Getting the Right Rainfall?
Gauged versus Stochastic Rainfall Data for Urban Drainage Modelling

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Abstract

Present wastewater planning guidelines recommend the use of high resolution historical rainfall time-series as the best data to use when designing engineering solutions through sewer network modelling. However, the hitherto poor accessibility of these data means that current best practice is for stochastically generated data to be used in their place. Many AMP3 storm sewage storage schemes have been designed using synthetic data. To improve this situation, the Met Office has made 740 years of quality controlled tipping bucket rain gauge data from across the UK widely available through bespoke software. It is scheduled to increase the amount of data as more gauge sites' data becomes available. This paper describes the work carried out to prepare these data and examines the effects of using 'real' rainfall inputs against stochastically generated data when undertaking sewerage design using existing hydraulic models. The results of a study to determine the sensitivity of engineering design to type of rainfall data input are presented.

1. Introduction

An urban drainage rainfall data extraction tool, 'Deluge', has been developed by the Met Office over the past 12 months, in association with Halcrow Group Ltd. The tool has been developed in response to discussions between the Met Office and the water industry over the past 4 years. Deluge allows users to make use of continuous time-series rainfall data at 5-minute resolution for 73 sites around the UK. These sites are locations at which the Met Office has tipping bucket raingauges (which produce tip times*) with a continuous record of 1 year or more. The average gauge length is 10.1 years. The tip time record for each gauge has been converted to 5-minute interval data and has been quality controlled against nearby daily check gauges.

In order to assess the impact of using gauged 5-minute data against synthetic (stochastically generated) data comparisons of thirteen years of rainfall data for two sites have been made. Deluge rainfall data have also been tested in a realistic engineering design situation and the results are compared to those produced using synthetic rainfall data. These simulations highlight the consequences of differences in 'real' and 'synthetic' rainfall time-series at two UK locations.

Synthetic rainfall data have been generated using the daily regionalised model within industry standard Stormpac software. This approach is considered best practice in the absence of long observed rainfall time-series.

*each time the raingauge bucket receives 0.2mm of rainfall the bucket tips and this 'tip time' is recorded

Figure 1 – A typical tipping bucket raingauge

It should be noted that the comparison studies presented in this paper have been made purely to compare real and synthesised data for sewer modelling purposes and are not designed to highlight any perceived weaknesses in the Stormpac software. For this reason, Stormpac generated time-series data is referred to as 'synthetic'.

2. Rainfall data comparison

The Deluge software was used to extract storm events from gauges located at Church Fenton (20km east of Leeds) and Heathrow Airport (in West London). Both sites have 13 year records and all storms were extracted which met the minimum depth criteria of 1mm and minimum antecedent dry period criteria of 2hrs. Appropriate catchment wetness indices were automatically calculated from the database of soil moisture deficit (SMD) data held within Deluge. These sites were selected as they had relatively long rainfall records associated with them and were considered sufficiently different to be selected in this test from a climatological perspective.

Stormpac was used to generate 13-year synthetic records for the same locations. Generation parameters were calculated by processing, within Stormpac, long daily rainfall records from each location. The same storm event selection criteria were used to create comparative data sets to the Deluge storms. Monthly average SMD data were also applied within Stormpac to attribute appropriate wetness indices to each storm event.

Table 1 summarises the storm events created at each location by both methodologies.

	Church Fenton		Heathrow	
	Deluge	Synthetic	Deluge	Synthetic
Record length (years)	13	13	13	13
No. events	1567	1058	1528	1605
Total depth of events (mm)	6819	7941	6950	6607
Average depth of events /year (mm)	524.5	610.8	534.6	508.2
AAR (mm) (from 71-00 10km gridded data)	585		609	
5yr 3hr (mm)	22		27	
5yr 12hr (mm)	34		42	

Table 1 Comparison of rainfall time-series from Church Fenton and Heathrow

Differences in these summary statistics between actual (Deluge) and synthetic (Stormpac) rainfall time-series can disguise more complex patterns and effects. The differences between real and synthetic rainfall time-series at a location can be as profound as differences between two observed data sets from different locations.

2.1 Church Fenton

From Table 1 it is evident that there are more events in the Deluge series (50% more) but the synthetic series has a greater total rainfall depth. Figure 2 shows the cumulative number of events (over 13 years) by depth for the Deluge and synthetic time-series. While the synthetic series has a greater number of smaller events, the distribution of larger events is similar for both time-series.

Figure 3 shows the difference in the peak intensity (highest 5-minute amount) within every event. Here, it is clear that Deluge data encompasses a significant number of events with higher peak intensities than those generated in the synthetic time-series; Deluge has 55 events with a peak intensity of 25mm or more (up to 96mm/hr) where the synthetic series has one event (of 28mm/hour).

Analysing the mean intensity of all rainfall events (Figure 4) indicates that the synthesised data fails to capture the distribution of mean intensities measured by the gauge. The synthesised events do not have any mean intensities greater than 3 mm/hour in this case.

The last aspect of data examined is event duration. While there are more events in the Deluge time-series, it is apparent that the synthetic data set simulates only one event of greater than 20 hour duration. The Deluge time-series encompasses 12 events greater than 20 years, of duration up to 41.2 hours.

