Using TSRSim in Flooding Solution Development

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1. Summary

Historically, sewerage designers have been required to develop flooding solutions against discrete FSR or FEH design rainfall events. Whilst both are useful tools in the right circumstances, they have their limitations.

TSRSim arises from the UKWIR Project CL10, Climate Change and the Hydraulic Design of Sewerage Systems (2004) undertaken by HR Wallingford, the Met Office, MWH and Imperial College. The software generates long time series stochastic rainfall, calibrated for a specific rain gauge location using observed data and therefore addresses some of the limitations of other rainfall software.

This paper discusses the merits and shortcomings of using stochastic rainfall as an alternative to design storms, sets out the steps necessary to validate the rainfall series, and describes the differences in model results that can arise between the two approaches. It also details the methodology MWH has applied on the 4Delivery programme for Southern Water using TSRSim rainfall to assess sewer flooding solutions.

2. History

In the past, designers have been required to develop solutions to sewer flooding based on flows predicted by hydraulic models using a single event design storm. The industry norm was previously to use the Flood Studies Report (FSR) approach or more recently since 1999 Flood Estimation Handbook (FEH) approach for design rainfall.

Design storms are a very useful tool, simplifying the characteristics of the rainfall for a single location into a small number of events. This in turn allows a rapid assessment of a sewerage system and its response to this rainfall. They are used to provide efficiencies in model simulation time and are a simplification of reality.

However, using a single design rainfall event for developing flood alleviation schemes assumes that the return period of flow and hence the resulting scheme performance is the same as the return period of that single rain event. Such events and system performance lie well beyond the range of the data used in the original calibration of modelling software. The validity of this assumption has therefore never really been tested.

In addition, with their simplicity and convenience design storms have inherent limitations, as with other rainfall tools.

- Data processing to produce synthetic design storms results in inaccuracies

- Uniform profile, critical duration storms are never seen in reality and are therefore conservative.
- They are one-off events that do not address the issue of multiple follow-on storms and impact on e.g. storm tank drain down.

The use of conventional design storms does not give a complete picture of the level of protection afforded by solutions. Running all design events assuming a fully wet catchment could be overly conservative, for example.

Time series rainfall tools, such as Stormpac, can be used to generate continuous periods of rainfall that contain a range of common and extreme events. They can be used to test sewerage networks against a variety of storms and against the impact of multiple follow-on storms. However, as documented in previous papers (Kellagher, 2005), Stormpac has limitations representing less frequent, extreme events above 1 in 10 years. In this way, its use for developing flooding solutions is limited where target flooding protection levels are often 1 in 10 year frequency or greater.

TSRSim addresses some of the limitations of both design storms and short duration stochastic rainfall series. It generates non-uniform, long-term rainfall series representative at long return periods.

3. What is TSRSim

TSRSim is a software tool developed by HR Wallingford in 2005 with permission from UKWIR. It is based on work carried out by HR Wallingford, the Met Office, MWH and Imperial College for the UKWIR Project CL10, Climate Change and the Hydraulic Design of Sewerage Systems.

The purpose of the software is to generate long stochastic rainfall series based on local observed rainfall records. Each series is calibrated for the specific location of the input rainfall. It can therefore be used both in the UK and abroad. The series generated can be used in hydraulic modelling activities to determine the response of drainage networks to extreme rainfall events and to more normal conditions.

The software also includes climate change information taken from UKWIR Project CL10.

Data Requirements

The input data required by TSRSim are as follows:

- Observed rainfall data
- Minimum of 3 years hourly data
- Single continuous file in .RED, .SCF or .CSV format

Whilst the software requires a minimum of three years input data, the recommendation is to use at least ten years, up to maximum of 40 years. TSRSim therefore requires more input data than other currently used rainfall software, such as FEH and Stormpac.

Analysis Modules

TSRSim consists of four modules that carry out analysis of the input rainfall to develop rainfall parameters specific to the input data. Seven calibration parameters and three disaggregation parameters are created characterising the input rainfall. These are subsequently used to generate an output series of a user-specified length, up to 200 years.

