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Evaluation of SuDS Device-scale Simplified Modelling Methods in SWMM

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Abstract

As Sustainable Drainage Systems (SuDS)/Low Impact Development (LID) methods are increasingly utilised to manage stormwater in urban areas, it becomes crucial for drainage engineers to accurately represent their hydrological and hydraulic impacts within drainage modelling tools. However, not all tools include explicit SuDS modelling capabilities, or their utilisation may be considered too computationally expensive in some practical contexts. This research examines the potential for representing two common SuDS devices – a green roof and a bioretention cell – using generic hydrological/hydraulic model components. Approaches including initial losses, storage, catchment area disconnection, and reassignment to permeable surfaces were compared against outputs from the SWMM LID module. The findings indicate that all approximation approaches have limitations. Methods involving complete disconnection or transferring catchment areas to pervious surfaces failed to accurately simulate the hydrological dynamics at the device scale. In contrast, approaches based on initial losses and storage showed greater potential, with continuous losses based on evapotranspiration (ET) providing more realistic responses than those using a daily fixed recharge depth. However, neither model performed acceptably in scenarios where detention effects were dominated by substrate percolation.

Highlights

- All simplified modelling approaches have limitations when simulating runoff processes during continuous simulation.
- Simple disconnection or transfer-to-pervious-area modelling methods fail to capture SuDS hydrological dynamics and underestimate runoff.
- Initial losses and storage-based methods, especially with continuous evapotranspiration, yield realistic runoff responses during rainfall events with high rainfall amounts.

Introduction

A range of stormwater models has been used to predict SuDS performance. The most commonly reported models used are SWMM, MUSIC, InfoWorks ICM and MIKE. Accurate representation of the potential hydrological and hydraulic impacts of SuDS within drainage network modelling tools, some of which lack explicit capabilities for modelling these systems, is a persisting challenge. Even where SuDS modelling capabilities are available, their use may be judged to be too complex and computationally intensive in some practical application contexts.

Researchers did not always have access to explicit SuDS modelling tools, such as the SWMM LID module, which led to the development of alternative approaches to SuDS simulation. Stovin et al. (2013a) modelled proposals for retrofitted SuDS in the Thames Tideway catchment using InfoWorks CS by adjusting area type percentages and/or the adjustment of initial loss depth and storage/attenuation depth. Lashford et al. (2020) also noted that in commercial modelling tools SuDS are often represented using hydraulic units (e.g., tanks) or by altering surface types. In neither case were the modelling approaches supported by validation work, underscoring the need for more rigorous validation and refinement of these modelling techniques to ensure the accurate representation of SuDS performance. The aim of the paper is to understand how simplifications to key hydrological processes impact on the accuracy and usefulness of model outputs, specifically in the context of vegetated SuDS devices. The objectives of this study were to: (1) establish four alternative modelling approaches for individual SuDS at the device scale; (2) assess the accuracy of outflow predictions from these models using real rainfall time series for both a green roof and a bioretention cell.

Methodology

Hydrological Model Setup

Hydrological modelling was performed using the Storm Water Management Model (SWMM 5.2), developed by the USEPA (Rossman, 2016a, 2016b, 2016c). Two SuDS types (Table 1), a Green Roof (GR) and a Bioretention (BIO) were selected for SuDS intervention scenario simulation. All model formulations utilised a 10×10 m 100% impermeable subcatchment. This subcatchment was connected to a junction and subsequent outfall by a conduit that was over-sized to cause no impediment to flow. The green roof was modelled as occupying 100% of the subcatchment. The bioretention system was modelled as occupying 20% of the subcatchment area, receiving incident rainfall on its own area and collecting surface runoff generated from the other 80% of impervious area (loading ratio of 5:1). The rainfall time series was the 5-minute resolution monitored Mappin (Sheffield) rainfall record for 2007 (Stovin, 2024). Table 2 highlights 8 significant rainfall events from the 2007 continuous rainfall series.

