Testing of the New Stochastic Rainfall Generator Model of STORMPAC3 Against STORMPAC2 and Historic Data

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Summary

This paper assesses the performance of STORMPAC3, presenting a series of comparisons between historical records and rainfall results generated by STORMPAC2 and STORMPAC3 at various sites around the UK, namely Kent, North West, Southern Ireland, Eastern Scotland. The paper also assesses the implications of using these results with respect to sewer system design within AMP3.

Introduction

The wet weather performance of sewers and sewage treatment works is, by definition, governed by rainfall. Thus, a crucial factor affecting the accuracy of simulation models developed for the design of sewerage systems is the method used to represent the local rainfall patterns. A good representation of rainfall inputs for a model will enable the development of the most cost effective solution required to meet the standards set by EC Directives and domestic legislation.

The Urban Pollution Management (UPM) Programme requires long continuous series of rainfall data to allow tests on environmental standards to be conducted. The UPM specifies that these data should be in one-hour intervals for simple sewer flow/quality models and five-minute intervals for detailed sewer flow/quality models.

Historical records are available from the Meteorological Office (Met Office). However, the availability of hourly resolution data, and especially five-minute resolution data, is limited and the cost of such data is high. In addition, more than one long rainfall record may be needed if rainfall is suspected to vary spatially across the catchment. This situation may arise if, for example, the catchment is large or if rainfall is influenced by orography within the catchment.

The problem of limited availability of hourly and five-minute rainfall data has been partly addressed by the development of the Stochastic Rainfall Generator (SRG) as part of the UPM toolkit. The SRG model (Cowpertwait *et al.*, 1991) was developed to enable the generation of representative hourly rainfall series for the majority of UK urban areas. These series are catchment specific and can be used to;

- fill in gaps or augment historical hourly records;
- provide a reliable translation of historical daily data to an hourly timestep or;
- generate representative rainfall for a catchment where historical data is not available or considered too expensive.

Readily available, catchment specific information is required such as; standard average annual rainfall (SAAR), grid reference, altitude and distance from coast.

The resolution of this hourly data can also be increased to five-minutes by means of a Dissaggregation model, which was developed in parallel with the SRG. These models were made commercially available by the production of the STORMPAC software package.

STORMPAC was developed by WRc in conjunction with the Department of Civil Engineering at the University of Newcastle.

Until recently STORMPAC version 2 was the most up-to-date version of the software commercially available. This has been successfully adopted in several UPM studies in a variety of locations around the UK. However, it has become apparent that recent rainfall patterns are changing as extremes in weather are experienced more frequently. More extreme storms, i.e. high intensities over a short duration, are being observed with longer dry periods in between (Hulme & Jenkins, 1998). The debate is open as to whether these extremes are caused by 'climate change' or are just part of the natural variation in weather. However, forecasts from Global Climate Models (GCM) suggest a trend toward more frequent occurrence of extreme weather and one should be prudent to include these effects in the design of sewage systems. Consequently the use of older historical records and possibly STORMPAC2 results in simulation models in the near future may not provide an accurate representation of catchment conditions.

STORMPAC2 has been shown to provide a good fit to average annual rainfall and individual monthly totals (Cowpertwait & Threllfall, 1994). However, on some occasions it is unable to reproduce the number of extreme storm events that have been observed in recent records. To address this problem a new SRG model has been developed by WRc in association with Paul Cowpertwait. This has considered data from a greater number of rainfall gauge stations around the UK (120 in total) to develop revised statistical algorithms for the model. Results from the new model have compared favourably with historical data and suggest representative hourly simulations can be obtained with return periods in excess of 20 years (Cowpertwait, 2000). Importantly the model is now capable of reproducing the extreme events that have been observed in recent data.

