CHRISTCHURCH HARBOUR HYDROWORKS MODELLING

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1. Keywords

Real Time Control (RTC), River Model, Ammonia, PID coefficients,

2. Synopsis

This paper is a case study describing the modelling of a complex system which uses RTC to control both sewer system and treatment works. The RTC system operates so that polluting impacts on both river and bathing waters are minimised. The paper focuses on particular aspects of the modelling of the RTC system for the STW and upstream trunk sewer.

3. Introduction

Figure 1 shows a simplified schematic of the Bournemouth sewerage system.

Holdenhurst STW is located inland and discharges to the River Stour and thence to Christchurch Harbour, which is a tidal estuary with a narrow entrance to the sea. Consequently, available dilution for treated and storm discharges from the STW is far less than would be possible with a coastal STW and long sea outfall. Flows in the river Stour can fall below 250 Ml/d (2.9m^3/s) in the summer, whilst storm flows into the sewerage system can exceed 400 Ml/d (4.6m^3/s).

Therefore, to prevent serious deterioration in river water quality, available storage in the Coastal Interceptor Sewer (CIS) is mobilised during heavy storms so that when spill occurs, the spill flow **rate** is kept below a pre-set level.

A long record of river and sewer flows and recorded ammonia concentrations from two bathing seasons was analysed. This was used to give an initial assessment of the water quality elements of the control system without recourse to water quality and river impact modelling.

Schemes are currently under construction to limit spills from coastal CSOs to 3 per bathing season, causing increased total flow to the STW. The HYDROWORKS model was used to assess the performance of the whole system both before and after the commissioning of these schemes, and also to assess options for further improvements, including substantial increases in storm storage at the STW.

4. Current Control strategy

Figure 1 also shows the essential elements of the control strategy, which works as follows:

a) Under normal conditions, flows to the STW are less than the treatment capacity of 123 Ml/d, and the shaft 1 penstock is fully open.

b) During storms, when incoming flows increase beyond 123 Ml/d, the storm tanks at the STW will begin to fill. The Shaft 1 penstock will operate (if necessary) to limit incoming flows to 400 Ml/d, the capacity of inlet works.

c) Once the storm tanks are 80% full, the penstock closes so that flows to the STW are limited to treatment capacity (123 Ml/d). This causes the water level in the CIS to rise.

d) Once the CIS is 25% full (intermediate level) the control system then opens the penstock to allow spill from the STW storm tanks. The control system at the STW then regulates shaft 1 so that the flow through the STW (Q_w)

satisfies the following equation such that the river ammonia concentration ($A_{d/s}$) does not exceed 1mg/l:

$$Q_{max} = \frac{Q_r . (A_{ds} - A_{u/s})}{A_w - A_{d/s}}$$

(Q = flows, A = Ammonia concentration)

