CALCULATING STORM TANK SIZE USING CONTINUOUS SIMULATION

Helen Udale, Guy Morbey & Martin Osborne
Reid Crowther Consulting Limited,

Summary

We have developed a method that uses a simplified lumped catchment model for continuous simulation of rainfall data for bathing seasons. The critical periods from the rainfall data are selected by looking for the predicted peak volumes of storage and spill. These critical periods are then simulated with a detailed HydroWorks model. The method is quick and simple and can be adapted to suit even complex catchments.

The methodology and results given in this paper describe the use of this method for a particular study. The follow on discussion explores issues regarding data handling and other applications.

Introduction

The problems of using long rainfall timeseries to predict compliance with bathing water standards were described at the 1998 WaPUG Spring Meeting by Illari and Page. They set out a useful method to overcome some of these problems by using a regression equation of rainfall event characteristics to rank events, so as to select the critical ones for use with a detailed model. Their reasons for using this methodology were justifiable, but some issues remain outstanding.

The paper did not address how to divide the rainfall record into appropriate events in the first place. In particular, how long does the dry period between the storms need to be to classify storms as discrete events? Should it be one hour; six hours; or a time interval equivalent to the time of concentration for the catchment upstream? Is it, instead, easier to carry out a continuous simulation of the entire rainfall record? This paper argues that continuous simulations need not be as troublesome as they first appear.

There are three main issues related to continuous simulation that have made engineers reluctant to adopt this method. These are:

- the need to use the new Wallingford runoff model to simulate the continuous wetting and drying of the catchment,
- the use of simplified models, rather than detailed models, in order to reduce simulation run times, i.e. can a simplified model represent a complex system sufficiently accurately?
- data handling difficulties.

It is now generally recognised that the new Wallingford runoff model represents the runoff from long duration storms or sequences of storms more accurately than the PR equation.

A description of the new model can be found in WaPUG User Note 28. Version 2 of the user note includes recommendations on its use in HydroWorks and was described at the WaPUG training day this year.

Methodology

The methodology described here is one we adopted for determining the required storage volume of the storm tanks at a wastewater treatment works, so that the spill frequency did not exceed, on average, three times per bathing season. We were requested to determine this using continuous simulation of a long rainfall timeseries and we were given one week to complete the task.

We were provided with a detailed model of the sewerage system using the old PR equation and 20 years of stochastically generated rainfall data, generated using STORMPAC.

The main steps were the following:

- update the detailed model to use the new Wallingford runoff model
- build a simplified model

- calibrate the simplified model against the detailed model
- run the simplified model with continuous rainfall timeseries
- check results using selected storms with the detailed model

Updating the detailed model

The original detailed HydroWorks model, using the old PR equation, was updated to use the new Wallingford runoff model. The two versions of the same model were compared using individual storms. Minor modifications were made to the runoff parameter file for the new version, in order to match the runoff from the original model.

As we were not provided with the original survey data used for verification of the HydroWorks model, we were unable to assess the extent of verification achieved using the PR equation. Therefore as there is a tendency for the PR equation to underestimate total volumes for longer duration storms and sequences of storms, we matched the two models using only short duration storms. Care should always be taken when comparing the old PR equation with the new runoff model, as each is designed to represent certain characteristics of runoff. Ideally the original survey data should always be used to guarantee accurate representation of whichever criterion is most important for a particular study, e.g. peak flows to determine flooding or total volumes to determine storage volumes.

Building a simplified model

We built a simplified HydMod model using the detailed HydroWorks model.

HydMod was developed in-house. It is based on the new Wallingford runoff model and features include the following:

- represents the runoff from large contributing areas using average characteristics
- represents the delay and attenuation of flows in local sewers using a simple linear reservoir
- takes into account the wetting and drying of the catchment
- uses different soil classes for different catchments
- can use a continuation flow limit, that represents the effect of CSOs in the sub-catchment, spilling flows above the continuation flow from the system
- can use rainfall data with a timestep of the user's choosing, providing results at the same timestep
- produces hydrographs that can be used as inflow files for a HydroWorks model
- produces an output file with APIs for the catchment for each rainfall data interval

It is also very quick to run. A bathing season takes one second to run through a lumped catchment.

