# An Urban Pollution Management Approach to Storm Tank Design

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**Summary**

This paper describes preliminary investigations undertaken into the sizing of sewage treatment works storm tanks for a major asset renewal project. The following issues are addressed.

- Comparison of results from traditional methods with UPM methods.
- How sensitivity analyses may be applied in place of certain detailed information.
- Measures of environmental acceptability.
- How these techniques may be applied in the future.

## Introduction

Storm tanks at sewage treatment inlet works generally perform two roles: balancing and storing storm flows and providing preliminary treatment prior to spillage to river. The size of storage volume, the flow rate arriving at the overflow to the tanks and the continuation flow rate are critical physical parameters. Past practice and guidance primarily from the Technical Committee on Storm Sewage(1), The Scottish Development Department (SDD)(2) and most recently the AMP(2) Guidelines(3) have resulted in the norm being a Formula A overflow, if required, prior to a storm tank overflow set to limit the Flow to Full Treatment (FFT) to 3PG+I+3E and a storm tank volume equivalent to 68 l/head. The first edition of the Urban Pollution Management (UPM) manual(4) gave the first structured opportunity to depart from such empirical standards, enabling particular case specific circumstances, such as abnormal sewage loads, flow rates at the inlet works and, most importantly, the assimilative ability of the receiving watercourse to be accommodated into the design. Most of the UPM type studies which have been performed to date have been triggered by an unacceptable environmental impact driving asset improvement schemes. In certain circumstances, however, a UPM study may be performed where the environment is already achieving the appropriate environmental goals, but when major changes to the assets are required by the water company and the study is used to determine the appropriate level of investment.

## Preliminary Assessment of Storm Tank Requirements

The wastewater system of Derby and the River Derwent have received considerable attention over the past 5 years from water quality planners and engineers. The UPM demonstration project carried out in Derby by WRc illustrated how UPM methods could be applied to a city which was to under go major sewerage system modification driven by flooding and unsatisfactory overflows. The study demonstrated the environmental acceptability of the chosen sewerage strategy, implementation of which is now almost complete. The sewage works is now to be rebuilt because of its age and condition, to address local environmental problems and to meet tighter quality standards. The capacity of the existing storm tanks at Derby is significantly in excess of the normal requirements and the tanks are to be rebuilt due to poor condition and maintenance difficulties. Severn Trent Water commissioned Haswell Consulting Engineers to undertake a preliminary study to determine the optimum sizing for the new tanks.

The inlet works flow settings are tabulated below; storm tank volumes estimated by several empirical methods are also shown. The flow settings result from the sewerage strategy and are not considered a variable in these investigations.

**Sewage Flow Rates**

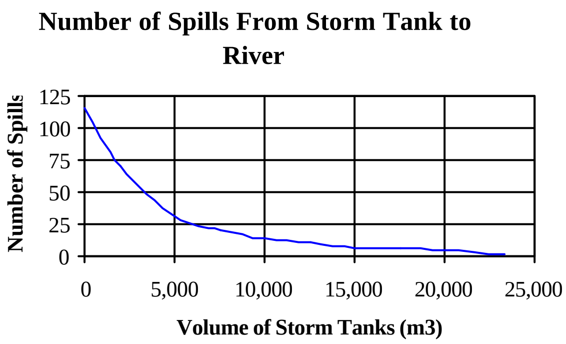
| | |
|---|---|
| Formula A | 3.5 $m^3/s$ |
| Maximum Incoming flow rate | 4.5 $m^3/s$ |
| Flow to Full Treatment (3Pg+I+3E) | 2.1 $m^3/s$ |
| Max. flow rate to storm tanks | 2.4 $m^3/s$ |
| Formula A - FFT | 1.4 $m^3/s$ |

