Derby Case Study: Runoff Modelling Issues

Dave Terry (Severn Trent Water)

Jamie Margetts (Clear Environmental Consultants Ltd)

1.0 Introduction and Catchment Description

In 2002 Severn Trent Water (ST) commissioned 14 Drainage Areas Plans (DAP) for the whole of the Derby catchment, covering 8,000ha and a population of over 250,000. The aims of these studies were to identify the catchment needs in each drainage area and to produce a tool appropriate for the design of improvement options to alleviate high priority DG5 flooding in the South West Derby area of the catchment. Due to complex hydraulic interactions between the trunk sewers in the catchment, it was not possible to construct individual models representing each of the 14 drainage areas. The overall model development was split into three phases, each containing a number of drainage areas. The phasing priority was based on the criticality of drivers within each area, with each phase focusing on a key trunk sewer configuration within the catchment.

Phase 1 of the model construction and verification was undertaken by Haswell Consulting Engineers (Haswell), accompanied by Clear, and covered the three main drainage areas contributing to the Southern and Central Interceptor Sewers (SIS and CIS) to the south and west of Derby. The critical DG5 flooding locations in SW Derby were located in this area of the catchment, and priority construction of this model was required to allow outline solutions to be developed at an early stage. This part of the catchment contained 12 CSOs and 20 PS, and a 42 monitor flow survey was carried out between February and April 2002.

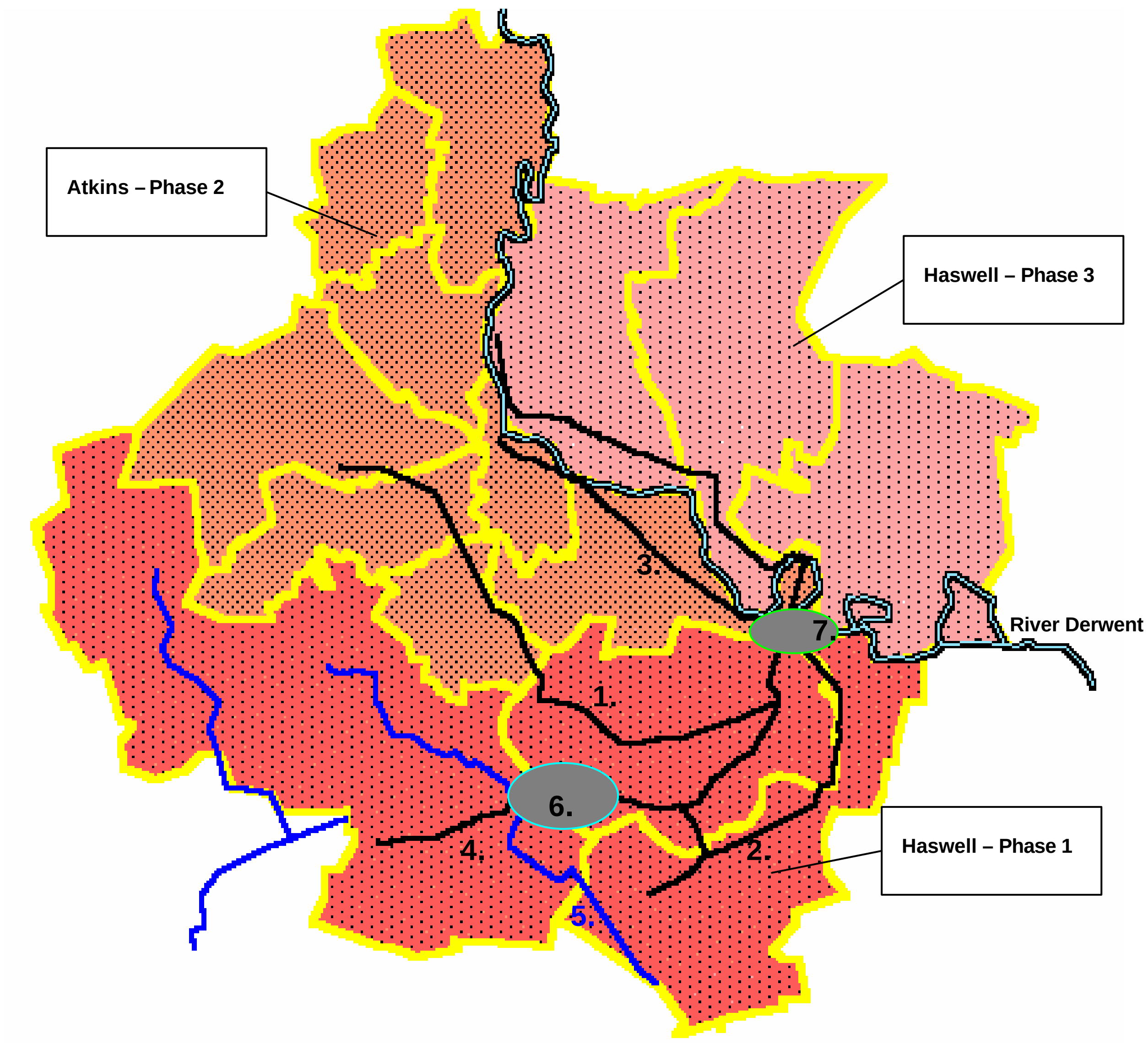
Phase 2 was undertaken by WS Atkins Consultants Ltd (Atkins), and covered the eight drainage areas contributing to the Northern Interceptor Sewer (NIS) and head of the SIS and CIS to the centre and north of the catchment. This part of the catchment contained 39 operational CSOs and 4 PS, and a 58 monitor flow survey was undertaken between April and July 2002. Whilst this area of Derby contained few key drivers, the flows produced via the SIS, CIS and NIS have the potential to interact with the flooding locations in SW Derby, thus it was essential that these flows were represented within the model.

