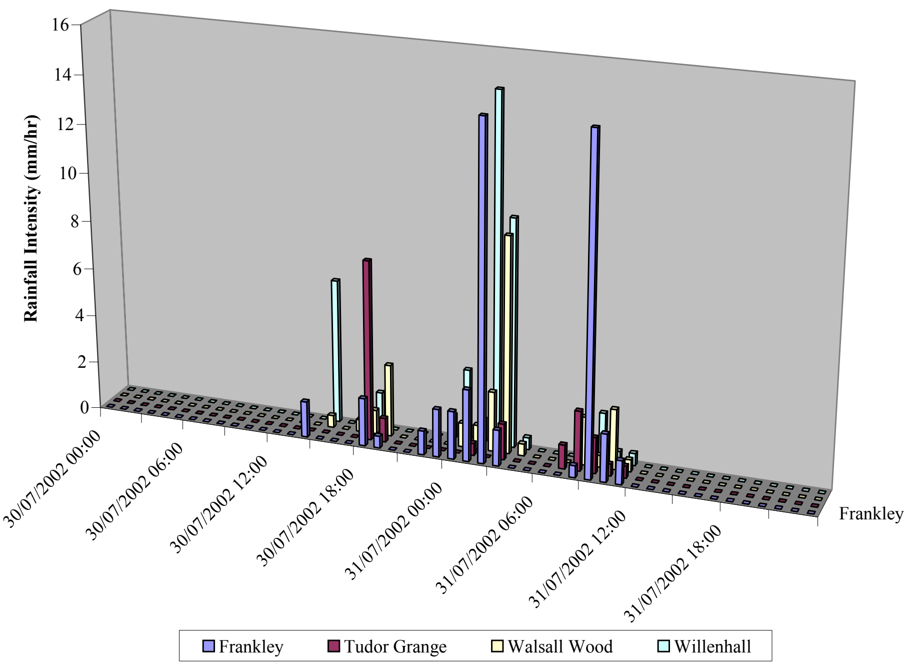

Figure 1 Recorded hourly rainfall for the event of 30th July 2002

The model was then run using the same conditions, but with the CSO spills "disconnected" from the river, so that their impact could be quantified. This is illustrated in Figure 2, which shows the river response with and without the CSO spill contribution and demonstrates the CSO contribution for that event to be 16% of the total river flow.

