https://doi.org/10.71573/2rdsg226

The effect of minimum inter-event dry period definition for storm event identification and SuDS hydrological performance evaluation

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Abstract

Urban drainage practitioners and academics increasingly recognise the value of using continuous rainfall/outflow data to derive a comprehensive understanding of how vegetated Sustainable Drainage Systems (SuDS) respond to long time-series rainfall inputs. For event-based analysis, an agreed definition of 'an event' is crucial. Typically events are defined based on a Minimum Inter-Event Time (MIT). The objective of this research was to understand how the specific MIT impacts upon event metrics and on the selection of suitable initial conditions for design storm simulations. This was achieved using modelled outflow from a representative green roof (GR) and bioretention cell (BIO) combined with MITs of 6, 12, 24 and 48 hours. The choice of MIT used to separate events in rainfall/outflow analysis has an impact on the derived performance metrics, particularly for devices offering significant detention. The analysis has also highlighted that – for SuDS that do not include infiltration – the most probable retention storage is small, around 5 mm for typical green roofs and 0 mm for bioretention cells in a temperate climate.

Highlights

- MIT used to identify events in rainfall/outflow analysis affects derived performance metrics.
- This is particularly important for devices offering significant detention.
- Without infiltration, available retention storage is typically negligible.

Introduction

Urban drainage practitioners and academics increasingly recognise the value of using continuous rainfall/outflow data (either monitored or modelled) to derive a comprehensive understanding of how green infrastructure employed for stormwater management responds to long time-series rainfall inputs. Data analysis will often comprise both long-term performance and event-based analysis. For the latter, an agreed definition of 'an event' is crucial. Typically, events are defined based on an agreed minimum inter-event dry weather period, or Minimum Inter-Event Time (MIT).

However, the choice of a suitable MIT is context specific, depending on factors that include hydrological scale (consider large catchments versus individual SuDS) and the temporal resolution of the input rainfall time-series. A response on the SWMM knowledge base (1997) to the question of defining a suitable inter-event period stated "There is no answer which is always right. The purpose of the analysis will define the data required." The topic continues to generate discussion in related fields.

For example, Meier and Kafle (2024) explored how the choice of MIT affects regionally derived rainfall depth-duration-frequency values, while Tu et al. (2023) focused on the relevance of MIT (0.5-24 hours) in the context of soil erosivity work.

In the context of SuDS, The USEPA (1992) guidance suggests a Minimum Inter-Event Time (MIT) of 6 hours, and many green roof researchers have adopted this approach, confirming that drainage typically finishes within 2-3 hours (Stovin et al., 2013). On the other hand, Davis (2008), focusing on bioretention cells, noted that '… small effluent flows continued from the bioretention cells for several days, occasionally overlapping the next inflow event'. Similarly, De-Ville et al. (2024) noted long outflow durations in retrofitted bioretention cells in Mansfield, UK, reflecting the intended outflow control associated with a small orifice. Davis (2008) adopted a pragmatic approach, defining the event retention based on the outflow collected in the 24-hours following the start of outflow.

In practice, SuDS design – as with conventional drainage – is often based on the use of synthetic design storms with specified return periods. In this case, particular attention needs to be paid to the setting of the initial moisture content in any SuDS growing media or storage volumes. Traditional (piped) drainage systems are designed to drain quickly. It is therefore reasonable to design a system assuming that it will be empty, i.e., at full capacity, at the start of the rainfall event. However, the restoration of full capacity in sustainable drainage systems (SuDS) depends on slower processes (e.g., evapotranspiration, infiltration, or the consumption of harvested rainwater) occurring at rates that may be hard to predict. Current design guidance (such as The SuDS Manual, Woods-Ballard et al. 2015) often does not provide clear guidance on reasonable assumptions to make regarding SuDS retention capacity. An additional benefit of continuous simulation is that it also permits the most likely initial moisture contents to be estimated for specific SuDS design scenarios. However, the retention depths obtained will be affected by the MIT adopted in the definition of individual rainfall events.