Table 1. SuDS devices key parameters for LID module

Parameter	Unit	Green Roof	Bioretention	Notes
Surface				GR parameters from Peng and Stovin (2017) BIO parameters from De-Ville et al. (2021)
Berm Height	mm	0	100	
Vegetation Volume Fraction	v/v	0	0	
Surface Roughness (n)		0.15	0	
Surface Slope	%	2.60	0	
Substrate				GR parameters from Rossman (2016c) BIO parameters from Berretta et al. (2018); De-Ville et al. (2021)
Thickness	mm	100	700	
Porosity	v/v	0.5	0.44	
Field Capacity	v/v	0.3	0.15	
Wilting Point	v/v	0.1	0.12	
Conductivity	mm/hr	1000	200	
Conductivity Slope		40	40	
Suction Head	mm	50	50	
Drainage/Storage				From National Cooperative Soil Survey (2006); Rossman (2016c)
Thickness	mm	50	300	
Void Fraction		0.5	——	
Void Ratio		——	0.8	
Roughness (n)		0.03	——	
Seepage Rate	mm/hr	——	0	
Clogging Factor		——	0	

Drain				1000 represent no orifice control. Other parameters from Rossman (2016c)
Flow Coefficient	mm/hr	——	1000	
Flow Exponent		——	0.5	
Offset	mm	——	0	

Table 2. Rainfall characteristics for the significant rainfall events (Return period > 1 year)

Event start	Rain duration (hh:mm)	Rainfall depth (mm)	ADWP (hh:mm)	Mean intensity (mm/h)	Peak 5-min Intensity (mm/h)
18/01/2007 01:11	24:20	27	10:25	1.11	21.6
20/01/2007 19:47	24:20	38.6	9:00	1.59	14.4
13/05/2007 12:34	21:30	29.8	16:05	1.39	12.0
12/06/2007 05:38	2:05	12.8	199:15	6.24	28.8
13/06/2007 15:39	42:30	99.6	32:00	2.34	21.6
15/06/2007 17:54	9:20	16.2	7:45	1.74	12.0
24/06/2007 22:12	22:40	58	6:00	2.56	28.8
26/07/2007 06:56	13:30	12.6	13:25	0.93	33.6

SuDS Device-scale Modelling Methods

Five device-scale SuDS modelling methods were trialled. The SWMM *LID* model outputs were considered to provide baseline predictions, against which the four simplified models could be compared. The four simplified models were also constructed in SWMM, utilising generic hydrological/hydraulic controls expected to also be available within the broader range of drainage network modelling tools. The four simplified models (termed *Disconnect, TransferP, Daily Loss and Cont. Loss*) represent a progression from the most basic to the most complete.

The *Disconnect* model removes impermeable areas treated by SuDS. Runoff from this subcatchment will always be zero. The *TransferP* model alters SuDS treated areas to permeable areas by adjusting the percentage of permeable area (exfiltration rate = 7.2 mm/hr) in the subcatchment.

Figure 1 illustrates the *LID*, *Daily Loss* and *Cont. Loss* modelling frameworks.

The *Daily Loss* model aims to combine the initial losses and storage options adopted by Stovin et al. (2013a). To model the replenishment of initial losses, the recharge tank (sized in plan to match the SuDS device) is designed to empty every 24 hours. The recharge depth is assumed to represent SuDS that provide retention as a result of ET during the antecedent dry weather period (ADWP). Once the recharge tank reaches its full recharge depth, any additional inflow during the 24-hour period is directly discharged into a 'detention' storage unit fitted with an orifice control. This orifice control is used to represent the detention effects of either percolation through the growing media or downstream flow control. In the 'detention' storage unit, the exfiltration rate can be set to represent a seepage loss to the natural soil.

The *Cont. Loss* (i.e. continuous losses) model represents an evolution of the *Daily Loss* approach, in which initial losses are represented by depression storage (sized in plan to match the SuDS device) within the subcatchment. This modification enables the initial losses to be dynamically updated through ET losses, offering a more realistic depiction of the SuDS substrate's retention capacity recovery. The detention storage component is consistent with the *Daily Loss* model.

