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Modelling assessment of Bioretention Zones using GIS and SWMM

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Abstract

This study assesses the potential implementation of Bioretention Zones (BRZ) in the Bogota campus at the Universidad Nacional Colombia. The goal of the paper is to present a simplified methodology that considers a BRZ scenario for mitigating runoff peaks in the campus. The project methodology is three folded: (1) a suitability analysis for BRZ implementation, (2) configuration and calibration of a rainfall-runoff model, and (3) simulation and assessment of one BRZ scenario in the study area. The GIS-based suitability analysis revealed that at least 10% of the delineated urban catchment may be suitable for BRZ implementation. An 11-BRZ scenario that captures runoff from 11.9% of the catchment area resulted in a subcatchment's peak-runoff reduction between 10% to 42%. However, the overall peak reduction may not achieve the 30% peak reduction required by Colombian regulations. Besides the potential location of BRZ, the potential subcatchment runoff is suggested as a planning variable to improve the assessment of this SUDS typology for peak-runoff reduction.

Highlights

- At subcatchment level, at least 10% surface disconnection led from 10% to 42% peak reduction
- The calibrated SWMM model performed outstanding (NSE=0.92) with the glue technique

Introduction

Urbanization has adversely impacted hydrological and ecological systems on global, regional, and local scales (Sang-Soo, et al., 2019), where Bogotá, Colombia is not an exception (SDA, 2011). The Sustainable Urban Drainage Systems (SUDS), such as bioretention zones (BRZ), have been used to improve hydrological, environmental, and social outcomes by imitating natural water infiltration and retention processes (IDIGER, 2025). Since 2014, several studies in collaboration between local authorities and academia in Bogotá have resulted in: [1] a technical regulation for SUDS "NS-166" (EAAB, 2018), and [2] a map with SUDS typologies potential locations in Bogotá (Otero-Dura, et al., 2023). However, the Bogotá Campus of Universidad Nacional de Colombia remains unexplored by the aforementioned studies. The campus has over 60% green space offering significant opportunities to implement several SUDS solutions. Besides the BRZ been widely used in the U.S. for runoff volume, rate, and quality control, it has also become popular worldwide due to its ability to be easily retrofitted into urban areas while providing additional aesthetic and social benefits. However, few studies have focused on modeling bioretention systems (Whitney, et al., 2021). Seventeen BRZ structures have been implemented in Bogotá, representing 24% of the city's total SUDS implemented by 2025 (SIGREH, 2021). Nonetheless, there is a lack of studies focusing on the modeling of BRZ in Colombia which is crucial to assess their implementation performance and guarantee design guidelines applicable for different scenarios and climates. This study assesses the modelling of BRZ in the Campus, by combining suitability analysis for BRZ location with BRZ modeling in SWMM5. SWMM with its LID module, is a widely used tool for assessing the hydrological and environmental performance of BRZ systems, among other SUDS. (Whitney et al., 2021).

Methodology

The methodology is three folded: [1] The **suitability analysis for BRZ** uses a GIS-weighted overlay multicriteria analysis in ArcGIS Pro to identify potential areas. Criteria are defined from specific characteristics of the campus and adaptation of NS-166 guidelines. For each criterion a weight is assigned, providing more weight in variables related to bioretention structures. The BRZs are assumed impermeable, and their excess runoff is draining to the stormwater system. Thus, infiltration rates are not used in this assessment. The BRZ are assumed impermeable because the water table is very high at the study area. BRZ must be at least 20 meters away from any buildings and have a 5-meter buffer from trees. Proximity to inlets and ponding surfaces is prioritized. GIS layers are reclassified in a 1 to 3 scale (being 3 suitable) at a 5-meter spatial resolution. A restriction layer for unsuitable areas, such as buildings and roads, is used as a mask in the suitability process. [2] A **rainfall-runoff model is configured and calibrated**. The urban catchment area is delineated using a modified Thiessen Polygons methodology that allows drainage areas to delineate flowing directly into the sewer pipes (Beltran, et al. 2022). After defining the drainage area, an SWMM5 model is developed, implementing a conversion of the area to a kinematic wave cascading plane for the width computation. For model calibration, the following settings are used: flow and precipitation from a storm event on October 8, 2007; evapotranspiration values are excluded; infiltration uses the Soil Conservation Service Curve Number method; the flow through the sewer pipelines uses the Dynamic Flow Wave (full Saint-Venant equations). Calibration followed the GLUE methodology (Beven, 2012) automated in R with 16,000 Monte Carlo simulations. Model performance is assessed using the Nash-Sutcliffe efficiency coefficient (NSE) (Nash & Sutcliffe, 1970). [3] The **simulation of BRZ scenario in the campus** is carried out using the calibrated SWMM5 model. The design of a standard BRZ followed the NS-166 general predesign criteria. The simulation scenario is constructed by selecting subcatchments with the highest potential for BRZ implementation from phase 1. For each selected subcatchment, the LID module is used to configure the corresponding BRZ without creating new subcatchments. Hydrological analysis is conducted to compare runoff before and after BRZ implementation, comparing it with the national standard 30% reduction of peak flow expected by any SUDS.

