Abbey Lane – Verification of Slow Response Flows

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The Abbey Lane Drainage Area Zone (DAZ) is in the south west of Sheffield and was verified as part of the Yorkshire Water AMP5 DAP programme. The modelled area covers approximately 500 hectares and comprises 2319 nodes. 116 flow and depth monitors were installed across the catchment between May and June 2012.

Flow monitor data from approximately 40 flow and depth monitors installed in the Jordanthorpe, Batemoor and Lowedges areas, in the south of the catchment, displayed significant slow response flows induced by rainfall. These areas are served by extensive surface water and foul systems which might appear to be separate on initial inspection. Some of the observed slow response appeared to be made up of two distinct flow profiles, one quicker and one slower, this was predominantly observed in the foul/combined systems.

This paper documents the investigations into the sources of the slow response flows and details the technical requirements for representing them in InfoWorks.

The Ground Infiltration Module

The ground infiltration (GI) module is a modelling tool in InfoWorks which is commonly used to replicate the attenuated response to storm flows observed after the initial peak rainfall response. The module replicates the attenuation provided by runoff percolating through the soil and entering the sewerage system as rainfall induced infiltration.

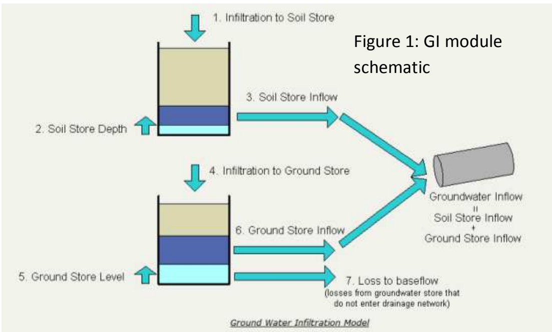


Figure 1: GI module schematic

The GI module applies infiltration to the model through two mechanisms, the first mechanism is the soil storage reservoir. Rainfall falling on pervious parts of the catchment enters the Soil Storage Reservoir (Soil Store), if a user defined depth (the Percolation Threshold) is reached within the soil store, flow will then contribute to the sewer system as Soil Store Inflow. Whilst a proportion of the infiltration will contribute directly to the sewerage system, as defined by the Percolation Percentage Infiltrating, the remaining infiltration percolates into to the Groundwater Storage Reservoir (Ground Store). From the Ground Store it either contributes to the sewerage system, once a second user defined depth is reached (the Infiltration Threshold), or is lost from the model as baseflow. Baseflow losses this again occurs above a user defined depth (the Baseflow Threshold). Evaporation losses occur in the soil store only and is applied linearly based on depth (Reeves, 2002).

The ground store is less often utilised by modellers, as an acceptable degree of verification can normally be achieved through the use of the Soil Store only. The ground store is generally used to replicate the more highly attenuated response which is observed much later than the initial storm peak. This can be considered to have a much slower response than the Soil Store. The use of Soil Store only can be achieved by effectively disabling the ground store in areas where the ground store contributions are not observed in the flow survey data.

Use of the ground infiltration module in Abbey Lane DAP verification

In certain areas of the model large rainfall responses were observed in both the foul and surface water systems which, from all available data sources, appear to be separate. Both systems displayed significant amounts of slow response. An initial desk study and subsequent site investigations suggested that all runoff would drain to the storm system. No evidence of soakaways or any other formal attenuating mechanisms were identified.

Initial attempts at verifying the slow response flow in both systems using impermeable and New UK runoff, did not provide a good fit with the observed data. It became evident that very little impermeable area was contributing directly to the foul system therefore it was considered that the majority of the response occurred as a result of ground infiltration processes. The GI module was then utilised to try to replicate the observed slow response. Initial trails using a single GI profile based on Soil Store parameters only, resulted in only partial matches with the observed data. It became evident that two distinct elements of slow response were acting: a relatively quick initial response followed by slower, longer duration, response. Model tests showed that these two elements could not be replicated using a single GI profile using only contributions from the Soil Store.