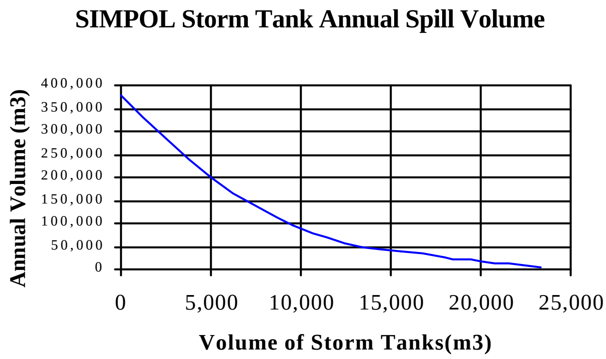
**Storm Tank Volumes**

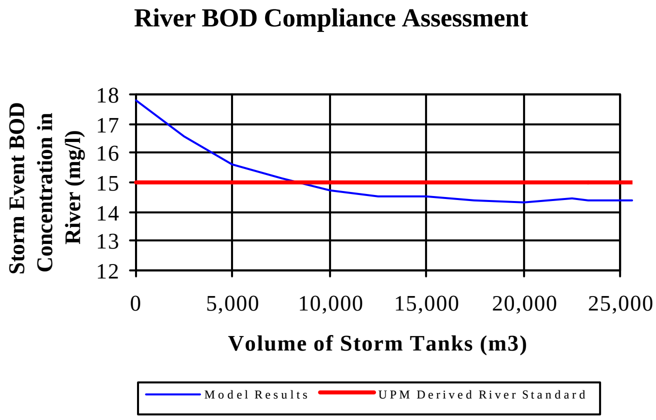
| | |
|---|---|
| Existing tank volume | 23,346 $m^3$ |
| 68 P (Total Population) | 16,400 $m^3$ |
| 68 P1 (Combined Partially/Separate Population) | 9,300 $m^3$ |
| 2 hrs at Formula A - 3Pg+I+3E | 10,080 $m^3$ |
| 2 hrs at max. inflow - 3Pg+I+3E | 17,280 $m^3$ |

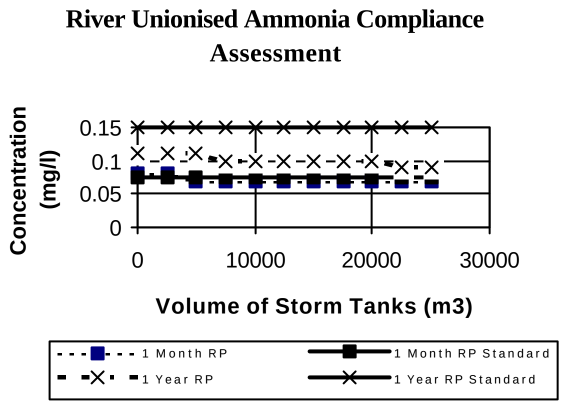
The sewerage system controls flows to Formula A on all but two of the main trunk sewers and there is no Formula A overflow at the inlet works. Flow rates at the inlet works are up to 1 cumec greater than the Formula A norm. This extra cumec will cause the storm tanks to fill more quickly and spill larger volumes to the River Derwent at the works, but will not increase the frequency of spills to the tanks compared with a conventional inlet works. It does not necessarily follow that larger flows going to the storm tanks should result in the storm tanks being of larger than the normal design volume. Simple logic demonstrates that, when the system is viewed in a holistic manner, there are possibly significant benefits in passing the extra cumec through the storm tanks, even when sized at 68l/hd. If the extra cumec was controlled within the sewerage system it would have possibly been at a CSO without storage. Thus the extra cumec would have been spilt direct from the sewerage system to the watercourse. Conversely, passing the flow on to the works provides attenuation, storage within the sewerage system and storage and settlement in the storm tanks prior to spillage. On the basis of the above table traditional methods for sizing the storm tanks at Derby would give a figure between 9,300 $m^3$ and 16,400$m^3$, both of which are considerably less than the 23,346$m^3$ there at present. Apart from the cost of providing extra capacity, there is some evidence that it may be disadvantageous to have oversized storm tanks [5].