The new SRG has been incorporated into the recently released STORMPAC3. This new software features the following enhancements over its predecessor:

- The inclusion of a skewness function in the new SRG generates a better fit to the extremes, i.e. more intense storms and longer dry periods;

- Increased functionality when defining statistical parameters enables increased accuracy when regionalisation with daily historical records is performed;

- More accurate regionalisation based on rainfall statistics generated from more recent rainfall data and using an increased number of gauge sites across the UK;

- Longer inter-event dry periods can be specified. This is important in large catchments with lots of storage where drain down times are long;

- Not limited to single storm durations of 72 hours, as in STORMPAC2;

- Significantly longer rainfall time series can be produced – up to 50 years;

- Calculation of UCWI and API30 values, which can then both be included in the export file format;

- Greater range of rainfall file formats can be imported and data can be exported in Hydroworks/Infoworks/MicroDrainage, SIMPOL and RWIN formats;

- Up-to-date Windows software platform, which can be easily modified to include new modules, thus increasing functionality. The software can also be run on newer operating systems;

- HTML help system.

Assessment of STORMPAC3

It is important, if STORMPAC3 is to be used as design tool within future AMP projects, that the accuracy of the simulations it produces are fully realised. Therefore, to achieve this aim, a series of rainfall series were generated using both STORMPAC2 and STORMPAC3 for various sites around the UK, namely Kent, North West, Southern Ireland, Eastern Scotland. In the following section a selection of comparison techniques are presented, which assess the accuracy of the simulated data compared to the historical records on which they are based. In addition, the implications of using these results with respect to sewer system design within AMP3 are assessed.

A number of sites were chosen for investigation. These provided a range of locations across the UK that in combination generated an "umbrella" coverage of different climatic regions within the UK. The test sites are shown in the map in Figure 1. They were:

- Annfield, Edinburgh. Position A on map shown in Figure 1.
- Manston, Kent. Position B.
- Wigan, North West. Position C.
- Leixlip, Dublin. Position D.

Figure 1 Map showing UK rainfall sites investigated

At each site a daily historical rainfall record was available. The availability of these data meant the SRG could be Daily Regionalised as well as Annually Regionalised:

- Annual Regionalisation is based upon the five parameter site information and relies upon the in-built regionalisation model in STORMPAC to generate an hourly rainfall time-series.
- Daily Regionalisation uses historic daily data obtained within a catchment as well as the in-built regionalisation model and calculates statistics directly from the historic time-series. These statistics are then used to generate the hourly data.

In the tests performed in this investigation the length of each available daily record was different so it was decided that each SRG simulation should run for the same duration as the corresponding historical daily record. This would simplify the comparison process.

The SRG also provides a seed parameter to enable fine-tuning of the regionalisation process to maximise the degree of fit to historical records. In other words a slightly wetter or drier rainfall time series can be produced which is still representative of the rainfall within the region. The magnitude of the seed is between 0 and 1. In STORMPAC2 the seed parameter is only available when annually regionalising. In STORMPAC3 the seed can influence all forms or regionalisation. For the regionalisation scenarios that could be influenced by a seed, the test program investigated the effect of three different seed values, 0.1, 0.5 and 0.9, which were chosen as representative of the range of values available.

The following options were therefore used to generate hourly rainfall time-series, see Table 1:

Table 1 Different options used to generate hourly data

Daily Regionalisation				Annual Regionalisation					
SP2	**SP3**			SP2			SP3		
Seed 0.5	**Seed <u>0.1</u>**	Seed 0.5	**Seed <u>0.9</u>**	Seed 0.1	Seed 0.5	Seed 0.9	Seed 0.1	Seed 0.5	Seed 0.9

Note: SP2 or SP3 = STORMPAC Version 2 or 3
Underlined values represented enhanced functionality of STORMPAC3

Table 1 illustrates an important feature of STORMPAC, which is its flexibility with respect to the range of options available to the user to generate an hourly series that is comparable to historic data. It is important for UPM studies to make full use of this flexibility so that representative rainfall time-series are produced.

Comparison of rainfall data

After the generation of rainfall data a series of different analysis techniques were adopted to compare the performance of STORMPAC versions 2 and 3.

A threshold analysis was performed on each time series. The hourly SRG data were aggregated to daily totals to facilitate direct comparison to the daily historic data. The numbers of days exceeding a series of pre-defined thresholds were then calculated for each option. Due to the rainfall records being different lengths the frequencies of each threshold were normalised by calculating average annual values rather than frequencies over the whole record length. Typical examples of this are plotted in Figure 2 and the data used in these plots is shown in Table 2.