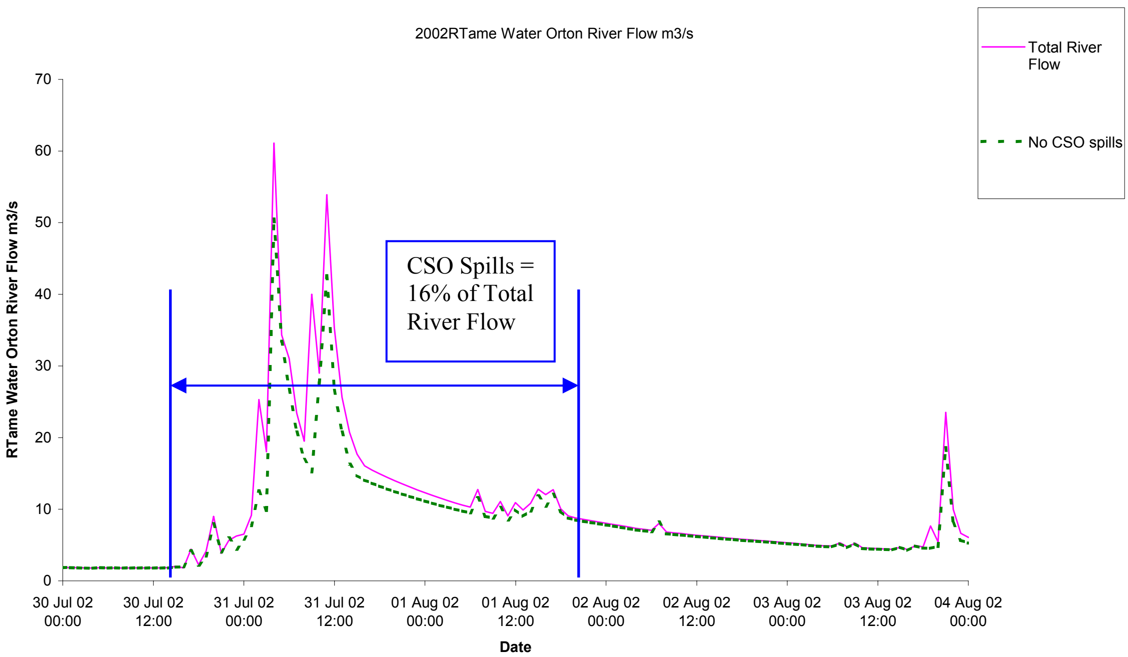

Figure 2 River flow at Water Orton with and without CSO spills

These results only represent the CSO spills which have been included in the SIMPOL3 model. Although the SIMPOL3 model was conceptualised to include all the major spillers, there will be some additional volume resulting from minor unmodelled spills and any surface water systems that have never been included in the HydroWorks or InfoWorks models and then in the SIMPOL3 model. Increased final effluent flows from Minworth are not included in the calculation, as Water Orton is upstream of the final effluent discharge; all other upstream works flow is included.

The same flow figures are presented below in Figure 3. However in this figure the modelled CSO spill flows are expressed as a percentage of the total river response, and it can be seen that at 02:00 on 31 July 2002 the CSO spills contributed half of the flow in the river, with the CSO flow contribution falling to less than 10% after midnight on the 1 August 2002, but overall the additional flow contribution from the CSOs equates to approximately 16% of the total river response.

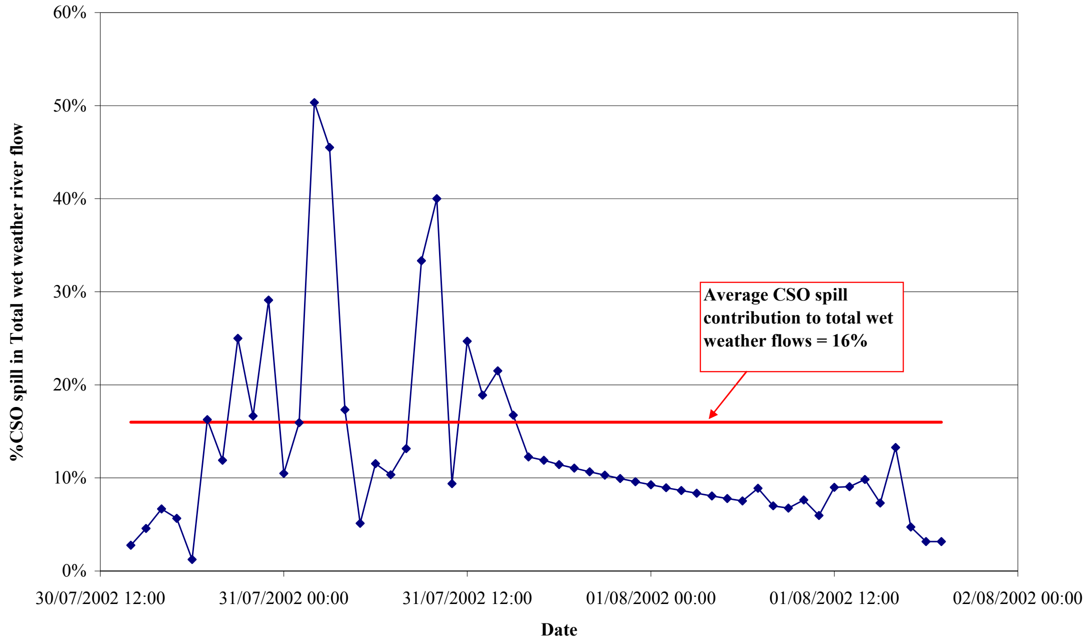

Figure 3 CSO spill contribution to total wet weather river flow at Water Orton

Figure 4 shows clearly the river and sewer response for the event of the 30th July. There was a small discharge from the Minworth storm tanks for this event. The river flow peaks at around $60m^3/s$, which is a 30 fold increase from its dry weather flow rate of $2m^3/s$. At the same time as the peak river response, the CSO spill flow adds a further $10m^3/s$. The maximum flow in the downstream section of the BCTS before the Minworth inlet reached $18m^3/s$. However, the sewer flow into Minworth can only increase from its dry weather mean of $5m^3/s$ to the FFT of $12m^3/s$, before the excess inlet flow is diverted to the storm tanks. Figure 4 shows the FFT maintained for around 12 hours, producing a spill from the tanks after 8 hours.

