Are models too conservative leading to over designed solutions?

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1 Introduction

Modelling to date is known to be on the conservative side in order to ensure that any solutions which are constructed to resolve catchment drivers do not cause detriment elsewhere in the catchment. The potential problem with this approach is that schemes may be over designed and therefore additional expenditure is incurred for system capacity which may never be utilised.

Models are conservative due to the assumption that water continues to enter the sewerage system even when the system is full and with no capacity remaining. This can lead to models generating large flood volumes which appear unrealistic or showing flooding which is never likely to occur. Model verification is generally carried against a flow survey which includes relatively small events which do not stress the sewerage system. Hence the models are not verified against events which cause the system capacity to be reached. The models are then used to test the system performance for large design storms when the amount and timing of the inflow is likely to be significantly different.

In reality flows can only enter the sewerage system via a select number of specified routes all of which have their limits and are not replicated in InfoWorks. These prevent flow from entering the system once a number of parameters are met. This could be the limit of the downpipe, the capacity of a gully, or water infiltrating into the pipe until it is surcharged.

This paper plans to look at the different ways that storm flows enter the sewerage system and to try to understand if, by altering the representation of these inflows, it is possible to not only replicate the small verification storms but also the larger events. Different catchments will be used for the analysis where small storms were initially recorded but where at least one large storm was also recorded during the flow survey period. Through normal verification approaches both of these scenarios could not be replicated. The aim is to show that by changing the way that verification is carried out, and applying specific limitations, it may mean that models could better represent the reality of the flows entering the sewers. This will improve the confidence in model verification and the subsequent extrapolation to large design event, minimising potential over design of solutions and reducing overall capital expenditure.

2 Current Practice

The standard practice currently applied in the modelling industry is to draw subcatchments around areas which are believed to drain to a particular pipe. Within these subcatchments the amounts of impermeable and permeable area are adjusted in order to verify against the recorded storms. The issues with this are:

- Verification storms are normally of low intensity and depth generally of a return period of 1 year or lower
- No flooding is observed during verification which means that the system is not overly stressed
- The way the system operates in verification storms is normally different to that in design storms as the rainfall profile is different between these storms.

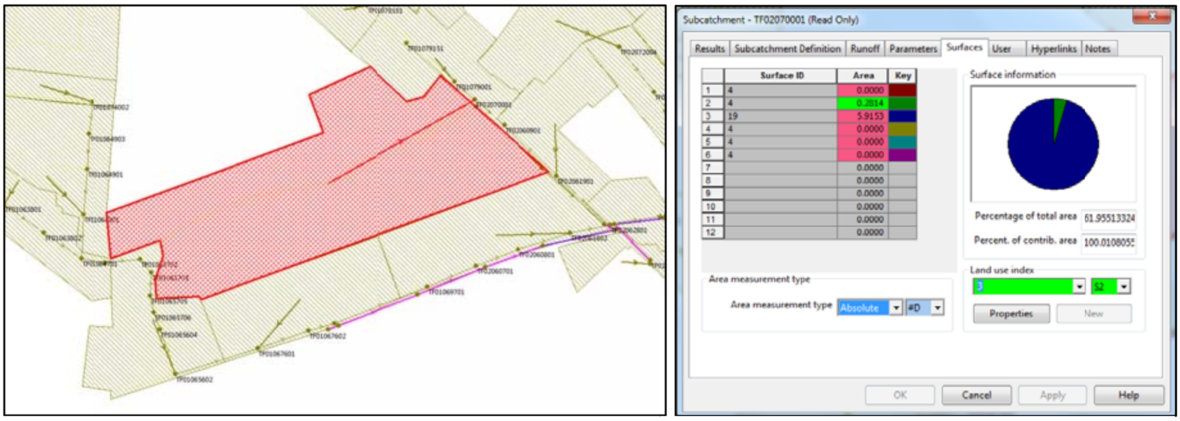


Figure 2.1 – Subcatchment and area definition

Once verification is achieved, then design storms are run through the model in order to assess flooding. However, as the sewer system is not under stress during verification, large amounts of flooding can sometimes be predicted. The reasons for this are mainly due to the lack of any restriction on the flow which can enter the sewer system even if the pipe is surcharged or flooding. The restrictions include downpipes, road drainage or inflow from permeable areas.