Annual average rainfall depths and annual average bathing season (May to September) rainfall depths were also calculated for each option and these comparisons are displayed in Table 3.

It is clear from these data that both STORMPAC 2 and 3 are capable of generating rainfall series that are close representations of the historical data they are simulating. Each case study presented demonstrates that STORMPAC3 provides an improved simulation in terms of threshold analysis compared to STORMPAC2. This result is also seen in the data presented in Table 3. The average annual and bathing season totals should match to within about 5% of the historic value to be considered a good simulation. In general, this is achieved and STORMPAC3 produces rainfall data with SAAR and bathing season totals closer to historical records than STORMPAC2.

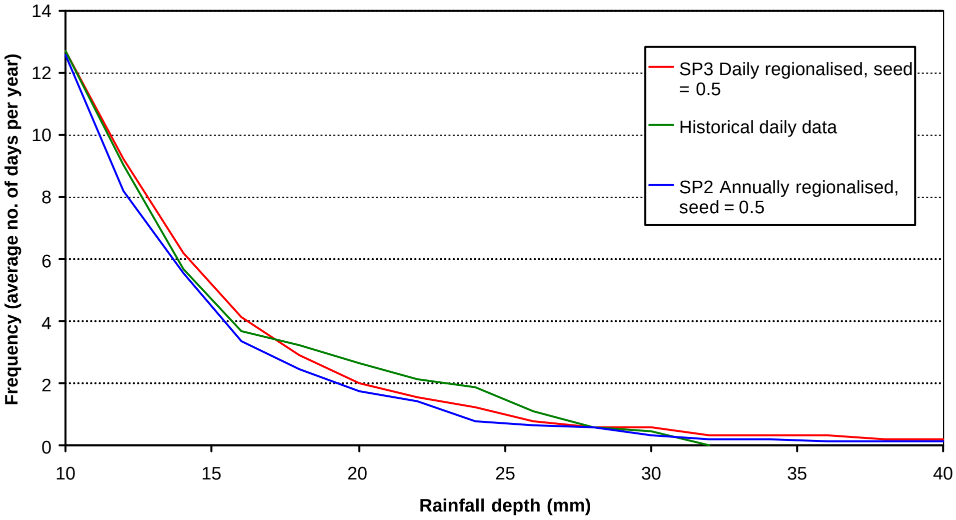
These results highlight the additional flexibility of STORMPAC3 with its ability to “tune” simulations to the historical record using the seed value. It also highlights the necessity of comparisons of this type to ensure the user has developed a representative series.

It is noted that in some of the data presented STORMPAC2 shows a slightly closer match to the historical series. This enforces the point that the choice of seed in STORMPAC3 has a strong bearing upon the accuracy of the rainfall series produced. It is important to note that the nature of both versions of STORMPAC mean that care must be taken to ensure the best possible rainfall simulation is obtained. Thus, a thorough assessment of the influence of seed values and different types of regionalisation (if historic data are available) is recommended to determine the best simulation.

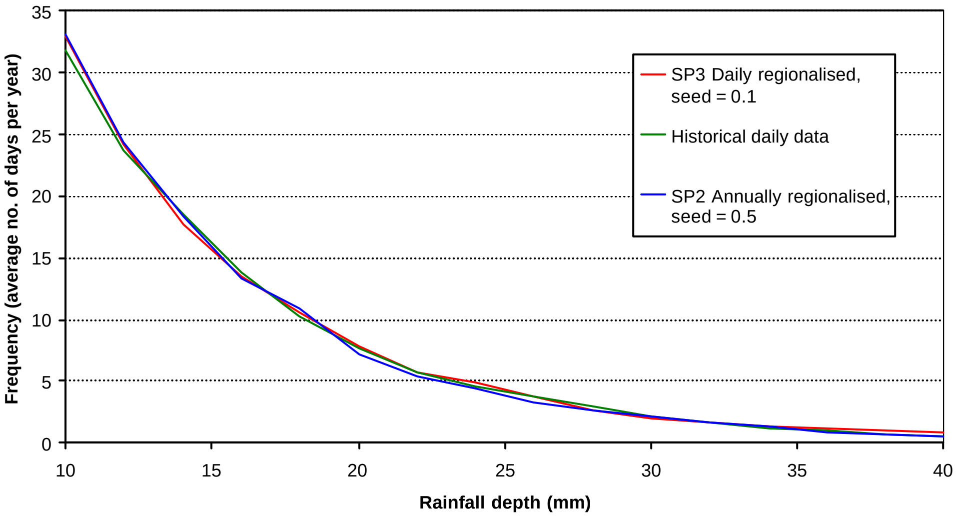
Table 2 Threshold analysis data obtained from test sites rainfall series