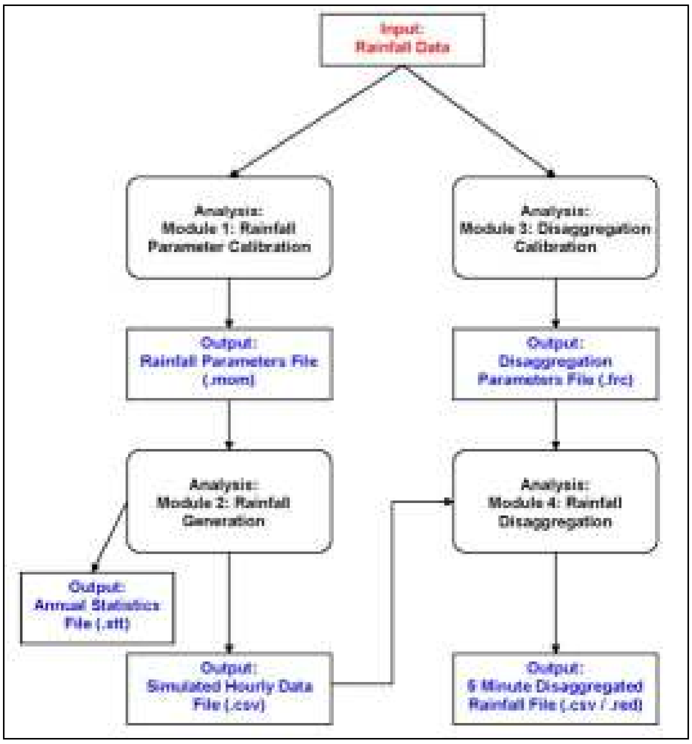


Figure 1: TSRSim Program Flow Chart (extract from TSRSim User Guide)

TSRSim is reliant on the quality of the data fed into it. Erroneous data can adversely impact and skew the calibration of the monthly parameters the software generates. This in turn can affect the pattern of rainfall in the output rainfall series.

Checks on the quality of the input data are therefore necessary to ensure errors are not carried through and extrapolated into the output series. These can include checks on:

- Event rain gauge daily totals compared to adjacent daily rain gauge totals
- Blank or missing periods in input rainfall
- Data flags identifying missing, suspect or unchecked rainfall

Output files

The main outputs from TSRSim are:

- Stochastically generated 60-minute timestep .CSV file
- Disaggregated .CSV or. RED file of user defined length.
- Summary files of calibrated parameters and generated rainfall

The user must then process the output files into a workable format for hydraulic modelling.

TSRSim and Historical Verification of Models

TSRSim requires a significant amount of rainfall data as an input compared with other rainfall software, which can be difficult or expensive to source. This data can be valuable tool for historical verification and has the potential to 'repay' its worth in improving the verification of a hydraulic model.

The importance of historical verification of models has been documented in previous papers (Osborne, 2005). It gives an improved understanding of the real performance of a sewerage system, especially with respect to individual flood events. It also gives an understanding of the frequency of surcharge under real conditions.

Models are generally verified against recorded flow survey data, including data from flow monitors, rain gauges, pumping station monitors and client telemetry data. Whilst this is generally considered a robust approach for model verification, flow survey data also has its limitations, especially when verifying models for sewer flooding. These include:

- Verification events rarely approach the intensities and durations experienced in extreme events
- Short time period to collect data
- Poor data from small diameter pipes, ragging on monitor, monitor failure etc
- Unable to install flow monitor at every flooding location

The WaPUG Code of Practice recommends the use of long term rainfall data to aid historical verification. This is probably most important when models are to be used to develop solutions to sewer flooding.

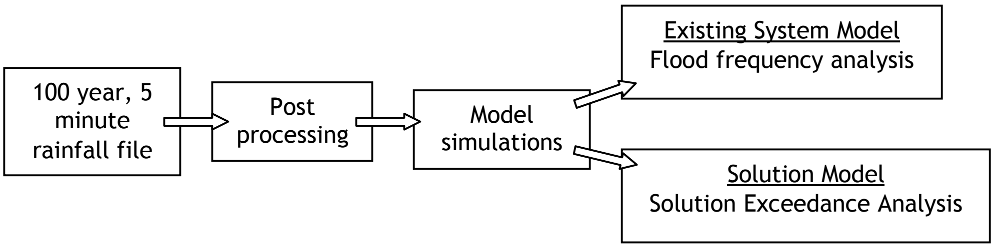
The accuracy of the model predictions of flooding can be tested using real rainfall events and documentary evidence of flooding, such as customer complaints databases detailing flooding incidents or overflow operation from telemetry data. More often, data is available from rain gauge stations for periods longer than the minimum three years required for TSRSim, adding to the ability to historically verify against known response in the sewerage network.

