Integrated Modelling Using Data Driven Models

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1 INTRODUCTION

1.1 Background

A Water Quality Impact Assessment has been undertaken to determine if it would be possible to reduce the Flow to Full Treatment (FFT) at a Sewage Treatment Works (STW) and potentially increase the risk of intermittent discharges to the receiving watercourse without causing a detriment to the water quality. This is normally done with the use of a network model and a simplified representation of the STW to generate inputs suitable for use with a mass balance water quality assessment tool. In this case it was found that the network model did not represent the intermittent discharges because of manual operation and operational failures. This problem required development of a novel approach based on data from a telemetry system to generate satisfactory spill flow data to represent current performance. The approach was extended through the use of modified network models to determine the effects of the following; growth within the catchment, changes to FFT and improvements in the operation of the intermediate pumping station and storm tanks.

The STW inlet works (top left pane, Figure 1) is divided into three levels, the 'low level' comprises two principal pumping stations which are the primary sources of inflow to the system. The 'intermediate level' comprises primary treatment (screens and detritors), the intermediate level pumping station and the storm tanks. Under normal conditions all flow from the intermediate level is pumped forward from the intermediate pumping station to the 'high level' containing treatment processes. During periods where the inflows to the intermediate level exceed the intermediate level pumping capacity, flow enters storm tanks with a combined capacity of approximately 11,000m^3. When this storage is full, gravity overflows can occur from the storm tanks to the receiving watercourse.

1.2 Regulatory Context

Water Quality Assessments studies for urban discharges on receiving water systems are known as Urban Pollution Management (UPM) (FWR, 1998). UPM studies are used to quantify water quality impacts of intermittent discharges in order to better understand the impacts of changes to wastewater systems. Up until recently water quality classification for watercourses was determined through use of the River Ecosystem (RE) classification system based on the 10th, 90th and 99th percentile concentrations of waterborne pollutants, dissolved oxygen and pH. The use of this classification system is being phased out and replaced by the Water Framework Directive (WFD) standards (De Toffol *et al*., 2005; Freni *et al.,* 2009) which includes classification bandings for a much wider range of environmental indicators than employed by the RE classification system. Current WFD guidance provides classification bands for 90th percentile concentrations but not the 99th percentile. Intermittent discharges impact the 99th percentile and therefore it is useful to have a classification system for these values. The results presented are classified on both RE and WFD scales for 90th percentile values and the RE class scale for 99th percentile concentrations.

2 METHODOLOGY

2.1 Modelling

A verified network model was available which could predict the intermittent discharges from the existing system. The representation of the intermediate pumping station and storm tanks were altered to represent the future situation including the growth within the catchment. The results showed that there were no predicted intermittent discharges using a ten year period of rainfall in the existing situation and eight in the future.

These results suggested an acceptable performance in terms of water quality. However, doubts were raised over the validity and confidence levels in these model results when they were compared to the anecdotal evidence. This showed that there were intermittent discharges every year which the model was not predicting. Bertrand and Muste (2008) discuss that the uncertainty in planning, design, operation and management are often neglected.

A review of the modelling was carried out and several reasons were found to explain why existing performance was not replicated accurately. The factors which the modelling were unable to replicate, resulting in the discrepancy between observed and predicted spills include:

- Manual isolation and emptying of the storm tanks;
- Variable pass forward pumping rates from the intermediate level pumping station;
- Human factors affecting the operational of the intermediate works;
- Operational failures.

Due to all of these issues an alternative methodology for determining the number of intermittent discharges for both the existing and future situations was developed.

2.2 General Approach

There is active research into the quantifying and assessing uncertainties in integrated urban drainage modelling regarding not only quantity but quality variables (Willems, 2008; Schellart *et al.,* 2010).

The methodology was developed to use historical telemetry data to calculate the intermittent discharges from the storm tanks. This was done to overcome the potential uncertainties in the variables and operational management. Using the telemetry data, the intermittent discharges were calculated for two main scenarios: the existing, and the future performance.

2.3 Existing/Historic Inferred Performance

Telemetry spill flow data was available for flow in the gravity outfall pipe from the storm tanks. However there were doubts over the accuracy. There were also issues with erroneous or missing data. This data was therefore used to indicate spill performance but was not considered suitable as a volumetric input for UPM water quality assessments.

The methodology developed involves a number of steps to calculate the inflows and the outflows from the intermediate level system (Figure 1, top left pane) and from these to infer the intermittent discharges. The operation of the inlet works can be broken down into four principal flows; inflow from the inlet pumping station, inflow from the northern TPS, outflow to treatment and the value ‘D’ which represents the volumetric rate of change within the intermediate system, or when storage is filled, the spill flow rate.

