Probabilistic detention performance standards for SuDS

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Introduction

Many researchers have analysed monitored green roof rainfall and runoff data to derive quantitative descriptions of the systems' hydrological performance. The derived measures typically include retention parameters (cumulative volumetric retention or mean/median/minimum/maximum per-event retention) and detention parameters (percentage *Peak Attenuation* and indicators of lag time such as *Time to Start of Runoff*, *Peak Delay, Centroid Delay* and t_{50} *Delay*). Indicators of average performance (such as cumulative volumetric retention, mean per-event retention, mean t_{50} *Delay*) facilitate comparisons between different systems and/or the same system exposed to different climatic inputs. However, these indicators have limited value for stormwater management purposes, where system design requires a more direct understanding of what performance may be expected in response to specific rainfall inputs, e.g. 1 in 10, 1 in 30 or 1 in 100 year return period events.

Design storms are appropriate to ensure that drainage systems meet minimum performance thresholds in extreme conditions, particularly concerning flood protection. However, they provide no insight into the contribution that alternative drainage options may make to day-to-day stormwater management within a catchment; this is particularly pertinent when assessing water quality impacts. Continuous simulation methods are therefore increasingly utilised within urban stormwater management planning.

Observed detention performance is strongly influenced by both the rainfall event characteristics and antecedent conditions (retention processes). However, the fundamental hydrological detention processes occurring within the green roof are essentially independent of these factors and dependent only on the roof's physical configuration (its slope, substrate type and depth, drainage layer composition etc.). If the underlying detention processes can be described by an hydrological model, then the model may be employed to objectively predict the detention effects associated with a specific design storm or rainfall time series. Continuous simulation modelling tools can provide the same range of retention and detention performance metrics as monitored data, including cumulative retention, median *Peak Attenuation*, etc. The question is, which of these performance metrics is the most relevant and useful for stormwater management purposes?

In many environmental contexts, where complex and interacting factors lead to high degrees of variability in performance, it is common to express performance in terms of acceptable probabilities of failure. For example, the UK's UPM (Urban Pollution Management) Manual describes how percentile-based river quality standards for BOD, dissolved oxygen, total ammonia and un-ionised ammonia may be utilised to regulate impacts associated with intermittent discharges from combined sewer overflows. The objective of this paper is to demonstrate the value of probabilistic performance metrics derived from a validated hydrological model in providing a complete description of the hydrological performance of SuDS.

Methodology

Stovin *et al.* (2013) presented a detailed comparison of long-term green roof retention performance, using four contrasting UK climatic regimes. Climatic inputs for the model were taken from the UK Climate Projections (UKCP09, http://ukclimateprojections.defra.gov.uk/).

The retention model estimates the soil moisture content based on a balance between the moisture gains due to rainfall and losses due to evapotranspiration (ET). ET is modelled using the Thornthwaite formula to estimate Potential ET and a linear SMEF (Soil Moisture Extraction Function) is applied to account for the influence of soil moisture content on actual ET rates. The roof has 80 mm substrate with an assumed maximum retention capacity of 20 mm. The model is fully explained and validated in Stovin *et al.* (2013).

Based on Stovin *et al.* (2015), detention of any net rainfall is modelled using reservoir routing concepts:

$$h_t = h_{t-1} + Qin_t \Delta t - Qout_t \Delta t \qquad (1)$$

in which *Qin* and *Qout* represent the flow rates into and out of the substrate layer respectively, in mm/min. *h* represents the depth of water temporarily stored within the substrate, in mm. *Δt* represents the discretisation time step. *Qout* is given by:

$$Qout_t = kh_{t-1}^n \qquad (2)$$

in which *k* and *n* are the reservoir routing parameters (scale and exponent respectively). For *h* in mm and *Q* in mm/min, *k* has the units $mm^{(1-n)}$/min, whilst *n* is dimensionless. Based on a typical extensive green roof test bed, values of 0.03 and 2.0 for *k* and *n* respectively are used.