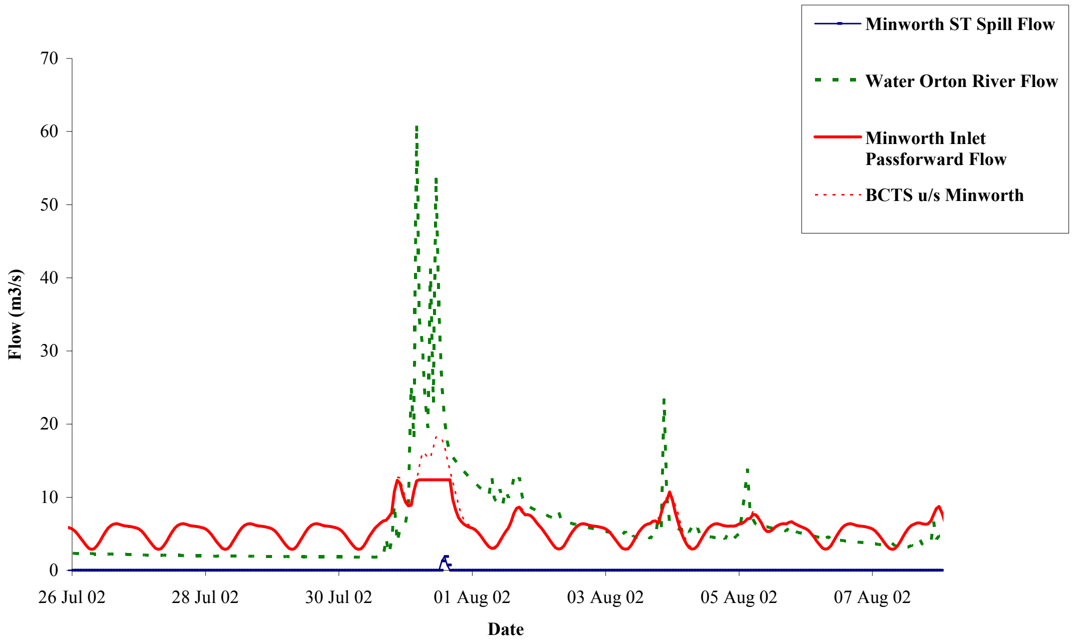

Figure 4 Modelled river flow, BCTS u/s of Minworth inlet, Minworth inlet Passforward and Minworth storm tank spill

Summary of catchment response investigation

The detailed examination of this event, which was one of the most significant summer events in 2002, using data collected around the catchment, has helped to indicate how much of the rainfall is likely to contribute to increased river flows via the hydrological response and also give an indication of the rainwater volume likely to contribute to CSO pollution. The hydrological response suggests that 18% of the total catchment rainfall runoff drains to the river. Use of the SIMPOL3 model has identified that the volumetric increase in sewer flows arriving at Minworth is equivalent to approximately 4.5% of the total rainfall volume over the entire catchment for the same event.

The SIMPOL3 model also helped to quantify that the proportion of the increased river flow due to CSO discharges was approximately 16% over a two day period but 50% over a two hour period. An analysis of the additional load resulting from this event suggests that approximately an additional two tonnes of ammonia is observed in the river at Water Orton over the four day period of the full storm response in the river. This is equivalent to 5% of the DWF load to Minworth over the same period. However, during the hour of the peak river load response, the load in the river was the same as the predicted DWF flow into the works. Analysis of continuous ammonia data at Water Orton showed that this magnitude of load response (>250kg/hr) occurred for 1% of the time in 2001-2002. This illustrates how frequently rainfall events can generate these considerable ammonia loads in the urban catchment and that these could be responsible for failures of the FIS standards. But given the moderate pH value (7.7) and that these loads would be associated with moderate to high flows (>6xDWF) and not necessarily with high concentration, this would explain the relatively few non-compliances of the unionised ammonia FIS observed at Water Orton. However, episodes of low DO are predicted to remain a problem, particularly in the lower Tame, despite improvements to final effluent quality and with additional in-sewer storage.