Phase 3 was also undertaken by Haswell, and covered the three drainage areas to the north and east of the River Derwent which contribute to the Eastern Interceptor Sewer (EIS). This part of the catchment contained 15 CSOs and 11 PS, and a 52 monitor flow survey was carried out between July and November 2002. Whilst these catchments do not directly interact with the SW Derby Flooding locations, they do impact on the Derby Sewage Treatment Works (STW), and thus have the potential to exacerbate backing up within the lower sections of the NIS, SIS and CIS.

Following the construction of the individual phase models, and the development of outline solutions for SW Derby, the three models were combined to produce a single hydraulic model of the Derby sewerage system, and thus allowing all interactions between the trunk sewers, Derby STW, CSOs and flooding locations to be fully represented. This combined model was subsequently passed forward for detailed option development. Throughout the flow survey period, 10 key flow monitors were maintained in the downstream sections of the main trunk sewers to allow verification of the whole model following the combining process.

The observed flow survey data indicated that there were a variety of different runoff processes to be considered and modelled; in particular, slow response runoff was evident. In addition, an apparent variable or delayed impermeable response was observed under storms of differing return period. Over the last year, various authors have identified issues with the current runoff modelling techniques, specifically the New UK Runoff model (e.g. Squibbs and Jack 2003), and how best to apply some of the complex models being produced to design situations. This appears to have caused general concern within some parts of the industry as to the applicability of the current runoff models. The Derby case study highlights examples of how complex processes can be represented using the current runoff models, and then identifies how whilst there are limitations with these models they can still be used with confidence providing that a pragmatic approach to sensitivity testing is applied at design stage.

Plan 1 – The Derby Catchment



1. Central Interceptor and Southern Interceptor Trunk Sewers
2. Chellaston Trunk Sewer
3. Northern Interceptor Sewer
4. Sinfin Relief Sewer
5. Cuttle Brook
6. SW Derby Flooding area
7. Derby STW

2.0 'Delayed' Impermeable Response

The Phase 2 verification events were varied in characteristics. Event 1 consisted of a single burst of rainfall over 5 hours, totalling between 5mm and 8mm across the catchment. Event 3 consisted of two successive periods of rainfall over a day, with the first part comprising of approximately 12 hours of steady rainfall, equating to depths of between 12mm and 15mm. Following a 6 hour dry period, a second period of rainfall occurred lasting only 2 hours, but containing 5mm of rainfall. During the initial stages of verification, the model tended to slightly over predict the impermeable response during Event 1, and replicate to a good degree of the impermeable response for the first part of Event 3. However, the model failed to replicate the high amounts of impermeable response observed during the second part of Event 3. This is highlighted in Figure 1.

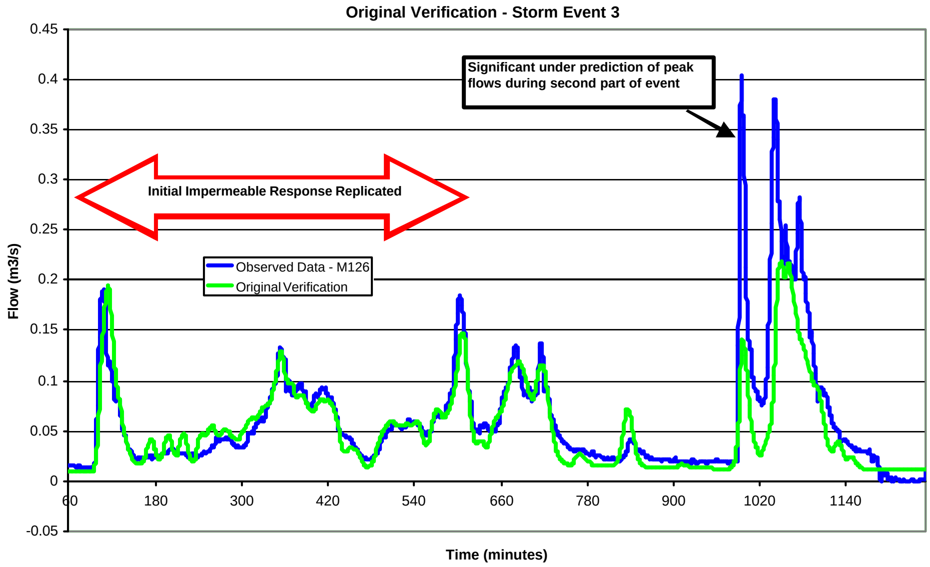


Figure 1 Initial Verification

In order to try and replicate this second high flow peak, the impermeable area assumptions were reviewed. However, due to the fact that the initial impermeable response predicted at the start of the event was acceptable, then it is unlikely that large areas of directly contributing impermeable areas had not been included in the model, and that the original assumptions and sample surveys were correct. The New UK runoff model was used to represent the flows from the permeable areas and this improved the model representation of the second peak slightly, due to the modelled increasing catchment wetness. Despite this change, the model still under predicted peak flows by up to 50% for this second part of Event 3. This un-modelled response is observed to be very fast, and typical of impermeable contributions. It was hypothesised at the verification stage that a variety of impermeable responses are being observed in some areas of the catchment, with each only beginning to contribute under increasingly wet conditions. For example, the initial response observed is immediate, where rainfall falls on surfaces directly contributing to the sewer system, and after a period of initial catchment wetting/filling of depression storage an impermeable runoff response is observed. These type of areas would include the obvious road and paved contribution identified through the initial desktop and sample impermeability studies. The adequate verification at the start of Event 3 (and slight over prediction during Event 1) indicates that these immediate impermeable contributions are adequately represented.