The UKCP09 30-year time-series climatic inputs are provided at a one-hour time-step. Although an hourly time-step is appropriate for retention studies, it does not permit the (meaningful) modelling and interpretation of the roof's detention (i.e. lag and attenuation) performance. The present study utilises the same rainfall input data, temporally disaggregated to 5-minute time-steps, to comment on the influence of local climatic controls on green roof runoff detention performance. The rainfall was disaggregated from hourly to 5-minute time-steps using STORMPAC (WRc, 2009). In addition to the influence of climate, we also compare the performance of a typical extensive green roof system (k = 0.03, n = 2.0) with the performance of a system with increased levels of detention (assumed k = 0.003, n = 2.0). This configuration was only assessed for Sheffield rainfall data, and is referred to as 'Shef-HighDet'.

Individual storm events were isolated from the continuous simulation record based on an assumed six-hour inter-event period. Retention was determined for each event, as well as overall volumetric retention. Given that per event retention may vary from 0 to 100%, it may be argued that a mean value is of limited use. Therefore, Probability Density Functions (PDFs) of both absolute and proportional retention are presented.

The data was analysed to identify any significant trends in the detention parameters as a function of rainfall depth (not reported here), and then in terms of PDFs to assess the effects of location and of increased detention at the Sheffield location only. This analysis included a probabilistic evaluation of *Peak Runoff* compared with potential greenfield runoff rates.

Results

Figure 1 presents the PDFs for the retention performance metrics for each of the four locations. Note that the same retention data applies to both of the two alternative detention configurations for Sheffield. Across the four locations, the absolute retention depth distributions are similar, with the two drier, eastern, locations – Sheffield and East Midlands – experiencing marginally lower retention depths overall when compared with the two western locations. It is particularly interesting to note that, although the roof has an assumed maximum retention capacity of 20 mm, this depth is extremely rarely retained in practice. This is because, for the vast majority of rainfall events, the event depth is less than 20 mm or the available retention capacity prior to the onset of rainfall is less than 20 mm. Only 10% of events experience retention in excess of 5 mm. In terms of percentage retention, there are more obvious locational differences, with the drier East Midlands and the wetter NW Scotland locations experiencing respectively far greater and far lower per event retention compared with Cornwall and Sheffield. Only 20% of events in NW Scotland are fully retained, compared with 50% full retention in the East Midlands.

Figure 2 presents the PDFs for *Peak Runoff* for the four locations and also for the Shef-HighDet configuration. The PDFs permit a probabilistic approach to the assessment of performance against design standards. Figure 2 includes sample greenfield runoff rates of 5 and 2 l/s/ha, with 2 l/s/ha appearing in the UK SuDS Standards (DEFRA, 2011). It is evident that the highest *Peak Runoff* rates are associated with the locations that experience the greatest total rainfall (NW Scotland and Cornwall).