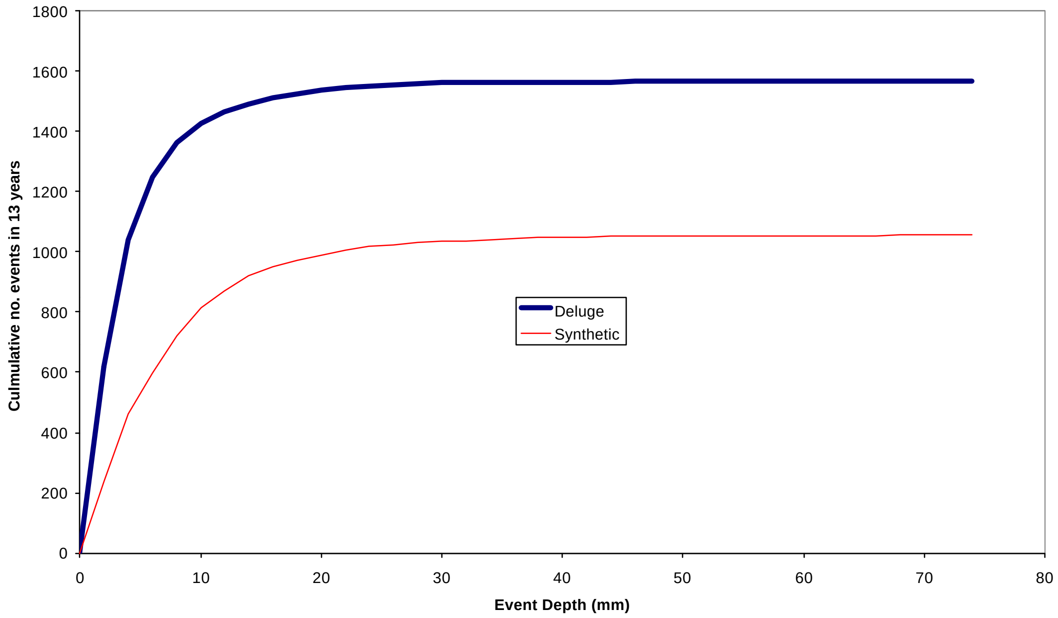

Figure 2 – Cumulative rainfall depth of all rainfall events >1mm in 13 year record at Church Fenton

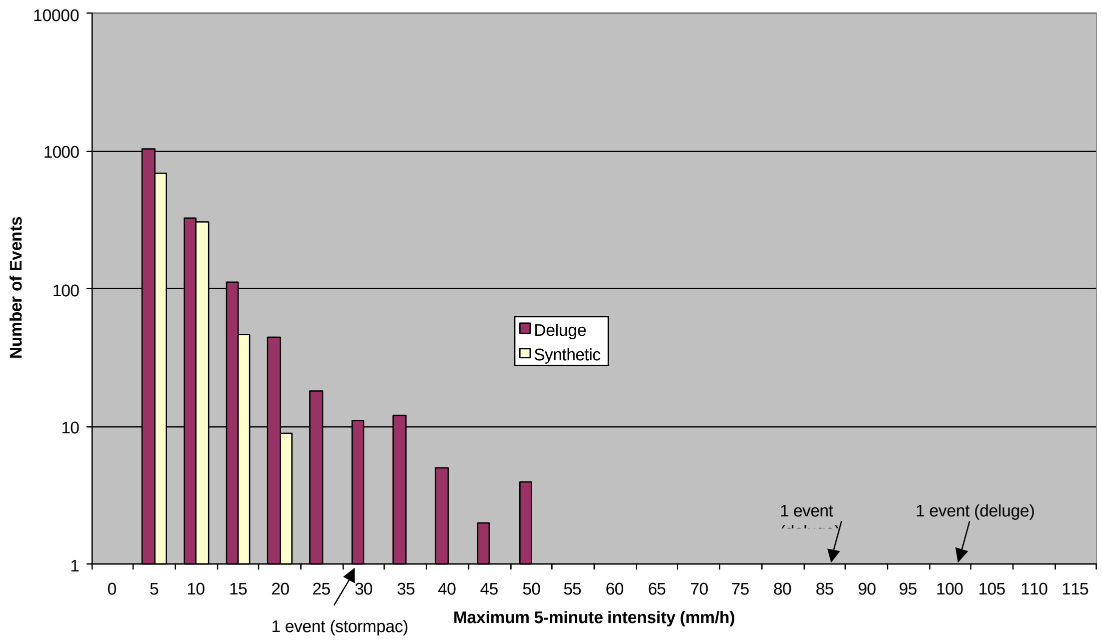

Figure 3 – Peak 5-minute intensity values in all events > 1mm in 13 year record at Church Fenton