3 Design of Roof Downpipes

Figure 3.1 – Roof downpipes

Downpipes from houses are designed to have a limit on the flows entering the system. This limit is 75mm/hr[1], which equates to a flow rate of 2.5 l/s for a roof area of 122m^2. Currently InfoWorks models have no limit applied to the intensity of the rainfall which enters the sewer system through the downpipes.

This means that the flows can continue to increase as the rainfall intensity increases. In reality the inflow is limited and any rainfall in excess of the capacity of the downpipes will bypass the downpipe and overflow onto the ground. That flow which goes onto the ground will then either permeate and be lost or could enter the pipes due to their condition.

4 Design of Road Drainage

Gullies are the mechanism by which the runoff from roads enters the drainage systems. These are designed to have a limited flow rate, generally between 10 l/s to 19 l/s[2] depending on the type of gully and the arrangement of the road.

[1] https://www.angelplastics.co.uk/Guides/list_guides/installation_guttering_technical_print

[2] Design Manual for Roads and Gullies, Volume 4: Geotechnics and Drainage, Section 2: Drainage, Part 3: HA102/00: Spacing of Road Gullies, November 2000

Under normal situations there would be no restrictions to this flow. This means that as the intensity and volume of rainfall increases the flow entering the sewer system also increases.

As well as gullies there are also other ways that the flows can enter the drainage. One of these is beany blocks which do not have the same restrictions as normal gullies. These are 100mm holes in the kerb which are all connected together by a pipe which runs underneath the pavement. At the end of the pavement these pipes are then connected to the main road drainage.

Figure 4.1 – Road gullies and beany blocks

5 Permeable Area

Within the model, permeable runoff is modelled as an area. This area is calculated in order to achieve the best fit to the observed data in the same way as the impermeable area. However, it is not easy to measure. The amount of flow from these areas can be affected by the condition of the pipe and also, for larger design events, additional areas may start to generate runoff. As it is represented as an area in the same way as the impermeable area, the flow which enters the sewer system will keep on increasing as the rainfall increases and there is no restriction based on the surcharging within the system. This can mean that the model can generate very large volumes entering the sewer system which are unrealistic.

Within the software there are a number of different ways that this flow can be represented these are:

- Wallingford
- NewUK
- Ground Water Infiltration (GWI)
- UKWIR.

The majority of water companies either use the NewUK runoff or the GWI method with the UKWIR equation not yet being widely applied.

The NewUK runoff method uses the type of soil from the Winter Rainfall Acceptance Potential (WRAP) map and the wetness of the soil through the calculation of the Net Antecedent Precipitation Index (NAPI) value to generate the runoff. A routing value is used which can control the speed of runoff.

The GWI method requires 12 different values to represent the soil storage and the ground storage. These values define the depth of the soil storage and then the speed and timing at which flows can either move between the stores, enter the drainage system, or be lost. The ideal when using this is that there is a long-term record of flows to understand how the flows may vary over a significant time period. Issues can arise with the use of this method which can lead to significant volumes entering the sewer system and lead to the model generating large flood volumes that are unrealistic. To address this, historic verification should be undertaken as well as verification against recorded flow survey data.