However, in addition to this, there would appear to be a second additional delayed impermeable response occurring following the first body of rainfall. Urban catchments are littered with impermeable type surfaces that may not directly contribute runoff as flows either gradually percolate into the surface (e.g. gravel surfaces, slab / block paving, heavily cracked hard surfaces) or are simply held in massive depression stores (large puddles, very poor condition hardstanding, or enclosed by kerbs). Under small storms, no contribution may occur but under increasingly large events these surfaces are capable of generating flow as these stores fill. Eventually, rather than being confined within the boundaries of these poor condition surfaces (i.e. within the depression stores), flows over-top the stores and gravitate to impermeable surfaces that may contribute to the sewer system. It is also likely that fully saturated permeable surfaces can act as rapid response surfaces, particularly in urban areas where gardens may be underlain by less permeable fill type substances. Finally, it may be possible that the percentage contribution from a surface varies as it becomes increasingly wetted by previous rainfall.

The model build failed to include these sources of potential delayed impermeable response, however, investigation has shown that these types of surfaces are rarely identified at the initial contributing area definition. For example, in many of the older residential areas in Derby, the properties have poor condition paved or gravel front gardens and back yards, which have the potential to store significant amounts of rain before draining directly to the adjacent road and combined sewer system.

The model was subsequently calibrated in some areas, in an attempt to replicate these responses, by including additional area with a very high depression storage, which only becomes active following the occurrence of large depths of rainfall. For example, the model was updated to include additional area with a 12mm depression storage factor. This high depression storage prevents any runoff contribution from the first part of the event (thus maintaining the adequate initial verification) yet then contributes significant runoff during the second part of the storm. The effect of this calibration is highlighted in Figure 2.

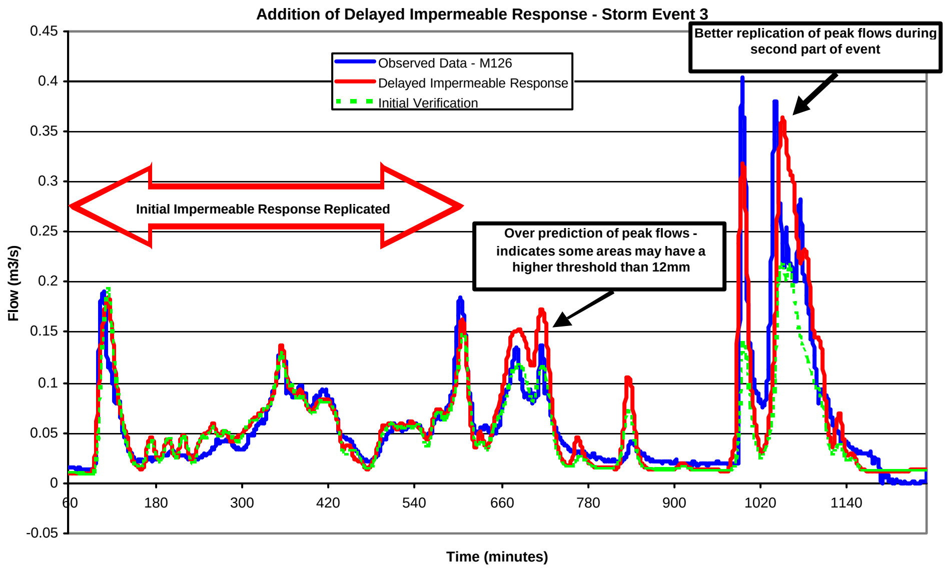


Figure 2 Variable Impermeable Response Verification

The implications of this are numerous, and throw questions over both the model build and runoff modelling methodology. Firstly, it is likely that these surfaces exist within most catchments, but are frequently not identified during the initial impermeability assessment. Should impermeability surveys go further to attempt to establish not only whether a surface contributes directly, but also whether a surface has the potential to contribute should it become wet enough? Again, the slab paved front garden would fall into this category, as these are frequently missed by impermeability surveys, yet do have the potential to contribute.

By limiting verification flow survey periods to only a few weeks, it is likely that on many occasions the large storms that cause these areas to be activated are not measured and used for verification purposes, and thus the effect not noticed. This effect is one of the issues that raises concern over extrapolating models that have been verified on very low return period events up to use on large return period design events. It is likely that as storm return period increases, an increasing amount of impermeable area will be activated, from increasingly remote and unlikely sources. Only by verifying models to large return events can we be sure that the possibility of this process occurring has been considered. Is this another reason to consider extending the length of flow survey periods?