The catchment was represented as two simple lumped sub-catchments. We assumed that these catchments acted dendritically during storm events of particular concern, i.e. the cross-connections between the two catchments did not operate during storm events with frequencies of between 2 and 4 times per bathing season. This proved to be the case during the calibration.

Calibrating the simplified model

We extracted events from the 20 years of stochastically generated rainfall data to be used for the calibration of the simplified lumped catchment model. All storms within all bathing seasons were ranked by total depth. Events were selected between the 30th and 90th in the series (the 60th event having a frequency of about three times per season). Events were selected in such a way that the ranges in duration, intensity and UCWI were represented.

We then needed to determine appropriate antecedent precipitation indices (APIs) for these calibration events. Therefore we generated continuous hourly rainfall timeseries for each bathing season, using the STORMPAC data provided. We then ran the bathing seasons through the uncalibrated HydMod model in order to use the API calculation facility and determine the mean and range of APIs. It was assumed that the API at the start of each bathing season was zero. This was a reasonable assumption for this particular catchment with a soil class of one. (However, if 30 days of data preceding the bathing season is available, the API can easily be determined more accurately.) Appropriate APIs were then allocated to the calibration events.

The calibration events were then run through the simplified model and the detailed HydroWorks model.

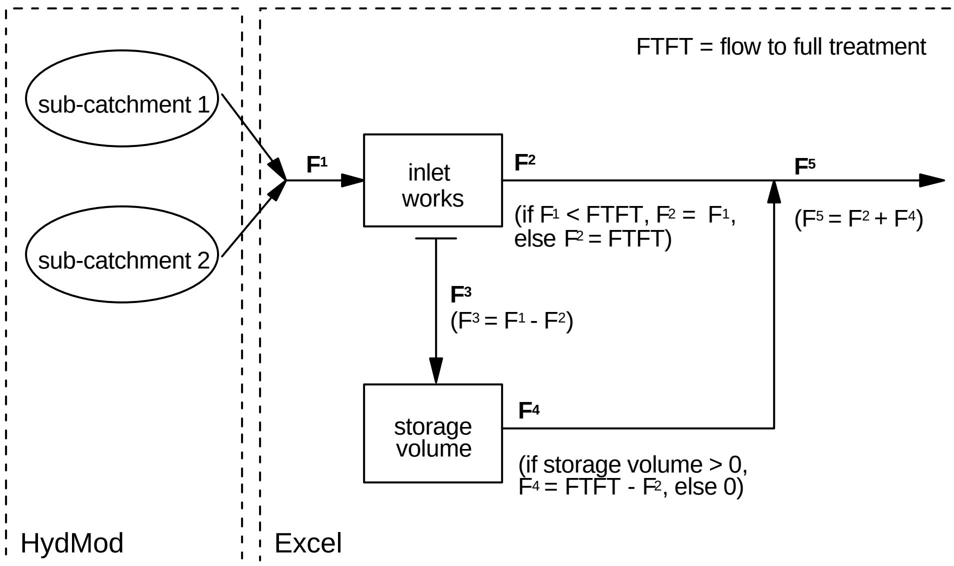
A good calibration fit was achieved for peak flows, total volumes and hydrograph shapes.

Running continuous rainfall timeseries

The continuous hourly rainfall timeseries for each bathing season was then run through the calibrated simplified model. This produced outflows from the two catchments and APIs throughout each bathing season. This only took a matter of seconds for each bathing season.

We determined the peak storage volumes for all events in each bathing season using an Excel spreadsheet. The spreadsheet combined the flows, determined the flow to full treatment, and determined the remaining volume to be stored. This took into consideration the rate of return of stored flows into the flow to full treatment once flows dropped. This process is shown in Figure 1.