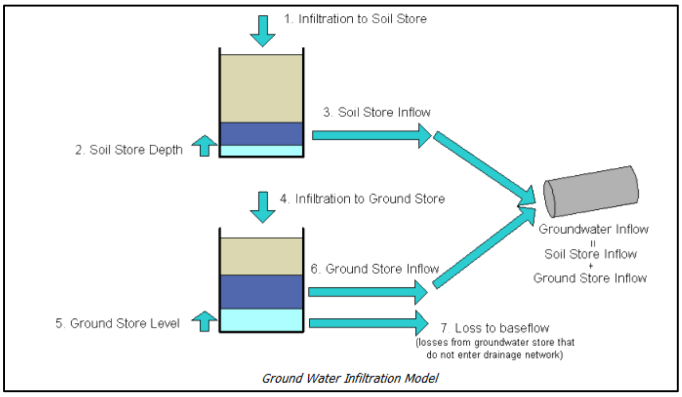


Figure 5.1 – Representation of Ground Water Infiltration Model in InfoWorks

6 Proposed Methodologies

To develop an alternative methodology to limit the flows, different approaches have been looked at. These have included:

- Using routing values
- Limiting the flows entering the system with the use of orifices and sluices
- Applying the rainfall to a 2D mesh

There could be a number of other potential methodologies, but one of the key requirements for any new methodology is that it needs to be simple and could be used for both small and large models. With the use of this new methodology there should not be a large increase in any model run times. The issue with any methodology is that the restrictions which exist may not be easily represented within the model. With this in mind, the sections below describe ways in which they can be modelled within InfoWorks modelling software.

6.1 Routing value

Within InfoWorks there is a way to restrict the flows without making any significant changes. This is the routing value which can be used to slow the flow down. However, the issue is that, as the routing value is increased, not only is the flow reduced but the rising limb of the hydrograph is also made shallower which would not therefore reflect how the flow would enter the sewer. This means that this methodology would not work.

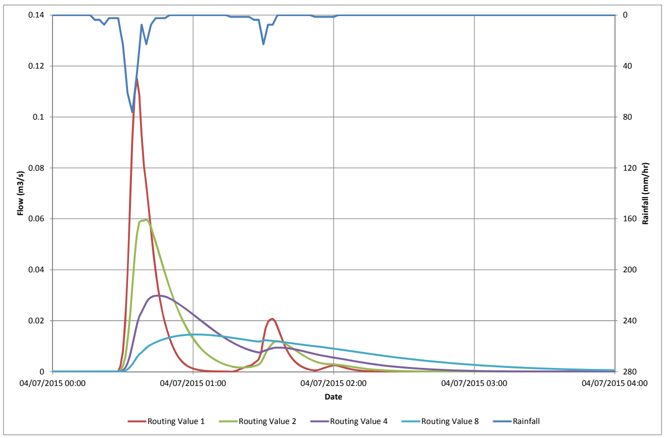


Figure 6.1 – Effect of routing value

6.2 Limiting flows into sewer

This methodology attempts to replicate the restrictions which exist in reality. Within the model, the arrangement of how every subcatchment is connected to the sewer needs to be altered. For impermeable areas the subcatchment needs to be connected to a restriction which is limited to a flow equal to the flows which can enter via the down pipes or gullies. This restriction could be an orifice, gully or inlet unit within the model. Included in this subcatchment are the domestic flows and the infiltration.

For the permeable area, a new subcatchment would need to be connected to a sluice which has a real time control applied so that it closes once the downstream system is surcharged.

With this methodology it would be possible to apply different rules for different subcatchments and also different types of models. This would not affect the simulation times. This methodology has been used for the case studies in section 7 of this paper.

6.3 Carrying out 2D modelling

With the development of 2D modelling within InfoWorks CS, and now as part of InfoWorks ICM, it is possible to apply the rainfall directly onto a generated mesh. This is then routed overland and is able to enter the sewer system through gullies or manholes.

At the 2008 Autumn conference, Andrew Bailey and Jamie Margetts[3] presented a paper based on applying rainfall directly to the mesh to verify the model. This paper looked at a catchment within the Severn Trent region and carried out a comparison between verifying the model using the standard current methodologies and then applying the rainfall directly. In order to get the flows generated by the roofs into the sewer system, a wall was drawn around the properties where the downpipes were connected and then 100mm pipes were connected to the main sewer. For the permeable areas it was assumed that the rainfall would be converted to runoff and would then enter the sewer system through the nearest manholes. As part of the paper, several limitations were identified a number of these still exist.