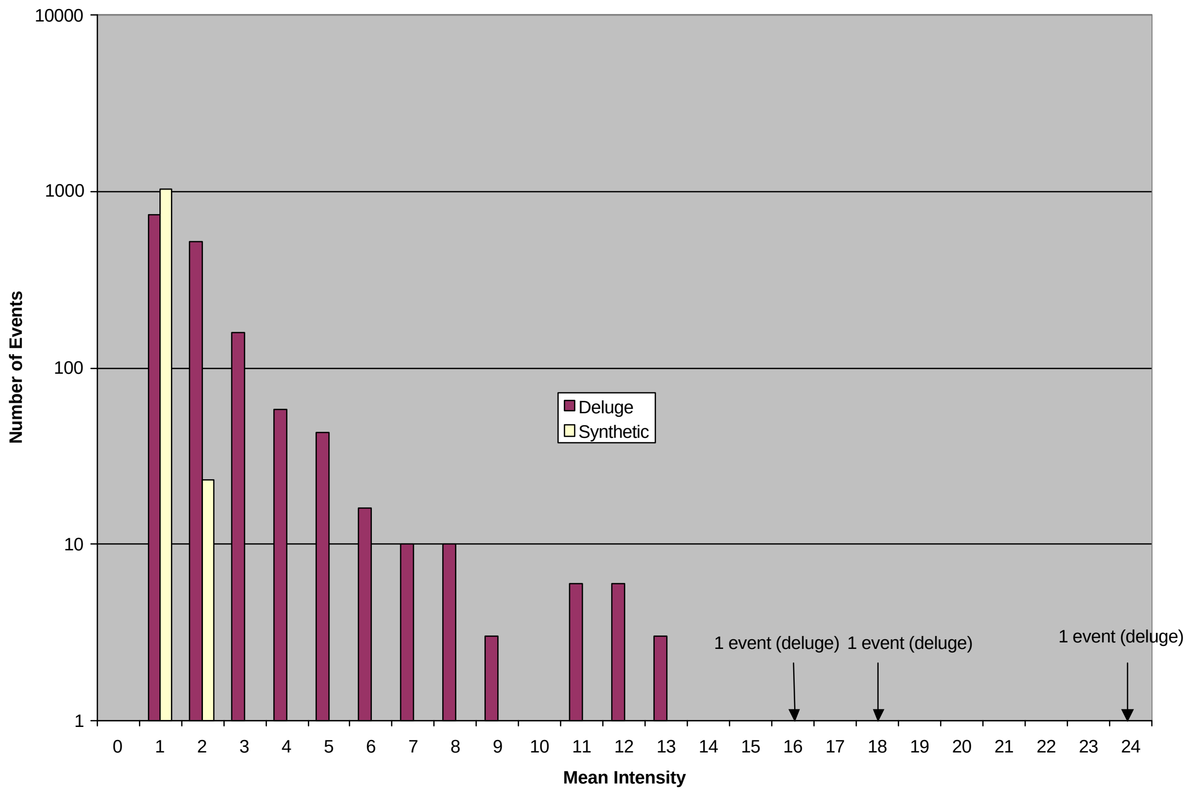

Figure 4 – Mean intensity of all events > 1mm in 13 year record at Church Fenton

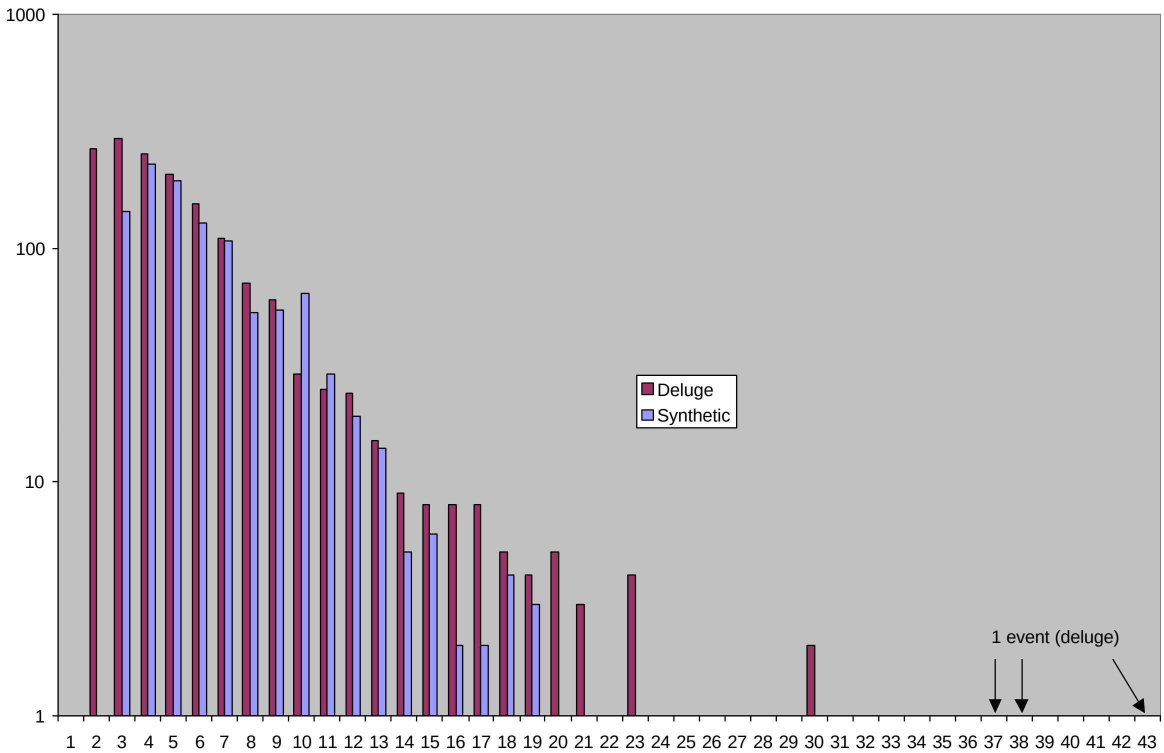

Figure 5 – Event duration of all events > 1mm in 13 year record at Church Fenton

2.2 Heathrow

In the case of Heathrow, the Deluge and synthetic data are more closely matched in terms of number of events in the record and mean depth of the events (as shown in Table 1). Figure 6 shows the cumulative number of events (over 13 years) by depth for the Deluge and synthetic time-series. The two series are more closely matched than at Church Fenton, suggesting that the synthetic series is more representative of some aspects of observed rainfall patterns in west London than it is in North Yorkshire.

However, examining peak intensities within each data set reveals a variation between the two, particularly at intensities of 30mm/hour and greater, shown in Figure 7. The synthetic data set includes no events with peak intensities greater than 40mm/hour. Figure 8, examining mean intensity, also indicates that the highest mean rainfall intensities (greater than 8mm/hour) in the gauged record (Deluge) are not simulated in the synthesised data set.

Figure 9 indicates that event duration is similar for both data sets.

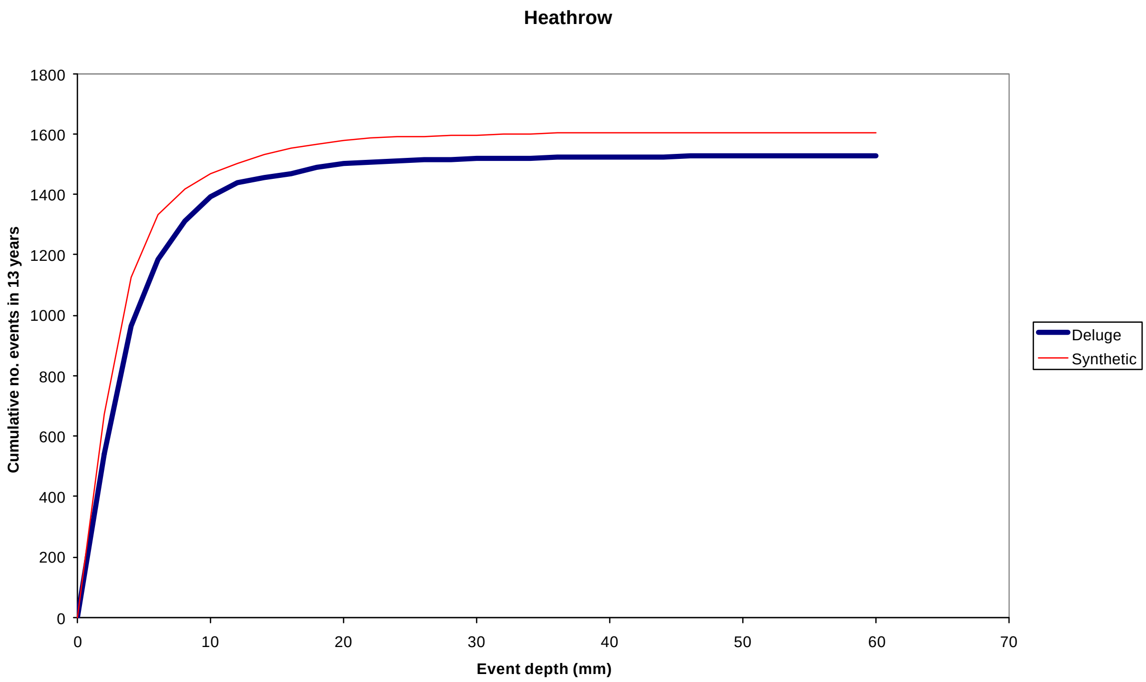

Figure 6 – Cumulative rainfall depth of all rainfall events > 1 mm in 13 year record at Heathrow