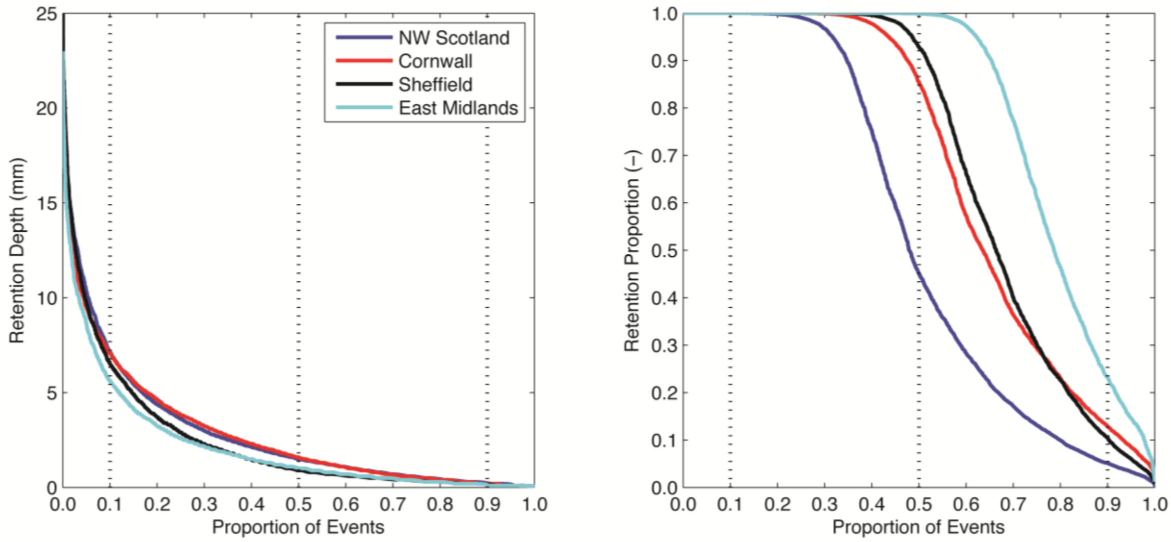

Figure 1 Retention performance PDFs for all events at all locations

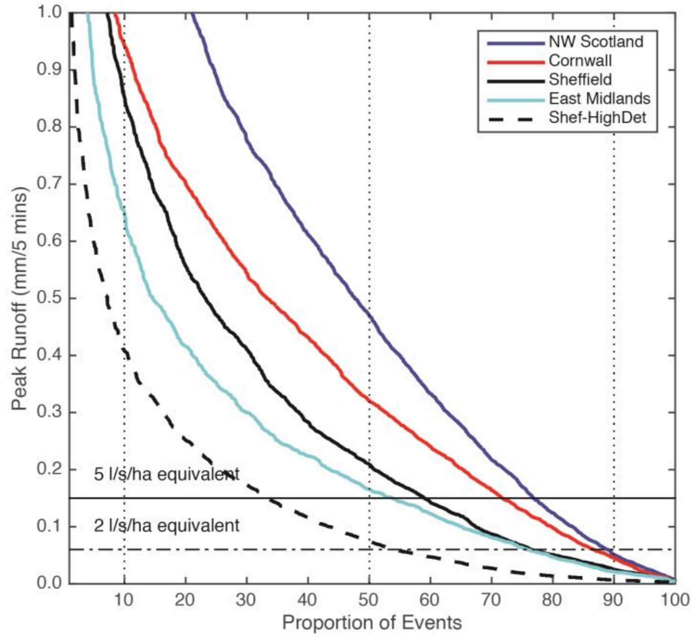

Figure 2 Peak Runoff PDFs

In NW Scotland more than 50% of runoff-generating events have a peak 5-minute runoff rate of nearly 0.5 mm per 5 minutes. This is equivalent to 16 l/s/ha (1 mm/5 mins = 33 l/s/ha). In contrast, the same roof located in the East Midlands would achieve the 5 l/s/ha target for almost 50% of events. In NW Scotland and Cornwall almost 90% of runoff-generating events would exceed the 2 l/s/ha threshold, whereas in Sheffield and the East Midlands this falls to less than 80%. An alternative view of the same data is that we can be 90% confident of achieving peak runoff rates of less than 20 l/s/ha for the East Midlands, but only less than 50 l/s/ha in NW Scotland.

The Shef-HighDet system demonstrates a very significant improvement in the *Peak Runoff* performance, with *Peak Runoff* rates generally being halved compared with the baseline extensive system's performance at the same location. The 90 percentile confidence limit would be improved from 30 l/s/ha down to 13 l/s/ha through the implementation of system that offered this level of increased detention.

The performance data in Figure 2 relates only to runoff-generating events. However, it should be appreciated that the events that do not generate runoff (i.e. are fully retained) also form part of the overall system performance characteristics. For example, whilst Figure 2 suggests that the East Midlands roof limits *Peak Runoff* to below 5 l/s/ha for approximately 50% of the runoff-generating events, this equates to 83% of the total number of rainfall events. It is difficult to definitively state which of these versions of the PDF data is likely to be most useful for stormwater management purposes.