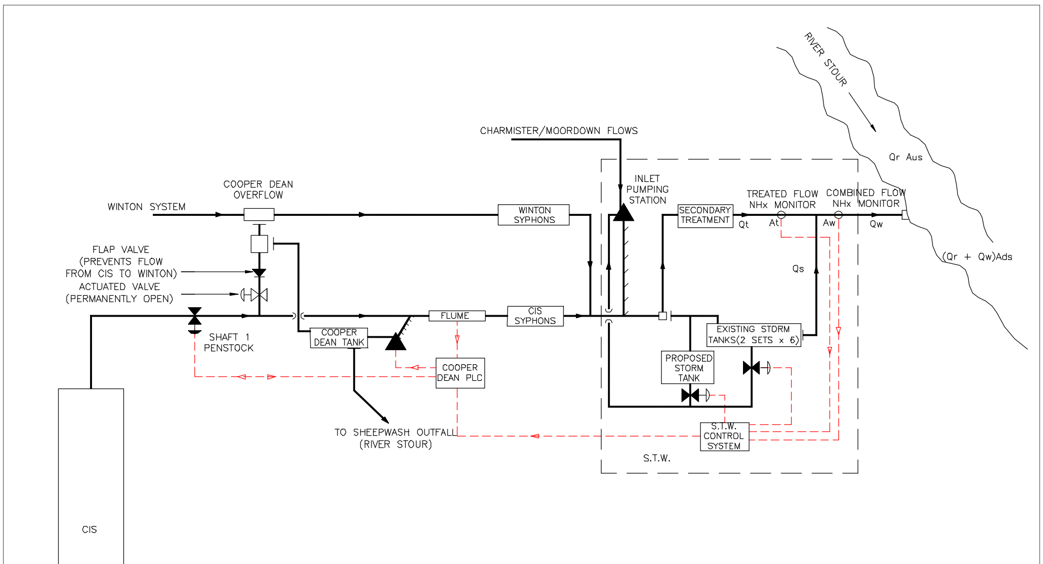
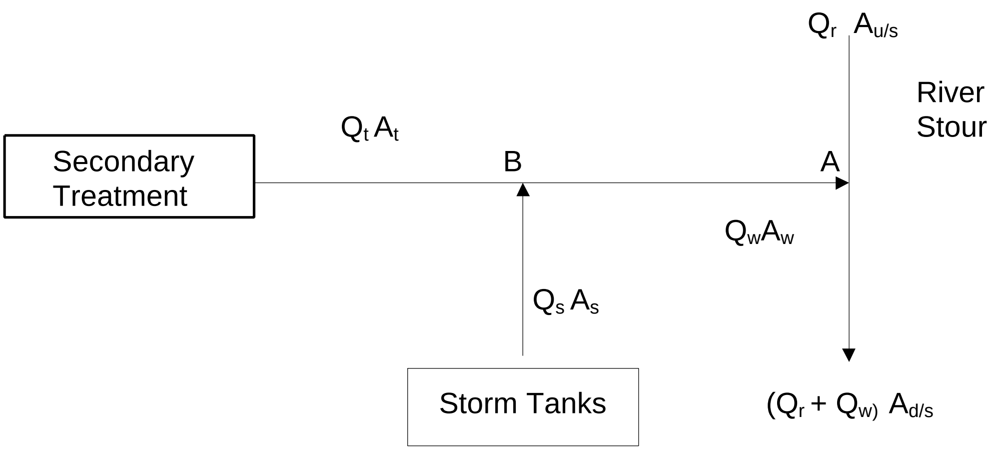


Figure 1 : Simplified Schematic of the Bournemouth Sewerage System



(The controller assumes that Q_w is equal to the flow into the STW when the storm tanks are full – negligible flow losses through the STW)

e) In extreme events, the CIS will fill completely. Under these circumstances, flooding from manhole covers on the CIS is prevented by switching off or 'overriding' pumps at Hengistbury Head and Bournemouth No 1, so that flow to these stations is mechanically screened and diverted down long sea outfalls. This happens approximately once per bathing season.

5. Simulation of Control Strategy with HYDROWORKS RTC

The sewer system incorporates both local and global control systems. These were modelled in HYDROWORKS resulting in complex RTC files of over 200 lines. The following sections outline how the two major global controls were modelled.

5.1 Shaft 1 control of CIS flows

a) Ammonia mass balance model

The main elements of the control system are outlined in Figure 1. At the various stages of the control strategy outlined in section 4, the STW control system calculates the maximum permitted flow to the STW (Q_{max}). It then evaluates the 'uncontrolled' flow (flow to the STW not passing through the CIS flume). This value is subtracted from the required Q_{max} to give the required flow from the CIS. This is then communicated to the Cooper Dean PLC via telemetry. The Cooper Dean PLC then adjusts the shaft 1 penstock such that the flow through the flume reaches the required value. For accuracy, HYDROWORKS RTC files were developed to make the model work in exactly the same way as the real system.