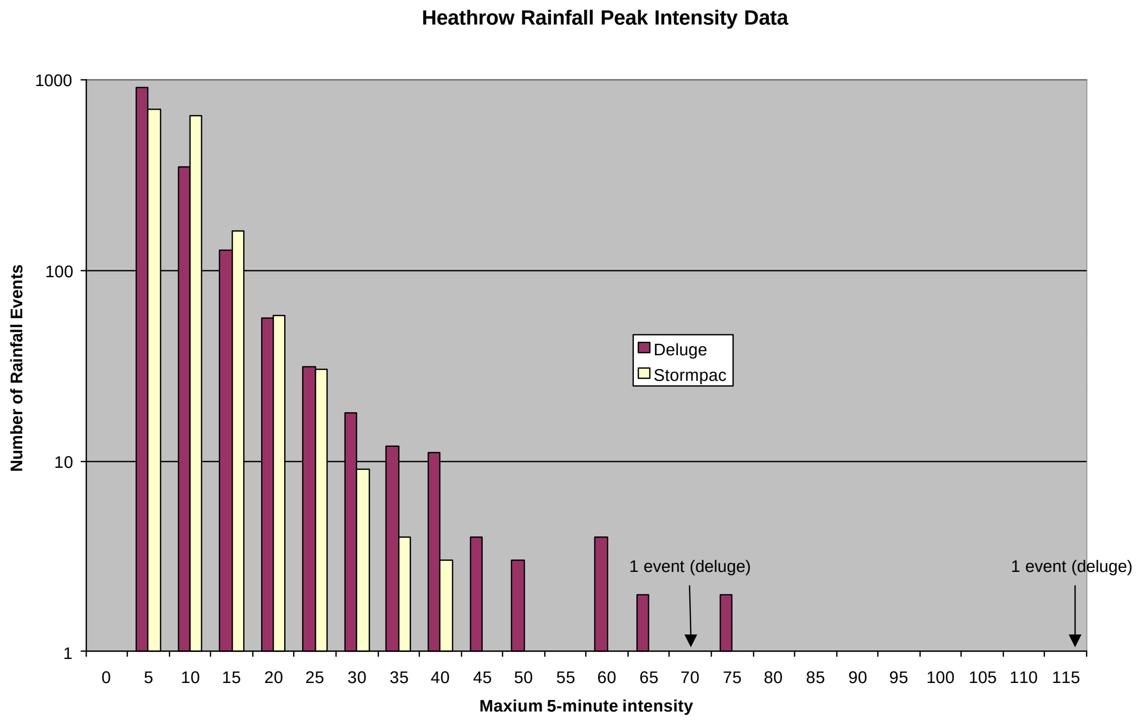

Figure 7 - Peak 5-minute intensity values in all events > 1mm in 13 year record at Heathrow