Results and discussion

Table 1. Criteria for BRZ location

Criteria	Weigh	Range (m)	Reclassification	Potential of location
Distance to buildings	30	>20	3	Suitable
		<20	1	Unsuitable
Distance to trees	20	>10	3	Suitable
		10 a 5	2	Suitable with modifications
		<5	1	Unsuitable
Distance to drain inlets	20	0 a 50	3	Suitable
		50 a 100	2	Suitable with modifications
		>100	1	Unsuitable
Distance to water accumulation points	30	<20	3	Suitable
		20 a 50	2	Suitable with modifications
		>50	1	Unsuitable

Table 1 summarizes the criteria used for BRZ location in this study. The criteria-weights are defined in collaboration with the Environmental Office of the University. The weighted overlay process produced the map depicted in Figure 1. The analysis reveals that 3.71 ha (3.1% of the campus) is suitable for locating BRZ, while 12.58 ha (10.38% of the campus) is suitable with modifications such as hydraulic and terrain adjustments. On the other hand, 38.31 ha (31.6% of the campus) is unsuitable and the remaining 66.43 ha (54.92% of the campus) are restricted areas for BRZ. From a manual inspection with an aerial image, it is found that suitable and suitable with modifications areas (16.29 ha in green

and orange color pixels) mainly correspond to green spaces that meet the distance from buildings, roads, trees, and showing ponding during rainy seasons. So, the Figure 1 may indicate an effective location process for BRZ placement. However, in the northern campus area, a cluster of gray pixels, primarily grass-covered and distant from buildings, is selected as unsuitable due to the lack of ponding data and the lack of drain inlets close by. This GIS-based method is a useful tool but is subject to uncertainty due to a lack of information. It is suggested that field validation and/or incorporating comprehensive input data covering the entire study area is considered when using these overlapping techniques.
Observed flow data is available only in two manholes within the campus (see Figure 2). Therefore, the delimitation process is obtained for the draining areas contained by these manholes (see Figure 2). The delineated urban catchment has an area of 46.85 ha where 1.5 ha (3.2%) is suitable for locating BRZ, 3.7 ha (7.9%) is suitable with modifications, and 13.4 ha (28.6%) is unsuitable for BRZ. The remaining 28.25 ha (60.3%) are restricted areas. This land cover along with a DEM of 5-m spatial resolution are the main input data to calculate most of the SWMM5 parameters. The discretization of the catchment is kept as dense as there are sewer segments in the network from the modified Thiessen Polygons process. Thus, this catchment area is used to configure the model on SWMM5. The model calibration obtained an NSE of 0.92, indicating that the model accurately replicates the observed data (see Figure 3).