MANAGEMENT STRATEGIES

Passive Control

The traditional engineering solution adopted to overcome the problem of controlling the polluting effects from sewer under capacity has been to build either large storage tanks or lay larger sewers. Both of these options have their drawbacks, particularly in areas where the urban catchment is congested and consequently these solutions are both expensive due to location and difficult due to lack of space. For the Tame UPM study significant storage (an additional 90%) was identified as necessary to achieve the required river quality compliance.

Alternative options for the "big hole in the ground" have been discussed for many years (Schilling 1994) and the idea that a sewer network could be managed in response to rainfall is not new. But there has been a great deal of resistance to managing a sewer system in this way for a number of operational reasons. Any moving part in a sewer has to be powered by intrinsically safe methods and will require regular maintenance, thus incurring operating costs over and above any routine sewer maintenance.

Real Time Control

In order to investigate whether some form of active control would be advantageous in reducing the amount of storage identified under the traditional passive control methodology in the Tame catchment, the coding for the SIMPOL3 model had to be modified. The general principle behind the use of active, or Real Time Control, is to utilise any spare capacity within the sewer system, such that any hydraulically overloaded sections can be prioritised and allowed to drain down, whilst flows in other under utilised sewer sections or storage facilities are held back and storage mobilised.

RTC VB code changes to SIMPOL3.

The VB code was changed, to allow key storage locations to be identified and computationally linked together so that the discharge from one would be dependent on the volume status of the others. In this way, the available storage around the catchment would be utilised more evenly, allowing under utilised storage to be used, by reducing the maximum passforward rate from the storage tank. The major change required to the code was to allow different passforward rates to be tested at each of the key storages locations such that their individual storage volumes could be brought inline with the average of all the key storage locations i.e. a controlled storage which was less full than the average would have its passforward rate reduced to allow its extra capacity to be utilised and thereby easing pressure on any downstream storage, which could be more overloaded. New passforward rates could be tested and the timestep repeated. These iterations continue until an optimum passforward has been calculated for each of the key storages.

Model Set-up.

The initial task in model set up was identification of suitable storages to be controlled. The key criteria governing this selection were size i.e. large enough to be able to store sufficient volume to affect an impact and location i.e. in an area where throttling the passforward flow will impact downstream. Four storages were identified from the Tame SIMPOL3 model that could be suitable for control; these are shown in Table 1.

Table 1 Storage identified for control

Storage	SIMPOL3 module name	Capacity (m^3)
Sir John's Road	LRea1_off	15,891
Saltley Syphon (Walker Drive)	SaltleySyphon	30,000
BCTS	BCTS_spill1	10,000
Ray Hall STW Storm tanks	RayhallStTNK	12,000

They were selected because they were the largest storage facilities in the catchment and although their size had already been optimised to give adequate protection when tested with the 10 year historical rainfall record, the full capacity would not be utilised for all events; therefore this spare capacity could be made available for controlled storage during smaller events. Their locations are shown in Figure 5. The controlled storages are then linked indirectly in the model connectivity, so that information can be passed from one to the other.