The objective of this paper is to understand how the specific MIT chosen to define discrete events impacts upon event metrics and also on the selection of suitable initial conditions for design storm simulations of SuDS performance. This is achieved using modelled outflow from a representative green roof (GR) and bioretention cell (BIO).

Methodology

A rainfall time series with a 5-minute resolution collected from the Mappin Roof in Sheffield, UK during 2007 was used (Stovin, 2024b). The rainfall data was discretised into independent events based on MITs of 6, 12, 24 and 48 hours. The authors are not aware of any precedent for the application of an MIT of less than 6 hours. At the other extreme, SuDS design codes often require devices to drain down within 24 or 48 hours; hence, 48 hours was the longest MIT explored here.

The rainfall time series was input into models representing a green roof (GR) and a bioretention cell (BIO), following Stovin (2024a). Both models represent the development of retention capacity in the SuDS due to evapotranspiration (ET) occurring during the antecedent dry weather period. The BIO model assumed a 10:1 loading ratio, and included a flowrate restriction intended to represent the combined effects of detention due to internal percolation through the growing media and/or a controlled outlet, with a maximum percolation/drainage rate of 7.2 mm/hr (0.6 mm/5-min). For this illustrative case, exfiltration was not considered. The GR configuration permits a maximum retention storage of 20 mm, and temporary detention storage of 25 mm. The BIO configuration incorporates 160 mm retention storage associated with the growing media and 300 mm temporary detention storage distributed over the drainage layer, growing media and ponding zone. Given the 10:1 loading ratio, these depths are equivalent to 16 mm and 30 mm catchment rainfall respectively. With a total temporary storage depth of 300 mm, drainage at 7.2 mm/hr would require 41.66 hours to empty.

Outflow was calculated based on the combination of drainage and overflow. Total outflow per event was calculated based on the outflow recorded during the event and during a period equivalent to the specified MIT following the end of the rainfall.

Per event retention (-) and per event peak attenuation (-) were evaluated for the two different devices (GR and BIO) with the four different MITs. In addition, the Initial Moisture Content (IMC) at the start of each event (in mm rainfall equivalent) was also extracted from the continuous simulation results. IMC is relevant for determining suitable initial conditions to apply in design storm simulations.

Results and discussion

Rainfall analysis

Figure 1 shows the rainfall record, with the 'x' symbols indicating identified event start times associated with the four different MITs (6, 12, 24, 48 hours). As the MIT increases, the number of events falls [172, 122, 71, 35], but their mean depth [5, 7, 12, 23 mm] and duration [404, 766, 2019, 5797 mins] increase. The 24-hr and 48-hr MITs had, respectively, five and nine events with durations exceeding 100 hours.

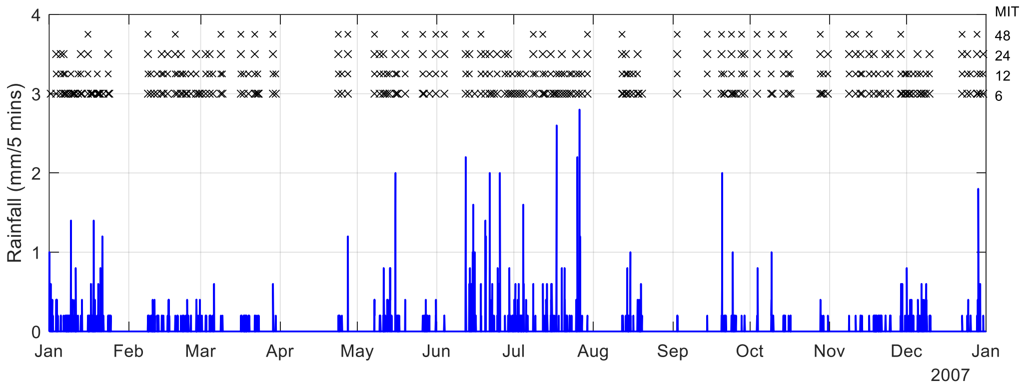

Figure 1. Rainfall time series and event start times as a function of MIT for the 2007 Mappin rainfall time series