Within this paper, this methodology has not been tested due to the increased run times which would occur. With more data it may be possible to utilise this methodology to verify the models and to better represent the larger design storms, but at this time it is not felt that the hardware and potentially the software is able to do this.

7 Case Studies

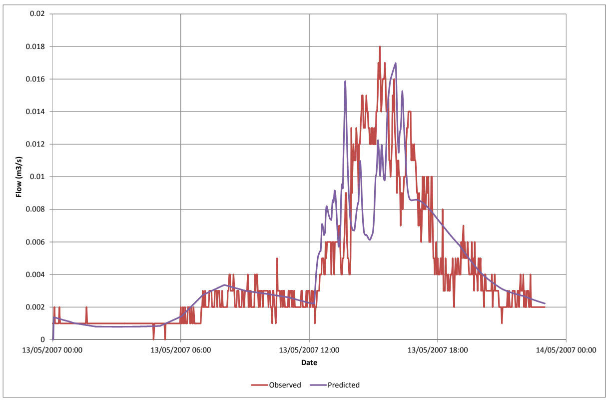
7.1 Case Study 1

A catchment from the Anglian Water region has been used which was verified using a flow survey from May 2007. During the flow survey, events were recorded of around a 1 year return period and also one with a return period of 30 years. The existing method of verification did not achieve a verification match to both of these storms. This is because, to achieve the best match, different amounts of area would be required. Table 7.1 shows the amount of area which is required to achieve the best match for two of these storms. Figure 7.1 shows the match between the observed and recorded data using the areas in Table 7.1. Figure 7.2 shows the match if the areas of Storm B are used for Storm A and the areas for Storm A are used for Storm B.

Storm event	Rainfall depth (mm)	Duration (hrs)	Return Period	Amount of impermeable area required (ha)	Amount of permeable area required (ha)
Storm A	18.8	5	1.2	0.75	22
Storm B	35.4	1	30	0.22	15

Table 7.1 – Amount of contributing area required to achieve good verification match

[3] Bailey A and Margetts J, 2D Runoff Modelling – A Pipe Dream or the Future?, 2008



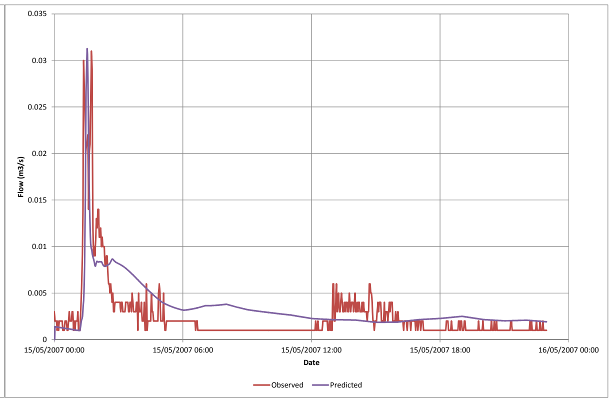
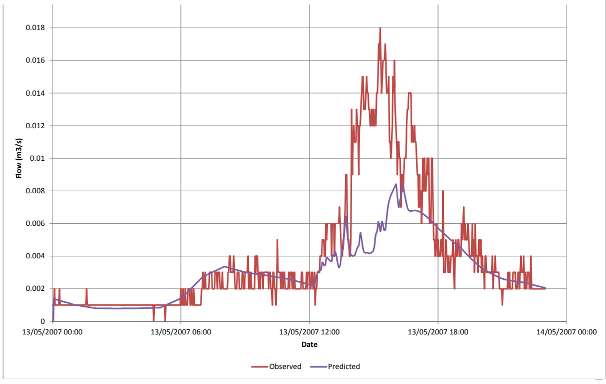


