The Impact of Tails on CSO Discharges

Or heads you win, tails you lose

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Introduction

The United Utilities (UU) AMP3 UID programme is the largest programme of work in the UK to identify and address pollution of surface waters by urban wastewater discharges in wet weather. The 914 UIDs were initially identified for assessment, grouped into 77 study areas. UU undertook water quality based Urban Pollution Management (UPM) studies in 38 of the study areas in the programme. The number of catchments which required assessment probably made this the largest hydroinformatics programme ever carried out in the UK.

These studies demanded integrated modelling of all elements of the wastewater networks and the watercourses that the networks discharge to. The studies required the building and verification of sewer models for flow and quality; the constructing and calibration of river quality models; the development of design rainfall series; and the production of wastewater treatment works (WwTW) models. To feed this modelling effort vast amounts of data had to be collected. Table 1 illustrates the scale of the modelling and data collection exercise.

Table 1 - The scale of the data collection and modelling required for the UU UPM Studies

Flow monitors installed (all studies)	1750
Quality samplers installed	255
CSOs / Manholes surveyed	1750/8500
Study catchments (inc. Bathing Waters and Spill Frequency)	77
Water Quality Studies	38
Number of "design" long duration rainfall series	34

With the amount of hydraulic model build and verification carried out as part of the programme, which amounted to re-building / upgrading of models covering approximately 70% of the population of the North West, there have obviously been many problems encountered and lessons learned. This paper will look at some of the issues raised by the modelling of the observed slow run-off response, in terms of methodologies that have had to be adopted by UU, and other issues that these have raised.

UU Modelling Policies

At the commencement of the AMP3 modelling studies in 1998, UU Urban Pollution Management Guidelines stated:-

"Where possible the standard Wallingford run-off model should be used. Only in exceptional circumstances should the new UK run-off model be used to obtain improved calibration wet weather calibration fits."

The reasons for this policy were:-

- Experience of the new UK model was limited at the time
- The use of the model was seen to be a calibration exercise.
- There was no accepted methodology for calculation of API30 for design storms
- There was a concern that the New UK run-off model would over estimate run off in large storm events.

Although the preference in UU is still to use the standard Wallingford run-off model, in practice on the UID programme the use of the standard model was in fact the exception, and the rule has been to use either the new UK run-off model, the Ground Infiltration tool in Infoworks, and in some cases both.

The main reason for this change in direction has been due to the observed flow survey datasets, and the obvious impact that the slow response tails have to the performance of some of the CSOs. Also the requirements to match volumes of flow to WaPUG COP criteria in verification makes the specific modelling of the permeable response almost, but not quite, obligatory.

Flow Monitoring for CSOs

As the model building and study work carried out has been for the UID programme, inherently the majority of the flow monitoring carried out has been specifically round CSOs and WwTW inlets. This has meant that a considerable number of monitors have been deliberately placed close to CSOs, and in a number of cases have been close enough to be able to determine the depth of flow in the CSO chamber, and hence whether the CSO is actually spilling. The advantage of this is that it is easy to see if the model is predicting the duration of spill.

After what has been a sharp learning curve, the policy which has now been adopted by UU is to have flow monitoring upstream and downstream of major CSOs, with the upstream monitor being placed as close as possible to the CSO. This means that on anything other than very steep catchments it is possible to measure both the flow entering the CSO and the depth of flow in the CSO chamber. In some cases we have placed monitors in the CSO spill pipe, which again shows the duration of spill together with an indication of spill volume. Even though these locations are traditionally not looked on as favourable sites for flow survey, good results at these locations can make acceptance of models by auditors far easier. For smaller CSOs, UU policy is where possible to use one flow monitor upstream of the CSO, again close to the CSO. Hence if the flow entering the CSO is well modelled, and the spill duration is correct, the continuation flow will be modelled correctly.

Table 2 below shows the location of monitors adjacent to CSOs in a typical UID study catchment.