2.3.1 Inflows from Low Level Pumping Stations

The top right pane of Figure 1 shows the basic inputs for calculating the inflows from the low level (screw pumps) wet well. This includes telemetry depth data for the level within the wet well (on the left) and the pump head discharge curve (on the right). The maximum design flow from one of the screw pumps is 1,350 l/s and in the low level pumping station there are two pumps making the maximum inflow from the pumping station 2,700 l/s although this is believed to only happen infrequently. To calculate the inflow, information was also required for:

- Stop/start telemetry for the screw pumps;
- Conversion formula to convert the percentage depth to depth in metres;

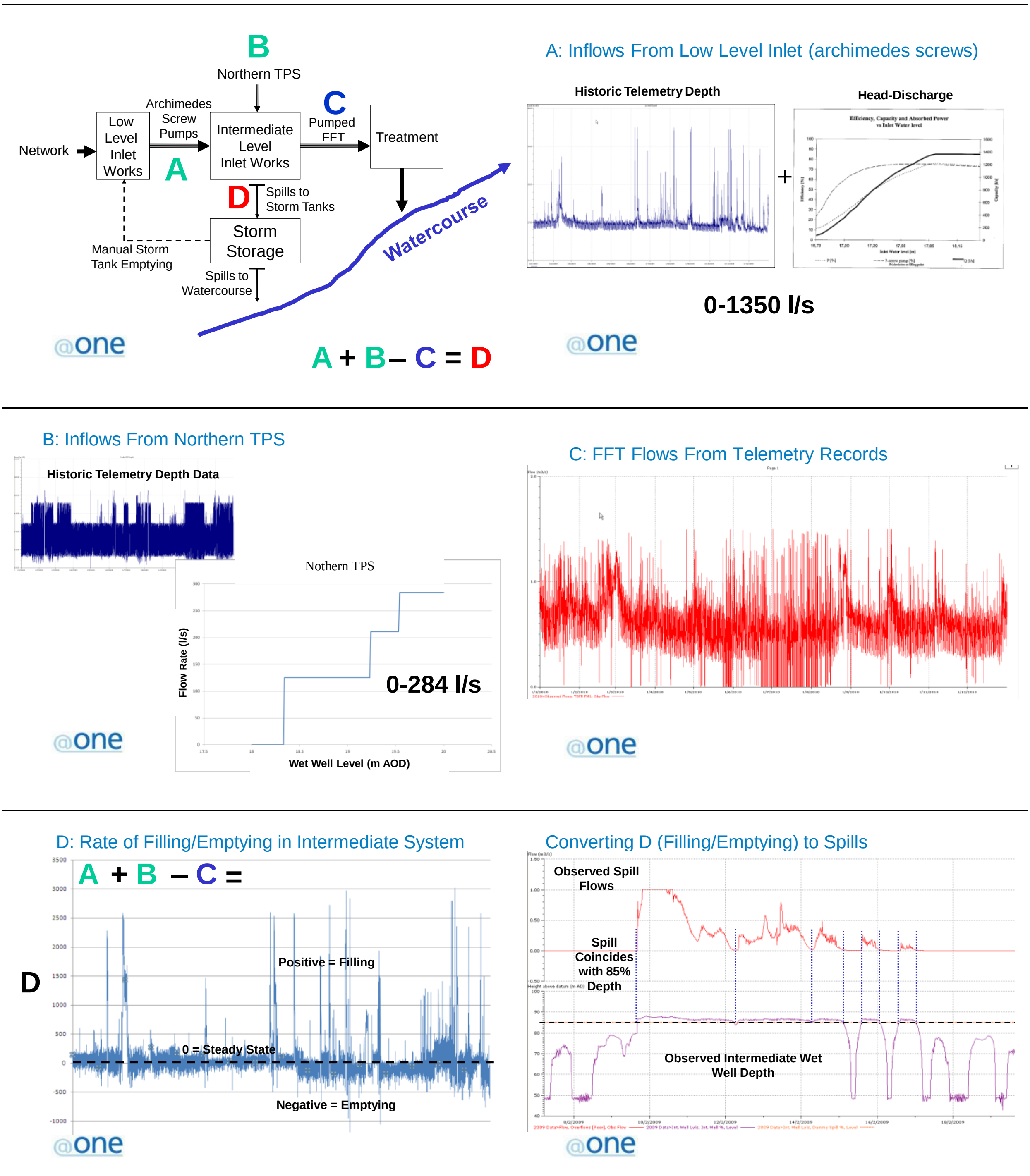

Figure 1. Schematic of inlet works operation with principal inflow and outflow components.