In an attempt to improve verification of the observed slow response flows, the use of two separate Soil Store only ground infiltration profiles, one faster profile and one slower profile, was tested. In order to apply two different ground infiltration profiles upstream of a given flow monitor it was necessary to apply one profile to the existing digitised upstream subcatchments and the other to a new dummy subcatchment. The addition of dummy subcatchments resulted in 156.5 Ha of dummy area being applied to the model in 21 different dummy subcatchments.

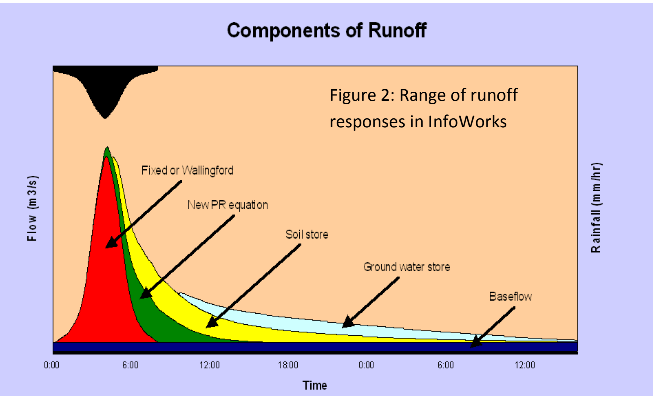


Figure 2: Range of runoff responses in InfoWorks

A Comparison of the various runoff modules available in InfoWorks CS indicated that the very slow response observed on the foul system may potentially be due to contributions from the Ground Store. By altering the properties of the two different Soil Store only profiles to replicate the highly attenuated observed flows the runoff contributions from the ground store, which had not been utilised at this stage, were being replicated through the application of dummy area.

In an effort to simplify the modelling approach it was decided to test the application of the ground store element of the ground infiltration module in the Abbey Lane DAP model. If successful this would remove the need to include the 21 dummy subcatchments modelled previously.

Utilisation of the Ground Store

The ground store was enabled in the GI file by specifying a groundwater level type 'REL' in the sub-event parameters. An initial groundwater level of 0.0m was applied to cause contributions from the Ground Store to occur immediately as suggested by the observed data. No groundwater level data was available to suggest an initial groundwater level in the catchment. The subsequent runs produced reasonable model predictions at a number of flow monitor sites in the foul system.

Once the ground store had been activated, predicted slow response flows at several flow monitor sites across the catchment, were significantly over predicted. It was considered that the Ground Store was not contributing in these locations, possibly due to lower groundwater levels in these areas (relative to the invert levels of the sewer network), as indicated in areas with separate systems in which the ground store inflows were only observed in the deeper of the two systems. Other factors such as greater structural integrity of the sewer network may also be a contributing factor. In these areas where slow response flows were significantly over predicted the Ground Store was disabled.

The ground infiltration profile was prevented from contributing Ground Store Inflow by applying a very high Infiltration Threshold value. An Infiltration Threshold value of 100m was found to be a suitable value. In addition, a very low Baseflow Coefficient was applied to create a high rate of baseflow loss from the model, thus preventing depths in the Ground Store from reaching the Infiltration Threshold. A Baseflow Coefficient value of 0.01 was found to be a suitable value. With such a high storage volume and a high rate of baseflow loss, the ground infiltration profile will only contribute runoff from the Soil Store. This may be considered beneficial as the number of variables and hence overall complexity of the model is reduced.

The main perceived benefit of using the Ground Store is that the more complex mechanics that exist in reality can be mimicked and therefore the model is more likely to remain valid over a greater range of conditions than a Soil Store only model. A further benefit is to reduce the reliance on dummy subcatchments and excess area in the models. The use of the ground store in the Abbey Lane DAP has allowed all of the slow response in the model to be generated by the available area in the digitised subcatchments. This is considered to provide a more realistic representation of the contributing permeable area and distribution of slow response in the network. This is likely to be beneficial for the prediction of flooding and possible pollution incidents in the upstream catchment.