Whilst this additional step in the verification process can prove useful, it can be limited if the historical data set is short or contains few high return period events large enough to cause flooding.

This problem can be addressed by using long-term TSRSim-generated series of, for example, 100 years and testing the predicted flood frequency over a long period. This in turn can increase confidence in the model predictions of flooding.

4. TSRSim Approach on Flood Alleviation Schemes

The flow chart below outlines how TSRSim can be used on flood alleviation schemes:



Post processing

A 100 year, 5minute rainfall file generated by TSRSim is approximately 80MB in size and requires post-processing for use in hydraulic modelling. Before the rainfall can be used for modelling, the following post-processing needs to be carried out:

- Extraction of events using thresholds for intensity, depth and inter-event period to define an event
- Application of UCWI/API_{30}
- Application of evaporation rates

MWH has developed a software tool to carry out all of the above post-processing. The thresholds used to define an event can be varied. For example, the inter-event period can be extended to account for significant slow response in the model and to ensure the emptying of storage tanks can be fully assessed.

Further checks comparing the input data to the output data are recommended to validate the TSRSim series including checks on:

- Average annual rainfall depth
- Monthly rainfall depth
- Summer/winter rainfall depths

Due to the size of the rainfall series from TSRSim, significant data processing is required to carry out these checks.

5. Use of TSRSim on 4D Programme

MWH has trialled the use of TSRSim on the 4D programme for Southern Water. 4D is a joint venture company comprising United Utilities, Costain and MWH who are contracted to implement a major part of Southern Water's AMP4 Capital Works Programme. This programme of work is valued at £655m, with flooding projects making up £80m of this total.

4D are contracted to deliver flood alleviation to 178 DG5 properties and 119 linked external properties, 151 other properties suffering external flooding and 25 properties with restricted toilet use.

Southern Water, as with most other water companies, require solutions to sewer flooding to be developed against FEH design rainfall of a specific return period depending on the nature of flooding. Alongside this approach, MWH have used TSRSim to test the historical verification of existing models and the potential of proposed solutions to meet performance criteria.

Southern Water has access to data from 136 tipping bucket rain gauges across their region covering a period from as early as 1985 to present day. Tip time data from these gauges has been used to develop TSRSim series for a number of locations.

Analysis of Existing Network Flooding

Where available historical rainfall does not extend far enough into the past to cover known flooding occurrences, a TSRSim series can be used to gauge the performance of the existing network and to determine the predicted flood and surcharge frequency over a 100 year period. Predicted flood frequency can then be compared to the frequency of known flooding events based on:

- Client customer complaints databases
- Client asset telemetry data
- Operations incident reports
- Customer questionnaires or interviews
- Press reports

The predicted flood frequency for the existing systems also provides a baseline to compare potential solutions against.

Assessment of Proposed Flood Alleviation Schemes

Proposed solutions are optioneered in the normal way against critical duration FEH rainfall events for the required return period, as specified by the client.

The proposed solution model can then be tested against a 100 year rainfall series generated by TSRSim. The frequency of exceedance, or failure of the solution to prevent sewer flooding, over the 100 year series is then determined.

The flood frequency can then be compared to the target return period of the flooding solution. For example, a solution to garden flooding may be designed to a 1 in 20 year return period event. It would therefore not be expected to fail to prevent flooding more than 5 times over the 100 year TSRSim series. Any more than 5 failures indicates a shortfall in the solution and the need to revise the proposed solution.

InfoWorks Statistical Templates and Grid Reports can be used to determine the number and date of events exceeding the threshold and a breakdown of the flood volumes by event. The threshold can be defined as cover level for surface flooding or the level of the lowest property connections, depending on the specific problem being addressed.

The response of the system to the extreme events from the TSRSim series can also be assessed to check the performance of solutions outside the scheme envelope.

6. Examples from 4D Schemes

Offline Storage - South Street, Portslade

High Street, Portslade

This scheme addresses both combined and surface water sewer flooding of 13 properties and highway flooding in High St and South Street, Portslade.

The hydraulic model of the existing system predicted significant combined and surface water sewer flooding of High Street and South Street. Solutions to flooding were developed using 1 in 30 year critical duration FEH rainfall.