Return flows also gravitate to this location from the storm tanks and this could result double counting of flows. Calculation of the return flows is difficult due to the lack of monitoring.

For the historic spill performance this does not impact on the spill volumes or the timing as the return flows only occur when there are no intermittent discharges. The impacts of utilising these flows as inflow for hydraulic modelling are also minimal as tank return systems are only operated when there is sufficient capacity to prevent surcharging or spills from the intermediate works.

The middle left pane Figure 1 shows the other significant inflow to the intermediate works from the northern terminal pumping station (TPS). This inflow has been calculated in a similar manner to the screw pumps. The head discharge curve for this pumping station was defined based on the information in the verified model.

As per the screw pump modelling, a conversion formula was utilised to convert from percentage depth data to depth in metres. This data series was used in conjunction with the head discharge relationship to infer inflows.

The operation of the northern pumping station is more complex due to the number of pumps which pass the flow forward. Different methodologies were investigated but due to the flow from this pumping station being small when compared to the flow from the screw pumps a simplified head-discharge was utilised to generate the flow.

The other inflow to the intermediate works is from the emergency pumping station. This was included because during the calculation of the intermittent discharges there were occasions when the level in the intermediate wet well was increasing but the inflows from the screw pumps and the northern TPS were less than FFT. The following information was provided on the pumping station:

- Each pump is rated as 650 l/s;
- There are two rising mains with valves:
  - Normal operation is to pump to the low level inlet wet well;
  - Emergency operation is to pump directly to the high level inlet.

With the use of telemetry data regarding the on/off status of the pumps this inflow has been included when inferring the inflow. The maximum inflow from these pumps has been assumed to be 1,300 l/s.

2.3.2 Outflows from the Inlet Pumping Station

The middle right pane of Figure 1 shows the FFT telemetry data measured within the high level gravity system downstream of the intermediate level pumps; this is the primary outflow from the intermediate works.

The bottom left pane of Figure 1 shows the volumetric change in the intermediate wet well as calculated by summing the inflows and subtracting the FFT, during periods when the storage within the intermediate system is filled to capacity positive values indicate intermittent discharges. Further logic was required in order to determine periods where storage is full and hence define spill events.

2.3.3 Defining Spills to the Watercourse

The annotation applied in the bottom left pane of Figure 1 demonstrates the strong correlation between a recorded level of 85% depth in the intermediate level wet well and recorded intermittent discharges. This relationship is logical as the storm tanks and the intermediate wet well are hydraulically linked when the storm tanks are filled, therefore once storm tanks are filled any increase in level within the intermediate level wet well indicates spill to watercourse.

The confirmation of this relationship therefore allowed spill periods to be defined based as periods when the recorded wet well level is at or above 85%.

The spill flow rate during these periods can then be defined as the rate of filling ‘D’ as displayed in the bottom left pane of Figure 1.

2.4 Future Modelling

Inflows inferred based on historic data are acceptable for the modelling of current performance but cannot be used for the modelling of the future performance.

In order to generate inflows representing the future scenario including growth of 30,000 properties a new methodology was devised. This methodology involved utilising a modified version of the future network model to generate storm response for major storms which occurred during the same historic periods as inference of historic spills. This network model was modified to remove all current subcatchments, leaving only the growth regions.

To generate modelled storm response flows historic rainfall records were imported to InfoWorks software and simulations undertaken using the modified network model.

Storm flows were extracted from this model at the two low level pumping stations. An allowance for the base flow including infiltration and foul flow from the future sub catchments was added manually.

This data was then converted to depths within the wet wells using the dimensions of the wet wells from the model. This depth was then added to the current depths within the wet well. Using the head discharge curves for the pumping stations a new flow entering the works was calculated. Within the calculation additional logic was included to limit the inflow to the existing FFT when the level in the wet well is below the weir level into the storm tanks. This has been done because modelling was showing increases in the intermittent discharges which will not occur following the improvements.

The flow calculated was then input as an inflow to the InfoWorks model of the modified treatment works. The model was then run for a year and the intermittent discharges were extracted. As with the existing situation any spills that occur when there is river flooding or snow melt have been removed.

This methodology is conservative for the following reasons:

- The future flows arriving at the pumping stations are not being throttled by the flows from the existing sub-catchments
- Return flows are being double counted as they are included in the existing levels of the wet well for the screw pumps and they are also being calculated by the model.