Figure 7.1a: Storm A with numbers in Table 7.1

Figure 7.1b: Storm B with numbers in Table 7.1



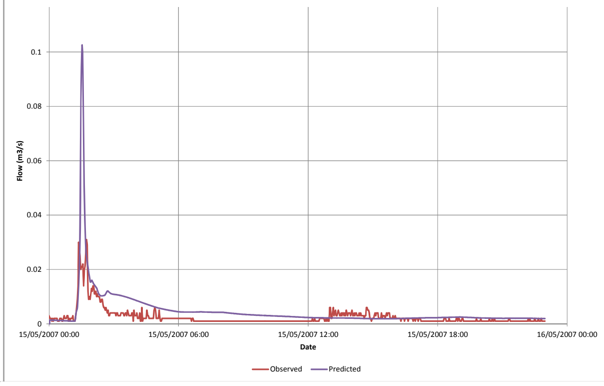


Figure 7.2a: Storm A with Storm B's areas

Figure 7.2b: Storm B with Storm A's areas

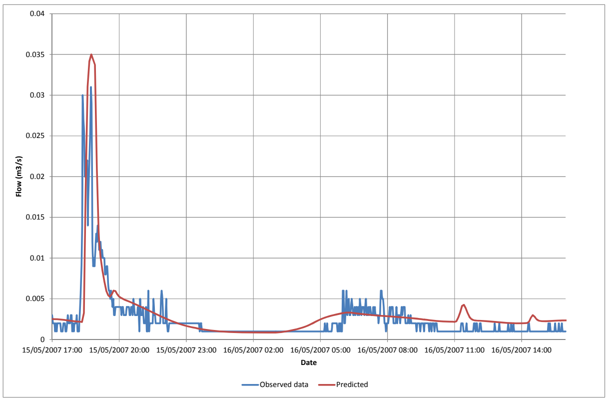


Figure 7.3: Verification achieved including a restriction of 25mm/hr

In order to try and obtain a match for both events, a test has been carried out using a restriction to the flow. Initially a restriction equal to 75 mm/hr has been used. However, it was found that this did not affect the results so the level of restriction was increased. Figure 7.3 shows the results of the larger storm.

To obtain a match, it was found that a restriction of 25 mm/hr was required. This amount of restriction is significantly more than expected. The reasons behind this could be:

- The system does not operate as designed
- The design of the system was not to current standards

7.2 Case Study 2

This catchment is also located within the Anglian Water region. The catchment is significantly more urbanised than Case Study 1 and drains a larger area. During the flow survey there were not only the normal small storms but also a larger storm which was over a 30 year design storm.

The verification made use of the groundwater infiltration module to obtain a match to the small storms as well as the large storms. However, this potentially causes a large amount of volume to enter the system during design storms. To try and overcome this, the model has been re-verified to one flow monitor without the use of the groundwater infiltration module. The initial verification showed that different amounts of contributing area are required which is similar to the conclusions from Case Study 1. Table 7.2 shows the areas required. Figure 7.4 shows the level of verification achieved.

Storm event	Rainfall depth (mm)	Duration (hrs)	Return Period	Amount of impermeable area required (ha)	Amount of permeable area required (ha)
Storm A	13.2	14	<1	4.5	6
Storm B	90	78	38.8	0.55	20

Table 7.2 – Amount of contributing area required to achieve good verification match