Table 2 Location of Monitors Relative to Overflows

FM Reference	FM Level (mAOD)	CSO Spill Level (mAOD)	Distance from FM to Overflow (m)	Overflow Control	Overflow Type
FM050 FM048	86.95 86.95	90.71	In CSO u/s In CSO d/s	High Level weir	525mm dia (Hole in wall)
FM046 FM045	79.90 72.81	79.93	In CSO u/s 203m d/s	N/A	Single-sided weir
FM062 FM063	56.58 56.38	56.95	In CSO u/s 101m d/s	N/A	Single-sided weir
FM054 FM053	98.10 96.23	97.46	In CSO u/s 98m d/s	N/A	Double-sided weir
FM059 FM058	85.60 85.12	85.37	49m u/s In CSO d/s	N/A	Benched weir
FM047 FM046	83.95 79.90	84.25	109m u/s 128m d/s	Bifurcation Throttle Pipe	Stilling Pound
FM044 FM042	45.73 44.85	46.40	18m u/s In CSO d/s	Throttle Pipe	Single-sided weir
FM055	90.40	91.85	In u/s of PS Storage Tank	Pump	Single-sided weir
FM064 FM065	106.06 105.84	106.11	25m u/s 7m d/s	Penstock/Gate	Double-sided weir

The monitoring close to CSOs has highlighted the major impact that tails can have on spill volumes and duration from CSOs with a low setting. In some instances spills from CSOs have been underpredicted by a factor of 2 when using the standard run-off model.

A significant number of UIDs in the AMP3 programme have been at supposedly foul only pumping stations. In the majority of cases, the only way it has been possible to work out the storm response in the catchment has been by flow survey. The policy developed by UU and our consultants MWH is to carry out pumping station drop tests, monitor the depth of flow in the pumping station wet well, and if the incoming pipe is large enough to insert a flow monitor in the incoming sewer. In some instances at larger pumping stations we have also monitored downstream of the pumping station rising main.

Due to the relatively low pump rates at these “foul only” pumping stations, the permeable response can have a significant impact on the performance of the station, and in a number of cases where pumping stations have been modelled, the new UK run-off model has had to be used to adequately represent the observed flows and depths at the station.

Use of the New UK Run-Off Model in Design

Because it was obvious at an early stage in the modelling programme that permeable response would have to be modelled, there was then a need to work out a means of using the new UK run-off model in design mode before it could be used for model verification. This was on the basis that there is little point calibrating a model if it cannot then be used in more extreme events when the antecedent conditions are not known.

For the 34 ten year rainfall series developed for the UID programme, it was possible to calculate API30 from the antecedent conditions in the rainfall time series. This was done for all the soil classes covered by the rainfall series. However it was a more difficult task to calculate API30 values for design storms when the antecedent conditions are unknown.

In the end the following methodology was used:-

For each of the 34 rainfall series:-

- Including Evaporation (Sinusoidal Model) calculate API30 for all rainfall events for each of the five soil types.
- From these records select the API30 values on days with total rainfall depth >10mm
- Divide these values into Winter and Summer events.
- Calculate the Median API30 value for the Summer and Winter subsets.

In this way design API30 values have been developed for each soil type, for each of the 34 rainfall series in the North West of England.

It is also not possible to use the traditional TSR storms with the new UK run-off model, as these are UCWI storms. In order to get round this, for each of the rainfall series a "typical" years rainfall has been identified which is used instead of the traditional Time Series Rainfall events.

Verification using New UK and Ground Infiltration

It is UU policy to commence verification using the standard Wallingford run-off model. When initial fits have been examined, a decision is then taken on which run-off model to use. This decision will be based on a number of factors, some of which are:-

- Initial volume balances
- Initial shape of the flow hydrograph
- Fits against spill duration at CSOs
- Which software is being used. If Hydroworks is being used then it is not possible to use the Ground Infiltration tool.

Generally it has been found that in models built using the "10 metre" rule, there is insufficient permeable area in the models to produce the volume of run-off actually observed in the observed data. Additional permeable area has to be included in the model.

For Bathing Water and Shellfish projects, it is UU policy to carry out design work using continuous simulation techniques, including the inter event dry periods. In these instances it is particularly important to model the permeable responses, as the filling and emptying of any storage constructed as part of any solutions will be susceptible to the base flow in the sewers.

Because of the use of continuous simulation, we were concerned that the models developed should be stable over a long period. In order to add confidence to our modelling in these situations, verification on these projects is checked against the full period flow survey data, to ensure that the shape of the hydrographs and volume balances are maintained throughout the survey period. Any shortfalls are made up using the Ground Infiltration Tool in Infoworks, as Infoworks is the software engine used for the continuous simulation runs.

When using the Ground Infiltration tool, only the Rainfall Induced component of the tool is utilised. All the base infiltration variability is effectively switched off, as we have found this is difficult to calibrate.