2.5 Calculation of Return Flows

An estimate of the return flow is required in order to remove some conservatism in future modelling. Return flows are not currently monitored which means that they had to be calculated.

A model was constructed of the intermediate works to provide an estimate of the return flows. This model used the following information:

- Depth in the screw pump wet well;
- Inferred inflow to the intermediate wet well;
- Observed FFT flows.

It was assumed that the penstocks which are opened and closed to allow the return flow from the storm tanks back to the screw pump wet well could only be opened between 10am and 3pm each day and the level within the intermediate wet well needs to be below 23.4m AOD. The penstock would also open just before there is a discharge to the watercourse. This was done because it could be seen in the levels in the wet well that the levels would drop but the FFT would not change. This suggests that something changes within the storm tanks and it was assumed it was the opening of the penstock.

The estimate of the calculated return flow was removed from the future inflow used in the InfoWorks model which represents the future inlet works. The results with and without the subtraction of return flows for the future scenario have been presented due to the uncertainties that are still present.

3 RESULTS AND DISCUSSION

3.1 Results

Using the methodology discussed above spill results were generated for data sets from 2006, 2007, 2008, 2009 and 2010.

Due to the unreliability of the telemetry data and an inability to verify the pump status during certain periods, the 2009 and 2010 data sets have been discounted from the analysis.

Therefore spill flow calculation and UPM analysis have been carried out on 2006, 2007 and 2008 data sets. Using this data as an input for both the inferred and modelled scenarios, spill flow data was generated, analysed and used to quantify UPM water quality results (Table 1). During these years there are a number of times when there has been either river flooding or snow melt. These have been discounted as the STW is exempt from the normal consent during these periods.

Spill events for the purpose of the UPM calculations were defined based on the following logic in order to provide suitable inputs for the UPM water quality analysis tool.

- Minimum flow rate: 1 l/s
- Minimum volume: 1 m3
- Merge spills less than 6 hours apart
- Split long spills after each 12 hour period

Table 1 displays the results indicating the water quality impacts of this UPM for current and future scenarios along with comparison with river only performance and impacts of final effluent only discharges. The results shown are for all three years combined together.

Table 1. Modelled Spill Events and UPM Percentile Results

Scenario No.	Description	Total Spill Volume (m3)	Spills Per Year	90%ile concentration BOD (mg/l)	90%ile concentration Amm (mg/l)	99%ile Concentration BOD (mg/l)	99%ile Concentration Amm (mg/l)
1	River Only	N/A	N/A	2.78	0.09	5.5	0.38
2	River & STW (Current)	N/A	N/A	3.28	0.34	5.54	0.65
3	2006-2008 (Current)	1,557,879	36	3.42	0.36	7.01	0.73
4	River & STW (Future)	N/A	N/A	3.35	0.37	5.61	0.69
5	2006-2008 with growth (return flows included)	1,480,713	24	3.46	0.38	6.82	0.78
6	2006-2008 with growth (return flows removed)	1,157,296	20	3.44	0.38	6.54	0.75

Table 2. UK Water Quality Standard Thresholds - WFD and RE Classes

	90%ile BOD (mg/)	90%ile Amm (mg/)	99%ile BOD (mg/)	99%ile Amm (mg/)
(WFD High) RE1	(4.0) 2.5	(0.3) 0.3	5.0	0.6
(WFD Good) RE2	(5.0) 4.0	(0.6) 0.6	9.0	1.5
(WFD Moderate) RE3	(6.5) 6.0	(1.1) 1.3	14.0	3.0
(WFD Poor) RE4	(9.0) 8.0	(2.5) 2.5	19.0	6.0

3.2 UPM Results Discussion

3.2.1 Current Scenarios

a) Scenario 1 – River only

Sensitivity test with no pollutant input to the watercourse from STW or storm tanks. River only performance is reasonable with the river classified as WFD 'Good'/ RE2 for BOD 90 and 99 percentiles. Ammonia concentrations are better with the river classified as WFD 'High' / RE1 for 90 and 99 percentiles.

b) Scenario 2 – River & STW

Sensitivity test with no intermittent discharge input to the watercourse. Final effluent (FE) discharges from the STW are predicted to have a marked effect on the water quality of the receiving watercourse. BOD percentile values increase as a result of FE discharges however classification remains the same. Increases in Ammonia percentile values resulting from the introduction of the FE discharges changes the classification for ammonia performance from WFD 'High' / RE1 to WFD 'Good' / RE2.

c) Scenario 3 – Historic Inferred for 2006 to 2008

Historic performance run with all inputs to the watercourse considered. The results show a negative impact on all of the percentile values with the largest impact on the 99 percentile values. The values are still within the WFD 'Good / RE river classification. This shows that with the operational issues at the works the spills do not cause the river to fall below the WFD 'Medium' / RE3 classification. The total volume w spilling during these three years is equal to 1,557,879m^3 and the spill frequency per year is 36. These values are high due to the operational issues which occurred.