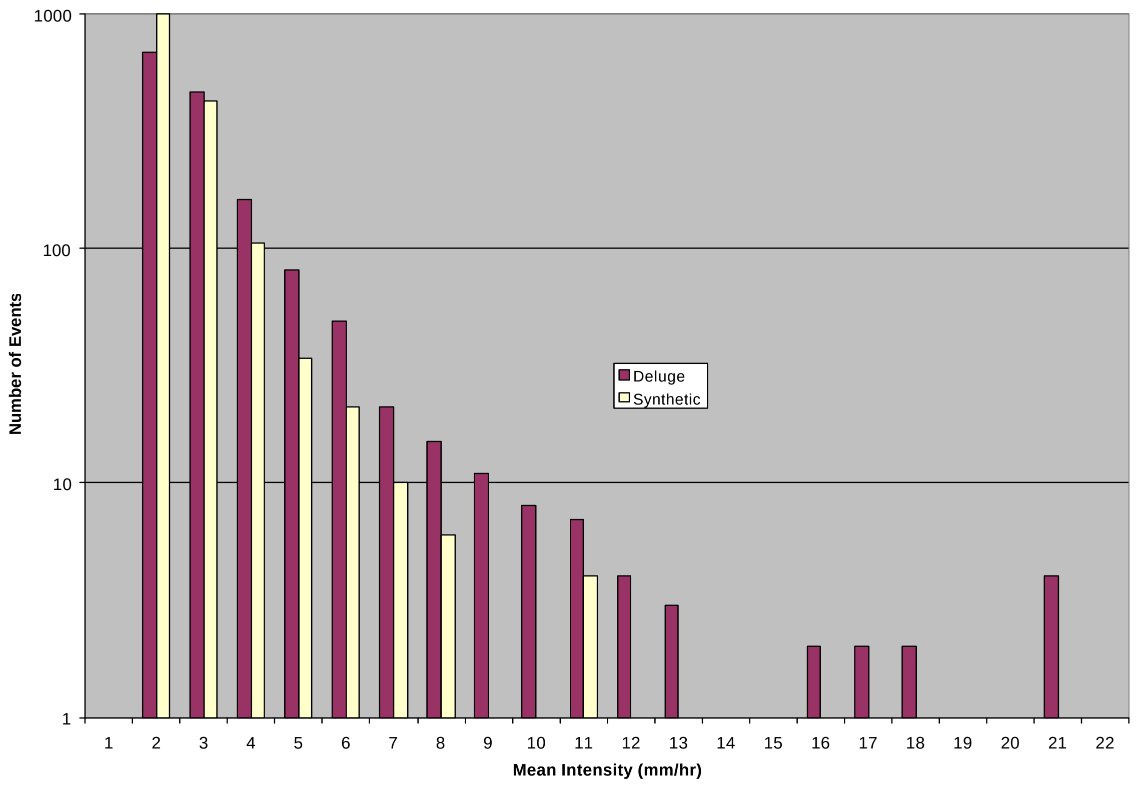

Figure 8 - Mean intensity for all events > 1mm in 13 year record at Heathrow

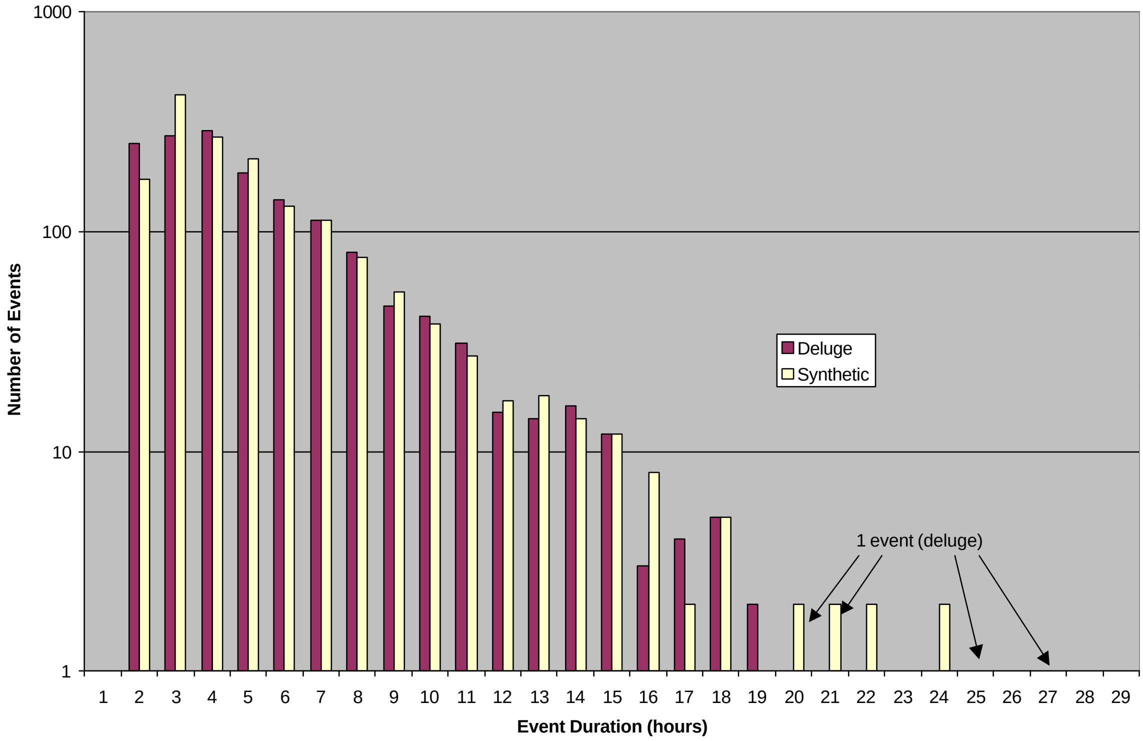

Figure 9 – Event duration of all events > 1mm in 13 year record at Heathrow

2.3 Summary and Explanation of Differences

Key differences in the two data sets at Church Fenton are that 50% more events occur in Deluge than the synthesised data, the synthesised data does not include events at higher peak and mean intensity and tends to produce events of durations up to 20 hours only, whereas Deluge produces some longer-duration events.

Key differences in the two data sets at Heathrow are that the synthesised data does not include as many peak and mean intensity values as Deluge (though more than at Church Fenton). Number of events and the distribution of event duration are similar for both data sets.

Reasons for the variations in the gauged and synthetic data sets from these gauges are suggested below. However, without in-depth analysis, these reasons are speculative and differentiating the effects of each would be difficult or impossible. It is considered that potential reasons for differences may be:

i) as a result of failings in the synthetic process to generate sufficiently high peak rainfall intensities
ii) failure of the synthetic software to replicate the same number of events (separated by a given inter-event dry period) as occurs in reality
iii) failure of the synthetic software to produce long duration events (in the case of Church Fenton)
iv) failings in the tipping bucket raingauge in recording a representative record of rainfall (that may be better represented by daily rain gauges) or, better still, by radar.

Point iv) is included as the synthesised data are not being compared against *actual* rainfall, but against gauged rainfall – clearly this is a topic for further debate.

2.4 Other UK Sites

Having examined the data in Table 1, it was considered that a site with higher average annual rainfall would make a useful contrast to the sites of Heathrow and Church Fenton. Due to the constraints of this analysis it is not possible to thoroughly examine the differences of another site so a descriptive presentation of the results is given for a third site.

The site selected was Princetown, on Dartmoor, with an elevation of 453m ASL and an average annual rainfall (1971-2000) figure of 1802mm. The Deluge software has 14 years of continuous data for this gauge.

A brief analysis of the data set shows that Deluge has 24,718 events of 1mm or more (with an antecedent dry period of 2 hours) compared to 17,895 events in the synthetic data set. Divided by 14, this gives average annual rainfall totals of 1766mm and 1278mm respectively. Event depth results show the synthetic data set producing consistently smaller rainfall depths (approximately 50% fewer events in most depth categpories). However, in this case the synthetic data set does include a greater number of 'heavy' events (> 70mm). As for the other gauges, peak and mean intensity is both higher in the Deluge data set, particularly in the peak intensity data, as was the case for Heathrow. However, a significant difference at Princetown is that the synthetic data include 9 events with a mean intensity of 20mm or more, where Deluge has none.

3. Sewer Modelling Results

Deluge and synthetic rainfall time-series from both locations were used in a InfoWorks sewer hydraulic model of a mainly combined sewer system. The spill volume and frequency at a significant combined sewer overflow (CSO) in this model were investigated together with predictions of sewer flooding. The InfoWorks model used is a verified, existing model of a UK sewer catchment.

The experiment aims to highlight the impact on engineering design of differences between synthetic and actual rainfall time-series in a catchment. Such differences are examined in section 2.3 above.