Threshold (mm)	Annfield (25yrs)			Leixlip (19yrs)			Manston (9yrs)			Wigan (19yrs)		
	SP2	SP3	Historic	SP2	SP3	Historic	SP2	SP3	Historic	SP2	SP3	Historic
10	414	412	246	630	626	605	113	114	114	544	521	594
12	282	288	143	464	460	450	74	83	81	380	362	431
14	193	201	92	350	335	351	50	56	51	284	272	289
16	139	151	68	254	257	262	30	37	33	200	194	202
18	96	105	50	207	201	193	22	26	29	143	134	154
20	66	83	31	137	147	146	16	18	24	105	95	110
22	48	56	24	102	109	108	13	14	19	75	72	81
24	37	39	21	84	92	87	7	11	17	52	55	51
26	24	24	15	63	70	70	6	7	10	39	45	40
28	15	17	13	48	49	55	5	5	5	30	31	27
30	10	13	10	40	38	41	3	5	4	20	18	19
32	9	9	8	31	30	30	2	3	0	12	12	16
34	8	9	5	26	26	23	2	3	0	7	8	11
36	4	5	4	17	22	19	1	3	0	7	4	8
38	3	5	4	13	19	12	1	2	0	4	2	6
40	3	4	3	9	17	11	1	2	0	4	1	4