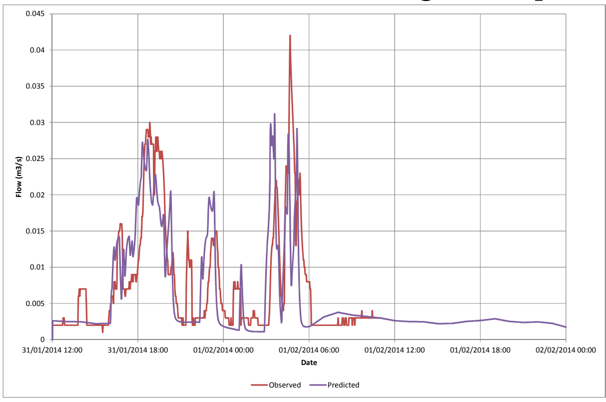


Figure 7.4a: Storm A with numbers in Table 7.2

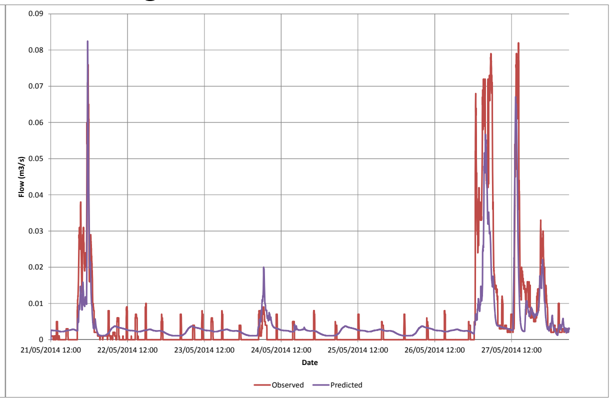


Figure 7.4b: Storm B with numbers in Table 7.2

However, using restrictions to the flow it was found that if the restriction was equal to 25 mm/hr then a match could be made to both storms. The nodes within the model which the subcatchments drain to upstream of the restriction needed to be set to flood type 'lost' otherwise the flow continued to enter the system for longer than observed. Figure 7.5 shows the level of verification achieved for the larger storm with the restriction. This gives a significantly reduced amount of runoff entering the system.

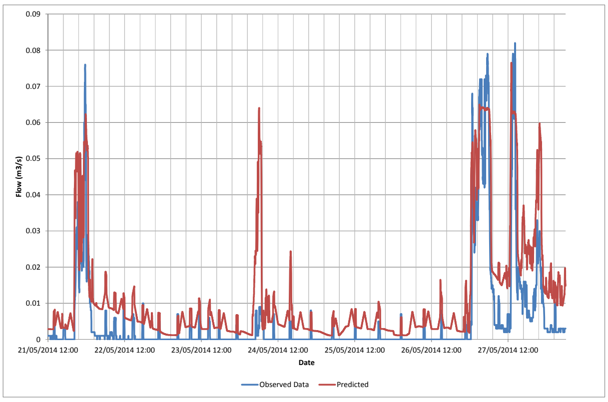


Figure 7.5: Verification achieved including a restriction of 25mm/hr

As part of verification it is important to look at historic verification as well. An analysis has been undertaken looking at the amount of flooding and the amount of runoff which could enter the system for the following four scenarios:

1. Verification achieved as part of model build
2. Small storm verification only
3. Large storm verification only
4. Small storm verification with restrictions to the flow

Initially this was run using a 5 year 30 minute storm and for scenarios 1 and 2 there was limited flooding and none of the flood volumes were above 25m^3. For scenario 3 and 4 there was no flooding predicted by the model. This shows that with all scenarios the historic verification in this area was correct. However, when these scenarios are then run for a 30 year 30 minute storm the amount of flooding for scenarios 1 and 2 is significant. For scenarios 3 the amount of flooding is reduced to only a minimal amount and for scenario 4 the model predicts no flooding at all. This would suggest that these two scenarios are potentially representing the existing situation more realistically for the larger events and for scenario 4 it is possible to represent not only the small storms but also the large storms. Figure 7.6a shows the different amount of flooding and runoff generated during the 5 year 30 minute storm and Figure 7.6b shows the flooding and runoff generated during a 30 year 30 minute storm.