The use of the groundwater storage reservoir is not without limitations. The additional parameters in the ground infiltration profiles that are required to generate realistic contributions for the Ground Store introduce another unfamiliar set of variables to the model which need calibration. The Abbey Lane DAP model showed that the Ground Store contributions do not necessarily occur over all parts of a catchment therefore Ground Store contributions must be disabled in certain areas.

Seasonal Variation - Slow Response

The Abbey Lane DAP model was built and verified as part of the wider Upper Don Drainage Area Study which will ultimately provide a drainage area planning model for all catchments draining to Blackburn Meadows WwTW. During the preparation of the Upper Don Catchment model the flow survey and verification has been undertaken in a number of phases. The first flow survey was installed in the downstream areas of the catchment with the intention of understanding the complex hydraulics in the city centre and the Don Valley. This area was known as the 'CZone'. During the CZone flow survey approximately 30 control monitors were installed at strategic locations in the sewer network, notably at boundaries between the individual DAZs. These control sites were installed to allow flow comparisons to be made between the individual DAP models and

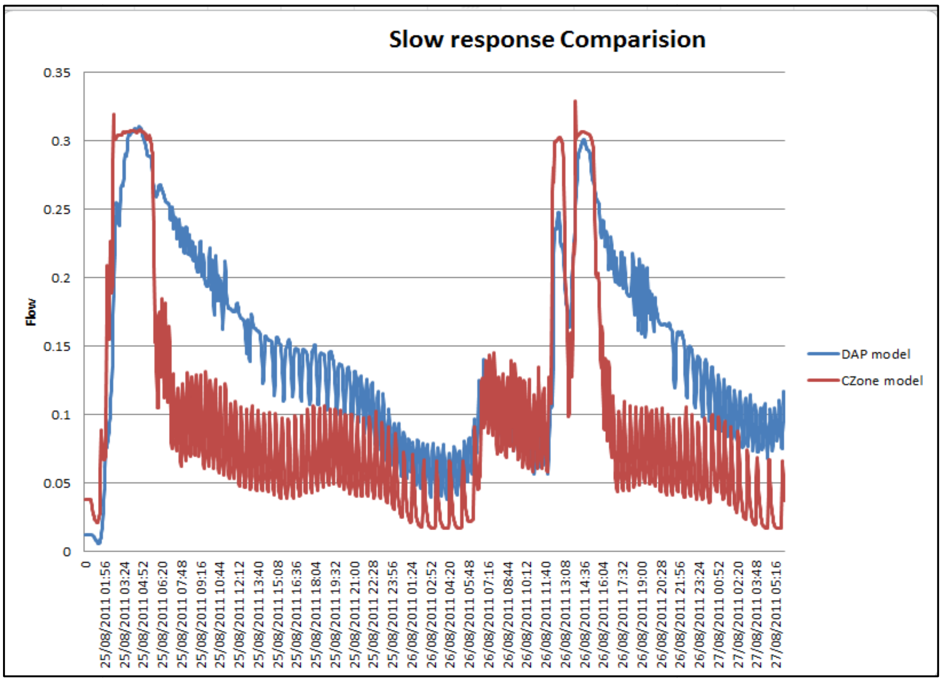
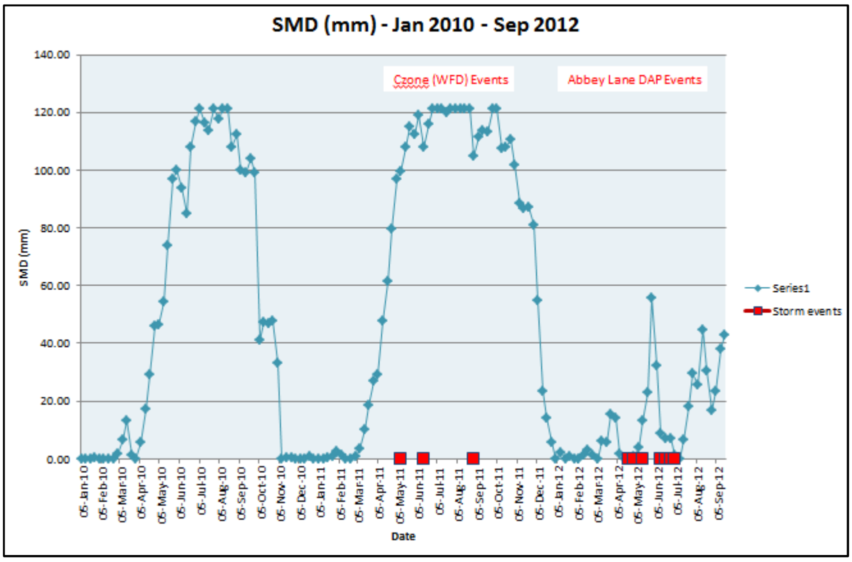