Manston - Threshold Analysis of Daily Totals



Leixlip - Threshold Analysis of Daily Totals



Wigan - Threshold Analysis of Daily Totals

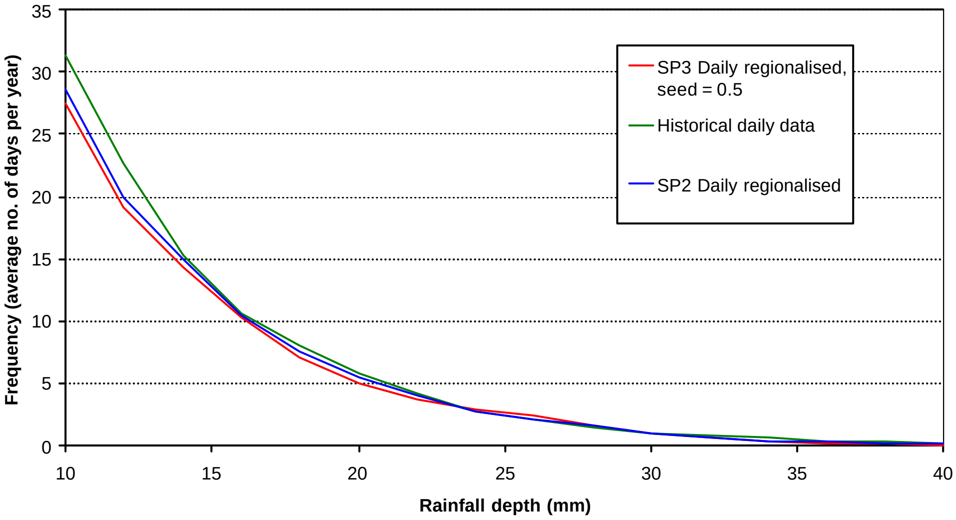


Figure 2 Examples of threshold analysis of daily totals of simulated rainfall

Table 3 SAAR and bathing season totals for simulated rainfall series

Location	SRG type	Mean annual rainfall		Mean bathing season rainfall	
		Simulated value (mm)	% error from historic	Simulated value (mm)	% error from historic
Annfield	STORMPAC2	668	**4.7**	268	**0.8**
	STORMPAC3	652	**2.2**	252	**-0.8**
Leixlip	STORMPAC2	1093	**4.7**	349	**-7.7**
	STORMPAC3	1108	**6.1**	401	**6.1**
Manston	STORMPAC2	569	**7.9**	245	**12.8**
	STORMPAC3	543	**2.9**	224	**3.4**
Wigan	STORMPAC2	980	**-2.5**	394	**7.6**
	STORMPAC3	1008	**0.3**	345	**-5.7**

Storm events were extracted from the time series data, where an event was defined by the inter-event dry period, which was set initially to one hour. The exercise was then repeated with an inter-event dry period of four hours. The results obtained from this analysis are shown in Table 4. It should be noted that only the scenarios that best fit the historical data have been selected for this analysis.

Table 4 Storm event analysis data for simulated rainfall series

Location	SRG type	Length of series (years)	Inter event dry period	Number of events in series	Max. mean intensity (mm/hr)	Max. intensity (mm/hr)	Max. storm duration (hours)
Annfield	SP2	25	1 hour	6351	21	24	28
			4 hour	4560	12	24	50
	SP3		1 hour	8548	17	23	19
			4 hour	5309	12	23	49
Leixlip	SP2	19	1 hour	5817	13	23	47
			4 hour	3978	13	23	54
	SP3		1 hour	9787	19	28	43
			4 hour	5747	19	28	92
Manston	SP2	9	1 hour	2000	16	16	26
			4 hour	1479	8	16	33
	SP3		1 hour	2875	13	16	18
			4 hour	1847	10	16	59
Wigan	SP2	19	1 hour	5761	10	18	30
			4 hour	4017	10	18	42
	SP3		1 hour	9898	11	17	33
			4 hour	5761	11	17	82

The results show a significant increase in the number of individual storms produced by STORMPAC3 over STORMPAC2 within the best-fit rainfall series. This reflects the improved representation of more extreme weather by STORMPAC3. This is further reinforced by the detection of storms with greater intensities and longer durations by STORMPAC3, as shown in Table 4. STORMPAC3 is able to produce additional and more extreme events due to the use of a single cell design for the Neyman-Scott model on which the SRG is based. The single cell approach enables the generation of both short-light and long-heavy rain, where as STORMPAC2 adopted a multi-cell approach with separate cells for short-light and long-heavy rain. This latter approach has been shown to be not as adept at the generation of more extreme events (Cowerpertwait, 2000).

Monthly totals that represented an average year from the entire time series were calculated for every scenario. This was achieved by calculating the average rainfall for each month and then selecting the actual monthly data from each time series that produced the closest match to each calculated average. The wettest and driest 12 months were also extracted from each time series. Considering one of the test sites, Figure 3 shows a typical example of how the monthly totals compare for each version of STORMPAC, adopting the simulations that best reproduced the historical data with respect to thresholds.

It can be seen from the data displayed in Figure 3 that both versions of STORMPAC produce, on average, a close representation of historic rainfall in terms of monthly totals. However, the reproduction of more extreme weather, in terms of significantly wet or dry months is better achieved by STORMPAC3, with a greater range displayed between the wettest and driest months, which is closer to the historic data than STORMPAC2.