Simulations were carried out with both Deluge and synthetic data from each location to estimate the CSO spills occurring at a single overflow with a range of offline storage volumes in place. The overflow selected for this analysis is typical in that it currently allows approximately 5 times the dry weather flow to pass forward before spill occurs. The analysis allows the determination of the engineering implications of using actual rainfall over synthetic rainfall (at these locations only) if the design standard is for either annual spill volume or spill frequency. These crude measures are used as surrogates for more sophisticated receiving water quality standards.

The volume and frequency of sewer flooding by both rainfall methods is also reported and discussed.

3.1 CSO Spills

Table 2 details the outcome of simulations with the hydraulic model. The results are discussed further in Sections 3.2 and 3.3.

	Storage required to achieve spill frequency standard (m^3)			
	Church Fenton		Heathrow	
	10 spills per year	3 spills per bathing season	10 spills per year	3 spills per bathing season
Synthetic rainfall	300	500	950	1400
Deluge rainfall	600	800	650	800

Table 2 - Storage required to achieve spill frequency standard (m^3)

3.2 Church Fenton

Figure 10 shows the annual average spill volume at the CSO for a range of storage volumes using the two Church Fenton rainfall time-series. Figure 11 is similar but reports average spill frequency.

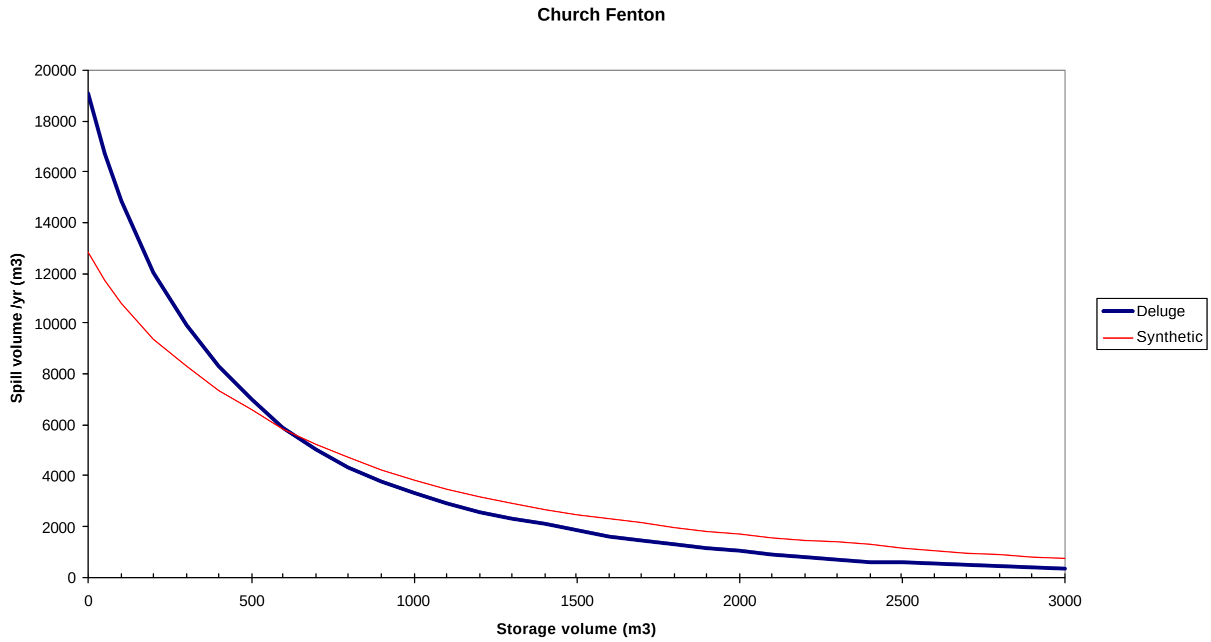

Figure 10 - Average annual spill volume with different CSO storage volumes – Church Fenton

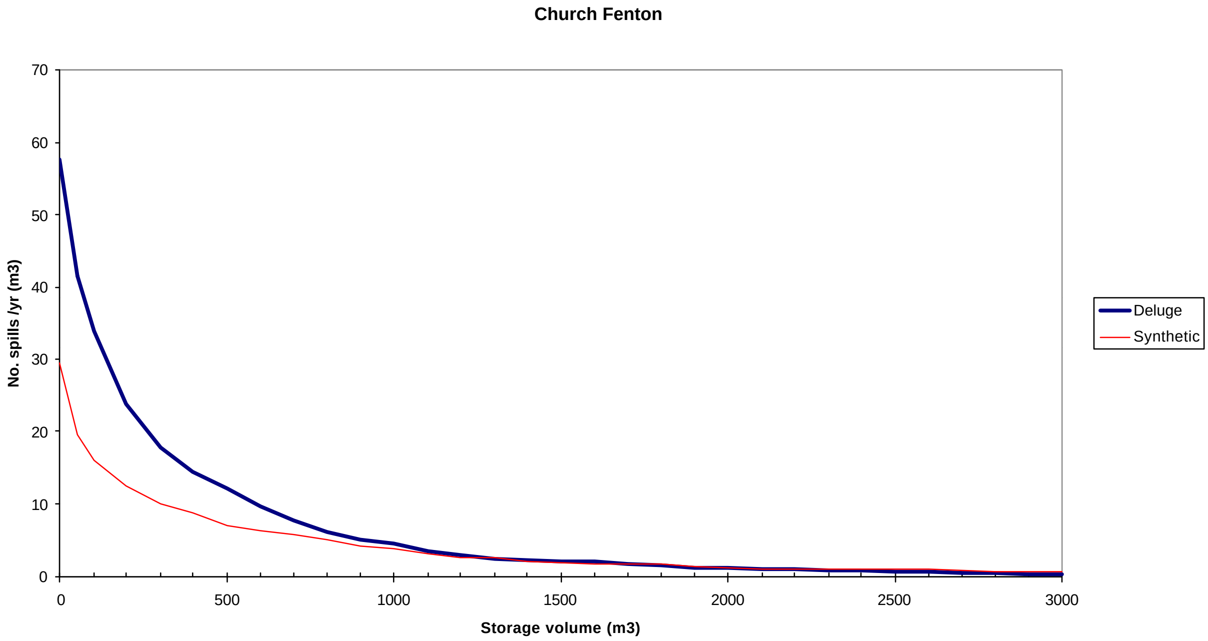

Figure 11 - Average annual spill frequencies with different CSO storage volumes – Church Fenton

There are a number of ways of looking at these data :

If the CSO was being designed to limit spills to 10 per year on average, simulations with the synthetic series indicate that a storage volume of 300m^3 would suffice. The expected annual spill volume would be approximately 8000m^3.