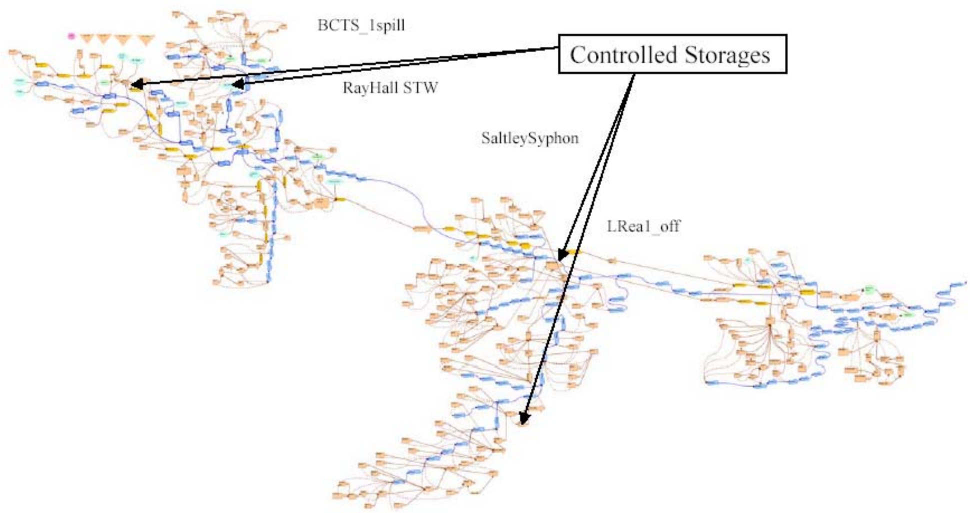

Figure 5 Locations of the storages identified for control in the SIMPOL3 model

RTC RESULTS

The Tame SIMPOL3 model was run with 3 years (1998 – 2000) of rainfall data initially, to determine the effect that utilising the RTC functionality would have on the existing spill pattern.

<u>Spill Reduction</u>.

The results show that, utilising the RTC functionality, the total spill volume is reduced by approximately 32,000m^3 per year, which is approximately 5% of the total volume spilt from the catchments affected by the control strategy. The spill from Minworth storm tank is reduced the most, by almost 37,000m^3, approximately 9% and small reductions are achieved at the 8ftspill and 14ftspill CSOs just upstream of the works. However, spills are increased at BCTS_1spill, Ray Hall STW, Sir John's Road (LRea1_off) and SaltleySyphon by approximately 6,000m^3 in total.

The largest spill reduction in volume terms, for that time period, was for the event on 20th September 1999. The spill was reduced by 28,000m^3, approximately 74%. The effect of the RTC strategy on the BCTS_spill1 storm tank (an upstream storage) is shown in Figure 6. The red line shows volume in the tank when the passforward flow is being controlled by the RTC rules and demonstrated how the tank is being utilised more fully, thus providing hydraulic relief further downstream.

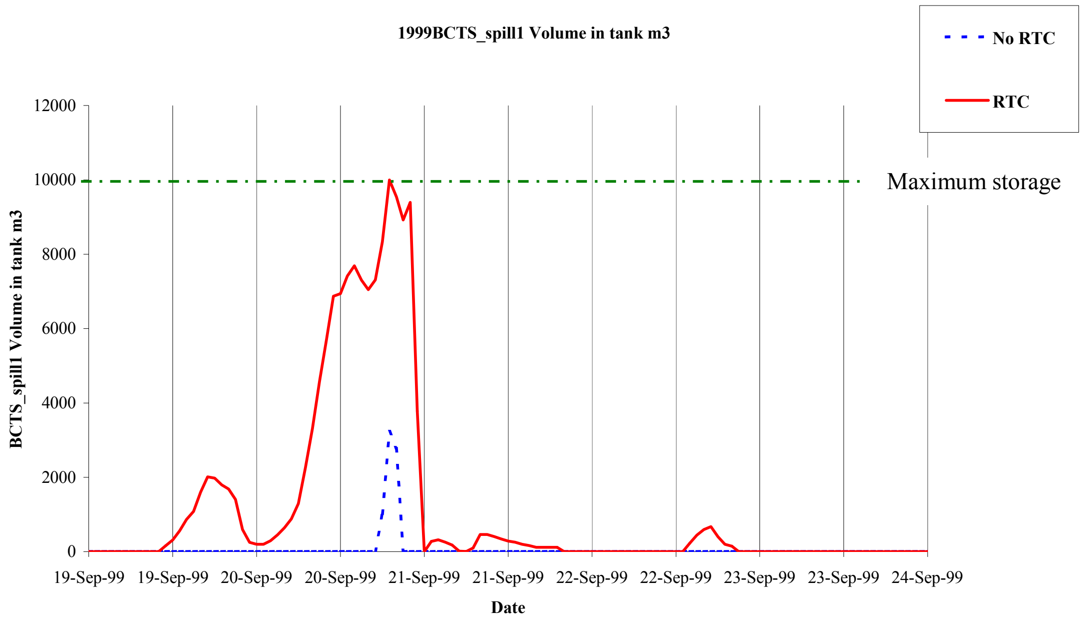

Figure 6 Volume in BCTS_spill1 storm tank with and without RTC

Figure 7 shows how the volume in the Minworth storm tanks is reduced using RTC. The inflow to the works is reduced sufficiently, i.e. below FFT, for the storm tanks to begin to empty for a short time before they start it fill again and hence, reduce the resultant total spill from the tanks from 38,000m^3 to 9,800m^3, which is illustrated in Figure 8.