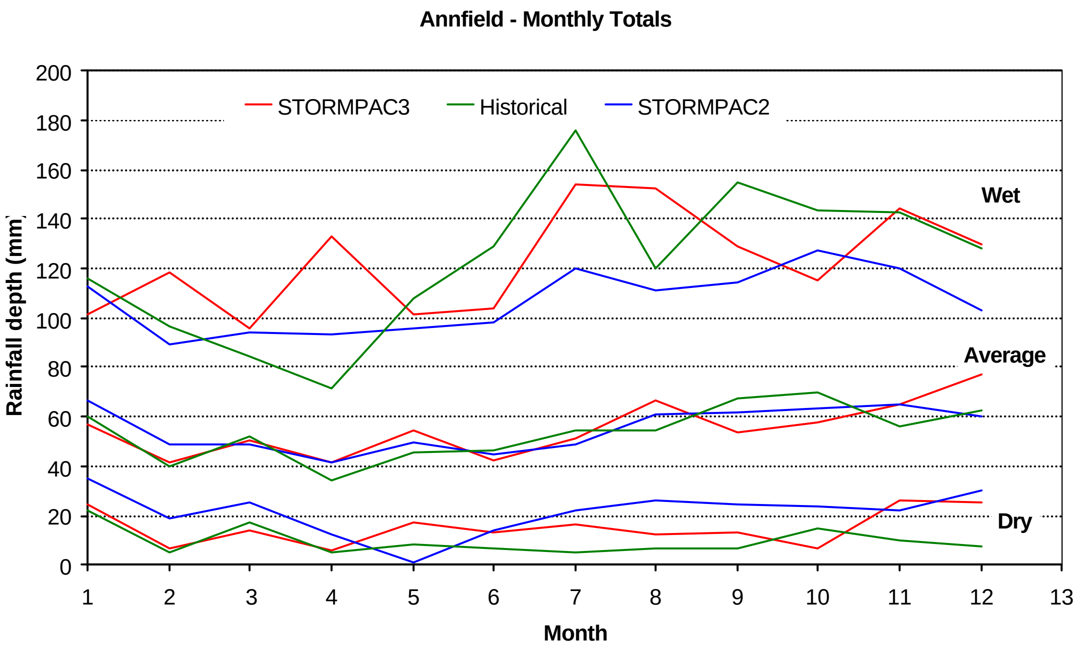


Figure 3 A comparison of simulated and historic monthly totals at one test site

Influence of rainfall on Sewer Modelling

Ultimately, the generated hourly rainfall is used in sewer models, which calculate spill volumes, pollutant loads, pass forward volumes etc. For the purposes of this paper we aimed to test spill frequency using a simple model, concentrating in the 3 and 10 spills per year criteria defined in the UPM manual. There was not enough time to test other compliance standards such as 99 percentile or Fundamental Intermittent Standards (FIS).

Therefore, the rainfall series obtained from STORMPAC2 and STORMPAC3 were applied to a simple sewer model and the effects on spill volumes from the sewerage system were investigated.

An existing SIMPOL model of a basic sewer catchment was selected. A schematic diagram of the sewer network adopted is shown in Figure 4. The best fit STORMPAC 2 and 3 hourly data from each of the five test sites were run through the model and a detailed record of spill events across the catchment was obtained for each rainfall series.

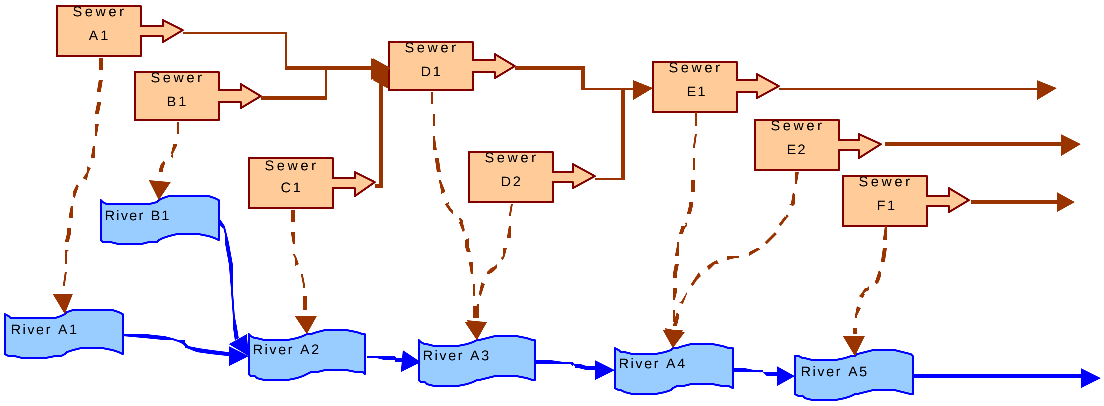


Figure 4 Schematic of simplified sewer catchment model

Table 5 Storage requirements predicted from different generated rainfall series

Location	SRG type	Storage required in sewer catchment (m^3)	
		For 3 spills per year limit	For 10 spills per year limit
Annfield	SP2	26000	12200
	SP3	24500	11500
Leixlip	SP2	39900	19400
	SP3	39900	19800
Manston	SP2	22000	11100
	SP3	22500	10900
Wigan	SP2	30400	15800
	SP3	30800	16000