Figure 1 Simplified representation of flow split at works

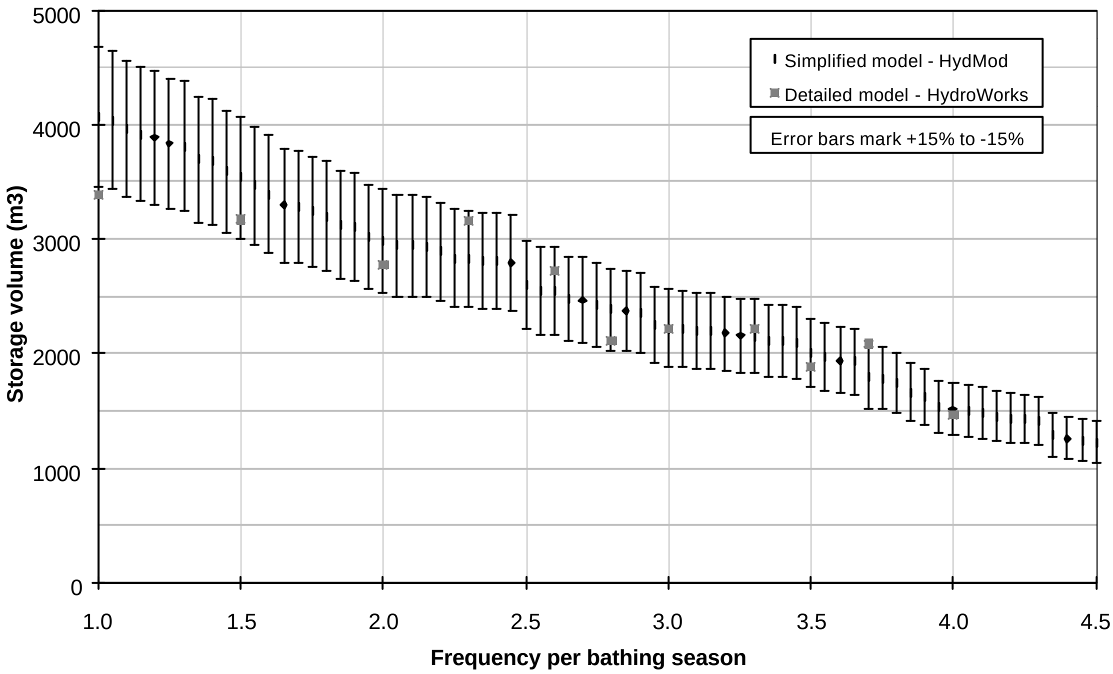


Once checks had been carried out that the highest peak for each separate storm event had been selected, we collected and ranked the peak storage volumes for all bathing seasons as shown in Figure 2. It was assumed that peaks that occurred within 24 hours of each other counted as one event.

Checking results

From the Excel spreadsheets, peak volumes with frequencies ranging from 0.5 to 4.5 per bathing season were inspected to determine the associated storm event and API at the start of the storm. Twelve storms were then extracted from the 20 bathing seasons and simulated in the detailed HydroWorks model to check the HydMod results. The required storage volumes for these twelve events determined with the detailed model were compared with the HydMod results as shown in Figure 2.

Figure 2 Storage volumes from the simplified and the detailed model



Results

Figure 2 shows that the HydMod and HydroWorks results were comparable. The best correlation was achieved at a frequency of 3 times per bathing season. This is to be expected as the calibration of the HydMod model concentrated on storms with frequencies of 2 to 4 times per season.

It is also to be expected that the HydroWorks model would predict lower volumes for rarer events, as the effect of upstream restrictions not modelled in HydMod would have a greater influence on the flows in the catchment.

This figure shows that in order to limit the spill frequency to 3 times per bathing season, on average, a volume of at least 2 250 m^3 was required. However, due to the scatter of the HydroWorks results compared to the HydMod results, it was prudent to apply a safety factor.

A possible conservative design would have been to draw an envelope around the HydroWorks results, as shown by the error bars in Figure 2, which would have given a 15% safety factor. However, inspection of the HydMod results showed that this had little extra benefit compared to a 5% or 10% safety factor. This is illustrated by Table 1.

Table 1 Design storage volumes with added safety factors

Safety factor (%)	Design storage volume (m^3)	**Average*** no. of spills per bathing season	**Maximum** no. of spills in any bathing season	**Minimum** no. of spills in any bathing season
0	2 250	3.00	6	0
5	2 360	2.85	6	0
10	2 475	2.65	6	0
15	2 590	2.50	5	0
50	3 375	1.60	3	0

*based on 20 bathing seasons

This table also highlights the difference in storage volume required to limit spills to 3 times **on average** per bathing season compared to a **maximum** of 3 times in any bathing season.

An alternative approach would be to run more storms through the detailed HydroWorks model and the error (or safety factor) could have been based on the standard deviation of the results.