As the discussion and flow diagram in section 4 shows, the permitted spill rate from the storm tanks is inversely proportional to the ammonia concentration (A_s) of this flow. Therefore it is important to determine typical values of A_s. Due to the lack of a verified quality model, it was decided to use an empirical approach to do this. A long term data set of flows and ammonia was evaluated, giving the results shown in Figure 2:

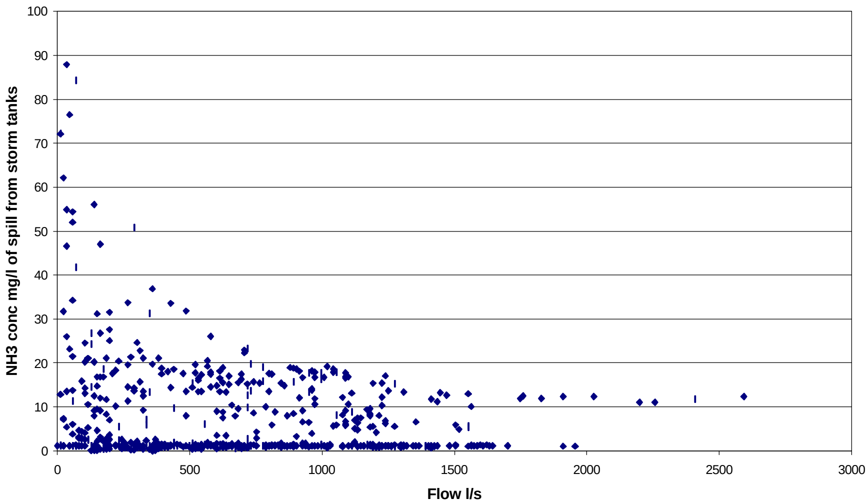


Figure 2

Observed NH3 concentrations for various flows from storm tanks.

Analysis of this data gives a 90%ile value of 20 mg/l NH_3 for the spill flow from the storm tanks. Similar analysis of the treated effluent ammonia levels gave long term values of 1.5mg/l. Use of these values in the ammonia mass balance model described in section 4 allowed the permitted spill flow from the storm tanks, and hence permitted flow to the works, at various values of river flow to be calculated. Figure 3 highlights the flow permitted to the STW for various river flows, assuming an NH_3 concentration of 20 mg/l (modelled) and 10 mg/l (lowest observed). This shows that permitted spill flows at the STW are relatively low and also the permitted spill is particularly sensitive to the NH_3 concentration of the spill flow.

The intention of this study was to evaluate compliance of the system to existing discharge consents, and is not intended to be a UPM type study, particularly with regards to integrated quality modelling. It was felt that use of a long set of 'real' operational data in this way was sufficient for an initial evaluation of typical system performance. It is anticipated that future modelling studies on this catchment will adopt a more integrated approach, as outlined in the UPM. A verified QSIM model could be linked with STOAT and MIKE 11 to allow accurate deterministic predictions regarding the interaction between sewer flows, treatment flows, river flows and the quality aspects of each to be made. The RTC would be relatively simple to develop, with flows to the STW being directly controlled by the NH_3 concentration in the river.