Due to site constraints, options were limited to flow transfer and storage tanks within a nearby car park for both combined and surface water systems.

Storage tank location in car park, off High Street

Using the FEH design rainfall and the critical duration event for each system, the tank sizes were assessed as 809 m^3 for the combined sewer tank and 308 m^3 for the surface water tank.

Predicted spill flows into each tank were assessed for the 100 year series. Figures 2 and 3 below show the spills into the tanks using TSRSim events plotted with the tank volume indicated by 1 in 30 year FEH rainfall.

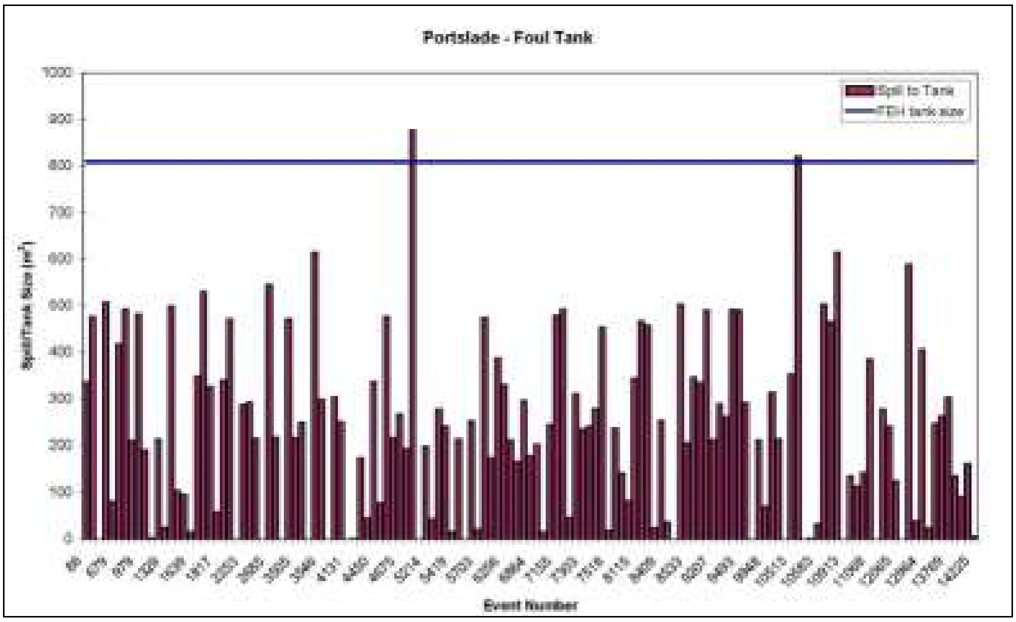


Figure 2 – Predicted spills to Combined tank using TSRSim Rainfall

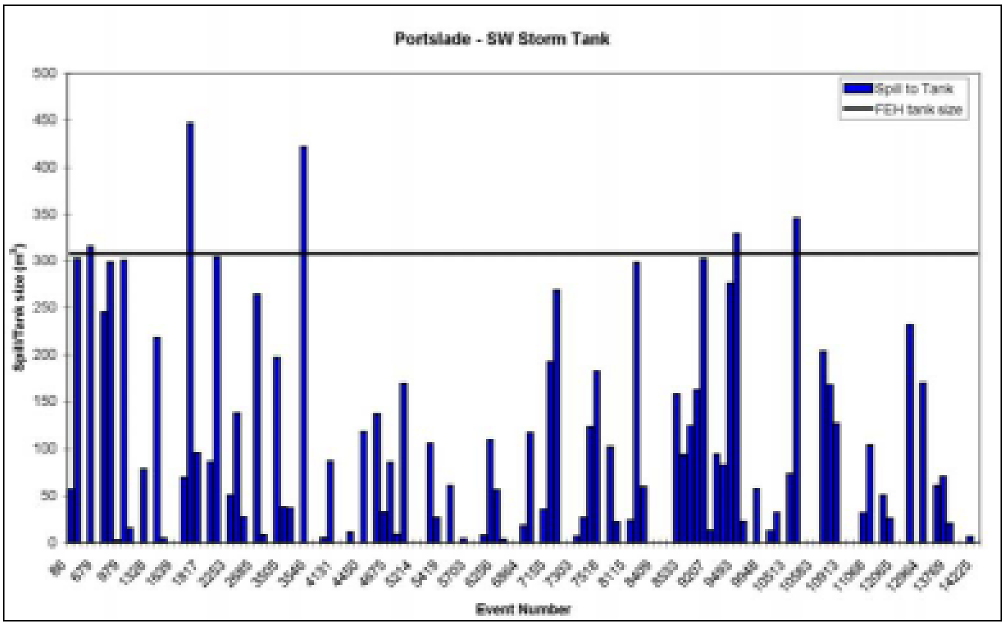


Figure 3 – Predicted spills to Surface Water tank using TSRSim rainfall

Surface Water Tank			Combined Tank		
Rank	Event Number	Spill to tank (m^3)	Rank	Event Number	Spill to tank (m^3)
1	1677	447	1	5080	877
2	3545	423	2	10515	821
3	10515	346	3	3545	615
4	**9493**	**330**	**4**	**10845**	**615**
5	566	315	5	12227	589
6	1942	304	6	2685	545
7	8766	303	7	1677	530
8	430	303	8	566	507

Table 1 – Ranked Spills to Surface Water and Combined tanks using TSRSim Rainfall

Allowing for 3 failures over the 100 year series (i.e. 1 in 30 year protection), the model results indicate a slightly increased storage tank requirement for the surface water system using TSRSim (330 m^3) compared to the FEH design storm requirement (308 m^3). However, for the combined sewer tank, the TSRSim results show a significantly lower tank requirement (615 m^3) compared to the FEH 30 year event (809 m^3).