Other applications

HydMod has been designed specifically so that its output is compatible with HydroWorks. It is very simple to use its output as inflow hydrographs into a detailed model of the downstream system. With careful simplification of the detailed model, this can greatly reduce simulation times.

However, a similar simplified model can be created using the Large Catchment model in HydroWorks. The hydraulic component of the Minworth catchment strategic sewerage model described by Udale *et al* (1997) was successfully converted from HydMod to HydroWorks using the Large Catchment model. Using HydroWorks can be a little laborious as the model needs to be built using a sequence of nodes and links, while HydMod only requires the input of parameters. Also calibration of the Large Catchment model requires modifications to the parameters in the runoff parameter file. Simulation times are generally longer for the HydroWorks version than using HydMod, but need not be unreasonable.

A bonus with using HydMod is that it provides APIs at each timestep in the output file that can be used with individual storms extracted from the timeseries. If using a simplified HydroWorks model, it is necessary to devise an alternative method for determining APIs.

We are looking to develop HydMod further by representing the delay and attenuation of flows using a cascade of reservoirs, rather than a single reservoir. This should make calibration easier, particularly for larger catchments. With a single reservoir, using the reservoir time lag parameter to achieve sufficient attenuation can flatten the peak of the hydrograph. This is also a limitation for the Large Catchment model in HydroWorks. With a cascade of reservoirs it should be possible to adjust the time lag and number of reservoirs in order to maintain the peak more accurately.

Data handling issues

We have carried out several simulations using different combinations of lumped catchment models and detailed HydroWorks models, in order to assess time requirements. One sewerage system we looked at consisted of 3 simple lumped catchments in HydMod that provided inflows into a HydroWorks model of the trunk sewers and controls at the downstream end of an otherwise dendritic sewerage system. The HydroWorks model had 39 nodes, 24 links, 25 ancillaries and real-time control (RTC). We ran a whole bathing season through the HydMod model of the 3 catchments, which took a couple of seconds. These results were then run through the HydroWorks model in less than 3 hours with a 60 second time step. Twenty bathing seasons could therefore be simulated in less than 3 days.

If the model is relatively stable, it may be possible to use a longer time step, such as 120 seconds. As the majority of a continuous timeseries usually consists of dry weather, doubling the time step approximately halves the simulation time. This, of course, assumes that the model does not require more than 10 time step halvings during rapidly changing flows.

Using different time steps can have a significant effect on variable controls or RTC, as this can alter the number of times a control changes. For example, increasing the time step from 60 to 120 seconds can half the number of times a control gate is opened, but doubles the flow volume through that gate for the period that it is open. This kind of problem can be overcome by first running at the longer time step, then determining the periods when control structures are changing rapidly. These periods could then be run separately at a smaller time step. This no longer becomes an issue if you are using the InfoWorks version of HydroWorks, which gives the user the option to set different maximum timesteps for dry and wet weather.

These variations in results do not have a significant effect on calculations for determining storage volumes, but may have a dramatic effect on intermittent discharges from CSOs in the HydroWorks model. Therefore care needs to be taken that such variations have been identified and the response times of control structures have been modelled accurately.

One of the limiting features of HydroWorks is that it only allows 16 383 (2^{14}-1) results intervals. Therefore it is necessary to optimise the simulation timestep and the results timestep multiplier in order to stay within this limit. For example, you can run a whole bathing season using a timestep of 120 seconds and a results timestep multiplier of 10 (20 minutes), but not using a timestep of 60 seconds and a results timestep multiplier of 10.

Conclusions

Storm tanks can be sized quickly and simply using the new Wallingford runoff model, simplified lumped catchment models and continuous simulations of long rainfall timeseries.

It is even possible to carry out continuous simulations for complex systems, as long as an appropriate simplified model is used and this is combined with a detailed model for downstream locations of particular concern.

References

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DISCUSSION

Question Nick Orman WRc

You chose to use the new runoff model because the original PR model does not include a mechanism for updating UCWI for continuous simulation. Did you consider developing a methd for updating UCWI and using the original PR model?

Answer

We were unhappy with trying to adapt a model that was developed for single event use to make it suitable for continuous simulation. We were much happier with using the new runoff model that was developed for this type of continuous simulation. We have had good results with the new runoff model on previous studies and would prefer to use it whenever possible.