

Prioritizing Sustainable Urban Drainage Systems to mitigate Combined Sewer Overflows in Girona (Spain)

Prioriser les systèmes de drainage urbain durable pour atténuer les déversements d'eaux usées mixtes à Gérone (Espagne)

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RÉSUMÉ

Les déversements d'eaux unitaires (CSO) constituent un problème environnemental majeur dans les villes européennes dotées de réseaux combinés. Cette étude applique un modèle hydrologique et hydraulique (SWMM) pour évaluer le potentiel des Systèmes Urbains de Drainage Durable (SUDS) à réduire les CSO dans la ville de Gérone (Espagne). Une pluie synthétique de 12 heures et de période de retour de 50 ans a été simulée afin d'évaluer 22 sites candidats de bassins de biorétention, sélectionnés selon leur contribution aux débordements et la disponibilité d'espaces publics ouverts. Les simulations montrent qu'un SUDS individuel peut réduire jusqu'à 9,4 millions de litres de déversement, tandis que la mise en œuvre simultanée des 22 candidats permettrait une réduction totale de 35 millions de litres ($\approx 5\%$) pour l'événement extrême. Les zones les plus efficaces se situent dans les sous-bassins drainant vers les rivières Ter et Onyar. Des co-bénéfices supplémentaires incluent une légère amélioration de l'accès aux espaces verts et de la qualité de l'air. Cette approche intégrée, combinant modélisation hydrodynamique et indicateurs spatiaux, constitue un outil d'aide à la décision pour la planification urbaine et l'adaptation au changement climatique dans les villes méditerranéennes.

ABSTRACT

Combined Sewer Overflows (CSOs) remain a major environmental issue in European cities with combined sewer networks. This study applies a hydrological–hydraulic model to assess the potential of Sustainable Urban Drainage Systems (SUDS) to reduce CSOs in the city of Girona (Spain). A synthetic 12-hour storm with a 50-year return period was simulated to evaluate 22 candidate sites for bioretention cells, selected according to their contribution to overflow volumes and availability of public open space. Each scenario represents the implementation of one SUDS, and results were compared to the current baseline. The simulations show that individual SUDS can reduce overflow volumes by up to 9.4 million litres, while implementing all 22 candidates simultaneously would reduce total discharges by 35 million litres ($\approx 5\%$) for the extreme rainfall event. The most effective locations correspond to subcatchments draining toward the Ter and Onyar rivers. Co-benefits include slight improvements in green space accessibility and air quality through enhanced vegetation cover. The study demonstrates how hydrodynamic modelling combined with spatial indicators can guide the prioritization of SUDS in dense urban environments. This integrated approach supports evidence-based planning for climate adaptation and water quality improvement in Mediterranean cities.

KEYWORDS: sustainable urban drainage systems, nature-based solutions, combined sewer overflow, low impact development, SWMM

1 INTRODUCTION

Combined Sewer Overflows (CSOs) are a major environmental challenge in cities with combined sewer systems, where stormwater and wastewater are collected together. During intense rainfall, system capacity is exceeded, and untreated discharges reach receiving waters, degrading ecosystems and posing health risks (Passerat et al., 2011; Radinja et al., 2019). Traditional end-of-pipe measures such as detention tanks or screens can partially mitigate impacts but often involve high costs and limited spatial flexibility (Botturi et al., 2021).

Nature-based solutions, and specifically Sustainable Urban Drainage Systems (SUDS), represent a more decentralized, adaptive, and multifunctional approach. They enhance infiltration, evapotranspiration, and temporary storage, thereby reducing CSO frequency while delivering co-benefits such as air pollutant capture, microclimate regulation, and improved urban liveability (La Rosa & Pappalardo, 2020; Joshi et al., 2021).

This study presents a modelling exercise to prioritize SUDS implementation in the city of Girona (Catalonia, Spain). Building on a previously calibrated hydrological-hydraulic model (SWMM, Rossman, 2015), we simulated storm events under different implementation scenarios to quantify the reduction in CSO volumes at city wide scale and assess additional environmental indicators. The approach aims to support evidence-based green infrastructure planning to strengthen urban resilience to climate change.