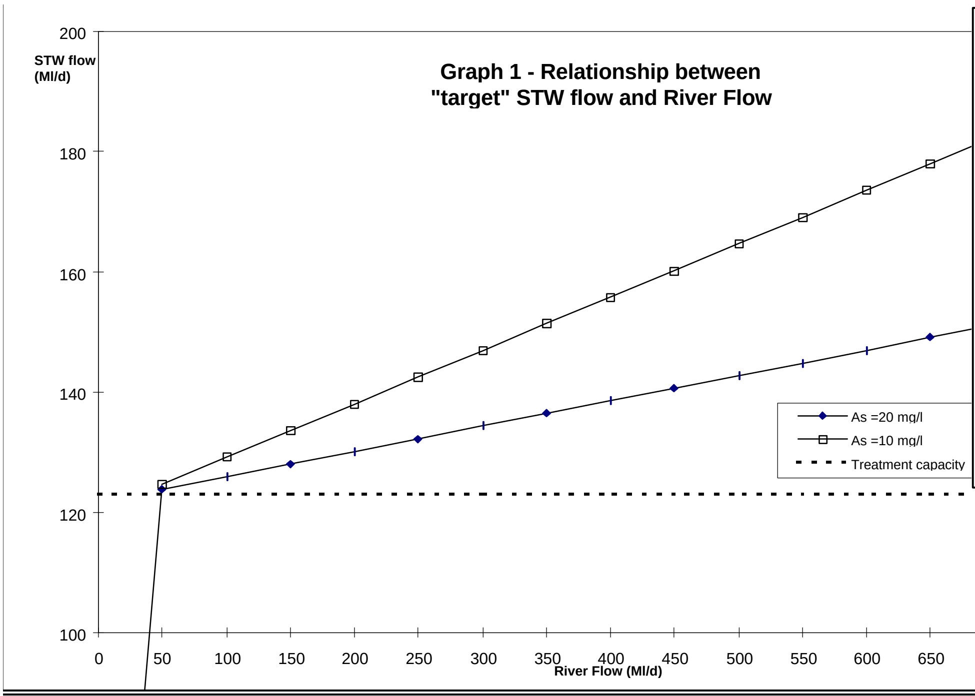


Figure 3

Relationship between permitted STW flow and River flow.

User Note:

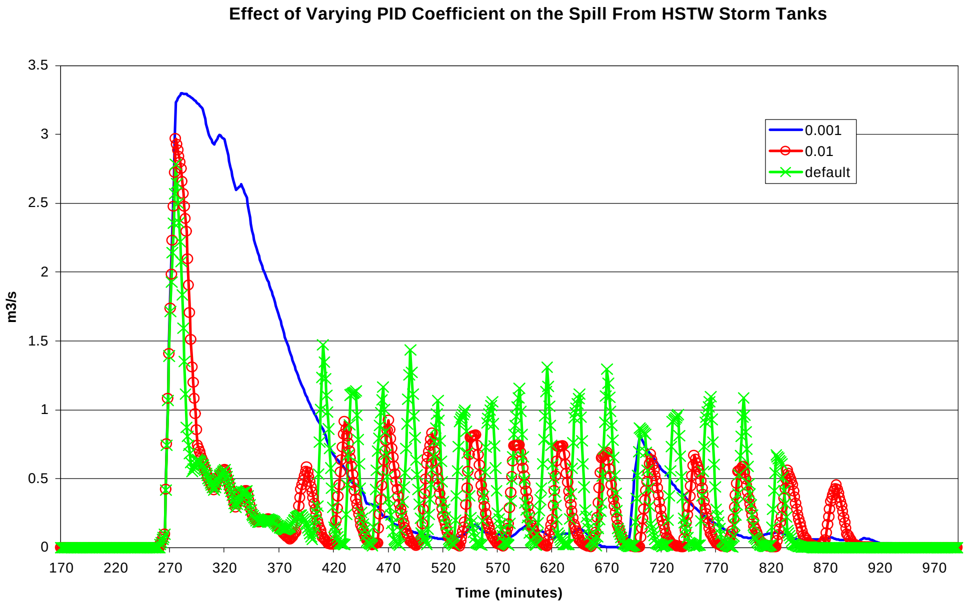
> *Meetings with operations staff and analysis of operational data are particularly important when trying to unravel complex operating regimes such as this. They are vital for identifying many of the improvements and 'tweaks' to the system that may have occurred since any original procedural documentation was written*

b) PID coefficients for shaft 1

In initial model runs the default PID values from HYDROWORKS were used. This resulted in major instabilities in the STW/Shaft 1 Penstock control loop. Detailed analysis of operational data and commissioning documents for the system revealed that the performance of the real system was best matched by using PID values of 0.013,0 and 0 respectively. Figure 4 below highlights the effect of varying the PID controller on model predictions. As can be seen, the shape of the spill hydrograph and the total volume spilled varies substantially with differing PID coefficients. This would obviously have implications on other parts of the system

User Note:

> *Consideration should be given to the PID coefficient values, as model results may be very sensitive to changes in these. This aspect is often misunderstood and neglected. Models may be more accurately verified if the PID coefficients are manually altered.*