The UPM demonstration project models had demonstrated the acceptability of the proposed sewerage improvement strategy. There are many benefits in using such tools particularly the way that local conditions may be incorporated into the design. Simulation models allow the performance of one asset to be judged against another whilst maintaining the desired constant level of environmental protection. The SIMPOL model used in this analaysis was a modified version of the one applied in the demonstration project. Various continuation flow rates and volumes had changed since the original SIMPOL model had been built by WRc. The main hydraulic changes to the system were represented in the new SIMPOL model by adjusting the configurations and settings of key throttles. A range of storms was run through both the SIMPOL model and the up to date HydroWorks model. The adjusted SIMPOL model gave a very similar response in terms of spill volumes to the storm tanks and continuation flow rates at the inlet works to those produced by the HydroWorks model. Water quality parameters were not adjusted as there would be no basis of confirming adjustments made without data collection and /or constructing a detailed sewer system water quality model. The SIMPOL model described in the first edition of the UPM manual (FWR 1994) models the flow and water quality response to a rainfall event in a dynamic manner within the sewerage system. This dynamic response is then condensed into a single value - a total event load of either BOD or ammonia before being input into a very simplified river impact mass balance model, to give an event mean river concentration. The upstream natural catchment boundary conditions are derived from stochastic representations of field data. To assess Dissolved Oxygen (DO) compliance, BOD is compared against either Table 3.3 in the UPM manual[4] or specifically derived standards as in this case. The following figures show how key environmental measures as derived from SIMPOL vary as a function of storm tank volume.




The model illustrates that with a storm tank volume of 23,346m$^3$ the number of spills from the tanks to the river is approximately 3 per annum. A storm tank volume of 15,000m$^3$ gives approximately 5 spills per annum and a tank volume of 10,000m$^3$ gives approximately 13 spills per annum. The annual volume of spill from the storm tanks to the river is small compared to all of; annual dry weather flow treated at Derby works, fully treated storm flows treated at Derby works and most notably CSO spill volumes to the River Derwent in Derby. For a storm tank volume greater than approximately 10,000m$^3$ the total annual spill volume to the River Derwent from the storm tanks is less than 2% of all of the total annual storm flows entering the combined sewerage system in Derby and less than 0.2% of the total annual storm and dry weather flows entering the combined sewerage system. The BOD derived standard produced during the UPM demonstration study of Derby is achieved for storm tank volumes greater than approximately 8,000m$^3$. Compliance is by a small margin as in the case of unionised ammonia. However, for a storm tank volume greater than approximately 12,000m$^3$ the storm event BOD in the river is insensitive to the volume of the storm tanks at Derby works. The model shows that storm event, unionised ammonia concentration in the River Derwent is largely insensitive to the size of storm tanks at the Derby Works. Both 1 month and 1 year return period standards are met if storm tank volume is greater than 5,000m$^3$. Although the model predicts that the unionised ammonia water quality standard will be met, it should be noted that compliance is not by a wide margin, particularly in the case of the 1 month return period compliance assessment.

The four analyses from SIMPOL have one common theme, that within the range of volumes derived from the traditional approaches, the size of storm tanks at the inlet works does not have a significant affect on the River Derwent. The principle reason for the decrease in sensitivity of the chosen analysis parameters as storm tank volume increases is that frequency and volume of spill from the tanks becomes small for larger tank volumes. The extra cumec arriving at the inlet works will mean that the tanks will be fuller more often and for longer periods of time, which may have an influence on system performance during subsequent storms. In these analyses only discrete storm events have been investigated. A simulation with consecutive storm events is likely to give more critical results and may be undertaken as the next stage of these investigations.