Should we then be questioning the validity of the current impermeable runoff models? For example, the New UK runoff model goes some way towards considering the effect of increasing catchment wetness/evaporation by taking the percentage of impermeable surfaces which are less effectively connected to the drainage system from the fixed areas and adding them to the permeable area contribution. A fixed surface of say 60% (normal urban paved surface) will then generate 40% area contribution to the permeable area where runoff is varied at each timestep by NAPI/PF (Net Antecedent Precipitation Index/Soil storage depth). Does this need to be progressed a step further whereby the impermeable contribution, currently fixed, is expressed as a variable surface similar to the way in which increasing wetness is represented in the New UK permeable surfaces (i.e. use of a NAPI type parameter to replicate this variable impermeable contribution). The draw back to the current application of the New UK runoff model is that you cannot allocate different variable wetness type surfaces within the same sub-catchment (and thus allocate a different NAPI and PF to the various surfaces). Allocating NAPI and PF would allow greater flexibility in representing variable response (and rates) from different surfaces, which can only currently be represented with the single variable permeable surface in the current setup. This is possibly why there is frequently difficulty in verifying models where variable response has been observed.

Therefore, should a similar runoff model representing the increasing wetness exist for the impermeable surfaces. A sub-catchment typically contains a mixture of runoff surfaces all of which runoff differently due to the effects of rainfall/evaporation, ground condition, different amounts of depression storage and flow path. If all the different surfaces could then have variable runoff, similar to NAPI/PF in the New UK runoff equation, then by representing the variable parameters (initial losses, NAPI, PF etc) for each surface type then the degree by which each area could achieve say 100% runoff could be better represented in a model.

3.0 Winter or Summer Models

The different infiltration and runoff effects observed during the winter and summer are well known, though often these issues still limit the use of models due to factors that force the periods in which flow surveys are carried out. This Derby case study was no different, and the effects of the different winter and summer runoff processes were observed in both the Phase 1 and Phase 2 parts of the catchment.

The Phase 1 model was verified utilising storm events from the winter (all events in February and March), and the New UK runoff model was required to replicate the slow response runoff / rainfall responsive infiltration that was evident in the flow survey data. This was generally obtained by re-applying all permeable area within property and contributing areas (which had initially been reduced for the 10m rule and application of the PR model). Some additional permeable areas were also added to the model to represent slow response runoff from other areas not identified at the initial model build stage. By applying the New UK runoff model, a good verification of the observed prolonged flow recession, which lasted for a day after rainfall, was obtained. This is highlighted in Figure 3, at a location at the downstream end of the Chellaston Trunk Sewer (CTS), which is a key sewer downstream of the flooding locations in SW Derby.

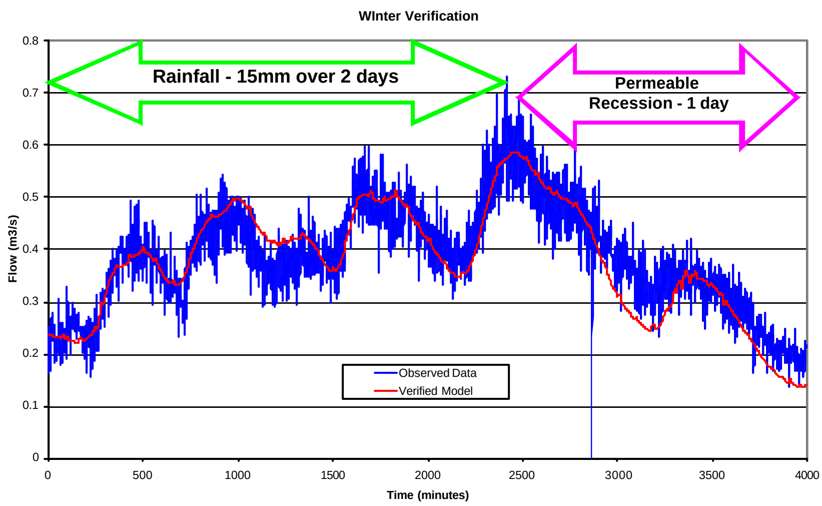


Figure 3 Winter Verification

Additional summer flow survey data was obtained from the key flow monitors that remained in the trunk sewers throughout all phases of the model build (i.e. for most of 2002). When simulated with the verified winter model, the results indicated that the model significantly over predicted the recession limb of the flow hydrograph along the CTS. Only by reducing the permeable area within the model by 80%, could a verification of the summer events be achieved. This is highlighted in Figure 4.

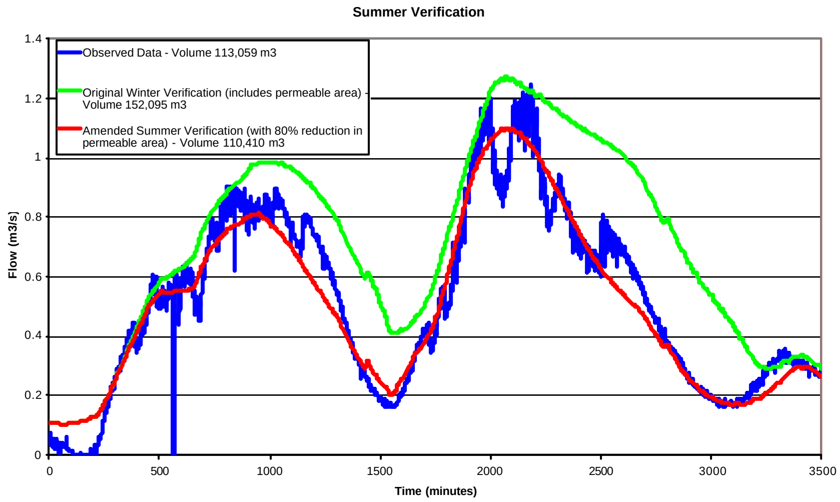


Figure 4 Summer Verification

In contrast, the Phase 2 area of Derby was verified against flow survey data obtained from late spring and summer. During the verification process, it was necessary to also implement the New UK runoff model in large parts of the catchment to represent a slight tail to some of the observed flow hydrographs. A further winter event was then selected from the long flow survey period (December 2002), and this was simulated with the verified summer Phase 2 model. The summer verified model significantly under predicted flows for the winter event, particularly during the recession limb of the flow hydrograph, which showed the typical characteristics of slow response runoff / rainfall responsive infiltration. For example, in the main CIS running from the central area to SW Derby, the summer model only predicted 57% of the observed flow. Experimental sensitivity simulations indicated that large amounts of permeable response were required to be added to the model to replicate these processes that were apparent during the winter events but not the summer events. Figure 5 clearly demonstrates the under prediction of flows by the verified summer model, and the improved verification obtained by significantly increasing the representation of permeable area.