Increasing the number of controlled storages had a beneficial effect. Two additional storages were tested, and the spill saving at Minworth was increased to 16% with the total saving increasing to 9%.

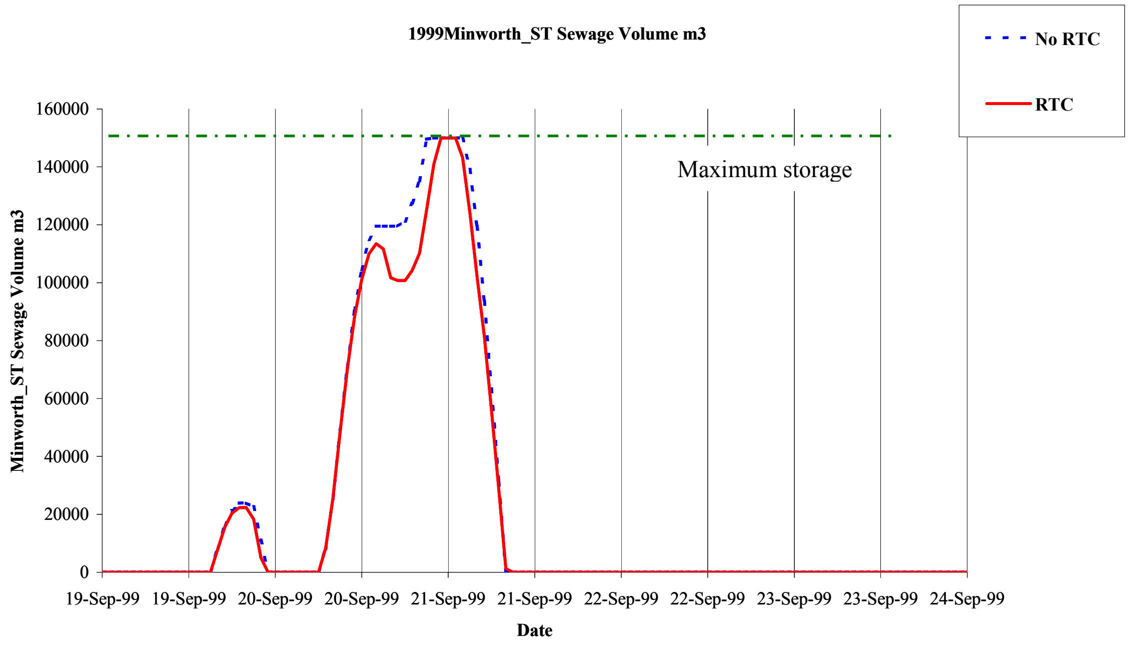

Figure 7 Volume in Minworth STW Storm Tank with and without RTC

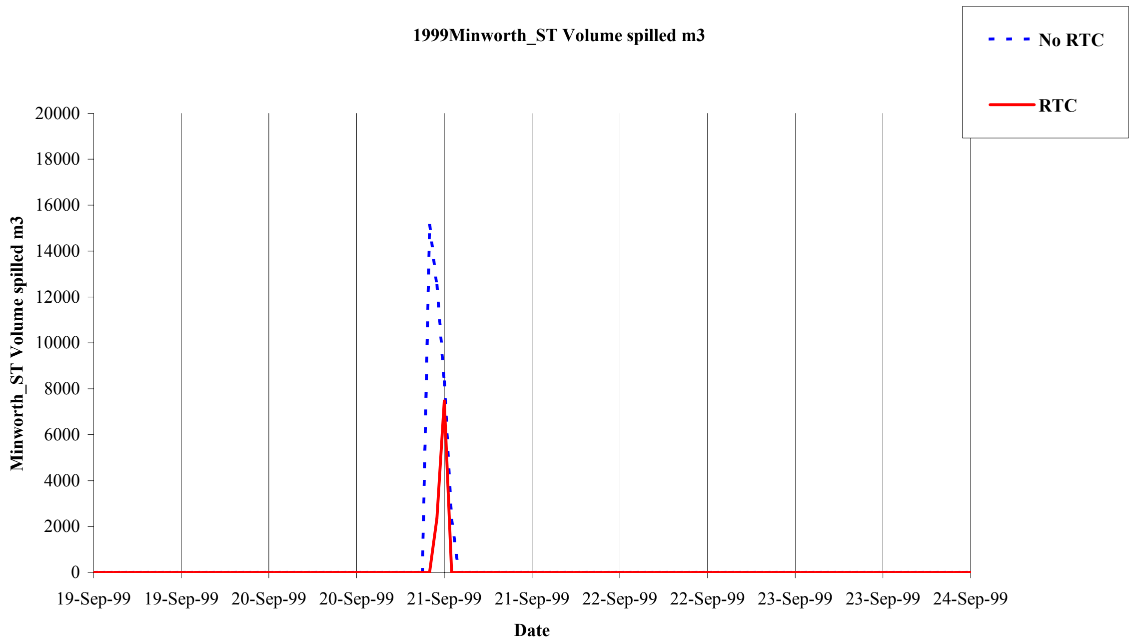

Figure 8 Predicted volume spilled at Minworth STW with and without RTC for event of 20th September

River Quality Impact

The model was then run with 10 years of rainfall to identify whether the spill reduction was sufficient to influence the CSO impact on the receiving river water quality. The CSO discharge was assumed to have a DO concentration of 4.5 mg/l. The resultant river quality was assessed against the RE99% percentile standards and the Fundamental Intermittent Standards (FIS). The results, although significant in volumetric terms, were not of sufficient size, or frequency, to have any appreciable effect on the river quality.

The RTC and non-RTC RE results were not significantly different and the number of FIS breaches was reduced by only 1 in the whole 10 year period at the downstream end of the catchment.

The sensitivity of the results to the concentration of dissolved oxygen in the spills was investigated further by simulating the effect of removing all the spills and observing the predicted dissolved oxygen levels in the river, as shown in Figure 9. There is still an observable DO sag due to the effects of surface runoff and increased STW effluent and the dissolved oxygen at Water Orton is only improved by a little over 1mg/l for the event of 20th September 1999. Even though the Minworth storm tank spill volume is reduced by 74% through RTC, it does not significantly impact on the resultant river quality. Although the total CSO spill volume can be reduced by approximately 9%, the timing of the CSO spills means that the immediate impact can be ameliorated by the river response, although the effect of CSO spills volume can be more significant for short periods, see Figure 3.