3.2.2 Future Scenarios

Future scenarios are necessary in order to understand the likely impacts of future growth within the catchment on the water quality of the receiving watercourse downstream of the STW.

Future scenarios shown in Table 1 do not allowances for the potential improvements in FE quality in the future following proposed tightening of the current ammonia consent therefore results presented are conservative. Scenario 5 includes the improvements to the emptying of the storm tanks and the reduction in FFT. The results shown are a range to show the effect of removing the return flows.

a) Scenario 4 – Future River & STW

Scenario 4 demonstrates the predicted water quality of the receiving watercourse assuming increases in foul flows as a result of growth equal to a population equivalent (PE) of 30,000 across the catchment. The scenario assumes that the average FE flow increases by 63 l/s but the pollutant concentrations in FE remain the same. The increase in FE flow rate results in some detriment to water quality percentile performance but doesn't change the river classification.

b) Scenario 5 – Future Modified Works for 2006 to 2008

When the spills for the three years are combined it is possible to see that there is an overall reduction in the spill volume and spill frequency per year when compared to the current situation. This reduction is due to there being no operational issues.

If the return flows are removed then the total volume for the three years is reduced as is the frequency of spilling per year. This is due to the removal of the double counting of the return flows.

When comparing the percentile values for the BOD and Ammonia it is possible to see that there is an increase in all of the values apart from the 99 percentile for Ammonia when compared to the current situation. For the 99 percentile value for Ammonia there is a decrease in the value. The increases are due to an increase in the FE flows and not due to spills.

From the results in Table 1 the amount that the percentile figures change in the future is less than the changes due to the increased FE flow in the future in all cases apart from the 99 percentile value for

Ammonia. For the 99 percentile value for BOD the future value is actually less than the value for the current situation. For the 99 percentile value for Ammonia the increase in the future is 0.01 more than the increase due to the increased FE flow. This shows that the proposed modifications could improve the quality of the receiving watercourse due to the removal of the operational failures.

The percentile values when the return flows are removed are all reduced except the 90 percentile value for Ammonia. This would mean that the quality of the river will be slightly improved however the WFD and the RE class will not be altered.

3.3 General Discussion

As historic data has been used for the entire BOD and Ammonia modelling, the results for the various scenarios tested are comparable. The baseline set by inferring the performance for 2006 to 2008 shows that water quality impacts of storm discharges are predicted to be relatively small, due primarily to the high degree of dilution provided by the receiving watercourses however the spill frequency and volumes calculated for this period are very high.

There is a suggestion that operational issues are responsible for a number of spills. It has been confirmed that under the current flow conditions a significant number of spills could have been eliminated through the modifications to the inlet works to ensure that the storm tanks are effectively emptied storms and to ensure that the pass forward pumping to treatment is always achieve design pumping rates.

Future predictions show a slight detriment in the water quality relative to the historic scenario.

Future predictions to the inlet works configuration in combination with additional inflows from all aspects of growth show a slight detriment relative to current baseline performance for 90 percentile BOD and ammonia and 99 percentile ammonia levels. The majority of this detriment may be attributed to the increase in FFT flows and therefore an increase in the continuous pollutant loadings in the watercourse. 99 percentile BOD levels show a significant reduction from baseline levels due to the reduction in intermittent discharges relative to the current scenario. Some of the detriment in water quality may be mitigated by the proposals to lower the consent for ammonia discharges and the improvements to treatment.

4 CONCLUSIONS

Overall UPM modelling results suggests that there is no issue with meeting the specified targets of RE3 and WFD classification, or 'no detriment' targets for 90 percentile pollutant concentrations. These targets are met for all scenarios tested.

From the work carried out many of the current spills from the STW intermediate works to the watercourse are occurring due to operational performance and the proposed modifications to the intermediate works will improve the reliability and reduce the intermittent discharges causing an improvement in the water quality. With a more reliable, modified intermediate works system, the spills to the watercourse should only occur following significant storms. At these times the flows within the watercourse should be high and the watercourse will be less sensitive to pollution, therefore the risk to wildlife will be reduced.

With the current conditions where operational issues are causing and exacerbating the spill events the risk to the wildlife is high as it cannot always be guaranteed that the spills are following storm events or comprise solely dilute sewage.

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