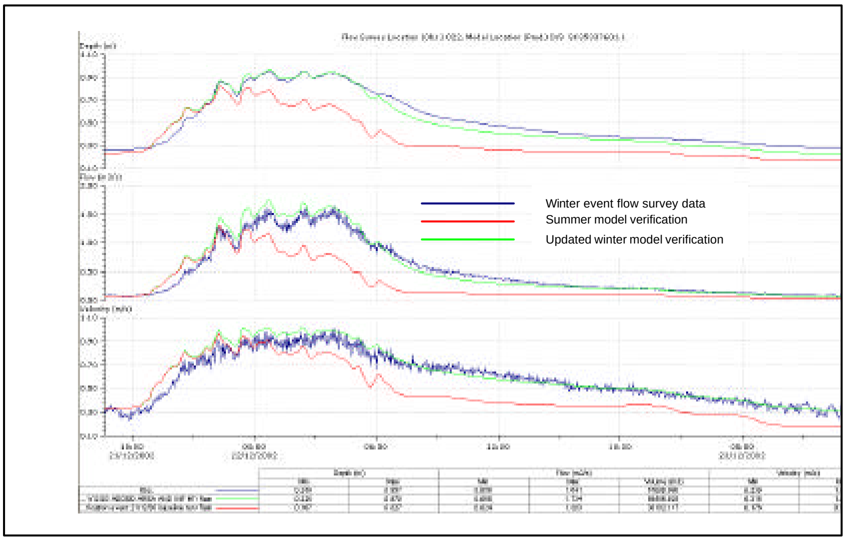


Figure 5 Phase 2 Winter /Summer Verification

The occurrence of this effect posed a series of questions. Firstly, was the combined model of Derby truly representative of all the runoff and sewer flow processes on an annual basis? Do issues arise with some areas over predicting flows, yet others under predicting the volume of flow? To address these questions the sensitivity of the model, and any proposed improvement schemes, to this winter / summer effect was assessed at the design stage, and this is discussed in more detail later in this paper. Of more concern is the uncertainty this raises in the whole approach to modelling that is currently undertaken. In particular, the use of short term flow surveys should be questioned. Whilst long term flow surveys can considerably increase the study costs, this study has certainly benefited from obtaining data throughout the year, allowing numerous processes that would not have been identified in the 'summer' model areas to be taken into account. In addition to higher cost, long term flow surveys have programme issues. It is strongly recommended that at the earliest possible moment in initial planning stage of any study, background information (historical / local knowledge or STW flow data) be obtained to allow informed decisions to be made as to whether long term flow surveys will be required. Should the long term element of the survey be cost prohibitive, then this data should be used to confirm that any short term flow survey should be undertaken in the winter months only.

Of equal concern is the applicability of the current runoff modelling techniques. Whilst the New UK runoff model was adequately calibrated to provide what appeared to be well verified individual models, the application of the model to the opposite seasons was questionable, with both the winter and summer verified models giving poor representations when simulated with rainfall from other seasons. This adds to the concern raised recently regarding the operation of the New UK runoff model for design purposes, particularly for summer models. If summer models under predict under normal winter conditions, how much will they under predict during large return period events? Conversely, should we be using winter verified models for annual time series investigations at CSOs, especially when summer or bathing season discharges are the key consideration?

4.0 <u>Design Considerations</u>

As highlighted in the previous sections, the verification of both the individual and combined Derby models identified a number of interesting issues relating to runoff. As the model was to be used immediately to deliver a significant flood alleviation scheme in SW Derby it was important that some of these issues, which frequently do not get resolved and simply get reported as 'requiring further study or investigation', were addressed to improve the confidence that could be placed in the model predictions. As a result, a sensitivity analysis was undertaken to address the effect of some of the issues on the proposed improvement schemes in SW Derby. The data presented in this paper should be treated as interim, and primarily for sensitivity indicative purposes, as the final schemes have still to be confirmed and designed.

4.1 Winter or Summer Models

The verification process confirmed much higher volumes of flow within the system during the winter, due to the predominance of slow response runoff / rainfall responsive infiltration. As a result, the Phase 2 model was identified as a limitation, due to it being verified to only summer storms and shown to under predict winter flows. An experimental winter model was developed, with the Phase 2 model re-calibrated to the winter storm highlighted in the previous discussion. This 'full winter' model was then simulated with the key optioneering design storms, and impact on the various proposed improvement schemes assessed. One of the proposed improvement schemes to prevent flooding involves sewer diversion, the construction of a new surcharge / flood relief overflow, and storage to limit spill frequencies to acceptable levels (with the exact storage size to be determined by river impact analysis). To illustrate the winter / summer effects, in a separate exercise, the Phase 1 winter model was recalibrated to the summer condition, and combined with the Phase 2 model, to create a 'full summer' model. The effect of updating the Phase 2 model to the full winter situation was to increase the runoff throughout the whole model, for a range of design storms of differing durations, by generally 25%. Table 1 details the predicted spill volumes at the proposed flood relief CSO.