Modelled outflow

Figure 2 presents modelled responses to an extreme rainfall event that occurred 13-16 June 2007. The models clearly reproduce the expected outflow profiles. Once initial losses due to retention have been exhausted, i.e. at 21:25 on 13/06, the GR model outflow follows the rainfall. It may be seen that overflow occurs from the BIO model (i.e. the outflow rate exceeds 0.6 mm/5 min) after 22:15 on 14/06, indicating that the temporary storage was fully utilised for a period of time. The BIO model behaviour is reflective of the dynamics observed in local retrofitted SuDS in Mansfield (De-Ville et al., 2024), which are controlled by a small orifice, leading to long (24-48 hour) emptying times. It is expected that per-event retention for BIO will be more sensitive to MIT than GR.

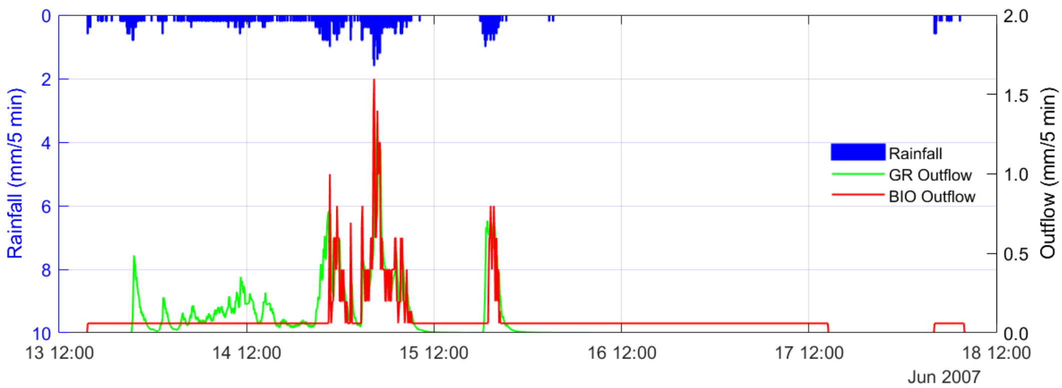

Figure 2. Outflow comparisons for the two SuDS devices in response to the 13-16 June 2007 rainfall

Event-based performance metrics

The event-based performance metrics are presented in Figure 3. For GR, there is very little difference in median per-event retention as a result of varying MIT. Mean values (not shown) are also consistent, though lower, at 0.737, 0.742, 0.738 and 0.793 for MITs of 6, 12, 24 & 48 hours respectively. Note that the median and mean values reported are all consistent with the data presented in Stovin et al. (2013). For GR, peak attenuation is generally high, with no systematic variation as a function of MIT.

Not surprisingly, the longer the MIT, the lower the IMC (Initial moisture content). For a GR, IMC is primarily a function of losses due to ET during inter-event dry periods. The data suggests a median retention capacity of 2.13 mm & 6.14 mm for 6 & 24-hour MITs respectively. In other words, the most likely value for initial losses associated with a GR, in the UK's temperate climate, is a maximum of 6.14 mm. This is consistent with CIRIA requirements for 5 mm of 'interception' storage (equivalent to initial losses), and supports the use of 5 mm initial losses in design storm simulations.