However, simulations with the gauged rainfall at this location (Deluge data) indicate that if this solution were constructed the average annual spill frequency would be 17 and the annual spill volume would be approximately 10,000m^3. To provide the desired level of protection (10 spills per year) the actual storage requirement would have to be doubled to 600m^3.

The higher the design spill frequency standard, the larger the difference between the two series. At lower spill frequency standards, the differences are negligible. However, analysis of bathing season only data suggests a more complex pattern.

If the CSO were being designed to limit spills to 3 per bathing season, simulations with the synthetic series would indicate a storage volume of 500m^3 would suffice. But the actual bathing season spill frequency with this level of protection is likely to be 6. To provide the desired level of protection (3 spills per bathing season) the actual storage requirement would be 800m^3.

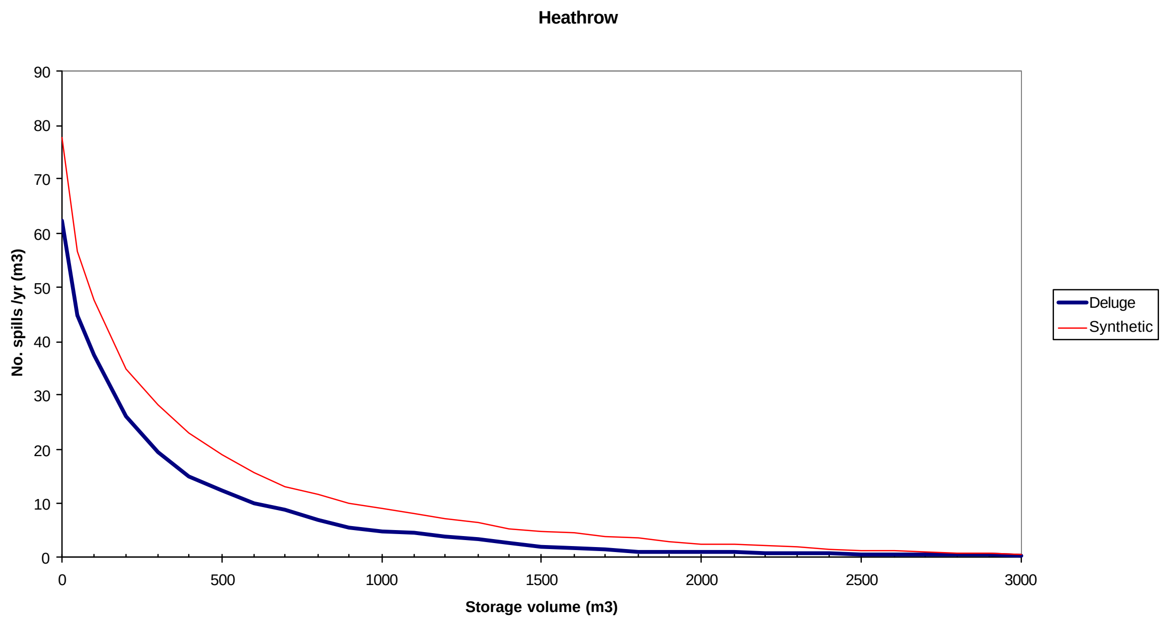

Figure 12 - Average annual spill volume with different CSO storage volumes – Heathrow

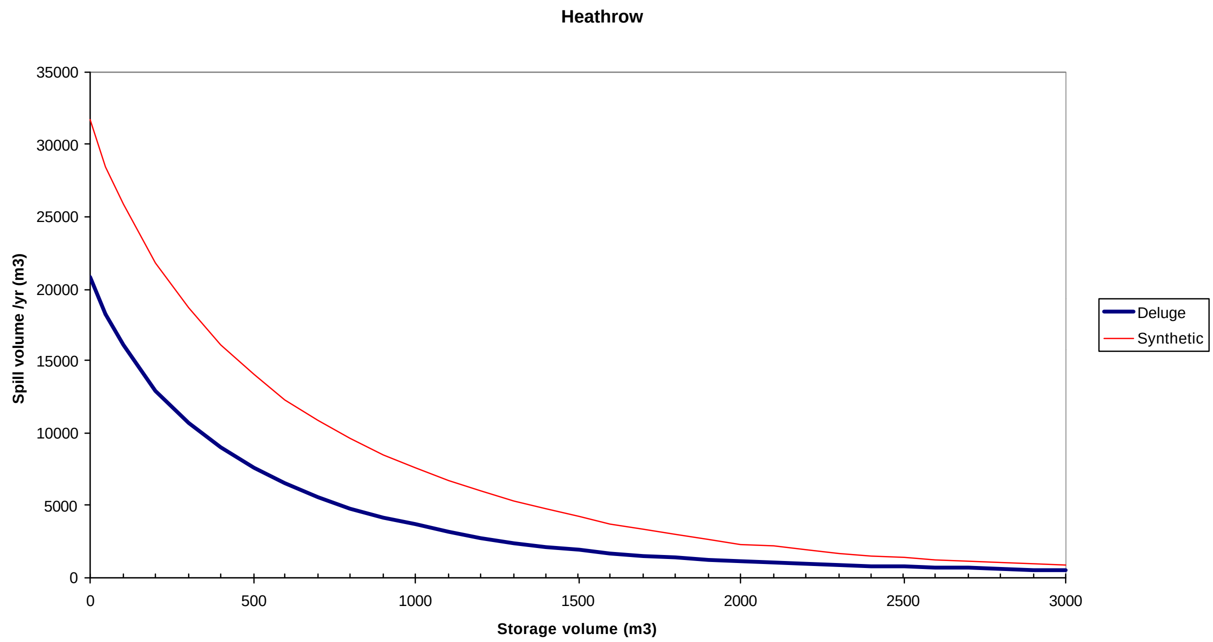

Figure 12 - Average annual spill frequencies with different CSO storage volumes – Heathrow

3.3 Heathrow

Figure 12 shows the annual average spill volume at the CSO for a range of storage volumes using the two Heathrow rainfall time-series. Figure 13 is similar but reports average spill frequency.