Impact of Modelling Tails on CSO Discharges

Below is a typical example of the impact of adequately modelling tails on the modelled performance of CSOs. The catchment used consists of a combined wastewater network, which has an approximate catchment area of 10.82 km^2 and serves a total residential population of approximately 31,000. There are a number of CSOs in the catchment, some of which spill at less than formula A pass forward flows. The catchment has a number of fields adjacent to the developed areas.

The model was verified with the new UK run-off model due to the observed tails and a good verification was achieved which has been audited. For the purposes of this paper the model was re-verified using the Standard run-off model and Ground Infiltration in Infoworks. This was carried out quickly and the verification is not quite as good as the new UK run-off model, hence the slightly increased spills.

In order to assess the differences in model performance, three models were used, being the Ground Infiltration model, the standard UCWI model and the verified new UK model. Each model was run hydraulically through a "typical" year of rainfall extracted from the ten year Stormpac Series for the area.

The results of the exercise are shown below. This clearly shows a large increase in spill volumes and duration between both the models with tails represented and the standard UCWI model. The largest difference is as expected in the three overflows with low pass forward settings. In each of these cases the modelling of the tails has more than doubled the spill volumes and duration. The largest spill volume in a single event in all cases has also more than doubled.

To put it into context, if there was a need on these three CSOs to reduce spills to less than once per year, the standard run-off storage volume would be 8800 m^3 and the new UK storage volume would be 19,300m^3. If the standard run-off storage volumes were built, based on the new UK model the CSOs would still spill between 10 and 15 times per annum.

Spill volumes have still increased in CSOs spilling less frequently, although to a lesser extent.

It is interesting to note that although in general the Ground Infiltration model has been calibrated to give slightly more overall spills than the new UK model, in the majority of instances the Ground Infiltration model gives a smaller spill volume on the largest spilling event, and this is a phenomenon which will be discussed later in the paper.

GAUGE	SPILL FREQUENCY (Per ANNUM)			Increase
	Ground Infiltration	Standard UCWI	New UK	New UK / Standard
91919801.1	33	25	31	1.24
92919201.1	29	24	25	1.04
93896606.1	128	126	126	1.00
93905412.1	128	122	126	1.03
93925506.1	2	1	1	1.00
94901001.1	109	104	107	1.03

GAUGE	TOTAL SPILL VOLUME (M3 Per Annum)			Increase
	Ground Infiltration	Standard UCWI	New UK	New UK / Standard
91919801.1	3788	1922	3282	1.71
92919201.1	2445	1576	1876	1.19
93896606.1	193075	92824	188213	2.03
93905412.1	149472	64942	146962	2.26
93925506.1	86	10	58	5.89
94901001.1	61686	26019	61181	2.35

GAUGE	SPILL DURATION (HRS Per ANNUM)			Increase
	Ground Infiltration	Standard UCWI	New UK	New UK / Standard
91919801.1	49	25	41	1.69
92919201.1	26	16	21	1.27
93896606.1	1175	544	1147	2.11
93905412.1	1068	493	1041	2.11
93925506.1	2	1	2	4.44
94901001.1	553	259	550	2.13

GAUGE	MAXIMUM SPILL VOLUME (M3)			Increase
	Ground Infiltration	Standard UCWI	New UK	New UK / Standard
91919801.1	460	284	538	1.89
92919201.1	355	262	304	1.16
93896606.1	6159	3317	7241	2.18
93905412.1	6642	3678	7979	2.17
93925506.1	75	10	58	5.77
94901001.1	3428	1790	4127	2.31

Although this is only one example it serves to show the differences that adequately modelling the “tails” of storm events can make to modelled CSO performance. There are a number of similar examples that could be used which will give differences in the same order of magnitude.

Problems and Issues using New UK and Ground Infiltration

There are a number of issues raised by the use of the new UK run-off model and the Ground Infiltration Tool.

- Both are calibration techniques, and are only as good as the data available for calibration purposes.
- The new UK model was developed to take account of varying wetness on a catchment during a rainfall event, and the direct run-off from permeable surfaces. It was not developed to represent the very slow permeable run-off presumably by Ground Infiltration entering the pipes through the soil.
- There is a need to make sure in all cases that the base infiltration in the model is correct, and the dry weather flows are well matched. Instances have occurred where obvious under-prediction of base flow has been rectified by calibrating the new UK run-off model with potentially disastrous results.
- When using the new UK model, it is important to ensure that API30 values are used in red files and not UCWI. We have had situations in design and verification when UCWI values have been used rather than API30 with the result that huge run-off volumes have been generated.
- It has not been possible in a number of cases to match the run-off volumes over all verification events. This suggests that there are limitations in the new UK run-off model such that the model does not match all situations.
- There are still concerns that these run-off models will over-predict run-off volumes and peak flows in extreme event conditions. Below are two examples of using the New UK model in extreme event situations and the results produced.