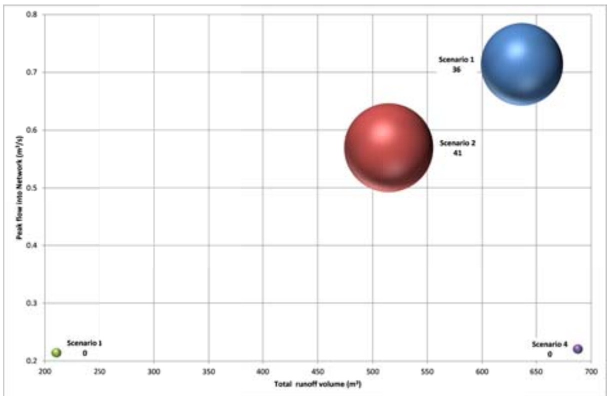


Figure 7.6a: Runoff and flooding for a 5 year 30 minute storm

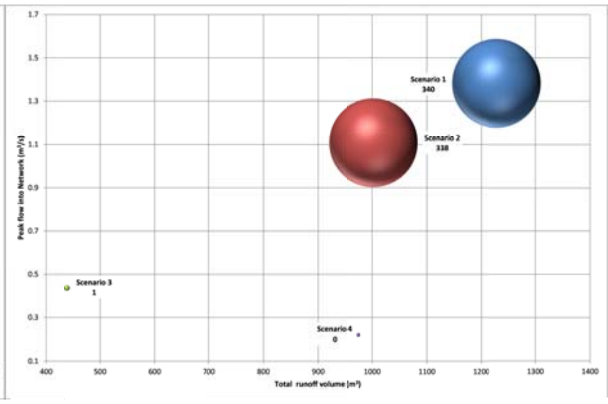


Figure 7.6b: Runoff and flooding for a 30 year 30 minute storm

8 Conclusions

Models are known to over predict because they are verified against small events and then are extrapolated to larger return period design storms, which can overly stress the system. This leads to potential uncertainty in models as, no matter how good the verification, large amounts of flooding may occur during design storm simulation.

Restrictions exist for getting flows into the system from downpipes and gullies for the impermeable area and cracks or holes in the sewer system, or from overland flow for the permeable area. Within the model there are no restrictions applied so as the rainfall increases the amount of volume entering the system increases.

To try to overcome this issue a new methodology is required. This methodology needs to work for not only small storms but also when large design storms are run through the model. With improvements in technology it has become possible to include additional detail within the model without significantly increasing the run times.

Within this paper the use of 2D modelling has not been looked at as this was previously tested as part of a paper written by Margetts and Bailey in 2008. Since then, modelling software has changed, but a lot of the issues still remain. This means that, although it would be possible to verify a model with 2D, the run times would be increased which would still make it impractical to use in designing current schemes where timescales of the modelling are critical.

As an alternative methodology, two different catchments have been looked at to see if it is possible to use just a 1D model and make some adjustments to how the flows enter the system. These adjustments have added a restriction on the inflow in order to slow the flow down. For both of these catchments in order to achieve verification for the large and small storms it has been found that a restriction equal to 25mm/hr is required. This suggests that the capacities of the restrictions which allow flow into the drainage system reduce over time. It should be noted that although this is the level of restriction required for these two catchments, it may be that if additional catchments were investigated that different levels of restriction would be required. To determine if standard levels of restriction could be applied then this would require additional research which is beyond this paper.

For one of the catchments looked at it is possible to see that when the model is used for running large design storms the amount of flooding which is predicted is significantly reduced and potentially gives a better representation of the amount of flooding which would occur in these areas. However, the catchment as it was previously verified does not show any significant flooding and could be classed as being historically verified, it is only when a 30 year design storm is run through the model that the amount of flooding predicted is large. With the restriction applied the amount of flooding for both the small and large return period events are felt to be closer to actually representing what would occur.

The rainfall which is predicted to not get into the network would potentially cause flooding locally but for the water companies this is volume which may never enter the drainage system and therefore would never be seen as flood volume further downstream in the system. This becomes more important for larger return periods as the amount of runoff will increase and therefore potentially the amount of predicted flooding will also increase.

If the restrictions could be included in the model then it would be possible to improve the representation of inflows into the system. As a minimum it would be useful if the permeable area could be restricted once the system downstream is full. This would reduce the flooding predicted to a more realistic level which could then reduce the size of potential solutions and the corresponding capital expenditure on schemes.

9 Acknowledgements

Anglian Water for allowing the use of their models and data for the case studies

10 References

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