The 30-year continuous simulations ensure a statistical validity that is often difficult to achieve with real field monitoring programmes. Probabilistic representations of the data have the advantage of clearly showing the range of performance that is to be expected; this can be missed when only global mean or median values are presented. It is suggested that the use of probabilistically-defined thresholds may provide a useful basis for setting performance targets. For example, it would be feasible to specify a maximum proportion (or a minimum return period) of events that may be allowed to exceed a threshold such as the greenfield runoff rate.

To overcome the bias introduced by large numbers of small events that may not be relevant for flow control planning purposes, the data may be classified in terms of rainfall event depth or based on return period thresholds. An extension of this idea is to consider a design storm. For a 30mm storm, with 10 mm available retention capacity, expected values for Peak Attenuation and Centroid Delay would be 0.34 and 16.95 mins respectively for the extensive system compared with 0.77 and 48.8 mins respectively for the high-detention system (Figure 3). This equates to enhancements of 125% to Peak Attenuation and 188% to the Centroid Delay.

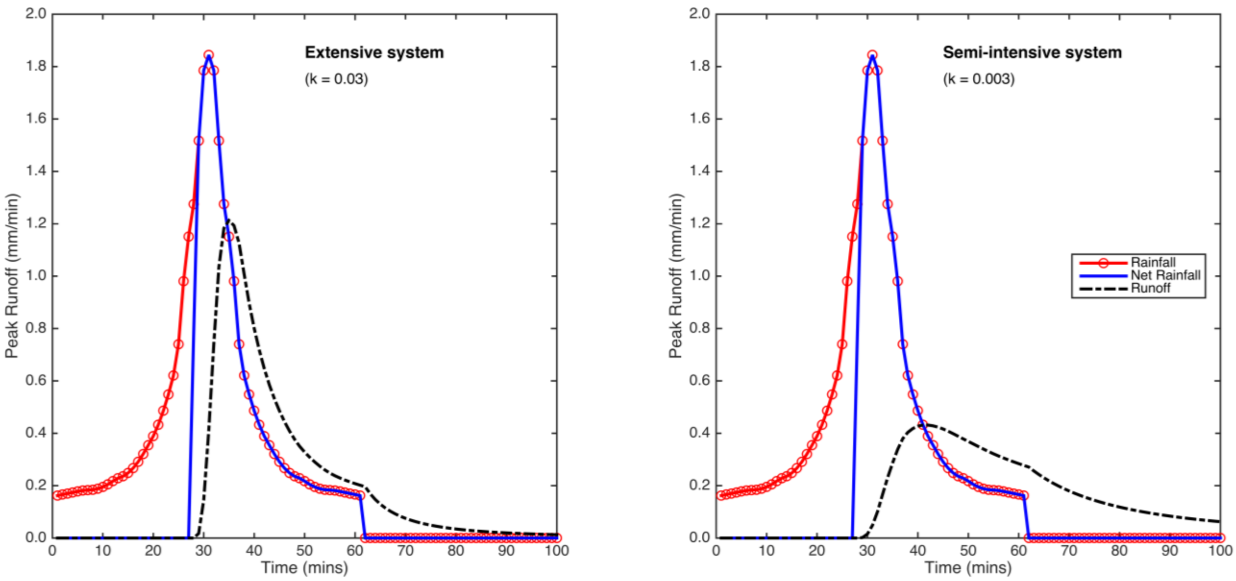

Figure 3 Detention for design storms with 30 mm rainfall and 10 mm retention capacity

Conclusions

The use of PDFs derived from long-term continuous simulation can facilitate the use of probabilistic performance metrics, such as an assessment of the 90 percentile *Peak Runoff* in comparison with a regulatory greenfield runoff rate.

References

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