In both the *Daily Loss* and *Cont. Loss* models, the storage unit (detention) is used to represent the detention effects due to either a physical flow control/orifice or percolation through a deep substrate (soil) layer. The percolation characteristics of the SuDS substrate limit the outflow rate to its saturated hydraulic conductivity. For the storage unit and orifice-controlled outflow in the *Daily Loss* and *Cont. Loss* models, the maximum outflow rate was set to reflect the lower value of the saturated hydraulic conductivity (K_{Sat}) or the underdrain outflow control.

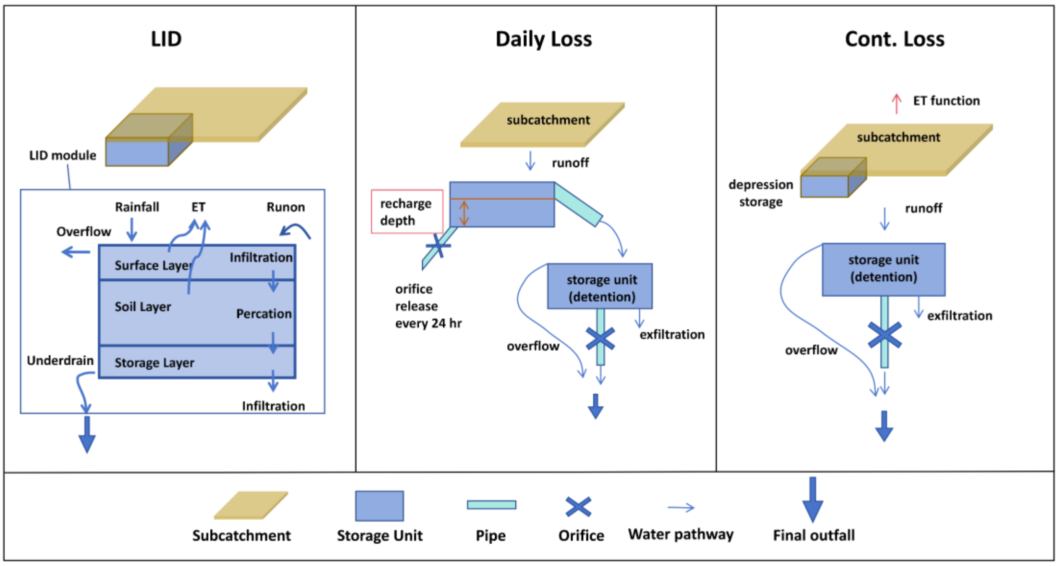

Figure 1. *LID, Daily Loss* and *Cont. Loss* Modelling Frameworks

Results and discussion

Figure 2 presents modelled responses to an extreme rainfall event that occurred 13-16 June 2007.

The *Disconnect* method led to a complete absence of outflow. This approach is clearly not realistic in terms of outflow volumes, rates, or timings.

The *TransferP* model converts SuDS-treated areas (100% of the subcatchment for both GR and BIO) to permeable areas, allowing a portion of the stormwater to infiltrate directly into the natural soil. Once the stormwater inflow exceed the soil conductivity, and the default depression storage is full, outflow (surface overland flow) occurs. This model basically ignores the physical characteristics of SuDS, leading to identical profiles for GR and BIO.

In the GR scenario, the *Cont. Loss* model result was closest to the *LID* method with NSE = 0.21. Despite this similarity, the outflow profile showed more fluctuations and was less smooth than the *LID* profile. This indicates that, despite the weak detention effect of GR, the percolation function in the *LID* method dynamically controls the outflow rate based on soil moisture, resulting in a smoother outflow profile. The *Daily Loss* model produced results similar to the *Cont. Loss* method after 21:00 on June 13. Before this time, the *Daily Loss* method generated runoff whenever there was rainfall, due to the recharge depth tank not being empty at the beginning of the event. It is encouraging to note that the runoff peaks were estimated well by both approaches.

