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Sustainable Urban Stormwater Management: Hydrologic Performance of Low-Impact Drainage Design in an Urbanising Catchment

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ABSTRACT

Urbanisation increases impervious cover and accelerates the conveyance of rainfall to drainage networks, raising peak flows and the risk of urban flooding. This paper assesses the hydrologic performance of low-impact development (LID) and sustainable drainage systems (SuDS) relative to conventional drainage in an urbanising catchment. A rainfall-runoff model was developed for a representative catchment, and the runoff response was simulated for conventional drainage and for a configuration incorporating distributed LID measures. The simulated hydrographs show that the LID configuration attenuates the peak discharge and delays the time to peak while reducing total runoff volume. The discussion considers the design and planning implications of distributed source-control measures, including their integration into urban layouts and the influence of catchment characteristics on performance. The study concludes that sustainable drainage offers a robust complement to conventional networks and that its benefits are maximised when source-control measures are embedded within the planning of urban development rather than added retrospectively.

KEYWORDS: *Stormwater management, Low-impact development, Sustainable drainage systems, Runoff hydrograph, Peak attenuation, Urban flooding, Catchment hydrology*

INTRODUCTION

Urban development alters the natural hydrological cycle by replacing permeable surfaces with impervious cover, reducing infiltration and increasing the volume and rate of surface runoff
(1). The resulting rise in peak flows places conventional drainage networks under strain and Contributes to urban flooding, particularly under intense rainfall (7).

Sustainable drainage systems and low-impact development have emerged as approaches that seek to manage runoff closer to its source, mimicking natural processes through infiltration, storage, and slow release (2). These measures include permeable pavements, bioretention cells, green roofs, and detention features distributed across a catchment (4).

Although the principles of source control are well established, their adoption depends on demonstrated hydrologic benefit and on integration with urban planning (10). This study quantifies the runoff response of an urbanising catchment under conventional and LID-based drainage to clarify the performance gains achievable through distributed measures (8).

LITERATURE REVIEW

The literature on sustainable drainage has expanded alongside growing concern over urban flooding and water quality. Studies consistently report that LID and SuDS measures reduce peak flows and runoff volumes, though the magnitude of the benefit varies with measure type, catchment imperviousness, and rainfall characteristics (4). Hydrologic modelling has become a standard means of evaluating these effects prior to implementation (8).

Categories of Source-Control Measures

Source-control measures reported in the literature can be grouped according to their dominant hydrologic function:

- Infiltration measures such as permeable pavements and soakaways that promote recharge (4).
- Detention and retention features that store runoff and release it slowly (3).
- Vegetated systems including bioretention cells and green roofs that combine storage with evapotranspiration.
- Conveyance controls such as swales that slow flow and encourage infiltration (2).

The combined deployment of several measures within a catchment, often termed a treatment train, generally yields greater benefit than any single measure applied in isolation (7, 10).

RESEARCH GAP

While the benefits of individual LID measures are documented, catchment-scale assessments that compare a distributed LID configuration directly with conventional drainage under consistent rainfall remain valuable, particularly for rapidly urbanising contexts. Studies that connect the hydrologic results to planning decisions about where and how measures should be embedded are comparatively scarce. This paper provides such a comparison and draws out the associated planning implications.

OBJECTIVES

- To develop a rainfall-runoff model for a representative urbanising catchment.
- To simulate the runoff response under conventional drainage and a distributed LID configuration.
- To quantify peak discharge, runoff volume, and time to peak for each configuration.
- To examine the planning implications of embedding source-control measures in urban layouts.

METHODOLOGY

A representative urban catchment was characterised in terms of area, imperviousness, and slope, and a rainfall-runoff model was constructed to simulate its response (5). Runoff was generated using an established loss method, and the routing of flow through the drainage system was simulated for design storm conditions (6).

Catchment Characterisation and Model Setup

The principal catchment parameters and the design rainfall adopted in the model are listed in Table 1. The catchment was discretised into sub-areas to represent the spatial distribution of imperviousness, and the LID configuration was introduced by assigning source-control measures to selected sub-areas (5, 8). The same rainfall input was applied to both configurations to ensure a consistent comparison.

Table 1: Catchment characteristics and design rainfall

Parameter	Value
Catchment area	42 hectares
Impervious fraction (conventional)	0.68
Average slope	1.8 percent
Design storm return period	10 years
Design storm duration	60 minutes
Peak rainfall intensity	78 mm/h

Drainage Configurations Compared

Two configurations were simulated. The conventional configuration conveyed runoff directly to the piped network, while the LID configuration incorporated permeable pavements, bioretention cells, and detention storage distributed across the catchment (4). The measures were sized in accordance with established guidance, and their combined effect on the catchment hydrograph was evaluated (3).