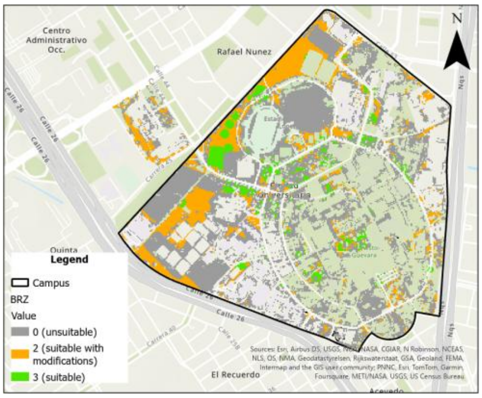

Figure 1. Bioretention zone's location

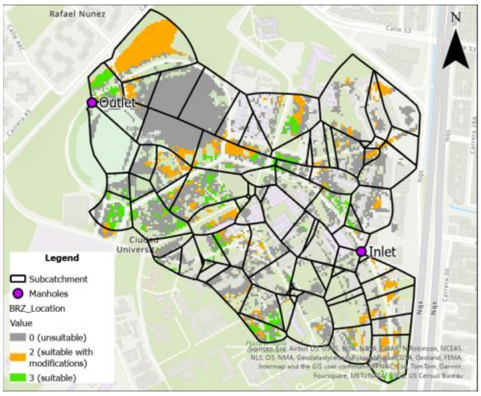

Figure 2. Delimitation of the catchment

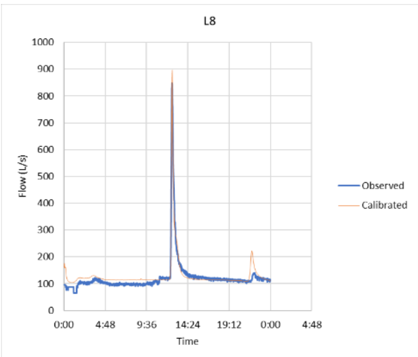

Figure 3. Observed and calibrated hydrograph

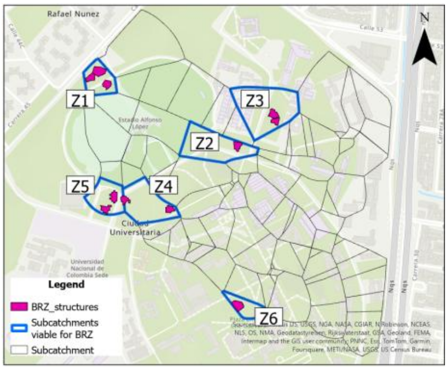

Figure 4. Selected subcatchments for ZBR.

The BRZ scenario is constructed with 6 subcatchments as shown in the blue polygons of Figure 4. These subcatchments have the highest suitability for BRZ within the delineated catchment (see Figure 2). A standard BRZ is designed to capture runoff from 508.33 m², with the following characteristics: area of 350m², total depth of 1.23m, berm depth of 250mm, Manning's number of 0.1, conductivity of 1mm/hr, conductivity slope of 5, suction head of 273mm, and a storage of 650mm. A total of 11 BRZ are installed in the 6 subcatchments, covering 0.385ha (0.82% of the catchment) for capturing runoff from 5.59ha (11.9% of the catchment). Table 2 presents vegetation volume fraction, surface slope, and number of BRZ.

Table 2. Model parameters for each zone

Model parameters	Z1	Z2	Z3	Z4	Z5	Z6
Vegetation volume fraction (%)	0.8	0.7	0.7	0.7	0.6	0.8
Slope (%)	3.07	1.17	1.60	1.35	1.06	2.32
Number of BRZ	3	1	2	2	2	1

The subcatchments with highest peak-runoff reduction are Z2 (26.7%) and Z3 (41.8%) (see Figure 5a), that also had the biggest subcatchment areas and impermeability percentage (see Table 3).

Table 3 shows that the impermeability percentages in each subcatchment may be directly related to the runoff reduction achieved, as they reflect the interaction between soil and precipitation. However, the Z2 and Z3 do not have a direct relationship with the number of BRZ-units located at each subcatchment. This result may imply that the runoff potential of each subcatchment should be considered, besides the potential location of BRZ, in selecting the number of BRZ-units to be allocated per subcatchment. For instance, Z1 and Z6 (see Figure 5b) presented the lowest peak-runoff reduction with the lowest impermeability but with a different number of BRZ units. Although, this scenario achieves between 10% and 42% peak-runoff reduction by treating runoff from 11.9% of the catchment area, the overall compliance of the 30% peak-runoff reduction may not be totally achieved for the catchment under a BRZ with no infiltration. Further analysis of Table 3 shows that on average, for each percentage unit of impermeable area in a subcatchment being connected to a BRZ, a 0.73% peak-runoff reduction may be expected. It may be expected improvements in this ratio if infiltration is permitted in the BRZ units as the soil and water table conditions are allowed.