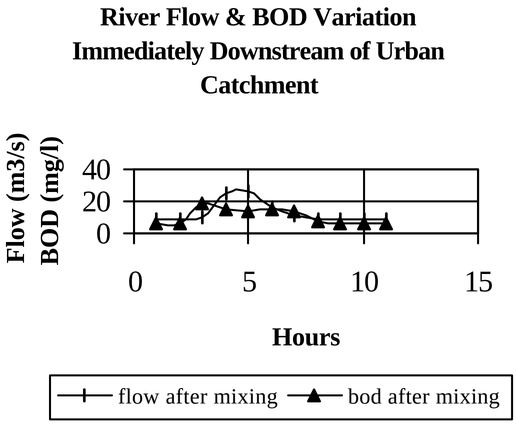
**DO Model Development and Sensitivity Study**

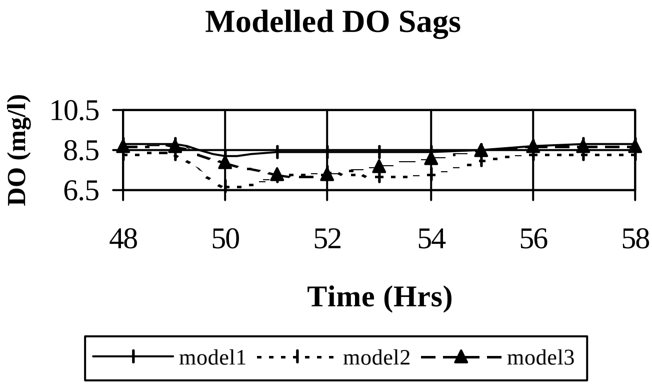
The SIMPOL model has provided a relationship between storm tank volume and the key event mean BOD and unionised ammonia concentrations for the respective critical return periods. Such values may show acceptability, but it is often difficult to relate these measures to perceptions of the real system performance, particularly how DO as a matter of interest varies dynamically during a critical storm. A modelling package such as MIKE11 or ISIS could be applied to investigate the dynamic response in the receiving watercourse. In the early stages of these storm tank investigations it was not deemed necessary to undertake detailed modelling, however, it was decided to undertake a simplified preliminary assessment of the impact of storm tank capacity on DO in the river.

For this assessment, a simplified dynamic river impact model was linked to the output from the SIMPOL model. The river impact model has not been verified against field data, but has value as it applies well documented mechanisms and process rates and is for comparative purposes only. Sensitivity analyses have been undertaken to give confidence to the results. The simplified river impact model was constructed in steps, with increasing complexity, a total of five models were built, of which the three described in this paper involve various first order representations of oxygen demand and reaeration. A constant river channel slope, roughness and width were applied.

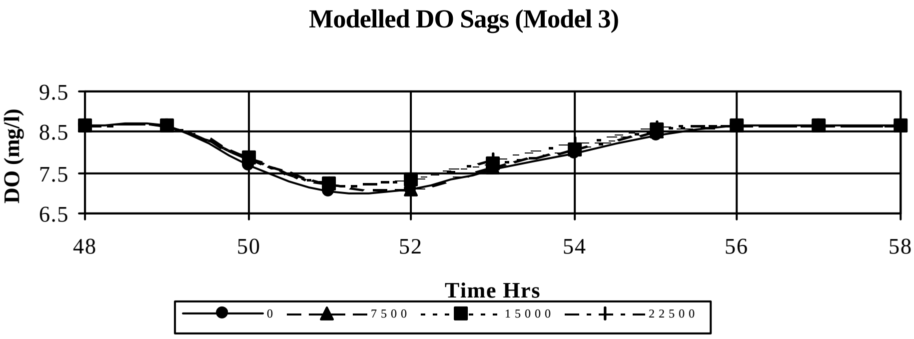
| | **DO Utilisation** | **Reaeration - Derivation of $K_2$** |
|---|---|---|
| **Model 1** | 1st Order Oxygen Demand | Mean River Flow and Churchill expression to derive fixed $K_2$ |
| **Model 2** | 1st Order Oxygen Demand | Maximum Modelled Dynamic River Flow and Churchill expression to derive minimum $K_2$ |
| **Model 3** | 1st Order Oxygen Demand | Modelled Dynamic River Flow and Churchill expression to derive dynamic $K_2$ |