Table 2: Source-control measures in the LID configuration

Measure	Hydrologic function	Catchment coverage
Permeable pavement	Infiltration and detention	Parking and minor roads
Bioretention cells	Storage and evapotranspiration	Landscaped pockets
Detention basin	Peak attenuation	Downstream open space
Vegetated swales	Conveyance with infiltration	Roadside corridors

RESULTS AND FINDINGS

The simulated runoff hydrographs for the two configurations are presented in Figure 1. The hydrographs capture the rate of discharge at the catchment outlet over the duration of the storm event and its recession.

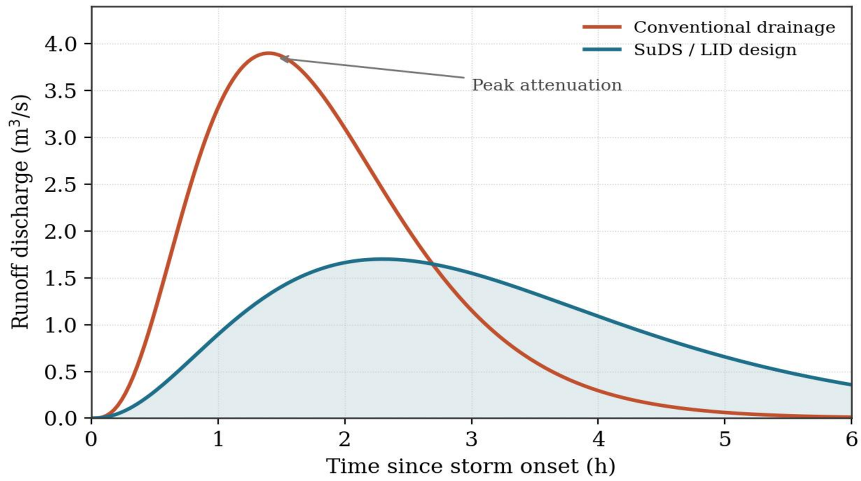

Figure 1: Runoff hydrographs for conventional and SuDS-based catchment configurations

The LID configuration produced a markedly lower and later peak than the conventional configuration, reflecting the combined effect of infiltration, storage, and slow release. The recession was extended, indicating that runoff was distributed over a longer period. The quantitative comparison of peak discharge, runoff volume, and time to peak is given in Table 3.

Table 3: Hydrologic response of the two drainage configurations

Response parameter	Conventional	LID / SuDS	Change (%)
Peak discharge (m3/s)	3.9	1.7	-56.4
Runoff volume (1000 m3)	11.8	7.9	-33.1
Time to peak (min)	84	138	+64.3
Runoff coefficient	0.61	0.41	-32.8

DISCUSSION

The simulated results confirm that distributed source-control measures substantially attenuate the catchment peak and reduce runoff volume relative to conventional drainage (4, 8). The delay in time to peak is particularly significant, since it eases the coincidence of flows within a network and can reduce downstream flood risk (7).

The magnitude of these benefits depends on catchment characteristics, especially the degree of imperviousness and the available space for measures (10). In highly developed areas the opportunity to retrofit source control may be constrained, which underlines the importance of embedding such measures during the planning of new development rather than adding them later (2).

From a planning perspective, the results argue for treating drainage as an integral element of urban layout. Allocating space for bioretention, detention, and permeable surfaces at the design stage allows source control to be distributed effectively and to perform as a treatment train (3). Sustainable drainage is therefore best regarded as a complement to conventional networks, enhancing resilience while delivering ancillary benefits for water quality and amenity (1, 9).

CONCLUSION

This study assessed the hydrologic performance of low-impact drainage relative to conventional drainage in an urbanising catchment. The LID configuration attenuated the peak discharge by more than half, reduced runoff volume, and delayed the time to peak, demonstrating the effectiveness of distributed source-control measures under design storm conditions.

The findings support the wider adoption of sustainable drainage as a complement to conventional networks. The benefits are greatest when measures are distributed across a catchment and embedded within the planning of urban development, allowing drainage to contribute to flood resilience, water quality, and the quality of the urban environment.

LIMITATIONS

- The analysis relied on a single design storm and did not consider continuous long-term simulation.
- Water-quality performance of the measures was not quantified.
- Maintenance requirements and their effect on long-term performance were not modelled.
- Infiltration parameters were based on typical values rather than site investigation.

FUTURE SCOPE

- Continuous simulation across a range of storm events and seasons.
- Assessment of water-quality treatment provided by the measures.
- Incorporation of maintenance and clogging effects in performance prediction.
- Coupling of hydrologic results with urban planning and land-use scenarios.

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