2 METHODOLOGY

2.1 Rainfall event simulation

A synthetic storm event with a 50-year return period and 12-hour duration was generated using the Chicago method (Keifer & Chu, 1957) based on IDF curves for Girona by Catalan Meteorological Service. The resulting hyetograph, with peak intensity at 40% of the storm duration, accumulates a total precipitation of 151 mm, representing $2.85 \times 10^6 \text{ m}^3$ over the modelled area.

2.2 SUDS implementation scenarios

From a calibrated SWMM model, subcatchments were ranked by their contribution to CSOs (based on lateral inflows at outlets). Candidate locations were defined as those within the top 20% of contributors (in terms of flow rate) and with the 20% largest available public open space. A total of 22 candidate subcatchments were identified across the urban area (average 1.1 ha).

Each scenario represents the implementation of a bioretention cell within one candidate subcatchment. The bioretention design followed standard SWMM LID parameters: a 150 mm surface layer, 500 mm soil layer (porosity 0.5, conductivity 50 mm/h), and 400 mm storage layer (void ratio 0.4). Where possible, SUDS were connected to nearby outfalls (<50 m) through underdrains; otherwise, drainage occurred through infiltration and evapotranspiration.

2.3 Scenario simulation and analysis

Each SUDS scenario was simulated independently using GNU Parallel on a high-performance cluster (Tange, 2011). CSO volumes at each outfall were extracted and compared with the baseline (no-SUDS) scenario.

Additionally, three spatial indicators were computed using the edibility R package (Pueyo-Ros et al., 2023):

- Accessibility to green areas (>0.5 ha within 300 m of residences)
- Equity in green space distribution (ratio of $\text{m}^2/\text{inhabitant}$ between least and most vegetated districts)
- Nitrogen dioxide (NO_2) sequestration by urban vegetation

Finally, a combined scenario with all 22 SUDS implemented simultaneously was simulated to evaluate the cumulative impact.

3 RESULTS AND DISCUSSION

For the 50-year storm, the current combined sewer system discharged 725 million litres (ML) of overflow (continuity error 0.7%), equivalent to 25% of total rainfall.

3.1 Effectiveness of individual SUDS

Simulated SUDS reduced CSO volumes between 1.8 and 9.4 ML, depending on location and drainage connectivity. The most effective site achieved a reduction of 9.4 ML, with a relevant difference regarding the second most performant, that reduced 6 ML the volume discharged (Figure 1).

Environmental co-benefits were modest: NO₂ sequestration increased by up to 0.15%, while green accessibility and spatial equity remained nearly unchanged due to the small incremental area converted to vegetated surfaces.