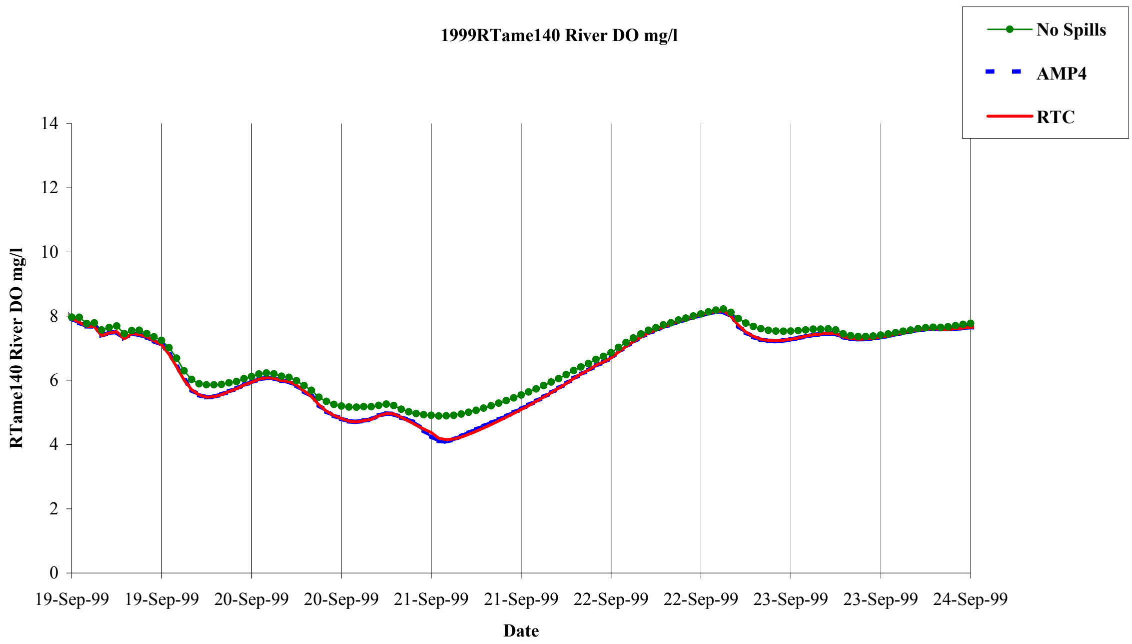

Figure 9 Predicted dissolved oxygen in River Tame at Water Orton showing effect of RTC and removal of all spills – 20th September 1999

<u>*Minworth storm tank reduction*</u>.
The work also demonstrated that the storm tank volume at Minworth STW could be reduced by 10% and the same level of quality compliance could be achieved in the river when the RTC strategy was utilised.

DISCUSSION

The results have shown that the effectiveness of any RTC strategy will depend on the nature of the rainfall, the amount of storage available in the sewer system and the assimilative capacity of the river. For the rain event on the 20th September 1999 an average of 25mm fell on that day. This gave rise to flows in the river at Minworth in the order of 31m^3/s, i.e. a large event, but not significant in terms of intensity, with the maximum intensity below 6mm/hr. Therefore, the sewer system would have been more able to accommodate the steady increase in runoff, and give more scope for active control, which could explain the success of the RTC strategy in terms of spill reduction, (74% reduction in spill volume). Larger events would quickly inundate the system and an RTC strategy will not be effectual, because even with spill volumes saving, the river response will often ameliorate the CSO effects.

The River Tame represents a severe test of the RTC methodology. The river is heavily impacted by the sewerage system. The storage within the system is limited with many CSOs operating below 3DWF and the receiving water capacity is limited by the effects of the STW effluent and surface water runoff. It is likely that this RTC strategy would be more successful in a catchment with more sewerage storage capacity and a river with more assimilative capacity during wet weather.

CONCLUSIONS

The SIMPOL3 ICM has made it possible to simulate the rainfall response in a large complex catchment, such that the sewer and river network respond to the same rainfall. This made it possible to quantify the CSO spill contribution to the river flow.

Analysis of a large intense summer event in the upper Tame catchment demonstrated that the CSO spill flow can account for 50% of the river flow over short periods. The instantaneous ammonia load in the river can be the same as that predicted at Minworth STW inlet in dry weather.

There are a number of regulatory failures (DO) which persist despite the provision of extra CSO storage, particularly in the lower Tame. These are due in part to the final effluent load from the upstream works.

The SIMPOL3 ICM has allowed the impact of the CSO and storm tank discharges within the catchment to be quantified in terms of their effect on in-river DO. Model simulations have demonstrated that removal of all the CSO and storm tank spills from the river network improved the resultant storm induced DO sag by only 1mg/l. However, this observation is subject to the modelling assumptions of the DO concentration in the CSO and storm tank spill.

The hypothesis that RTC can be used to reduce the size of previously identified storage requirements to achieve comparable river quality compliance with current standards has been tested. The results have indicated that a small reduction (15,000m^3) of storm tank storage at Minworth is possible as the Minworth storm tank spill volume can be reduced by 16%, Globally CSO spill volumes can be reduced by 9% with the use of RTC, but this would not be economically viable given the Capex and Opex costs of the RTC scheme.

Further work is required to gain a better understanding of the DO concentration in CSO and storm tank spills, given that their volume contribution has been shown to be significant for short periods. In addition, this demonstrates that CSO design is crucial if CSO effects are to be minimised and that this issue should be addressed as a matter of some urgency.

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