In this case the Church Fenton situation is reversed – for Heathrow, the synthetic rainfall data leads to over-designed engineering solutions. Using the same example as for Church Fenton:

If the CSO were being designed to limit spills to 10 per year on average, simulations with the synthetic series indicate that a storage volume of $950m^3$ would be required. The expected annual spill volume would be c. $7500m^3$.

However, simulations with the gauged rainfall at this location (Deluge data), indicate that if this solution were constructed the average spill frequency would be only 5 and the annual spill volume would be approximately $4000m^3$. To provide the desired level of protection (10 spills per year) the actual storage requirement would only have to be $650m^3$.

Difference between the time-series and resulting design are maintained across a range of spill frequencies and hence storage volumes.

If the CSO were being designed to limit spills to 3 per bathing season, simulations with the synthetic series would indicate a storage volume of $1400m^3$ would be required. But the actual bathing season spill frequency with this level of protection is about 1.5. To provide the desired level of protection (3 spills per bathing season) the actual storage requirement could be lowered to $800m^3$.

It is interesting to note that the actual storage required to limit spills to 3 times per bathing season is the same for Church Fenton and Heathrow ($800m^3$). However, the synthetic rainfall series at these locations suggest that either $500m^3$ (too little) or $1400m^3$ (too much) would be needed.

3.4 Links to Rainfall Characteristics

To some extent it is difficult to link these results directly to the comparison of rainfall statistics given in section 2. Church Fenton synthetic data quite clearly under-represents rainfall depth and intensity when compared to Deluge data and this explains the storages needed to prevent spills when using synthetic data.

The Heathrow picture is more complex, however. Similarities in the synthetic and Deluge data sets are reflected in the similarities in spill frequencies (Figure 12). But the reason why spill volumes are greater using synthetic data is not very evident from examining the differences in rainfall. It may be due to the higher frequency of low intensity events. Further analysis would be needed to verify this.

3.5 Flooding

The catchment experiences sewer flooding at a limited number of manholes. This is predicted well by the sewer model.

The analysis in Table 3 gives the annual volume and return period of flooding (assessed through frequency over 13 years) at each node for both rainfall time-series at each location.

	Church Fenton				**Heathrow**			
	Deluge		**Synthetic**		**Deluge**		**Synthetic**	
	Total Vol (m^3)	Flood RP (yrs)	Total Vol (m^3)	Flood RP (yrs)	Total Vol (m^3)	Flood RP (yrs)	Total Vol (m^3)	Flood RP (yrs)
Node 1	210	1.00	0	0	661	0.52	tbc	tbc
Node 2	292	4.33	0	0	1665	1.63		
Node 3	1306	0.23	16.7	6.50	2928	0.20		
Node 4	3223	0.08	432	0.72	4976	0.07		
Node 5	4308	0.07	718	0.60	5983	0.05		
Node 6	114	3.25	0	0	515	1.44		
Node 7	176	0.65	0	0	555	0.38		

Table 3 – Flooding Analysis

These results show that synthetic data consistently underestimate the volumes and frequency of sewer flooding in Church Fenton's case, as would be expected from the rainfall statistics.

3.6 Climate change implications

Most of the analysis described here assumes that engineering design is based on the simulation of long records of either recently observed or synthetic rainfall. In both cases the assumption is that rainfall patterns in the future will be the same as those in the recent past.

Work undertaken by the Met Office for Severn Trent Water (2000) and, more recently, for UKWIR (20002) has examined climate change effects on short-period rainfall (15-minute to 12-hour durations) that are predicted by Met Office climate models run at the Hadley Centre.

Improved rainfall data for engineering design and urban pollution monitoring is likely to need climate change effects to be taken into account.

4 Conclusions

Comparisons of Deluge and synthetic rainfall data for two sites in the UK have highlighted differences in the two data sets. At one site (Church Fenton) the synthesised data set does not include as many events as the Deluge (gauged) data set and fails to produce long duration rainfall events (greater than 20 hours). At both sites, peak and mean rainfall intensity is significantly less in the synthesised data sets than the Deluge data sets.

A cursory analysis of a much ‘wetter’ location, Princetown, Dartmoor, shows that the variations in peak and mean intensity of events shown by Church Fenton and Heathrow are also borne out where annual rainfall is much greater. Like Church Fenton, some 50% fewer events are produced in the simulated data set for this site.

As a result, synthetic data can result in either under or over designed solutions to sewer network problems. There has been insufficient work carried out in this analysis to establish any real geographical patterns for this.

Simulations carried out indicate that using the most recent 5 years of rainfall data gives designs that are either the same as or slightly ‘larger’ than if longer records (of 10 years or more) are used. For this reason it might be recommend that sites with at least 5 years of Deluge data are used for design of sewer storage and that 5 years of real data might be better than 10 years synthetic data for this purpose.

It is considered that this paper can serve as a health warning for schemes designed with synthetic rainfall – particularly if consent conditions stipulate spill volume or frequency. It also reinforces previous comments at WaPUG (Morrow, 2001; Kellagher, 2001) which highlight inabilities of synthetic data to replicate high intensity rainfall. In line with EA guidelines (2002), real rainfall data should be used wherever possible and for the previous 10 – 15 years ideally.

Deluge does not yet have complete UK coverage, unlike the synthetic alternative, and care is needed in selecting which rain gauge’s data can be used for catchments being studied. It is anticipated that data from more gauges will be included in the software at a later date. There is no space in this paper to cover this aspect but information on gauge selection is included within the Deluge software and described in the supporting documentation.

5 Further Work

Further analysis to improve our knowledge of the differences in the two forms of data could be made by

i) examining seasonal differences in rainfall, or by comparing events only from the bathing season for example

ii) examining other sites around the UK with different rainfall characteristics

References

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Morrow, B. (2001) AMP3 UIDs – So you think you know what you have to do and how to do it? – Paper presented at WaPUG Autumn Meeting, November 2001

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