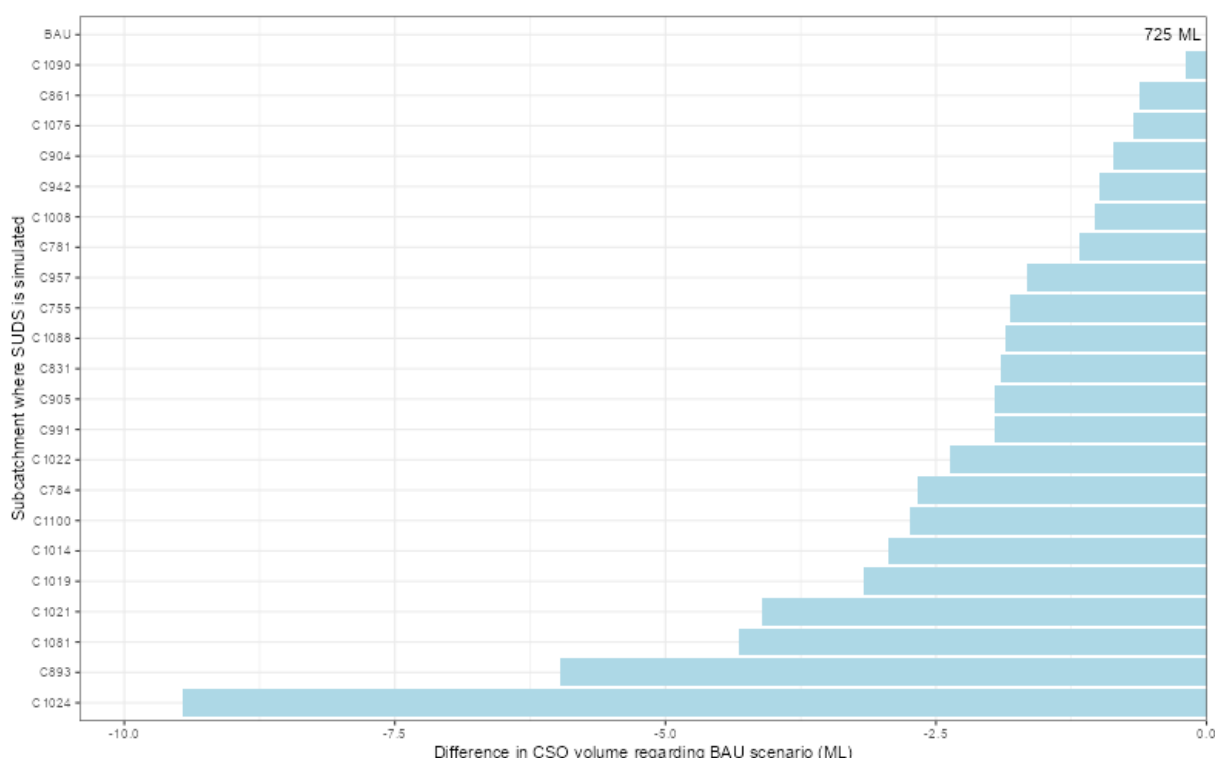


Figure 1. Effectiveness of SUDS reducing CSO volume in each scenario

3.2 Combined scenario

Implementing all 22 candidate SUDS yielded a total CSO reduction of 35 ML (~5% of baseline overflow) under the 50-year storm. For a 2-year event (61 mm in 12 h), the reduction was slightly higher (6.5%), indicating that SUDS maintain consistent performance across rainfall intensities. The most significant overflow reductions occurred at outfalls along the Ter River (Hospital Trueta, Pont de la Barca) and the Bullidors creek, highlighting priority zones for intervention.

Co-benefits in the combined scenario included a 5% increase in population with access to large green areas and a 0.47% increase in NO₂ sequestration. Spatial analysis revealed localized improvements in deprived districts such as Santa Eugènia and Mas Xirgu, contributing to greater environmental justice.

Table 1. Summary of indicators of 22 SUDS implemented versus BAU scenario

Indicator	BAU	22 SUDS implemented
CSO volume avoided by SUDS	0 ML	35 ML
Population with a green area larger than 0.5 ha closer than 300 m.	66%	71%
Ratio of green per capita (greenest / greyest neighbourhood)	6907	6907
NO ₂ sequestration by urban green	1474 g/s	1481 g/s

4 CONCLUSIONS

The modelling results demonstrate that SUDS can substantially reduce combined sewer overflows in Girona, even when applied selectively to the most influential subcatchments. Individual interventions may prevent up to 9.4 ML of overflow, while a network of 22 SUDS could reduce total discharges by approximately 5% during an extreme rainfall event.

Although hydrological benefits dominate, secondary gains in air quality and green accessibility further justify the multifunctional nature of SUDS. The analysis underscores the need to integrate hydraulic modelling with multi-criteria spatial planning to identify interventions with the highest environmental and social return.

Future work will extend this approach with cost-benefit analyses and finer-scale hydraulic validation. The proposed framework provides a replicable decision-support basis for municipalities aiming to combine stormwater management, pollution reduction, and urban green infrastructure planning within climate adaptation strategies.

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