In the BIO simulation, the *Daily Loss* model result was similar to the *Cont. Loss* model, but both differed from the *LID* simulation. At approximately 21:00 on June 13, the two simplified approaches failed to retain moisture: outflow began immediately with rainfall, producing a minor peak of about 50 L/5min, while the *LID* model released only a negligible discharge. The *Daily Loss* and *Cont. Loss* models underestimated the peak runoff by roughly 20% compared to the *LID* approach. In these two models, the water volume stored in the tank cannot accurately represent the moisture content within the BIO substrate. The use of a single orifice control fails to replicate the outflow dynamic.

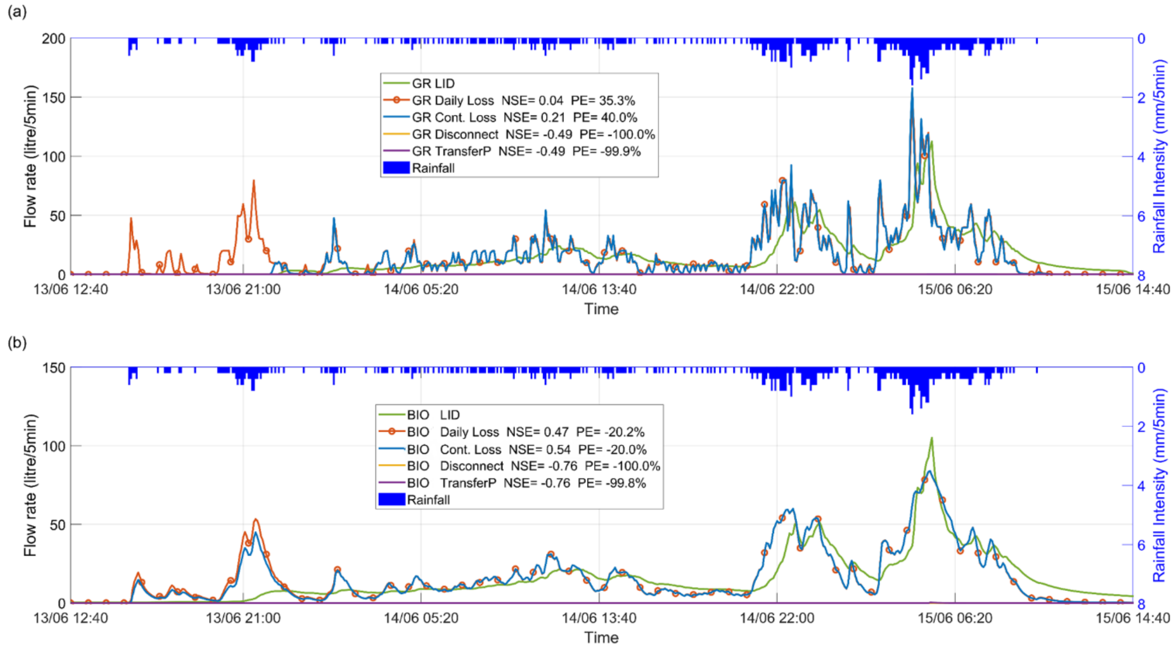

Figure 2. Modelled runoff profiles of (a) GR and (b) BIO for event June 13th 2007

Figure 3 shows the retention performance during 8 significant events from the 2007 rainfall series. Since the GR occupies the entire subcatchment area, and both the *Cont. Loss* and *LID* models used the same ET loss mechanism, their retention performance was consistent. For GR, the match is exact, whereas in BIO, the *Cont. Loss* model introduced some errors compared to the *LID* module. This is due to some surface runoff from the subcatchment bypassing the depression storage and escaping ET loss. The *Daily Loss* model led to more random retention performance for both GR and BIO. This is because there is no link between the volume of water released by the recharge mechanism and the amount of rainfall during a single event.

Figure 4 shows the peak runoff values for eight significant events from the 2007 rainfall time series simulation. Ignoring any GR detention caused the *Daily Loss* and *Cont. Loss* methods to significantly overestimate the peak flow. In most rainfall events, the *Cont. Loss* model exhibited higher peak flows than the *Daily Loss* model. In the BIO scenario, these two simplified models overestimated the peak flow rates in most cases, indicating that the detention function modelled by these two simplified methods is inaccurate. The difference is greater in events with smaller rainfall amounts.