The results presented above represent only spills into the tanks and no emptying regime has been included in this analysis. The required tank size using TSRSim could be reduced further by modelling a tank-emptying regime between sub-events, maximising the available storage. Using FEH design rainfall alone does not allow the impact of the tank-emptying regime to be assessed and therefore, can lead to overly conservative solutions.

Offline Storage - Green Close, Ringmer

This scheme addresses 4 properties suffering garden flooding from the foul system. Solutions were developed to 1 in 20 year return period FEH rainfall with peak intensity of 173 mm/hr (30 minute critical duration summer event). The proposed scheme based on FEH rainfall involves flow transfer and offline shaft storage of 250 m^3.

Green Close, Ringmer

The results indicate that using TSRSim rainfall and allowing for 5 failures of the solution over a 100 year series (1 in 20 year protection), the predicted tank volume could be as low as 172 m^3. Similarly, the TSRSim results indicate that providing 223m^3 of storage would result in 3 failures over 100 years (1 in 33 year protection) and 253m^3 would result in 2 failures (1in 50 year protection).

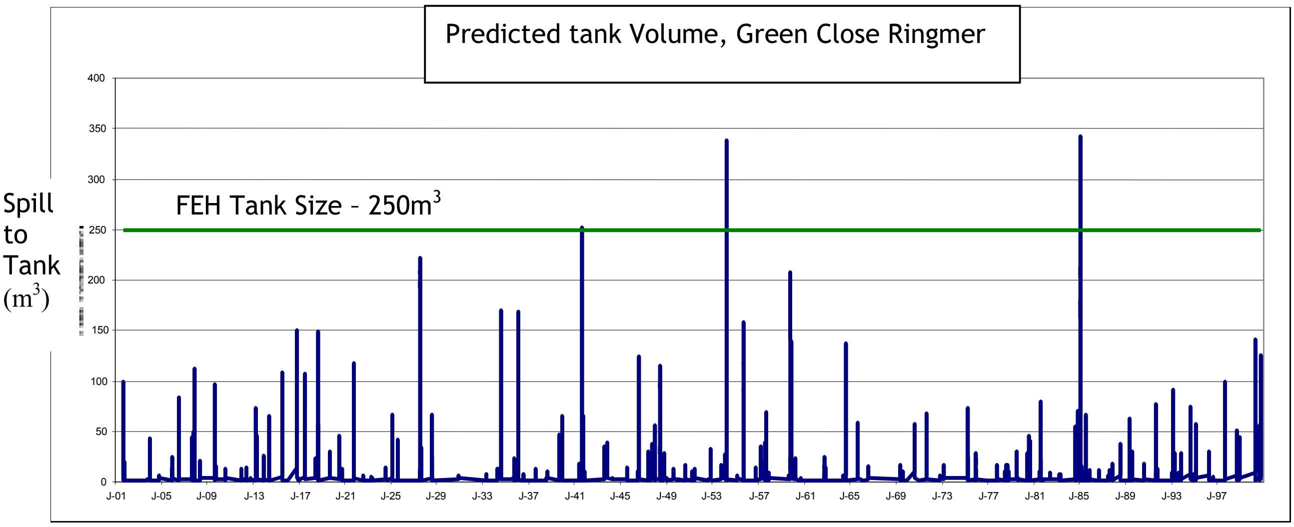


Figure 3 – Ranked spills to storage tank and FEH storm tank size, Green Close Ringmer