The sensitivity analysis confirms the need to consider the winter conditions in all cases, particularly as CSO storage is a possible solution. It also highlights the potential difference between models calibrated in full summer conditions and full winter conditions. The final proposed storage solution is likely to be developed as part of a river impact analysis / UPM approach. Such an approach will consider the predicted spills at the proposed CSO through the course of the year. As a result, the following approaches will need to be considered: 1. The use of a full winter model (i.e. worst case) to design the initial scheme, particularly in top water levels, 2. The use of both winter and summer models to assess the annual performance of the proposed CSO for the river impact analysis. By using the winter model for the full time series analysis, the cost of the scheme could be unrealistically an over prediction of summer spill volumes.

Design Storm	Original model (summer Phase 2, winter Phase 1)	Full Summer Situation	Full Winter Situation
1 year 480 minutes	348	0	886
40 year 480 minutes	69,387	36,954	74,320

Table 1Effect of Winter and Summer Models on Predicted Spill (m^3)

4.2 Design NAPI values

A number of methodologies exist to determining the appropriate NAPI value to use for design purposes. For example, WaPUG User Note 28a recommends the utilising long series of rainfall data to determine a historical range of NAPI from which a design estimate can be chosen. Other approaches have extrapolated results from numerous catchments where the WaPUG UN28a methodology has been followed, to develop a correlation of design NAPI to SAAR (Davidson and Margetts, 2002). The SW Derby flood alleviation modelling study utilised a 10 year series of historic rainfall data to determine the average NAPI. This equated to a starting NAPI value of 12 for soil type 4 and 4 for soil type 3. The historical series indicated that NAPI values as high as 60 (soil type 4) were attained during very wet periods, and NAPI values above 15 for soil type 4 occurred 22% of the time. It is not unimaginable that the 40 year return period event, which the flood alleviation measures are to be designed to, may occur when antecedent conditions are high. As a result, the sensitivity of the proposed improvement schemes to variations in the design NAPI value were considered. Table 2 highlights the expected trend that by changing the initial NAPI condition (from 12 for soil type 4) the predicted modelled runoff varies considerably. The effect of this was to increase the predicted spill at the proposed CSO by an order of magnitude, as detailed in Table 3.

Design Storm	NAPI (ST4) = 0	NAPI (ST4) = 9	NAPI (ST4) = 12	NAPI (ST4) = 15	NAPI (ST4) = 60
1 year 60 minutes	182,389	205,179	215,002	223,155	334,325
1 year 480 minutes	367,956	412,649	427,547	442,445	572,630

Table 2Effect of Design NAPI Values on Modelled Runoff (m^3)

Design Storm	NAPI (ST4) = 0	NAPI (ST4) = 9	NAPI (ST4) = 12	NAPI (ST4) = 15	NAPI (ST4) = 60
1 year 60 minutes	0	0	0	0	2,857
1 year 480 minutes	0	0	348	2,364	37,473

Table 3Effect of Design NAPI Values on CSO performance (spill m^3)

It is clear to see from these figures that the effect of changing the initial NAPI value is considerable, and the implications of this on design are significant, even when only a 1 year return period design storm is considered. However, this has to be put into context with the likelihood of high antecedent conditions occurring prior to a particular storm return period. In the 10 year historical rainfall series analysed there were 11 events greater than or equal to 12 month (1 year) return period and of those events the maximum initial starting NAPI (ST4) value was 23.1 with the average value being 8.3. From Table 3 it can be observed that this average of 8.3 with a one year return period will not cause spill at the CSO and therefore the longer term average used (12) is slightly conservative for the one year design event storm.

4.3 Extreme Event Analysis

As part of the flow survey, an event was recorded on 30th July 2002 that varied between a 1 in 10 year and a 1 in 58 year return period event across the catchment (with the average being 1 in 30 year return period). The occurrence of such a large scale event offers a rare opportunity to check the sensibility of model predictions under large return period events. Many modelling studies are limited by the uncertainty raised when extrapolating models verified on low return period events to high return period extreme events.

4.3.1 Extrapolation to large events

One of the concerns with the New UK runoff model is that unrealistically excessive amounts of runoff are occasionally predicted when verified models are extrapolated up for use with large return period design events, particularly of a long duration. The occurrence of the large return period event during this flow survey should have allowed the sensibility of the model predictions to be assessed under such large return period situations, however, the quality of the flow survey obtained during this large event could be considered poor at best. Figures 6 and 7 below compare the modelled flows and depths with those recorded during this large event. Whilst complete verification is not obtained, the model appears to predict the observed flows and depths to a degree that adds confidence in the model predictions during large return period events. The model also predicted flooding at five of the seven key flooding locations where flooding was reported on this day.