Example A:

Drainage Area model used in the CSO example above, with significant permeable responses, calibrated using four individual events. Data is shown for a typical verification event, and the largest rainfall event in the ten-year rainfall series. The verification event is a 20mm rainfall event, while the ten-year series event is a 60mm rainfall event.

Run-Off Type	Verif. Event 1 Run-off (m3)	Rainfall Series Event	
		Run-Off (M3)	Flooding (M3)
New UK Model	25211	159607	48000
Standard Model	13326	52066	8000
Ground Inf.			24000

The increase in run-off between the new UK and the standard run-off model on the verification events is in the order of a factor of 2, i.e. there is as much additional permeable run-off as the direct run-off from paved surfaces. However in the case of the more extreme rainfall event, the difference in run-off is a factor of 3, with twice as much run-off from the additional permeable run as the direct run-off from the paved surfaces. Also flood volumes are an order of magnitude different. There was no flooding on the verification events.

Of course this is only one example, but it is considered there are many more similar examples. The concern raised is in the extrapolation from "calibrated" parameters on verification events to extreme events. From historic flooding incidents it looks like the model is over-predicting flood volumes. However from the verification events the model is representing the run-off well and matching the spill volumes and duration at CSOs. Hence it is not possible to change the set up of the model. The concern is that there is no means of limiting the run-off from the pervious surfaces on these wetter events.

As previously detailed, the model was re-calibrated using the Ground Infiltration tool and the standard run-off model. This showed a significantly lower flood volume than the new UK model. This together with the previously discussed reductions in spill volumes with the Ground Infiltration model on larger events suggests that the Ground Infiltration Model gives a lower permeable run-off volume on extreme events than the new UK model.

Example B

The second example is a small foul only pumping station. This station is consented as an Emergency Overflow only and acts as a CSO. We were asked to look into what was required to prevent spill on a 30-year event.

A flow survey was carried out and a significant tail was identified. The model was verified using the New UK run-off model. For the purposes of this paper, the model was re-calibrated using the Ground Infiltration Tool in Infoworks. The new UK model, Ground Infiltration Model and standard run-off model were all run over a suite of 30-year events. The spill volumes from the Emergency Overflow were noted as an indication of the likely work required to convert the station back to EO status.

Table 3 Design Event Spill Volumes

Design Event 30 Year:-	15 mins (m^3)	30 mins (m^3)	60 mins (m^3)	120 mins (m^3)	240 mins (m^3)	480 mins (m^3)	960 mins (m^3)
Standard Wallingford	0	7	22	31	28	7	15
Ground Water Infiltration	158	238	340	441	532	626	721
New UK Runoff Model	254	414	616	844	1105	1391	1750

The results show that there is a huge difference in spill volumes between the standard run-off model and the other two run-off models. A difference is to be expected as the standard run-off model was obviously under-predicting inflows to the station. However the volumes generated are large in relation to the catchment size. The pumping station only has a capacity of 11 l/sec. Also the two “permeable” run-off models never actually reach a peak volume due to the slow permeable response being sufficient to beat the pumps for a significant duration of time.

This modelling phenomenon has occurred in other similar situations. The question is whether this is really the situation or another example of the permeable run-off models over-predicting run-off in extreme events. Again the Ground Infiltration model gives lower run-off than the new UK model on extreme events.

Conclusions

- The close monitoring of CSOs has highlighted the issue of the impact of permeable run-off on CSO spills.

- In order to match WaPUG COP guidelines on volume balances in verification, this permeable run-off must be modelled.
- It is possible to model this permeable run-off using currently available run-off models.
- There are limitations currently in the ability of the run-off models used here to represent the run-off from all storms observed in flow surveys.
- The modelling of permeable run-off has shown that the impact can be large, sometimes in excess of the direct run-off from impermeable areas.
- There are concerns that the new UK run-off model could be considerably over-predicting run-off in extreme events and design storms, causing problems with the use of the models for assessment of foul flooding and CSO performance in larger time series events.

Recommendations for Further Work

- There is a need for the industry to carry out further development of permeable surface run-off models as quickly as possible.

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