Table 3. Model results in SWMM for BRZ scenario

Subcatchments	Z1 (%)	Z2 (%)	Z3 (%)	Z4 (%)	Z5 (%)	Z6 (%)
Peak reduction	19.3	26.7	41.8	20.8	23.8	10.7
Impermeability	1.23	23.04	38.13	15.87	14.79	2.8

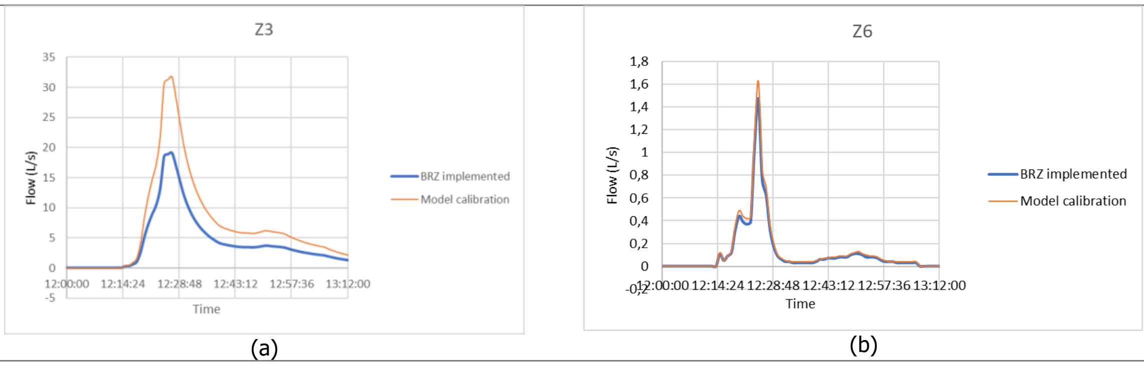

Figure 5. Runoff reduction graphs for Z3 and Z6 zones.

Conclusions and future work

The modelling assessment of a 11-BRZ scenario in SWMM resulted in peak-runoff reductions between 10% and 42%, with the highest reductions observed in highly impermeable subwatersheds for a critical case where no infiltration is allowed. The BRZ simulation scenario selected for subcatchments with the highest BRZ potential may not provide the best performance in peak reduction. The potential of runoff generated by each subcatchment should be included in future assessment. The use of a calibrated SWMM5 rainfall-runoff model provides a robust tool for assessing the hydrological performance of the BRZ scenario when no modification in the subcatchment is made. However, for simulating BRZ, creating new subcatchments may invalidate the calibrated model. It is recommended to assess the BRZ scenario for continuous rainfall events as data becomes available on the campus.

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References

Beltrán, D., Sandoval, J., Mancipe, N. y Riaño, M.F. (2022). Hydrological and environmental assessment of Sustainable Urban Drainage Systems (SuDS) case of study campus of Universidad Nacional de Colombia-Bogotá. 39th IAHR World Congress, from Snow to Sea. Granada, España. 19-24 junio 2022. https://www.iahr.org/library/infor?pid=21658.

Beven, K. (2012). Rainfall-Runoff Modelling: The Primer. doi:10.1002/9781119951001

EAAB. (2018). Norma técnica NS 166 Criterios para Diseño y Construcción de Sistemas Urbanos de Drenaje Sostenible (SUDS). Bogotá.

IDIGER. (2025). Caracterización General del Escenario de Riesgo por Inundación. Retrieved from https://www.idiger.gov.co/rinundacion

Nash, J., & Sutcliffe, J. (1970). River flow forecasting through conceptual models part I - A discussion of principles.

Otero-Dura, L., Martínez, J., Vicente, C., & Robles, J. (2023). Implementación de SUDS en proyectos de infraestructura de trasporte y espacio público: Caso Bogotá (Colombia). Retrieved from https://www.researchgate.net/publication/367380219_IMPLEMENTACION_DE_SUDS_EN_PROYECTOS_DE_INFRAESTRUCTURA_DE_TRANSPORTE_Y_ESPACIO_PUBLICO_CASO_BOGOTA_COLOMBIA

Sang-Soo, B., Mayzonee, L., Jong-Pyo, P., Hyun-Suk, S., Yongsung, K., Joseph T, B., & Kyung Hwa, C. (2019). Developing a hydrological simulation tool to design bioretention in a watershed. Environmental Modelling & Software, 122.

SDA. (2011). Sistemas urbanos de drenaje sostenible. Retrieved from https://www.sdp.gov.co/sites/default/files/anexo91.pdf

SIGREH. (2021). *Plataforma Oficial de SUDS Bogotá D.C.* Retrieved from https://www.arcgis.com/apps/dashboards/c3bffe521d494e6bbe6215bb0c2f2ce8

Whitney, L., Jon, H., Matthew, B., & Fletcher, T. (2021). Modeling bioretention stormwater systems: Current models and future research needs. Environmental Modelling & Software.