Figure 3: Observed WFD response (red) vs. predicted DAP model response (blue). WFD and DAP model are both considered verified to their respective flow surveys

to check the catchment response for both survey periods in order to assess any seasonal differences. Three of these control monitors were located in the Abbey Lane DAP and were re-installed for the DAP flow survey.

The CZone flow survey was undertaken in a relatively dry period between February and December 2011 and the Abbey Lane DAP survey was undertaken in a very wet period between May and July 2012. The preceding month of April 2012 is noted as being the wettest April on record. Comparison of the storm response at the control sites across the two flow surveys demonstrate a significant difference in the observed slow response flows between the two periods. It is suspected that this can be attributed to the different catchment wetness conditions described above.



A comparison of the soil moisture deficit between January 2010 and September 2012 highlights the vastly different groundwater conditions during the two surveys. The DAP flow survey is considered to be in a 'wet' state whilst the CZone flow survey is considered to be in a 'Dry' state. The two states are considered to be close to the extremes of the SMD range. The differences in both wetness conditions and in modelling and survey detail have resulted in the modelling of 138Ha of ground infiltration area in the Abbey Lane DAP model where no ground infiltration was required in this part of the Upper Don CZone model, to achieve a suitable level of verification.

Due to limitations in the software and available research, there may be no single parameter set in the ground infiltration profiles which can be reliably applied to generate the correct wetness conditions for any specific wetness scenario, hence the verification is specific to one period or another.

One possible solution is to provide series of initial wetness conditions (specified in the ground infiltration file) to cover events in the wet, dry or a mid-range condition. This can be done by specifying a different initial soil saturation and groundwater level, thus changing the volume of runoff needed to reach the percolation or infiltration threshold.

Conclusions

The utilisation of the Ground Store element of the ground infiltration module in the Abbey Lane DAP models has been successful in replicating the observed slow response flows which consist of faster and slower elements. It was considered beneficial to provide a realistic distribution of slow response contributions across the catchment using area available in the modelled subcatchments rather than to rely on excessive dummy areas

This study has also highlighted the potential for significant variation in slow response flows dependant on the catchment wetness conditions. A verification is a snapshot in time, consideration should be given to the effect that any increases or decreases in catchment wetness may have on catchment response and therefore any scheme design and future model uses.

A worthwhile subject for further study would be an investigation into holistic long term calibration of the ground infiltration profiles. It is thought possible that if the catchment wetness is calculated prior to slow response calibration then the setting of the percolation threshold could be adjusted to take into account the greater effect of evapo-transpiration losses towards the top of the soil store in dry conditions. This may result in more robust solutions over a range of catchment wetness conditions.

References

Mike Reeves, ***The groundwater infiltration Module***, WaPUG Training Day March 2002

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