Overall, while the simplified approaches show qualitatively reasonable responses to rainfall events, limitations to the ways in which retention and detention are represented generally lead to notable quantitative errors in the temporal runoff profiles.

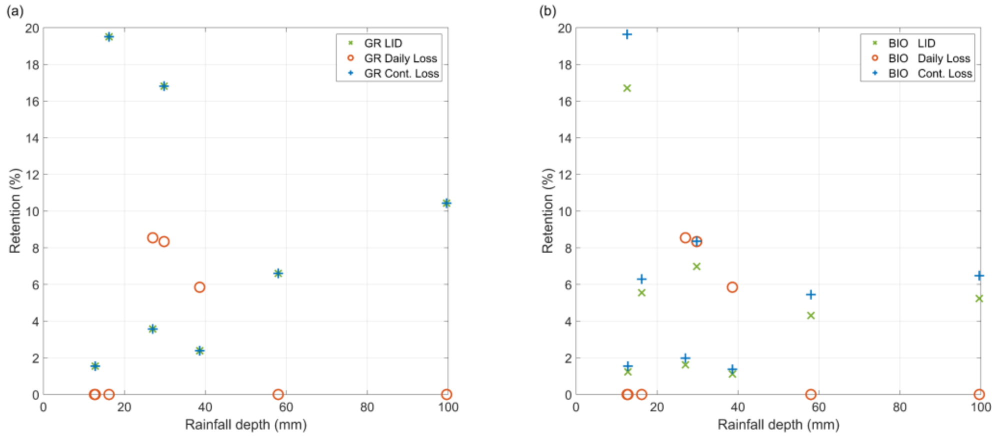

Figure 3. Scatter plots for selected key rainfall/runoff parameters in significant events from the 2007 rainfall time-series (a) GR and (b) BIO

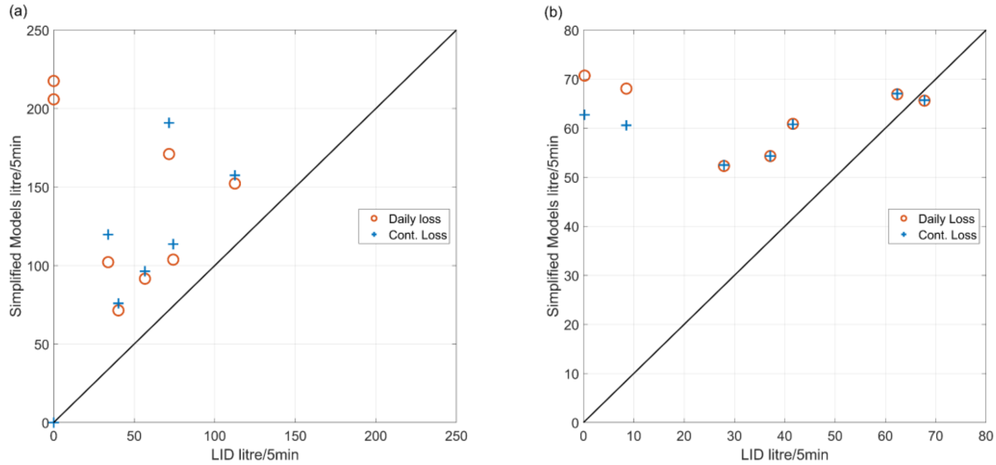

Figure 4. Scatter plots for peak runoff rate in significant rainfall events in significant events from the 2007 rainfall time-series (a) GR and (b) BIO

Conclusions and future work

The findings highlight inherent limitations in simplified models for accurately simulating device-scale hydrological dynamics.

- Simple *Disconnect* and *TransferP* fail to capture SuDS hydrological dynamics and underestimate runoff as neither account for the physical configuration of the SuDS.
- Initial losses and storage-based methods provide better indications of likely runoff profiles, but neither simplified modelling approach captures the complex hydrological and hydraulic processes as comprehensively as the full LID model.

Future research should explore applying these alternative SuDS models in street-scale simulations with multiple installations to evaluate their collective impact and scalability.

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