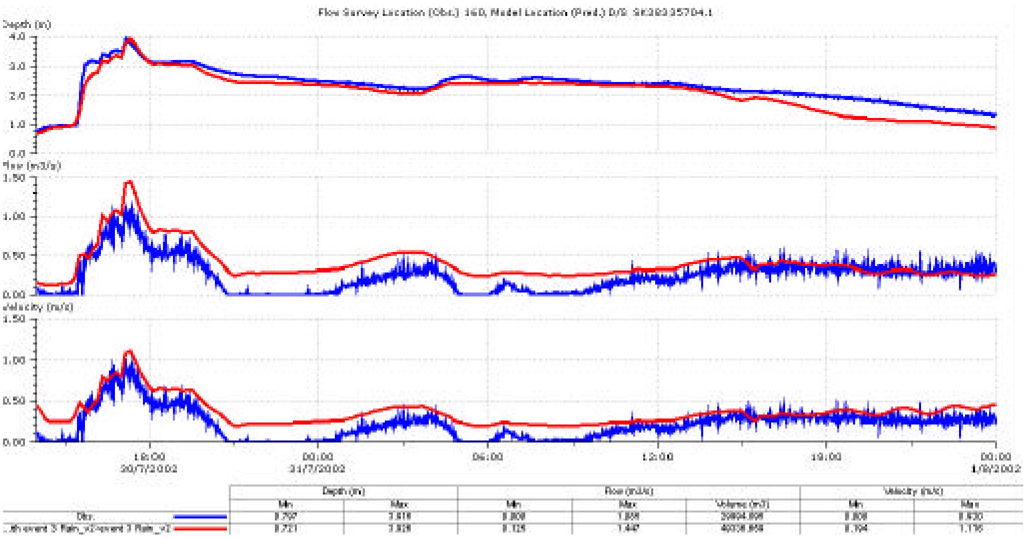


Figure 6 Model Performance – Large Event – Site 160

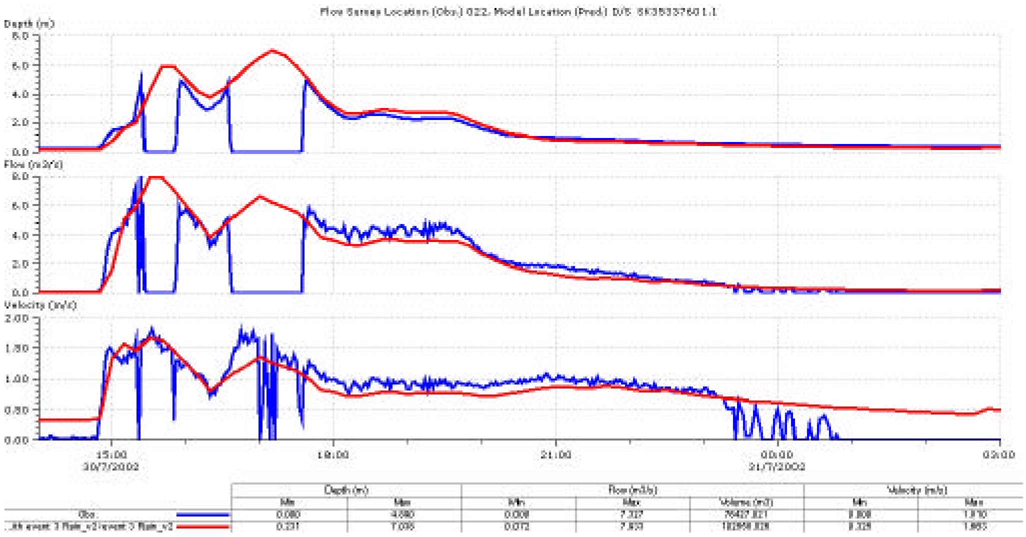


Figure 7 Model Performance – Large Event – Site 22

4.3.2 Effect of spatially varying rainfall

The observed 1 in 30 year return period event was observed to track across the catchment (southwest to northeast), with different amounts of rainfall occurring across the catchment. For example, 76mm was observed to fall in 460 minutes in the west of the catchment, and 51mm in 450 minutes in the SW Derby area. As there were over 20 raingauges distributed across the catchment during this event, any spatial variation was recorded. As a test, the model was simulated with the following rainfall scenarios:

- Detailed measured 2-minute intensity spatially varying rainfall data from the flow survey for event on 30th July 2002.
- Single profile StormPAC disaggregated TSR event based on historical hourly data for 30th July 2002 from Draycott (east Derby).
- Single profile design event generated to give similar characteristics to the observed large return period event n 30th July. A 1 in 35 year return period, 480 minute duration, design event was used to replicate the main part of the observed storm, followed by the second peak being represented as a 1 in 2 month return period, 600 minute duration, design event.

The characteristics of these different rainfall scenarios are highlighted in Figure 8, with the detailed data presented being that which occurred over the SW Derby area. The first obvious difference is the variation in rainfall intensities between those observed at in SW Derby, and those generated from hourly StormPAC data from a site to the east of Derby. The depth at the Draycott site was in the order of 62mm (once processed through StormPac) in comparison with the higher average of 72.2mm collected by the rain gauges to the SW and centre of Derby itself. This in itself demonstrates that there is a considerable amount of spatial variation for this particular storm.