Rank	Event Number	Spill Volume to Tank (m^3)	Max Intensity (mm/hr)
1	12099	343	177.6
2	7706	338	98.4
3	5814	252	144
4	3813	222	67.2
5	8431	208	88.8
6	4817	171	134.4
7	5101	168	105.6

Table 2 – Spill to Storage Tank using TSRSim Rainfall, Green Close Ringmer

Depending on the rainfall storms used, a storage volume of 250m^3 would provide 1 in 20 year protection using FEH rainfall or nearly 1 in 50 year protection using TSRSim rainfall.

The use of TSRSim rainfall in this case has the potential to reduce the requirement for storage at this location and in turn reduce cost of construction. Alternatively, using the storage volume indicated by the traditional FEH design rainfall (250m^3), the TSRSim results indicate a higher level of protection is achieved than suggested by FEH.

Pipe upsizing - Western Road, Brighton

There are 65 properties on the DG5 flooding register in Western Road, Brighton. All properties suffer from basement flooding. Flooding also occurs on two adjacent streets. There are over 120 records of flooding in this area over a 23 year period.

Western Road, Brighton

Initial solution development used a 1 in 30 year FEH 30 minute rainfall event with a peak intensity of 194 mm/hr. The only viable option to prevent basement flooding and to cope with the flows generated from this event was around 400 m of upsizing to an existing sewer and a new connection into the main storage tunnel sewer at great depth and significant cost.

Further investigation revealed that the high instantaneous flow peak caused by the 30 minute duration FEH rainfall was driving the need for this extensive upsizing. The proposed system coped easily with the flows generated from 1 in 30 year FEH storms with durations above 60 minutes.

A 100 year TSRSim series was generated using nearby rain gauge information and run through the model. Following assessment of the results, it was found that using TSRSim rainfall achieved two main benefits against using FEH design rainfall:

- The proposed sewer diameters could be reduced based on the maximum surcharge levels observed during the TSRSim rainfall events, resulting in reduced costs.

Length of Pipe Upsizing (m)	TSRSim diam. (mm)	FEH diam. (mm)
9	1050	1200
205	700	825
55	825	975
21	1050	1350
117	1350	1650

Table 3 – Pipe upsizing required based on TSRSim and FEH rainfall events

- The main benefit of using TSRSim on this scheme is the availability of a second viable option to solve flooding. In this case, a smaller diameter and shorter sewer upsize (280m of 900mm diameter sewer) combined with a cut-and-pump solution could also be considered. This option avoids the need to connect into the deep tunnel sewer and the significant disruption to the public and associated project costs involved.

7. Conclusions

- TSRSim provides a means of generating long-term rainfall series up to 200 years in length, calibrated to a specific location.
- It provides an alternative approach to traditional design rainfall.
- Historical rainfall data used as an input to TSRSim can be a very useful tool in the historical verification of models.
- TSRSim output rainfall requires significant post-processing and a means of extracting events needs to be adopted before use in hydraulic model.
- Rainfall series produced by TSRSim are a very useful tool for checking the historical verification of the model and the levels of service provided by sewer flooding solutions.
- Examples reported in this paper demonstrate how using TSRSim rainfall series can show significantly different requirements to resolve sewer flooding than using FEH rainfall alone, with potential for associated project cost savings.

References

HR Wallingford (2005) TSRSim Statistical Time Series Rainfall Data Software User Guide.

Kellagher, R. (2005), Comparison and assessment of 2 stochastic extreme time series rainfall generators.

Onof,C (2006), Note on extremes from TSR hourly simulator

Osborne, M (2005), The Importance of Historical Verification

UKWIR (2004) Climate Change and the Hydraulic Design of Sewerage Systems.UKWIR Project CL10.

WaPUG (2002), Code of Practice for the Hydraulic Modelling of Sewer Systems, Version 3.