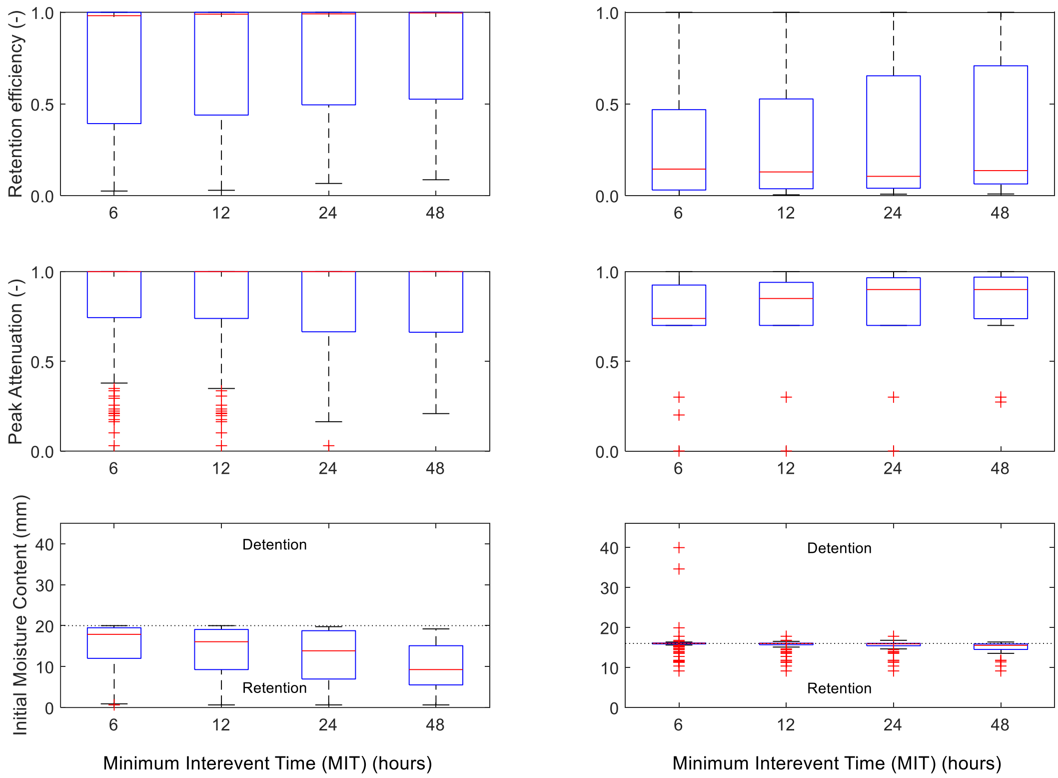

Figure 3. Performance metrics for the 2007 rainfall input. Left – GR; right – BIO. In the bottom row, the horizontal dotted line indicates the transition between 'retention' storage and temporary 'detention' storage and the units are relative to rainfall depth.

For BIO, as anticipated, the mean retention (not shown) increases with MIT (0.157, 0.295, 0.299, 0.381). The median retention is much less sensitive, suggesting that it may only be a few larger events that are affecting the mean values. IMC again correlates with MIT, but the variations are small. Importantly, the data suggests that the most reasonable assumption for initial conditions is that the retention store is full, but the detention store is empty, i.e. IMC ≈ 16 mm rainfall in this case.

While the differences in metrics observed as a result of varying MIT are relatively minor, this exercise has highlighted the importance of employing consistent and clearly-defined analysis processes. Indeed, this may be more critical than the identification of a specific 'optimal' or 'correct' approach. The effects of the choice of MIT are stronger when detention processes are important. The 6-h inter-event period has been widely adopted by green roof researchers, and its consistent use supports like-for-like comparisons between different GR data sets. However, for bioretention cells and other SuDS expected to offer significant detention, a longer inter-event period is more suitable. Our recommendation is to adopt the 24-h standard for these devices. If GR are to be compared against these devices, then the 24-h standards should also be adopted for the GR, making sure to note that this differs from recent practice in GR research.

Conclusions and future work

The choice of MIT used to separate events in rainfall/outflow analysis has an impact on the derived performance metrics, particularly for devices offering significant detention. It is therefore important to apply consistent and well-defined rules. Our recommendation is to adopt the 24-h standard for SuDS devices.

The analysis has also highlighted that – for SuDS that do not include infiltration – the most probable retention storage available at the start of a rainfall event is small, around 5 mm for GR and 0 mm for BIO.

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