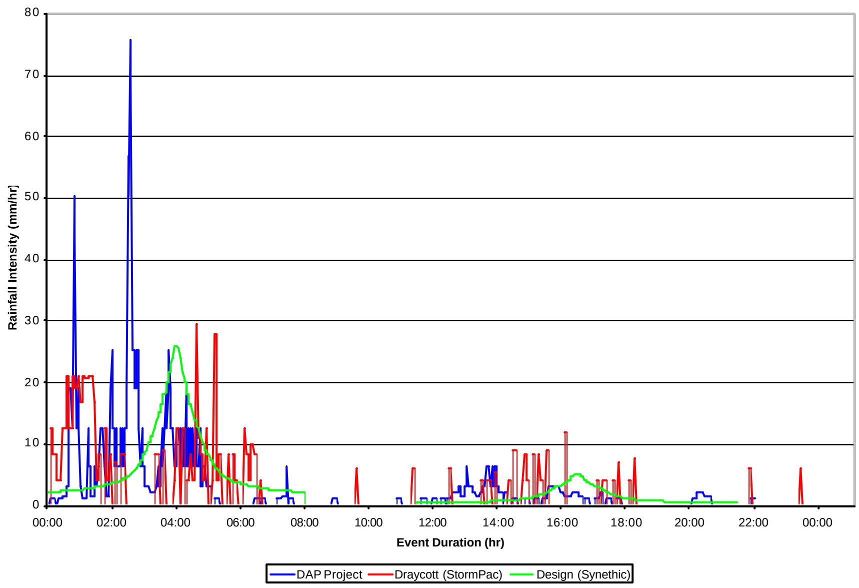


Figure 8 Different Rainfall Data

The model was simulated with each of these rainfall scenarios, with the implications being that any significant differences in model performance would then be due to the difference in rainfall application with regard single profiles and numerous profiles representing spatial variation. The model predictions (As shown in Table 4) indicate that the total runoff predicted by the models for each scenario was broadly similar, the StormPAC data from Draycott had the lowest runoff, due to the lower rainfall depth. However, in terms of total flooding, the three scenarios were markedly different, with the spatially varying rainfall causing much larger total flood volumes to be predicted. This is due to the period of very high intensity rainfall, which was not generated by the StormPAC data, or included within the equivalent depth / duration design storm.

However, in terms of predicted flooding in the SW Derby area, the flood volumes predicted by the model were relatively similar for the spatially varying rainfall data and equivalent depth / duration design event rainfall. This is encouraging, indicating that it is suitable to utilise single profile events in the SW Derby area.

Method of Rainfall Application	Predicted Volume of Total Runoff (m3)	Volume of Predicted Model Flooding (m^3)			
		SW Derby Area 1	SW Derby Area 2	SW Derby Area 3	Full Model
DAP Rain Gauge Data	2,974,352	745	273	116	311,946
Draycott (StormPac)	2,731,220	723	79	48	138,951
Design Rainfall	2,947,517	889	204	101	221,443

Table 4Effect of Spatially Varying Rainfall

5.0 Conclusions and Recommendations

The Derby DAP study has identified a number of interesting issues relating to runoff modelling. It has benefited from having winter and summer flow monitoring with the added bonus of an extreme event. It has also benefited from a pragmatic approach to testing the sensitivity of the model to the key parameters to which uncertainty with the runoff models exists.

Key conclusions and recommendations:

- **Is variable impermeable and permeable response an issue?** – **Yes, it is an issue.**

This study has highlighted the fact that variable impermeable and permeable response to the catchment occurs. All the different responses would not have been noticed had the flow survey period not covered the winter as well as the summer events. Adding additional area to represent the observed impermeable and permeable responses was possible with the current runoff model equations but we were not able to represent both the winter and summer condition within one model. The Derby area now has two models, Winter and Summer. These models must now be used with caution as they represent different runoff conditions. Sensitivity testing of the key parameters is recommended as this gave greater confidence in the model predictions. More consideration to the antecedent conditions, depression storage should probably be given at flow survey and verification stage where longer rainfall events and runoff drain down times are an issue on the catchment.

- **Can representation of impermeable runoff be improved? – Yes it can**

If we intend to move towards modelling longer duration events or even continuous simulation then a new runoff equation needs to be researched. An equation which can vary the runoff under wetting and drying conditions for all surfaces is needed so that longer duration and higher rainfall events can be represented. It may then be possible to have one model that represents the Derby catchment in the future!

- **Should long term flow surveys be the norm? – Yes / No / Maybe**

This is always a contentious issue as long term flow surveys are time consuming and expensive but where appropriate can lead to better understanding of the different responses in larger catchments. The cost/benefit will have to be balanced with the intended use of the model. The issues to be explored are:

  - The need to increase the chance of measuring increased response of variable impermeable areas.
  - Summer Winter issues should be given more consideration

- If storage is a proposed option, especially for flooding, definitely should consider winter verification.
- Provides more data for assessment of affect of spatially varying rainfall

- **Design NAPI values? – <u>As a minimum, undertake sensitivity testing</u>**

The starting value of NAPI (12 for soil type 4) was taken from the average calculated over a 10 year historical rainfall series. Sensitivity testing of design NAPI values can demonstrate how significant the value you have estimated (from whatever method you choose) can have on your project and it is recommended that this should be carried out on a case by case basis to add confidence to model predictions.

Although the starting value of NAPI can influence the runoff as shown in the sensitivity testing the authors recognise that other parameters which influence the runoff from the variable surfaces are equally as important to understand and can affect runoff significantly. These are included for completeness:-

- The depression storage (in the model) and antecedent rainfall condition (in the rainfall file) which controls when runoff begins to occur.
- The quantity of area attributable to the variable runoff surfaces. The greater the potential area the greater the potential runoff.
- The starting value of NAPI.
- The value NAPI attains during rainfall. NAPI increases due to rainfall and decays during dry periods.
- The amount by which NAPI decays and evaporates from the rainfall file.
- The value of the soil store (PF) for each surface.
- The ratio of NAPI/PF which should be considered for each variable surface.

Other modelling parameters were sensitivity tested on the Derby model but are not reported in this paper as they are not directly related to runoff issues.

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