Analysis was performed on the spill volume outputs from the model in order to select the spill events and sort them by magnitude (summed across the whole catchment). The storage volume that would be required to enable the catchment to meet a 3 spills per year standard and the less stringent 10 spills per year standard were then calculated. These results are shown in Table 5.

A spill event within the sewer catchment was defined by the inter-event dry period, i.e. the length of dry period between spills, from any point within the catchment. This was set at one hour. In addition a minimum spill rate was set to prevent negligible outputs been registered as spills. This was set at 1l/s.

The data in Table 5 shows that, for this particular investigation, both versions of STORMPAC produced similar results in terms of storage requirements within the sewer model. However, the evidence from the comparison of rainfall against historic records suggests that STORMPAC3 will give a more accurate result. Therefore, the fact that there are no major changes in storage in these cases demonstrates simply a refinement by STORMPAC3. However, it should be noted that the updated algorithms in STORMPAC3 may lead to differences in predicted spill volumes and spill frequency from STORMPAC2. These results can be considered more accurate as STORMPAC3 produces a more representative pattern of rainfall for a particular catchment. It should be noted that, due to the catchment specific nature of the SRG, it is not possible to predict from catchment to catchment whether the differences from STORMPAC2 will be manifested as either increases or decreases in storage requirements.

Conclusion

STORMPAC3 has been shown to produce extreme events with greater accuracy than STORMPAC2 when compared to historic data. The increased functionality of STORMPAC3 due to the greater influence of seed values means that rainfall in the majority of UK sites can be generated with increased accuracy. This has been reflected in this investigation by the improved accuracy of STORMPAC3 over STORMPAC2 in comparisons to historic data in terms of rainfall statistics such as annual average depth, bathing season depth and monthly total depths. However, it is important to note that care must be taken when generating simulated rainfall in STORMPAC3 to ensure the selected seed value produces the best representation of historical data.

Also, for the case studies investigated, storage volumes within an arbitrary sewer network have not shown significant differences when using STORMPAC3 and STORMPAC2 data to meet 3 and 10 spill criteria. This is an important result given that existing designs have been based upon STORMPAC2 rainfall data. The fact that STORMPAC3 is better able to represent extremes in rainfall is important when studying worse case scenarios. The user can be more confident that a generated time series will contain extreme events that are comparable to similar events observed in historic data. However, it should be noted that this better representation of historic data could lead to increases or decreases in design storage volumes compared to results obtained from STORMPAC2.

Future Work

This investigation has highlighted the need for a thorough assessment of different simulation scenarios to obtain accurately generated rainfall. Therefore STORMPAC3 will be undergoing continuous development to incorporate analysis tools to enable the acceleration of this procedure.

References

Cowpertwait P.S.P. ‘An Updated Regionalised Stochastic Rainfall Generator for the UK’. *Written for the Water Research Centre, Swindon, UK, 2000*.

Cowpertwait, P.S.P and Threlfall J.L. ‘Further Developments of the Stochastic Rainfall Generator’. *Published by the UK Foundation for Water Research, Report Number FR0438, 1994.*

Cowpertwait P.S.P., O’Connell P.E., Metcalfe A.V., Mawdsley J.A. and Threlfall J.L. ‘Stochastic Generation of Rainfall Time Series’. *Published by the UK Foundation for Water Research, Report Number FR0217, 1991*.

Hulme M., Jenkins G. ‘Climate Change Scenarios for the United Kingdom’ *Summary Report for UKCIP Technical Report No.1, 1998*.