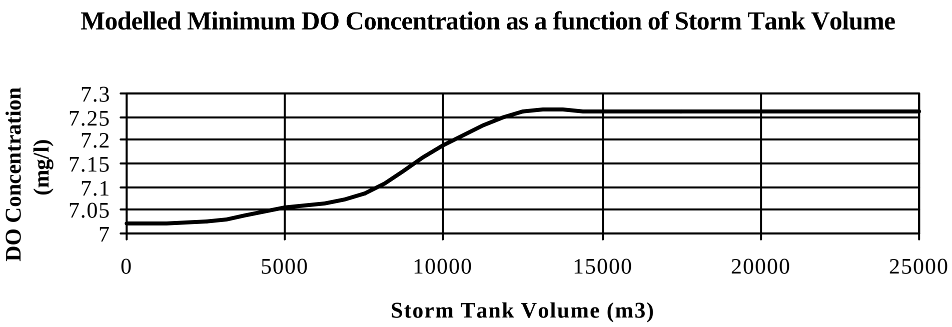
The results illustrated in the following figures show how the flow rate, BOD and DO sag downstream of the urban catchment vary as mechanisms are refined within the model. The rainfall event applied was a long profile high volume storm, chosen so to provide the opportunity for the larger volume storm tanks to spill. It is worth noting that the river BOD concentration shows an initial peak and then a decrease corresponding to peak river flow and hence dilution. Model 1 demonstrates that the influence on DO is minimal if a constant reaeration rate based on mean river flow is applied. Model 2 shows the computed DO sag assuming a constant reaeration rate based on the same channel geometry as applied for model 1, but applying the maximum storm flow rate to drive the Churchill[6] reaeration expression to fix the reaeration rate at an event minimum for the whole event. Model 3 takes the same approach as Model 2 but allows the reaeration coefficient to vary during the event with flow. Model 1 gives the smallest DO sag whereas models 2 and 3 predict similar, lower DO concentrations at the peak river flow rate. Model 3 was chosen for further analysis as it appeared to provide a reasonable basis for the comparative assessment of storm tank requirements.




The next step was to determine the relationship between DO sag characteristics and storm tank volumes for the same storm. The two figures below show the results for Model 3. It is interesting to note that the DO sag is not highly sensitive to the size of storm tanks, particularly for storm tank volumes greater than approximately 12,500 $m^{3.}$ It was noted that although the minimum DO concentration is insensitive to increasing storm tanks volume once this is greater than 12,500 $m^3$, the storm tanks do spill even for a storm tank volume of 22,500 $m^3$ although progressively smaller volumes.




## Conclusions

The results from investigations described in this paper show that there is a case for Severn Trent Water Ltd. to investigate further, both through discussions with the Environment Agency and by future modelling, a reduction in size of the storm tanks at Derby sewage treatment works. Decreasing the storm tank size will increase spills to the river but these initial investigations have shown that the impact will be minimal and not endanger any agreed water quality standards. The development of a simplified dynamic river impact model has shown the potential of such models, particularly in carrying out preliminary assessments or in the initial stages of a full UPM study.

**Acknowledgement**

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**DISCUSSION**

**Question George Hare Montgomery Watson**

What were the drivers for the study if the tanks were already bigger than that required ?

**Answer**

The storm tanks were in a poor state, it needed to be refurbished, there was also a problem with manual desludging. The STW needed to be renewed.

**Question Clint Cantrell Montgomery Watson**

Did you do any monitoring to confirm the performance of the DO model.

**Answer**

No monitoring at this stage because it was a preliminary assessment. We would probably use STOAT and MIKE11 if to be taken further.

**Question John Frake Environment Agency**

Do all the DO sags conform to max sag of about 51 hours ? In high flows it will be further from Derby? If spill occurs earlier will it be damaging to Derby?

**Answer**

Current model is only intended to give a feel for the tank size. More detailed modelling could reveal these other effects. 50 hours would place the sag out of the Derwent and into the Trent.

**Question Adrian Saul University of Sheffield**

Presumably increasing the storm tank size increased the sedimentation performance. In a detailed model would you take into account the improved quality of spill from a larger tank.

**Answer**

In the simpler model there is a factor to take treatment into account. This was calibrated from earlier more detailed structures.