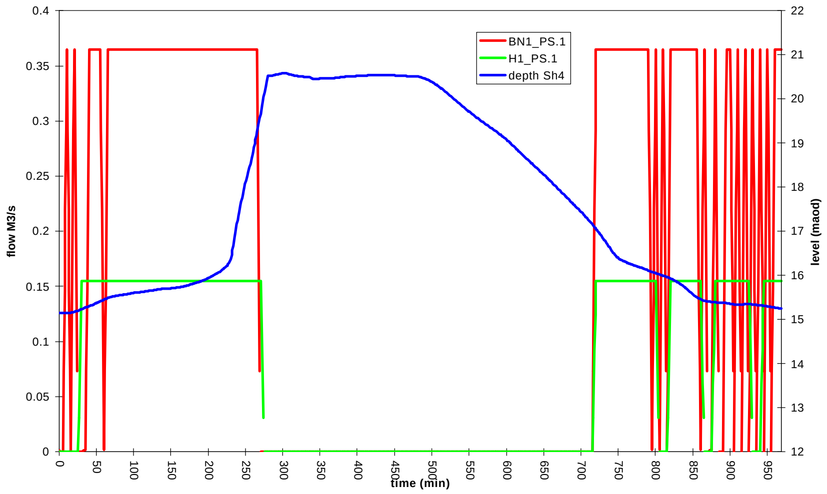


5.2 Override of Hengistbury/Bournemouth No1 pumping stations

When the CIS is surcharged to 19.9 mAOD, as measured by sensors in Shaft 4, there is an override facility which switches off Bournemouth No 1 and Hengistbury Head PS to reduce flows into the CIS. The pumping stations switch back on when levels in the CIS fall to around 17.1m.

The modelling of this behaviour was actually more complex than an initial interpretation would suggest. In particular, the code had to incorporate rules that allowed the pumps to operate if the CIS water level was between 17.1 and 19.9 mAOD when the level had not previously been above 19.9 mAOD, yet prevent them from operating in this range if the CIS level had previously exceeded 19.9 mAOD. The override facility would reset should the level go below 17.1 mAOD.

To model this, pump control was passed to the RTC file (using local commands) as normal for RTC. Global commands were then used to turn off the pumps when the CIS levels rise above the cut-off point, and also to turn the pumps on when the levels fall below the reactivate point. Figure 5 shows the modelled override in



operation.

User Note:

When pumps are controlled by an RTC file they may fai initialisation as an unrealistically high pump switch on level the dsd to allow the pumps to operate during simulati erroneous surcharge or flooding at the pumping station. Th by inserting dummy variable penstocks (discharging to dur pumping stations. These are left open during initialisation the simulation began (Time = 0), so that the pumping statio full at this point.

User Note:

Always check RTC results in graphical format to check the correctly (i.e. graph above). The RTC validator may read will function correctly, but in complex situations the results may show otherwise. Visual comparisons of the results are by far the best check.

Figure 5

Override facility at Shaft 4

Bournemouth No 1 PS and Hengistbury Head PS switch off at 19.886 and 19.386 m respectively. Both reactivated when level in Shaft 4 falls to 17.086 m.

6. Conclusions

- The existing model of the Bournemouth system has been converted from WALLRUS and extensively updated. The STW/CIS control regime has been successfully modelled with HYDROWORKS RTC. This has allowed the performance of the whole system to be adequately assessed, both prior to and following upgrading schemes.
- The existence of long term records of system performance has proved invaluable in confirming the stated control strategy and evaluating the actual performance of the controls in the sewer system. It appears that the more complex an RTC system, the greater the amount of performance data needed to evaluate its performance.
- Use of simple mass balance equations and analysis of long term effluent quality data has been used to gain an initial evaluation of the ammonia model used to

control the system. A more detailed integrated approach, including sewer quality, treatment works and river impact models may be used in the future.

- The system uses available storage both to reduce spill frequency and to constrain spill rate once spill occurs. In this way impact on the receiving watercourse is minimised. This mode of operation could possibly be applied to other wastewater systems/receiving watercourses.

7. Acknowledgements

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DISCUSSION

No Questions